State of Washington **February 2019**

Lower Columbia River Fisheries and Escapement Evaluation in Southwest Washington, 2011

Edited by Daniel Rawding, Bryce Glaser, Thomas Buehrens, and Todd Hillson

Washington
Department of
FISH and
WILDLIFE

FPT 19-01

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This document should be cited as follows:

Lower Columbia River Fisheries and Escapement Evaluation in Southwest Washington, 2011. 2019. Edited by Edited by Daniel Rawding, Bryce Glaser, Thomas Buehrens, and Todd Hillson. Washington Department of Fish and Wildlife, Southwest Region. FPT 19-01

Individual chapters should be cited as follows:

Daniel Rawding, Wilson J., Glaser B., and Buehrens T. 2019. Fall Chinook Salmon Abundance Estimates and Coded-Wire-Tag Recoveries in Washington's Lower Columbia River Tributaries in 2011. *in* Lower Columbia River Fisheries and Escapement Evaluation in Southwest Washington, 2011. Edited by Daniel Rawding, Bryce Glaser, and Thomas Buehrens. Washington Department of Fish and Wildlife, Southwest Region. FPT 19-01

Daniel Rawding, Buehrens T., Brown L., Glaser B., VanderPloeg S., and Serl J. Coho Salmon Escapement Estimates and Coded-Wire-Tag Recoveries in Washington's Lower Columbia River Tributaries in 2011. 2018. *in* Lower Columbia River Fisheries and Escapement Evaluation in Southwest Washington, 2011. Edited by Daniel Rawding, Bryce Glaser, and Thomas Buehrens. Washington Department of Fish and Wildlife, Southwest Region. FPT 19-01

Daniel Rawding, Warren B., VanderPloeg S., and Cochran C. Detection Probabilities for Passive Integrated Transponder (PIT) Tags in Adult Steelhead with Hand Held Scanners. 2015. *in* Lower Columbia River Fisheries and Escapement Evaluation in Southwest Washington, 2011. Edited by Daniel Rawding, Bryce Glaser, and Thomas Buehrens. Washington Department of Fish and Wildlife, Southwest Region. FPT 19-01

Thomas Buehrens, Rawding D., Warren B., Glaser B., Hymer J., VanderPloeg S., and Case D. Estimates of Columbia River Salmon and Steelhead Harvest Rates for 2011 Sport, Commercial, and Treaty Fisheries based on Passive Integrated Transponder (PIT) Tags. 2019. *in* Lower Columbia River Fisheries and Escapement Evaluation in Southwest Washington, 2011. Edited by Daniel Rawding, Bryce Glaser, and Thomas Buehrens. Washington Department of Fish and Wildlife, Southwest Region. FPT 19-01

Executive Summary

In 2010, The Washington Department of Fish and Wildlife (WDFW) began implementation of an expanded monitoring program for Chinook and coho salmon populations in the Lower Columbia River (LCR) region of Southwest Washington (WDFW's Region 5) and fishery monitoring in the lower mainstem of the Columbia River. The focus of this expanded monitoring was to 1) gather data on Viable Salmonid Population (VSP) parameters – spawner abundance, including proportion of hatchery origin spawners (pHOS), spatial distribution, diversity, and productivity and 2) to increase the Coded Wire Tag (CWT) recovery rate from spawning grounds to meet regional standards, and 3) to evaluate the use of PIT tags to develop harvest rates for salmon and steelhead populations by having fishery samplers recovery PIT tags from fish being sampled for CWT in existing fisheries monitoring programs. Monitoring protocols and analysis methods utilized were intended to produce unbiased estimates with measurements of precision in an effort to meet NOAA monitoring guidelines (Crawford and Rumsey 2009).

Funding for this program came from multiple sources: 1) the Bonneville Power Administration (BPA) through the Lower Columbia Coded Wire Tag (CWT) Recovery Project (BPA Project #: 2010-036-00) ; 2) the National Oceanic and Atmospheric Administration (NOAA) via Mitchell Act Monitoring, Evaluation and Reform (MA MER) funds; 3) NOAA via Pacific Coastal Salmon Recovery Funds (PCSRF) (administered thru the Washington State Recreation and Conservation Office (RCO); 4) Washington State; 5) PacifiCorp (Lewis River Basin) and 6) Tacoma Power (Cowlitz River Basin).

This report is structured into four components:

1) Fall Chinook Salmon Escapement Estimates and Coded-Wire-Tag Recoveries in Washington's Lower Columbia River Tributaries in 2011

- Key Results
    - Adult fall Chinook abundance was estimated using weir counts, open and closed mark-recapture models, Area-Under-the-Curve (AUC), redd counts, and peak count expansion depending on resources and survey conditions.
    - We estimated 39,383 adult Tule, 278 adult Rogue River Bright hatchery, 8,205 adult Lewis River Bright natural origin, and 1,035 adult Bonneville (BON) Pool Bright fall Chinook salmon in the Washington portion of the LCR ESU.
    - For Tules and BON Brights the proportion of marked adults was 69% and 66%, respectively. Age structure varied by population but most Tule Chinook salmon were age 3 or 4.
    - Most Tules populations were comprised primarily of hatchery fish except the Coweeman (88% unmarked), Lewis (81% unmarked), and the White Salmon (89% unmarked).
    - A total of 204 snouts were collected from the field and examined for CWT. CWT recoveries were uploaded to the regional coded-wire-tag database (RMIS). Unexpanded CWT recoveries indicate most Tule hatchery fish returned to the basin of release or an adjacent basin.
    - BON Brights are not native to this ESU and are successfully spawning in the Upper Gorge and White Salmon populations. Rogue River Brights, also not native to this ESU, are successfully spawning in the Grays River.

2) Coho Salmon Escapement Estimates and Coded-Wire-Tag Recoveries in Washington's Lower Columbia River Tributaries in 2011

- Key Results
    - The adult coho salmon population monitoring program used trap and haul census counts, mark-recapture, smolt expansion, and redd-based methods to monitor adult coho salmon.
    - We estimated a mean escapement of 53,305 (95% CI 44,130 – 70,140) adults and 3 ,776 jacks (95% CI 2,047 - 7,828) for the Washington portion of this ESU below Bonneville Dam excluding the mainstem Lower Cowlitz, mainstem Lower North Fork Lewis, mainstem Toutle/ lower North Fork Toutle (below the Sediment Retention Structure), and Salmon Creek populations.
    - The total mean estimate of unmarked coho salmon adults was 25,364 (95% CI 19,740 – 35,360).

  - As expected in general, populations with an operating coho salmon hatchery, including the Grays, Elochoman, Upper Cowlitz/Cispus, Kalama and NF Lewis rivers, had high proportions of hatchery spawners (mean = 97%, 57 %, 61%, 75%, and 58%, respectively). The converse was generally true for populations without hatcheries, such as the Mill-Abernathy-Germany, Lower Cowlitz, Coweeman, South Fork Toutle, and EF Lewis populations, where we observed low percentages of marked adults (mean = 21%, 5%, 5%, 19%, and 3% respectively).
  - From carcass recoveries on stream surveys, a total of 244 CWTs were recovered from coho salmon in 2011.

3) Detection Probabilities for Passive Integrated Transponder (PIT) Tags in Adult Salmon and Steelhead with Hand Held Scanners

- Key Results
  - We completed a study to evaluate detection rates for PIT tags in adult steelhead in a fisheries sampling setting using a variety of tag scanner types under conditions similar to those expected in sampling of fisheries catch.
  - From 14 trials, the sample mean detection rate was 97.9%. The individual reader model & antenna combinations (Destron Fearing FS2001F-ISO Reader Base Unit with racquet antenna, a Destron Fearing FS2001F-ISO Reader Base Unit with flat plate antenna, a Destron Fearing FS2001F-ISO Reader Base Unit with 24” square antenna, an All Flex Model RS601-3, and a Psion Teklogic data logger) mean detection rates were 97.4%, 97.1%, 99.3%, 99.7%, and 96.8% respectively
  - Short-term PIT tag retention estimates were approximately 98%.

4) Estimates of Columbia River Salmon and Steelhead Harvest Rates for the 2011 Sport and Commercial Fisheries below Bonneville and Summer and Fall Treaty Fisheries above Bonneville based on Passive Integrated Transponder (PIT) Tags

- Key Results
  - Estimates of harvest rates below BON in the commercial fisheries, and particularly in the sport fisheries, were less precise than above BON due to lower tagging rates and smaller numbers of tag recoveries. To address this concern, we calculated harvest rates at a range of population scales including individual release groups and major tributaries, Evolutionary Significant Units (ESU)/Distinct Population Segments (DPS), and for larger population aggregates.
  - Sport Fisheries below Bonneville: Comparisons of harvest rate estimates using PIT tags with those developed by the Columbia River Technical Advisory Committee (TAC) was difficult for sport fisheries because many sport fisheries are mark-selective and PIT tag estimates for these fisheries were specific to

hatchery stocks. TAC estimated a lower mainstem sport spring Chinook harvest rate of 4.29%. This was very similar to the harvest rate based on PIT tags for Snake "ESU/DPS" spring Chinook of 4.2% (95% CI 3.5-4.9%) which had a substantial number of PIT recoveries (n =19), and overlapped the 95% CIs for other stocks for which PIT tag estimates were based on few recoveries. TAC estimated a harvest rate of 5.1% for Up-River Bright fall Chinook, and 1.7% for Wild Snake River fall Chinook in below BON sport fisheries. The PIT tag harvest rate estimated for hatchery Snake fall Chinook was 1% (95% CI 0.6-1.2%), which is lower than both estimates, but it was based on only four tag recoveries. We did not recover any summer Chinook, sockeye or coho salmon PIT tags from sport fisheries. Steelhead sport fisheries are mark-selective and are therefore not directly comparable to TAC estimates of wild stock non-retention impact rates in sport fisheries.

- Below Bonneville Commercial Fisheries: TAC estimated a below BON commercial fishery harvest rate of 1.5% on upriver spring Chinook during the spring fishery. PIT tag based estimates were 0.7, 2.2, and 1.2%, respectively, for hatchery LCR (BON pool), MCR, and Snake spring Chinook, and were similar to TAC's estimates. TAC estimated a harvest rate of 6.2% on Upper Columbia summer Chinook during the below BON summer commercial fishery. The PIT tag estimate was 0.6% based on three tag recoveries. Interestingly, PIT tag recoveries revealed that in addition to Upper Columbia summer Chinook, Upper Columbia Snake spring Chinook were caught in the summer commercial fishery, with respective harvest rates of 0.7 and 1.0%. TAC estimated a Wild Snake River fall Chinook harvest rate of 6.6% which was slightly higher than the PIT based estimate of 4.3% (95% CI 4.3-4.8%) based on 30 recovered tags. For coho, TAC estimated lower river harvest rates of 2.6% and 6.9%, on early and late coho (including lower river coho stocks), respectively. This compared to the PIT based estimate of 3.5% (95% CI 2.8-4.4%) for coho, which mixture model analysis suggested were early timed. .
- Above Bonneville Summer Treaty Fisheries: TAC estimated a harvest rate of 29.5% for Upper Columbia summer Chinook in the summer treaty fishery. PIT tag harvest estimates for this fishery included many more stocks including several spring Chinook stocks. Harvest rates were 4.5% for hatchery Snake spring Chinook and 9.0% for wild Snake spring Chinook, and 2.7% for hatchery Upper Columbia summer Chinook. TAC estimated a harvest rate of 6.9% for Snake River sockeye in the Zone 6 treaty summer fishery, which was very similar to the PIT based harvest rate of 7.2 (95% CI 4.9-9.6%) for Snake River sockeye based on three tag recoveries and to the total upriver sockeye harvest rate 6.7% (95% CI 5.4-8.0%) based on nine tag recoveries. TAC estimated a steelhead harvest rate of 0.84% for A-runs during summer treaty fisheries, which

  compared with PIT based estimates that were closer to 2.0% for MCR, Snake, and UCR hatchery and wild steelhead encountered during this fishery.

  - Above Bonneville Fall Treaty Fisheries: TAC estimated a treaty harvest rate of 53.7% for Bonneville Pool Hatchery (BPH) Chinook. The PIT based estimate was 40% (95% CI 23-58%) based on three tag recoveries and was not statistically different from the TAC estimate. The TAC harvest rate estimate for the Snake River Wild URB grouping was 24.9%, which was higher than the PIT based estimates for hatchery Snake fall Chinook (9.5%; 95% CI 8.6-10.3%) based on a large sample size including 101 tag recoveries. The TAC estimate for the Pool Upriver Brights (PUB) was 39.0%, which was higher than the PIT based estimate of 15.7% (95% CI 10.5-21.8%). TAC reported a 7.2% impact for wild Group A steelhead and a 21.1% impact for Group B steelhead. PIT based estimates for the fall fishery to steelhead included a harvest rate of 3.8% (95% CI 3.1-4.6%) based on 15 tag recoveries for Snake A-run hatchery stocks, and 6.2% (95% CI 6.2-7.8%) for Snake B-run steelhead. Interestingly, LCR wild steelhead from the Wind River were also caught in the fall fishery, yielding a harvest rate of 12.1% (95% CI 7.0-18.4%) in this fishery, despite their management by TAC within the Skamania aggregate, thought to pass BON by June 31, and presumably clear the fishery area shortly thereafter.
  - Sockeye Salmon Population Composition Based on PIT Tags: We were able to successfully estimate the timing and abundance of upriver sockeye stocks at BON based on PIT tags in returning adults detected at BON and tagging rates of adults determined from tributary dam census counts and tag detections. We estimated that 2,338 and 37,680 Snake and Wenatchee sockeye passed BON, respectively, based on an expansion of tagged sockeye counts at BON. Using the subtraction method, the Okanogan sockeye run size at BON was 145,800.
  - Size Selectivity: The results of our selectivity tests suggest that for most commercial and treaty fisheries, our reported harvest estimates were biased high for jacks and younger adults, which were caught at low rates, and were biased low for older fish, which were caught at relatively higher rates. This was less of a problem for sport fisheries, which appeared to be less size- and age-biased. Our analysis suggested age structured models are a more defensible approach for estimating harvest rates in mainstem Columbia River fisheries. Attempts to use travel days to assign ocean age were very successful for sockeye, coho, and Chinook salmon, but were less successful and required data sub-setting for steelhead.

Relationship to the 2008 Federal Columbia River Power System Biological Opinion

Work conducted by the BPA Lower Columbia River CWT Recovery Project (#2010-036-00) supports the following Reasonable and Prudent Actions (RPA) as identified in the 2008 Federal Columbia River Power System Biological Opinion (FCRPS BiOp). http://www.nwr.noaa.gov/hydropower/fcrps_opinion/federal_columbia_river_power_system.html

RPA:

50.4: Fund pilot studies in Wenatchee/Methow/Entiat
Fund status and trend monitoring as a component of the pilot studies in the Wenatchee, Methow, and Entiat river basins in the Upper Columbia River, the Lemhi and South Fork Salmon river basins, and the John Day River Basin to further advance the methods and information needed for assessing the status of fish populations. (Initiate in FY 2007-2009 Project Funding)

Relationship: This project provided PIT tag-based estimates of run timing and fishery-specific harvest rates for these salmon and steelhead populations at hierarchical spatial scales.

50.5: Provide additional status monitoring of SR B-Run Steelhead populations
Provide additional status monitoring to ensure a majority of Snake River B-Run Steelhead populations are being monitored for population productivity and abundance. (Initiate by FY 2009)

Relationship: This project provided PIT tag-based estimates of run timing and fishery-specific harvest rates for wild and hatchery B-run steelhead populations at hierarchical spatial scales.

50.6: Review/modify existing fish pop status monitoring projects
Review and modify existing Action Agencies fish population status monitoring projects to improve their compliance with regional standards and protocols, and ensure they are prioritized and effectively focused on critical performance measures and populations. (Initiate in FY 2008)

Relationship: Through increased monitoring conducted under this project, WDFW was able to develop comprehensive LCR ESU wide VSP monitoring estimates of NOR abundance, pHOS, spatial distribution, and data points for several abundance and productivity metrics (adult to adult recruitment, smolt to adult returns, and natural origin spawners) for Washington Chinook and coho populations; including estimates of precision for the LCR ESU and for individual populations in an effort to meet NOAA monitoring guidelines (Crawford and Rumsey 2009).

51.1: Report available information on population viability metrics in annual and comprehensive evaluation reports. (Initiate in FY 2008).

Relationship: Reported population viability metrics and indicators for Washington's portion of the LCR Chinook and coho salmon. These indicators are formatted to be entered into the Coordinated Assessments data exchange standard.

51.1: Synthesize fish population metrics thru Regional Data Repositories. Support the coordination, data management, and annual synthesis of fish population metrics through Regional Data Repositories and reports such as the CBFWA State of the Resource. (Annually).

Relationship: In 2010, WDFW began implementing standardized data collection and storage protocols for information collected at fish traps and weirs, and during spawning ground surveys. Data was stored in corporate databases including WDFW's Spawning Ground Survey (SGS) and Age & Scales (A&S) databases. Also, WDFW began development of a regional relational database, entitled Traps, Weirs, & Surveys (TWS), to store all monitoring data in a single location and to further facilitate standardization of data collection, data entry, and quality assurance, in order to increase quality, efficiency, and improve analysis/reporting timeliness. This database will feed statewide corporate databases and regional reporting platforms as they are developed.

62.1: Evaluate the feasibility of obtaining PIT-tag recoveries between Bonneville and McNary dams (Zone 6) to determine whether recoveries can help refine estimates of in-river harvest rates and stray rates used to assess adult survival rates. For FY 2009, focus on a pilot to test the feasibility of PIT-tag recoveries of harvested fish in this reach (spring, summer, and fall Chinook salmon and summer steelhead). (Initiate in FY 2007-2009 Projects).

Relationship: This project developed PIT tag harvest rates by modifying the current mainstem lower Columbia River fisheries sampling program to include the collection of PIT tag information along with CWT recovery. Our PIT tag harvest rates provided harvest rates for fall Chinook and steelhead at a finer resolution than previously available. Using PIT tag methods we provided harvest rates for natural origin populations that are currently not available using CWT.

62.4: Support coded-wire tagging and coded-wire tag recovery operations that inform survival, straying, and harvest rates of hatchery fish by stock, rearing facility, release treatment, and location. (Initiate in FY 2007-2009 Projects)

Relationship: This project increased the frequency and intensity of spawning ground surveys in LCR tributaries for CWT recoveries. This lead to additional CWT recoveries and more precise CWT expansion estimators to estimate survival, straying and harvest rates by release group.

Acknowledgements

We thank all the field, data management and hatchery staff who participated in the activities that supported these reports. Funding for this work came from multiple sources: 1) the Bonneville Power Administration through the Lower Columbia Coded Wire Tag (CWT) Recovery Project (BPA Project #: 2010-036-00) ; 2) the National Oceanic and Atmospheric Administration via Mitchell Act Monitoring, Evaluation and Reform funds; 3) NOAA via Pacific Coastal Salmon Recovery Funds (administered thru the Washington State Recreation and Conservation Office; 4) Washington State; 5) PacifiCorp (Lewis River Basin) and 6) Tacoma Power (Cowlitz River Basin). Todd Hillson updated the Executive Summary and compiled the overall document. Todd Hillson, Elise Olk and Julie Grobelny provided comments, edits and feedback on draft versions.

References

Crawford, B.A. and S. Rumsey. 2011. Guidance for Monitoring Recovery of Pacific Northwest Salmon & Steelhead listed under the Federal Endangered Species Act (Idaho, Oregon, and Washington). National Marine Fisheries Service, NW Region. https://www.westcoast.fisheries.noaa.gov/publications/recovery_planning/salmon_steelhead/domains/rme-guidance.pdf

Fall Chinook Salmon Abundance Estimates and Coded-Wire-Tag Recoveries in Washington's Lower Columbia River Tributaries in 2011

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January 2019

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Acknowledgements

We compiled a single fall Chinook salmon monitoring and CWT recovery report because this organizes all the information from study designs to results in a single reference and it was cost-effective to do this. The major funders for Chinook salmon monitoring and reporting are the Bonneville Power Administration (BPA), the National Marine Fisheries Service (NMFS) through the Mitchell Act and Pacific Coast Salmon Recovery Fund (PCSRF). The latter was administered through the Washington RCO. However, we received significant funding through the Pacific Salmon Treaty (PST), specifically from the Coded Wire Tag Implementation Team (CWTIT), Chinook Technical Committee (CTC) and the Southern Fund. This PST funding was used for study design development, improvements in WDFW's internal CWT database, and purchase of CWT wands used to recover CWT on spawning ground surveys. Tacoma Public Utilities provided the numbers of Chinook salmon released into the Tilton and Upper Cowlitz/Cispus Rivers. Martin Liermann (NWFSC) provided assistance with the code for the Jolly-Seber model as parameterized by Schwarz et al. (1993). We thank Erik Kraig for CRC salmon harvest estimates; Bob Woodard, Steve VanderPloeg, Michelle Groesbeck, Danny Warren, Ari Storm, and Gill Lensgrav from the Biological Data Systems Unit for assistance with WDFWs CWT and Spawning Ground Survey database development and management; Lynn Anderson and her staff from the WDFW Coded Wire Tag laboratory for decoding CWTs; John Sneva and Lance Campbell from the WDFW Age laboratory for assigning ages to readable scales; Greg Haldy, Matt Fischer, Amanda Danielson, and other Region 5 hatchery staff for operation and assistance in sampling at weirs, and Vancouver biologists and technicians for implementation of the study design, data collection, and data entry. We would also like to thank Rick Golden (BPA), Rob Jones (NOAA), Scott Rumsey (NOAA), and various committees of the PST for their support of this project. Mention of trade names or commercial products does not constitute endorsement for use.

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Abstract

The Lower Columbia River (LCR) Chinook Salmon Evolutionary Significant Unit (ESU) is composed of spring and fall Chinook salmon populations split between the states of Washington and Oregon. Washington has been estimating abundance and age structure for all its fall Chinook salmon populations for decades but often fell short of the accuracy and precision guidance recommended for salmon recovery monitoring and there was no standardized reporting of important management and salmon recovery indicators. In 2010, the Washington Department of Fish and Wildlife (WDFW) initiated an integrated and comprehensive monitoring program to estimate Chinook salmon spawner abundance, the proportion of hatchery-origin spawners (pHOS), proportion by age, percent females, spawning time, and to recover Coded Wire Tags (CWT). This report presents results from the second year of this monitoring program. Due to challenges in estimating jack Chinook salmon, we reported only adult Chinook salmon estimates. Adults were estimated using weir counts, open and closed mark-recapture models, Area-Under-the-Curve (AUC), redd counts, and/or peak count expansion, depending on resources and survey conditions. We estimated 39,383 adult Tule, 278 adult Rogue River Bright hatchery, 8,205 adult Lewis River Bright natural-origin, and 1,035 adult Bonneville (BON) Pool Bright fall Chinook salmon in the Washington portion of the LCR ESU. The marked proportion was adjusted for hatchery juvenile mass mark rates to account for hatchery production that was released unmarked (~2%). For Tules and BON Brights, the proportion of hatchery-origin adults was 69.2% and 65.9%, respectively. Operation of weirs successfully reduced the proportion of hatchery-origin spawners for some populations. Most Tule populations were comprised of predominately hatchery fish except the Coweeman (88.4% natural-origin), Lewis (81.1% natural-origin), and the White Salmon (88.5% natural-origin). Age structure varied by population, but most Tule Chinook salmon were age-3 or age-4. The adult sex ratio was skewed toward females for most populations. A total of 204 snouts were collected from the field for CWT decoding. CWT recoveries were uploaded to the regional coded-wire-tag database (Regional Mark Information System; RMIS) and unexpanded CWT recoveries indicate most Tule hatchery fish returned to the basin of release or an adjacent basin. BON Brights, not native to this ESU, are successfully spawning in the Upper Gorge and White Salmon populations. Rogue River Brights are successfully spawning in the Grays River. Assumption testing indicated our abundance and proportion estimates were relatively unbiased. Most adult abundance estimates had a coefficient of variation (CV) of less than 15%, and our proportion estimates had a 95% confidence interval of less than 5% except for natural-origin ages in small populations or populations with few unmarked fish. Thus, the majority of adult Chinook salmon monitoring meet the NOAA guidelines for accuracy and precision. This Chinook salmon monitoring program is currently the only Washington program to estimate multiple high level indicators and the associated uncertainty in these indicators at the population and ESU scales.

Introduction

Chinook salmon (*Oncorhynchus tshawytcha*) in the Lower Columbia River (LCR) Evolutionary Significant Unit (ESU) were listed for protection under the Endangered Species Act (ESA) in 1998. In a recent five-year review, the National Oceanic and Atmospheric Administration (NOAA) Fisheries concluded that these fish should remain listed as threatened under the ESA (NOAA 2016). The LCR Chinook Salmon ESU is composed of spring and fall populations split between the states of Washington and Oregon (Myers et al. 2006). The Washington Department of Fish and Wildlife (WDFW) has monitored these populations for decades (WDFW 2011) focused primarily on providing an abundance estimate. However, the need for monitoring of additional indicators and more accurate and precise estimates of these indicators, especially for the fall Chinook populations, has been identified as a high priority for salmon management and recovery (LCFRB 2004, Rawding and Rodgers 2013, Crawford and Rumsey 2011).

The coast-wide Coded-Wire-Tag (CWT) program was developed in the 1970s to evaluate the contribution of different salmonid populations and hatchery programs to various fisheries and to estimate salmon fishery harvest rates, along with evaluation of hatchery rearing practices. The initial protocols for the CWT program included the insertion of a CWT into the snout of a juvenile hatchery salmon, which was accompanied by an adipose fin clip. A proportion of hatchery fish released from selected facilities had a CWT inserted. When salmon were recovered from fisheries and spawning areas, the snout of fish with missing adipose fins were taken to fisheries agency labs for decoding. Later the purpose of the CWT program was expanded to include forecasting run sizes to meet conservation and harvest objectives. For conservation purposes, the vast majority of Chinook salmon released from hatcheries are now adipose fin clipped (sometimes referred to as mass marked and from here on referred to as marked) and WDFW has implemented selective fisheries, which require the release of all adipose-intact (natural-origin and unclipped hatchery-origin; from here on referred to as unmarked) fish. CWTs are now detected electronically by scanning fish with handheld or stationary detectors, rather than using the adipose fin clip as an indicator of CWT presence.

In 2010, the WDFW updated and modified its program to sample LCR spawning grounds for Chinook salmon (Rawding et al. 2014). This program had dual objectives: 1) to estimate Viable Salmonid Population indicators (VSP)(McElhaney et al. 2000) and measure specific indicators to assess Chinook salmon viability (Rawding and Rodgers 2013) including Chinook salmon spawner abundance, the proportion of hatchery-origin spawners, spatial distribution, and sex ratio including the proportion of jacks; and 2) to recover CWTs from spawning fish to provide complete accounting of CWTs, so that harvest rates could accurately be determined and to more comprehensively implement hatchery effectiveness monitoring. The first objective addressed a salmon recovery monitoring gap while the second objective addressed a gap identified from the CWT expert panel (Hankin et al. 2005) and Hatchery Scientific Reform Group (HSRG 2014). This report summarizes population monitoring of VSP indicators for LCR Chinook salmon returns and CWT recoveries in 2011 including overall abundance, abundance by sex, abundance by age and origin, the proportion of hatchery-origin and natural-origin adults, the proportion of marked and unmarked adults, and the proportion of each age class by origin.

Methods

Study area

The LCR Chinook salmon ESU extends from the mouth of the Columbia River up to and including the Big White Salmon River in Washington and Hood River in Oregon, and includes the Willamette River to Willamette Falls, Oregon. Within this ESU, there are a total of 13 Washington populations, 8 Oregon populations, and 2 populations (Lower and Upper Gorge) that are split between the states (Figure 1). In this document, we report on 11 populations in Washington. The Salmon Creek population is believed to have been extirpated, and it is unclear if the Lower Gorge historically supported a Chinook salmon population, but if it did this population is likely extirpated. The Lower Cowlitz and North Fork Lewis populations are surveyed using funds provided by hydropower companies and their results have a separate reporting structure. In addition, we report on Rogue River and Bonneville Pool Brights populations, which have established themselves in the Grays/Chinook population (Roegner et al. 2010) and in the Lower Gorge, Upper Gorge, and White Salmon populations, respectively.

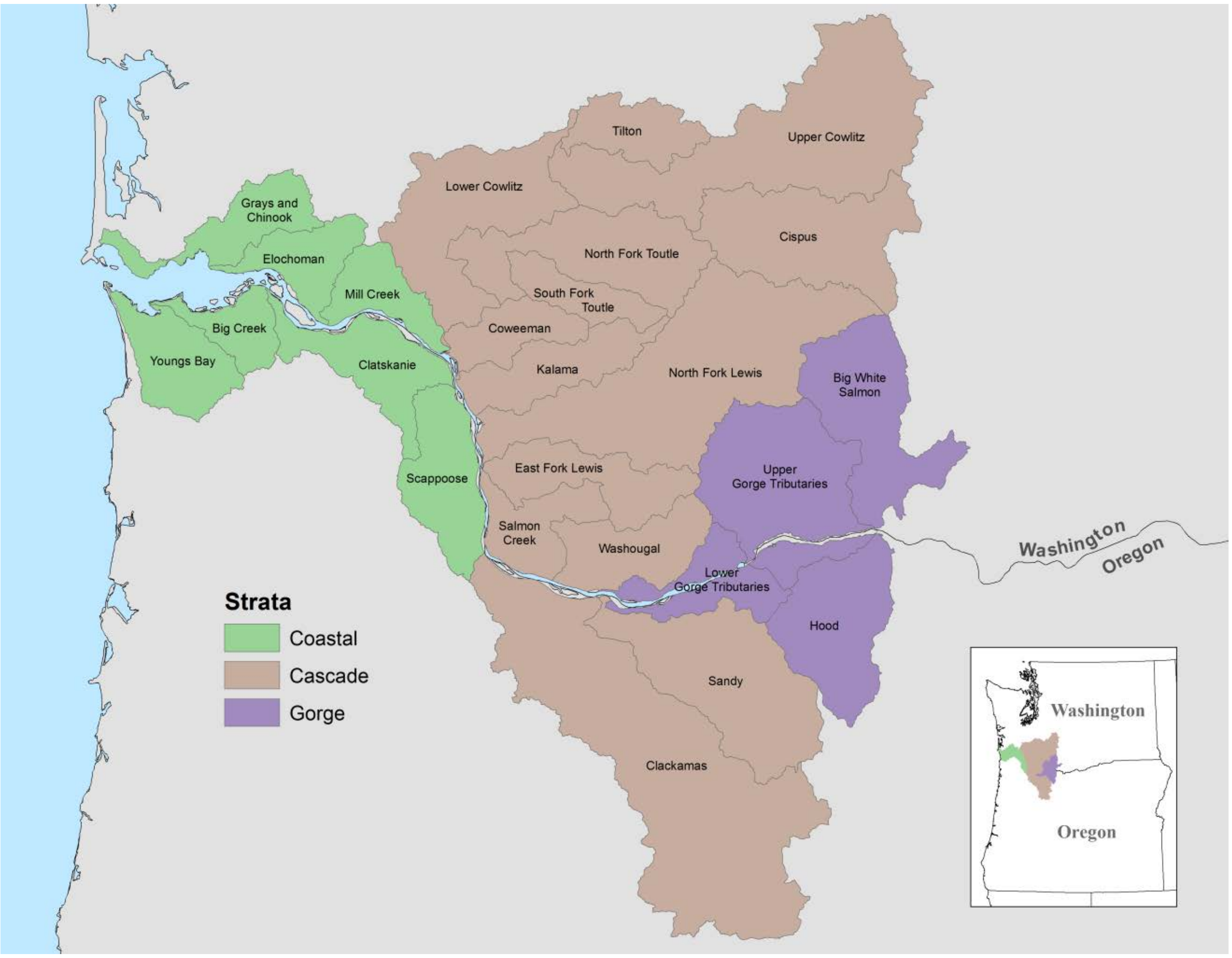

Figure 1. Lower Columbia River Chinook salmon populations and the regional groupings (i.e., strata) in which they occur within the LCR subunit recovery domain.

Monitoring Design

The Chinook salmon monitoring design for the study area used a variety of methods including weir counts, mark-recapture estimates based on live and carcass tagging, redd counts, and periodic counts of live spawners to estimate abundance (Schwarz and Taylor 1998; Sykes and Botsford 1986; Gallagher and Gallagher 2005; Parken et al. 2003, Parsons and Skalski 2010) (Figure 2). When facilities existed, we used census weir counts because these provide the most accurate measure of escapement (Cousens et al. 1982). A permanent dam (Barrier Dam) and the adjacent sorting facility on the Cowlitz River (rkm 82.08) provided census counts of Chinook salmon trapped and hauled to the upper basin (Tilton, Upper Cowlitz, and Cispus rives). Seasonal fall Chinook salmon monitoring weirs are located on the Grays River (rkm 16.50), Elochoman River (rkm 4.39), Green River (rkm 0.64), Coweeman River (rkm 10.94), and the Washougal River (rkm 19.15). However, none of the seasonal weirs provided census counts because a portion of Chinook salmon by-passed the weirs during high flow events. We anticipated that the weirs would not provide a census, so all weir operations simultaneously implemented a mark-recapture design (Schwarz and Taylor 1998), where fish were tagged at the weir and recovered on spawning ground surveys (Grays, Elochoman, Green, Coweeman, and Washougal rivers). We implemented carcass tagging mark-recapture studies (Sykes and Botsford 1986) in Grays, Skamokawa, Elochoman, Mill, Germany, Abernathy, Lower Green, SF Toutle, Coweeman, and Washougal basins. We tracked individual, unique redds on spawning ground surveys in Grays, Coweeman, and SF Toutle basins. In all basins, we counted lives and deads, as well as redds, which allowed us to use Area -Under-the Curve (AUC) using live counts of Chinook salmon identified as "spawners" (Parken et al. 2003; English et al. 1992; Hilborn et al. 1999; Rawding et al. 2014) or peak count expansion based on historic peak count expansion factors from Jolly-Seber carcass tagging projects in the 1960's and 1980's (Tracy et al. 1967; Stockley 1965; Hymer 1991) when census, mark-recapture, or redd-based estimates were not available. As mentioned above, estimates for the Lower Cowlitz and NF Lewis populations were conducted in conjunction with hydropower companies and are not reported here.

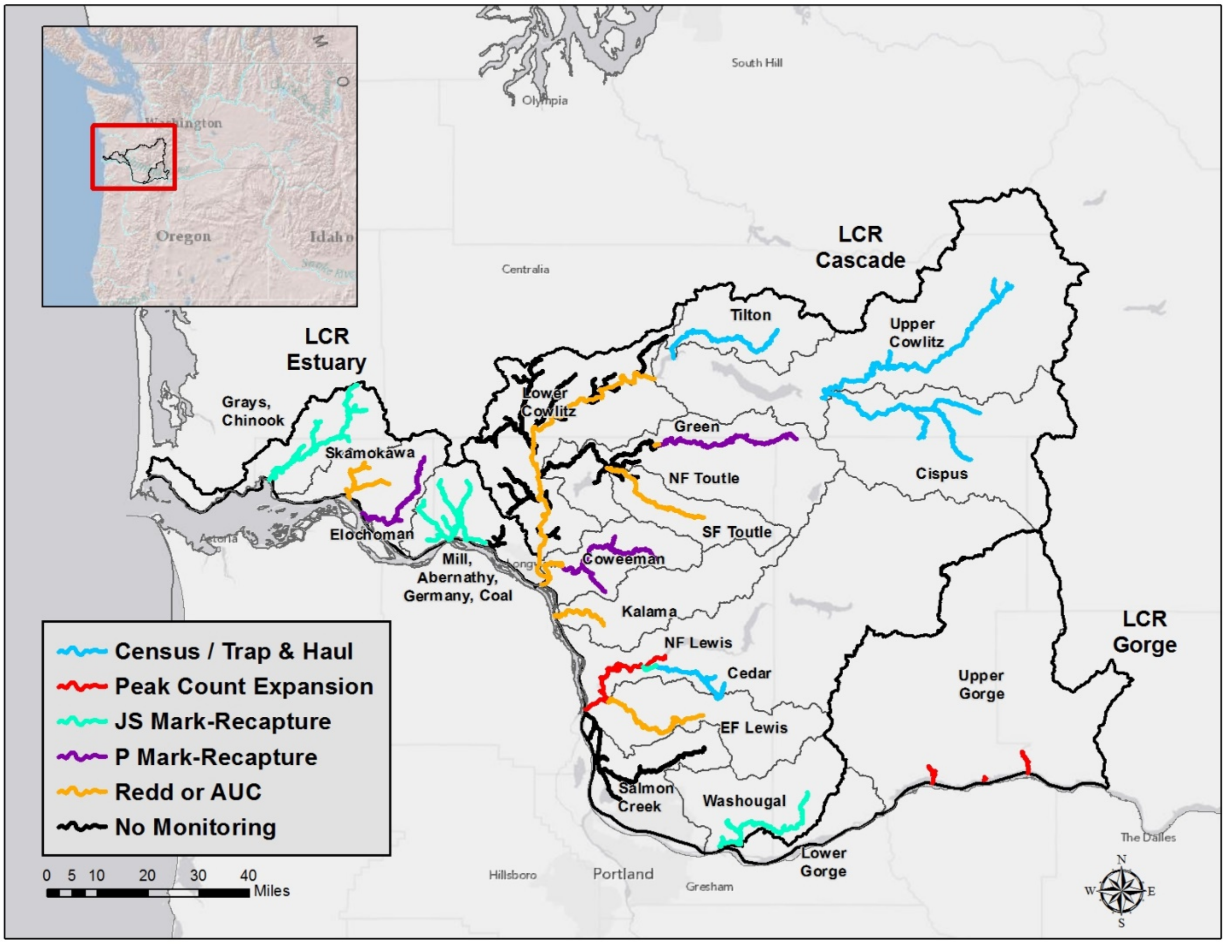

Figure 2. Watersheds comprising the Washington populations of the Lower Columbia River Chinook salmon ESU and the methods WDFW used to estimate their abundance, 2011.

Weirs

Temporary weirs were operated to estimate escapement and obtain biological data in the Grays River (rkm 16.50), Elochoman River (rkm 4.39), Green River (rkm 0.64), Coweeman River (rkm 10.94), and Washougal River (rkm 19.15). The Barrier Dam on the Cowlitz River (rkm 82.08) and the Toutle Fish Collection Facility (TFCF) on the NF Toutle River (rkm 19.31) were also operated. No Chinook salmon were transported into the NF Toutle River because there are no mainstem release sites above the Sediment Retention Structure (SRS) for Chinook salmon trapped at the TFCF. As a result, any Chinook salmon trapped were released downstream into the North Fork Toutle River. In Cedar Creek, a tributary to the NF Lewis River, a ladder trap was operated in a fishway adjacent to a natural falls (rkm 3.22).

Depending on management objectives, Chinook salmon collected at these facilities were used for hatchery broodstock, donated to food banks, used for nutrient enhancement, or transported and released above the facility. We made the following key assumptions for the weir programs: 1) the count of all transported fish was without error, 2) all unmarked fish released survived to spawn except on the Green, Elochoman, and Coweeman rivers where we had estimates of pre-spawning mortality, 3) transported fish spawned in the watershed they were released in, 4) when fisheries in the Elochoman, Green, Upper Cowlitz, Cispus, and Tilton rivers occurred only marked fish were harvested in accordance with regulations, 5) there was no illegal harvest of salmon, 6) survival of all unmarked caught and released fish was 100%, and 6) the WDFW methodology to expand catch record card (CRC) reported catch to total harvest and variance are correct.

Closed Population Models

To measure the success of weir operation in the Grays, Elochoman, Green, and Coweeman rivers, we implemented mark-recapture studies. Chinook salmon captured at these sites were tagged with uniquely numbered Floy tags and secondary mark prior to release upstream of the weir with recaptures occurring at either upstream traps or during spawning ground surveys. This allowed us to use the Darroch estimator, which was developed for time stratified Petersen mark-recapture abundance estimates (Darroch 1961, Seber 1982). Schwarz and Taylor (1998) indicate that the following assumptions must be met to provide an unbiased estimate of abundance using the Petersen estimator: 1) no tag loss, 2) no handling mortality, 3) all tagged and untagged fish are correctly reported, 4) the population is closed, and 5) equal capture probability during the tagging or recapture events, or tagged fish mix uniformly with untagged fish.

Open Population Models

The Jolly-Seber (JS) model estimates population abundance in mark-recapture studies where the population is open (Jolly 1965; Seber 1965), and has been widely used in estimating Pacific salmon spawning escapement using both live fish (Schwarz et al. 1993; Jones and McPherson 1997; Rawding and Hillson 2003) and salmon carcasses (Parker 1968; Stauffer 1970; Sykes and Botsford 1986). The carcass tagging model has been used extensively in LCR tributaries to estimate Chinook salmon abundance (McIssac 1977; Rawding et al. 2006). The JS model utilizing carcass tagging was used to generate estimates for the Grays, Mill, Abernathy, Germany, Lower Cedar Creek, and Washougal basins. Seber (1982) and Pollock et al. (1990) provide details of study design, assumptions, and analysis of mark-recapture experiments using the JS model. The five assumptions of the Jolly-Seber model that must be met in order to obtain unbiased population estimates from the model (Seber 1982) are: 1) equal catchability, 2) equal survival of tagged and untagged individuals between sampling events, 3) no handling mortality, 4) no tag loss, and 5) instantaneous sampling.

Peak Count Expansion

We used historic JS estimates to develop peak count expansion (PCE) factors for the Wind, Little White Salmon, and Big White Salmon basins. There are a number of ways to estimate the peak count expansion factor including the mean of the ratios (Parken et al. 2003), calibrated regression, and inverse prediction (Parsons and Skalski 2009). Using a Bayesian framework (detailed in Methods-Data Analysis), we divided the posterior distribution of the abundance estimate by the highest single weekly count (or peak count) of live fish plus carcasses or the peak count of carcasses only, depending on the basin, to obtain a PCE factor. Rawding and Rogers (2013) list the following critical assumptions for the PCE method: 1) the peak day of abundance is known and the survey takes place on the peak, 2) if the entire spawning distribution is not surveyed, the proportion of fish in the index or indices sections is similar to that of the year(s) used to develop the PCE factor, 3) observer efficiency is similar in all years, and 4) the proportion of fish observed on the peak day is similar over all years.

Spawning Ground Surveys

The purpose of spawning ground surveys was to collect data required to estimate abundance and to collect biological information from sampled fish. Surveys were scheduled weekly from the beginning of fish entry (August to September) until completion of spawning (October to December), depending on the population, and over the entire spawning distribution as developed by Rawding et al. (2010). Exceptions were cases where the PCE method was used to estimate abundance. For those areas, three weekly surveys were scheduled around the historical peak spawning week in the index area to capture the actual peak week. Since we had no successful weir or mark-recapture estimates in Skamokawa, Green and Coweeman areas below the weirs, SF Toutle, Kalama, and EF Lewis rivers, we needed alternate methods to estimate abundance. We used previous JS estimates in conjunction with surveys designed to provide the number of unique redds to develop estimates of apparent females per redd on the Coweeman and EF Lewis rivers from 2003-2011, where the apparent females per redd is the number of unique redds counted during the season divided by the mark-recapture estimate of females. In addition, we used the 2011 mark-recapture data to develop estimates of apparent residence time from the Grays, Abernathy, Germany, and Washougal basins, where apparent residence time is the estimate of Area-Under-the-Curve (in fish days) divided by the mark-recapture adult abundance estimate. These females per redd and apparent residence time estimates were applied to redd and live fish counts to estimate abundance in the Skamokawa, Lower Green, Lower Coweeman, SF Toutle, Kalama, and EF Lewis rivers. Rawding and Rodgers (2013) listed the critical assumptions for redd surveys used to estimate abundance: 1) representative spatial and temporal sampling throughout the spawning period, 2) estimates of apparent females-per-redd which are from adjacent populations, or from the same population in previous years, are consistent between the study population (one used to derive the females per redd estimate) and the treatment population and the methods used to identify and enumerate redds follow a standard redd survey protocol, and 3) the apparent females-per-redd and sex ratio from other streams, or years, accurately represent the females-per-redd and sex ratio of the treatment population. For the AUC method, Rawding and Rodgers (2013) identified the first assumption is that representative spatial and temporal sampling occurs throughout the spawning period. If concurrent observer efficiency and survey life estimates are made, the second critical assumption for AUC is that these estimates are spatially and temporally representative of the survey area and occur throughout the spawning period. Finally, survey frequency should occur every 7 to 10 days and surveys should not be missed during peak spawning time (Hill 1997). The methods used to estimate abundance for each monitoring unit are found in Table 1.

Table 1. Methods used to estimate fall Chinook salmon abundance in 2011.

Subpopulation	Abundance Method
Grays	Jolly-Seber model based on carcass tagging
Skamokawa	AUC using mean apparent residence time from 2011
Elochoman	Petersen estimate minus pre-spawn mortality & CRC harvest
Mill	Jolly-Seber model based on carcass tagging
Abernathy	Jolly-Seber model based on carcass tagging
Germany	Jolly-Seber model based on carcass tagging
Tilton	Trap and haul census count minus CRC harvest
Upper Cowlitz/Cispus	Trap and haul census count minus CRC harvest
Green	Above weir: Petersen estimate minus pre-spawn mortality and CRC harvest; Below weir: redds with mean apparent female per redd and population specific sex ratio
SF Toutle	Redds with mean apparent females per redd and population specific sex ratio
Coweeman	Above weir: Petersen estimate minus pre-spawn mortality and CRC harvest; Below weir: AUC with mean apparent females per redd and population specific sex ratio
Kalama	AUC using mean apparent residence time from 2011
Cedar	Above ladder: census count ; Below ladder: Jolly-Seber model based on carcass tagging adjusted for ladder fallbacks
EF Lewis	AUC using mean apparent residence time from 2011
Washougal	Jolly-Seber model based on carcass tagging
Wind	PCE of combined live and carcass counts based on 1964 Jolly-Seber Tule carcass tagging analysis
Little White Salmon	PCE of carcasses based on 1966 Jolly-Seber Tule carcass tagging analysis
Big White Salmon	PCE of combined live and carcass counts based on 1989 Jolly-Seber Bright carcass tagging analysis
Grays (Rogue)	Jolly-Seber model based on carcass tagging and the % Rogue Bright (based on left ventral clips) from carcasses recoveries on spawning ground surveys.
Wind (Brights)	PCE of combined live and carcass counts based on 1964 Jolly-Seber Tule carcass tagging analysis
L. White Salmon(Brights)	PCE of carcasses based on 1966 Jolly-Seber Tule carcass tagging analysis
B. White Salmon (Brights)	No estimate due to turbid conditions post Condit Dam removal.

Data Collection

Traps and Weirs

Data collection at weirs was similar to the standardized methods for collecting salmon data at weirs described in Zimmerman and Zubkar (2007). Chinook salmon populations originating above dams in the Cowlitz watershed were trapped at the Barrier Dam and hauled into the Tilton and Upper Cowlitz /Cispus rivers allowing for their enumeration and the collection of biological data. Cowlitz River Chinook salmon captured at the Barrier Dam were anesthetized using electro-anesthesia and sampled for sex and origin. In addition, male Chinook salmon were classified as jacks or adults based on size. Adult salmon captured at the Barrier Dam were released to their natal watersheds based upon differential marking they received as smolts when they were transported downstream of the Cowlitz dams; since out-migrants caught at the Mayfield trap were tagged with blank CWT and not adipose fin clipped, these fish were released in the Tilton River which empties into Mayfield Lake, whereas non-CWT positive unmarked fish were transported to the Upper Cowlitz and Cispus Rivers where they presumably originated. In addition, adipose clipped hatchery Chinook salmon were also trucked and released in the Tilton, Upper Cowlitz and Cispus rivers to provide recreational fishing opportunity and spawners to seed the available habitat.

Temporary weirs were installed on the Grays, Elochoman, Green, Coweeman, and Washougal rivers on August 17, August 9, August 4, September 9, and August 20, respectively. The Grays River Weir was removed on October 20. The Elochoman River Weir was removed during a high-water event on October 21 and not re-installed because Chinook salmon entry into the Elochoman basin was believed to be complete for the season. The Green River Weir operated until November 17 for a coho salmon study. The Coweeman River Weir was removed on October 31, well past the last Chinook captured date. The Washougal River Weir was removed on October 10. Because of the possibility of weir failure due to high water events, we tagged fish to implement a mark-recapture study at each of the locations. All fish (except the Green River Weir where the sample rate was every other) passed upstream at the weirs were double tagged with uniquely numbered Floy™ (hereafter Floy) tags (FD 68BC T-bar Anchor tags; Floy™ Tag & Mfg., Inc. Seattle, WA). Floy tags were placed adjacent to the posterior edge of the dorsal fin, with one tag on each side of the fish. An operculum punch was applied as a secondary mark, and punch shapes were rotated weekly, allowing assessment of Floy tag loss and assignment of a recovered fish back to the weekly release group if both Floy tags were lost. Additionally, all fish were sampled for biological data (fork length, gender, mass mark status) and samples (genetics and scales).

All fish passed upstream at the Elochoman and Coweeman river weirs were sampled for biological data and Floy tagged prior to release. At the Green River Weir, every other fish passed upstream was sampled for biological data and Floy tagged prior to release.

A ladder trap was installed in the fishway at the Grist Mill Falls on Cedar Creek. It was operational on August 18 and was operated continuously throughout the entire Chinook salmon migration period. Due to variability in ladder efficiency (some fish likely jump the falls at certain flows), a mark-recapture study was implemented. All Chinook salmon passed were tagged with a single, uniquely numbered operculum tag and sampled for biological data.

Biological data consisted of collecting scale samples, sex determination, measuring the fork length, and recording fin clips to determine mass mark status (hatchery or natural-origin).

Except for the trap at the Barrier Dam on the Cowlitz River, scales were taken from live fish from the preferred area, as described in Crawford et al. (2007b). Scales were also collected from carcasses (see Spawning Ground Survey section below). Biological sampling included the following: fork length, which was taken by running the tape measure from the tip of the snout to the fork in the tail, gender, which was determined, based on morphometric differences between males and females, and mass mark status, which was determined by the presence or absence of the adipose fin.

Spawning Ground Surveys.

Data collection during scheduled weekly spawning ground surveys was similar to the standardized methods for collecting salmon data from carcass counts, redd surveys, and foot-based visual counts described in Crawford et al. (2007a and 2007b) and Gallagher et al. (2007). Data were collected at the reach scale, which often were based on historical WDFW section breaks but in some cases were collected at finer scale (Grays, Mill, Abernathy, Germany, and Coweeman). The start and end of each survey reach was geo-referenced and its coordinates were recorded on a on a Garmin Oregon 550 unit set in NAD 83.

All live adult and jack salmonids were identified to species based on physical characteristics unique to each species and recorded by species (Crawford et al. 2007a). Live salmon were classified as adults or jacks although this can be difficult to accurately determine on live fish during visual surveys. Live salmon were also classified as either a “spawner” or a “holder”. Salmon were classified as a spawner if they were on redds or observed in spawning habitat (in, on, or around tailouts, riffles, and glides with spawnable substrate). A fish was classified as a holder if it was observed in an area not considered spawning habitat, such as pools or observed in areas of large cobble, bedrock or in boulder riffles (Parken et al. 2003).

Redd surveys in the Grays, Coweeman, and the SF Toutle followed the protocols of Gallagher et al. (2007). Surveys were scheduled weekly and followed methods described in Rawding et al. (2006a and 2006b). All identifiable redds were flagged, and their location (latitudinal and longitudinal coordinates) was recorded. Prior to recording a redd’s location, GPS units were allowed to acquire satellites until an accuracy of ± 100 feet or less was obtained. In subsequent surveys, previously flagged redds were inspected to determine if they should be classified as “still visible” or “not visible”. A redd was classified as “still visible” if it would have been observed and identified without the flagging present, and was recorded as “not visible” if it did not meet these criteria. These data were collected to generate an estimate of the time period redds were visible to surveyors, or apparent redd life.

All carcasses that were not totally decomposed were sampled for external tags (Floy T-bar or carcass tags), secondary marks (e.g., operculum punches), and biologically sampled for fork length, sex, adipose fin presence, and condition (extent of decomposition). Sex was determined based on morphometric differences between males and females. If necessary, the abdominal cavity was cut open to confirm sex and determine spawning success. Spawning success was approximated based on visual inspection, ranging from 100% to 0% success. A fish with <25% spawning success (>75% egg retention) was considered a pre-spawning mortality. Carcass condition and gill color were recorded to qualitatively assess carcass freshness (Sykes and Botsford 1986). Scale samples were collected by selecting scales from the preferred area as described in Crawford et al. (2007b). Preferred scales were sampled from an area ~ 1-6 scale rows high, and ~15 scale rows wide, above the lateral line in a diagonal between the posterior insertion of the dorsal fin and anterior insertion of the anal fin. Scales were removed using forceps with special care to select scale samples that were of good quality (round shape, non-regenerated) and not adjacent to one another (to minimize the effects of regeneration) as described in a WDFW technical report (Cooper et al. 2011). Scales were placed on the gummed portion of WDFW scale cards with their exterior surfaces facing up. The scale card number, position number, date, and location created a unique code in the age and scales (A&S) database. Due to a high number of carcasses on the Washougal and Kalama rivers, these carcasses were systematically sampled for biological data and scales.

For analysis and reporting purposes, Chinook salmon carcasses were grouped into the following categories: unmarked, marked, and unknown. Unmarked fish had an intact adipose fin and an intact snout, marked fish have an intact snout but were missing their adipose fin, and unknown fish either damaged caudal peduncle (e.g., adipose fin area unexaminable unknown) or missing portions of the snout. All unmarked and marked fish were sampled for CWT following standard protocols (NWMT 2001). The surface of the CWT wand with radiating arrows was placed in contact with the snout and moved from the right to the left eye, and then up and over the snout area. The wand was also inserted into the mouth with the radiating arrows rubbed against the roof of the mouth in vertical strokes. If a CWT was detected, the wand's red LED light illuminated and the wand emitted a beep. When a CWT was detected, the snout was collected by cutting across the head straight down behind the eyes (Crawford et al. 2007b). The snout was placed in a plastic bag with a numbered tag to link the snout to biological data (length, sex, fin clips, spawning success for females, and scale sample number) recorded on the scale card or other datasheet. Snouts were stored in a freezer and periodically delivered to the WDFW's CWT lab in Olympia for CWT recovery and decoding.

All carcasses were inspected for carcass tags. Untagged carcasses in the Grays, Skamokawa, Elochoman, Mill, Germany, Abernathy, Lower Green, SF Toutle, Coweeman, and Washougal basins were tagged on the inside of both opercula with uniquely numbered plastic tags (McIssac 1977). Tags were placed on the inside of the operculum to limit predation and potential bias in recovery rates due to observation of brightly colored tags. Tagged carcasses were then placed into moving water to facilitate mixing with untagged carcasses (Sykes and Botsford 1986). When tagged carcasses were recovered, surveyors recorded the tag numbers, the tags were removed, and the carcass was mutilated by removing the tail to prevent re-sampling/tagging (a loss on re-capture event in the Jolly-Seber model).

Sample Processing

Scale Analysis

Scale preparation and analysis followed WDFW protocols (Cooper et al. 2011). Acetate impressions were made of the scale samples using a scale card press, samples were covered with strip of clear acetate (0.5mm thickness) and pressed under 1200-1300 PSI @ 100 degrees C for 30 seconds to 1 minute. The acetate impressions of the scales were aged using a modified Gilbert/Rich ageing notation (Groot and Margolis 1991), where annuli were counted along with the scale edge to produce a total age in years. Annuli were defined as an area of narrowly spaced circuli that represent winter/early spring growth. Age was recorded as the total age in years followed by the age at outmigration. For example, a typical fall Chinook salmon adult is age 4_1. This notation indicates a total age of 4 and that as a juvenile this individual only spent one winter in freshwater and migrated to the ocean as a fry or sub-yearling. . After being aged in Olympia by an ageing specialist, scale samples were returned and entered into the Region 5 Age & Scales database.

CWT Lab Analysis

The recovery of CWT tags at the WDFW lab follows the procedures outlined in the tag recovery chapter (Blankenship and Hiezer 1978) of the Pacific Coast Coded Wire Tag Manual and is briefly repeated here. Each snout is passed through a magnetic detector to determine “tagged” and “untagged” status. Untagged snouts are set aside and rechecked after following protocols to re-magnetizing the tag. To re-magnetized a tag, the length of the tag must pass through a horseshoe magnet in a plane parallel with a straight line connecting the poles. If the tag angle is off more than 40 degrees, the tag may not be magnetized. Therefore, the head is passed through the magnet in three positions corresponding to the X, Y, and Z-axes of the magnet and then passed through the magnetic detector again. Large heads are often dissected to maximize tag detections. Snouts determined to have no CWT after re-magnetization attempts have been made are saved and an x-ray machine is periodically used to determine tag presence in these “no tag” snouts. After determining a tag is present, the snout is dissected, and the tag located by process of elimination. After recovering the tag, the binary code is determined by observation under a microscope. Recovered CWT data is then entered into the WDFW CWT database and provided to managers as needed and uploaded into the Regional Mark Information System (RMIS).

Data Analysis

Overview

Chinook salmon abundance estimation was relatively straightforward for mark-recapture, trap and haul, and peak count expansion areas, but required combining multiple sources of information for AUC and redd survey areas. Briefly, a spawning habitat model was developed for the ESU to predict the extent of spawning habitat (i.e. the spawning habitat sampling frame) (Rawding et al. 2010). Either the entire sampling frame was surveyed weekly or an index reach was surveyed weekly with the entire sampling frame surveyed near peak abundance. The estimate for the remainder of the frame was based on the ratio of the total count within the index compared to the count within the index on the day the entire sampling frame was surveyed. For the purpose of reporting metrics in the document, we classified adult Chinook salmon as $\geq$60 cm.

Modeling Approach

Data analysis was conducted using a Bayesian framework. Bayes rule states the posterior distribution, $p(\theta|y)$, is the product of the prior distribution, $p(\theta)$, and the probability of the data given the model or likelihood, $p(y|\theta)$, which is expressed by

$$p(\theta \mid y) = \frac{p(\theta)\, p(y \mid \theta)}{p(y)} \tag{1}$$

where y are the data, θ are the parameters, and $p(y) = \Sigma_\theta\, p(\theta)p(y|\theta)$ for all discrete values or $p(y) = \int p(\theta)\, p(y \mid \theta) d\theta$ for continuous data (Gelman et al. 2004). The formula of the posterior distribution may be complex and difficult to directly calculate. Samples from the posterior distribution can often be obtained using Markov chain Monte Carlo (MCMC) simulations (Gilks et al. 1996). WinBUGS is a software package that implements MCMC simulations using a Metropolis within Gibbs sampling algorithm (Spiegelhalter et al. 2003) and has been used to estimate fish abundance (Rivot and Prevost 2002, Link and Barker 2010). For the Bayesian methods we tested the sensitivity of the prior and convergence based on the Brook-Gelman-Rubin statistic (Su et al. 2001, Appendix 1).

We chose to specify vague priors for parameters because there was little prior information and we wanted an objective analysis to “let the data speak for themselves”. Currently, there are not consensus reference priors for objective Bayesian analysis, although there has been much work in this area (Tuyl et al. 2009). For the binomial or multinomial distributions, we chose to evaluate the Beta and Dirichlet priors parameterized with $\alpha = \beta = 1$ or 0.5, which are the Bayes-LaPlace uniform prior and the Jefferies prior, respectively. We adopted the Bayes/LaPlace prior for our analysis but conducted a sensitivity analysis by comparing the results of the two priors in select cases. For abundance estimates in mark-recapture, we chose a uniform prior, so that the minimum and maximum bounds did not truncate the posterior distribution.

Bayes rule was used for null hypothesis testing based on the Bayes factor (BF), which is similar to the likelihood ratio. However, the likelihood ratio is based on the parameters that maximize the likelihood while the Bayes factor integrates over the values of the parameter specified by the prior distribution. The BF can be expressed as

$$\Pr(H_i \mid D) = \frac{\Pr(H_i) \text{x} \Pr(D \mid H_i)}{\sum_j \Pr(H_j) \text{x} \Pr(D \mid H_j)} \tag{2}$$

where D is the data, H is the hypothesis, Pr is the probability, and subscripts i and j indicate individual and multiple hypotheses, respectively. Zhou (2002) and Murdoch et al. (2010) noted that Chinook salmon carcass recoveries are biased toward longer fish and females. For the equal capture assumption, we used a logistic regression to test the null hypothesis that there is no difference in recapture probabilities by sex or length (Link and Barker 2006).

$$\text{logit}(\pi_i) = B_0 + B_1 x_{1i} + \ldots B_k x_{k\,i}\,. \tag{3}$$

where model 1: constant, model 2: sex, model 3: length, and model 4: sex + length. The covariates were centered and standardized to allow for better mixing and interpretation of the covariates and we used a Reverse Jump Markov Chain Monte Carlo (RJMCMC) to simultaneously evaluate all models and calculate the posterior model probabilities. Due to the sensitivity of Bayes Factors to vague priors, we followed the approach in Link and Barker (2006) to assign mean zero normal priors with variance $V/(k_i + 1)$ to the regression coefficients. This way, regardless of the number of parameters in the model, the total prior uncertainty in the linear predictor is fixed. We used an inverse Gamma prior (3.2890/7.8014) for the variance because this distribution for the logit (π_i) so that π_i are approximately uniform (0,1). The Bayes factors were calculated from the model posteriors (Link and Barker 2006, 2010).

The Bayes factors for proportions were computed analytically from the marginal likelihood using the beta binomial distribution (Ntzoufras 2009). Bayes factors are known to be sensitive to the prior distribution to estimate θ. However, since our analysis is limited to comparison of binomial models, we adopted the standard reference prior, which is a uniform distribution between 0 and 1. We tested the null hypothesis using this method to test the complete mixing and equal proportion hypothesis tests (Schwarz and Taylor 1998) to determine if the pooled Petersen was appropriate (Table 2) (see closed population abundance estimates below). These null hypothesis tests are: 1) there is no difference in the proportion of marked fish by recovery period and 2) there is no difference in the proportion of recovered fish by release periods. In addition, we also tested the null hypothesis that the there was no difference in the proportion of marked fish by recovery location.

Table 2. Bayes factor interpretation from Kass and Rafferty (1995).

B_{10}	Evidence against H_0	B_{10}	Evidence for H_0
1 – 3	Negligible Support	1-0.33	Negligible Support
3 – 20	Positive Support	0.33-0.05	Positive Support
20-150	Strong Support	0.005-0.0067	Strong Support
>150	Very Strong Support	<0.0067	Very Strong Support

Due to computational challenges, it is difficult to estimate Bayes factors when using MCMC approaches (Ntzoufras et al. 2009, Lunn et al. 2012) and this occurred in mark-recapture model selection. As a practical solution, we limited the number of JS models to four (Table 3), and used the Deviance Information Criteria (DIC) developed by Spiegelhalter et al. (2002) for model selection:

$$DIC = Dev(\theta_m) + pv \tag{4}$$

where $D(\theta_m)$ is the posterior mean deviance for the model and $pv = Var(D(\theta|Y))/2$ and is a measure of the number of effective terms in the model. We choose pv over the more commonly used pD for an estimate of effective parameters, because pv performs well when there is weak prior information and is invariant to parameterization (Gelman et al. 2004). DIC is a Bayesian analog of Akaike Information Criteria (AIC) but based on MCMC outputs (Burnham and Anderson 2002). Similar to the model support scale developed by Burnham and Anderson (2002), Spiegelhalter et al. (2002) suggested that models ΔDIC of less than two have considerable support, models with ΔDIC having three-seven have less support, and models with ΔDIC > 10 have negligible support.

Table 3. Model notation used for JS carcass tagging (from Lebreton et al. 1992). Model names indicate whether capture, survival, or entrance probabilities were allowed to vary over time (“t”) or were held constant (“s”).

Model	Probability of capture (*p*)	Probability of survival (φ)	Probability of entry (b^*)
t t t	varies over periods	varies over periods	varies over periods
s t t	equal over periods	varies over periods	varies over periods
t s t	varies over periods	equal over periods	varies over periods
s s t	equal over periods	equal over periods	varies over periods

In the Bayesian models, there is extrinsic non-identifiability when the posterior distribution is dominated by the prior due to sparse data (Kery and Schaub 2012). In these cases, the parameter estimates are considered sensitive to the prior. One method of testing for extrinsic non-identifiability in a Cormack-Jolly-Seber (CJS) model is a sensitivity analysis based on different priors (Brooks et al. 2000). Since it can be time consuming to re-run models with different priors, Gimenez et al. (2009) proposed to test for extrinsic non-identifiability in mark-recapture models by comparing the overlap between a flat prior and the resulting posterior distribution. They proposed that parameters are considered weakly identifiable, thus sensitive to the prior, if the overlap between the prior and posterior is greater than 35%, which was the standard we used in our analysis. For our CJS models, we specified priors using the beta distribution where $\rho \sim$ Beta(1,1) and ϕ ~Beta(1,1), which was used as an objective prior and its role in assessing weak identifiability (Brooks et al. 2002, Tuyl et al. 2009, Gimenez et al. 2009).

Goodness of Fit (GOF) Tests

The purpose of a GOF test is to identify potential inadequacies in the fit of the model to the observed data. One Bayesian approach used for GOF testing is posterior predictive checking, which is a comparison of the posterior predictive distribution of replicated data from the model with the data analyzed by the model (Gelman et al. 2004). In other words, the predictive data ($y.rep_i$) is the expected observation after replicating the study having observed the data (y_i) and assuming the model is true. When using MCMC simulations, a measure of discrepancy (D) is computed for the actual and replicated datasets for each iteration. An assessment of the posterior distributions of $D\ (y^{rep},\theta)$ and $D\ (y,\theta|y)$ provides individual and overall GOF measures. With the posterior or Bayesian *p*-value = $\Pr(D(\ y^{rep},\theta) > D(y,\theta|y)$. The interpretation of the Bayesian *p*-value is the proportion of the times the discrepancy measure of the replicated data is more extreme than the observed data. If there is a good fit of the model to the data, we would expect the observed data to be similar to the replicated data, resulting in a Bayesian *p*-value of 0.50, while values near 0 or 1 indicate that the model does not fit the data.

There are many possible types of discrepancy measures including the Freeman-Tukey, standardized Pearson residual, chi-square, and deviance statistics (Brooks et al. 2000, Lunn et al. 2012). Since mark recapture counts consist of many zeros and this test statistic does not require the pooling of bins with small or zero values, we used the Freeman-Tukey statistic (Brooks et al. 2000), which is expressed as

$$d_i(\theta) = \sqrt{y_i} - \sqrt{E(y_i \mid \theta)} \qquad (5)$$

where d_i is an individual discrepancy, y_i is an individual data point, and $E(y_i|\theta)$ is the fitted value of y_i based on the function to determine the parameter θ. When estimating independent values such as the proportion of hatchery fish or the age of hatchery fish in a single population, Bayesian *p*-values are typically near 0.5. Although Bayesian *p*-values are commonly used for model checking, there have been criticisms of this approach. First, it uses the data twice to build and check the model, which may not be as robust as other methods for testing model adequacy (Carlin et al. 2009, Kery 2010). Second, it is unclear what cut off values to use for the interval (5% to 95%) to indicate lack of model fit. Third, the posterior distribution is influenced by the prior distribution, thus a Bayesian *p*-value is influenced by the prior distribution (Brooks et al. 2000). These concerns have been addressed (Gelman et al. 2004, Carlin et al. 2009, and Brooks et al. 2000) but are beyond the scope of this paper. Due to these concerns, we used posterior predictive model checking as a qualitative measure of model adequacy and if a Bayesian *p*-value indicated the model did not fit the data, we considered this to indicate significant lack of model fit (Link and Barker 2009). We primarily used GOF to test the recapture portion of the JS model, which is similar to the RELEASE GOF test or parametric bootstrapping in the program MARK (White and Burnham 1999), and to test the recapture portion of the Darroch model.

Tag Loss

There was no need to assess tag loss in our closed population experiments because we used a permanent operculum punch that was rotated weekly as secondary mark. We conducted double tagging/marking experiments to estimate tag loss in open population studies, except in Cedar Creek, where only a single tagged was applied. We assumed tag loss was the same for each of the tags because the tag type and location were the same and that individual tag loss was independent. The summary statistics include carcass recoveries with one and two tags, and the number of tags released (Table 4). The fundamental parameter is the probability of losing a tag and the derived parameters include the probability of recovering a fish with one or two tags, the probability of losing two tags, the probability of retaining at least one tag, and the number of tags adjusted for tag loss (Table 5). The likelihoods for single and double tag recoveries are found in Table 6.

Table 4. Summary statistics used in a double tagging experiment to estimate tag loss.

Statistic	Definition/Equation
t_1	Number of fish recovered with one tag
t_2	Number of fish recovered with two tags
t_all	Number of fish with one or two tags, *t_all* = *t_1* + *t_2*
Tags	Number of tags release

Table 5. Fundamental and derived parameters in a double tagging experiment to estimate tag loss assuming the probability of losing a tag was the same for each tag, and the loss of an individual tag was independent.

Parameter	Definition/Equation
p_tl	Probability of losing a tag
p_1	Probability of recovering a fish with one tag, $p\_1 = ((2*p\_tl)*(1-p\_tl))/(1-p\_tl*p\_tl)$
p_2	Probability of recovering a fish with two tags, $p\_2 = ((1-p\_tl)*(1-p\_tl))/(1-p\_tl*p\_tl)$
p_0	Probability of losing two tags, $p\_0 = p\_tl * p\_tl$
q_0	Probability of retaining at least one tag, $q\_0 = 1 - p\_tl*p\_tl$
T_adj	Number of tags released adjusted for tag loss, $T\_adj = Tags * q\_0$

Table 6. The likelihoods for the independent tag loss model when using the same tag type.

Description	Likelihood
Pr(capture of fish with one tag)	$t\_1 \sim$ Binomial(p_1,t_all)
Pr(capture of fish with two tags)	$t\_2 \sim$ Binomial(p_2,t_all)

Abundance Estimates

Weirs

A census count of Chinook salmon occurred in the Cowlitz River at the Barrier Dam. Based on the Cowlitz management plan (Tacoma Power 2004), Chinook salmon were trucked for release into the upper Cowlitz/Cispus and Tilton rivers. At the Green, Elochoman, and Coweeman weirs, a portion of the trapped fish were released above the weir, depending on WDFW management objectives for that basin. In some cases, not all fish released above a weir successfully spawned. To estimate the proportion of successful spawners (*pSuc*) female carcasses are inspected for spawning success (Table 7). In some cases, a fishery may occur above the weir, and harvest is estimated through a statistical expansion of catch record card (CRC) returns (Kraig 2014). The number of spawners above the weir (*WeirSpawners*) is the weir count (*count*) times the proportion of successful spawners minus the estimated harvest (Table 8).

Table 7. Summary statistics used to estimate spawners above weirs.

Statistic	Definition/Equation
count	Number of fish released and passed above the weir
Fcarc	Number of females examined above the weir for spawning success
Fsuc	Number of females examined that had spawned (i.e., egg retention < 25%)

Table 8. Likelihoods and derived parameters to estimate spawner abundance above weirs.

Description	Likelihood/Derived Estimates
Mu	*mu* is the mean catch from CRC harvest estimates
Prec	*prec* = 1/variance from the CRC harvest estimates
Pr(catch)	$catch \sim$ Normal($mu,prec$) estimated from CRC returns
Pr(spawn success)	$Fsuc \sim$ Binomial($pSuc,Fcarc$)
WeirSpawners	*WeirSpawners* is the number of fish above the weir that attempted to spawn, $WeirSpawners = count*pSuc-catch$

Closed Population Abundance Estimates

Our study design was developed based on stratified Petersen, or Darroch, closed population mark-recapture models because they are relatively robust to heterogeneity in capture and movement probabilities (Seber 1982). Using this study design, we recorded the number of fish marked and released above the trap, and the number of captured and recaptured fish (carcasses) per week during spawning ground surveys (Table 9).

Table 9. Summary statistics used to estimate abundance using the Darroch (1961) model.

Statistic	Definition/Equation
d_m_i	Number of fish marked and released at sample time i.
d_r_{ij}	Number of marked fish recaptured at sample time ij, $i = 1,\ldots, s$, $j = 1,\ldots, s$.
$d\_m_i - d\_ r_i$	Number of marked fish not recaptured
d_u_j	Number of fish captured at sample time j that were not previously marked.

The fundamental parameters include the probability of capture, probability of movement between strata, probability a fish is caught in a stratum, and the population estimate at the time of tagging (Table 10), are estimates based on the likelihoods in Table 11.

Table 10. Fundamental and derived parameters for the Darroch (1961) model.

Parameter	Definition/Equation
d_s	Number of sample times
d_p_j	Probability of capture at sample time j, $j = 1,\ldots, s$.
d_θ_{ij}	Probability that a fish from m_i moves to stratum j, $i = 1,\ldots, s$, $j = 1,\ldots, s$. Since the population is closed & no mortality the $\sum \theta_{ij} = 1$, $i = 1,\ldots, s$.
d_ψ_{ij}	Probability that a fish from m_i is caught at time j, $i = 1,\ldots, s$, $j = 1,\ldots, s$. $\psi_{ij} = \theta_{ij}\, p_j$. Probability of not being captured, $\psi_{ij} = (1-\sum\psi_{ij})$, $i = 1,\ldots, s$, $j = s + 1$.
d_U_j	Number of fish at sample time j. $N = \sum U_j$, which is the population estimate

Table 11. The likelihoods for the Darroch (1961) model.

Description	Likelihood/Derived Estimates
Pr(capture)	$d\_u_j \sim \text{Binomial}(d\_p_j, d\_U_j)$, $j = 1,\ldots, s$.
Pr(capture at time$_j$)	$d\_r_{ij} \sim \text{Binomial}(d\_\psi_{ij}, d\_m_i)$, $i = 1,\ldots, s$, $j = 1,\ldots, s$.

When there is an equal probability of capture during the tagging event, or an equal probability of capture during the second tagging event, or there is complete mixing of tagged and untagged fish between events, all releases, recoveries and captures may be combined into a "pooled" Petersen estimator (Schwarz and Taylor 1998). The summary statistics include the number of marks, recaptures, and captures (Table 12). The fundamental parameter is the population size estimated from the summary statistics and hypergeometric distribution (Table 13). The hypergeometric distribution is appropriate to use when there is sampling without replacement as salmon carcasses captured in the second event were mutilated (tail-chopped) and not available for recapture in future sampling events.

Table 12. Summary statistics used in the hypergeometric Petersen model where Chinook salmon were live tagged and recovered as carcasses.

Statistic	Definition/Equation
m_h	Number of fish marked in the first sample (*n1*) for the hypergeometric model
r_h	Number of marked fish recaptured in the 2nd sample (*m2*) for the hypergeometric model
c_h	Number of fish captured in the second sample (*n2*) for the hypergeometric model

Table 13. The fundamental parameters and likelihoods for the hypergeometric Petersen model.

Description	Definition/Likelihood
Nh	The population size *Nh*
Pr(Recapture)	$r_h \sim \text{Hypergeometric}(m_h, c_h, N_h)$

Open Population Abundance Estimates

We parameterized the Schwarz et al. (1993) "super population" JS model into a Bayesian framework. Rather than using individual capture histories, we used summary statistics to increase the computational speed (Table 14). It is important to note that in the more popular Schwarz and Arnason (1996) model the super population and other fundamental parameters are based on births while in the Schwarz et al. (1993) model the super population is the total of gross births or salmon abundance (Table 15). This model allows salmon abundance estimates to be hierarchically modeled (Rivot and Prevost 2002) and the probability of entry to be modeled based on various distributions (Hilborn et al. 1999). Derived parameter estimates in Table 16 are based on the Schwarz et al. (1993) and Manske and Schwarz (2000). We included the later author's derived estimates for cases when the mark-recapture study ends early, as they proposed a method to estimate abundance based on the residence time estimated from the mark-recapture data and AUC method, which is a plot of the population size at each sampling period. The JS likelihood is the product of three likelihoods: 1) the probability of first capture based on a super population (N) that enter the population (b^*_i) following a multinomial distribution, 2) the probability of release on capture (v_i) from a binomial distribution using total fish sampled (n_i) and number of n_i that are released (R_i), and 3) the probability of recapture which is the product of two binomial distributions to estimate the probability of capture (p_i) and survival (φ_i) (Burnham 1991) (Table 17).

Table 14. Summary statistics used in the Jolly-Seber model.

Statistic	Definition/Equation
m_i	Number of fish captured at sample time i that were previously marked.
u_i	Number of fish captured at sample time i that were unmarked.
n_i	Number of fish captured at sample time i. $n_i = m_i + u_i$.
l_i	Number of fish lost on capture at time i.
R_i	Number of fish that were released after the ith sample. R_i need not equal n_i if there were losses on capture or injections of new fish at sample time i.
r_i	Number of R_i fish released at sample time i that were recaptured at one or more future sample times.
z_i	Number of fish captured before time i, not captured at time i, and captured after time i.
T_i	Number of fish captured at or before time i and captured at or after time i. $T_i = m_i + z_i$.

Table 15. Fundamental parameters for the Jolly-Seber model under the salmon escapement super population model (Schwarz et al. 1993).

Parameter	Definition/Equation
s,tm	Number of sample times and length of interval between samples
p_i	Probability of capture at sample time i, $i = 1,\ldots, s$.
φ_i	Probability of a fish surviving and remaining in the population between sample time i and sample time $i + 1$, given it was alive and in the population at sample time i, $i = 1,\ldots, s\text{-}1$.
b^*_i	Probability that a fish enters the population between sample times i and $i + 1$, $i = 0,\ldots, s\text{-}1$ under the constraint that $\sum b^*_i = 1$. These are referred to as entry probabilities.
v_i	Probability that a fish captured at time i will be released, $i = 1,\ldots, s\text{-}1$.
N	Total number of fish that enter the system before the last sample time or the abundance. This is referred to as the super population.

Table 16. Derived parameters for the Jolly-Seber model under the salmon abundance super population model (Schwarz et al. 1993) and the stream residence time model (Manske and Schwarz 2000).

Parameter	Definition/Equation
λ_i	Probability that a fish is seen again after sample time i, $i = 1,\ldots, s$. $\lambda_i = \varphi_i p_{i+1} + \varphi_i (1 - p_{i+1}) \lambda_{i+1}$, $i = 1,\ldots, s$-1; $\lambda_s = 0$.
τ_i	Conditional probability that a fish is seen at sample time i given that it was seen at or after sample time i, $i = 1,\ldots, s$. $\tau_i = p_i/(p_i + (1-p_{i+1}) \lambda_i)$.
ψ_i	Probability that a fish enters the population between sample time i-1 and i and survives to the next sampling occasion. $\psi_i = b^*_0$, $\psi_{i+1} = \psi_i (1 - p_i)\varphi_i + b^*_i(\varphi_i - 1)/\log(\varphi_i)$
B_i	Number of fish that enter after sample time i and survive to sample time i +1, i = 0,…, s-1. These are referred to as net births. $B_0 = B^*_0$, $B_i = B^*_i(\varphi_i - 1)/\log(\varphi_i)$.
B^*_i	Number of fish that enter between sampling occasion i-1 and i, $i = 0,\ldots, s$-1. These are referred to as gross births. $B^*_i = N (b^*_i)$
N_i	Population size at time i, $i = 1,\ldots, s$. $N_1 = B_0$, $N_{i+1} = (N_i – n_i + R_i) \varphi_i + B_i$
N^-_i	Number of fish alive immediately before sample time i, $i = 1,\ldots, s$. $N^-_1 = B_0$; $N^-_{i+1} = N^+_i \varphi_i + B_i$
N^+_i	Number of fish alive immediately after sampling time i, $i = 1,\ldots, s$. $N^+_i = (N^-_i – n_i + R_i)$. N^+_i may differ from N^-_i if there were losses on capture or injections of new fish.
RT	Average residence time; for $i = 1,\ldots, s$-1. $\mathrm{RT} = 0.5\sum tm_i N^+_i(\varphi_i + 1) + 0.5\, tm_s N^+_s + 0.5 tm_0 B_0 + \sum B_i tm_i(\varphi_i/ \varphi_{i-1} – 1/\log(\varphi_i))$
AUC	Aggregate residence time over all spawners. This is referred to as the total fish days or Area-Under-the-Curve. $\mathrm{AUC} = 0.5\, tm_0 N^-_1 + \sum 0.5\, tm_i(N^+_i + N^-_i) + 0.5\, tm_s N^+_s$.
ESC	Escapement. ESC = AUC/RT. This is slightly greater than N, which is also a measure of escapement due to accounting for fish before and after sampling.

Table 17. The likelihoods for the Schwarz et al. (1993) model.

Description	Likelihood
Pr(first capture part a)	$u. \sim \mathrm{Binomial}(\sum\psi_i p_i,N)$, $i = 0,\ldots, s$-1. $u. = \sum u_i$
Pr(first capture part b)	$u_i \sim \mathrm{Multinomial}\ (\psi_i p_i/\sum\psi_i p_i,u.)\ )$, $i = 0,\ldots, s$-1.
Pr(release on capture)	$R_i \sim \mathrm{Binomial}(v_i,n_i)$, $i = 1,\ldots, s$-1.
Pr(recapture part a)	$m_i \sim \mathrm{Binomial}(\tau_i,T_i)$, $i = 2,\ldots, s$-1.
Pr(recapture part b)	$r_i \sim \mathrm{Binomial}(\lambda_i,R_i)$, $i = 1,\ldots, s$-1.

Spawning Ground Survey Abundance Estimates

Three types of abundance estimates may be obtained from weir or mark-recapture estimates when counts of redds, fish, or peak counts are collected concurrently (Table 18). Using the summary statistics, we estimated apparent females per redd, apparent residence time, and peak count expansion factors (Tables 19 and 20) (Gallagher et al. 2007, Parken et al. 2003).

Table 18. Summary statistics used from spawning ground surveys.

Statistic	Definition
Redd_tot	Total number of new redds observed during the spawning period
$Spawners_i$	Number of fish classified as spawners on day *i*
PC	The greatest number of live fish and/or carcasses observed on a single day during the spawning period

Table 19. Derived parameters for spawning ground abundance methods.

Parameter	Definition/Equation
F	Number of females in the population, $F = pF * N$
AFpR	Apparent females per redd, $AFpR = F / Redd\_tot$
AUCsp	The total number of fish days for spawners or Area-Under-the-Curve. $AUCsp = 0.5\ t_0 Spawner_1 + \sum 0.5\ t_i(Spawner_i + Spawner_{i+1}) + 0.5\ t_s Spawner_{s+1}$. For days $i = 1, \ldots, s+1$.
ART	The apparent residence time, which is the average number of days a fish remains in the survey area, $ART = AUCsp / N$
PCEF	Peak count expansion factor , PCEF = N/PC

Table 20. Derived parameters for spawning ground abundance methods.

Parameter	Definition/Equation
Nredds	Redd-based spawner abundance, $Nredds = (Redd\_tot * AFpR) / pF$
Nauc	AUC-based spawner abundance estimate, $Nauc = AUCsp / ART$
Npc	Peak count-based spawner abundance estimate, $Npc = PC * PCEF$

Proportions

Important indicators for salmon populations include the number of females and marked (hatchery-origin) fish (Rawding and Rodgers 2013). In addition, ages are a measure of diversity and are needed to reconstruct salmon runs for forecasting and spawner-recruit analysis (Rawding and Rodgers 2013, Hilborn and Walters 1992). When the data allow for only two possibilities, such as the sex being male or female, the binomial distribution is an appropriate model for analysis, but when there are more than two possibilities, such as adult ages, the multinomial model is appropriate.

Adipose fin excision as a mass mark for hatchery-origin salmonids is highly successful and 97-99% of juveniles examined post marking typically display acceptable marks (mass mark rate). However, the small proportion of hatchery fish that remain unmarked may lead to significant bias when attempting to enumerate natural-origin salmon abundance in small populations with large hatchery programs where substantial proportions of returning hatchery-origin adults spawn in the wild. We accounted for this source of bias by adjusting the estimate of marked and unmarked spawner abundance for each subpopulation by the hatchery specific mass mark rate for each age class. We examined CWT recoveries from both spawning ground surveys and weir removals to determine which hatchery mass rate to use for each subpopulation. Failure to adjust natural-origin abundance estimates for unmarked hatchery fish could lead to positively biased natural-origin abundance estimates.

The summary statistics and likelihoods for the proportions of males, females, marked, unmarked, hatchery-origin, natural-origin, age by origin, and marked juveniles by age are found in Tables 21 and 22. The total number of marked and unmarked adults, adult males and females, and subtotals of marked and unmarked fish by age were estimated by multiplying these proportions by the total abundance estimates.

Table 21. Summary statistics from spawning ground surveys to estimate proportions.

Statistic	Definition/Equation
Females	Number of adults that were females
Males	Number of adults that were males
Adults	Number of adults examined for sex and origin
HOS	Number of hatchery-origin adults that were mass marked (adipose fin clipped) and adjusted for unmarked hatchery releases
NOS	Number of natural-origin adults that were not mass marked (adipose fin clipped) and adjusted for unmarked hatchery releases
Marked	Number of adults that were mass marked (adipose fin clipped)
Unmarked	Number of adults that were not mass marked (adipose fin intact)
HOS_Age_i	Number of hatchery-origin adults that are age i, i=3,4,5
NOS_Age_i	Number of natural-origin adults that are age i, i=3,4,5
M_Age_i	Number of marked adults that are age i, i=3,4,5
U_Age_i	Number of unmarked adults that are age i, i=3,4,5
pF	Proportion of adults that are females
pM	Proportion of adults that are males
pHOS	Proportion of adults that are hatchery-origin
pNOS	Proportion of adults that are natural-origin
pMS	Proportion of adults that are mass marked
pUS	Proportion of adults that are not mass marked
$pHOS\_Age_i$	Proportion of hatchery-origin adults that are age i, i=3,4,5
$pNOS\_Age_i$	Proportion of natural-origin adults that are age i, i=3,4,5
pM_Age_i	Proportion of adults that are marked adults that are age i, i=3,4,5
pU_Age_i	Proportion of adults that are unmarked adults that are age i, i=3,4,5
pCH_Age_i	Proportion of juv. hatchery releases that are marked by brood year/age i, i=3,4,5

Table 22. The likelihoods and derived parameters for sex, origin, and age and their proportions.

Description	Likelihood
Pr(Females)	*Females* ~Binomial(*pF*,*Adults*)
Pr(Males)	*Males* ~Binomial(*pM*,*Adults*)
Pr(HOS)	$HOS = \sum HOS\_age_i$
Pr(NOS)	$NOS = \sum NOS\_age_i$
Pr(Marked)	*Marked* ~Binomial(*pMS*,*Adults*)
Pr(Unmarked)	*Unmarked* ~Binomial(*pUS*,*Adults*)
$Pr(HOS\_age_i)$	$HOS\_age_i = MS\_Age_i / pCH\_Age_i$
$Pr(NOS\_age_i)$	$NOS\_ age_i = US\_Age_i - HOS\_Age_i + MS\_Age_i$
$Pr(pHOS\_age_i)$	$pHOS\_age_i = HOS\_Age_i / (HOS\_Age_i + NOS\_Age_i)$
$Pr(pNOS\_age_i)$	$pNOS\_ age_i = NOS\_Age_i / (HOS\_Age_i + NOS\_Age_i)$
$Pr(M\_age_i)$	$M\_age_i \sim \text{Multinomial}(pM\_Age_i, Adults)$
$Pr(U\_age_i)$	$U\_age_i \sim \text{Multinomial}(pU\_Age_i, Adults)$

ESU abundance

The ESU estimates by reporting group are the sum of the population estimates.

Cross Validation of AUC and Redd Estimates

To test the robustness of our redd- and AUC-based estimates we used a leave-one-out cross validation (CV-1) approach. In places where we had concurrent mark-recapture and AUC or redd-based estimates, we compared the results of the AUC or redd-based estimate to the mark-recapture estimates. In this case, we used the mean ART and AFpR to adjust and develop abundance estimates from AUC and redds, respectively. These mean ART and AFpR estimates did not include population specific estimates of ART or AFpR (Parken et al. 2003). For comparison, we tested the hypothesis that the redd or AUC estimate was greater than the mark-recapture estimate by monitoring this node in WinBUGS.

Timing

We used period (weekly) counts of spawners and divided these counts by the total count of spawners to estimate the cumulative timing of spawning for each Tule Chinook salmon population.

Results

Model Convergence and Diagnostics

We ran two chains with a 10,000 iteration for a burn-in, followed by 25,000 iterations, in which every fifth iteration was saved using the Gibbs sampler in WinBUGS. We saved 10,000 iterations for the posterior distribution of each of the 2,400 parameters monitored. Chains were thinned to save space given the large number of parameters that were monitored. Visual inspection of the trace and history plots suggested the chains mixed and converged. The Brooks-Gelman-Rubin (BGR) diagnostic test for convergence yielded values of less than 1.01 for each parameter, which is less than the recommended value of 1.2. While it is impossible to conclusively demonstrate a simulation has converged, the above diagnostic tests did not detect that the simulations did not converge. The MCMC error rate was less than 5% of the standard deviation of the parameter estimates, which suggests our posterior distributions were accurate. Our population abundance estimates were similar for the different vague priors and the proportion results were not sensitive to the priors except when we had few observations.

Apparent Residence Time and Females per Redd

We used open population estimates to develop estimates of apparent residence time (ART) in four basins in 2011. The longest ART was observed in Germany Creek (6.35 days) and the shortest ART was 4.18 days for the Abernathy subpopulation. The mean ART was ~ 5.06 days (95% CI 4.45-5.67) (Table 23) which was to derive all 2011 AUC-based abundance estimates.

Table 23. Estimates of apparent residence time (ART) for Lower Columbia River Tule populations from weir census and mark-recapture studies, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Grays	4.23	0.86	2.52	4.24	5.85
Abernathy	4.18	0.64	2.88	4.21	5.42
Germany	6.25	0.54	5.09	6.30	7.19
Washougal	5.59	0.35	4.91	5.59	6.29
Mean 2011	5.06	0.31	4.45	5.07	5.67

We repeated a similar procedure to develop estimates of apparent females per redd (AFpR). These estimates were based on the female abundance estimates from the JS model in previous years, we used DIC for model selection and Bayesian *p*-values to test GOF for the historic redd data sets. These include 2003 and 2004 Coweeman data along with 2005 and 2006 EF Lewis data. DIC favored models tst, ttt, tst, and ttt, respectively. The Bayesian *p*-values were 0.05, 0.86, 0.76, and 0.65, respectively. This indicated some lack of fit between the JS model and data for the 2003 Coweeman estimate. The 2011 redd-based abundance estimates were derived using the mean of the seven years where AFpR were derived, which was ~1.13 (Table 24).

Table 24. Apparent Female per Redd (AFpR) estimates for Lower Columbia Tule Fall Chinook mark-recapture studies.

Parameter	Mean	SD	2.50%	Median	97.50%
Coweeman 03	1.019	0.048	0.928	1.018	1.118
Coweeman 04	1.282	0.155	1.037	1.262	1.653
EF Lewis 05	1.050	0.211	0.754	1.012	1.573
EF Lewis 06	1.025	0.233	0.701	0.985	1.600
Coweeman 09	1.173	0.114	0.961	1.168	1.405
Coweeman 10	1.188	0.206	0.823	1.175	1.634
Coweeman 11	1.202	0.110	0.996	1.200	1.423
Mean 03-11	1.134	0.063	1.022	1.130	1.273

Grays/Chinook Population

The Grays/Chinook population of Chinook salmon is comprised of two subpopulations: the Grays and Chinook rivers. The Chinook River was not included in our sampling frame for several reasons: 1.) there is a tide gate near the mouth which limits anadromous adult fish passage, 2.) the WDFW Chinook distribution model does not predict any use in the basin, and 3.) a limited number of surveys have been conducted for chum and coho salmon which begin in mid-to-late October and no adult Chinook have been observed spawning during these surveys. The Grays subpopulation consists of three stock components; a hatchery-origin Tule, a hatchery-origin Rogue Bright population, and a natural-origin population likely comprised of Tules, naturalized Rogue River Brights, and their hybrids. Abundance estimates used the JS model applied to carcass tagging data and include both the historic distribution below the Grays River canyon and spawning areas upstream of the canyon.

The logistic regression for selectivity favored the constant model but there was similar support for the sex model (BF=1.42) (Table 25). Since there was similar support for both models, we chose the constant model and did not stratify estimates by sex.

Table 25. Results from model selection using the logistic model used to assess factors affecting carcass recapture probabilities for adult Grays River Chinook salmon, 2011.

Model	Constant	Sex	Length	Sex + Length
Posterior Model Probabilities	0.55	0.39	0.02	0.04
Bayes Factor	1.00	1.42	32.15	13.47

The results from the GOF test indicated the data marginally fit the tt, st, and ts models and did not fit the ss model. For the time varying models, there were six survival and capture parameters but for the constant model, there was only one survival or capture parameter. Due to sparse recoveries, the weakly identifiability tests indicated the posterior distributions were influenced by the prior distribution for the time varying models. Posteriors were not weakly identifiable when survival, capture, or both were constant. This suggests that even the non-informative priors had some influence on the posterior distribution (Table 26).

Table 26. Results from goodness of fit test for the CJS models and posterior identifiability tests for adult Grays River Chinook salmon, 2011.

CJS Model	Bayesian p-values	Weakly Identifiable - ρ	Weakly Identifiable - ϕ
tt	0.04	6	6
st	0.02	0	6
ts	0.02	6	0
ss	0.00	0	0

Model selection was based on DIC, which favored the sst model with support for the tst, and ttt models as well (Table 27). In this table, we report on the model deviance, pv (the effective number of parameters in the model), the DIC value (lower DIC indicates the preferred model), change in DIC and DIC weights for model comparison, and median abundance estimates from the model (to assess the sensitivity of model selection). We chose to use the ttt model based on GOF tests (Table 26) and DIC support for the model.

Table 27. JS model selection for Chinook salmon adults in Grays River, 2011.

Model	Deviance	JS_pv	JS_DIC	Δ DIC	DIC Weights	Median Abundance
ttt	91.7	18.2	109.8	2.1	0.166	386
stt	93.6	20.1	113.7	6.0	0.024	356
tst	93.2	15.3	108.5	0.8	0.327	350
sst	92.9	14.8	107.7	0.0	0.483	319

The mean abundance estimate was 405 adult Chinook salmon (95% CI 278-646). Based on left ventral fin clips and adjusting for unmarked hatchery fish from the SF Klaskanine Hatchery (an Oregon Department of Fish and Wildlife (ODFW) facility), we estimated 278 adults (95% CI 187-448) were stray hatchery-origin Rogue River Brights. For the ad-clipped Tule component, we used Big Creek Hatchery's (an ODFW facility) mass mark rates. The proportion of hatchery-origin (adipose and/or left ventral clipped) adults was 82.7% and most adults were age-3 and age-4. Population abundance, origin, sex, and age estimates are found in Tables 28-30.

Table 28. Abundance, including sex- and origin-specific estimates, for the adult Grays/Chinook Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	405	97	278	386	646
Males	147	39	93	139	241
Females	258	64	173	246	414
HOS Rogue Bright	278	68	187	264	448
HOS Tule	57	18	31	55	101
NOS	70	22	39	67	122
LV-Marked	269	66	181	256	434
AD-Marked	56	18	31	54	99
Unmarked	80	23	46	76	136

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 29. Abundance by total age and origin for the adult Grays/Chinook Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Rogue Bright Age-3	195	50	127	186	318
HOS Rogue Bright Age-4	74	22	41	70	127
HOS Rogue Bright Age-5	6	4	1	5	17
HOS Rogue Bright Age-6	3	3	0	2	10
HOS Tule Age-3	30	11	14	28	57
HOS Tule Age-4	23	9	9	21	45
HOS Tule Age-5	3	3	0	2	10
HOS Tule Age-6	2	3	0	2	9
NOS Age-3	32	13	13	30	63
NOS Age-4	33	13	14	31	63
NOS Age-5	3	3	0	2	11
NOS Age-6	3	3	0	2	11

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 30. Proportions of the adult Grays/Chinook Chinook salmon population by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.362	0.039	0.288	0.362	0.440
pFemale	0.638	0.039	0.561	0.638	0.712
pHOS (includes Rogue Bright & Tule HOS)	0.827	0.033	0.760	0.828	0.887
pNOS (includes Rogue Bright & Tule HOS)	0.173	0.033	0.113	0.172	0.240
pMark (includes Rogue Bright & Tule HOS)	0.803	0.032	0.738	0.804	0.861
pUnmark (includes Rogue Bright & Tule HOS)	0.197	0.032	0.139	0.196	0.262
p Age-3 HOS Rogue Bright	0.703	0.047	0.610	0.705	0.790
p Age-4 HOS Rogue Bright	0.266	0.045	0.183	0.264	0.359
p Age-5 HOS Rogue Bright	0.021	0.014	0.003	0.018	0.056
p Age-6 HOS Rogue Bright	0.010	0.010	0.000	0.007	0.037
p Age-3 HOS Tule	0.518	0.102	0.321	0.518	0.711
p Age-4 HOS Tule	0.396	0.100	0.211	0.393	0.597
p Age-5 HOS Tule	0.044	0.042	0.001	0.032	0.155
p Age-6 HOS Tule	0.042	0.041	0.001	0.030	0.151
p Age-3 NOS	0.453	0.107	0.250	0.452	0.662
p Age-4 NOS	0.468	0.106	0.265	0.467	0.679
p Age-5 NOS	0.039	0.039	0.000	0.027	0.142
p Age-6 NOS	0.040	0.039	0.001	0.029	0.142

Elochoman/Skamokawa Population

Historically, WDFW has reported on these subpopulations separately and we continue that in this report. However, they were combined into a single recovery population as well.

For Skamokawa Creek, the abundance estimate was obtained by dividing AUC by mean SL yielding an abundance estimate of 467 adults (95% CI 416-529). Based on adipose fin clips and adjusting for unmarked hatchery fish using Big Creek Hatchery's mass mark rates, the proportion of hatchery-origin spawners was 94.1%. Most adults were age-3 with very few age-5 or age-6 fish. Subpopulation abundance, origin, sex, and age estimates are found in Tables 31-33.

Table 31. Abundance, including sex- and origin-specific estimates, for the adult Skamokawa Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	467	29	416	465	529
Males	251	26	204	250	304
Females	216	24	171	215	266
HOS	440	30	387	438	501
NOS	28	11	9	26	52
Marked	432	29	380	430	493
Unmarked	35	11	17	34	59

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 32. Abundance by total age and origin for the adult Skamokawa Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	366	29	312	365	425
HOS Age-4	63	15	37	62	94
HOS Age-5	7	5	1	6	20
HOS Age-6	4	4	0	2	13
NOS Age-3	15	8	2	14	33
NOS Age-4	4	4	0	3	15
NOS Age-5	6	4	1	5	16
NOS Age-6	3	3	0	2	11

The sum of abundance by mark status, sex, and age not may equal the abundance estimate due to rounding errors.

Table 33. Proportions of the adult Skamokawa Chinook salmon subpopulation by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.538	0.043	0.453	0.538	0.621
pFemale	0.462	0.043	0.379	0.462	0.547
pHOS	0.941	0.023	0.889	0.944	0.980
pNOS	0.059	0.023	0.020	0.057	0.111
pMark	0.925	0.023	0.874	0.928	0.963
pUnmark	0.075	0.023	0.037	0.072	0.126
p Age-3 HOS	0.832	0.034	0.761	0.834	0.894
p Age-4 HOS	0.143	0.032	0.086	0.141	0.211
p Age-5 HOS	0.017	0.012	0.002	0.014	0.046
p Age-6 HOS	0.008	0.008	0.000	0.006	0.030
p Age-3 NOS	0.524	0.183	0.147	0.531	0.849
p Age-4 NOS	0.156	0.135	0.000	0.128	0.477
p Age-5 NOS	0.211	0.139	0.023	0.184	0.550
p Age-6 NOS	0.110	0.104	0.003	0.078	0.390

For the Elochoman subpopulation, the logistic regression model to test for bias in carcass recoveries from live tagged fish favored the constant model over the sex model, which was the second best model (BF=3.33), which indicated that the carcass recovery rates were not sex or length-dependent (Table 34). Therefore, all adults were analyzed as a single group. A total of 723 of the trapped adults were released above the weir of which 717 were tagged. The BF, computed from the marginal likelihood, for the null hypothesis that a constant proportion of fish recovered at the weir and during carcass surveys rates was 8.7, which provided support for pooling weir and spawning survey carcass recoveries for abundance estimation. The BF for the null hypothesis of constant proportion of recovery marked by time period was 29,839, which is very strong support for pooling recoveries by time period. These tests indicate the pooled Petersen estimator would provide an unbiased estimate of adult abundance above the weir, and this estimate was 756 (95% CI 739 - 781). To estimate the number of spawners, we multiplied the run size estimate by the proportion of successful spawners and subtracted the estimated sport harvest, which results in an estimate of 636 adult spawners (95% CI 570 - 693). Adjusting for unmarked hatchery fish using Elochoman Hatchery's mass mark rates, the proportion of hatchery-origin spawners was 95.2%. Most fish were age-4. Subpopulation abundance, origin, sex, and age estimates are found in Tables 35-37.

Table 34. Results from model selection using the logistic model used to assess factors affecting carcass recapture probabilities for adult Elochoman River Chinook salmon, 2011.

Model	Constant	Sex	Length	Sex + Length
Posterior Model Probabilities	0.76	0.23	0.01	0.00
Bayes Factor	1.00	3.33	85.38	226.82

Table 35. Abundance, including sex- and origin-specific estimates, for the adult Elochoman Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	636	32	570	638	693
Males	245	28	193	245	301
Females	391	32	328	391	454
HOS	606	32	538	607	665
NOS	30	12	11	29	57
Marked	601	32	533	602	659
Unmarked	35	12	16	34	62

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 36. Abundance by total age and origin for the adult Elochoman Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	146	24	104	146	196
HOS Age-4	451	33	385	451	514
HOS Age-5	4	4	0	3	16
HOS Age-6	4	4	0	3	16
NOS Age-3	6	5	0	5	19
NOS Age-4	18	9	5	17	38
NOS Age-5	3	3	0	2	11
NOS Age-6	3	3	0	2	11

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 37. Proportions of the adult Elochoman Chinook salmon subpopulation by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.386	0.039	0.311	0.385	0.464
pFemale	0.614	0.039	0.536	0.615	0.689
pHOS	0.952	0.018	0.912	0.954	0.982
pNOS	0.048	0.018	0.018	0.046	0.088
pMark	0.944	0.018	0.904	0.946	0.974
pUnmark	0.056	0.018	0.026	0.054	0.096
p Age-3 HOS	0.242	0.037	0.174	0.240	0.317
p Age-4 HOS	0.744	0.037	0.667	0.746	0.813
p Age-5 HOS	0.007	0.007	0.000	0.005	0.026
p Age-6 HOS	0.007	0.007	0.000	0.005	0.026
p Age-3 NOS	0.193	0.143	0.000	0.172	0.513
p Age-4 NOS	0.612	0.163	0.278	0.618	0.908
p Age-5 NOS	0.097	0.093	0.000	0.069	0.344
p Age-6 NOS	0.099	0.090	0.003	0.073	0.334

Both the Skamokawa and Elochoman estimates were summed to obtain an estimate for the Elochoman (Elochoman/Skamokawa) population. The total population estimate was 1,103 (95% CI 1,018-1,187). The portion of hatchery-origin Chinook salmon was 94.8% and most fish were age-3 and age-4. Population abundance, origin, sex, and age estimates are found in Table 38-40.

Table 38. Abundance, including sex- and origin-specific estimates, for the adult Elochoman/Skamokawa Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	1,103	43	1,018	1,103	1,187
Males	496	38	424	496	573
Females	607	40	529	607	687
HOS	1,045	44	959	1,045	1,132
NOS	58	16	30	57	92
Marked	1,033	44	948	1,033	1,118
Unmarked	70	16	43	69	105

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 39. Abundance by total age and origin for the adult Elochoman/Skamokawa Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	512	37	442	511	589
HOS Age-4	514	36	442	513	585
HOS Age-5	12	7	2	10	28
HOS Age-6	8	6	1	7	22
NOS Age-3	21	10	5	20	42
NOS Age-4	23	10	8	22	45
NOS Age-5	8	5	1	7	21
NOS Age-6	6	4	1	5	17

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 40. Proportions of the adult Elochoman/Skamokawa Chinook salmon population by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.450	0.029	0.393	0.450	0.508
pFemale	0.550	0.029	0.492	0.550	0.607
pHOS	0.948	0.014	0.917	0.949	0.973
pNOS	0.052	0.014	0.027	0.051	0.083
pMark	0.936	0.014	0.905	0.937	0.961
pUnmark	0.064	0.014	0.039	0.063	0.095
p Age-3 HOS	0.490	0.028	0.434	0.489	0.546
p Age-4 HOS	0.491	0.029	0.435	0.492	0.547
p Age-5 HOS	0.011	0.006	0.002	0.010	0.027
p Age-6 HOS	0.008	0.005	0.001	0.006	0.021
p Age-3 NOS	0.355	0.125	0.122	0.354	0.604
p Age-4 NOS	0.394	0.122	0.175	0.390	0.643
p Age-5 NOS	0.148	0.083	0.029	0.135	0.349
p Age-6 NOS	0.102	0.068	0.013	0.087	0.270

Mill/Abernathy/Germany Population

The Mill/Abernathy/Germany (MAG) Chinook salmon population is composed of three subpopulations that enter the Columbia River within 2 miles of each other. We report on these subpopulations separately due to the historical WDFW reporting structure and because they are part of Washington State's Intensively Monitored Watershed (IMW) program, which requires reporting at this scale. Subpopulation estimates were based on individual JS models for each creek. For the Mill Creek subpopulation the test for length and sex selectivity in carcass recoveries for all adults provided positive support for the length-dependent recovery model over the constant model (BF=33.25) (Table 41). Therefore, we stratified the carcass recovery at 90cm. This length stratification point was based on a visual breaking point using a cumulative distribution plot of carcasses tagged and recovered versus carcasses tagged and not recovered (results not shown), ensuring we had adequate sample sizes for each group, and to be consistent with the analysis conducted in Rawding et al. (2014). We re-tested the same hypothesis after stratifying. For adults $\geq$90 cm, there was positive support for the constant compared to the sex model (BF=3.38). For adults <90 cm there was similar support for constant, length (BF=2.24), and sex (BF=2.23) models. We summed the two independent estimates of $\geq$90 cm and <90 cm and compared it to the original constant model estimate (no size stratification). The estimates were not significantly different from one another. Therefore, final Jolly-Seber estimates were done without stratifying by length.

Table 41. Results from model selection using the logistic model used to assess factors affecting carcass recapture probabilities for adult Mill Creek Chinook salmon, 2011.

Model	Constant	Sex	Length	Sex + Length
Posterior Model Probabilities	0.02	0.00	0.66	0.32
Bayes Factor	33.25	169.81	1.00	2.09

The results from the GOF tests favored the tt model (Bayesian *p*-value of 0.28) and had no support for the ss, ts and st models. For the time varying models, there were nine survival and capture parameters, but for the constant model, there was only one survival or capture parameter. Due to sparse recoveries early and late in the run, the weakly identifiability tests indicated the posterior distributions were influenced by the prior distribution for the time varying models. Posteriors were not weakly identifiable when survival, capture, or both were constant. This suggests that some periods were influenced by non-informative priors (Table 42).

Table 42. Results from goodness of fit test for the CJS models and posterior identifiability tests for adult Mill Creek Chinook salmon, 2011.

CJS Model	Bayesian p-values	Weakly Identifiable - ρ	Weakly Identifiable - ϕ
tt	0.28	4	3
st	0.00	0	2
ts	0.00	1	0
ss	0.00	0	0

We used DIC to select the best model (Table 43). Abundance estimates were relatively similar across all models thus they were not very sensitive to model choice. DIC favored the ttt model, which was used.

Table 43. JS model selection for Chinook salmon adults in Mill Creek, 2011.

Model	Deviance	JS_pv	JS_DIC	Δ DIC	DIC Weights	Median Abundance
ttt	183.7	35.0	218.7	0.0	0.997	1,179
stt	213.0	30.3	343.3	124.6	0.000	1,094
tst	201.3	28.8	230.1	11.4	0.003	1,127
sst	291.1	21.7	312.8	94.1	0.000	1,048

The abundance estimate for the Mill Creek subpopulation was 1,188 adults (95% CI 1,086-1,337). We adjusted for unmarked hatchery fish using mass mark rates from Elochoman Hatchery and the proportion of hatchery-origin adults was 95.1%. The proportions of age-4 hatchery-origin and natural-origin fish were 88.1% and 76.7%, respectively. Subpopulation abundance, origin, sex, and age estimates are found in Tables 44-46.

Table 44. Abundance, including sex- and origin-specific estimates, for the adult Mill Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	1188	66	1086	1179	1337
Males	424	31	371	422	491
Females	764	47	688	759	867
HOS	1130	63	1031	1122	1273
NOS	58	10	40	58	80
Marked	1122	63	1024	1114	1265
Unmarked	66	10	48	65	88

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 45. Abundance by total age and origin for the adult Mill Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	117	15	90	116	148
HOS Age-4	996	57	905	989	1127
HOS Age-5	16	5	8	16	28
HOS Age-6	2	2	0	1	6
NOS Age-3	12	4	5	11	21
NOS Age-4	45	8	30	44	63
NOS Age-5	1	1	0	0	4
NOS Age-6	1	1	0	1	4

The sum of abundance by mark status, sex, and age may equal the abundance estimate due to rounding errors.

Table 46. Proportions of the adult Mill Chinook salmon subpopulation by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.357	0.016	0.325	0.357	0.390
pFemale	0.643	0.016	0.610	0.643	0.675
pHOS	0.951	0.008	0.934	0.951	0.966
pNOS	0.049	0.008	0.035	0.049	0.066
pMark	0.945	0.008	0.928	0.945	0.959
pUnmark	0.055	0.008	0.041	0.055	0.072
p Age-3 HOS	0.103	0.011	0.082	0.103	0.127
p Age-4 HOS	0.881	0.012	0.856	0.882	0.904
p Age-5 HOS	0.014	0.005	0.007	0.014	0.024
p Age-6 HOS	0.001	0.001	0.000	0.001	0.005
p Age-3 NOS	0.198	0.060	0.091	0.194	0.327
p Age-4 NOS	0.767	0.064	0.633	0.771	0.882
p Age-5 NOS	0.015	0.019	0.000	0.008	0.066
p Age-6 NOS	0.020	0.019	0.000	0.014	0.071

The Germany Creek subpopulation was estimated by applying the JS model to the carcass tagging data. For this subpopulation, the test for sex and length selectivity provided positive support for the constant (Table 47).

Table 47. Results from model selection using the logistic model used to assess factors affecting carcass recapture probabilities for adult Germany Creek Chinook salmon, 2011.

Model	Constant	Sex	Length	Sex + Length
Posterior Model Probabilities	0.65	0.30	0.03	0.02
Bayes Factor	1.00	2.20	19.48	31.89

The results from the GOF test varied. The fit was best for tt and st model (Bayesian *p*-values of 0.72 and 0.68, respectively) and poorest for the ss model. For the time varying models, there were seven survival and capture parameters, but for the constant model there was only one survival or capture parameter. Due to sparse recoveries early and late in the run, the weakly identifiability tests indicated the posterior distributions were influenced by the priors in about half of the periods for the time varying models. Posteriors were not weakly identifiable when survival, capture, or both were constant. This suggests that some periods were influenced by non-informative priors (Table 48).

Table 48. Results from goodness of fit test for the CJS models and posterior identifiability tests for adult Germany Creek Chinook salmon, 2011.

CJS Model	Bayesian p-values	Weakly Identifiable - ρ	Weakly Identifiable - ϕ
tt	0.72	5	4
st	0.68	0	4
ts	0.06	5	0
ss	0.00	0	0

Model selection was based on DIC and favored the stt model, which was used (Table 49).

Table 49. JS model selection for Chinook salmon adults in Germany Creek, 2011.

Model	Deviance	JS_pv	JS_DIC	Δ DIC	DIC Weights	Median Abundance
ttt	108.7	25.3	133.9	4.1	0.113	350
stt	107.1	22.7	129.8	0.0	0.886	332
tst	121.7	21.4	143.2	13.4	0.001	324
sst	147.9	17.9	165.8	36.0	0.000	303

The mean abundance estimate for the Germany Creek population was 337 (95% CI 291-411). Based on adipose fin clips and adjusting for unmarked hatchery fish using Big Creek Hatchery's mass mark rates, the proportion of hatchery-origin spawners was over 91%. Age-4 adults were the dominant age class comprising over 62% and 48% of the HOS and NOS adults, respectively. Subpopulation abundance, origin, sex, and age estimates are found in Tables 50-52.

Table 50. Abundance, including sex- and origin-specific estimates, for the adult Germany Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	337	31	291	332	411
Males	164	19	134	162	206
Females	173	19	142	171	218
HOS	308	29	263	303	377
NOS	29	8	15	29	47
Marked	294	28	251	289	359
Unmarked	44	8	30	43	62

The sum of abundance by mark status, sex, and age may equal the abundance estimate due to rounding errors.

Table 51. Abundance by total age and origin for the adult Germany Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	112	15	87	111	145
HOS Age-4	191	21	156	189	240
HOS Age-5	3	2	0	3	9
HOS Age-6	1	1	0	1	5
NOS Age-3	12	5	4	11	22
NOS Age-4	15	6	4	14	28
NOS Age-5	1	2	0	1	6
NOS Age-6	2	2	0	1	6

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 52. Proportions of the adult Germany Chinook salmon subpopulation by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.514	0.032	0.450	0.514	0.576
pFemale	0.486	0.032	0.424	0.486	0.550
pHOS	0.913	0.023	0.866	0.914	0.953
pNOS	0.087	0.022	0.047	0.086	0.134
pMark	0.870	0.021	0.826	0.872	0.909
pUnmark	0.130	0.021	0.091	0.128	0.174
p Age-3 HOS	0.364	0.034	0.300	0.364	0.431
p Age-4 HOS	0.621	0.034	0.554	0.622	0.686
p Age-5 HOS	0.010	0.007	0.001	0.008	0.028
p Age-6 HOS	0.005	0.005	0.000	0.003	0.017
p Age-3 NOS	0.410	0.135	0.172	0.401	0.695
p Age-4 NOS	0.486	0.143	0.186	0.496	0.741
p Age-5 NOS	0.049	0.054	0.000	0.032	0.195
p Age-6 NOS	0.054	0.053	0.001	0.038	0.193

For the Abernathy population, the BF provided similar support for the constant model compared to the sex-dependent carcass recovery model (BF=3.18) (Table 53). Since there was similar support for both models, we chose the constant model and did not stratify estimates by sex.

Table 53. Results from model selection using the logistic model used to assess factors affecting carcass recapture probabilities for adult Abernathy Creek Chinook salmon, 2011.

Model	Constant	Sex	Length	Sex + Length
Posterior Model Probabilities	0.22	0.70	0.02	0.06
Bayes Factor	3.18	1.00	37.47	11.25

The results from the GOF test indicated the data fit the models. The fit was similar between all four models. For the time varying models, there were six survival and capture parameters but for the constant model, there was only one survival or capture parameter. Due to sparse recoveries, the weakly identifiability tests indicated the posterior distributions were influenced by the priors in all of the periods for the time varying models. This suggests that most periods were influenced by non-informative priors (Table 54).

Table 54. Results from goodness of fit test for the CJS models and posterior identifiability tests for adult Abernathy Creek Chinook salmon, 2011.

CJS Model	Bayesian p-values	Weakly Identifiable - ρ	Weakly Identifiable - ϕ
tt	0.84	6	6
st	0.89	0	6
ts	0.88	6	0
ss	0.90	0	0

We used DIC to select the best model (Table 55). Abundance estimates were relatively similar across all models thus they were not very sensitive to model choice. DIC favored the tst but had some support for the ttt model. We chose to use the tst model.

Table 55. JS model selection for Chinook salmon adults in Abernathy Creek, 2011.

Model	Deviance	JS_pv	JS_DIC	Δ DIC	DIC Weights	Median Abundance
ttt	84.9	17.6	102.5	0.5	0.400	161
stt	88.1	18.4	106.5	4.5	0.053	154
tst	85.9	16.1	102.0	0.0	0.513	143
sst	91.9	15.6	107.5	5.5	0.034	159

The mean abundance estimate was 148 (95% CI 111-209). Based on adipose fin clips and adjusting for unmarked hatchery releases using mass mark rates from Big Creek Hatchery, the proportion of hatchery-origin fish was almost 85%. Over 60% of the adults were females. Most adults were age-4 with very few age-5 or age-6 fish. Subpopulation abundance, origin, sex, and age estimates are found in Tables 56-58.

Table 56. Abundance, including sex- and origin-specific estimates, for the adult Abernathy Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	148	25	111	143	209
Males	58	13	37	56	89
Females	90	18	63	87	131
HOS	125	23	92	122	179
NOS	22	8	10	22	40
Marked	120	22	88	116	171
Unmarked	28	8	15	27	46

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 57. Abundance by total age and origin for the adult Abernathy Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	48	11	30	47	75
HOS Age-4	73	16	49	71	110
HOS Age-5	2	2	0	1	7
HOS Age-6	2	2	0	1	7
NOS Age-3	8	4	2	7	18
NOS Age-4	11	6	2	10	24
NOS Age-5	2	2	0	1	6
NOS Age-6	2	2	0	1	6

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 58. Proportions of the adult Abernathy Chinook salmon subpopulation by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.392	0.055	0.289	0.391	0.501
pFemale	0.608	0.055	0.499	0.610	0.711
pHOS	0.848	0.046	0.752	0.851	0.930
pNOS	0.152	0.046	0.070	0.149	0.248
pMark	0.810	0.044	0.718	0.813	0.888
pUnmark	0.190	0.044	0.112	0.187	0.282
p Age-3 HOS	0.384	0.059	0.272	0.383	0.502
p Age-4 HOS	0.586	0.060	0.465	0.587	0.701
p Age-5 HOS	0.015	0.015	0.000	0.011	0.056
p Age-6 HOS	0.014	0.014	0.000	0.010	0.052
p Age-3 NOS	0.355	0.145	0.109	0.344	0.663
p Age-4 NOS	0.489	0.157	0.164	0.496	0.774
p Age-5 NOS	0.074	0.076	0.000	0.051	0.278
p Age-6 NOS	0.081	0.076	0.002	0.060	0.279

The Mill, Abernathy, and Germany Creek estimates were summed to obtain an estimate for the Mill, or MAG (Mill/Abernathy/Germany) population. The total population estimate was 1,673 (95% CI 1,547-1,848). The proportion of hatchery-origin spawners was 93.4% and over 80% of the hatchery-origin adults were age-4. Population abundance, origin, sex, and age estimates are found in Tables 59-61.

Table 59. Abundance, including sex- and origin-specific estimates, for the adult Mill (MAG) Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	1,673	77	1,547	1,665	1,848
Males	646	38	579	644	727
Females	1,027	54	936	1,023	1,145
HOS	1,563	74	1,443	1,555	1,726
NOS	110	15	83	110	142
Marked	1,536	72	1,418	1,528	1,697
Unmarked	138	15	110	137	170

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 60. Abundance by total age and origin for the adult Mill (MAG) Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	277	24	234	275	326
HOS Age-4	1260	63	1156	1254	1402
HOS Age-5	21	6	11	21	35
HOS Age-6	5	3	1	4	12
NOS Age-3	31	7	18	31	47
NOS Age-4	70	12	49	70	95
NOS Age-5	4	3	0	3	11
NOS Age-6	4	3	1	4	11

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 61. Proportions of adult Mill (MAG) Chinook salmon population by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.386	0.014	0.358	0.386	0.415
pFemale	0.614	0.014	0.585	0.614	0.642
pHOS	0.934	0.008	0.917	0.935	0.950
pNOS	0.066	0.008	0.050	0.066	0.083
pMark	0.918	0.008	0.901	0.918	0.933
pUnmark	0.082	0.008	0.067	0.082	0.099
p Age-3 HOS	0.177	0.013	0.153	0.177	0.203
p Age-4 HOS	0.806	0.013	0.780	0.807	0.831
p Age-5 HOS	0.014	0.004	0.007	0.013	0.022
p Age-6 HOS	0.003	0.002	0.001	0.003	0.008
p Age-3 NOS	0.285	0.056	0.182	0.283	0.400
p Age-4 NOS	0.639	0.060	0.516	0.641	0.751
p Age-5 NOS	0.035	0.023	0.004	0.031	0.093
p Age-6 NOS	0.041	0.023	0.008	0.037	0.097

Toutle Population

The Toutle population is comprised of two subpopulations: the Green and SF Toutle. A third subpopulation may exist in the mainstem/NF Toutle but these areas were not surveyed due to poor survey conditions as a result of high sediment loads, and the low probability that spawners are present in these areas. The Green population was comprised of spawners above and below the weir that were summed together. Carcass recoveries above the weir were not found to be length or sex-dependent (Table 62).

Table 62. Results from model selection using the logistic model used to assess factors affecting carcass recapture probabilities for adult Green River Chinook salmon, 2011.

Population	Model	Constant	Sex	Length	Sex + Length
Green>Weir	Posterior Model Probabilities	0.81	0.16	0.02	0.01
Green>Weir	Bayes Factor	1.00	4.99	37.30	157.09

The weir operated over the entire spawning run. A total of 1,254 of the trapped adults were released above the weir of which 632 were tagged. The tests for variable marked carcass recovery proportions among survey areas and time periods provided positive support for pooling of recoveries among locations and time periods. The BF of the null models were 20.3 and 471, respectively. These tests indicated that the pooled Petersen estimator would provide an unbiased estimate of adult abundance, and this estimate was 1,513 (95% CI 1,353-1,705). To estimate the number of spawners upstream of the weir, we multiplied the run size estimate by the proportion of successful spawners, based on carcasses recovered during surveys, and subtracted the estimated sport harvest, which resulted in an estimate of 1,178 adults (95% CI 1,014-1,359). The

AUC estimate below the weir was 23 (95% CI 21-26). Based on adipose fin clips and adjusting for unmarked hatchery fish using North Toutle Hatchery's mass mark rates, the proportion of hatchery-origin spawners for the Green subpopulation was 85.3%. Most hatchery-origin and natural-origin fish were age-4. Subpopulation abundance, origin, sex, and age estimates are found in Table 63-65.

Table 63. Abundance, including sex- and origin-specific estimates, for the adult Green Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	1201	88	1037	1198	1381
Males	546	54	448	544	660
Females	655	60	542	653	778
HOS	1024	80	875	1021	1190
NOS	177	30	122	175	241
Marked	1009	79	862	1006	1172
Unmarked	192	30	138	191	256

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 64. Abundance by total age and origin for the adult Green Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	283	106	106	273	514
HOS Age-4	625	123	385	625	863
HOS Age-5	61	57	3	44	212
HOS Age-6	55	53	1	40	195
NOS Age-3	14	16	0	9	55
NOS Age-4	116	32	58	115	183
NOS Age-5	30	22	1	26	81
NOS Age-6	17	16	1	12	59

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 65. Proportions of the adult Green Chinook salmon subpopulation by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.455	0.030	0.396	0.454	0.514
pFemale	0.545	0.030	0.486	0.546	0.604
pHOS	0.853	0.023	0.805	0.854	0.896
pNOS	0.147	0.023	0.104	0.146	0.195
pMark	0.840	0.022	0.794	0.841	0.882
pUnmark	0.160	0.022	0.118	0.159	0.206
p Age-3 HOS	0.276	0.101	0.105	0.268	0.492
p Age-4 HOS	0.610	0.111	0.385	0.615	0.811
p Age-5 HOS	0.059	0.054	0.003	0.043	0.204
p Age-6 HOS	0.054	0.052	0.001	0.038	0.191
p Age-3 NOS	0.079	0.086	0.001	0.050	0.312
p Age-4 NOS	0.655	0.146	0.348	0.665	0.909
p Age-5 NOS	0.171	0.116	0.005	0.150	0.439
p Age-6 NOS	0.096	0.086	0.004	0.071	0.322

A carcass tagging study was scheduled for the SF Toutle in 2011, but too few tags and recoveries occurred to produce an estimate. However, additional data collected concurrently with carcass tagging during spawning ground surveys (e.g. number of unique redds and live counts) allowed for alternative methods to be used to generate abundance estimates. However, some surveys were missed or ineffective due to high turbid water, when this occurred redd and spawner counts were adjusted based on linear interpolation between survey dates. The redd based estimate was 406 (95% CI 248-713), which is over five times greater than the AUC based estimate of 72 (95% CI 64-81). We decided to use the redd-based estimate to generate the other population metrics because this estimate required making fewer assumptions that may have been violated during difficult environmental conditions (i.e. missed fish on surveys). Redd based abundance estimates may be slightly biased high due to the small number of carcass recoveries used to generate this populations sex ratio which had a higher than expected proportion of males. Based on adipose fin clips and adjusting for unmarked hatchery fish using North Toutle Hatchery's mass mark rates, the proportion of hatchery-origin fish was 60.2%. Most adults were age-3 and 4. Subpopulation abundance, origin, sex, and age estimates are found in Tables 66-68.

Table 66. Abundance, including sex- and origin-specific estimates, for the adult SF Toutle Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	406	123	248	380	713
Males	239	85	122	223	448
Females	167	67	71	155	332
HOS	245	87	126	229	461
NOS	161	66	68	150	324
Marked	240	85	123	224	452
Unmarked	166	66	73	154	330

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 67. Abundance by total age and origin for the adult SF Toutle Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	122	54	46	113	252
HOS Age-4	70	39	18	62	164
HOS Age-5	37	28	4	30	106
HOS Age-6	17	18	0	12	64
NOS Age-3	43	29	7	37	116
NOS Age-4	90	44	29	81	200
NOS Age-5	13	16	0	8	56
NOS Age-6	15	16	0	10	60

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 68. Proportions of the adult SF Toutle Chinook salmon subpopulation by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.589	0.103	0.384	0.592	0.784
pFemale	0.411	0.103	0.216	0.408	0.616
pHOS	0.602	0.104	0.393	0.606	0.795
pNOS	0.398	0.104	0.205	0.394	0.607
pMark	0.591	0.102	0.385	0.593	0.780
pUnmark	0.409	0.102	0.220	0.407	0.615
p Age-3 HOS	0.497	0.129	0.252	0.497	0.746
p Age-4 HOS	0.284	0.116	0.089	0.273	0.533
p Age-5 HOS	0.149	0.093	0.021	0.132	0.374
p Age-6 HOS	0.070	0.065	0.002	0.050	0.242
p Age-3 NOS	0.268	0.133	0.056	0.254	0.560
p Age-4 NOS	0.557	0.149	0.266	0.560	0.834
p Age-5 NOS	0.081	0.085	0.000	0.056	0.301
p Age-6 NOS	0.094	0.086	0.002	0.069	0.322

Both the Green and SF Toutle subpopulation estimates were summed to obtain an estimate for the Toutle population. The total population estimate was 1,607 (95%CI 1,364-1,956). The proportion of hatchery-origin Chinook salmon was 79.0% and most fish were age-4. Population abundance, origin, sex, and age estimates are found in Tables 69-71.

Table 69. Abundance, including sex- and origin-specific estimates, for the adult Toutle Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	1607	151	1364	1590	1956
Males	785	101	622	773	1018
Females	822	89	666	815	1023
HOS	1269	118	1065	1260	1529
NOS	338	72	225	328	512
Marked	1249	116	1048	1240	1501
Unmarked	358	73	244	348	535

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 70. Abundance by total age and origin for the adult Toutle Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	405	120	200	396	662
HOS Age-4	694	129	443	694	944
HOS Age-5	98	63	18	83	258
HOS Age-6	72	56	8	57	218
NOS Age-3	57	33	12	51	137
NOS Age-4	206	55	115	200	331
NOS Age-5	44	27	6	39	107
NOS Age-6	32	23	4	27	90

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 71. Proportions of the adult Toutle Chinook salmon population by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.488	0.036	0.419	0.487	0.559
pFemale	0.512	0.036	0.441	0.513	0.581
pHOS	0.790	0.035	0.716	0.793	0.852
pNOS	0.210	0.035	0.148	0.207	0.284
pMark	0.778	0.034	0.705	0.781	0.838
pUnmark	0.222	0.034	0.162	0.220	0.295
p Age-3 HOS	0.318	0.087	0.165	0.313	0.499
p Age-4 HOS	0.548	0.095	0.357	0.550	0.723
p Age-5 HOS	0.076	0.048	0.015	0.066	0.198
p Age-6 HOS	0.057	0.044	0.006	0.045	0.169
p Age-3 NOS	0.166	0.081	0.040	0.155	0.350
p Age-4 NOS	0.609	0.107	0.391	0.613	0.809
p Age-5 NOS	0.130	0.076	0.017	0.118	0.306
p Age-6 NOS	0.095	0.063	0.012	0.083	0.247

Upper Cowlitz/Tilton Population

The Upper Cowlitz/Tilton Chinook salmon population is composed of three subpopulations. We report on Tilton subpopulation independently and a pooled Upper Cowlitz and Cispus subpopulation due to proximately of release sites to one another and the potential for Chinook salmon to move between basins. The two subpopulation estimates were summed to develop population-level estimates.

Fall Chinook salmon are captured and sorted at the Barrier Dam, trucked, and released into the Tilton, Upper Cowlitz, and Cispus rivers. Prior to being transported Chinook salmon are classified as males, females, and jacks and their mark status is recorded. However, scales are not collected for ageing. We assumed the age structure of lower Cowlitz tules was the same as upper Cowlitz/Tilton tules and used the age structure of the lower Cowlitz population as a surrogate for upper Cowlitz/Tilton population. We subtracted the angler harvest from the number of salmon trucked and released, assumed no fall back into reservoirs or the lower Cowlitz population and no mortality.

A total of 5,799 adults (95% CI 5,798-5,801) were estimated to spawn in the Tilton River with over 73% of these being natural-origin. Subpopulation abundance, origin, and sex estimates are found in Tables 72-74.

Table 72. Abundance, including sex- and origin-specific estimates, for the adult Tilton Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	5,799	1	5,798	5,799	5,801
Males	2,536	36	2,466	2,536	2,607
Females	3,263	36	3,192	3,263	3,334
Marked	1,526	34	1,461	1,526	1,593
Unmarked	4,273	34	4,206	4,273	4,338

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 73. Abundance by total age and origin for the adult Tilton Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Marked Age-3	297	35	230	296	368
Marked Age-4	1,173	46	1,084	1,173	1,262
Marked Age-5	46	15	21	44	80
Marked Age-6	10	7	1	9	28
Unmarked Age-3	790	53	688	790	896
Unmarked Age-4	3,236	63	3,112	3,237	3,359
Unmarked Age-5	239	31	182	237	303
Unmarked Age-6	8	6	1	7	23

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 74. Proportions of the adult Tilton Chinook salmon subpopulation by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.437	0.006	0.425	0.437	0.450
pFemale	0.563	0.006	0.551	0.563	0.575
pMark	0.263	0.006	0.252	0.263	0.275
pUnmark	0.737	0.006	0.725	0.737	0.748
p Age-3 Marked	0.194	0.023	0.151	0.194	0.241
p Age-3 Marked	0.769	0.024	0.720	0.769	0.816
p Age-3 Marked	0.030	0.010	0.014	0.029	0.053
p Age-3 Marked	0.007	0.005	0.001	0.006	0.019
p Age-3 Unmarked	0.185	0.012	0.161	0.185	0.210
p Age-3 Unmarked	0.757	0.014	0.730	0.758	0.783
p Age-3 Unmarked	0.056	0.007	0.043	0.055	0.071
p Age-3 Unmarked	0.002	0.001	0.000	0.002	0.005

A total of 7,114 adults (95% CI 7,113-7,115) were estimated to be trapped and hauled to release sites in the upper Cowlitz and Cispus rivers. The proportion of marked fish was 100%. Subpopulation abundance, origin, and sex estimates are found in Tables 75-77.

Table 75. Abundance, including sex- and origin-specific estimates, for the adult Upper Cowlitz and Cispus Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	7,114	1	7,113	7,114	7,115
Males	4,267	40	4,189	4,267	4,347
Females	2,847	40	2,768	2,847	2,925
Marked	7,113	1	7,110	7,113	7,115
Unmarked	1	1	0	1	4

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 76. Abundance by total age and origin for the adult Upper Cowlitz and Cispus Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Marked Age-3	1,383	164	1,077	1,377	1,716
Marked Age-4	5,467	175	5,116	5,470	5,796
Marked Age-5	215	70	99	208	371
Marked Age-6	48	34	6	40	134
Unmarked Age-3	0	0	0	0	1
Unmarked Age-4	1	1	0	1	3
Unmarked Age-5	0	0	0	0	0
Unmarked Age-6	0	0	0	0	0

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 77. Proportions of the adult Upper Cowlitz and Cispus Chinook salmon subpopulation by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.600	0.006	0.589	0.600	0.611
pFemale	0.400	0.006	0.389	0.400	0.411
pMark	1.000	0.000	1.000	1.000	1.000
pUnmark	0.000	0.000	0.000	0.000	0.001
p Age-3 Marked	0.194	0.023	0.151	0.194	0.241
p Age-3 Marked	0.769	0.025	0.719	0.769	0.815
p Age-3 Marked	0.030	0.010	0.014	0.029	0.052
p Age-3 Marked	0.007	0.005	0.001	0.006	0.019
p Age-3 Unmarked	0.185	0.012	0.162	0.184	0.209
p Age-3 Unmarked	0.758	0.013	0.731	0.758	0.783
p Age-3 Unmarked	0.056	0.007	0.043	0.055	0.071
p Age-3 Unmarked	0.002	0.001	0.000	0.002	0.005

The Tilton and Upper Cowlitz and Cispus were summed to obtain the population abundance, origin, and sex estimates, and are found in Tables 78-80.

Table 78. Abundance, including sex- and origin-specific estimates, for the adult Upper Cowlitz Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	12,910	2	12,910	12,910	12,920
Males	6,803	53	6,699	6,803	6,908
Females	6,110	53	6,005	6,110	6,215
Marked	8,639	34	8,575	8,639	8,706
Unmarked	4,274	34	4,208	4,274	4,338

The sum of abundance by mark status, sex, and age may equal the abundance estimate due to rounding errors.

Table 79. Abundance by total age and origin for the adult Upper Cowlitz Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Marked Age-3	1,680	168	1,366	1,676	2,018
Marked Age-4	6,640	181	6,279	6,643	6,986
Marked Age-5	261	72	142	254	421
Marked Age-6	58	35	13	51	146
Unmarked Age-3	790	53	689	790	897
Unmarked Age-4	3,237	63	3,112	3,237	3,360
Unmarked Age-5	239	31	182	237	303
Unmarked Age-6	8	6	1	7	23

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 80. Proportions of the adult Upper Cowlitz Chinook salmon population by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.527	0.004	0.519	0.527	0.535
pFemale	0.473	0.004	0.465	0.473	0.481
pMark	0.669	0.003	0.664	0.669	0.674
pUnmark	0.331	0.003	0.326	0.331	0.336
p Age-3 Marked	0.194	0.019	0.158	0.194	0.234
p Age-3 Marked	0.769	0.021	0.727	0.769	0.808
p Age-3 Marked	0.030	0.008	0.016	0.029	0.049
p Age-3 Marked	0.007	0.004	0.001	0.006	0.017
p Age-3 Unmarked	0.185	0.012	0.161	0.185	0.210
p Age-3 Unmarked	0.757	0.014	0.730	0.758	0.783
p Age-3 Unmarked	0.056	0.007	0.043	0.055	0.071
p Age-3 Unmarked	0.002	0.001	0.000	0.002	0.005

Coweeman Population

For the Coweeman subpopulation, the logistic regression model to test for bias in carcass recoveries favored the length model over all other models (Table 81). While there was statistical support for a length dependent model, we choose to use the constant model because at other weir operations (e.g. Green and Elochoman) the null model was supported. The weir operated from the start of the run through October 31, its target removal date. A total of 386 trapped adults were tagged and released upstream. The BF, computed from the marginal likelihood, for the null hypothesis that a constant proportion of fish recovered at the weir and during carcass surveys rates was 3.1, which provided support for pooling weir and spawning survey carcass recoveries for abundance estimation. The BF for the null hypothesis of constant proportion of trap efficiency by time period was 17.5, which is strong support for pooling mark releases by time period.

Table 81. Results from model selection using the logistic model used to assess factors affecting carcass recapture probabilities for adult Coweeman River Chinook salmon, 2011.

Model	Constant	Sex	Length	Sex + Length
Posterior Model Probabilities	0.00	0.00	0.71	0.28
Bayes Factor	152.84	552.13	1.00	2.53

To estimate the number of spawners above the weir, we multiplied the run size estimate past the weir of 571 (95% CI 520-634) by the proportion of successful spawners, which resulted in an estimate of 466 adult spawners (95% CI 394-540). Below the weir, we used a redd based method which generated an estimate of 100 adults (95% CI 69-153). The estimate above the weir was summed with the estimate below the weir for a population estimate of 566 (95% CI 484-657).

Based on adipose fin clips and adjusting for unmarked hatchery fish using Kalama Falls Hatchery's mass mark rates, the proportion of hatchery-origin fish was 11.6%. In contrast to other LCR populations, there tended to be older fish in the Coweeman population in 2011. Population abundance, origin, sex, and age estimates are found in Tables 82-84.

Table 82. Abundance, including sex- and origin-specific estimates, for the adult Coweeman Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	566	44	484	565	657
Males	270	30	215	269	332
Females	296	31	238	295	361
HOS	66	15	40	64	98
NOS	500	41	424	499	583
Marked	65	15	39	64	97
Unmarked	501	41	424	500	584

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 83. Abundance by total age and origin for the adult Coweeman Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	26	9	11	25	46
HOS Age-4	26	9	12	25	46
HOS Age-5	8	5	2	7	21
HOS Age-6	6	4	1	5	16
NOS Age-3	85	17	56	84	121
NOS Age-4	379	35	314	378	451
NOS Age-5	26	9	11	25	48
NOS Age-6	10	6	2	9	24

The sum of abundance by mark status, sex, and age may equal the abundance estimate due to rounding errors.

Table 84. Proportions of the adult Coweeman Chinook salmon population by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.477	0.037	0.405	0.477	0.551
pFemale	0.523	0.037	0.449	0.523	0.595
pHOS	0.116	0.024	0.073	0.114	0.167
pNOS	0.884	0.024	0.833	0.886	0.928
pMark	0.115	0.024	0.072	0.114	0.167
pUnmark	0.885	0.024	0.834	0.886	0.928
p Age-3 HOS	0.392	0.101	0.205	0.390	0.597
p Age-4 HOS	0.398	0.102	0.207	0.396	0.605
p Age-5 HOS	0.124	0.066	0.027	0.113	0.280
p Age-6 HOS	0.085	0.057	0.011	0.073	0.229
p Age-3 NOS	0.171	0.030	0.116	0.169	0.233
p Age-4 NOS	0.757	0.034	0.687	0.759	0.821
p Age-5 NOS	0.052	0.018	0.023	0.050	0.093
p Age-6 NOS	0.020	0.011	0.004	0.018	0.047

Kalama Population

A total of 8,422 (95% CI 7,498-9,546) adults are estimated to have spawned in the Kalama based on the AUC model. Based on adipose fin clips and adjusting for unmarked hatchery fish using Kalama Falls Hatchery’s mass mark rates, the proportion of hatchery-origin fish was 93.2%. Most Chinook salmon spawners were age-3 and 4. Population abundance, origin, sex, and age estimates are found in Tables 85-87.

Table 85. Abundance, including sex- and origin-specific estimates, for the adult Kalama Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	8,422	526	7,498	8,383	9,546
Males	3,842	303	3,293	3,827	4,479
Females	4,579	343	3,959	4,557	5,302
HOS	7,853	492	6,986	7,818	8,907
NOS	570	59	464	567	695
Marked	7,790	488	6,929	7,755	8,834
Unmarked	632	61	523	629	762

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 86. Abundance by total age and origin for the adult Kalama Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	3,205	272	2,703	3,191	3,772
HOS Age-4	4,352	324	3,758	4,336	5,037
HOS Age-5	279	71	157	272	433
HOS Age-6	17	17	0	12	63
NOS Age-3	188	54	92	184	305
NOS Age-4	349	63	230	348	476
NOS Age-5	14	17	0	8	59
NOS Age-6	19	18	1	13	68

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 87. Proportions of the adult Kalama Chinook salmon population by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.456	0.022	0.413	0.456	0.500
pFemale	0.544	0.022	0.500	0.544	0.587
pHOS	0.932	0.006	0.921	0.933	0.943
pNOS	0.068	0.006	0.057	0.067	0.079
pMark	0.925	0.005	0.914	0.925	0.935
pUnmark	0.075	0.005	0.065	0.075	0.086
p Age-3 HOS	0.408	0.023	0.364	0.408	0.452
p Age-4 HOS	0.554	0.023	0.509	0.554	0.598
p Age-5 HOS	0.035	0.009	0.020	0.035	0.055
p Age-6 HOS	0.002	0.002	0.000	0.002	0.008
p Age-3 NOS	0.330	0.088	0.167	0.326	0.512
p Age-4 NOS	0.613	0.091	0.427	0.616	0.784
p Age-5 NOS	0.024	0.030	0.000	0.015	0.105
p Age-6 NOS	0.033	0.032	0.001	0.023	0.118

Lewis Population

This Tule population is comprised of three subpopulations: Cedar Creek, EF Lewis, and NF Lewis. We report on the first two components in this population as the NF Lewis is surveyed using funds provided by hydropower companies and their results have a separate reporting structure. Cedar Creek estimates are the sum of the JS model for fish spawning below the trap and a ladder trap count, which we assumed to be a census of upstream passage since the recapture event above the trap was not successful. For the JS analysis below the trap, Bayes factors slightly supported the sex-dependent carcass recovery model (BF=1.10) compared to the constant model, which equates to similar support for both models (Table 88). As with other subpopulations, we used the constant model and did not stratify the estimates based on sex.

Table 88. Results from model selection using the logistic model used to assess factors affecting carcass recapture probabilities for adult Cedar Creek Chinook salmon, 2011.

Model	Constant	Sex	Length	Sex + Length
Posterior Model Probabilities	0.45	0.49	0.02	0.04
Bayes Factor	1.10	1.00	20.05	13.26

The results from the GOF test varied. The data fit the tt model best (Bayesian p-value of 0.62) with the st and ts models having marginal fit and the ss model had lack of fit. For the time varying models, there were five survival and capture parameters, but for the constant model, there was only one survival or capture parameter. Due to sparse recoveries, the weakly identifiability tests indicated the posterior distributions were influenced by the prior distribution for the time varying models. Posteriors were not weakly identifiable when survival, capture, or both were constant. This suggests that even the non-informative priors had some influence on the posterior distribution (Table 89).

Table 89. Results from goodness of fit test for the CJS models and posterior identifiability tests for adult Cedar Creek Chinook salmon below ladder trap, 2011.

CJS Model	Bayesian p-values	Weakly Identifiable - ρ	Weakly Identifiable - ϕ
tt	0.62	4	2
st	0.09	0	2
ts	0.03	4	0
ss	0.00	0	0

Model selection was based on DIC and favored the ttt model with marginal support for the stt model (Table 90). We chose to use the ttt model.

Table 90. JS model selection for Chinook salmon adults in Cedar Creek, 2011.

Model	Deviance	JS_pv	JS_DIC	Δ DIC	DIC Weights	Median Abundance
ttt	90.1	17.4	107.4	0.0	0.942	262
stt	98.2	14.8	113.0	5.6	0.057	252
tst	109.0	15.9	124.9	17.5	0.000	261
sst	125.4	12.3	137.8	30.3	0.000	247

The abundance estimate based on the ladder count and the JS model was 410 adults (95% CI 371-485). Based on adipose fin clips and adjusting for unmarked hatchery fish using Fallert Creek Hatchery’s mass mark rates, the proportion of hatchery-origin fish was 46.9%. Most fish were age-4. Subpopulation abundance, origin, sex, and age estimates are found in Tables 91-93.

Table 91. Abundance, including sex- and origin-specific estimates, for the adult Cedar Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	410	30	371	404	485
Male	163	15	137	162	197
Female	247	23	211	243	301
HOS	193	19	161	190	237
NOS	218	19	186	216	262
Marked	191	19	159	188	235
Unmarked	220	20	188	218	264

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 92. Abundance by total age and origin for the adult Cedar Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	52	9	38	52	71
HOS Age-4	129	15	104	128	164
HOS Age-5	9	4	3	8	18
HOS Age-6	2	2	0	2	7
NOS Age-3	18	5	10	18	30
NOS Age-4	189	18	159	187	228
NOS Age-5	8	4	3	8	18
NOS Age-6	3	2	0	2	8

The sum of abundance by marked status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 93. Proportions of the adult Cedar Chinook salmon subpopulation by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.399	0.029	0.343	0.399	0.455
pFemale	0.601	0.029	0.545	0.601	0.657
pHOS	0.469	0.030	0.411	0.469	0.528
pNOS	0.531	0.030	0.472	0.531	0.589
pMark	0.464	0.029	0.407	0.464	0.522
pUnmark	0.536	0.029	0.478	0.536	0.594
p Age-3 HOS	0.272	0.037	0.203	0.271	0.348
p Age-4 HOS	0.671	0.039	0.592	0.672	0.746
p Age-5 HOS	0.044	0.018	0.016	0.042	0.087
p Age-6 HOS	0.013	0.010	0.001	0.010	0.037
p Age-3 NOS	0.083	0.023	0.045	0.081	0.133
p Age-4 NOS	0.866	0.029	0.805	0.868	0.916
p Age-5 NOS	0.039	0.017	0.013	0.036	0.078
p Age-6 NOS	0.012	0.009	0.001	0.010	0.035

The EF Lewis abundance estimates were based on AUC methods. Some surveys were missed or ineffective due to high turbid water, when this occurred spawner counts were adjusted based on linear interpolation between survey dates. The abundance estimate was 826 adults (95% CI 735-936). Based on adipose fin clips and adjusting for unmarked hatchery fish using Kalama Falls Hatchery's mass mark rates, the proportion of hatchery-origin fish was 5.0%. The majority were age-4 fish. Subpopulation abundance, origin, sex, and age estimates are found in Tables 94-96.

Table 94. Abundance, including sex- and origin-specific estimates, for the adult EF Lewis Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	826	52	735	822	936
Males	332	32	274	331	397
Females	494	39	422	492	576
HOS	41	11	22	40	65
NOS	785	50	695	782	893
Marked	41	11	22	39	65
Unmarked	785	50	696	782	893

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 95. Abundance by total age and origin for the adult EF Lewis Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	23	8	10	22	42
HOS Age-4	13	6	4	12	27
HOS Age-5	3	3	0	2	10
HOS Age-6	2	3	0	2	9
NOS Age-3	152	22	111	151	199
NOS Age-4	600	44	522	598	693
NOS Age-5	30	10	14	29	52
NOS Age-6	3	3	0	2	12

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 96. Proportions of the adult EF Lewis Chinook salmon subpopulation by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.402	0.029	0.346	0.401	0.459
pFemale	0.598	0.029	0.541	0.599	0.655
pHOS	0.050	0.013	0.027	0.048	0.078
pNOS	0.950	0.013	0.922	0.952	0.973
pMark	0.049	0.013	0.027	0.048	0.077
pUnmark	0.951	0.013	0.923	0.952	0.973
p Age-3 HOS	0.565	0.120	0.325	0.567	0.789
p Age-4 HOS	0.310	0.112	0.116	0.302	0.546
p Age-5 HOS	0.064	0.060	0.002	0.047	0.225
p Age-6 HOS	0.061	0.058	0.002	0.043	0.217
p Age-3 NOS	0.193	0.026	0.146	0.193	0.245
p Age-4 NOS	0.765	0.028	0.709	0.765	0.817
p Age-5 NOS	0.038	0.012	0.018	0.037	0.065
p Age-6 NOS	0.004	0.004	0.000	0.003	0.015

The combined EF Lewis and Cedar Creek population estimate was 1,236 (95% CI 1,132-1,366). As with the case in the two subpopulations, there was a high proportion of natural-origin fish (81.1%) and most adults were age-4 in the combined population metrics. Population abundance, origin, sex, and age estimates are found in Tables 97-99.

Table 97. Abundance, including sex- and origin-specific estimates, for the adult Lewis (excluding NF Lewis) Tule Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	1,236	59	1,132	1,232	1,366
Males	495	35	431	494	567
Females	741	45	660	740	840
HOS	233	22	195	231	282
NOS	1,003	53	908	1,000	1,117
Marked	231	22	193	229	279
Unmarked	1,005	53	911	1,003	1,119

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 98. Abundance by total age and origin for the adult Lewis (excluding NF Lewis) Tule Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	75	12	55	75	100
HOS Age-4	142	16	115	140	178
HOS Age-5	11	5	4	10	22
HOS Age-6	5	3	1	4	13
NOS Age-3	170	23	128	169	217
NOS Age-4	789	47	704	786	888
NOS Age-5	38	11	21	37	62
NOS Age-6	6	4	1	5	15

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 99. Proportions of the adult Lewis (excluding NF Lewis) Tule Chinook salmon population by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.400	0.022	0.359	0.400	0.443
pFemale	0.600	0.022	0.557	0.600	0.642
pHOS	0.189	0.016	0.159	0.188	0.221
pNOS	0.811	0.016	0.779	0.812	0.841
pMark	0.187	0.016	0.157	0.186	0.219
pUnmark	0.813	0.016	0.781	0.814	0.843
p Age-3 HOS	0.323	0.040	0.249	0.322	0.403
p Age-4 HOS	0.608	0.041	0.526	0.609	0.686
p Age-5 HOS	0.048	0.019	0.019	0.045	0.091
p Age-6 HOS	0.021	0.013	0.004	0.018	0.054
p Age-3 NOS	0.169	0.021	0.131	0.169	0.211
p Age-4 NOS	0.787	0.022	0.741	0.787	0.830
p Age-5 NOS	0.038	0.010	0.021	0.037	0.060
p Age-6 NOS	0.006	0.004	0.001	0.005	0.016

Washougal Population

The selectivity of carcass recoveries was tested using a logistic regression model with sex and length as covariates. The best model based on BF was the constant model, although there was also support for the sex-dependent model (BF=3.31) (Table 100). We used the constant model and did not stratify by sex.

Table 100. Results from model selection using the logistic model used to assess factors affecting carcass recapture probabilities for adult Washougal River Chinook salmon, 2011.

Population	Model	Constant	Sex	Length	Sex + Length
Washougal	Posterior Model Probabilities	0.74	0.22	0.02	0.01
Washougal	Bayes Factor	1.00	3.31	30.60	80.86

The results of the GOF test indicates the data fit one model (tt) (Bayesian *p*-value of 0.09) but did not fit the other three models. For the time varying models, there were 11 survival and capture parameters, but for the constant model, there was only one survival or capture parameter. Due to sparse recoveries early in the run, the weakly identifiability tests indicated the posterior distributions were influenced by the prior distribution for the time varying models. Posteriors were not weakly identifiable when survival, capture, or both were constant. These results suggest that some periods were influenced by non-informative priors (Table 101).

Table 101. Results from goodness of fit test for the CJS models and posterior identifiability tests for adult Washougal River Chinook salmon, 2011.

CJS Model	Bayesian p-values	Weakly Identifiable - ρ	Weakly Identifiable - ϕ
tt	0.09	9	10
st	0.01	0	7
ts	0.01	7	0
ss	0.00	0	0

We used DIC to select the best model (Table 102). DIC support was similar between the ttt and stt models. We chose to use the stt model since fewer parameters were dependent on the prior (weak identifiability).

Table 102. JS model selection for Chinook salmon adults in Washougal River, 2011.

Model	Deviance	JS_pv	JS_DIC	Δ DIC	DIC Weights	Median Abundance
ttt	202.8	36.9	239.7	0.0	0.587	4,522
stt	211.3	29.1	240.4	0.7	0.410	4,709
tst	221.1	29.2	250.3	10.7	0.003	4,572
sst	247.4	22.9	270.3	30.7	0.000	4,528

The mean abundance estimate was 4,727 (95% CI 4,188-5,369). Based on adipose fin clips and adjusting for unmarked hatchery fish using Washougal Hatchery's mass mark rates, the proportion of hatchery-origin fish was 82.2%. The majority were age-4. Population abundance, origin, sex, and age estimates are found in Tables 103-105.

Table 103. Abundance, including sex- and origin-specific estimates, for the adult Washougal Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	4,727	301	4,188	4,709	5,369
Males	1,743	122	1,522	1,736	2,000
Females	2,984	196	2,633	2,974	3,401
HOS	3,886	251	3,437	3,871	4,419
NOS	842	68	718	838	983
Marked	3,795	245	3,357	3,781	4,316
Unmarked	932	72	802	928	1,081

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 104. Abundance by total age and origin for the 2011 adult Washougal Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	1,546	139	1,295	1,540	1,839
HOS Age-4	2,224	175	1,898	2,215	2,585
HOS Age-5	105	34	50	102	183
HOS Age-6	10	10	0	7	37
NOS Age-3	109	35	48	107	187
NOS Age-4	664	67	541	662	803
NOS Age-5	58	24	20	55	115
NOS Age-6	10	10	0	7	37

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 105. Proportions of the adult Washougal Chinook salmon population by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.369	0.011	0.348	0.369	0.390
pFemale	0.631	0.011	0.610	0.631	0.652
pHOS	0.822	0.009	0.805	0.822	0.839
pNOS	0.178	0.009	0.161	0.178	0.195
pMark	0.803	0.009	0.786	0.803	0.819
pUnmark	0.197	0.009	0.181	0.197	0.214
p Age-3 HOS	0.398	0.025	0.351	0.398	0.449
p Age-4 HOS	0.572	0.025	0.522	0.573	0.620
p Age-5 HOS	0.027	0.008	0.013	0.026	0.046
p Age-6 HOS	0.003	0.003	0.000	0.002	0.009
p Age-3 NOS	0.129	0.041	0.058	0.127	0.216
p Age-4 NOS	0.789	0.048	0.691	0.791	0.877
p Age-5 NOS	0.069	0.029	0.024	0.065	0.134
p Age-6 NOS	0.012	0.012	0.000	0.008	0.045

Upper Gorge Population

The Upper Gorge Tule population consists of the Wind and Little White Salmon subpopulations. Since spawning ground surveys only occurred near the peak of spawning, the Wind subpopulation was estimated using a peak count expansion factor from a 1964 carcass tagging study based on the JS model (Stockley 1965). The peak count expansion factor for this population (based on a combined peak count of live and deads) was 1.19 (95% CI 1.13-1.28) (Rawding et al. 2014). The population estimate was 1,186 adults (95% CI 1,117-1,273). Based on adipose fin clips and adjusting for unmarked hatchery fish using Spring Creek National Fish Hatchery's mass mark rates, the proportion of hatchery-origin fish was 82.3%. Almost 96% of the hatchery-origin adults were age-3. Subpopulation abundance, origin, sex, and age estimates are found in Tables 106-108.

Table 106. Abundance, including sex- and origin-specific estimates, for the adult Wind Tule Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	1,186	40	1,117	1,182	1,273
Males	470	50	375	469	572
Females	716	53	615	716	821
HOS	977	53	875	976	1,081
NOS	209	41	134	208	295
Marked	939	51	841	939	1,040
Unmarked	247	40	174	245	330

The sum of abundance by mark status, sex, and age may equal the abundance estimate due to rounding errors.

Table 107. Abundance by total age and origin for the adult Wind Tule Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	936	54	831	936	1,043
HOS Age-4	25	14	5	22	59
HOS Age-5	8	8	0	6	29
HOS Age-6	8	8	0	5	29
NOS Age-3	60	27	15	58	119
NOS Age-4	134	31	81	132	200
NOS Age-5	7	8	0	5	28
NOS Age-6	8	7	0	5	27

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 108. Proportions of the adult Wind Tule Chinook salmon subpopulation by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.396	0.040	0.319	0.396	0.475
pFemale	0.604	0.040	0.525	0.604	0.681
pHOS	0.823	0.034	0.751	0.825	0.887
pNOS	0.177	0.034	0.113	0.175	0.249
pMark	0.792	0.033	0.723	0.793	0.853
pUnmark	0.208	0.033	0.147	0.207	0.277
p Age-3 HOS	0.959	0.018	0.916	0.961	0.987
p Age-4 HOS	0.025	0.014	0.005	0.023	0.060
p Age-5 HOS	0.008	0.008	0.000	0.006	0.030
p Age-6 HOS	0.008	0.008	0.000	0.005	0.030
p Age-3 NOS	0.283	0.103	0.087	0.282	0.489
p Age-4 NOS	0.645	0.105	0.438	0.645	0.848
p Age-5 NOS	0.036	0.036	0.000	0.024	0.133
p Age-6 NOS	0.036	0.035	0.001	0.026	0.127

For the Little White Salmon River subpopulation, a peak count expansion factor was developed from a 1966 carcass tagging study based on the JS model (Tracy et al. 1967). The expansion factor for this population (3.80 (95% CI 2.92-5.19)) is based only on carcasses only. This is slightly different than what was reported in Rawding et al. (2014) of 3.28 (95% CI 2.71-4.31) due to an error in model coding.

Based on this expansion factor, we estimated 627 adult Tule Chinook salmon spawned in the Little White Salmon River (95% CI 482-857). Based on adipose fin clips and adjusting for unmarked hatchery fish using Spring Creek National Fish Hatchery's mass mark rates, the proportion of hatchery-origin fish approximately 41%. Over 94% of the marked adults were age-3. Subpopulation abundance, origin, sex, and age estimates are found in Tables 109-111.

Table 109. Abundance, including sex- and origin-specific estimates, for the adult Little White Salmon Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	627	96	482	611	857
Males	270	48	193	263	384
Females	357	60	263	350	499
HOS	257	46	184	251	364
NOS	370	62	273	362	515
Marked	247	44	177	241	350
Unmarked	380	63	282	372	527

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 110. Abundance by total age and origin for the adult Little White Salmon Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	241	44	172	236	345
HOS Age-4	8	6	1	6	22
HOS Age-5	4	4	0	3	14
HOS Age-6	4	4	0	3	14
NOS Age-3	110	26	67	107	169
NOS Age-4	253	46	180	247	357
NOS Age-5	4	4	0	2	14
NOS Age-6	4	4	0	3	14

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 111. Proportions of the adult Little White Salmon Chinook salmon subpopulation by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.430	0.039	0.356	0.429	0.506
pFemale	0.570	0.039	0.494	0.571	0.644
pHOS	0.409	0.039	0.334	0.409	0.489
pNOS	0.591	0.039	0.511	0.591	0.666
pMark	0.394	0.038	0.322	0.393	0.470
pUnmark	0.606	0.038	0.530	0.607	0.679
p Age-3 HOS	0.941	0.029	0.875	0.945	0.983
p Age-4 HOS	0.030	0.021	0.004	0.025	0.081
p Age-5 HOS	0.015	0.015	0.000	0.010	0.055
p Age-6 HOS	0.015	0.014	0.000	0.010	0.053
p Age-3 NOS	0.296	0.048	0.206	0.295	0.392
p Age-4 NOS	0.683	0.048	0.584	0.685	0.776
p Age-5 NOS	0.010	0.010	0.000	0.007	0.038
p Age-6 NOS	0.010	0.010	0.000	0.007	0.037

The Upper Gorge Tule Chinook population (Wind and Little White Salmon Rivers combined) abundance, origin, sex, and age estimates can be found in Tables 112-114. The estimated abundance for this combined population is 1,813 adults (95% CI 1,648-2,054). The proportion of hatchery-origin fish was 68.1% with most fish being age-3.

Table 112. Abundance, including sex- and origin-specific estimates, for the adult Upper Gorge Tule Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	1,813	104	1,648	1,801	2,054
Males	740	69	616	736	886
Females	1,073	80	930	1,069	1,246
HOS	1,233	70	1,104	1,230	1,380
NOS	580	75	450	574	746
Marked	1,186	68	1,062	1,183	1,327
Unmarked	627	75	498	621	794

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 113. Abundance by total age and origin for the adult Upper Gorge Tule Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	1,178	70	1,047	1,175	1,324
HOS Age-4	32	15	10	30	68
HOS Age-5	12	9	1	10	35
HOS Age-6	12	9	1	9	34
NOS Age-3	170	38	104	167	251
NOS Age-4	387	56	292	383	510
NOS Age-5	11	9	1	9	34
NOS Age-6	11	8	1	9	33

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 114. Proportions of the adult Upper Gorge Tule Chinook salmon population by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.408	0.029	0.352	0.408	0.466
pFemale	0.592	0.029	0.534	0.592	0.648
pHOS	0.681	0.030	0.621	0.682	0.738
pNOS	0.319	0.030	0.262	0.318	0.379
pMark	0.655	0.029	0.597	0.656	0.710
pUnmark	0.345	0.029	0.290	0.345	0.403
p Age-3 HOS	0.955	0.016	0.918	0.957	0.980
p Age-4 HOS	0.026	0.012	0.008	0.024	0.055
p Age-5 HOS	0.010	0.007	0.001	0.008	0.028
p Age-6 HOS	0.009	0.007	0.001	0.008	0.028
p Age-3 NOS	0.293	0.048	0.201	0.292	0.391
p Age-4 NOS	0.668	0.050	0.568	0.670	0.763
p Age-5 NOS	0.019	0.015	0.002	0.016	0.057
p Age-6 NOS	0.020	0.014	0.002	0.016	0.056

A fall Chinook salmon “Bright” population has been established in the Wind and Little White Salmon rivers. We estimated 512 adults (95% CI 482-549) in the Wind Bright subpopulation. Based on adipose fin clips and adjusting for unmarked hatchery fish using Little White Salmon National Fish Hatchery’s mass mark rates, the proportion of hatchery-origin fish was 67.6%. Most adults were age-4. Subpopulation abundance, origin, sex, and age estimates are found in Tables 115-117.

Table 115. Abundance, including sex- and origin-specific estimates, for the adult Wind Bright Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	512	17	482	510	549
Males	197	25	151	197	247
Females	315	26	265	314	365
HOS	347	28	293	346	403
NOS	165	26	117	165	218
Marked	320	26	271	320	372
Unmarked	192	24	146	191	241

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 116. Abundance by total age and origin for the adult Wind Bright Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	83	18	51	82	122
HOS Age-4	224	27	173	223	279
HOS Age-5	31	12	11	29	59
HOS Age-6	9	6	1	7	25
NOS Age-3	30	11	12	29	56
NOS Age-4	129	24	85	128	179
NOS Age-5	2	4	0	0	14
NOS Age-6	4	4	0	3	16

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 117. Proportions of the adult Wind Bright Chinook salmon subpopulation by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.385	0.046	0.299	0.385	0.477
pFemale	0.615	0.046	0.523	0.615	0.701
pHOS	0.676	0.049	0.578	0.677	0.769
pNOS	0.324	0.049	0.231	0.323	0.422
pMark	0.626	0.045	0.535	0.626	0.712
pUnmark	0.374	0.045	0.288	0.374	0.465
p Age-3 HOS	0.241	0.049	0.152	0.239	0.342
p Age-4 HOS	0.645	0.056	0.532	0.646	0.751
p Age-5 HOS	0.088	0.034	0.033	0.084	0.165
p Age-6 HOS	0.026	0.018	0.003	0.022	0.070
p Age-3 NOS	0.182	0.065	0.074	0.176	0.325
p Age-4 NOS	0.777	0.071	0.625	0.782	0.900
p Age-5 NOS	0.014	0.023	0.000	0.002	0.082
p Age-6 NOS	0.027	0.026	0.001	0.019	0.098

For the Little White Salmon Bright subpopulation, we estimated 521 adults (95% CI 401-711). This estimate is slightly less than the Tule estimate of 627 adults. Based on adipose fin clips and adjusting for unmarked hatchery fish using Little White Salmon National Fish Hatchery's mass mark rates, the proportion of hatchery-origin fish was 64.0%. Most adults were age-4. Subpopulation abundance, origin, sex, and age estimates are found in Tables 118-120.

Table 118. Abundance, including sex- and origin-specific estimates, for the adult Little White Salmon Bright Chinook salmon subpopulation, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	521	80	401	508	711
Males	154	27	112	151	217
Females	366	58	278	359	506
HOS	333	53	250	326	458
NOS	187	32	136	183	263
Marked	305	49	229	298	419
Unmarked	216	36	160	211	300

The sum of abundance by mark status, sex, and age may equal the abundance estimate due to rounding errors.

Table 119. Abundance by total age and origin for the 2011 adult Little White Salmon Bright Chinook salmon subpopulation.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	53	12	34	52	81
HOS Age-4	228	38	169	223	318
HOS Age-5	50	12	31	48	76
HOS Age-6	2	2	0	1	6
NOS Age-3	24	7	13	23	40
NOS Age-4	133	25	94	130	190
NOS Age-5	29	8	15	28	48
NOS Age-6	2	2	0	1	6

The sum of abundance by mark status, sex, and age may equal the abundance estimate due to rounding errors.

Table 120. Proportions of the adult Little White Salmon Bright Chinook salmon subpopulation by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.296	0.024	0.249	0.296	0.345
pFemale	0.704	0.024	0.655	0.705	0.751
pHOS	0.640	0.029	0.582	0.641	0.696
pNOS	0.360	0.029	0.304	0.360	0.418
pMark	0.585	0.026	0.532	0.586	0.636
pUnmark	0.415	0.026	0.364	0.414	0.468
p Age-3 HOS	0.160	0.025	0.114	0.159	0.212
p Age-4 HOS	0.686	0.033	0.621	0.686	0.748
p Age-5 HOS	0.150	0.025	0.103	0.148	0.202
p Age-6 HOS	0.005	0.005	0.000	0.003	0.018
p Age-3 NOS	0.127	0.031	0.073	0.124	0.193
p Age-4 NOS	0.711	0.043	0.624	0.712	0.792
p Age-5 NOS	0.154	0.035	0.090	0.152	0.228
p Age-6 NOS	0.008	0.008	0.000	0.006	0.030

The combined Upper Gorge Bright estimate was 1,032 adults (95% CI 906-1,226). This is less than the Tule adult estimate of 1,813. Most of the adults from this Bright population were age-4 and proportion of hatchery-origin spawners was almost 66%. Population abundance, origin, sex, and age estimates are found in Tables 121-123.

Table 121. Abundance, including sex- and origin-specific estimates, for the adult Upper Gorge Bright Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	1,032	82	906	1,021	1,226
Males	351	36	287	349	429
Females	681	64	576	675	828
HOS	680	60	579	674	815
NOS	353	41	278	350	442
Marked	625	55	533	619	749
Unmarked	407	43	332	404	503

The sum of abundance by mark status, sex, and age may equal the abundance estimate due to rounding errors.

Table 122. Abundance by total age and origin for the adult Upper Gorge Bright Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	137	22	98	135	183
HOS Age-4	452	47	371	448	556
HOS Age-5	80	17	51	79	117
HOS Age-6	11	6	2	9	26
NOS Age-3	54	13	31	53	83
NOS Age-4	262	34	200	261	335
NOS Age-5	31	9	16	30	52
NOS Age-6	6	5	1	5	18

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 123. Proportions of the adult Upper Gorge Bright Chinook salmon population by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.341	0.026	0.290	0.340	0.393
pFemale	0.659	0.026	0.607	0.660	0.710
pHOS	0.659	0.029	0.603	0.659	0.715
pNOS	0.341	0.029	0.286	0.341	0.397
pMark	0.605	0.026	0.554	0.606	0.657
pUnmark	0.395	0.026	0.343	0.394	0.446
p Age-3 HOS	0.201	0.028	0.149	0.201	0.261
p Age-4 HOS	0.665	0.033	0.598	0.666	0.728
p Age-5 HOS	0.118	0.022	0.080	0.117	0.166
p Age-6 HOS	0.016	0.010	0.003	0.013	0.040
p Age-3 NOS	0.152	0.035	0.093	0.150	0.229
p Age-4 NOS	0.742	0.041	0.657	0.744	0.818
p Age-5 NOS	0.088	0.023	0.049	0.086	0.138
p Age-6 NOS	0.017	0.013	0.002	0.014	0.052

White Salmon Population

Historically, Tule Chinook salmon spawned in the White Salmon River but there are Tule and Bright populations currently spawning in this river. The White Salmon population was estimated using a peak count expansion factor from a 1989 Bright carcass tagging study based on the JS model (Hymer 1991). The expansion factor for this population based on a combined peak count of live and dead Chinook salmon was 2.4 (95% CI 2.3-2.5).

We used the Bright peak count expansion factor for this river to develop a Tule estimate, as we did not have an expansion factor specific for Tules. The mean abundance was 379 adults (95% CI 350-408). Based on adipose fin clips and adjusting for unmarked hatchery fish using Spring Creek National Fish Hatchery's mass mark rates, the proportion of hatchery-origin fish was 11.5%. Population abundance, origin, sex, and age estimates are found in Tables 124-126.

Table 124. Abundance, including sex- and origin-specific estimates, for the adult White Salmon Tule Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Abundance	379	15	350	379	408
Males	196	22	154	196	238
Females	183	21	142	183	226
HOS	44	13	22	43	73
NOS	335	18	298	335	371
Marked	42	13	21	41	70
Unmarked	337	18	300	337	372

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 125. Abundance by total age and origin for the adult White Salmon Tule Chinook salmon population, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
HOS Age-3	20	9	7	19	40
HOS Age-4	17	8	5	16	36
HOS Age-5	3	3	0	2	12
HOS Age-6	3	3	0	2	12
NOS Age-3	93	18	61	92	130
NOS Age-4	234	21	192	234	276
NOS Age-5	4	4	0	3	15
NOS Age-6	4	4	0	3	16

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors.

Table 126. Proportions of the adult White Salmon Tule Chinook salmon population by sex and origin, and proportions of each origin by age, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
pMale	0.517	0.053	0.413	0.517	0.620
pFemale	0.483	0.053	0.380	0.483	0.587
pHOS	0.115	0.034	0.057	0.113	0.191
pNOS	0.885	0.034	0.809	0.888	0.943
pMark	0.112	0.033	0.056	0.109	0.185
pUnmark	0.888	0.033	0.815	0.891	0.944
p Age-3 HOS	0.464	0.133	0.211	0.462	0.724
p Age-4 HOS	0.384	0.129	0.154	0.378	0.647
p Age-5 HOS	0.076	0.071	0.002	0.056	0.256
p Age-6 HOS	0.075	0.070	0.002	0.055	0.260
p Age-3 NOS	0.278	0.051	0.184	0.275	0.381
p Age-4 NOS	0.697	0.052	0.592	0.699	0.794
p Age-5 NOS	0.012	0.012	0.000	0.009	0.046
p Age-6 NOS	0.013	0.013	0.000	0.009	0.046

On October 26, 2011, Condit Dam (rkm 5.26) was breached. USFWS implemented a salvage plan and translocated 662 Tule adults to the area upstream of Condit Dam between September 6 and October 5. A total of 546 unmarked and 116 marked Tule adults were collected at a combination of collection sites which included the Spring Creek National Fish Hatchery, a resistance board weir at river mile 1.1, and seining efforts in the lower mile of the river (Engle 2013). Our estimates above (Tables 124-126) are for the historical spawning area downstream of Condit Dam and do not include these translocated fish.

We are not reporting a Bright estimate for the White Salmon population in 2011. While there could have been some Bright spawning, surveys were not conducted by WDFW staff during the typical Bright spawning period due to the turbid conditions in the lower White Salmon associated with Condit Dam removal.

Cross Validation of Redd and AUC Estimates

The redd-based abundance estimate for the Coweeman upstream of the weir site was 436 compared to the mark-recapture estimate of 466. The probability that the redd-based estimate was greater than the mark-recapture estimate was 0.27, which indicated similarity between the two estimates. These results are consistent with our 2010 comparison between redd based estimates and tGMR estimates for the Coweeman population (Rawding et al. 2014). This suggests applying the 1.1 AFpR to other populations should yield reasonable abundance estimates.

Our AUC cross validation estimates (Table 127) ranged from 4.67 to 5.36 days. There was marginal fit for all four subpopulations (Bayesian *p*-values: Grays=0.107, Abernathy = 0.051, Germany = 0.989, Washougal = 0.912). This analysis suggests that there was some variation in ART estimates across LCR Chinook populations during 2011, with clustering near 4.2 and 5.7 days. However, reasonable estimates of abundance should be achieved when applying the mean SL estimates to other populations throughout the ESU.

Table 127. Mean and cross validation estimates (using the leave one out approach) of Apparent Residence Time (ART) for Lower Columbia Tule Fall Chinook, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Mean 2011	5.06	0.31	4.45	5.07	5.67
Mean 2011 - Grays	5.34	0.30	4.74	5.35	5.92
Mean 2011 - Aber	5.36	0.36	4.65	5.36	6.05
Mean 2011 - Germ	4.67	0.38	3.92	4.67	5.40
Mean 2011 - Wash	4.89	0.40	4.11	4.89	5.65

Population Summary

The individual population estimates were summed to provide a Lower Columbia River (LCR) ESU-scale estimate for Washington populations of Tule, Lewis Brights, Rogue Brights, and Bonneville (BON) Pool Brights. We estimated 39,383 adult Tule Chinook salmon in the Washington portion of the LCR ESU. The proportion of natural-origin Tules was 30.8%, which yields and estimate of 12,397 unmarked Tules. The NF Lewis Brights abundance was estimated to be 8,205 (Shane Hawkins, WDFW, personal communication). BON Pool Brights in the Washington portion of the LCR ESU totaled 1,035 of which 65.9% were hatchery-origin (Tables 128-129).

The largest natural-origin populations of Tule Chinook salmon were estimated to be in the upper Cowlitz (4,274) and Lewis (excluding NF Lewis) (1,003) while the smallest natural-origin populations were found in the Grays (70) and Elochoman (58) populations (Figure 3).

Table 128. Abundance and origin estimates of adult Tule Chinook salmon populations in the Washington portion of the LCR ESU, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
Adult Tules	39,383	820	37,900	39,340	41,100
HOS Tules	27,273	689	26,030	27,240	28,740
NOS Tules	12,110	188	11,760	12,100	12,500
Marked Tules	26,986	680	25,770	26,950	28,430
Unmarked Tules	12,397	194	12,040	12,390	12,800
pHOS Tules	0.692	0.004	0.684	0.692	0.701
pNOS Tules	0.308	0.004	0.299	0.308	0.316
Prop. Of Marked Tules	0.685	0.004	0.677	0.685	0.693
Prop. Of Unmarked Tules	0.315	0.004	0.307	0.315	0.323

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors. Includes Cowlitz and NF Lewis Tule estimate from Chris Gleizes and Shane Hawkins, WDFW, personal communications.

Table 129. Abundance and origin estimates of adult Bright Chinook salmon populations in the Washington portion of the LCR ESU, 2011.

Parameter	Mean	SD	2.50%	Median	97.50%
BON Pool Brights	1,035	82	908	1,024	1,229
HOS BON Pool Brights	682	60	581	676	817
NOS BON Pool Brights	353	41	279	350	443
Marked BON Pool Brights	626	55	534	621	751
Unmarked BON Brights	408	43	333	405	504
pHOS BON Brights	0.659	0.029	0.603	0.659	0.714
pNOS BON Brights	0.341	0.029	0.286	0.341	0.397
Prop. Of Marked BON Brights	0.606	0.026	0.554	0.606	0.657
Prop. Of Unmarked BON Brights	0.394	0.026	0.343	0.394	0.446
Rogue Brights in Grays R.	278	68	187	264	448
Lewis River Brights	8,205	NA	NA	NA	NA

The sum of abundance by mark status, sex, and age may not equal the abundance estimate due to rounding errors. Includes Cowlitz and NF Lewis Tule estimate from Chris Gleizes and Shane Hawkins, WDFW, personal communications.

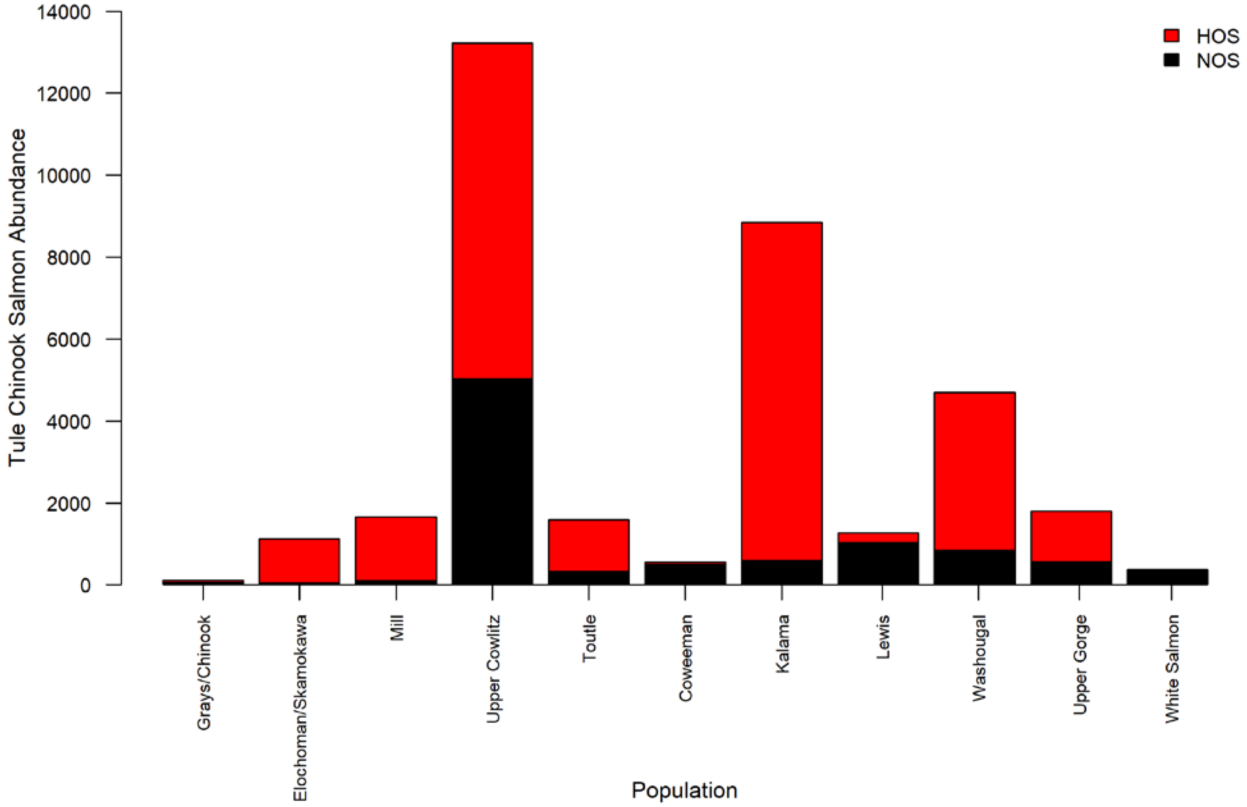

Figure 3. Tule Chinook Salmon Abundance by Origin and Population, 2011.

The proportion of hatchery-origin spawners for Tule Chinook salmon was lowest in the White Salmon (11.5%), Coweeman (11.6%), and Lewis (excluding NF Lewis) (18.9%) populations while the Elochoman (94.8%), Mill (93.4%), and Kalama (93.2%) populations had the greatest values (Figure 4).

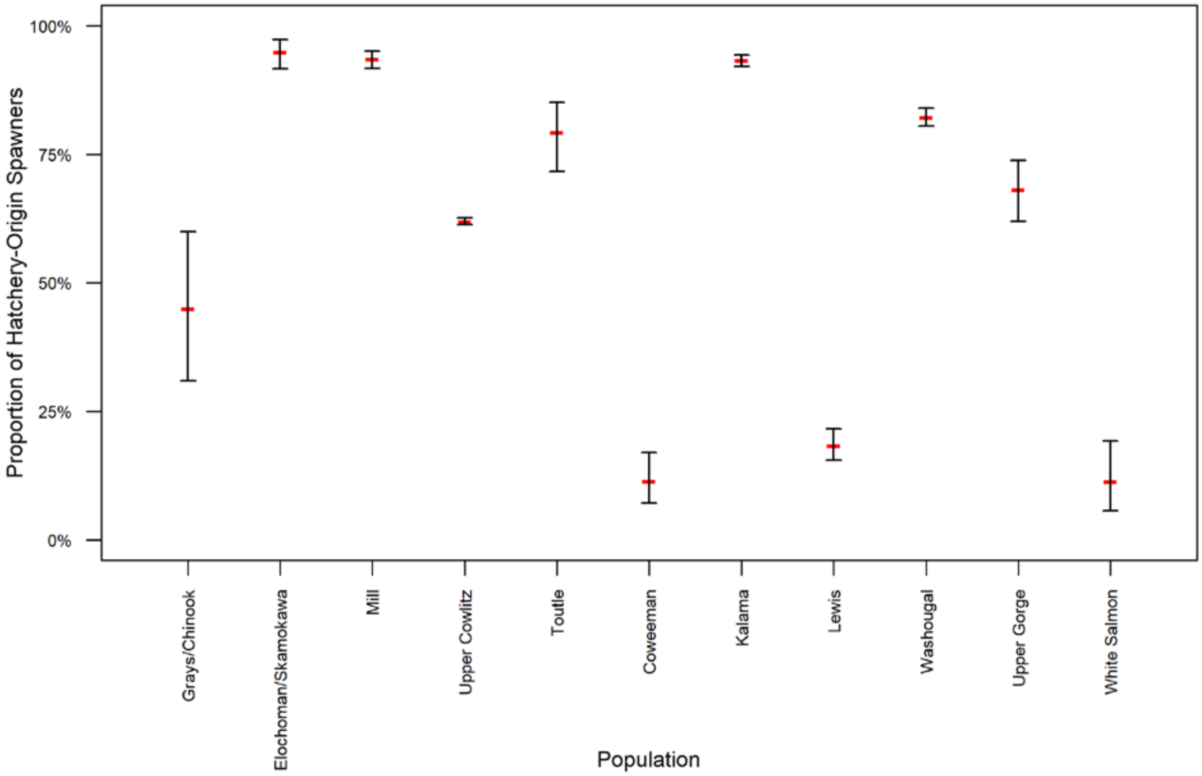

Figure 4. Proportion of Hatchery-Origin Tule Chinook Salmon Spawners by Population, 2011. The Grays population pHOS value of 45.2% increases to 82.7% when hatchery-origin Rogue Brights are included in the calculation.

Tag Loss

Tag loss for carcass tags was evaluated using a double tagging experiment. The median probability of losing a single tag was estimated to be 4.3% to 14.6% and the probability of retaining at least one tag was estimated to range from 99.3% to 100% (Table 130). Based on this analysis, no adjustment for tag loss was required for Jolly-Seber population estimates reported in this document. The estimated median probability for Floy tag loss was higher, ranging from 13.2% to 37.7% (Table 131). However, the estimated median probability of retaining at least one tag ranged from 85.6% to 98.2%. Males had a higher probability of losing Floy tags than females. While we assessed tag loss for Floy tags, tag loss did not affect our estimate because we used a permanent operculum mark that was rotated weekly allowing correct assignment to release period even if both Floy tags were lost for our mark-recapture estimates.

Table 130. Tag loss for Chinook salmon tagged with carcasses tags, 2011. t_2 is the number of fish retaining two tags, t_1 is the number of fish retaining one of two tags, p_i is the estimated probability of losing a single tag and q_0_i is the probability of a tagged fish retaining at least one tag.

Population	t_2	t_1	Parameter	Mean	SD	2.50%	Median	97.50%
Grays	33	1	p[1]	0.044	0.024	0.009	0.039	0.102
Skamokawa	44	7	p[2]	0.146	0.035	0.085	0.144	0.220
Mill	521	41	p[3]	0.074	0.008	0.059	0.074	0.090
Abernathy	23	3	p[4]	0.132	0.046	0.056	0.128	0.233
Germany	133	7	p[5]	0.054	0.014	0.030	0.052	0.083
Coweeman	58	3	p[6]	0.057	0.021	0.023	0.055	0.104
Washougal	145	6	p[7]	0.043	0.012	0.023	0.042	0.069
Grays	-	-	q_0[1]	0.999	0.001	0.997	1.000	1.000
Skamokawa	-	-	q_0[2]	0.993	0.003	0.985	0.994	0.998
Mill	-	-	q_0[3]	0.999	0.000	0.998	0.999	0.999
Abernathy	-	-	q_0[4]	0.994	0.004	0.983	0.995	0.999
Germany	-	-	q_0[5]	0.999	0.000	0.998	0.999	1.000
Coweeman	-	-	q_0[6]	0.999	0.001	0.997	0.999	1.000
Washougal	-	-	q_0[7]	1.000	0.000	0.999	1.000	1.000

Table 131. Tag loss for Chinook salmon tagged live with Floy tags and recovered as carcasses, 2011. t_2 is the number of fish retaining two tags, t_1 is the number of fish retaining one of two tags, and t_0 is the number of fish retaining no tags, p_i is the estimate of tag loss and q_0_i is the probability of a tagged fish retaining at least one tag.

Population	t_2	t_1	t_0	Parameter	Mean	SD	2.50%	Median	97.50%
Coweeman Males	21	10	8	p[1]	0.338	0.053	0.240	0.335	0.445
Coweeman Females	42	7	3	p[2]	0.132	0.033	0.075	0.129	0.203
Coweeman Adults	63	17	11	p[3]	0.217	0.030	0.161	0.216	0.280
Elochoman Males	22	21	6	p[4]	0.340	0.047	0.251	0.339	0.435
Elochoman Females	64	29	10	p[5]	0.240	0.030	0.183	0.239	0.300
Elochoman Adults	86	50	16	p[6]	0.271	0.025	0.223	0.271	0.322
Green Males	19	22	7	p[7]	0.377	0.048	0.286	0.376	0.472
Green Females	34	18	9	p[8]	0.298	0.041	0.222	0.297	0.381
Green Adults	53	40	16	p[9]	0.332	0.032	0.271	0.331	0.395
Coweeman Males	-	-	-	q_0 [1]	0.883	0.036	0.802	0.888	0.943
Coweeman Females	-	-	-	q_0 [2]	0.982	0.009	0.959	0.983	0.994
Coweeman Adults	-	-	-	q_0 [3]	0.952	0.013	0.922	0.953	0.974
Elochoman Males	-	-	-	q_0 [4]	0.882	0.033	0.811	0.885	0.937
Elochoman Females	-	-	-	q_0 [5]	0.942	0.015	0.910	0.943	0.966
Elochoman Adults	-	-	-	q_0 [6]	0.926	0.014	0.897	0.927	0.950
Green Males	-	-	-	q_0 [7]	0.856	0.036	0.777	0.859	0.918
Green Females	-	-	-	q_0 [8]	0.910	0.025	0.855	0.912	0.951
Green Adults	-	-	-	q_0 [9]	0.889	0.021	0.844	0.890	0.927

Timing

The cumulative timing for Tule Chinook salmon subpopulations are shown in Figure 5. These were adjusted for missed counts, which occurred for some of the later spawning populations such as the Grays, Coweeman, EF Lewis, and SF Toutle. The populations from the LCR Coastal strata including Skamokawa, Elochoman, Mill, Abernathy, and Germany subpopulations presented the earliest timing in 2011. The mean spawning date for these populations was mid-September. These populations have historically had high hatchery strays influence and CWT recoveries indicated most of the hatchery fish were from the Elochoman and Big Creek hatcheries. The exception to the trend of early spawning in the Coastal strata was the Grays population where a weir is used to removed hatchery-origin strays and the timing was more influenced by large numbers of Rogue River Brights that enter the system after the weir needs to be removed (before consistent high flows would prevent removal and spawn later than typical coastal Tule stocks. The next timing group includes the Green, Washougal, and Kalama subpopulations. All from the LCR Cascade strata and all of which have high proportions of hatchery-origin Chinook salmon spawners as a result of in-basin hatchery releases. The latest spawning populations were the EF Lewis, Coweeman, and SF Toutle. Again, all from the LCR Cascade strata but the EF Lewis and Coweeman populations have historically had the lowest estimated proportions of hatchery-origin Tule Chinook in the Washington portion of the LCR. Peak count surveys were conducted in the LCR Gorge strata populations, therefore we are unable to generate timing estimates for these populations.

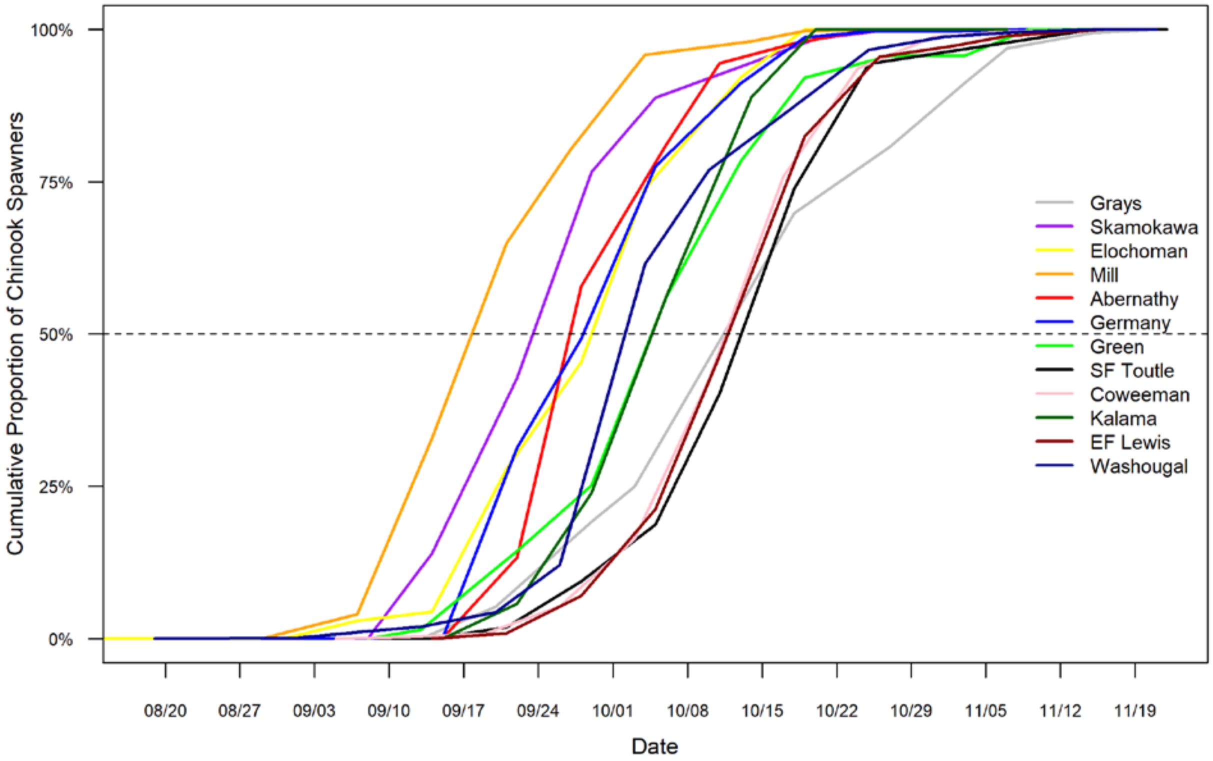

Figure 5. Tule fall Chinook salmon timing for Washington's Lower Columbia River populations based on period (weekly) counts of Chinook salmon classified as spawners, 2011.
Note the Grays timing includes both Tules and Rogue River Brights.

CWT Program

Chinook salmon CWT recoveries in the fall of 2011 were uploaded to the RMIS system on December 3, 2012. The uploaded data includes: 1) freshwater sport fishery recoveries, 2) hatchery facility recoveries, 3) trap and weir recoveries, and 4) spawning ground recoveries.

There were no CWT recoveries during spawning ground surveys in the SF Toutle, Abernathy, and EF Lewis subpopulations (Table 132). The lack of recoveries in these subpopulations is due to low overall abundance in the SF Toutle and Abernathy subpopulations and the low proportion of hatchery-origin fish sampled in the EF Lewis subpopulation in 2011. For some Washington hatcheries, the majority of CWTs were recovered in the basin they were released, including the North Toutle and Washougal, but for other hatcheries high numbers of recoveries occurred outside their release basins (Deep River, Elochoman, and Little White Salmon). The CWT release group with the largest number of recoveries occurred at the Little White Salmon Hatchery (64). Fish released from Oregon hatcheries were generally recovered at a low rate in Washington, with the largest number of recoveries coming from the Big Creek Hatchery. There were a few fish tagged at distant locations such as the Icicle Hatchery that were recovered during our surveys. CWT data for fisheries and carcass recoveries are presented in annual reports for missing production groups (e.g. Harlan 2013).

Table 132. Unexpanded CWT recoveries by subpopulation and hatchery of origin for Chinook salmon, 2011. Spring Cr. Hatchery recoveries in the White Salmon were considered in basin recoveries.

		Release Basin														
Recovery Basin		SF Klaskanine H.	Deep River N.P.	Big Cr. H.	Eloch H.	Cowlitz H.	Cowlitz H. at Mayfield	N. Toutle H.	Kalama Falls H.	Fallert H.	Wash H.	Bonn H.	LWS H.	Klick H.	Icicle H.	Blank
	Grays	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Skamokawa	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0
	Elochoman	0	1	1	4	0	0	0	0	0	0	0	0	0	0	0
	Mill	0	1	2	11	0	0	0	0	0	0	0	0	0	0	0
	Abernathy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Germany	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
	Lower Cowlitz	0	0	0	0	9	8	0	0	0	0	0	0	0	0	0
	Coweeman	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
	Toutle/Green	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0
	SF Toutle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Kalama	0	0	1	0	0	1	0	7	8	0	0	0	0	0	0
	NF Lewis	0	0	0	0	1	0	0	2	3	0	0	0	0	0	39
	Cedar	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
	EF Lewis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Washougal	0	0	0	0	0	0	0	1	1	14	0	0	0	0	0
	Wind	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0
	L White Salmon	0	0	0	0	0	0	0	0	0	0	1	48	3	1	0
	B White Salmon	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	TOTAL	1	2	9	16	10	9	8	12	14	14	1	64	3	2	39
	% Out of Basin	100%	100	100	75%	10%	11%	0%	42%	43%	0%	100	25%	100	100	NA

Note the last column is labeled “Blank”, however it represents recoveries of CWT placed on natural-origin fall Chinook salmon juveniles from the North Fork Lewis River.

Discussion

This is the second consecutive year we completed a comprehensive analysis of fall Chinook salmon returning to Washington's portion of the Lower Columbia ESU. We used weir census and mark-recapture estimates when possible, AUC and redd-based estimates for other populations, and peak count expansion when other methods were not possible. We adopted a Bayesian approach, but with vague priors, which lets the results be driven by the data. We used Bayesian hypothesis testing to identify mark-recapture models that met the required assumptions for unbiased estimates. We developed statistical methods to estimate the uncertainty in the abundance estimates and the proportions of natural- and hatchery-origin spawners by age.

We conducted sensitivity analysis to compare the results using our two vague prior (Jefferies and the uniform prior) for models that used proportion such as the JS and Darroch models, estimates of proportions by sex, origin, and age, and to adjust spawner counts if surveys were missed. The result of the sensitivity analysis (not shown) indicated the Jefferies prior yielded estimates with slightly more fish in most cases, although they were not very different than the estimates using the uniform prior. In the logistic regression, the vague uniform prior and the standard vague gamma (0.001, 0.001) for the standard deviation of regression coefficients produced similar results, which was the same conclusion reached by Link and Barker (2006).

We used two Bayesian approaches for multi-model inference including Bayes Factors and Deviance Information Criteria (DIC) (Kass and Rafferty 1995, Spiegelhalter et al. 2002). When using DIC for JS model selection, the uniform and Jefferies priors yield the same results. BF are sensitive to the choice of priors, which is often referred to as the Lindley-Bartlett paradox: if the priors are too vague the BF will select more parsimonious models (Link and Barker 2006, Ntzoufras 2009). To avoid this in our logistic model, we implemented the priors from Link and Barker (2006) that constrained the total prior variability to be constant between models. We also used a uniform prior in estimating BF when comparing proportions (Ntzoufras 2009, Link and Barker 2010, Lodewyckx et al. 2011). There are other approaches for selecting reference priors for model selection that include posterior, fractional, and intrinsic BF that we did not use (Aitkin 1991, O'Hagan 1995, and Berger and Pericchi 1996).

We tested if stratification of data into homogeneous groups (recapture probability by sex or length) for open and closed population models was needed by computing posterior model probabilities and BF (Link and Barker 2006). We also tested the various assumptions needed for the pooled Petersen estimator (Schwarz and Taylor 1998) using BF calculated from the marginal likelihood of the beta binomial model (Ntzoufras 2009). In the ten tests regarding recovery probabilities with uniform prior model weights, BF indicated there was support for models in which recovery probabilities were constant for five subpopulations and were length dependent in three subpopulations and sex dependent in two subpopulations. In eight of the ten populations, the constant had the first or second highest level of support. We explored the sensitivity of our prior on model selection by considering models that favored parsimonious models by developing prior model probabilities equal to exp(-k), where k is the number of covariates in the model, and complex models where the prior model probability was equal to exp(k). When we used a prior that favored a more parsimonious model, the BF favored the constant recovery model in almost all cases. When using a prior that favored complex models, the BF found evidence of positive support (BF<3) for the constant recovery model in most cases. Therefore, our prior model probability was not sensitive to the model selection when considering prior model probabilities that favor parsimony or complexity.

Due to the difficulty in estimating BF for open population models, we used DIC for model selection. Since we used vague priors we used pv instead of pD when estimating DIC because this is accurate when priors are vague and invariant to reparameterization (Gelman et al 2004). DIC is a Bayesian analog of AIC and used the Kullback-Leibler prior, which tends to favor more complex models (Link and Barker 2006, Ward 2008). Of the six current year JS datasets, half (3) favored the more complex model (ttt) while the other half (3) were split between the stt, tst, and sst models. However, in most cases abundance estimates were similar indicating that JS model selection using DIC did not influence the abundance estimate. Model selection, choosing between models, is a continuing area of research for statisticians and there is no consensus among statisticians regarding model selection (Ward 2008). We used vague priors for this analysis, thus the sensitivity of our priors had little effect on the results except when data was sparse in the proportion of ages for natural-origin fish. There is often some hesitancy in using Bayesian methods mostly due to how priors are developed. We used an objective analysis where priors were vague, with the intent that they would have little influence on the posterior distribution. There is often little difference in parameter estimates between maximum likelihood and Bayesian methods as long as the posterior is data driven, which occurred in this analysis (McCarthy 2007, Kery 2010).

Weir Estimates

Although the use of weirs in this study was primarily for broodstock collection and management purposes, such as limiting the number of hatchery fish on spawning grounds, in some cases the weirs were able to provide a census or very precise estimates of the Chinook salmon runs. When possible, we subtracted harvest and pre-spawn mortality estimates from the abundance estimate to provide an estimate of the number of adult Chinook salmon spawners. We did not have an estimate of the pre-spawn mortality or the number of transported fish that fell back and did not spawn on the Tilton and Upper Cowlitz/Cispus rivers. Therefore, in these cases, it is likely we overestimated the number of spawners.

We were not successful in operating weirs on the Washougal and Grays rivers to obtain abundance estimates of Chinook salmon. The run timing of the Chinook salmon population in the Washougal is later than many other LCR populations (Figure 5) and operating the weir later in the season makes it more susceptible to freshets and, thus, more challenging. On the Grays River, we were able to successfully operate the weir during the Tule time period. However, Rogue River “Bright” Chinook salmon from the Oregon’s Selective Area Fisheries Enhancement (SAFE) program have a broader run timing and stray into the Grays. As with the Washougal, our ability to successfully operate a weir on the Grays River after mid-October is challenging. However, both of these weirs were successful at reducing the proportion of hatchery-origin spawners, which was their primary purpose.

Closed Population Estimates

We developed closed population estimates for adult Chinook salmon in the Green, Elochoman, and Coweeman rivers. Using the "pooled" Petersen model, the estimate for Chinook salmon passing the weir site was different than the actual weir counts at each of the three weirs. Since our estimates of abundance accounted for pre-spawning mortality, our reported abundance estimate is less than the Petersen estimate and the weir count in the Elochoman and Green Rivers. Assuming the Petersen model estimate is correct, there were 184 adult Chinook salmon that passed the weir unsampled on the Coweeman, 256 on the Green, and 39 on the Elochoman. Weir capture efficiencies are estimated in the appendix of this report.

Schwarz and Taylor (1998) indicate that the following assumptions must be met to provide a consistent estimate of abundance: 1) Tag Loss - there is no mark loss, 2) Handling Mortality - there are no marking effects, 3) Tag Reporting - all tagged and untagged fish are correctly identified and enumerated, 4) Closure - the population is closed, and 5) Equal Capture - all fish in the population have the same probability of being tagged; or all fish have the same probability of being captured in the second sample; or marked fish mix uniformly with unmarked fish.

We addressed tag loss by adding a permanent secondary mark, which was a shaped punch applied to the operculum that was rotated weekly. All Chinook salmon were handled carefully to minimize mortality, but even if it did occur it did not affect our results since the population was closed and the estimate of abundance was at the time of tagging. All surveyors were trained and carefully inspected all carcasses for tags, so we believe there was high probability that all tagged and untagged fish were correctly identified and enumerated. The weirs and stream surveys were operated/conducted over the entire migration and spawning period and carcass recoveries were spatially representative, so the closure assumptions was met. We conducted Bayesian hypothesis testing for the equal capture assumption. The results from our logistic model indicated that sex and length did not influence recapture probabilities except on the Coweeman, and Bayes Factors favored models with a constant marked proportion of carcasses by location and by recovery period or a constant marked fraction, suggesting the pooled Petersen estimator was appropriate. Finally, we compared the weir census and closed population estimates on the Elochoman and Green rivers. The results indicate we missed a small proportion of the run (<6%) and our population estimates are consistent with our understanding of weir operations and population abundance.

Open Population Estimates

In the JS model, all parameters are not identifiable including the probability of capture (p) in the first and last periods. Therefore, to obtain a salmon population estimate the p's were modeled as $p_2 = p_1$, and $p_s = p_{s-1}$ unless survivals were modeled as a constant (Schwarz et al. 1993). Also, the probability of entry (b^*_i) must be constrained to sum to one. The recruitment parameters (B^*) at the beginning and end of the sampling periods cannot be estimated without further assumptions. At the start of the study, the JS model is not able to directly estimate births (B_0) but Schwarz et al. (1993) assume that a well-designed mark-recapture study should commence before a significant number of fish enter the stream or spawning area; thus $B_0 = N_1$ is a reasonable assumption in our analysis since we started surveys before spawning started. Also, if surveys extend to the end of recruitment, Schwarz et al. (1993) suggest that net births (B_{s-1}) should approach zero, with little effect on the population estimate.

Assumptions to recruitment between sampling occasions are needed to estimate annual salmon abundance from the JS model. One assumption is that recruitment takes place at the mid-point (Sykes and Botsford 1986); the adjustment factor for this assumption is (1/ sqrt(φ_i)), where φ_i = the probability that an animal alive at sampling occasion i will be alive at sampling occasion (i+1). An alternative assumption is uniform recruitment (Crosbie and Manly 1985; Schwarz et al. 1993) with an adjustment factor of (log φ_i / (φ_i -1)). Schwarz et al. (1993) conducted a sensitivity analysis to these and other distributions of adult recruitment. Adjustment factors are similar when survival is high because most fish survive to the next sampling occasion. When survival is low, the adjustment factors varied considerably. Schwarz et al. (1993) noted the actual distribution of recruitment is unknown and care should be taken in choosing a recruitment adjustment factor. In their analysis, the performance of the mid-point and uniform adjustment factors was similar and the uniform recruitment distribution was used in this analysis.

The JS model based on carcass tagging is not often used to estimate salmon abundance. Among the different carcass tagging mark-recapture models, the JS model is accurate, precise, and robust method for estimating salmon spawning abundance (Boydstun 1994) but may be slightly biased due to heterogeneity, no abundance estimate available for the last period, confounding parameters during the first and last period, and assumptions about the pattern/distribution of the arrivals within a period (Schwarz et al. 1993, Law 1994). However, Schwarz (1993) and Law (1994) found the Jolly-Seber model was robust to these violations through simulations. Sykes and Botsford (1986) found no difference in the adult Chinook salmon abundance estimate based on carcass tagging when compared to a census count at the weir on Bogus Creek, California.

Five assumptions of the Jolly Seber model that must be met in order to obtain unbiased population estimates from the model (Seber 1982) are: 1) Equal Catchability - every animal in the population whether tagged or untagged, has the same probability of being caught (p_i) in the i^{th} sample given that it is alive and in the population when the sample is taken, 2) Survival- every tagged animal has the same probability of surviving (φ_i) from the i^{th} to the $(i+1)^{th}$ sample and of being in the population at the time of the $(i+1)^{th}$ sample, given that it is alive and in the population immediately after the ith release, 3) Handling Mortality - every animal caught in the i^{th} sample has the same probability of being tagged and returned to the population, 4) Tag Loss & Reporting - tagged animals do not lose their marks and all marks are recognized on recovery, and 5) Instantaneous Sampling- all samples are instantaneous, i.e., sampling time is negligible and each release is made immediately after the sample.

With respect to our study, the JS model requires that all fish have identically independently distributed survival and capture probabilities, which are the equal catchability and survival assumptions. We addressed this through the use of a logistic regression model to develop homogeneous groups with respect to sex and length because these two covariates are known to influence recapture (survival and capture) probabilities. To help meet the equal capture assumption of tagged and untagged fish, we placed carcasses in flowing water to ensure mixing of fish, and placed carcass tags on the inside of the operculum so surveyors would not be attracted to tagged fish at a higher rate than untagged fish. The survival assumption may be violated when tagging live fish because survey life or residence time is positively correlated with date of entry (Schwarz et al. 1993), but this is not the case for carcasses. However, Chinook salmon carcasses decompose over time and may be available for capture for three weeks or more (Law 1994). To address the potential dissimilar survival of old and new carcasses assumption, we did not tag carcasses in advance stages of decomposition as they may have a lower probability of "surviving" to the next sampling period. Heavily decomposed fish had their tails cut off and were treated as loss on capture in the model. In addition, upon recapture all carcass tagged fish also had their tails cut and also treated as loss on capture by the model. Finally, we used a Bayesian GOF test, similar to the GOF test in the program RELEASE, to test the combined equal capture and survival assumptions.

Of the six JS datasets used to estimate abundance in 2011, the GOF tests indicated acceptable fit in four cases (Germany, Abernathy, Mill, and Cedar). The Washougal indicated marginal fit while the Grays indicated a lack of fit (Bayesian p-value = 0.04). This is related to different survival and captures probabilities for some releases. Our sample design calls for all recaptured fish to be treated as loss on capture. Therefore, if capture probabilities are consistent and high for every sampling occasion and all recaptures are lost on capture, the resulting m-array has a strong diagonal component, with few fish recaptured after the first recapture event. However, during a high water event, the higher stream flows can reduce capture probabilities and increase the proportion of tagged fish surviving to subsequent sampling occasions. This problem is compounded in carcass tagging because recaptured fish are not released (loss on capture) to meet the survival assumption, and do not have the chance to survive to an additional period. The effect on the abundance estimate from the lack of fit is usually that the estimate is unbiased but the confidence interval coverage is biased low (Nichols 2005), but may be explored through simulations (Schwarz et al. 1993, Law 1994).

The third assumption requires that there is no handling mortality, which is true for carcasses. The fourth assumption is that there is no tag loss and all tags are recognized and reported on recovery. We assessed tag loss through double tagging experiments, and surveyors followed protocol to inspect the inside of both opercula from every carcass to ensure all tagged and untagged fish were correctly identified and reported. Sampling was not instantaneous, but usually occurred during a single day within a weekly period. Schwarz et al. (1993) indicated that in these cases, this violation of instantaneous sampling is not believed to be a serious violation.

PCE Estimates

When weirs and mark-recapture were not available, we used alternate methods to estimate abundance. WDFW has been using PCE factors for over 40 years because they are the most cost-effective method for estimating abundance. The PCE factors for the Wind, Little White Salmon, and White Salmon rivers were based on a single study conducted 20 to 40 years ago. Except for some concerns regarding the GOF test in the JS abundance estimates from carcass tagging in the White Salmon population analysis, the PCE factors provide a statistical based population estimate. The following assumptions are used in the PCE method: 1) the peak day of abundance is known and the survey takes place on the peak, 2) if the entire spawning distribution is not surveyed, the proportion of fish used in the index or indices is similar to that of the years used to develop the peak count expansion factor, 3) observer efficiency is similar in all years, and 4) the proportion of fish observed on the peak day is similar over all years. Since the expansion factors were generated at least 20 years ago, there are concerns about changes over time in proportions of spawners using the index reaches and proportion of carcasses and live fish present on the peak day due to changes in run timing. Additionally, these studies lack of replication to better estimate the variability in the peak count expansion factors. Representative biological data and CWT samples do not usually occur using the peak count method because it relies on a single or a few surveys near the peak. Especially when the population may be comprised of a mixture of different populations (i.e., hatchery & natural-origin) with different timing. Since other methods (mark-recapture, AUC or redd expansion) require surveys from the beginning to the end of spawning, more representative biological and CWT data is likely to be collected with these methods.

Redd and AUC Estimates

Concurrent observer efficiency and survey life studies are costly, so AUC spawner abundance estimates often rely on observation efficiency and survey life from adjacent populations or from the same populations in other years. The use of these kinds of surrogate estimates in calculations of spawner abundance should be carefully considered. We successfully generated concurrent census or mark-recapture estimates and periodic counts of spawners in the Grays, Abernathy, Germany, and Washougal basins draining areas from 60 to 540 square kilometers to estimate a mean apparent residence time. Following the recommendation of Gallagher et al. 2010, we used annual mean estimates of apparent residence time to account for potential differences in environmental conditions and observer efficiency that may affect residence time. Since we had only one population in 2011 where we had concurrent mark-recapture estimates and a number of unique redds (Coweeman), we used six previous redd and mark-recapture estimates on the Coweeman and EF Lewis to estimate mean females per redd. Our CV-1 analysis supported that ART and AFpR are relatively consistent across populations thus application to other population should yield unbiased results.

Proportions

We used the binomial distribution to estimate the proportion of hatchery-origin spawners based on Chinook salmon adult carcass recoveries. This pHOS estimate is slightly different from the pMark estimate reported in 2010 as we accounted for unmarked hatchery releases based on sampling of hatchery juveniles prior to release. Without accounting for this source of bias, estimates of natural-origin spawners can be overestimated especially in populations with large hatchery influences and relatively low NOS abundance. To demonstrate this, we examined our Mill/Abernathy/Germany population level abundance estimate. Our overall estimate of Chinook abundance was 1,673, with a pMark of 91.8%, which equates to an unmarked abundance of 138 adults. When accounting for unmarked hatchery fish, our pHOS estimate was 93.4%, which yields an NOS abundance estimate of 110. In this case without accounting for the unmarked hatchery fish, there is an overestimate of NOS abundance.

Recommendations

Over the last decade or so there has been a significant shift in the monitoring of Chinook salmon populations in the LCR to estimate VSP parameters (McElhany et al. 2000), and other important management indicators (Rawding and Rogers 2013). While great progress has been made in the LCR region, opportunities remain for improvement of estimates of Chinook salmon VSP and indicator parameters. Therefore, we recommend the following: 1) a radio tag study to assess pre-spawn mortality and fall back in Tilton and Upper Cowlitz/Cispus River, 2) upgrade of the Modrow weir and trap facility on the Kalama River to improve broodstock management and increase sampling, 3) changing weirs to more flexible designs such as resistance board weirs that could be more successfully operated during freshets, 4) change of weir locations (Washougal and Grays rivers) if possible to be more effective at trapping during fall freshets, 5) as funding allows transition away from PCE estimates on the Wind, Little White Salmon, and the Big White Salmon rivers and more representative sampling of carcasses for biological and CWT data, 6) continue to improve current modeling that estimates abundance and proportions by exploring covariates, hierarchical and space-state models, 7) scan Chinook salmon for CWT at weir locations to improve CWT recovery rates rather than rely on spawning ground recoveries.

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Appendix A. LCR Chinook Management Weirs

Lower Columbia River Chinook Management Weirs

2011 Summary and Evaluation

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Jeremy Wilson and Bryce Glaser
Region 5 Fish Management

January 2019

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Introduction

Chinook salmon (*Oncorhynchus tshawytcha*) in the Lower Columbia River (LCR) Evolutionarily Significant Unit (ESU) were listed for protection under the Endangered Species Act (ESA) in 1998. In a recent five-year review, the National Oceanic and Atmospheric Administration (NOAA) Fisheries concluded that these fish should remain listed as threatened under the ESA (NOAA 2016). The LCR Chinook salmon ESU is composed of spring and fall populations split between the states of Washington and Oregon (Myers et al. 2006).

The Lower Columbia Fish Recovery Board's (LCFRB) Recovery Plan (2010) describes a recovery scenario for Lower Columbia River Chinook salmon. The plan identifies each population's role in recovery as a primary, contributing, or stabilizing population based on its baseline viability level and the desired recovery viability level. In 2007, the Hatchery Scientific Review Group's (HSRG) memo to the Columbia River Hatchery Reform Steering Committee stated that one of the key factors limiting recovery of naturally spawning populations is interaction with hatchery-origin fish on the spawning grounds. The HSRG recommended management targets of less than 5% proportion of hatchery-origin spawners (pHOS) for primary populations and less than 10% pHOS for contributing populations when the hatchery-origin spawners were produced from a segregated hatchery program. When the hatchery-origin spawners are the result of integrated programs, the pHOS goal is less than 30% hatchery-origin spawners (HSRG 2009).

In an effort to reduce pHOS to meet HSRG standards and improve abundance estimates to meet NOAA's accuracy and precision guidelines, detailed in Crawford and Rumsey (2011), WDFW began installing and operating river-spanning weirs for fall Chinook salmon management in LCR basins in 2008. This coincided with the phased implementation of LCR fall Chinook salmon mass marking (adipose clipping of all hatchery production) which began in 2005 and was fully realized in 2012 return when all age-2 through age-6 returns would be marked. The Grays River Weir was the first LCR weir focused on fall Chinook salmon management, which was installed in the fall of 2008. In the fall of 2009, the Elochoman River Weir was added for management purposes, followed by the Green River Weir in the fall of 2010. The Coweeman and Washougal weirs were added in the fall of 2011.

This appendix reports on the weirs operated in the fall of 2011 on the Grays, Elochoman, Green, Coweeman, and Washougal rivers. At all five weir locations, operations were primarily focused on fall Chinook salmon abundance monitoring, management, and broodstock collection (Green and Washougal rivers only); however, information gathered from other returning salmonids (chum and coho salmon, and steelhead) was also used to improve monitoring and management when possible.

At all five locations removal of known hatchery fish (identified by an adipose and/or left ventral fin mark) was utilized as a tool to promote recovery of wild stocks, meet management guidelines and objectives. The proportion of hatchery fish removed at each weir varied to meet management goals and objectives in the basin and, in some cases, was used to evaluate hatchery reform actions. WDFW annually conducts fall Chinook salmon spawning ground surveys on the Grays, Elochoman, Green, Coweeman, and Washougal rivers. Staff funded by these weir projects assist in these surveys to collect data necessary to estimate total abundance of fall Chinook salmon, estimate proportions of hatchery- and natural-origin, and evaluate weir effectiveness.

These projects have three objectives: 1) to complement existing adult salmonid monitoring efforts by developing accurate and precise estimates of total abundance, especially for fall Chinook salmon, 2) to promote recovery of fall Chinook salmon populations by meeting management guidelines/objectives for control of hatchery-origin Chinook allowed to spawn naturally (e.g. pHOS) and 3) for collection of broodstock in the Green and Washougal rivers for WDFW's North Toutle and Washougal Hatcheries, respectively.

Methods

Study area

The LCR Chinook salmon ESU extends from the mouth of the Columbia River up to, and including the Big White Salmon River, in Washington and the Hood River in Oregon, and includes the Willamette River to the Willamette Falls, Oregon. Within this ESU, there are a total of 13 Washington populations, 8 Oregon populations, and 2 populations (Lower and Upper Gorge) that are split between the two states. In 2011, WDFW installed temporary weirs in five of these populations in Washington for the purpose of fall Chinook salmon management- the Grays/Chinook population, the Elochoman/Skamokawa population, the Toutle Population (Green River), the Coweeman population, and the Washougal population (Figure 1). The Grays/Chinook population is comprised of two subpopulations: the Grays and Chinook and is identified as a contributing population with pHOS target of less than 10%. The weir is located on the lower Grays River at rkm 16.50 and only controlling pHOS within the Grays River basin. The Elochoman/Skamokawa Chinook population is comprised of two subpopulations: the Elochoman and Skamokawa and is identified as a primary population with a pHOS target of less than 5%. The weir is located on the lower Elochoman River at rkm 4.39 and is only controlling pHOS for the Elochoman subpopulation. The Toutle Chinook salmon population is made up of three subpopulations within the basin: Green, SF Toutle, and NF Toutle. The Toutle population is identified as a primary population with an integrated hatchery program and has a pHOS target of less than 30%. The weir is located on the lower Green River at rkm 0.64 and only controls pHOS for the Green subpopulation. The Coweeman Chinook salmon population consists of a single population and is identified as a primary population with a pHOS target of less than 5%. The weir is located on the lower Coweeman River at rkm 10.94. The Washougal Chinook salmon population also consists of a single population and is identified as a primary population with a pHOS target of less than 5%. The weir is located on the lower Washougal River at rkm 19.15

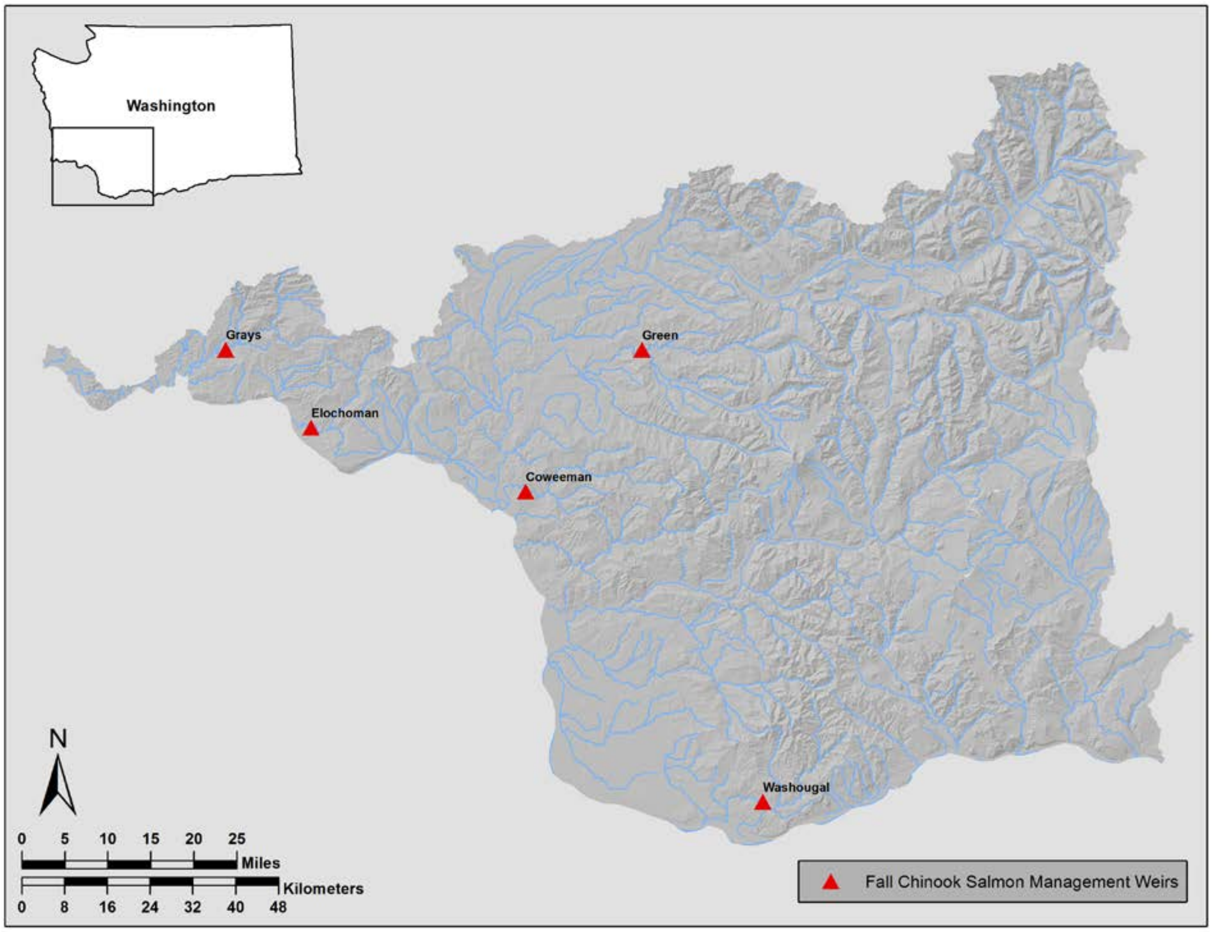

Figure 1. Location of weirs used for fall Chinook management in the Lower Columbia River.

Fish Capture

Weir designs varied based on the available infrastructure and goals of the specific weir. In general, three weir designs were used: a fixed panel design, a resistance board design, and a hybrid fixed/resistance design. Fixed panel weirs have been used for decades in LCR tributaries to collect broodstock for hatcheries. Fixed panel weirs can be highly effective at low, constant flows especially when paired with a concrete sill. This design was used in the Elochoman River in conjunction with existing infrastructure (a concrete sill and trap box) at river kilometer (rkm) 4.35. A hybrid resistance board/fixed panel design utilizing fixed wooden panels on the perimeter and a floating resistance board section in the center. This design was used in the Green River with conjunction with an existing concrete sill and fish ladder that diverts fish into the North Toutle Hatchery adult holding pond at rkm 0.60. A resistance board design utilizes a floating resistance board section made of PVC pipe river-wide. It is typically anchored to the riverbed using duckbill anchors and cables (Figure 2). This design was used in the Grays River at rkm 16.42. All weirs had 3.8 cm bar spacing in both fixed and floating resistance panels to prevent jack salmon passage through the weir panels.

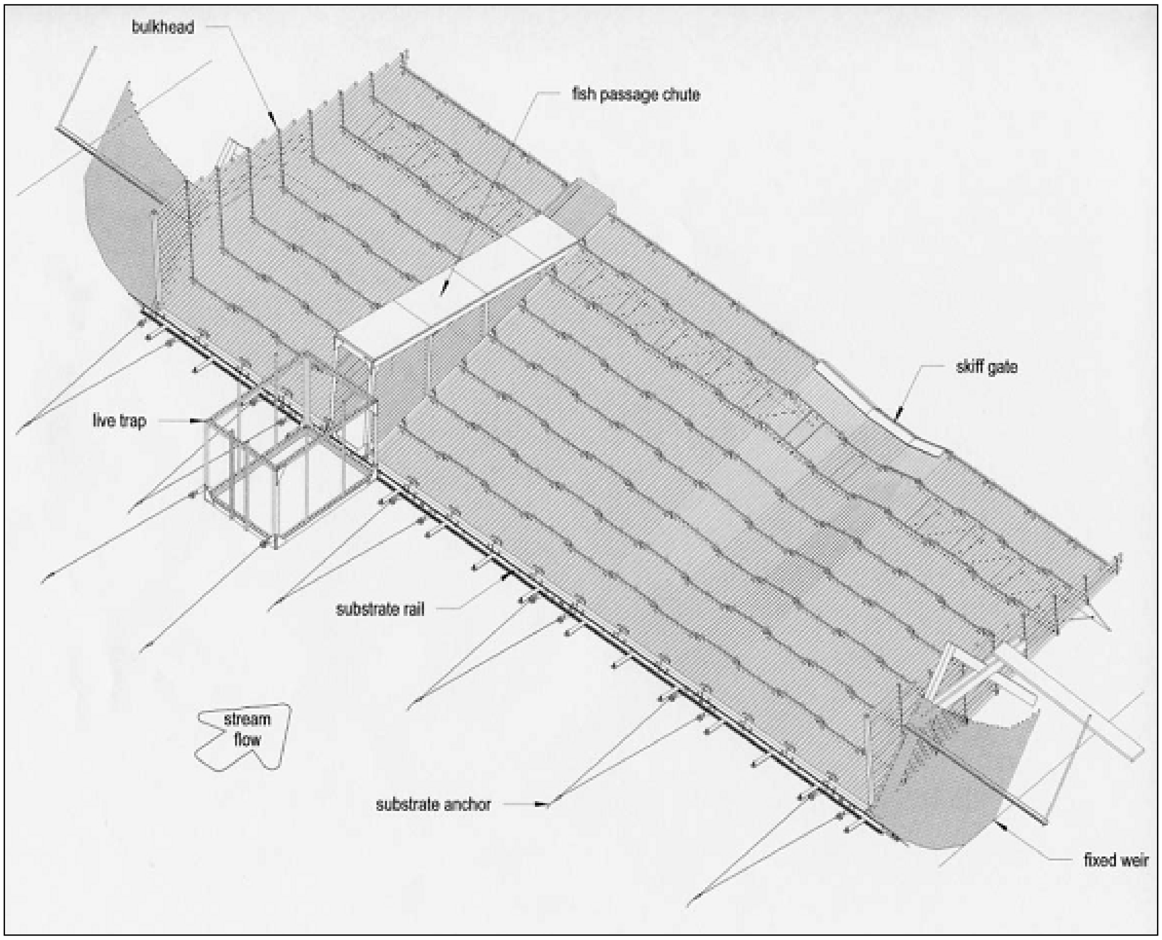

Figure 2. Schematic of a Resistance Board Weir from Stewart 2003.

Weir Operation and Sampling Protocols

Weirs and traps were staffed continuously while installed and the trap box was checked daily (multiple times per day when necessary). Close attention was paid to the recruitment of fish into trap boxes and accumulation of fish below the weir/trap. When the abundance of salmonids attempting to pass the weir exceeded the ability of staff to efficiently work through fish, modifications were made to trapping protocols to facilitate passage without handling. This was accomplished by either opening an upstream gate on the trap box and allowing fish to pass through without handling or by submerging panel sections of the resistance weir to allow fish passage.

Stream flow and weather forecasts were monitored closely to ensure the well-being of captured fish in the live box. The Washington Department of Ecology (WDOE) operates telemetry stream flow gauges that provide near real-time information on stream flows. Stream flow, weather forecast information, and ultimately direct observation, was used to determine when river flows began to limit staff accessibility to the trap box. When these conditions were encountered, the trap box was opened on the upstream side to allow unimpeded passage through the trap box. Marking/tagging of fish passed upstream at weirs combined with stream surveys provided a means for estimating abundance and weir efficiency when fish were allowed through the trap unsampled and/or high flows compromised the ability to trap fish at the weir.

Adult fall Chinook salmon captured at each weir were sampled and marked/tagged prior to release above the weir to evaluate weir efficiency and generate abundance estimates. Recoveries of tagged adults released above the weirs were made during weekly surveys via re-sighting of live fish and recovery of carcasses. When possible, independent estimates of spawner abundance were made for fall Chinook salmon via multiple methods (mark/re-sight & recapture, redd count expansion, and Area-Under-the Curve (AUC) methods) for comparison to weir estimates. All adult salmonids that were bio-sampled, except those able to be retained in sport fisheries upstream of weir sites, were anaesthetized using Tricaine Methanesulfonate (MS-222) prior to handle/tagging at the weir and allowed to fully recover before being released upstream of the weir. Table 1 outlines the planned disposition by species and origin at the Grays, Elochoman, Coweeman, Green, and Washougal weirs in 2011.

Table 1. Planned disposition of adult salmonids, by species and origin, at the Grays, Elochoman, Coweeman, Green, and Washougal weirs.

Species	Origin	Grays	Elochoman	Coweeman	Green	Washougal
Chinook	Unmarked	U	U	U	1 in 3 U*	U
	Marked	R	R	R	1 in 2 U	1 in 10 U*
Coho	Unmarked	U	U	U	U*	U
	Marked	U	R	R	R*	U
Chum	Unmarked	U	U	U	U	U
	Marked	U	U	U	U	U
Steelhead	Unmarked	U	U	U	U	U
	Marked	U	U	U	R	U

Unmarked fish are assumed to be of natural origin (NOR) and marked fish are assumed to be of hatchery origin (HOR). U=Upstream, R=Removed. * denotes in excess of weekly broodstock needs. The North Toutle (Green) had integrated fall Chinook and coho salmon hatchery programs – any unmarked Chinook and coho salmon not placed upstream were taken for broodstock. All LV-clipped fall Chinook salmon were removed at the weirs.

Data Analysis

Adult weir capture efficiency, pHOS without hatchery Chinook salmon removals at weirs, change in pHOS due to weir removals, and the proportion of Chinook salmon spawning occurring below the weir sites was estimated by adding additional equations, summary statistics, and parameters to the models already developed to estimate abundance for each subpopulation (Rawding et al. 2014). A Bayesian framework was utilized using WinBUGS (Spiegelhalter et al. 1999) and R using the R2WinBUGS package (Sturtz et al. 2005). Tables 2 and 3 outline the summary statistics, parameters, and equations used to calculate these metrics.

Table 2. Summary statistics used for weir reporting.

Statistic	Definition
N_{aw}	Total Chinook salmon abundance above the weir site
N_{bw}	Total Chinook salmon abundance below the weir site
W_{up}	Adult chinook salmon passed upstream at weir
W_{hrem}	Hatchery Chinook salmon adults (>59 cm) removed at weir
W_{wrem}	Unmarked adult Chinook salmon taken for broodstock or trap mortalities
H_{swim}	Chinook salmon swim-ins to hatchery facilities above weir
$pHOS$	Proportion of hatchery-origin Chinook salmon spawners based on the presence of an adipose and/or ventral fin clip and/or coded wire tag (CWT) after adjusting for unclipped hatchery fish.
HOS_{aw}	Hatchery-origin Chinook salmon spawners above weir

Table 3. Derived parameters for weir reporting.

Parameter	Definition/Equation
W_{eff}	Weir Capture Efficiency $((W_{up}+W_{hrem}+W_{wrem})/(N_{aw}+W_{hrem}+W_{wrem}+H_{swim}))$
$nwpHOS$	Estimated pHOS without hatchery removals. $((pHOS_{aw}+W_{hrem})/(N_{aw}+W_{hrem}+W_{wrem}))$
$cpHOS$	Estimated change in pHOS resulting from removal of hatchery fish at the weir site. $nwpHOS-pHOS$
$\%\ spbw$	Proportion of the spawning population that spawned downstream of the weir site. $N_{bw}/(N_{bw}+N_{aw})$

We provide estimates of age structure by mark type for Chinook salmon removed at each of the weirs based on scale readings.

Results and Discussion

The five weirs were installed in Lower Columbia River tributaries prior to the start of fall Chinook salmon upstream migration with the intent of operating them through the migration period. A total of 114, 2,120, 444, 4,382, and 4,311 Chinook salmon were captured at the Grays, Elochoman, Coweeman, Green, and Washougal weirs, respectively. Table 4 lists the catch at each weir site by species, origin, and disposition. Weir totals represent total number of fish that were captured at each weir site. Total spawning escapement may be more or less than weir totals depending on weir capture efficiency, spawning distribution, sport harvest above weir sites, and pre-spawning mortality.

Table 4. Weir capture totals by location, species, origin, and disposition.

		Number Trapped (Male/Female/Jack)					
Species	**Mark**	**Grays**	**Elochoman**	**Coweeman**	**Green**	**Washougal**	**Disposition**
Chinook	LV or ADLV	69 (14/55/0)	50 (23/27/0)	0	0	0	Removed
	LV or ADLV	1 (1/0/0)	0	0	0	0	Trap Mortality
	AD only	33 (18/12/3)	1347 (521/821/5)	57 (39/18/0)	2097 (955/1096/46)	1528 (673/763/92)	Removed
	AD only	0	645 (240/381/24)	0	1040 (479/540/21)	145 (78/59/8)	Released upstream
	AD only	0	0	0	760 (417/327/16)	2339 (1150/1146/43)	Trucked/Held for Brood
	AD only	7 (5/2/0)	4 (3/1/0)	0	18 (7/6/5)	26 (9/16/1)	Trap Mortality
	None	14 (5/8/1)	78 (35/40/3)	387 (164/207/16)	250 (127/108/15)	271 (134/134/3)	Released upstream
	None	0	0	0	209 (106/94/9)	0	Trucked/Held for Brood
	None	0	0	0	8 (4/2/2)	2 (2/0/0)	Trap Mortality
Coho	AD	296 (148/137/11)	1 (1/0/0)	0	0	10 (8/2/0)	Released upstream
	AD	0	10 (4/6/0)	8 (2/6/0)	1597 (829/665/103)	0	Removed
	AD	0	0	0	634 (291/334/9)	0	Trucked/Held for Brood
	AD	0	0	0	33 (9/21/3)	0	Trap Mortality
	None	25 (17/8/0)	83 (51/30/2)	46 (29/17/0)	902 (484/401/17)	1 (1/0/0)	Released upstream
	None	0	0	0	141 (67/71/3)		Trucked/Held for Brood
	None	0	0	0	11 (7/4/0)	0	Trap Mortality
Chum	None	0	2 (1/1/0)	0	0	0	Released upstream
Steelhead	AD	4 (0/4/0)	23 (5/18/0)	4 (2/2/0)	2 (1/1)	10 (7/3/0)	Released upstream
	AD	0	0	0	60 (29/31)	0	Removed
	None	0	2 (1/1/0)	4 (1/3/0)	1 (0/1/0)	7 (4/3/0)	Released upstream
	None	0	0	0	1 (0/1/0)		Trap Mortality

AD only = Fish with an adipose fin clip indicate hatchery-origin. LV or ADLV = fish with a left ventral or a left ventral and an adipose fin clipindicates a hatchery-origin Select Area Brights (SABs) from Oregon Select Area Fisheries Enhancement (SAFE) releases. None = All fins intact indicates a natural-origin or a fish that was not mass marked

Fish classified as jacks in the Table 4 are based on a fork length cutoff. Chinook salmon with fork lengths ≥60 cm were considered adults while those with fork lengths <60 cm were considered jacks. When done, stratification of abundance, pHOS, and weir efficiency estimates in this report were based on this fork length cutoff.

Grays River Weir

The Grays River Weir was initially established and operated in the fall of 2008 using Pacific Coast Salmon Restoration Fund (PCSRF) dollars; in 2009, funding to install and operate the weir was shifted to the Mitchell Act Monitoring Evaluation and Restoration (MER) program. The Grays River Weir is a resistance board design. In 2011, the Grays River weir was moved from its original location just downstream of the Grays River Covered Bridge (rkm 17.22) to rkm 16.50 due to landowner constraints. The weir configuration has changed slightly each year to try and improve fish recruitment and to adapt to changing site conditions. For the fall 2011 season, the weir was installed and operational on August 17. The first and last Chinook salmon were captured on August 23 and October 11, 2011, respectively. A high water event submerged the weir on October 11 and kept it submerged until October 15. The weir was removed in late October. Figure 3 shows the 2011 Grays River Weir configuration.

Figure 3. Grays River Weir configuration.
Photo credit: Josh Laeder (WDFW).

A total of 124 Chinook salmon were trapped at the Grays River Weir in 2011. Over 56% of the Chinook salmon catch were Select Area Brights (SABs) adults. SABs are hatchery fall Chinook salmon that are released into Youngs Bay as part of the Select Area Fisheries Enhancement (SAFE) program. This is a non-local stock that originated from the Rogue River, a coastal river in southern Oregon. Adult Chinook salmon weir capture efficiency was 22.9% (95% CI 15.3-29.3%) and the removal of hatchery-origin Chinook salmon at the weir reduced pHOS by 3.7% (95% CI 2.1-5.7%). No spawning was observed downstream of the weir site (Table 5). Age-3 fish dominated the age structure of fish removed at the weir (Table 6). We were unable to examine run timing by mark type past the weir site due to the low weir capture efficiency.

Table 5. Estimates of adult weir capture efficiency, pHOS, nwpHOS, cHOS, and percent spawning below weir for the Grays River Chinook salmon subpopulation (mean, median, SD, and 95% CI of the posterior distribution).

Parameter	Mean	SD	L 95%	Median	U 95%
W_{eff}	22.9%	3.6%	15.3%	23.1%	29.3%
pHOS (includes areas above and below weir)	82.7%	3.3%	76.0%	82.8%	88.7%
nwpHOS (includes areas above and below weir)	86.5%	2.6%	80.9%	86.6%	91.2%
cpHOS (includes areas above and below weir)	3.7%	0.9%	2.1%	3.6%	5.7%
% spbw	0.0%	0.0%	0.0%	0.0%	0.0%

Table 6. Age structure by mark type of Chinook salmon removed at the Grays River Weir based on scale readings.

Age Read	AD-clipped		LV-clipped	
	Scale samples	Proportion	Scale samples	Proportion
Age-2	7	21.9%	0	0.0%
Age-3	15	46.9%	56	86.2%
Age-4	10	31.3%	9	13.8%
Age-5	0	0.0%	0	0.0%
N=	32		65	

Note: not all Chinook salmon removed were sampled for scales.

Elochoman River Weir

The Elochoman River Weir currently utilizes a full fixed panel weir design that is installed annually on a permanent concrete sill with adjoining live box (Figure 4). The site is located just above Risk Road near the head of tide at rkm 4.39. For several decades, this site and configuration were used to collect broodstock for the WDFW's Elochoman Salmon Hatchery fall Chinook salmon program. In 2009, after closure of the Elochoman Hatchery (2008) and discontinuation of the fall Chinook salmon program, responsibility for operation of the weir transferred to WDFW's Region 5 Fish Management program and funding under Mitchell Act MER program was used to operate the weir. During this transition, weir panels were re-built with 3.8 cm spacing (instead of the previous 7.6 cm spacing) between panel bars. For the fall 2011 season, weir installation began on August 9 and was operational later that same day. The first and last Chinook salmon were captured on August 12 and October 21, 2011, respectively. On October 21st during a high water event, four of the fixed panels were removed to prevent weir damage during the event. Fish tight weir operations never resumed in 2011 and the weir was later removed as flows subsided.

Figure 4. Elochoman River Weir configuration.
Photo credit: Claire Landry (WDFW).

A total of 2,124 Chinook salmon were trapped at the Elochoman River Weir in 2011. Adult Chinook salmon weir capture efficiency was 97.2% (95% CI 96.1-98.0%) and removal of hatchery-origin Chinook salmon at the weir site reduced pHOS at the subpopulation level by 3.3% (95% CI 1.2-6.1%). No spawning was observed downstream of the weir site (Table 7). Age-4 fish dominated the age structure of adipose clipped Chinook salmon removed at the weir while age-3 fish were the prominent age class for left ventral clipped Chinook salmon removals (Table 8). There was very little difference in the timing between adipose clipped and unmarked Chinook at the weir. However, the 50% passage date for SABs was almost two weeks later (Figure 5).

Table 7. Estimates of adult weir capture efficiency, pHOS, nwpHOS, cHOS, and percent spawning below weir for the Elochoman River Chinook salmon subpopulation (mean, median, SD, and 95% CI of the posterior distribution).

Parameter	Mean	SD	L 95%	Median	U 95%
W_{eff}	97.2%	0.5%	96.1%	97.2%	98.0%
pHOS (includes areas above and below weir)	95.2%	1.8%	91.2%	95.4%	98.2%
nwpHOS (includes areas above and below weir)	98.5%	0.6%	97.2%	98.6%	99.5%
cpHOS (includes areas above and below weir)	3.3%	1.3%	1.2%	3.2%	6.1%
% spbw	0.0%	0.0%	0.0%	0.0%	0.0%

Table 8. Age structure by mark type of Chinook salmon removed at the Elochoman River Weir based on scale readings.

Age Read	AD-clipped		LV-clipped	
	Scale samples	Proportion	Scale samples	Proportion
Age-2	1	0.2%	0	0.0%
Age-3	87	21.5%	34	72.3%
Age-4	311	77.0%	13	27.7%
Age-5	5	1.2%	0	0.0%
N=	404		47	

Note that not all Chinook salmon removed were sampled for scales.

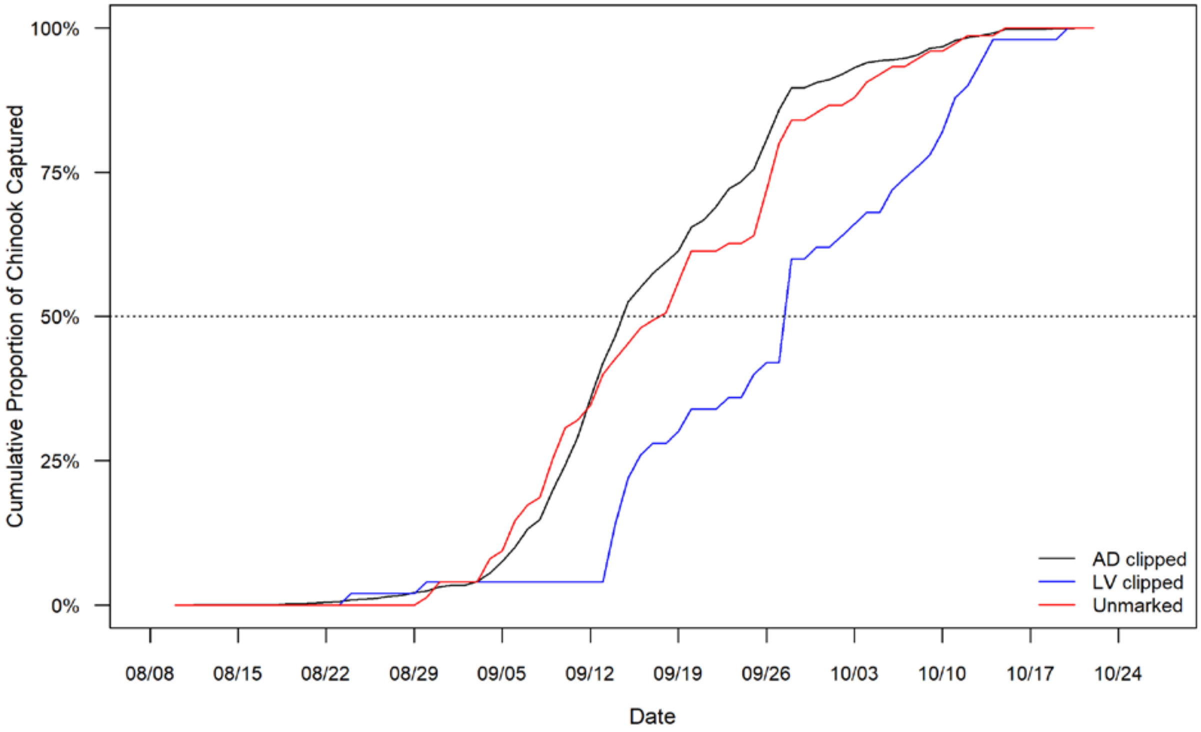

Figure 5. Elochoman River Weir Chinook salmon run timing by mark type.
AD clipped = adipose fin clipped (indicates hatchery-origin), LV clipped= left ventral fin clipped (indicates hatchery-origin SAB stock), Unmarked = all fins intact (natural-origin and unclipped hatchery-origin spawners).

Coweeman River Weir

The Coweeman River Weir was first installed and operated in 2011. This weir utilizes a full resistance board design with 3.8 cm spacing between panel bars. The site is located at rkm 10.94, approximately 0.8 kilometers above tidal influence. For the fall 2011 season, the weir was installed and operational on September 9. The first and last Chinook were captured on September 13 and October 23, 2011, respectively. The weir was fished nearly continuously until it was removed on October 31, 2011. Figure 6 shows the 2011 Coweeman River weir configuration.

Figure 6. Coweeman River Weir configuration.
Photo credit: Patrick Hulett (WDFW).

A total of 444 Chinook salmon were trapped at the Coweeman River Weir in 2011. Adult Chinook salmon weir capture efficiency was 68.3% (95% CI 61.9-74.2%) and removal of hatchery-origin Chinook salmon at the weir site reduced pHOS by 8.1% (95% CI 6.9-9.4%). A total of 17.6% (95% CI 12.7-25.1%) of the Chinook salmon spawning in the Coweeman basin spawned below the weir site (Table 9). Age-3 fish dominated the age structure of Chinook salmon removed at the weir (Table 10). Run timing past the weir site was nearly the same between unmarked and marked Chinook salmon (Figure 7).

Table 9. Estimates of adult weir capture efficiency, pHOS, nwpHOS, cHOS, and percent spawning below weir for the Coweeman River Chinook salmon population (mean, median, SD, and 95% CI of the posterior distribution).

Parameter	Mean	SD	L 95%	Median	U 95%
W_{eff}	68.3%	3.2%	61.9%	68.4%	74.2%
pHOS (includes areas above and below weir)	11.6%	2.4%	7.3%	11.4%	16.7%
nwpHOS (includes areas above and below weir)	19.7%	2.3%	15.6%	19.6%	24.5%
cpHOS (includes areas above and below weir)	8.1%	0.6%	6.9%	8.1%	9.4%
% spbw	17.6%	3.2%	12.7%	17.1%	25.1%

Table 10. Age structure by mark type of Chinook salmon removed at the Coweeman River Weir based on scale readings.

Age Read	AD-clipped	
	Scale samples	Proportion
Age-2	1	1.8%
Age-3	35	61.4%
Age-4	17	29.8%
Age-5	4	7.0%
N=	57	

Note that not all Chinook salmon removed were sampled for scales.

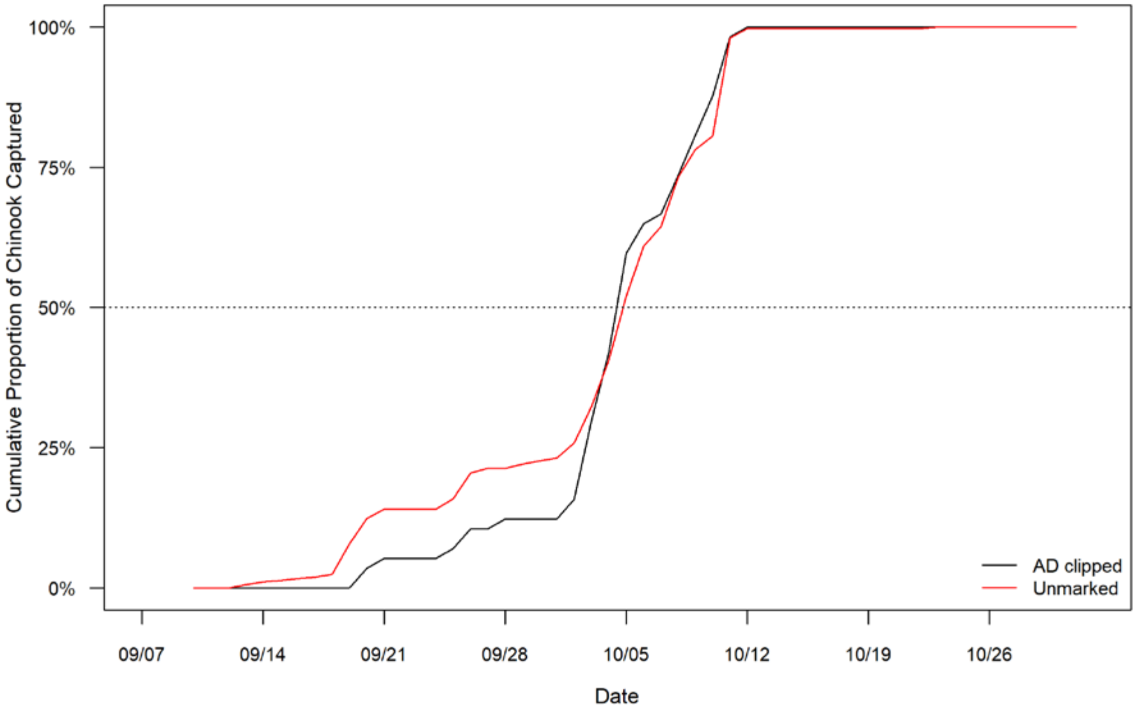

Figure 7. Coweeman River Weir Chinook salmon run timing by mark type.
AD clipped = adipose fin clipped (indicates hatchery-origin), Unmarked = all fins intact (natural-origin and unclipped hatchery-origin spawners).

Green River Weir

Prior to the fall of 2010, the Green River weir was solely operated as a broodstock collection site for WDFWs North Toutle hatchery. Beginning in 2010, protocols were implemented to accomplish fish management objectives (e.g. reduce pHOS) at the weir as well. This weir utilizes a hybrid resistance board design with 3.8 cm spacing between panel bars. The weir site is located at rkm 0.64 adjacent to the North Toutle Hatchery. For the fall 2011 season, the weir was installed and operational on August 4. The first and last Chinook salmon were captured on August 23 and November 15, 2011, respectively. The weir was topped and damaged on November 17th. Repairing the weir while installed was not feasible and the weir was removed when flows subsided. Figure 8 shows the 2011 Green River weir configuration.

Figure 8. Green River Weir configuration.
Photo credit: Amanda Danielson (WDFW).

A total of 4,382 Chinook salmon were trapped at the Green River Weir in 2011. Adult Chinook salmon weir capture efficiency was 94.5% (95% CI 90.7-97.8%) and removal of hatchery-origin Chinook salmon at the weir site reduced pHOS at the subpopulation level by 6.9% (95% CI 1.7-10.4%). Less than 2% (95% CI 1.6-2.3%) of the Chinook salmon spawning in the Green River subpopulation occurred below the weir site (Table 11). The 50% passage date past the weir site was almost two weeks later for unmarked Chinook salmon compared to marked Chinook salmon (Figure 9). Age data from hatchery-origin Chinook salmon removed at the weir was combined with Chinook salmon spawned and sampled at the North Toutle Hatchery. Therefore, we unable to report on age structure of Chinook salmon removed at the weir in 2011.

Table 11. Estimates of adult weir capture efficiency, pHOS, nwpHOS, cHOS, and percent spawning below weir for the Green River Chinook salmon subpopulation (mean, median, SD, and 95% CI of the posterior distribution).

Parameter	Mean	SD	L 95%	Median	U 95%
W_{eff}	94.5%	1.8%	90.7%	94.6%	97.8%
pHOS (includes areas above and below weir)	85.3%	2.3%	80.5%	85.4%	89.6%
nwpHOS (includes areas above and below weir)	92.2%	0.6%	90.9%	92.2%	93.4%
cpHOS (includes areas above and below weir)	6.9%	1.7%	3.8%	6.9%	10.4%
% spbw	1.9%	0.2%	1.6%	1.9%	2.3%

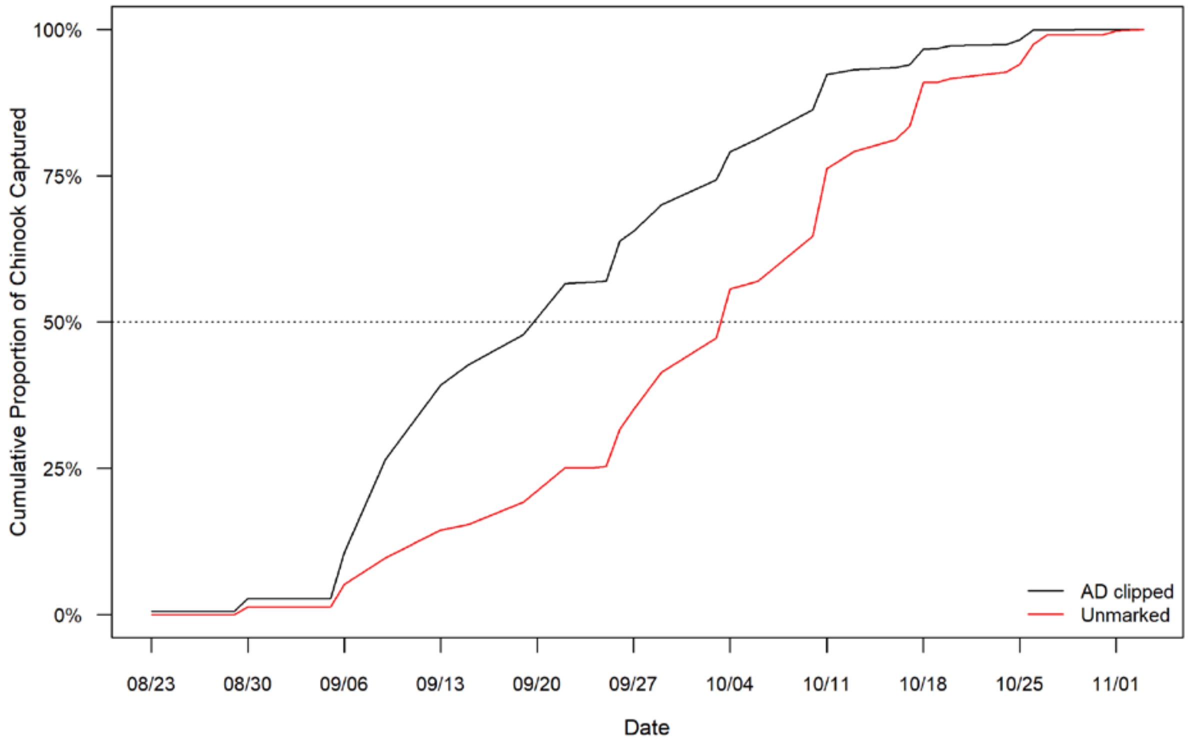

Figure 9. Green River Weir Chinook salmon run timing by mark type.
AD clipped = adipose fin clipped (indicates hatchery-origin), Unmarked = all fins intact (natural-origin and unclipped hatchery-origin spawners).

Washougal River Weir

The Washougal River Weir was first installed and operated in 2011. This weir utilizes a resistance board hybrid design with 3.8 cm spacing between panel bars. The weir is located at rkm 19.15 and serves as both a broodstock collection point for WDFW's Washougal Salmon Hatchery fall Chinook salmon program and a monitoring and management site for WDFWs Region 5 Fish Management program. For the fall 2011 season, weir installation began in mid-August and the weir was operational on August 19. The first and last Chinook salmon were captured on August 25 and October 10, respectively. A high water event submerged the resistance panels and the trap box on October 11. The upstream door of the trap box had been opened prior to the trap box being submerged to allow unimpeded fish passage in the event any fish swam in during the high flow event. Damage to the weir structure prevented fish tight weir operations from that point on. Figure 10 shows the 2011 Washougal River weir configuration.

Figure 10. Washougal River weir configuration.
Photo credit: Eric Kinne (WDFW).

A total of 4,311 Chinook salmon were trapped at the Washougal River Weir in 2011. Adult weir capture efficiency was 33.0% (95% CI 30.0-35.1%) and removal of hatchery-origin Chinook salmon at the weir site reduced pHOS by 7.9% (95% CI 7.0-8.8%). In 2011, 6.6% (95% CI 0.0-26.5%) of the Washougal Chinook salmon population spawned below the weir site (Table 12). Age-3 fish dominated the age structure of Chinook salmon removed at the weir (Table 13). We were unable to examine run timing by mark type due to late installation of the weir and poor weir capture efficiency.

Table 12. Estimates of adult weir capture efficiency, pHOS, nwpHOS, cHOS, and percent spawning below weir for the Washougal River Chinook salmon population (mean, median, SD, and 95% CI of the posterior distribution).

Parameter	Mean	SD	L 95%	Median	U 95%
W_{eff}	33.0%	1.3%	30.0%	33.1%	35.1%
pHOS (includes areas above and below weir)	82.2%	0.9%	80.5%	82.2%	83.9%
nwpHOS (includes areas above and below weir)	90.1%	0.6%	89.0%	90.1%	91.2%
cpHOS (includes areas above and below weir)	7.9%	0.5%	7.0%	7.9%	8.8%
% spbw	6.6%	12.3%	0.0%	8.1%	26.5%

Table 13. Age structure by mark type of Chinook salmon removed at the Washougal River Weir based on scale readings.

Age Read	AD-clipped	
	Scale samples	Proportion
Age-2	13	8.7%
Age-3	81	54.0%
Age-4	54	36.0%
Age-5	2	1.3%
N=	150	

Note that not all Chinook salmon removed were sampled for scales.

Coded-Wire-Tag Recoveries

Adults returning from SAFE program releases made up 100% of the CWT recoveries at the Grays River weir and made up ~14% of the Elochoman River weir CWT recoveries in 2011. Returns from the recently terminated Elochoman Hatchery fall Chinook salmon program constituted 77% of the Chinook salmon CWT recoveries at Elochoman River weir. CWT recoveries at the Coweeman weir were primarily from juveniles released into the Kalama River while the Green and Washougal weir CWT recoveries were almost entirely from hatchery programs within the basin (97% and 100% for the Green and Washougal, respectively) (Table 14).

Table 14. CWT recoveries from surplus Chinook salmon at Grays, Elochoman, Coweeman, Green, and Washougal weirs.

		Recovery Location				
		Grays Weir	Elochoman Weir	Coweeman Weir	Green Weir / N. Toutle Hatchery	Washougal Weir / Washougal Hatchery
Release Basin	SF Klaskanine H.	3				
	Deep River N.P.	3	6			
	Big Cr. H		3		1	
	Eloch H.		34			
	Coweeman			1		
	N. Toutle H.				67	
	Fallert H.			2		
	Kalama Falls H.			1	1	
	Wash H.					158
	John Cr. + Hamma R.		1			
	Total CWT recoveries	6	44	4	69	158

Note that Washougal Weir CWT recoveries were combined with CWT recoveries from Washougal Hatchery.

Weir Effects

Displaced spawning due to the weir structure was not an issue at any of the weir sites with the exception of the Coweeman River weir where approximately 17% of the Chinook salmon spawning in the Coweeman basin occurred downstream of the weir site. Historically, there has been minimal spawning in this reach. We need to evaluate ways to improve fish recruitment in the future or submerge the weir to allow a proportion of the fish to pass the weir site unimpeded.

To assess the effects of handling on live fish, we examined the number of pre-spawn mortalities in basins where we had “leaky” weirs resulting in adequate sample sizes of tagged and untagged female Chinook salmon carcasses being sampled for spawn success above the weir site. This occurred in both the Coweeman and Washougal rivers in 2011. A total of 29 untagged and 44 tagged female Chinook salmon carcasses were examined for spawn success in the Coweeman River. We conducted a chi-square test to test for significant differences between the two groups and the results were not significant (*p*-value =

0.67). A total of 1,153 untagged and 68 tagged female carcasses were examined for spawn success in the Washougal River. Again, the results were insignificant (*p*-value = 0.24). The results of these tests support the null hypothesis that there is no difference in the survival to spawning for females and supports our conclusion that handling effects on live fish at weirs was minimal (Table 15 and Figure 11).

Table 15. Tagged and untagged female Chinook salmon carcasses examined for spawn success in the Coweeman and Washougal rivers, 2011.

	Coweeman		**Washougal**	
Spawn Success	**Tagged**	**Untagged**	**Tagged**	**Untagged**
Yes	35	25	45	671
No (>75% eggs retained)	9	4	23	482

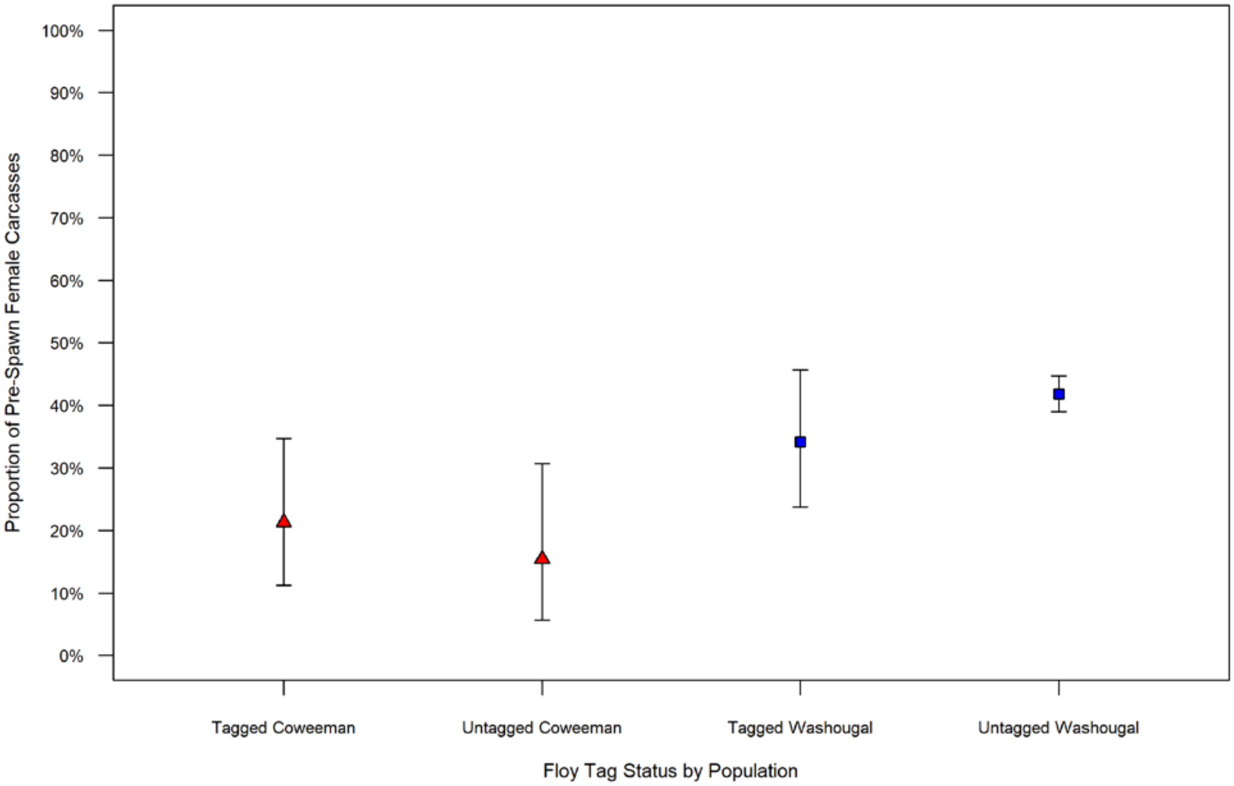

Figure 11. Proportion of tagged and untagged female carcasses encountered on spawning ground surveys that were pre-spawn mortalities in Coweeman (red triangles) and Washougal (blue squares) rivers.

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Coho Salmon Escapement Estimates and Coded-Wire-Tag Recoveries in Washington's Lower Columbia River Tributaries in 2011

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October 11, 2018

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Abstract

The Lower Columbia River (LCR) Coho Salmon Evolutionarily Significant Unit (ESU) is composed of 24 populations split between the states of Washington and Oregon. The Oregon Department of Fish and Wildlife (ODFW) began comprehensive monitoring of coho salmon populations in this ESU in 2002. Minimum adult coho salmon estimates in Washington's portion of this ESU have been limited primarily to counts at hatchery facilities and a few fish ladder traps. This is the second year the Washington Department of Fish and Wildlife (WDFW) has implemented a program to estimate coho salmon spawner abundance, the proportion of hatchery origin spawners (pHOS), the proportion of spawning reaches occupied, spatial distribution, sex ratio including the proportion of jacks, and to recover Coded Wire Tags (CWT). The adult coho salmon population-monitoring program used trap and haul census counts, mark-recapture, smolt expansion, and redd-based methods to monitor adult coho salmon. We estimated a mean escapement of 53,305 (95% CI 44,130 - 70,140) adults and 3,376 jacks (95% CI 2,047 - 7,828) for the Washington portion of this ESU below Bonneville Dam excluding the Tilton River, Upper Cowlitz/Cispus Rivers, mainstem Lower Cowlitz, and mainstem Toutle/ lower North Fork Toutle (below the Sediment Retention Structure). Individual population estimates for spawners ranged from a high of 20,279 adults for the combined upper Cowlitz/Cispus population to a low of 364 adults for the Kalama population. As expected, populations with an operating coho salmon hatchery, including the Grays, Elochoman, Upper Cowlitz/Cispus, Tilton, and Kalama rivers, had high proportions of hatchery spawners(mean = 97%, 57%, 62%, 70%, and 75%, respectively). The converse was true for populations without hatcheries, such as the Mill-Abernathy-Germany, Lower Cowlitz (tributaries), Coweeman, South Fork Toutle, and EF Lewis populations, where we observed low percentages of marked adults—(mean = 21%, 5%, 5%, 19%, and 3%, respectively). The total mean estimate of unmarked coho salmon adults was 25,364 (95% CI 19,740 - 35,360). Estimates of precision for the aggregate estimate for all marked adults and unmarked adults as measured by the coefficient of variation (CV) were 13% and 17%, respectively. The precision of individual population estimates of unmarked adults based on redd surveys was low—the most precise estimate occurring in the Green River with a CV of 32%. In two study streams redd surveys were conducted in conjunction with mark-recapture to estimate the number of redds per female in order to expand redd counts throughout the ESU. The mean estimate of observed redds per female was 0.654 (95% CI 0.434 - 0.917), which indicates that we likely only observed about 65% of the redds assuming each female constructed one redd. This estimate was consistent with poor water clarity and periods of high discharge which limited observer efficiency and erased physical evidence of redds. Trap counts and mark-recapture estimates of coho salmon abundance were more precise than the redd-based estimates. To improve the precision of adult coho salmon redd-based estimates, we recommend obtaining more precise estimates of redds per female, increasing the number of reaches surveyed per population, and exploring possible density-based stratification of the Generalized Random Tessellation Stratified (GRTS) sampling design used to select redd survey reaches.

Introduction

Coho salmon (*Oncorhynchus kitsuch*) in the Lower Columbia River (LCR) Evolutionarily Significant Unit (ESU) were listed for protection under the Endangered Species Act (ESA) in 2005. In a recent five-year review, the National Oceanic and Atmospheric Administration (NOAA) Fisheries concluded that these fish should remain listed as threatened under the ESA (NOAA 2011). The LCR coho salmon ESU is composed of 24 populations split between the states of Washington and Oregon (Myers et al. 2006). The Oregon Department of Fish and Wildlife (ODFW) began comprehensive monitoring of LCR coho salmon populations in 2002 (Suring et al. 2006). However, estimates of adult coho salmon escapement in Washington's portion of the LCR were limited primarily to counts at hatchery facilities and a few fish ladder traps until this project was funded in 2010.

The coastwide Coded-Wire-Tag (CWT) program was developed in the 1970's to evaluate the contribution of different salmonid populations and hatchery programs to various fisheries and to estimate salmon fishery harvest rates, along with evaluation of hatchery rearing practices. The initial protocols for the CWT program included the insertion of a CWT into the snout of a juvenile hatchery salmon, which was accompanied by an adipose fin clip. A proportion of hatchery fish released from selected facilities had a CWT inserted. When salmon were recovered from fisheries and spawning areas, the snout of fish with missing adipose fins were taken to fisheries agency labs for decoding. Later the purpose of the CWT program was expanded to include forecasting run sizes to meet conservation and harvest objectives. For conservation purposes, the vast majority of coho salmon released from hatcheries are now adipose fin clipped (sometimes referred to as mass marked or marked) and WDFW has implemented selective fisheries, which require the release of all adipose-intact (assumed to be natural-origin) fish. CWTs are now detected electronically by scanning fish with handheld or stationary detectors, rather than using the adipose fin clip as an indicator of CWT presence. Upon implementation of mass marking, standard CWT protocols were modified to include inserting a CWT into a proportion of a hatchery release that was not adipose fin clipped—referred to as a Double Index Tag (DIT) group. The DIT groups were released from a few select hatcheries. These DIT groups are unmarked hatchery fish with a CWT that allow the evaluation of the harvest rates specific to selective fisheries (harvest restricted to adipose clipped adults only) and these DIT groups serve as surrogates for wild coho harvest rates for stocks subject to selective fisheries.

In 2010, the Washington Department of Fish and Wildlife (WDFW) initiated a program to sample LCR spawning grounds for coho salmon. This program had dual objectives: 1) to estimate Viable Salmonid Population (VSP) indicators (McElhany et al. 2000) and measure specific indicators to assess coho salmon viability (Rawding and Rodgers 2013) including coho salmon spawner abundance, the proportion of hatchery origin spawners, the proportion of spawning reaches occupied, spatial distribution, and sex ratio including the proportion of jacks; and 2) to recover CWT from spawning fish to provide complete accounting of CWT, so that harvest rates could accurately be determined. The first objective addressed a salmon recovery monitoring gap while the second objective addressed a gap identified from the CWT expert panel (Hankin et al. 2005). The framework of Rawding et al. (2014) was modified from 2010 to summarize population monitoring of VSP indicators for LCR coho salmon returns and CWT recoveries in 2011, which are detailed in this report.

Methods

Study area

The LCR coho salmon ESU extends from the mouth of the Columbia River up to and including the Big White Salmon River in Washington and the Hood River in Oregon, as well as the Willamette River to Willamette Falls, Oregon. Within this ESU, there are a total of 15 Washington populations, 7 Oregon populations, and 2 populations (Lower and Upper Gorge) that are split between the states (Figure 1). In this document we report on 15 populations in Washington. The upper Cowlitz and Cispus populations are combined into a single population because there is currently no way to determine spawning locations from the Cowlitz River trap and haul program for fish that are placed above Cowlitz Falls Dam. In 2011, mainstem Lower Cowlitz and Toutle and the Upper Gorge populations (including the Big White Salmon River) were not surveyed. It should be noted that coho salmon in the Lower Gorge population spawn in both states, but this report only contains information on the Washington proportion of the Lower Gorge population.

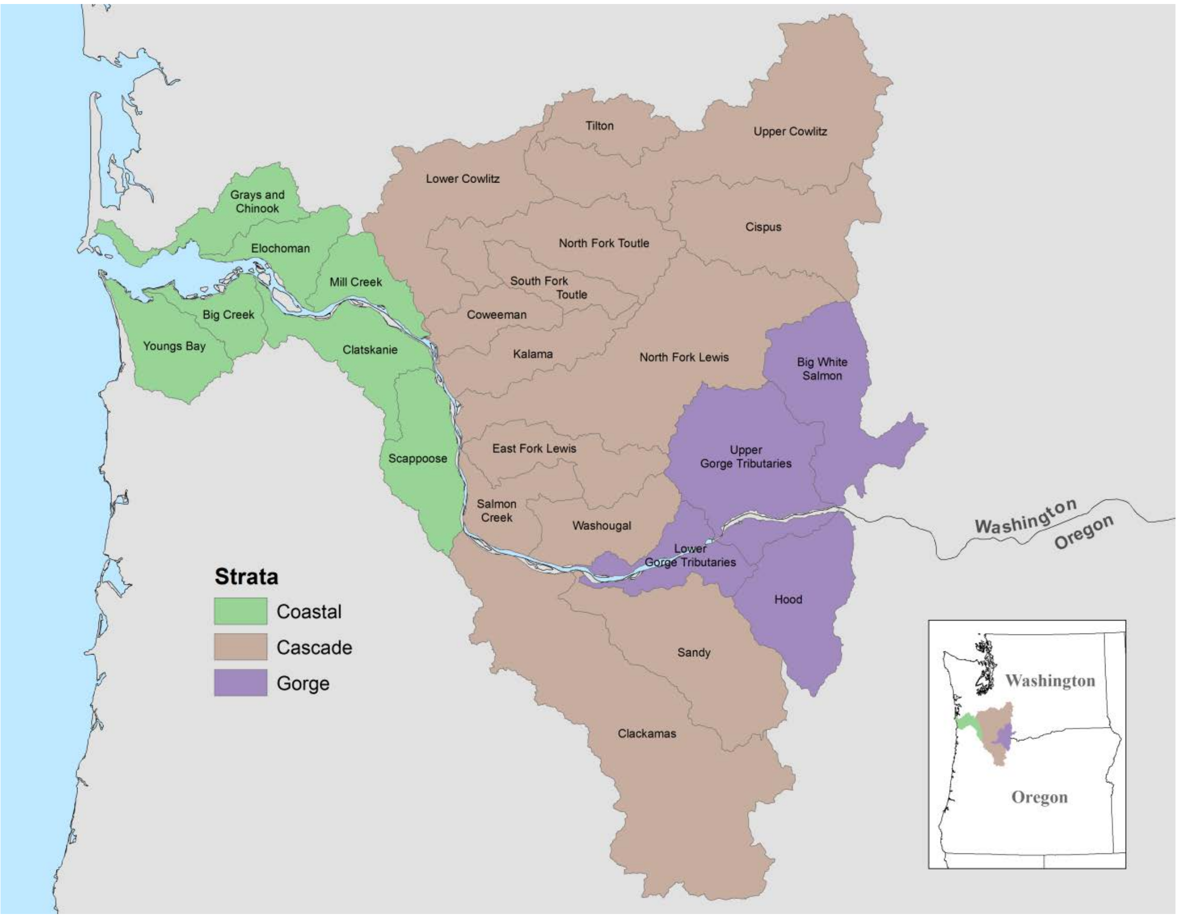

Figure 1. Lower Columbia River coho salmon populations and the regional groupings (i.e., strata) in which they occur within the LCR subunit recovery domain. The White Salmon population is considered part of the Upper Gorge Population.

Monitoring Design

We used dam counts and trapping, mark-recapture, and spawning ground surveys to estimate population parameters of LCR coho salmon (Figures 2 & 3). Field personnel were experienced and/or trained on adult salmon identification. Field data collection protocols varied but were based on the methods from the American Fisheries Society for salmon monitoring (Johnson et al. 2007). Coho salmon redd, live fish, and carcass counts along with environmental and header information collected during coho salmon surveys were stored in the WDFW Spawning Ground Survey (SGS) database. Biological data collected on spawning ground surveys was stored in the WDFW Region 5 Age and Scales (A&S) database. Individual trap counts, tagging, and recovery data were stored in individual watershed databases or spreadsheets.

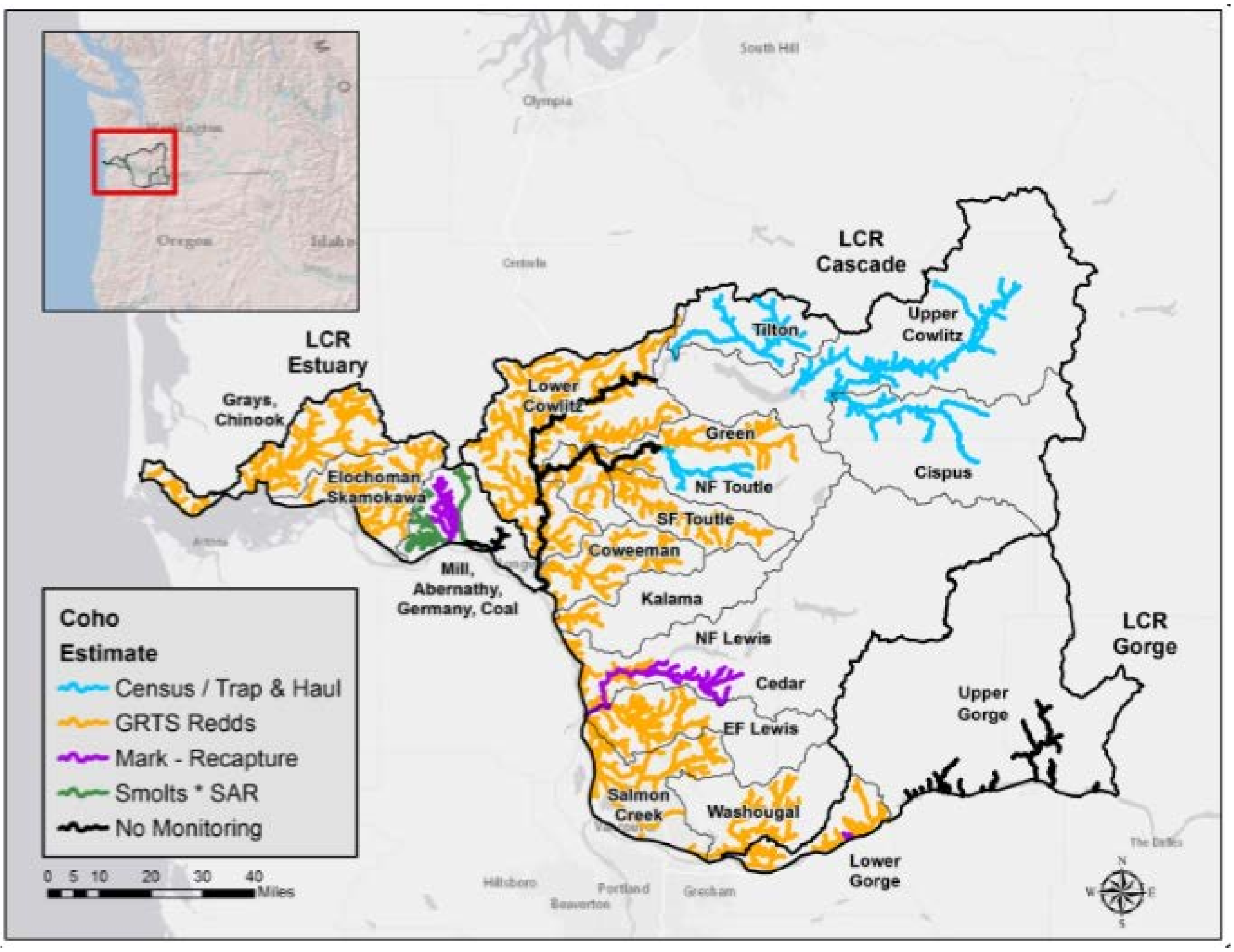

Figure 2. Watersheds containing the Washington populations of the Lower Columbia River coho salmon ESU and the methods WDFW used to estimate their abundance in 2011.

Trap & Haul

Dam counts were used at the Barrier dam on the Cowlitz River (RM 50), and the Toutle Fish Collection Facility (TFCF) on the NF Toutle River (RM 12). Depending on management objectives, coho salmon collected at these facilities were used for hatchery broodstock, surplused (donated to food banks, sold to the state fish buyer, or used for nutrient enhancement) or transported and released above the facility. We made the following key assumptions for the trap and haul programs: 1) the count of all transported fish was without error, 2) all unmarked fish released survived to spawn, 3) transported fish spawned in the watershed where they were released (there was no fall back), 4) when fisheries in the Upper Cowlitz, Cispus, and Tilton rivers occurred only marked (adipose clipped fish) were harvested in accordance with regulations and there was no illegal harvest, 5) survival of all unmarked released fish was 100% (catch and release mortality was negligible), and 6) the WDFW methodology to expand catch record card (CRC) reported catch to total harvest and variance are correct.

Mark-Recapture

Petersen mark-recapture estimates for adult coho salmon were attempted in the Green River and Abernathy, Cedar, and Duncan creeks. However, high water undermined the weir at the Green River so escapement in this basin was determined using spawning ground surveys. Coho salmon were captured in adult traps located adjacent to the resistance board weir in Abernathy Creek at RM 0 (Kinsel et al. 2009), the fishway in Cedar Creek (RM 2.4), and Duncan Creek fishway (RM 0). Traps were installed prior to immigration of adult coho and fished through the end of migration in January or February.The Duncan Creek location fished through December due to lack of staffing. Recapture of fish occurred at upstream traps or during spawning ground surveys. A study design at all three locations was based on the Darroch estimator, which was developed for time stratified Petersen mark-recapture abundance estimates (Darroch 1961, Seber 1982). Schwarz and Taylor (1998) indicate that the following assumptions must be met to provide a consistent estimate of abundance: 1) there is no mark loss, 2) there are no marking effects, 3) all marked and unmarked fish are correctly identified and enumerated, 4) the population is closed, and 5) all fish in the population have the same probability of being tagged or all fish have the same probability of being captured in the second sample; or marked fish mix uniformly with unmarked fish.

The Jolly-Seber (JS) model estimates population abundance in mark-recapture studies where the population is open (Jolly 1965; Seber 1965) and has been widely used in estimating Pacific salmon spawning escapement from live fish (Schwarz et al. 1993; Jones and McPherson 1997; Rawding and Hillson 2003) but also using salmon carcasses (Parker 1968; Stauffer 1970; Sykes and Botsford 1986). The carcass tagging model has been used extensively in the Lower Columbia to estimate Chinook salmon abundance (McIssac 1977; Rawding et al. 2006a). The Jolly-Sever (JS) method was usedfor estimating escapement on the mainstem North Fork (NF) Lewis. Seber (1982) and Pollock et al. (1990) provide details of study design, assumptions, and analysis of mark-recapture experiments using the JS model. Five assumptions of the Jolly Seber model must be met in order to obtain unbiased population estimates from the model (Seber 1982), these are: 1) equal catchability 2) equal survival between periods, 3) no handling mortality, 4) no tag loss, and 5) instantaneous sampling. For more details on the application of this approach to Lower Columbia River tributary salmonid spawning populations see Rawding et al. (2014).

Smolt Expansion

The number of coho salmon smolts emigrating from Mill, Abernathy, and Germany creeks are estimated annually based on a mark-recapture design (Kinsel et al. 2009). In addition, adult coho salmon returning to Abernathy Creek are estimated based on a mark-recapture study design. All three creeks enter the Columbia within a few miles of each other. We assumed that the smolt to adult return (SAR) and stray rates were the same between the three sites, and were therefore able to estimate the number of returning unmarked adults in Mill and Germany creeks by dividing their smolt estimates by the estimated Abernathy Creek SAR.

Spawning Ground Surveys

The monitoring design components for spawning ground surveys consist of basic elements (Stevens et al. 2007). These included: 1) the development of the sampling frame covering the entire spawning area, 2) a probabilistic sampling design to representatively survey the spawning area, 3) a temporal component to ensure the entire spawning period was sampled, and 4) a decision on the metric (e.g., live fish, carcass, or redd counts) used to estimate escapement, the observer efficiency, and the relationship between the metric and the escapement.

Spawning Distribution

The upper extent of the coho salmon spawning distribution was estimated based on the methods of Fransen et al. (2006). The upper extent of adult and juvenile coho salmon presence was estimated from focused and randomly selected surveys over two years. For sampled streams, fish presence protocols from the Washington Forest Practices Board (WFPB) for juveniles were followed. Following AFS electroshocking protocols (Temple and Pearsons 2007), juveniles were continuously sampled moving in an upstream direction until fish were not observed for at least ¼ mile or a waterfall was encountered. This protocol was adapted for adult salmon except fish presence was based on visual sampling of live or dead adult coho salmon or their redds. The uppermost presence of fish was recorded using a global position satellite (GPS) device. This location was plotted on the WDFW Geographic Information Systems (GIS) stream and attribute layer. GIS attributes were recorded for the last reach where coho salmon were found, as well as the seven reaches downstream and eight reaches upstream of that point. Using logistic regression, a model was developed to predict the upper extent of coho distribution as a function of the GIS covariates including drainage area, mean annual flow, annual precipitation, confinement, elevation, and gradient. Akaike Information Criterion (AIC) was used to compare models and select the best model following Burnham and Anderson (2002). The coefficients for GIS covariates included in the best predictive model of upstream coho extent were drainage area, gradient, and elevation. The model was used to predict upstream extent throughout the ESU; the upstream extent was then further truncated by applying the WDFW fish passage barriers layer. The lower extent of coho salmon spawning was defined by the lowest location surveyed for steelhead or Chinook salmon redds in previous years; typically the downstream most extent of gravel in each watershed. More complete details of the upstream extent model development for Chinook salmon are provided in Rawding et al. (2010), which was adapted as described above for coho salmon. The spawning distribution drainage network as described above was the sampling frame used to develop the spatial sampling design for redd surveys.

Generalized Random Tessellation Stratified (GRTS) Survey Sampling Design

A spatial sampling design was developed for 14 of the 17 coho salmon populations in Washington. The Upper Gorge population was excluded due to limited resources, the Mill-Abernathy-Germany (MAG), Upper Cowlitz/Cispus, and Tilton populations were excluded because we used alternate methods. For each population a Generalized Random Tessellation Stratified (GRTS) sampling design was used to establish a set of random, spatially balanced sample points for coho salmon surveys (Stevens 2002). Reach selection was based on the LCR GRTS web based sampling tool developed by Oregon State University (OSU) through the Pacific Northwest Aquatic Monitoring Partnership (PNAMP) with assistance from Don Stevens (OSU). Reaches, one mile in length, were established based on these points. Points were located in the center of the reach, except in cases where the point fell in the bottom half mile. In a few cases the reach length was less than one mile. This occurred when the GRTS point was located in a small tributary less than one mile in overall length or there was an anadromous barrier falls less than a mile from the mouth. In the case of a tributary being less than 1 mile in length, the reach length was extended to the top fork of the 24k Washington Lakes and Rivers Information System (WLRS) stream layer regardless of sample frame.

A three-year rotating panel design was established for each coho salmon population (Firman and Jacobs 2004). In this design about 1/3 of the surveys for the 9-year period are repeated annually, 1/3 are repeated every third year, and new points are chosen each year for the remaining 1/3 of all surveys. For Oregon coastal coho salmon, the ODFW surveys 30 sites for each population, or enough sites to cover 30% of the coho spawning habitat for each coho salmon population (Lewis et al. 2009). The 30 sites or 30% of the habitat, whichever is lower, is expected to yield an average CV near 15% (Jeff Rodger, ODFW, pers. comm.). However, due to limited resources, WDFW only sampled from 2 to 25 reaches per population (Appendix 1).

Weekly spawning ground surveys were scheduled for each reach from the start of spawning in mid-to late October until there was no observed spawning activity, which usually occurred in December or January depending on the population. However, due to high turbid flows and personnel challenges the designed temporal pattern did not always occur and some scheduled weekly surveys were missed.

Data Collection

Trap & Haul

Returning adults from coho salmon populations originating above dams in several Lower Columbia watersheds were trapped and fish were hauled above those dams allowing for their enumeration and the collection of biological data. These watersheds included areas above the Sediment Retention Structure (SRS) on the North Fork Toutle River, and the upper Cowlitz watershed above the Barrier Dam, including separate populations in the Tilton River and the Upper Cowlitz/Cispus Rivers. NF Toutle River coho salmon were trapped, anesthetized in CO_2, and sampled for biological data including length, sex, origin, and scale samples were taken for ageing. Adipose intact fish were transported and released in Alder and Bear creeks. While hatchery fish, those with adipose fin clips, were recycled below the TFCF. Cowlitz River coho salmon captured at the Barrier Dam were anesthetized using electro-anesthesia and sampled for sex and origin. In addition, male coho salmon were classified as jacks or adults based on size. Adult salmon captured at the Barrier Dam are returning to the Cowlitz Salmon Hatchery as well as both the upper Cowlitz/Cispus Rivers and the Tilton River. Natural origin coho release location were based upon coded wire tags they received as smolts. Smolts and parr caught at the Mayfield Dam trap were tagged with a CWT and not adipose fin clipped, so these fish were released in the Tilton River which empties into Mayfield Lake. Adipose intact fish without a CWT were transported to the Upper Cowlitz and Cispus rivers where they presumably originated. In addition, adipose clipped hatchery coho salmon were released in the Tilton, Upper Cowlitz and Cispus rivers to provide recreational fishing opportunity and spawners to seed the available habitat. This action is needed because the current juvenile collection efficiency rate at the Cowlitz Falls dam (CFD) is approximately 30% and too low to support self-sustaining runs

(Serl and Morrill 2009). Other adipose clipped coho salmon collected at the Barrier dam were used for broodstock or surplused.

Mark-recapture

Fish in good condition were anesthetized, bio-sampled, double Floy (FD 68BC T-bar Anchor tags, Floy Tag & Mfg., Inc. Seattle, WA) tagged and released upstream in Duncan Creek at RM 0.2, Abernathy Creek at RM 0, and Cedar Creek at RM 2.4. Opercle punches were applied as a secondary mark, allowing assessment of Floy tag (ft) loss and assignment of a recovered fish back to the weekly release group in Duncan and Abernathy creeks. In Cedar Creek, the opercle punch was not used but a third plastic tag was stapled to the inside of the opercle (op) to assess tag loss. The recapture events occurred at the Abernathy Fish Technology Center (AFTC) located at RM 4, the Cedar Creek resistance board weir (RM 6). In addition to the recapture events described above, carcass recovery events occurred in Duncan and Abernathy creeks along with a resight event of live tagged and untagged spawning fish during scheduled weekly spawning ground surveys. Recovery events were concurrent with spawning ground surveys in all creeks. Due to their small size, the sample frame for Duncan and Abernathy Creeks was the entire spawning distribution, which resulted in a redd census rather than a probabilistic sample (e.g., from a GRTS design).

In addition, on the North Fork Lewis all carcasses were inspected for tags. Untagged carcasses were tagged on both opercles with uniquely numbered plastic tags (McIssac 1977). Tags were placed on the inside of the opercle to limit predation and potential bias in recovery rates due to observation of brightly colored tags. Tagged carcasses were then placed into moving water to facilitate mixing with untagged carcasses (Sykes and Botsford 1986). When tagged carcasses were recovered, surveyors recorded the tag numbers , the tags were removed and fish were marked by removing the tail (denoted as loss on capture in the Jolly-Seber model).

Spawning Ground Surveys.

Redd surveys followed the protocols of Gallagher et al. (2007). The start and end of each survey reach based on the GRTS design was geo-referenced and its coordinates were recorded on a Garmin Oregon 550 unit set in NAD 83. Surveyors typically located the upper most point in the reach and walked downstream to the coordinates at the end of the reach. Surveys were scheduled weekly and followed methods in Rawding et al. (2006a) and Rawding (2006b). All identifiable redds were flagged, and their location (latitudinal and longitudinal coordinates) were recorded. GPS units were allowed to acquire satellite locations until an accuracy of ± 100 feet or less was obtained, most often accuracies averaged 5 to 50 feet. In subsequent surveys, previously flagged redds were inspected to determine if they should be classified as “still visible” or “not visible”. A redd was classified as “still visible” if it would have been observed and identified without the flagging present and was recorded as “not visible” if it did not meet this criteria. This data was collected to allow us to estimate the time period redds were visible to surveyors.

In addition, all live adult and jack salmonids were recorded by species (Crawford et al. 2007a). Salmon were identified as either spawning or holding. A fish was classified as holding if it was observed in an area not considered spawning habitat, such as pools or large cobble and boulder riffles (Parken et al. 2003). Salmon were classified as spawners if they were on redds or not classified as holders. Counts of live Chinook, coho, and chum salmon were recorded separately for each survey reach. During these surveys, counts of tagged and untagged coho salmon occurred in the Abernathy, Cedar, and Duncan watersheds to provide one potential method to estimate abundance based on a mark-resight estimator (Jacobs et al. 2002).

All carcasses that were not totally decomposed were sampled for external tags (Floy T-bar or opercle tags) and biologically sampled for fork length, sex, adipose fin presence, and condition (extent of decomposition). Sex was determined based on morphometric differences between males and females and/or by cutting open the abdominal cavity to confirm sex and determine spawning success. The spawning success was approximated based on visual inspection, ranging from 100% to 0% success. A fish with 0% success was considered a pre-spawning mortality. Scale samples were collected by selecting scales from the preferred area as described in Crawford et al. (2007b). Preferred scales are samples in an area ~ 1-6 scale rows high, and ~15 scale rows wide, above the lateral line in a diagonal between the posterior insertion of the dorsal fin and anterior insertion of the anal fin. Scale samples were removed with forceps with special care to select scale samples that were of good quality (round shape, non-regenerated) and not adjacent to one another (to minimize the effects of regeneration) as described in a WDFW technical report (Cooper et al. 2011). Scales were placed on the gummed portion of WDFW scale cards with their exterior surfaces facing up. The scale card number, position number, date, and location create a unique code in the A&S database.

All coho carcasses were sampled for CWT following standard protocols (NWMFT 2001). The surface of the CWT wand with radiating arrows was placed in contact with the snout and moved from the right to the left eye, and then up and over the snout area. For large fish, the wand was also inserted into the mouth with the radiating arrows rubbed against the roof of the mouth in vertical strokes. If a CWT is detected, the red LED will light up and a beep is emitted from the wand. When a CWT was detected, the snout was severed by cutting across the head straight down behind the eyes (Crawford et al. 2007b). The snout was placed in a plastic bag with a tag number linking the snout to biological data (length, sex, fin clips, spawning success for females, and scale sample number) recorded on the scale card, stream survey card, or other datasheet. Snouts were stored in a freezer and periodically delivered to the WDFW CWT lab in Olympia for processing.

Sample Processing

Scale Analysis

Scale preparation and analysis followed WDFW protocols (Cooper et al. 2011). Acetate impressions were made of the scale samples by a scale card press, where samples were covered with clear acetate (0.5mm thickness) and pressed under 1200-1300 pounds per square inch (PSI) at 100 degrees Celsius for 30 seconds to one minute. Acetate impressions were then slightly cooled and removed from the scale card. Acetate impressions of scale samples were aged using a modified Gilbert/Rich ageing notation (Groot and Margolis 1991), where annuli are counted along with the scale edge to produce a total age in years. Annuli are defined as an area of narrowly spaced circuli that represent winter/early spring growth. Age was recorded as the total age in years followed by the year at outmigration. For example a typical coho salmon adult is age 3_2. This notation indicates a total age of 3 and the juvenile salmon left its natal freshwater habitat within its second year of life. After being aged in Olympia by an aging specialist, scale samples were returned to Vancouver for entry into the Age and Scales (A&S) database.

CWT Lab Analysis

The recovery of CWT tags at the WDFW lab follows the procedures outlined in the tag recovery chapter (Blankenship and Hiezer 1978) of the Pacific Coast Coded Wire Tag Manual and is briefly repeated here. Each snout is passed through a magnetic detector to determine tagged and untagged snouts. Untagged snouts are set aside and rechecked after magnetizing the tag. To ensure the tag is magnetized the length of the tag must pass through the horseshoe magnet in a plane parallel with a straight line collecting the poles. If the tag angle is off more than 40 degrees the tag may not be magnetized. Therefore, the head is passed through the magnet in three positions corresponding to the X, Y, and Z axes and then through the detector. Large heads are often dissected to maximize tag detections. Snouts with no tags are saved and an x-ray machine is periodically used to determine tag presence in these "no tagged" snouts. After determining a tag is present, the snout is dissected, and the tag is located by process of elimination. After recovering the tag, the binary code is determined by careful observation under a microscope. CWT data is then entered into WDFW CWT access database, and provided to managers as needed and uploaded into the Regional Mark Information System (RMIS).

Data Analysis

Overview

Coho salmon abundance estimation was relatively straightforward for mark-recapture areas and trap and haul areas, but required combining multiple sources of information for GRTS survey areas (Figure 3). Briefly, a spawning habitat model developed for the ESU was parameterized with data from each GRTS survey sub-basin to predict the spawning habitat sampling frame. A subsample of reaches in this area was surveyed for redds, live fish, and carcasses, and the mean redd density was multiplied by the spawning habitat frame to estimate total redds for the GRTS sub-basin. Total redds were converted to total females by applying an ESU-wide estimate of redds per female based on the ratio of female abundance to census redd counts in mark-recapture basins. Female abundance was converted to adult abundance which could also be assigned marked and unmarked proportions based on hierarchically modeled sex ratios and marked to unmarked ratios from carcass recoveries in GRTS surveys. Jack abundance was estimated based on total male abundance from an ESU-wide estimate of the proportion of males that were jacks from adult fishway traps.

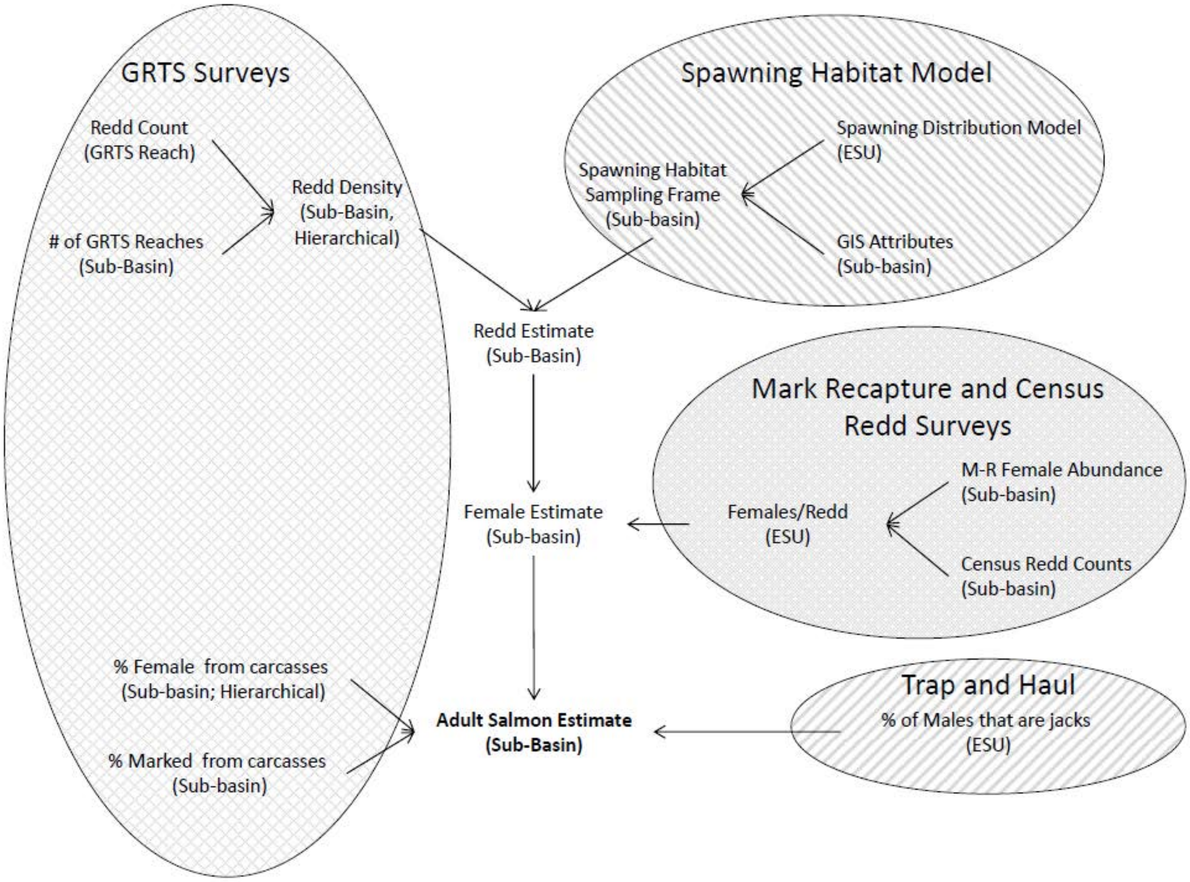

Figure 3. Overview of study design and data inputs used to generate coho salmon abundance estimates for GRTS survey sub-basins. Shaded circles show general information sources while wording describes specific parameters and arrows show how specific parameters were combined to generate estimates. Spatial scales are listed below parameters and hierarchically modeled parameters are noted.

Modeling Approach

Data analysis was conducted using a Bayesian framework. Bayes rule states the posterior distribution, $p(\theta|y)$, is the product of the prior distribution, $p(\theta)$, and the probability of the data given the model or likelihood, $p(y|\theta)$, which is expressed by

$$p(\theta \mid y) = \frac{p(\theta)\,p(y \mid \theta)}{p(y)} \tag{1}$$

Where y are the data, θ are the parameters, and $p(y) = \Sigma_\theta\, p(\theta)p(y|\theta)$ for all discrete values or $p(y) = \int p(\theta)\,p(y \mid \theta)d\theta$ for continuous data (Gelman et al. 2004). The formula of the posterior distribution may be complex and difficult to directly calculate. Samples from the posterior distribution can often be obtained using Markov chain Monte Carlo (MCMC) simulations (Gilks et al. 1995). WinBUGS is a software package that implements MCMC simulations using a

Metropolis within Gibbs sampling algorithm (Spiegelhalter et al. 2003) and has been used to estimate abundance and densities in fish and wildlife studies (Rivot and Prevost 2002, Wyatt 2002, Link and Barker 2010). All of the modeling results described in this paper have undergone tests to assess chain convergence and the uncertainty in the parameter estimates due to Markov Chain variability (Plummer et al. 2006, Su et al. 2001). We used multiple chains starting at divergent initial values and monitored the chains until they reached equilibrium, which was assessed visually and using the Brooks-Gelman-Rubin statistic (Lunn et al. 2013). Values less than 1.1 are considered to have converged (Gelman et al. 2004). After discarding the burn-in, iterations before convergence, we monitored the Monte Carlo standard error (MCSE) until it was less than 5% of the standard deviation to obtain accurate parameter estimates (Lunn et al. 2013). We also monitored the estimate of effective parameters; Rafferty and Lewis (1992) suggested that if the effective parameters equaled 4,000 then the estimate of the 2.5% and 97% quantiles are within ± 0.01 with a 95% probability. It is therefore assumed that our reported estimates are accurate and represent the underlying stationary distributions of the estimates parameters.

The mode, median, and mean are commonly reported measures of central tendency for posterior distributions, which are reported in the form of point estimates. The mode is the most frequent value in the dataset. The middle value of the data is the median and the mean is the sum of the numbers in the dataset divided by the numbers in the dataset. For symmetric distributions these measures of central tendency are the same. However, for asymmetric distributions it is not always clear on which measure of central tendency to report. The median is often used because it is intermediate to the mode, which can be a poor choice when it is distant to the middle of the distribution, and the mean, which can give substantial weight to extreme values (Carlin and Louis 2009). Many of our estimates include the combination of two distributions (e.g. the number of fish by age which include the multinomial distribution for age and various distributions for abundance). Because these two distributions are often asymmetrical for fish monitoring data when we sum the medians of abundance by age they may not equal the median abundance estimate. Therefore, to limit confusion we have decided that the reported estimate will be the mean, which has a property that the individual estimates sum to the total estimate. The summary table will also include the median and the standard deviation based on the posterior distribution. We reported the equal-tailed or symmetric 95% confidence intervals which exclude 2.5% from each tail of the posterior distribution rather than the highest probability interval, which is the shortest 95% interval of the posterior mass and is sometimes preferred (Lee 2004).

We specified vague priors for parameters. First, because this was the first study to estimate coho salmon in the Washington’s portion of LCR, there was little prior information. Second, vague priors are developed not to influence the posterior distribution and therefore “let the data speak for themselves”. We chose Beta and Dirichlet priors parameterized with $\alpha = \beta = 1, 0.5$, or 0.01 for binomial or multinomial distributions, which are referred to as the Bayes-LaPlace, Jefferys’, and Haldane, respectively. We used the Jefferys’ prior in the model and tested sensitivity using the other priors. For abundance estimates in mark-recapture, we chose a Uniform prior, so that the minimum and maximum bounds did not truncate the posterior distribution. When hierarchical modeling binomial proportions, we chose the logit-normal model with mean having a vague Normal(0,100) and a Uniform (0,100) for the standard deviation (Gelman et al. 2004).

We also considered a Gamma (0.001, 0.001) constrained to less than 100 for each of the alpha and beta hyper-priors in the hierarchical models to test the sensitivity of the logit-normal priors.

In some cases we used hierarchical models (e.g., Gelman et al. 2004). For example, we believe that the sex ratio of adult coho salmon in each LCR population should be near 50% females (Sandercock 1991, Dittman et al. 1998), but may vary slightly between populations, and may be subject to measurement error due to small carcass sample sizes. In this case, hierarchical models should adequately describe the percentage of females in each spawning population while allowing the hierarchical posterior distribution of sex ratio estimates to reduce the influence of small sample sizes in contributing to measurement error. Following this same logic, hierarchical models were used to estimate the percentage of jacks within the male population from trap data and to estimate watershed redd density based on the negative binomial distribution, which is appropriate for over-dispersed count data. The hierarchical redd density model was also necessary for some populations, because the small number of reaches surveyed resulted in challenges obtaining stable numerical redd density estimates unless the method of moments was used to estimate parameters for the negative binomial distribution.

A key assumption in hierarchical models is that of exchangeability (Kery and Schaub 2012). In our sex ratio model, this means that all the individual population sex ratios are assumed to come from a common distribution of sex ratios for all LCR coho salmon populations and their ordering does not affect the results. An important characteristic of hierarchical models is that the individual estimates borrow strength from the group estimate. This results in shrinkage of the individual estimates toward the population mean (Gelman et al. 2004). The amount of shrinkage depends on the variance between the populations and their sample sizes. We chose the hierarchical approach as a compromise between treating each population's sex ratio independently and pooling all data to estimate a single sex ratio. An advantage of this approach is less over-fitting of the data than would occur in generating independent estimates for each population, while still accounting for individual variability to influence estimates for a particular population (Kery and Schaub 2012).

Goodness of Fit (GOF) Tests

The purpose of GOF tests are to identify potential inadequacies in the fit of the model to the observed data. One Bayesian approach used for GOF testing is posterior predictive checking, which is a comparison of the posterior predictive distribution of replicated data from the model with the data analyzed by the model (Gelman et al. 2004). In other words, the predictive data ($y.rep_i$) is the expected observation after replicating the study, having observed the data (y_i) and assuming the model is true. When using MCMC simulations, a measure of discrepancy (D) is computed for the actual and replicated datasets for each iteration. An assessment of the posterior distributions of $D(y^{rep},\theta)$ and $D(y,\theta|y)$ provides individual and overall GOF measures. The posterior or Bayesian *p*-value = $\Pr(D(y^{rep},\theta) > D(y,\theta|y)$. The interpretation of the Bayesian *p*-value is the proportion of the times the discrepancy measure of the replicated data is more extreme than the observed data. If there is a good fit of the model to the data, we would expect the observed data to be similar to the replicated data, resulting in a Bayesian *p*-value of 0.50 while values near zero or one indicate that the model does not fit the data.

There are many possible types of discrepancy measures including the Freeman-Tukey, standardized Pearson residual, chi-square, and deviance statistics (Brooks et al. 2000, Lunn et al. 2013). Residuals measure the difference between observed and fitted data. The standardized Pearson residual is one measure of this difference and is expressed by

$$r_i(\theta) = \frac{y_i - E(y_i \mid \theta)}{\sqrt{Var(y_i \mid \theta)}} \tag{2}$$

where r_i is an individual residual, y_i is an individual data point, and $E(y_i|\theta)$ is the fitted value of for y_i based on the function to determine the parameters θ. We used standardized Pearson residuals to assess GOF in hierarchical binomial models following Kery (2010). To assess the GOF for redd densities and to test GOF for the recapture portion of the JS model, we used the Freeman-Tukey statistic (Brooks et al. 2000). Our binned redd count data consisted of many zero counts and this test statistic does not require the pooling of bins with small or zero values. The Freeman-Tukey statistic is expressed as

$$d_i(\theta) = \sqrt{y_i} - \sqrt{E(y_i \mid \theta)} \tag{3}$$

where d_i is an individual discrepancy, y_i is an individual data point, and $E(y_i|\theta)$ is the fitted value of y_i based on the function to determine the parameter θ. When estimating independent values, such as the proportion of hatchery fish in a single population, Bayesian *p*-values are typically near 0.5. Therefore, we conducted GOF tests for hierarchical estimates and not independent estimates. Although Bayesian *p*-values are commonly used for model checking, there have been criticisms of this approach. First, it uses the data twice to build and check the model, which may not be as robust as other methods for testing model adequacy (Carlin and Louis 2009, Kery 2010). Second, it is unclear what cut off values to use for the interval (5% to 95%) to indicate lack of model fit. Third, the posterior distribution is influenced by the prior distribution, thus a Bayesian *p*-value is influenced by the prior distribution (Brooks et al. 2000). These concerns have been addressed, but are beyond the scope of this paper (Gelman et al. 2004, Carlin and Louis 2009, and Brooks et al. 2000). Due to these concerns, we used posterior predictive model checking as a qualitative measure of model adequacy—if a Bayesian *p*-value indicated the model did not fit the data, we considered this to indicate significant lack of model fit (Link and Barker 2010).

In some cases we tested the probability that one estimate was greater than another. These tests included determining if female density was greater than the density needed to seed habitat and greater than NOAA proposed occupancy rates (Crawford and Rumsey 2011). In these cases we monitored the difference between these two variables and assigned a value of 1 when the first estimate was higher than the second for each iteration. The proportion of times the first estimate was higher than the second estimate was the sum of the “1s” divided by the total iterations. We refer to this probability as a *p*-value, which is different than the Bayesian *p*-value described above.

Modeling Approach

In our coho salmon study, data was sparse and thus formal model selection techniques were unlikely to be very informative. Therefore, model development relied more on our knowledge of LCR coho salmon biology and population dynamics than formal model selection (Mäntyniemi and Romakkaniemi 2002). The exception to this was the use of Deviance Information Criteria (DIC) developed by Spiegelhalter et al. (2002) for formal model selection between the Negative Binomial and Poisson distribution for the redd counts, and model selection for the Jolly-Seber model using carcass tagging to estimate population abundance on the mainstem NF Lewis.

Due to computational challenges it is difficult to estimate Bayes Factors when using MCMC approaches (Ntzoufras et al. 2009, Lunn et al. 2013) and this occurred in mark-recapture model selection. As a practical solution we limited the number of JS models to four (Table 1), and used DIC for model selection:

$$\mathrm{DIC} = \mathrm{Dev}(\theta_m) + \mathrm{pv} \tag{4}$$

where $D(\theta_m)$ is the posterior mean deviance for the model and $\mathrm{pv} = \mathrm{Var}(D(\theta|Y))/2$ and is a measure of the number of effective terms in the model. We choose pv over the more commonly used pD for an estimate of effective parameters, because pv performs well when there is weak prior information and is invariant to parameterization (Gelman et al. 2004). DIC is a Bayesian analog of Akaike Information Criteria (AIC) but is based on MCMC outputs. Similar to the model support scale developed by Burnham and Anderson (2002), Spiegelhalter et al. (2002) suggested that models ΔDIC of less than 2 have considerable support, models with ΔDIC having 3-7 have less support, and models with ΔDIC > 10 have negligible support.

Table 1. Model notation from Lebreton et al. (1992) used for JS carcass tagging (from Lebreton et al. 1992). Model's name indicate whether capture, survival, or entrance probabilities were allowed to vary over time ("t") or were held constant ("s" = same).

Model	Probability of capture (p)	Probability of survival (φ)	Probability of entry (b^*)
t t t	varies over periods	varies over periods	varies over periods
s t t	equal over periods	varies over periods	varies over periods
t s t	varies over periods	equal over periods	varies over periods
s s t	equal over periods	equal over periods	varies over periods

Trap & Haul Escapement Estimates

The coho salmon abundance estimate for unmarked adults were simply the number of unmarked coho salmon trapped, hauled, and released into the upper NF Toutle, Tilton, and Upper Cowlitz/Cispus rivers. There were no marked adults released into the upper NF Toutle River. In the Tilton and Upper Cowlitz/Cispus rivers a recreational fishery occurred for marked coho salmon. All anglers retaining a marked coho salmon are required to record the fish on a CRC. At the end of the season, CRCs are returned to WDFW. However, successful anglers are more likely to return CRCs than unsuccessful anglers (Bob Leland, WDFW, pers. comm.). To account for this bias, WDFW contacts a random sample of anglers not returning their CRC by mail and they are reminded to turn in their CRC. Phone calls are then made to a random set of anglers receiving the reminder that still did not return their CRC in order to obtain their harvest information (Eric Kraig, WDFW pers. comm.). For each month the mean catch and variance are estimated (Kraig 2014). To obtain the total marked catch, the means and variances are summed. Therefore, we estimate the marked catch of adults and jacks by

$$Ad\_Catch_j \sim Normal(a\mu_j, asd_j) \tag{5}$$

$$J\_Catch_j \sim Normal(j\mu_j, jsd_j) \tag{6}$$

where *Ad_Catch* and *J_Catch* is the estimated catch assuming a normal distribution, $a\mu$ and $j\mu$ are the means for the adult and jack marked catch, *asd* and *jsd* are the standard deviation for the adult and jack marked catch, and *j* is an index for the Tilton and Upper Cowlitz/Cispus populations. The escapement of marked adults and jacks is the number trapped and hauled minus the catch

$$ATHm_j = AHm_j - Ad\_Catch_j \tag{7}$$

$$JTHm_j = JHm_j - J\_Catch_j \tag{8}$$

where *ATHm* and *JTHm* is the estimated adult and jack escapement and *AHm and JHm* are the number of transported adults and jacks, respectively.

Mark-Recapture Adult Escapement Estimates

Adult salmon escapement estimates were made using Peterson mark-recapture methods in Duncan, Abernathy, and Cedar creeks. The tagging event occurred near the mouth and the recovery events consisted of recoveries of live fish at adult traps upstream of the tagging site in Abernathy and Cedar creeks, and carcass recoveries in all three creeks during spawning ground surveys. Due to the sparseness of data and the results from 2010 (Rawding et al. 2014) we used the pooled Petersen estimator to estimate abundance by

$$rb_h \sim Binomial(q_h, tb_h) \tag{9}$$

$$cb_h \sim Binomial(q_h, Nb_h) \tag{10}$$

where *tb*, *rb*, and *cb* are the number of tagged, recaptured or resighted fish, and fish captured or observed in the second sample, respectively. The recapture efficiency and the population estimate are denoted by *q* and *Nb* and estimated by:

$$q_h \sim Beta(a, b) \tag{11}$$

$$Nb_h \sim Uniform(\min, \max). \tag{12}$$

Tag loss was assessed in 2010 with double tagging experiments and marking experiments. Since the secondary mark (opercle punch) was permanent and low tag loss was observed in our 2010 study (Rawding et al. 2014), we did not assess tag loss in 2011.

We parameterized the Schwarz et al. (1993) "super population" JS model into a Bayesian framework. Rather than using individual capture histories we used summary statistics to increase the computational speed (Table 2). It is important to note that in the more popular Schwarz and Arnason (1996) model the super population and other fundamental parameters are based on births, while in the Schwarz et al. (1993) model the super population is the total of gross births or salmon escapement (Table 3). This model allows salmon escapements to be hierarchically modeled (Rivot and Prevost 2002) and probability of entry to be modeled based on various distributions (Hilborn et al. 1999). Derived parameter estimates in Table 4 are based on Schwarz et al. (1993) and Manske and Schwarz (2000). We included the later author's derived estimates for cases when the mark-recapture study ends early, as they proposed a method to estimate escapement based on the residence time estimated from the mark-recapture data and area under the curve (AUC) method, which is a plot of the population size at each sampling period. The JS likelihood is the product of three likelihoods: 1) the probability of first capture based on a super population (N) that enter the population (b^*_i) following a multinomial distribution, 2) the probability of release on capture (v_i) from a binomial distribution using total fish sampled (n_i) and number of n_i that are released (R_i), and 3) the probability of recapture which is the product of two binomial distributions to estimate the probability of capture (p_i) and survival (φ_i) (Burnham 1991) (Table 5).

Table 2. Summary statistics used in the Jolly-Seber model.

Statistic	Definition/Equation
m_i	Number of fish captured at sample time *i* that were previously marked.
u_i	Number of fish captured at sample time *i* that were unmarked.
n_i	Number of fish captured at sample time *i*. $n_i = m_i + u_i$.
l_i	Number of fish lost on capture at time *i*.
R_i	Number of fish that were released after the *i*th sample. R_i need not equal n_i if there were losses on capture or injections of new fish at sample time *i*.
r_i	Number of R_i fish released at sample time *i* that were recaptured at one or more future sample times.
z_i	Number of fish captured before time *i*, not captured at time *i*, and captured after time *i*.
T_i	Number of fish captured at before time *i* and captured at or after time *i*. $T_i = m_i + z_i$.

Table 3. Fundamental parameters for the Jolly-Seber model under the salmon escapement super population model (Schwarz et al. 1993).

Parameter	Definition/Equation
s, tm	Number of sample times and length of interval between samples
p_i	Probability of capture at sample time i, $i = 1,\ldots, s$.
φ_i	Probability of a fish surviving and remaining in the population between sample time i and sample time $i + 1$, given it was alive and in the population at sample time i, $i = 1,\ldots, s\text{-}1$.
b^*_i	Probability that a fish enters the population between sample times i and $i+1$, $i = 0,\ldots, s\text{-}1$ under the constrain that $\sum b^*_i = 1$. These are referred to as entry probabilities.
v_i	Probability that a fish captured at time i will be released, $i = 1,\ldots, s\text{-}1$.
N	Total number of fish that enter the system before the last sample time or the escapement. This is referred to as the super population.

Table 4. Derived parameters for the Jolly-Seber model under the salmon escapement super population model (Schwarz et al. 1993) and the stream residence time model (Manske and Schwarz 2000).

Parameter	Definition/Equation
λ_i	Probability that a fish is seen again after sample time i, $i = 1,\ldots, s$. $\lambda_i = \varphi_i\, p_{i+1} + \varphi_i\,(1 - p_{i+1})\,\lambda_{i+1}$, $i = 1,\ldots, s\text{-}1$; $\lambda_s = 0$.
τ_i	Conditional probability that a fish is seen at sample time i given that it was seen at or after sample time i, $i = 1,\ldots, s$. $\tau_i = p_i/(p_i + (1\text{-}p_{i+1})\,\lambda_i)$.
ψ_i	Probability that a fish enters the population between sample time i-1 and i and survives to the next sampling occasion. $\psi_i = b^*_0$, $\psi_{i+1} = \psi_i\,(1 - p_i)\varphi_i + b^*_i(\varphi_i - 1)/\log(\varphi_i)$
B_i	Number of fish that enter after sample time i and survive to sample time $i+1$, $i = 0,\ldots, s\text{-}1$. These are referred to as net births. $B_0 = B^*_0$, $B_i = B^*_i(\varphi_i - 1)/\log(\varphi_i)$.
B^*_i	Number of fish that enter between sampling occasion i-1 and i, $i = 0,\ldots, s\text{-}1$. These are referred to as gross births. $B^*_i = N\,(b^*_i)$
N_i	Population size at time i, $i = 1,\ldots, s$. $N_1 = B_0$, $N_{i+1} = (N_i - n_i + R_i)\,\varphi_i + B_i$
N^-_i	Number of fish alive immediately before sample time i, $i = 1,\ldots, s$. $N^-_1 = B_0$; $N^-_{i+1} = N^+_i\,\varphi_i + B_i$
N^+_i	Number of fish alive immediately after sampling time i, $i = 1,\ldots, s$. $N^+_i = (N^-_i - n_i + R_i)$. N^+_i may differ from N^-_i if there were losses on capture or injections of new fish.
RT	Average residence time; for $i = 1,\ldots, s\text{-}1$. $\mathrm{RT} = 0.5\sum tm_i N^+_i(\varphi_i + 1) + 0.5\, tm_s N^+_s + 0.5 tm_0 B_0 + \sum B_i tm_i(\varphi_{i/}\, \varphi_{i-1} - 1/\log(\varphi_i))$
AUC	Aggregate residence time over all spawner. This is referred to as the total fish days or Area-Under-the-Curve. $\mathrm{AUC} = 0.5\, tm_0 N^-_1 + \sum 0.5\, tm_i(N^+_i + N^-_i) + 0.5\, tm_s N^+_s$.
ESC	Escapement. ESC = AUC/RT. This is slightly greater than N, which is also a measure of escapement due to accounting for fish before and after sampling.

Table 5. The likelihoods for the Schwarz et al. (1993) model

Description	Likelihood
Pr(first capture part a)	$u. \sim \text{Binomial}(\sum \psi_i p_i, N)$, $i = 0,\ldots, s-1$. $u. = \sum u_i$
Pr(first capture part b)	$u_i \sim \text{Multinomial } (\psi_i p_i / \sum \psi_i p_i, u.)$), $i = 0,\ldots, s-1$.
Pr(release on capture)	$R_i \sim \text{Binomial}(v_i, n_i)$, $i = 1,\ldots, s-1$.
Pr(recapture part a)	$m_i \sim \text{Binomial}(\tau_i, T_i)$, $i = 2,\ldots, s-1$.
Pr(recapture part b)	$r_i \sim \text{Binomial}(\lambda_i, R_i)$, $i = 1,\ldots, s-1$.

Expanded Smolts Abundance Estimates

Weekly redd surveys were not conducted over the entire spawning area in Mill and Germany creeks so adult abundance in these watersheds was estimated by applying the smolt to adult SAR rate from neighboring Abernathy Creek to smolt estimates from these basins. Smolt estimates following standard protocols are available for Mill, Germany, and Abernathy Creeks, and a mark-recapture estimate is available for adults in Abernathy Creek. The Abernathy Creek SAR was estimated for Abernathy Creek by

$$Ab\_SAR = AMRum_2 / Ab\_smolts \qquad (13)$$

where *Ab_SAR* is the Abernathy Creek SAR rate, *Ab_smolts* is the estimated smolt outmigration in 2009, and $AMRum_2$ is the mark-recapture estimate of adult abundance for unmarked fish. The unmarked adult abundance for Mill and Germany creeks is estimated by

$$ASum_f = smolts_f / Ab\_SAR$$

(14)

where *ASum* is the unmarked adult abundance estimate using the smolt expansion method and *smolts* is the estimated smolt abundance from Mill and Germany creeks in 2009 based on a stratified estimator (Volkhardt et al. 2007).

Redd based Abundance Estimates

To estimate the adult coho spawning escapement, the following estimates are required: 1) the number of redds per female, 2) the proportion of adult spawners that are females, and 3) the total number of redds in the population. In Duncan and Abernathy creeks we estimated the total abundance based on a mark-recapture study above trapping sites located at the mouth of these creeks (equations 9, 10, 11, and 12). Morphometric characteristics of live fish and carcass recoveries were used to estimate the proportion of females and the number of female spawners by

$$FMR_h \sim Binomial(pFMR_h, AMR_h) \qquad (15)$$

$$NbF_h = pFMR_h * Nb_h \qquad (16)$$

$$pMC_k \sim Beta(a, b) \qquad (17)$$

where *FMR* and *AMR* are the number of unique females and adults sampled in the mark-recapture study, respectively, while *pFMR* is the proportion of female adults in the mark-recapture study, and *NbF* is the estimated number of female spawners in the population. The redd counts and female spawners from Duncan and Abernathy creeks were summed and the redds per female was estimated using the Binomial distribution with a Beta distribution for the proportion of females by

$$MRF = \sum_{h=1}^{2} NbF_h \tag{18}$$

$$DA\_redds \sim Bin(RpF, MRF) \tag{19}$$

$$RpF \sim Beta(a, b) \tag{20}$$

where *MRF* is the sum of the mark-recapture estimate of females in Duncan and Abernathy creeks, *DA*_redds is the sum of the Duncan and Abernathy creek redd counts, and *RpF* is the estimated number of redds per female.

For each one mile redd survey reach, the sum of the new redds counted was the redd density for that reach. To estimate the redd density for the sampled reaches, parametric statistics were not considered due to concerns about the lack of fit using standard sampling theory (Courbois et al. 2008). The starting point for analysis of count data is often the Poisson distribution. However, in the Poisson distribution the mean is equal to the variance, which is often an unrealistic assumption for count data. The negative binomial distribution is a more flexible distribution for the analysis of count data and allows for over dispersion in count data (Link and Barker 2010). The Poisson distribution is a special case of the negative binomial distribution as the over dispersion parameter approaches ∞ the Poisson distribution is recovered (Hilborn and Mangel 1997). Redd counts were modeled using a hierarchical negative binomial distribution, with an adjustment to accommodate WinBUGS parameterization by

$$y_{ik} \sim NegativeBinomial(p_k, r_k) \tag{21}$$

$$\mu_k = r_k * (1 - p_k / p_k) \tag{22}$$

where *y* is the number of redds in reach *i* for population *k*, with hyperparameters *p* and *r*. Both hyperparameters were assigned vague hyperpriors including

$$logit(p_k) \sim Normal(p\_mu, p\_sd) \tag{23}$$

$$r_k \sim Gamma(a_1, a_2) \tag{24}$$

$$p\_mu \sim Normal(0{,}100) \tag{25}$$

$$p\_sd \sim Uniform(0{,}100) \tag{26}$$

where the *a, b, p_mu,* and *p_sd* are the hyperpriors.

The redd density for each population is estimated by

$$\lambda_k \sim NegativeBinomial(p_k, r_k) \tag{27}$$

where lambda is the redd density. Ntzoufras (2009) noted that the dispersion index is equal to Var(Y)/E(Y). This is estimated by

$$DI_k = 1/p_k \tag{28}$$

where *DI* is the dispersion index and *p* is the hyperparameter of the negative binomial distribution. Since by definition the variance equals the mean for the Poisson distribution, a dispersion index greater than one indicates support for the Negative Binomial over the Poisson distribution for each population, which was assessed with a Bayesian GOF test. The female and adult redd density, and the proportion of females are estimated by

$$FD_k = \lambda_k / RpF \tag{29}$$

$$AD_k = FD_k / pF_k \tag{30}$$

$$FC_k \sim Binomial(pF_k, AC_k) \tag{31}$$

where *FD* is the female density, *AD* is the adult density, *pF* is the proportion of females, *FC* is the number of female carcasses, and *AC* is the number of adult carcasses. We estimate *p*-values to estimate the probability that our observed female redd densities for each population was greater than the mode of the female density required to seed freshwater habitat from Bradford et al. (2000). The proportion of females was hierarchically modeled by

$$logit(pF_k) \sim Normal(pF\_mu, pF\_sd) \tag{32}$$

$$pF\_mu \sim Normal(0{,}100) \tag{33}$$

$$pF\_sd \sim Uniform(0{,}100) \tag{34}$$

where *pF_mu* and *pF_sd* are the hyperpriors.

The total escapement based on redd surveys was estimated by

$$AT_k = \left(y_k + yc_k + \sum_{i=1}^{mis\_miles} \lambda_k \right) / RpF \tag{35}$$

where y is the observed number of redds in GRTS reaches, yc is the number of redds in non GRTS reaches (typically index Chinook or chum salmon reaches), λ is the redd density, and mis_miles is the number of unsurveyed miles in the GRTS sampling frame from which to expand redd counts in GRTS reaches.

Estimates of Hatchery and Wild Adults

We used the carcasses collected during the stream surveys to estimate the proportion of marked and unmarked adults by

$$MC_k \sim Binomial(pMC_k, SC_k) \tag{36}$$

$$pUMC_k = 1 - pMC_k \tag{37}$$

$$pMC_k \sim Beta(a, b) \tag{38}$$

where MC_k is the number of marked adult carcasses sampled, SC_k is the number of sampled adult carcasses, pMC_k is the proportion of marked adults based on the carcasses sampled, and $pUMC_k$ is the proportion of unmarked adults. The estimated number of marked and unmarked adult coho salmon based on the stream surveys was estimated by

$$ARm_k = pMC_k * AT_k \tag{39}$$

$$ARum_k = pUMC_k * AT_k \tag{40}$$

where ARm_k is the estimate of marked adult coho and $ARum_k$ is the estimate of adult unmarked coho salmon. The same equations (36-38) were used to estimate the proportion of marked and unmarked adults in the mark-recapture studies except the subscript used was h instead of k to denote the difference between the mark-recapture and redd based proportions. Equations 36 to 38 were used to estimate the marked and unmarked adult abundance in the mark-recapture estimates.

Combining Data Sources to Generate Population Estimates

Finally, the adult marked and unmarked abundance estimates from redd, mark-recapture, and trap and haul methods were summed as needed to estimate population abundance. These population abundances were summed to estimate the total adult coho salmon abundance below Bonneville Dam except for areas not sampled including the mainstem of the Toutle, lower NF Toutle, and Cowlitz Rivers.

Estimating the Proportion of Males that are Jacks

Due to differential capture probabilities between jack and adult coho salmon carcasses during spawning ground surveys, we applied an aggregate estimate of the proportion of males that were jacks obtained from weirs and trap & haul operations to areas where redd counts were used. We used a hierarchical model to estimate the proportion of male coho salmon that were jacks based on trap data at Cedar Creek, Cowlitz Barrier Dam, and TFCF, and we used the subscript g to denote these 4 groups. The proportion of jacks was estimated by

$$TJ_g \sim Binomial(pJ_g, TM_g) \tag{41}$$

$$logit(pF_g) \sim Normal(pJ\_mu, pJ\_sd) \tag{42}$$

$$pJ\_mu \sim Normal(0{,}100) \tag{43}$$

$$pJ\_sd \sim Uniform(0{,}100) \tag{44}$$

where TJ_g is the count of jacks at a trap, TM_g is the number of trapped males, pJ_g is the proportion of jacks. We used the same hierarchical equations and priors based on the logit-normal distribution as in equations 32-34 provided in 42-44. The jack abundance for each population was estimated by

$$Jtot_k = AT_k * (1 - pF_k) * mean(hier\_pJ) \tag{45}$$

where $Jtot_k$ is the estimate of jacks within the population where AT_k is the adult abundance from the redd or mark-recapture estimate, pF_k is the proportion of females, and *mean(hier_pJ)* is the mean of the hierarchical estimate of the proportion of males that are jacks. .

Estimating the Proportion of One-Mile Reaches Occupied by Coho Salmon Spawners

The spawning reach occupancy rate of coho salmon was based on the redd surveys and estimated by

$$Oc_k \sim Bin(pOc_k, m_k) \tag{46}$$

where OC_k is the number of reaches in which at least one redd was observed, m_k is the number of reaches, and pOC_k is the percent of reaches occupied. In addition, we estimated the probability that 80% of the reaches in a population were occupied by recording the number of iterations the occupancy rate exceeded 80% by

$$p80Oc_k = pOc_k - 0.80 \tag{47}$$

where $p80OC_k$ is the probability that 80% of the surveyed reaches were occupied.

Results

Model convergence and diagnostics

We ran two chains with a thinning rate of 10 using the Gibbs sampler in WinBUGS. After discarding the 5,000 burn-in iterations, a total of 20,000 iterations for the posterior distribution of each parameter were saved. Visual inspection of the history plots suggested the chains mixed and converged. The Brooks-Gelman-Rubin (BGR) diagnostic test for convergence yielded values of less than 1.09 for each parameter, which is less than the recommended value of 1.1. While it is impossible to conclusively demonstrate a simulation has converged, the above diagnostic tests did not detect that the simulations did not converge. The MCSE was 1% of the standard deviation of the parameter estimates, which suggests our posterior distributions were accurate. In addition, the estimates effective number of parameters ranged from 1,200 to 20,000 for all monitored parameters but for the adult abundance parameters the minimum was 3,500 suggesting sufficient iteration for accurate estimates of 95% CI. It should be noted that some numbers presented in this report may not sum due to rounding.

We tested the sensitivity of our analysis based on the various priors. We used three vague priors for the beta distribution ($\alpha = \beta = 0.5$, 1, and 0.01), which correspond to Jeffreys, LaPlace-Bayes, and Haldane priors. We used vague hyper-priors for the binomial and negative binomial hierarchical models based on the gamma distribution (0.001, 0.001) and normal distribution (0, 0.001) for the mean, and a uniform distribution (0, 100) for the standard deviation for logit-normal model. Our results were not sensitive to the priors or hyperpriors except when we had few recoveries in some weeks during the NF Lewis JS population estimate. In addition for hierarchical models, the logit-normal provided slightly better mixing than the Gamma distribution. Our population abundance estimates were similar for all priors and the results reported here are based on Jeffreys prior for the beta distribution, and the logit-normal priors for the hierarchical binomial and negative binomial models mentioned above.

Trap and Haul Abundance Estimates

A total of 63 unmarked adult and five unmarked jack coho salmon were collected and released above the TFCF on the NF Toutle River (Table 6). These numbers are the total escapement above the TFCF. A total of 6,633 and 441 marked adult and jack coho salmon, respectively, were collected at Barrier Dam on the Cowlitz River and released into the Tilton River. Subtracting the fishery impacts for mass marked coho salmon left a mean Tilton River escapement of 4,807 and 427 marked adults and jacks, respectively. In addition, 2,088 unmarked adults and 48 unmarked jacks were released in the Tilton and were not available for harvest and therefore were assumed to have spawned. For the Cowlitz/Cispus population a total of 14,350 and 634 marked adults and jacks, respectively, were captured at Barrier Dam and released at CFD. Subtracting the expanded CRC catch of marked coho salmon leaves a mean escapement of 12,402 and 570 marked adults and jacks, respectively. Since we assumed no fishery impacts for unmarked fish, the Upper Cowlitz/Cispus escapements were the same as the release totals of 7,877 and 96 unmarked adults and jacks, respectively.

The proportion of male coho salmon that were classified as jacks was relatively consistent at three of four locations and ranged from 11.2% at the Barrier Dan on the Cowlitz River to 26.3%

on Abernathy Creek (Table 7). The Bayesian *p*-values ranged from 0.49 to 0.60 for these three populations based on an analysis of Pearson's residuals, which do not indicate any problems with the GOF test for these data using the hierarchical model. The mean proportion of males that were jacks based on the hierarchical model for the trap data was 16.0%.

Table 6. Trap and haul counts at TFCF, CBD counts transported to the Tilton and Upper Cowlitz/Cispus Rivers, estimate of recreational harvest of marked fish, and marked and unmarked escapement in 2011.

Parameter	**mean**	**sd**	**2.50%**	**50%**	**97.50%**
Toutle FCF Unmarked Adult Release	63				
Toutle FCF Unmarked Jack Release	5				
Upper Cowlitz Unmarked Adult Release	7877				
Upper Cowlitz Unmarked Jack Release	96				
Tilton Unmarked Adult Release	2088				
Tilton Unmarked Jack Release	48				
Upper Cowlitz Marked Adult Release	14350				
Upper Cowlitz Marked Jack Release	634				
Tilton Marked Adult Release	6633				
Tilton FCF Marked Jack Release	441				
Upper Cowlitz Marked Adult Catch	1948	135	1686	1948	2212
Upper Cowlitz Marked Jack Catch	64	22	21	64	107
Tilton Marked Adult Catch	1826	132	1569	1826	2084
Tilton Marked Jack Catch	14	10	1	14	34
Tilton Marked Adult Escapement	4807	132	4549	4807	5064
Tilton Marked Jack Escapement	427	10	407	427	447
Upper Cowlitz Marked Adult Escapement	12402	135	12140	12400	12660
Upper Cowlitz Marked Jack Escapement	570	22	527	570	613

Table 7. Estimates of the proportion on male coho salmon that are jacks from trap data at the TFCF, Cowlitz at Barrier dam, Abernathy trap, and Cedar trap in 2011.

Subpopulation	**mean**	**sd**	**2.50%**	**50%**	**97.50%**
Proportion of jacks (Toutle FCF)	10.9%	3.9%	4.4%	10.5%	19.4%
Proportion of jacks (Cowlitz-Barrier Dam)	11.2%	0.2%	10.8%	11.2%	11.6%
Proportion of jacks (Abernathy)	26.3%	4.2%	18.3%	26.2%	35.0%
Proportion of jacks (Cedar)	12.7%	1.4%	10.1%	12.6%	15.4%
Mean proportion of jacks	16.0%	10.3%	3.3%	14.2%	41.8%

Adult Mark-Recapture Results

For the JS model used to estimate carcass abundance on the NF Lewis, DIC favored the tst model. The Δ DIC was 7.1 compared to the next best model, which was the ttt model. However, the Bayesian *p*-value for tst model was 0.00 indicating lack of model fit. The ttt model slightly better fit the data (Bayesian *p*-value = 0.03) and was therefore chosen. Abundance estimates were relatively similar across all models, thus not very sensitive to model choice, but the abundance estimates were higher using the Jeffreys prior for φ and ρ compared to the uniform prior. The estimated escapement was 4,069 adult coho salmon with approximately 75% unmarked fish (3,045) (Table 8). Period abundance was low at the start of the study, peaked in the middle and declined toward the end.

Table 8. The estimated total, marked and unmarked escapement in the NF Lewis in 2011 and the estimated escapement by period (Bstar).

Parameter	mean	sd	25%	50%	97.50%
Escapement	4069	795	3506	3936	5962
Marked Escapement	1024	208	875	990	1515
Unmarked Escapement	3045	598	2619	2944	4485
Bstar[1]	173	156	66	127	577
Bstar[2]	192	152	95	151	587
Bstar[3]	121	120	43	86	439
Bstar[4]	179	198	57	117	732
Bstar[5]	1428	573	1011	1315	2842
Bstar[6]	571	195	462	603	879
Bstar[7]	237	72	190	239	378
Bstar[8]	462	157	352	446	820
Bstar[9]	90	68	37	76	251
Bstar[10]	60	52	21	47	194
Bstar[11]	216	239	62	141	881
Bstar[12]	340	327	116	245	1198

For other mark-recapture populations, the tagged adult recovery efficiency based on live fish and carcasses ranged from 31% to 75%. The adult abundance estimates ranged from a low of 43 in Duncan Creek to 1,251 in Cedar Creek. The proportion of unmarked adults was high in both Abernathy (79%) and Cedar Creek (75%). The estimates of marked and unmarked adult abundance with 95% CI for these creeks are found in Table 9. The number of female spawners in Duncan and Abernathy creeks was 20 and 139, respectively. The proportion of females was similar at both locations (Table 9). The estimate of redds per female for our study was 0.654 (95%CI 0.434 - 0.917). This estimate (0.654) equates to a detection efficiency (number of redds observed out of those actually constructed) of 65% if we assume one redd per female coho salmon.

Table 9. Results for mark-recapture populations in 2011 including estimates of mark-recapture tag recovery efficiency; total, unmarked, and marked adult escapement; proportions of marked, unmarked spawners, and female escapement; proportion of females; and redds per female.

Parameter	mean	sd	2.50%	50%	97.50%
Mark Recovery Efficiency					
Abernathy Cr.	30.5%	4.6%	22.0%	30.4%	39.9%
Cedar Cr.	74.7%	3.5%	67.6%	74.8%	81.1%
Duncan Cr.	66.4%	8.0%	50.2%	66.7%	81.0%
Adult Escapement					
Abernathy Cr. (Total)	231	44	160	225	334
Abernathy Cr.(Unmarked)	183	36	125	178	266
Abernathy Cr. (Marked)	48	13	28	46	79
Cedar Cr. (Total)	1251	62	1141	1247	1386
Cedar Cr. (Unmarked)	936	50	847	933	1042
Cedar Cr. (Marked)	315	23	272	314	364
Duncan Cr. (Total—all unmarked)	43	8	32	42	61
Proportion of Marked and Unmarked Adults					
Abernathy Cr.(Unmarked)	79.2%	3.9%	71.0%	79.4%	86.2%
Abernathy Cr. (Marked)	20.8%	3.9%	13.8%	20.6%	29.0%
Cedar Cr. (Unmarked)	74.8%	1.4%	72.1%	74.8%	77.5%
Cedar Cr. (Marked)	25.2%	1.4%	22.5%	25.2%	27.9%
Female Escapement, Proportions, and Redds per Female					
Duncan Cr. Female Escapement	20	5	11	19	32
Abernathy Cr. Female Escapement	139	29	93	136	206
Proportion of Females (Duncan)	46.2%	9.2%	28.7%	46.1%	64.2%
Proportion of Females (Abernathy)	60.3%	4.1%	52.2%	60.3%	68.2%
Redds per Female (Duncan & Abernathy)	0.654	0.122	0.434	0.647	0.917

SAR Expansion Adult Estimates

The 2009 coho salmon smolt emigration estimates ranged from 1,133 in Germany Creek to 13,593 in Mill Creek (Table 10). The 2010 SAR in Abernathy Creek was 4.2% (95% CI 2.8 - 6.4%). Coho salmon escapement based on smolt abundance and Abernathy Creek SAR in Mill and Germany creeks was 728 and 61 adults, respectively (Table 10). Unmarked and marked adult abundance in these basins based on the proportion of marked adults in Abernathy Cr. is also provided in Table 10.

Table 10. Estimates of 2011 smolt abundance and SAR rate, and 2011 total, unmarked, and marked coho spawner abundance based on SAR expansions for Germany and Mill creeks.

Parameter	**mean**	**sd**	**2.50%**	**50%**	**97.50%**
Smolt Abundance Estimate					
Abernathy Cr.	4341	346	3663	4341	4341
Germany Cr.	1133	56	1023	1133	1243
Mill Cr.	13593	694	12233	13593	14953
Smolt to Adult Return					
Abernathy Cr.	4.2%	0.9%	2.8%	4.1%	6.4%
Adult Escapement Estimates based on SAR Expansions					
Germany Cr. (Total)	61	13	40	59	91
Germany Cr. (Unmarked)	48	11	31	47	73
Germany Cr. (Marked)	13	4	7	12	21
Mill Cr. (Total)	728	157	478	708	1095
Mill Cr. (Unmarked)	576	128	374	560	875
Mill Creek (Marked)	152	44	84	146	255

Redd Based Estimates

A total of 188 reaches across 14 populations were surveyed as part of the GRTS design (Appendix 1). The number of sites ranged from 5 to 22 per population and averaged 13 (Appendix 1). The mean dispersion index for the redd data ranged from 4.1 to 53.6 and the lower 95% CI exceeded 1.1, which all exceeded the expected dispersion index of 1 from the Poisson distribution (Table 11). The NB GOF test indicated the probability that the replicated dispersion index based on the Negative Binomial model was more extreme than the dispersion index, and based on the observed data, ranged from 0.08 to 0.93. The P GOF test indicated the probability that the replicated dispersion index based on the Poisson model was more extreme than the dispersion index, and based on the observed data, was between 0.00 and 0.09. This provides strong evidence that the data is over dispersed and is consistent with the Negative Binomial model, but not consistent with the Poisson model.

Table 11. The estimated dispersion index for the negative binomial distribution from GRTS surveys in 2011. The last two columns are a Bayesian *p*-values for GOF tests to measure the probability that the dispersion index is less than 1 (NB GOF), which would favor the Poisson distribution or if the probability that the dispersion index is 1, which would favor the Poisson model (P GOF).

GRTS Survey Basin	mean	sd	2.50%	50%	97.50%	NB GOF	P GOF
Grays	53.6	58.6	16.6	40.3	163.2	0.08	0.00
Elochoman	11.9	6.1	5.3	10.4	27.6	0.11	0.00
L Cowlitz	4.8	2.3	2.3	4.3	10.4	0.41	0.00
Coweeman	16.4	6.9	7.9	14.9	33.7	0.83	0.00
Toutle Tribs	9.6	18.4	2.0	6.2	35.8	0.24	0.00
Green	4.1	2.5	1.7	3.4	10.4	0.73	0.03
SF Toutle	8.3	6.1	2.9	6.8	23.0	0.55	0.00
Kalama	9.3	16.2	1.8	6.0	35.6	0.32	0.01
NF Lewis	20.5	23.3	6.1	15.3	66.3	0.30	0.00
Cedar	6.1	2.3	3.1	5.6	11.8	0.85	0.00
EF Lewis	7.0	4.1	2.7	6.0	17.1	0.93	0.09
Salmon	10.9	13.8	3.0	8.1	35.5	0.55	0.00
Washougal	15.0	12.4	4.9	11.8	44.7	0.30	0.00
L Gorge	10.2	9.7	3.1	7.8	31.7	0.23	0.00

The hierarchical modeled redd densities followed a highly skewed (right-tailed) distribution, resulting in a mean being greater than the median. The observed mean redd density ranged from 1.3 to 12.1 (Table 12). The Grays populations had Bayesian *p*-values of 0.09 for the Negative Binomial indicating some lack of fit. For the Grays population we had a site near the Grays River Hatchery on the WF Grays River where we sampled 117 redds. This is much higher than the next two highest counts of 96 and 38 on the Coweeman and Elochoman, respectively. This suggests the Grays redd counts are more over dispersed than other areas. The remaining Bayesian *p*-values for the hierarchical Negative Binomial model for count data ranged from 0.09 to 0.78, indicating no significant lack of fit for the GOF test based on Freeman-Tukey test statistics. The Bayesian *p*-values from the Poisson model were not consistent with the data and 8 of 14 p-values equal to zero. In addition ΔDIC=1022, which also provide overwhelming support for the hierarchical Negative Binomial over the individual population Poisson model.

Table 12. Observed coho salmon redds per mile based on the negative binomial distribution from GRTS surveys in 2011. The last two columns are a Bayesian *p*-values for a GOF test to measure if the data are consistent with the Negative Binomial and Poisson models.

GRTS Survey Basin	**mean**	**sd**	**2.50%**	**50%**	**97.50%**	**NB GOF**	**P GOF**
Grays	5.5	20.9	0	0	49	0.09	0.00
Elochoman	4.0	7.8	0	1	25	0.78	0.00
L Cowlitz	2.0	3.4	0	1	11	0.71	0.19
Coweeman	12.1	15.3	0	7	52	0.64	0.00
Toutle Tribs	1.3	6.6	0	0	11	0.17	0.00
Green	1.3	2.6	0	0	8	0.58	0.10
SF Toutle	2.7	5.6	0	1	17	0.59	0.01
Kalama	2.1	7.6	0	0	15	0.37	0.05
NF Lewis	8.1	17.4	0	3	48	0.25	0.00
Cedar	4.2	5.2	0	3	18	0.57	0.00
EF Lewis	4.8	6.3	0	3	21	0.64	0.25
Salmon	3.7	7.9	0	1	23	0.16	0.00
Washougal	5.6	11.2	0	2	34	0.54	0.00
L Gorge	2.9	6.5	0	1	19	0.55	0.03

Based on the mark recapture estimates and redd census, we expanded the redd counts by 0.654 observed redds per female (Table 9) to convert the estimated redds to females (Table 13). The females per mile ranged from 2.1 to 19.1. Based on a meta-analysis, Bradford et al. (2000) found the mode of female coho salmon per mile needed to seed freshwater habitat was 15 females. The probability that our population estimates exceeded 15 females per miles ranged from 0.02 to 0.41.

Table 13. The estimated number of coho salmon females/mile based on GRTS surveys in 2011. The p-value is the probability the observed female density is greater than the mode of the full habitat seeding density based on Bradford et al. 2000.

GRTS Survey Basin	**mean**	**sd**	**2.50%**	**50%**	**97.50%**	***p*-value**
Grays	8.7	34.5	0.0	0.0	78.7	0.13
Elochoman	6.4	12.5	0.0	1.7	39.2	0.12
L. Cowlitz	3.2	5.4	0.0	1.4	17.6	0.04
Coweeman	19.1	24.6	0.0	11.0	84.9	0.41
Toutle Tribs.	2.1	10.4	0.0	0.0	16.9	0.03
Green	2.1	4.2	0.0	0.0	13.1	0.02
SF Toutle	4.2	9.1	0.0	1.3	26.9	0.07
Kalama	3.3	11.5	0.0	0.0	24.8	0.05
NF Lewis	12.9	28.6	0.0	4.1	76.6	0.24
Cedar	6.7	8.6	0.0	3.9	29.6	0.12
EF Lewis	7.5	10.4	0.0	4.2	35.2	0.15
Salmon	5.8	12.9	0.0	1.6	36.9	0.11
Washougal	8.9	18.2	0.0	2.7	54.2	0.17
L. Gorge	4.6	10.5	0.0	1.2	30.6	0.08

Using the hierarchical model we estimated the mean proportion of females among all adult coho was 49.2% based on carcass recoveries. Population-specific estimates ranged from 31.4% to 73.6% and, for all but one basin, the 95% credible intervals overlapped with 50%, which may be expected since the sex ratio should be near 1:1 (Table 14). The Toutle population had the most extreme GOF test value = 0.91. However, this is due to only two female carcasses observed. The GOF test based on Bayesian *p*-values ranged from 0.42 to 0.91 for the 14 populations, which indicates no concern with model fit.

Table 14. Estimates of the proportion of adult females in the 2011 population based on carcass recoveries during redd surveys. The last column is a Bayesian *p*-value for a GOF test.

GRTS Survey Basin	**mean**	**sd**	**2.50%**	**50%**	**97.50%**	**GOF**
Grays	40.9%	10.7%	20.2%	41.0%	61.6%	0.60
Elochoman	31.4%	13.0%	8.4%	31.1%	56.6%	0.44
L Cowlitz	41.1%	12.3%	17.3%	41.3%	64.7%	0.62
Coweeman	51.4%	5.8%	40.3%	51.4%	62.6%	0.55
Toutle Tribs	49.5%	16.3%	17.4%	49.7%	81.5%	0.91
Green	49.6%	14.7%	20.7%	49.8%	78.5%	0.80
SF Toutle	39.7%	13.1%	14.5%	40.0%	64.9%	0.62
Kalama	43.1%	17.4%	9.1%	43.8%	77.4%	0.78
NF Lewis	73.6%	9.3%	53.6%	74.3%	89.3%	0.42
Cedar	43.1%	7.7%	28.0%	43.2%	58.1%	0.56
EF Lewis	60.3%	10.5%	39.9%	60.3%	80.6%	0.57
Salmon	47.1%	11.5%	24.4%	47.1%	69.7%	0.66
Washougal	64.2%	13.6%	37.9%	64.1%	90.1%	0.50
L Gorge	54.4%	15.3%	24.1%	54.2%	84.6%	0.78
Mean Females	49.2%	7.4%	33.9%	49.4%	63.6%	

The female density estimates were expanded by the population-specific estimates of the proportion of females to estimate the adult densities (Table 15). The mean adults per mile ranged from a high of 37.6 in the Coweeman to a low of 4.8 in the Green basin. A total of 10 of 14 population estimates had mean adult densities greater than 10 per mile.

Table 15. Expanded coho salmon adults per mile based on GRTS surveys in 2011.

GRTS Survey Basin	mean	sd	2.50%	50%	97.50%
Grays	22.8	90.0	0.0	0.0	210.1
Elochoman	26.7	76.8	0.0	5.8	172.4
L Cowlitz	8.7	16.5	0.0	3.3	50.9
Coweeman	37.6	49.1	0.0	21.4	168.6
Toutle Tribs	5.1	26.7	0.0	0.0	39.5
Green	4.8	10.4	0.0	0.0	31.1
SF Toutle	12.5	31.2	0.0	3.0	82.6
Kalama	11.0	56.1	0.0	0.0	79.5
NF Lewis	17.9	39.9	0.0	5.6	104.8
Cedar	16.1	21.5	0.0	9.2	72.6
EF Lewis	12.9	18.2	0.0	7.1	60.3
Salmon	13.4	33.5	0.0	3.3	86.3
Washougal	14.7	32.0	0.0	4.2	91.3
L Gorge	9.3	23.2	0.0	2.0	65.3

The adult densities were then expanded by the proportion of the sample frame surveyed to estimate the adult abundance (Table 16). Adult coho salmon abundance estimates followed variably skewed right-tailed distributions; the mean adult coho salmon abundance estimated from redd surveys ranged from a low of 216 for the tributaries of the mainstem Toutle population to a high of 4,587 adults for the Grays population.

Table 16. The estimated adult coho salmon escapement based on redd surveys in 2011.

GRTS Survey Basin	mean	sd	2.50%	50%	97.50%
Grays	4587	3506	1424	3709	12880
Elochoman	2364	2343	673	1765	7555
L Cowlitz	3879	2362	1417	3286	9855
Coweeman	2594	822	1421	2457	4545
Toutle Tribs	216	364	21	133	855
Green	237	165	76	195	652
SF Toutle	704	609	189	551	2126
Kalama	364	968	33	181	1672
NF Lewis	855	621	248	698	2395
Cedar	633	216	331	593	1166
EF Lewis	1064	515	428	953	2375
Salmon	655	612	153	509	2010
Washougal	518	338	179	436	1348
L Gorge	1646	1588	355	1250	5250

Based on carcass surveys we estimated the percentage of marked (clipped adipose fin or CWT) and unmarked adult coho salmon. The four highest marked populations with hatcheries are the Grays, Elochoman, Toutle, and Kalama rivers which had mean estimates of 97%, 57%, 50%, and 75% marked carcasses, respectively (Table 17). Other populations had lower mark rates including the Lower Cowlitz, Coweeman, Green, SF Toutle, NF Lewis, Cedar, EF Lewis, Salmon, Washougal, and the Lower Gorge, which had mean estimates of 96%, 95%, 87%, 81%, 77%, 99%, 97%, 96%, 93%, and 88% unmarked fish, respectively (Table 18).

Table 17. The estimated percentage of adult coho salmon that are marked (adipose fin clipped or CWT) based on carcass recoveries during GRTS surveys in 2011.

GRTS Survey Basin	mean	sd	2.50%	50%	97.50%
Grays	97.3%	1.7%	93.2%	97.7%	99.6%
Elochoman	56.9%	10.4%	36.1%	57.1%	76.5%
L. Cowlitz	4.5%	6.0%	0.0%	2.2%	21.5%
Coweeman	5.0%	2.6%	1.2%	4.6%	11.0%
Toutle Tribs.	50.0%	25.1%	6.0%	50.2%	93.9%
Green	12.7%	15.0%	0.0%	6.8%	54.4%
SF Toutle	18.8%	13.0%	1.7%	16.2%	50.3%
Kalama	75.0%	25.0%	14.6%	83.7%	100.0%
NF Lewis	23.3%	7.9%	9.8%	22.6%	40.5%
Cedar	1.3%	1.9%	0.0%	0.6%	6.6%
EF Lewis	3.1%	4.2%	0.0%	1.5%	15.3%
Salmon	4.2%	5.6%	0.0%	2.0%	20.0%
Washougal	7.1%	9.2%	0.0%	3.5%	33.1%
L. Gorge	12.4%	14.6%	0.0%	6.7%	52.9%

Table 18. The estimated percentage of adult coho salmon that are not marked (no adipose fin clip or CWT) based on carcass recoveries during GRTS surveys in 2011.

GRTS Survey Basin	mean	sd	2.50%	50%	97.50%
Grays	2.7%	1.7%	0.4%	2.4%	6.8%
Elochoman	43.1%	10.4%	23.5%	42.9%	63.9%
L. Cowlitz	95.5%	6.0%	78.5%	97.8%	100.0%
Coweeman	95.0%	2.6%	89.0%	95.4%	98.8%
Toutle Tribs.	50.0%	25.1%	6.1%	49.8%	94.0%
Green	87.3%	15.0%	45.6%	93.2%	100.0%
SF Toutle	81.2%	13.0%	49.7%	83.8%	98.3%
Kalama	25.0%	25.0%	0.0%	16.3%	85.4%
NF Lewis	76.7%	7.9%	59.5%	77.4%	90.2%
Cedar	98.7%	1.9%	93.4%	99.4%	100.0%
EF Lewis	96.9%	4.2%	84.7%	98.6%	100.0%
Salmon	95.8%	5.6%	80.0%	98.0%	100.0%
Washougal	92.9%	9.2%	66.9%	96.6%	100.0%
L. Gorge	87.6%	14.6%	47.1%	93.3%	100.0%

There was a low percentage of marked fish in the NF Lewis and Cedar Creek, but these basins are heavily supplemented with hatchery fry releases from intensive use of remote site incubators (RSI) (Table 19). Since these hatchery releases are not externally marked, our estimates of unmarked fish are biased high in these basins. In addition, it should be noted that we reported on marked fish, which include hatchery fish that are adipose fin-clipped or CWT only, such as the NF Lewis River hatchery DIT group. There are also a small percentage of hatchery fish that are released unmarked due to machine or human error during marking. Therefore estimates of the true proportion of hatchery fish would increase slightly if adjusted for the percentage of unmarked hatchery fish.

Table 19. Off station hatchery releases (primarily from remote site incubators) of coho salmon expected to return in 2011.

Brood Yr	Month	River	Stage	UnMark	MassMark	Totals
2008	Mar	Salmon Cr.	Fry	133,455	0	133,455
2008	Jan-Feb	Lewis	Fry	860,000	0	860,000
2008	Mar	Cowlitz	Fry	227,900	0	227,900
2008	Jun	Cowlitz	Fingerling	1,000	0	1,000
						1,222,355

Estimates of marked and unmarked adult coho salmon abundance for GRTS areas followed variably-skewed distributions and were generally right-tailed. The mean estimate of marked adult abundance ranged from nine in Cedar Creek to 4,464 in the Grays (Table 20). As mentioned above the Grays estimate is likely influenced by a single survey reach located near the hatchery. Basins releasing hatchery fish had some of the highest number of marked fish especially the Grays and Elochoman. Mean estimates of unmarked adult abundance ranged from a low of 93 for the Kalama population to a high of 3,703 for the Lower Cowlitz population (Table 21). In the Cowlitz, Lewis, and Salmon Creek populations a total of 1,222,355 fry were released primarily from RSIs (Table 19). Since these hatchery fish are not externally marked, they are likely included in some of the unmarked samples in these populations and possibly other populations. At this time there is no straightforward method to determine the percentage of unmarked hatchery-origin adults as a result of RSI releases in these populations.

Table 20. Estimated adult marked coho salmon abundance from 2011 GRTS surveys.

GRTS Survey Basin	mean	sd	2.50%	50%	97.50%
Grays	4464	3404	1393	3602	12550
Elochoman	1344	1415	340	992	4367
L. Cowlitz	176	303	0	72	946
Coweeman	129	82	27	111	336
Toutle Tribs.	109	234	4	59	493
Green	30	48	0	13	158
SF Toutle	133	164	7	86	545
Kalama	271	704	14	130	1284
NF Lewis	199	165	43	155	612
Cedar	9	13	0	4	44
EF Lewis	33	53	0	14	179
Salmon	28	52	0	10	159
Washougal	37	60	0	15	197
L. Gorge	204	370	0	80	1129

*The sum of abundance by marked status may not equal the abundance estimate due to rounding.

Table 21. Estimated adult unmarked coho salmon abundance from 2011 GRTS surveys.

GRTS Survey Basin	mean	sd	2.50%	50%	97.50%
Grays	123	146	13	87	442
Elochoman	1020	1050	240	750	3397
L. Cowlitz	3703	2267	1326	3146	9445
Coweeman	2465	784	1347	2333	4337
Toutle Tribs.	107	199	4	59	489
Green	207	151	57	170	580
SF Toutle	571	507	144	441	1780
Kalama	93	445	0	27	529
NF Lewis	656	484	186	535	1865
Cedar	625	213	326	585	1151
EF Lewis	1031	501	412	923	2311
Salmon	628	591	145	487	1929
Washougal	481	320	161	404	1261
L. Gorge	1442	1443	282	1087	4736

*The sum of abundance by marked status may not equal the abundance estimate due to rounding.

The percentage of GRTS reaches having at least one redd ranged from 8% in the NF Lewis tributaries to 92% for the Coweeman population (Table 22). Some populations with high occupancy rates included the Elochoman, Green, and Kalama, which also have intensive hatchery programs; however, some populations with low hatchery influence, as measured by the percentage of marked fish, also had high occupancy rates including the Cowlitz, Coweeman, Cedar, and EF Lewis. We calculated the probability that 80% of the reaches were occupied based on observed redd counts, which is the NOAA occupancy rate standard (Table 22). The Coweeman and EF Lewis were the only populations for which there was a greater than 75% probability that 80% of reaches were occupied (Table 22). For most populations the probability that the occupancy rate was greater than 80% was near 0%, indicating that most populations were below the NOAA guideline. It should be noted that we are reporting on the observed occupancy rate based on redds. This is less than the true occupancy rate because our redd detection rate was about 65%, assuming 1 redd per female, and males and jacks were not included in the occupancy rate.

Table 22. Occupancy rate or the percentage of GRTS reaches that were occupied (had at least one redd) and the probability that the occupancy rate was above 80% (last column).

GRTS Survey Basin	**mean**	**sd**	**2.50%**	**50%**	**97.50%**	***p*-value**
Grays	26.3%	9.3%	10.4%	25.6%	46.5%	0.00
Elochoman	61.5%	10.1%	41.0%	61.9%	80.0%	0.02
L. Cowlitz	63.0%	9.9%	42.8%	63.4%	81.2%	0.04
Coweeman	92.2%	6.0%	77.0%	93.6%	99.4%	0.95
Toutle Tribs.	16.8%	11.8%	1.4%	14.4%	46.1%	0.00
Green	58.3%	11.4%	35.2%	58.7%	79.3%	0.02
SF Toutle	49.9%	13.3%	24.2%	49.9%	75.4%	0.01
Kalama	50.1%	20.3%	12.6%	50.2%	87.6%	0.08
NF Lewis	8.3%	10.4%	0.0%	4.2%	37.7%	0.00
Cedar	66.1%	9.3%	47.0%	66.5%	83.0%	0.06
EF Lewis	86.4%	9.9%	61.7%	88.6%	98.9%	0.77
Salmon	50.2%	17.6%	16.8%	50.4%	83.3%	0.04
Washougal	27.9%	14.1%	5.7%	26.3%	58.9%	0.00
L. Gorge	50.1%	15.8%	19.8%	50.2%	79.9%	0.02

We also estimated the density of unmarked females (Table 23). The mean density ranged from 0.02 to 18.1 females/mile in the Grays and Coweeman, respectively. Using a significance level of 0.05, there is a low probability that the Lower Cowlitz, Toutle Tribs, Green, and Kalama have unmarked seeding levels that exceed the mode from Bradford's analysis. As discussed earlier, the mean unmarked females densities in the NF Lewis, Cedar, and Lower Cowlitz are influenced by an unknown number of unmarked hatchery fish.

Table 23. The estimated number of unmarked coho salmon females/mile based on GRTS surveys in 2011. The *p*-value is the probability the observed wild female density is greater than the mode of the full habitat seeding density based on Bradford et al. 2000.

GRTS Survey Basin	**mean**	**sd**	**2.50%**	**50%**	**97.50%**	***p*-value**
Grays	0.2	1.1	0.0	0.0	2.1	0.13
Elochoman	2.7	5.5	0.0	0.7	17.3	0.12
L. Cowlitz	3.0	5.2	0.0	1.4	16.8	0.04
Coweeman	18.1	23.4	0.0	10.4	80.9	0.41
Toutle Tribs.	1.1	5.4	0.0	0.0	8.9	0.03
Green	1.8	3.7	0.0	0.0	11.5	0.02
SF Toutle	3.4	7.6	0.0	1.0	21.8	0.07
Kalama	0.8	4.5	0.0	0.0	6.8	0.05
NF Lewis	9.9	22.2	0.0	3.1	59.0	0.24
Cedar	6.6	8.5	0.0	3.9	29.2	0.12
EF Lewis	7.3	10.1	0.0	4.1	34.0	0.15
Salmon	5.6	12.4	0.0	1.5	35.7	0.11
Washougal	8.3	17.0	0.0	2.5	51.2	0.17
L. Gorge	4.0	9.4	0.0	1.0	26.6	0.08

Coho Salmon Escapement Estimates

Estimates for populations as designated by the NOAA Technical Recovery Team (TRT) were calculated by summing redd-based, mark-recapture, and trap and haul based estimates as appropriate. The mean estimates ranged from 364 to 20,279 for the Kalama and Upper Cispus/Cowlitz populations, respectively (Table 24). For the Upper Cispus/Cowlitz and Tilton populations the CVs were less than the NOAA guideline of 15% (Crawford and Rumsey 2011). Precise estimates were obtained for these populations because of the trap and haul program. In contrast, the CV for all redd based estimates did not meet the standard and had CV ranging from 32% to 266% on the Coweeman and Kalama, respectively. The NF Lewis and MAG estimates were primarily mark-recapture estimates and their CVs were 16% and 21%, respectively.

Table 24. Adult coho salmon population estimates by NOAA TRT population. The Upper Gorge populations were not monitored in 2011 and there were no GRTS surveys for the mainstem Toutle/mainstem NF Toutle or mainstem Lower Cowlitz populations.

Population	**mean**	**sd**	**2.50%**	**50%**	**97.50%**	**CV**
Grays	4587	3506	1424	3709	12880	76%
Elochoman	2364	2343	673	1765	7555	99%
MAG	1019	210	685	993	1506	21%
Cowlitz	3879	2362	1417	3286	9855	61%
Coweeman	2594	822	1421	2457	4545	32%
Green	517	408	201	428	1331	79%
SF Toutle	704	609	189	551	2126	86%
U Cispus/Cowlitz	20279	135	20020	20280	20540	1%
Tilton	6895	132	6637	6895	7152	2%
Kalama	364	968	33	181	1672	266%
NF Lewis	6175	1009	4726	6019	8514	16%
EF Lewis	1064	515	428	953	2375	48%
Salmon	655	612	153	509	2010	93%
Washougal	561	339	222	480	1391	60%
L Gorge	1646	1588	355	1250	5250	97%

*The sum of abundance by marked status may not equal the abundance estimate due to rounding.

As expected the marked population estimates were highest in basins with hatcheries (Table 20; Appendix 2). The population with the greatest number of marked fish was in the Upper Cispus/Cowlitz population where hatchery fish are released as part of a program to re-establish natural production above Cowlitz Falls Dam. This population estimate of 12,402 adults accounted for slightly less than 50% of the total marked population (Table 25). The largest producers of unmarked adults include the Upper Cispus/Cowlitz (7,877), Lower Cowlitz (3,703), NF Lewis (2,616), and Coweeman (2,465) populations (Table 26). The CVs for redd based estimates exceeded the NOAA guideline but trap & haul and mark-recapture estimates meet or were close to the NOAA guideline.

Table 25. Marked adult coho salmon population estimates by NOAA TRT population. Note: the Upper Gorge population was not surveyed in 2011 and there were no surveys for the mainstem NF Lewis, mainstem Toutle/mainstem NF Toutle, or mainstem Lower Cowlitz populations.

Population	**mean**	**sd**	**2.50%**	**50%**	**97.50%**	**CV**
Grays	4464	3404	1393	3602	12550	76%
Elochoman	1344	1415	340	992	4367	105%
MAG	212	60	119	205	353	28%
Cowlitz	176	303	0	72	946	172%
Coweeman	129	82	27	111	336	63%
Green	139	240	11	89	554	172%
SF Toutle	133	164	7	86	545	123%
U Cispus/Cowlitz	12402	135	12140	12400	12660	1%
Tilton	4807	132	4549	4807	5064	3%
Kalama	271	704	14	130	1284	259%
NF Lewis	3559	619	2641	3461	5038	17%
EF Lewis	33	53	0	14	179	159%
Salmon	28	52	0	10	159	189%
Washougal	40	63	0	17	210	159%
L. Gorge	204	370	0	80	1129	182%

*The sum of abundance by marked status may not equal the abundance estimate due to rounding.

Table 26. Unmarked adult coho salmon population estimates by NOAA TRT population. Note the Gorge populations were not surveyed in 2011 and there were no surveys for the mainstem Toutle/mainstem NF Toutle and mainstem Lower Cowlitz populations. An unknown number of NF Lewis and L. Cowlitz adults are from RSI releases.

Population	**mean**	**sd**	**2.50%**	**50%**	**97.50%**	**CV**
Grays	123	146	13	87	442	119%
Elochoman	1020	1050	240	750	3397	103%
MAG	807	171	535	784	1206	21%
Cowlitz	3703	2267	1326	3146	9445	61%
Coweeman	2465	784	1347	2333	4337	32%
Green	378	255	153	318	950	67%
SF Toutle	571	507	144	441	1780	89%
U Cispus/Cowlitz	7877					0%
Tilton	2088					0%
Kalama	93	445	0	27	529	480%
NF Lewis	2616	529	1982	2511	3882	20%
EF Lewis	1031	501	412	923	2311	49%
Salmon	628	591	145	487	1929	94%
Washougal	521	321	197	445	1305	62%
L. Gorge	1442	1443	282	1087	4736	100%

*The sum of abundance by marked status may not equal the abundance estimate due to rounding.

Applying the estimate of the percentage of males that were jacks from Table 7 leads to an estimate of jacks by population (Table 27). Jack estimates ranged from 32 to 666 fish in the Washougal and Upper Cispus/Cowlitz, respectively. Except for trap and haul programs the jack estimates were imprecise due the low sampling rate of jacks and the few sampling locations (a total of four locations) for jacks.

Table 27. Jack coho salmon population estimates by NOAA TRT population. Note the Upper Gorge population was not surveyed in 2011 and there were no surveys for the mainstem NF Lewis, mainstem Toutle/mainstem NF Toutle, or mainstem Lower Cowlitz populations.

Population	mean	sd	2.50%	50%	97.50%	CV
Grays	454	560	49	307	1770	123%
Elochoman	285	452	26	170	1245	158%
MAG	65	45	13	56	177	69%
Cowlitz	390	446	43	268	1460	114%
Coweeman	204	160	37	168	603	78%
Green	55	66	18	40	175	120%
SF Toutle	74	112	7	46	317	151%
U Cispus/Cowlitz	666	22	623	666	709	3%
Tilton	475	10	455	475	495	2%
Kalama	40	167	1	14	215	418%
NF Lewis	90	78	13	72	289	86%
EF Lewis	443	297	109	372	1211	67%
Salmon	368	426	62	264	1278	116%
Washougal	32	40	2	21	130	125%
L. Gorge	134	311	7	78	596	231%

The LCR ESU estimates for WA populations are found in Table 28. We estimated a mean total of 53,305 adults: 3,776 jacks, 27,941 marked adults, and 25,364 unmarked adults. The CV for marked adults met the NOAA standard and the CV for the total adults was 13% compared to the 15% NOAA standard. The CV for unmarked adults was 17%, which is only 2% more than the NOAA standard. It should be noted that no adult population estimates were made for the mainstem Toutle/mainstem NF Toutle below the SRS, mainstem Lower Cowlitz, or Upper Gorge populations. Without these, the reported total ESU population estimate should be considered a minimum. We believe these missed areas do not represent substantial production due to the observed level of coho salmon spawning during Chinook salmon surveys there.

Table 28. Washington's LCR ESU coho salmon population estimates for 2011. Note Salmon Creek and the Upper Gorge populations were not surveyed in 2011 and there were no surveys for the mainstem NF Lewis, mainstem Toutle/mainstem NF Toutle, or mainstem Lower Cowlitz populations.

Population	mean	sd	2.50%	50%	97.50%	CV
Marked Adults	27941	4132	23450	27045	37880	15%
Unmarked Adults	25364	4193	19740	24610	35360	17%
Total Adults	53305	7013	44130	51980	70140	13%
Total Jacks	3776	1647	2047	3415	7828	44%

*The sum of abundance by marked status may not equal the abundance estimate due to rounding.

The proportions of unmarked and marked adult coho salmon by population are found in Table 29. As described above, basins with hatcheries tended to have higher proportions of marked fish while basins without hatcheries tend to have higher proportions of unmarked fish. The precision estimates generally exceeded the 95% CI half width of 5% guideline except for populations with traps (Rawding and Rodgers 2013).

Table 29. Estimates of the unmarked and marked adult coho salmon proportion by NOAA TRT population. An unknown number of NF Lewis and Cowlitz unmarked fish are included in the proportions are from RSI releases.

	Proportion Unmarked			Proportion Marked		
Population	mean	sd	95%CI-1/2w	mean	sd	95%CI-1/2w
Grays	2.7%	1.7%	6.4%	97.3%	1.7%	6.4%
Elochoman	43.1%	10.4%	40.4%	56.9%	10.4%	40.4%
MAG	79.2%	3.9%	15.1%	20.8%	3.9%	15.1%
Cowlitz	95.5%	6.0%	21.5%	4.5%	6.0%	21.5%
Coweeman	95.0%	2.6%	9.8%	5.0%	2.6%	9.8%
Green	76.0%	14.8%	55.3%	24.0%	14.8%	55.3%
SF Toutle	81.2%	13.0%	48.6%	18.8%	13.0%	48.6%
U Cispus/Cowlitz	38.8%	0.3%	1.0%	61.2%	0.3%	1.0%
Tilton	30.3%	0.6%	2.3%	69.7%	0.6%	2.3%
Kalama	25.0%	25.0%	85.3%	75.0%	25.0%	85.3%
NF Lewis	42.3%	3.8%	15.0%	57.7%	3.8%	15.0%
EF Lewis	96.9%	4.2%	15.3%	3.1%	4.2%	15.3%
Salmon	95.8%	5.6%	20.0%	4.2%	5.6%	20.0%
Washougal	92.9%	9.2%	33.1%	7.1%	9.2%	33.1%
L. Gorge	87.6%	14.6%	52.8%	12.4%	14.6%	52.8%

CWT Program

The CWT recoveries of coho salmon in the fall of 2011 were uploaded to the RMIS system during 2012-13. The uploaded data includes: 1) freshwater sport fishery recoveries and hatchery facility coho recoveries uploaded in December 2012 and coho spawning ground recoveries uploaded in March 2013. RMIS is a coastwide database that stores CWT tag and release data along with recovery and sampling data.

CWT recoveries from carcass recoveries found during stream surveys are presented in Table 30. These do not include hatchery recoveries, thus the recoveries and percent of out of basin recoveries only apply to coho salmon that spawned in stream. There were no recoveries in the Coweeman, Green, SF Toutle, EF Lewis, Salmon, and Washougal populations. The recoveries are consistent with the low proportion of marked fish sampled in these populations (Table 15). A total of six or less CWT recoveries occurred in the Elochoman, MAG, Lower Cowlitz, and Kalama populations. We recovered 244 CWTs mostly in the Grays and NF Lewis. Most hatchery fish were recovered in the basin from which they were released, with the exception of coho salmon acclimated at Cascade Hatchery in Oregon above Bonneville Dam and transferred to the upper Columbia to complete juvenile rearing. Many of these fish were recovered in the Lower Gorge population. CWT data for fisheries and carcass recoveries are presented in annual reports for missing production groups (e.g. Harlan 2013).

Table 30. Unexpanded CWT recoveries by population and hatchery for adult coho salmon in 2011. Note there were no jacks with CWT recovered. Gray boxes indicate CWT was recovered in the same basin as released. The (W) indicates releases were from wild smolts and (H) indicates hatchery smolts.

		Release Basin							
Recovery Basin	**Population**	Grays H	MAG (W)	Cowlitz H	Kalama H	Lewis H	Leavenworth H	Winthrop H	**Total**
	Grays	71							71
	Elochoman						1		1
	MAG	1	3						4
	Lower Cowlitz			1					1
	Kalama				6				6
	NF Lewis					145	1		146
	Lower Gorge						14	1	15
	Total	**72**	**3**	**1**	**6**	**145**	**16**	**1**	**244**
	% Out of Basin	1%	0%	0%	0%	0%	NA	0%	

Discussion

One of the most controversial aspects of the Bayesian approach is the specification of priors. We used vague priors for this analysis with the intent that the posterior distribution be dominated by the observed data. When this occurs the results obtained from Bayesian and maximum likelihood methods yield similar results (Kery 2010). We used vague priors because this is only the second year of study on LCR coho and because it was unclear if other coho salmon information was applicable to the LCR (see below) given differences in climate, habitat, and experience of surveyors in conducting coho salmon surveys. The Bayesian framework provides an approach to account for this type of information in future years.

We used census counts and mark-recapture estimates to estimate coho salmon population abundance where feasible. These methods are preferred because all the data needed to make an abundance estimate is collected annually. However, this left a large area for which alternate methods had to be used to estimate abundance. Other methods such as AUC and redd surveys require assumptions about observer efficiency, survey life, and redd identification that may or may not be applicable to data collected from other basins or from other years (Irvine et al. 1992). We considered the use of AUC estimates, but survey life (e.g., the duration of time that live coho salmon remained in the survey area) and observer efficiency (of live coho adults) for LCR coho salmon are unknown. Suring et al. (2006) assumed the estimates for the Oregon coast are applicable for the Lower Columbia populations. However, Jacobs et al. (2002) noted that for some years the mark-recapture estimates for the Smith River, an Oregon coastal stream, were higher than the AUC estimates for the same area. If the Smith River mark-recapture estimates are correct, one possible explanation for this discrepancy is that the standard Oregon coastal estimates of survey life and/or observer efficiency are biased high for those years on the Smith River. Therefore, application of the standard Oregon coastal observer efficiency and survey life estimates may lead to underestimates of Washington LCR coho salmon abundance.

In addition, a review of the literature by Perrin and Irvine (1990) demonstrated high variability in survey life for coho salmon. Gallagher et al. (2010) estimates of survey life for coho salmon were approximately two times or greater than those used by ODFW. However, Gallagher et al. 2010 estimates include residence time from entry, while ODFW estimates (~11 days) focus more on residence time in spawning tributaries (Willis 1954). Lestelle and Weller (2002) used an average residence time of 15 days. Estimates of observer efficiency for coho salmon averaged 75.5% for Oregon coastal streams (Solazzi 1984), 22% (range 20-24%) for a Northern California stream (Szerlong and Rundio 2007), 65% (range 22-100%) for an Alaskan stream (Hetrick and Nemeth 2003), and 86.5% for a coho stream on Vancouver Island (Holt 2002). Gallagher et al. (2010) indicated that AUC estimates were very sensitive to survey life and observer efficiency estimates; consequently concluding they were less reliable than redd counts. Lestelle and Weller (2002) believed that AUC estimates under estimated escapement at low density because it is difficult to observe fish when their abundance is low. However at higher escapement they believed redd counts are likely to underestimate abundance due to superimposition and the difficulty in identifying individual redds.

After our AUC review we were uncomfortable in applying this method without LCR-specific observer efficiency and residence time estimates over varying spawning escapements, so we opted to use redd-based estimates because we could obtain a specific annual LCR estimate of redds per female. While redd surveys are widely used (WDFW 2011) and can provide unbiased estimates, they have their own set of challenges (Muhlfeld et al. 2006, Dunham et al. 2001). The key assumptions for redd surveys are: 1) the spatial spawning distribution is known and either sampled completely or expanded for in an unbiased manner as part of the sampling design, 2) surveys cover the entire temporal spawning period, 3) all redds are consistently identified with the same protocols, and 4) the variability in redds per adult or female is measured annually for that population or if derived from other population or years is similar to the population where redd surveys are conducted.

The first two assumptions indicate that redd surveys must be spatially or temporally complete otherwise redd abundance will be under estimated. We believe that we had a good spatial survey design based on using GRTS. However our temporal coverage was more problematic and there were missed scheduled surveys, particularly due to high and turbid water conditions. Training was provided to all staff to help with consistent redd identification (Crisp and Carling 1989) and to differentiate coho, chum, and Chinook salmon, and steelhead redds, which were all visible during coho salmon spawning time. We used physical differences in substrate size and location within the basin to help classify redds from different species (e.g., Gallagher and Gallagher 2005). In addition, we used two locations to estimate redds per female and these locations were geographically distant from each other, had different habitat, and survey conditions. A key assumption was that the number of redds constructed by females in these basins and the observer efficiency in identifying these redds together were representative of redds per female in all other redd survey reaches in the ESU. Provided this assumption was met, our design did address the key assumptions needed for an unbiased redd survey.

Curbois et al. (2008) noted that the 95% CI based on normally distributed data and large sample theory was not adequate to estimate redd abundance. This resulted from the clumpiness of the redd data and many reach counts of zero, particularly when population sizes were low. To address this problem, we used the Negative Binomial distribution, which is commonly used for over dispersed count data (Hilborn and Mangel 1997). Based on Bayesian *p*-values, the negative binomial distribution adequately fit the data. However, the precision of our estimates was worse than we anticipated. This occurred because the data were over dispersed resulting in large variances, which was consistent with our observations. Another factor that affected precision was the reach sample sizes, which were fewer than expected due to limited resources. Finally, our escapement estimates include most sources of uncertainty. Our redd based estimates included spatial uncertainty as with the Oregon coast surveys, but also include uncertainty in redds per female, adult sex ratio, and jack to adult male ratio. The trap and haul estimates included uncertainty associated with harvest of marked fish.

We explored a number of approaches to see if our estimates of adult coho abundance seemed reasonable. One approach we used was to compare our estimate of redds per female with other studies. For example, Gallagher et al. (2010) found that adult coho salmon redd-based abundance estimates were positively correlated with, and similar to, mark-recapture estimates in northern California streams. However, they noted that the coho salmon spawner to redd ratio varied annually and with the exception of 2006, the average adults per redd was 2.32; assuming a 1:1 sex ratio this would equate to 1.16 females per redd, which equates to an average of 0.86 redds per female. However, their annual point estimates for redds per female ranged from 0.55 to 1.67. In 2006, Gallagher et al. (2010) observed ~0.20 redds per female for each of three surveyed populations because of challenging observation conditions, which likely decreased redd detectability and life. Lestelle and Weller (2002) estimated coho salmon escapement in two Washington coastal streams between 1996 and 2000. They judged four mark-recapture experiments to be successful and in these years the redd based estimates were positively biased by ~15% in three of the four years. In one year, the redd based estimate was negatively biased by ~7% compared to the mark-recapture estimate. Assuming equal sex ratio the redds per female from Lestelle and Weller (2002) was approximately 0.87, which is similar to the average estimate from Gallagher et al. (2010).

Our estimate was 0.65 redds per female (95% CI 0.43 to 0.92), which is within the range reported in the California and Washington studies. However, if our estimate of redds per female is biased low and the true estimate is closer to 0.87 redds per female from the other Washington study (Lestelle and Weller 2002), or 1.0 as found for Chinook salmon (Murdoch et al. 2009), the true population estimates would be less than those reported.

Chinook salmon carcass recoveries may be biased by sex, age, and origin (Zhou 20012, Parken et al. 2003, and Murdoch et al. 2010). To minimize possible size bias in carcass recoveries for coho salmon, we estimated adult and jack abundance separately and used only trap data to estimate the proportion of males that were jacks. For coho salmon, carcass recoveries may be biased because females tend to guard the nest after spawning (Sandercock 1991). If we assume sex ratio for coho salmon should be approximately 50% females (Dittman et al. 1998), our hierarchical estimate for adults from carcass surveys (49% females) may indicate a bias that males are recovered at a higher rate. If this is the case, our redd-based population estimates may be slightly biased high; however some populations of coho salmon are known to maintain female-biased sex ratios (Holtby and Healey 1990), in which case our estimates may remain unbiased. Most coho salmon spawning carcass recoveries occurred in small streams and were based on weekly surveys using a spatially balanced design. Both the size of streams and the representative sampling design should minimize carcass recovery bias by origin and location within the basin.

We provided direct estimates of marked and unmarked coho salmon adults as surrogates for hatchery and natural origin spawners. If all hatchery origin juveniles were adipose fin clipped and/or CWT, then we could make the assumption that all marked fish were hatchery origin fish and all unmarked fish were wild origin fish. However, examining review of the actual hatchery marking data revealed that ~ 99.8% of the hatchery fish were mass marked and/or CWT. Therefore our estimates of unmarked and marked fish as surrogates for hatchery and natural origin spawners are slightly biased. In addition, we found no reliable method for correction for RSI and unfed fry releases, which would likely decrease the number of natural origin spawners reported in the NF Lewis and Lower Cowlitz populations.

We used two metrics to compare LCR coho salmon populations to other populations, including occupancy rate and the seeding level based on females spawners (Crawford and Rumsey 2011 and Bradford et al. 2000). The 80% occupancy guideline was based on coho salmon observations in small Oregon coastal streams. Since our sample frame included large rivers, areas less preferred by coho salmon for spawning (Sandercock 1991), the comparison is not equitable; we would expect lower occupancy rates when sampling over all possible spawning distribution as compared to a subset of preferred spawning sites, which is what we observed. The populations analyzed by Bradford et al. (2000) consisted of many low gradient productive habitats for coho salmon; thus it is expected that the seeding level (female spawners per mile) would be higher in these areas than in less productive habitat such as the higher gradient habitat present in most LCR basins. Both of these metrics should be further reviewed as they are currently applied to the LCR. For example, given sufficient monitoring sites, we could use the methods of Bradford et al. (2000) to develop LCR specific estimates of seeding.

The last NOAA status review suggested that all coho salmon populations in Washington's portion of the Lower Columbia ESU were at high risk for extinction because limited surveys suggested that the ESU was comprised of greater than 90% hatchery origin spawners. However, there was great uncertainty in the status due to the lack of comprehensive coho salmon surveys (NOAA 2011). In this report we estimate that ~25,000 unmarked adult coho salmon spawned in the WA portion of the LCR ESU in 2011. The actual estimate is likely higher since we did not include the mainstem Cowlitz, mainstem Toutle/lower NF Toutle rivers, and the Upper Gorge populations in our estimates. It is likely a small percentage (0.2%) of the unmarked population is comprised of unmarked hatchery origin fish. The total proportion of pHOS estimate, not corrected for missing mass marks, was 52%. If we subtract the hatchery origin adults released to spawn in the upper Cowlitz and Tilton rivers to maintain those populations until better juvenile passage exists, the total pHOS estimate decreases to 20% for the remainder of the Washington portion of the ESU. In contrast to the status review, we found only the Kalama population had greater than 90% hatchery origin spawners. Excluding the NF Lewis and Salmon Creek populations, due to the release of unmarked hatchery origin fish, a total of nine WA populations had proportions of natural origin spawners (pNOS) greater than 75%, with the Cowlitz, Coweeman, and EF Lewis populations having pNOS greater than or equal to 95%.

Recommendations

This was the second year WDFW conducted coho salmon spawning ground surveys. This was an enormous undertaking and it was met with considerable success, however many improvements can be made to reduce possible bias, improve precision, and improve repeatability of our study and results. Our recommendations for improvement include:

1) Develop a standardized manual of protocols for conducting coho salmon spawning ground surveys. This should at a minimum cover species and redd identification, a detailed description of the methods used to conduct surveys and how to record information, methods for data storage including the frequency of downloading information, and the methods used to establish and modify survey reaches based on GRTS points.
2) One key assumption is that the redd identification methods in Duncan and Abernathy creeks are the same as those used in all other basins. While difficult to test, supervisors and crew leaders should schedule periodic surveys following surveyors to ensure standard techniques described in the manual are being implemented during surveys. Standardized methods and proper training can minimize differences between surveyors (Willis 1964).
3) It is likely that early-timed hatchery coho salmon that spawn in the Kalama and possibly the Lewis rivers are under-represented by redd counts since these fish may be spawning in the same areas and at the same times as Chinook salmon. The coho sampling design should be refined to address this issue.
4) Redd locations are recorded electronically. However, the remainder of the data is transcribed on field datasheets then entered into electronic databases after the surveys are completed. WDFW should pursue the use of technology to electronically record data in the field to save time and reduce error generation during data entry. These field data entry and storage devices must be rugged and waterproof to minimize loss of data in difficult survey conditions.
5) Currently data for this analysis is obtained from different ARC-GIS databases, trapping spreadsheets, the WDFWs corporate spawning ground survey database, and a regional age and scales database. We have consolidated databases and are moving toward unified corporate databases, which will be available for the 2012 analysis (WDFW 2011b).
6) The current coho survey design used GRTS location draws developed for other purposes. As a result, there were a limited number of data points available to develop the coho salmon spawning ground survey design. A denser GRTS draw for the LCR area would eliminate this problem and should be pursued.
7) We recommend that the Upper Gorge populations be monitored for redds and other methods be explored to develop estimates for the mainstem of Lower Cowlitz River.
8) The precision of the redd-based estimates are low due to sampling a low fraction of the spawning area, over dispersed data, and the sampling design. To address these concerns, we recommend increasing the number of samples per population and considering stratification of sampling effort corresponding to higher and lower density coho salmon spawning areas. Stratification may lead to more precise estimates if a denser GRTS draw is available and homogeneous strata can be developed (Liermann et al. 2015).

9) Since the precision for the mark recapture estimates were low, the resulting redds per female estimate had low precision. Besides the clumpiness in our redd densities, the redds per female estimate is the largest source of error in our abundance estimates. We recommend efforts to improve trap operations at these sites to mark more fish to improve estimates or consider alternate approaches for estimating escapement such as those presented in Labelle (1994) or modification of Korman et al. (2002, 2007).
10) Over 860,000 unmarked hatchery origin fry releases occurred in the Lewis River and over 228,000 unmarked fry releases occurred in the Cowlitz for expected 2011 returns. Since fry are too small to be mass marked prior to release, we cannot use the mass mark to identify hatchery origin fish. Analysis should be undertaken to determine the extent to which these plants are contributing to adult returns and whether the receiving waters they are planted in are being fully seeded by natural origin spawners (?). If these programs are to be continued, we recommend funding of otolith thermal marking and recovery to identify hatchery origin adults originating from RSIs or fry releases. Rawding and Groesbeck (2006) used this method in Cedar Creek to estimate the proportion of hatchery and wild fish in the coho salmon smolt outmigration. These methods could be extended to adults. Alternatively, parental based tagging using genetic markers could be used (Anderson and Garza 2006).
11) Rawding and Rodgers (2013) suggested that efficiencies may be obtained by the WDFW and ODFW working together on salmon and steelhead escapement estimates in the LCR ESU. Since both agencies are estimating coho salmon abundance, we suggest annual workshops/coordination meetings to review and learn about different study designs, protocols, database management, and statistical analysis to explore these efficiencies would be beneficial.
12) The original coho sampling frame for redd surveys was developed based on a few years of adult and juvenile survey data. There are three additional years of adult and juvenile data now available. The sample frame should be updated based on these additional data.
13) We observed 117 redds in a reach adjacent to the Grays River Hatchery. The next highest reach redd count in the Grays river was 17. The effect of this on mean redd density was 8 redds per mile with the hatchery reach and 2 redds per mile without. An alternate approach is to consider the hatchery reach as a census reach because it is not representative and re-analyze the data. Preliminary analysis suggests little changes in the unmarked abundance but a great reduction in the marked abundance. Outlier detection, reaches next to hatcheries, and reaches downstream from weirs should be more carefully evaluated (Liermann et al. 2015).

Acknowledgements

The major funders for coho salmon monitoring and reporting are the Bonneville Power Administration (BPA), NOAAs National Marine Fisheries Service (NMFS) through the Mitchell Act and the Pacific Coastal Salmon Recovery Fund (PCSRF). The later was administered through the Washington Recreation and Conservation Office (RCO). Significant WDFW resources contributed to the success of this project. Pacific Salmon Treaty funding was used to assist with study design development, improvements in WDFW's internal CWT database, and the purchase of CWT detection wands used to recover CWT on spawning ground surveys. Tacoma Public Utilities provided the number of adult coho salmon released into the Tilton and Upper Cowlitz/Cispus rivers. This report would not be possible without the collection of field data led by Steve Gray, Chris Gleizes, Pat Hanratty, Julie Grobelny, and Josh Holowatz. We acknowledge the support of Region 5 and Olympia database managers and analysts including Robert Woodard, Michelle Groesbeck, Danny Warren, Ben Warren, Are Storm, Gil Lensegrav, Kelly Henderson, Catie Mains, and Leslie Sikora. Lance Campbell and John Sneva provided scale ages and the Olympia CWT lab staff extracted and read CWT. We thank Region 5 hatchery staff for operation and assistance in sampling at weirs, and the WDFW biologists and technicians for the implementation of the study design, data collection, and data entry. We thank Rick Golden (BPA), Rob Jones (NOAA), Scott Rumsey (NOAA), Brian Abbott (RCO), Tara Galuska (RCO), Kat Moore (RCO), and various committees of the PST for their support of this project. We thank Don Stevens from the Oregon State University for creating the Lower Columbia River web-based GRTS sampling tool proto-type and developing the spatial sample draws for the coho salmon spawning ground surveys, and Martin Liermann (NOAA) for statistical advice. In addition, we thank Jen Bayer from the United States Geological Survey (USGS) and Pacific Northwest Aquatic Monitoring Partnership (PNAMP) and Russell Scranton (BPA) for their support of in the development of the Lower Columbia River GRTS sampling tool. Mention of trade names or commercial products does not constitute endorsement for use.

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Appendices

Appendix 1

Appendix 1 a. GRTS reaches surveyed for Grays River coho salmon in 2011.

Section	Population	Stream Name	Miles	RM Start	RM Stop
ADR	Grays	Alder Creek	0.42	0.00	0.42
BLA	Grays	Blaney Creek	0.71	0.00	0.71
CRJ	Grays	Crazy Johnson	1.00	0.05	1.05
EBW	Grays	Elbow Creek	1.00	0.00	1.00
EGT	Grays	EF Grays LB Trib 1	1.00	0.68	1.68
FOF	Grays	Fossil Creek	1.00	0.91	1.91
GRD	Grays	Grays River	0.41	13.79	14.20
GRP	Grays	Grays River	1.00	25.12	26.12
GUS	Grays	Grays Upper LB Trib	0.24	1.41	1.65
GUST	Grays	Grays Upper LB Trib	0.76	1.65	2.41
GUT	Grays	Grays Upper LB Trib	0.24	2.41	2.65
HUD	Grays	Hull Creek	1.00	0.47	1.47
HUG	Grays	Hull Creek	0.18	2.68	2.86
HUGH	Grays	Hull Creek	0.82	2.86	3.68
HUH	Grays	Hull Creek	0.18	3.68	3.86
IMB	Grays	Impie Creek	1.00	0.86	1.86
MTD	Grays	Mitchell Creek	1.00	0.00	1.00
MTF	Grays	Mitchell Creek	1.00	0.96	1.96
NIA	Grays	Nikka Creek	1.00	0.00	1.00
SGG	Grays	SF Grays	1.00	4.08	5.08
WGB	Grays	WF Grays	1.00	3.26	4.26
WGC	Grays	WF Grays	0.60	4.39	4.99

Appendix 1 b. GRTS reaches surveyed for Elochoman River coho salmon in 2011

Section	Population	Stream Name	Miles	RM Start	RM Stop
BNA	Eloch/Skam	Birnie Creek	1.00	0.35	1.35
BVA	Eloch/Skam	Beaver Creek	1.00	1.63	2.63
CLA	Eloch/Skam	Clear Creek	0.58	0.06	0.64
CLAD	Eloch/Skam	Clear Creek	0.42	0.64	1.06
CLD	Eloch/Skam	Clear Creek	0.58	1.06	1.64
EFB	Eloch/Skam	EF Elochoman	0.63	0.61	1.24
EFBE	Eloch/Skam	EF Elochoman	0.37	1.24	1.61
EFE	Eloch/Skam	EF Elochoman	0.63	1.61	2.24
ELG	Eloch/Skam	Elochoman River	1.00	15.96	16.96
ELR	Eloch/Skam	Elochoman River	1.00	13.12	14.12
ETB	Eloch/Skam	Elochoman River LB Trib 2	1.00	0.00	1.00
FAC	Eloch/Skam	Falk Creek	1.00	4.57	5.57
FAE	Eloch/Skam	Falk Creek	0.81	0.00	0.81
FAEH	Eloch/Skam	Falk Creek	0.19	0.81	1.00
FAH	Eloch/Skam	Falk Creek	0.81	1.00	1.81
LSF	Eloch/Skam	LF Skamakowa	1.00	1.84	2.84
MDA	Eloch/Skam	McDonald Creek	1.00	0.00	1.00
NTA	Eloch/Skam	Nelson Creek LB Trib	0.35	0.80	1.15
RCK	Eloch/Skam	Rock Creek	0.80	0.00	0.80
SDC	Eloch/Skam	Standard Creek	1.00	1.27	2.27
SKT	Eloch/Skam	Skamakowa RB Trib 2	0.47	0.00	0.47
WET	Eloch/Skam	WF Elochoman LB Trib	1.00	0.00	1.00
WFC	Eloch/Skam	WF Elochoman	1.00	2.80	3.80
WIM	Eloch/Skam	Wilson Creek	1.00	7.42	8.42

Appendix 1 c. GRTS reaches surveyed for Lower Cowlitz River coho salmon in 2011

Section	**Population**	**Stream Name**	**Miles**	**RM Start**	**RM Stop**
AT1	Lower Cowlitz	Arkansas Trib 1	0.83	0.00	0.83
BAE	Lower Cowlitz	Baxter Creek	1.00	0.53	1.53
BLB	Lower Cowlitz	Blue Creek	1.00	4.13	5.13
DLB	Lower Cowlitz	Delameter Creek	1.00	2.45	3.45
DLD	Lower Cowlitz	Delameter Creek	1.00	7.21	8.21
GDB	Lower Cowlitz	Gardner Creek	1.00	1.07	2.07
JWC	Lower Cowlitz	Jack Welches Creek	0.98	0.00	0.98
KIT	Lower Cowlitz	King Trib	1.00	2.15	3.15
LKA	Lower Cowlitz	Leckler Creek	0.68	0.00	0.68
LKAB	Lower Cowlitz	Leckler Creek	0.32	0.68	1.00
LKB	Lower Cowlitz	Leckler Creek	0.68	1.00	1.68
OLB	Lower Cowlitz	Olequa Creek	1.00	2.85	3.85
OLE	Lower Cowlitz	Olequa Creek	1.00	8.48	9.48
OLK	Lower Cowlitz	Olequa Creek	1.00	15.94	16.94
OSB	Lower Cowlitz	Ostrander Creek	1.00	5.44	6.44
SMC	Lower Cowlitz	Salmon Creek	1.00	4.04	5.04
SMD	Lower Cowlitz	Salmon Creek	0.26	2.56	2.82
SMDE	Lower Cowlitz	Salmon Creek	0.74	2.82	3.56
SME	Lower Cowlitz	Salmon Creek	0.26	3.56	3.82
SMI	Lower Cowlitz	Salmon Creek	1.00	8.31	9.31
SMO	Lower Cowlitz	Salmon Creek	1.00	16.19	17.19
SMR	Lower Cowlitz	Salmon Creek	1.00	20.59	21.59
SMT	Lower Cowlitz	Salmon Creek	1.00	28.97	29.97
W4A	Lower Cowlitz	Stillwater Trib 4	1.00	0.04	1.04

Appendix 1 d. GRTS reaches surveyed for Green River coho salmon in 2011.

Section	Population	Stream Name	Miles	RM Start	RM Stop
CAA	Green	Cascade Creek	0.14	0.00	0.14
CAB	Green	Cascade Creek	0.19	0.81	1.00
CAC	Green	Cascade Creek	0.67	1.14	1.81
CAO	Green	Cascade Creek	0.67	0.14	0.81
CAV	Green	Cascade Creek	0.14	1.00	1.14
DTA	Green	WF Devils Creek	1.00	0.44	1.44
DVA	Green	Devils Creek	1.00	0.31	1.31
DVB	Green	Devils Creek	1.00	2.17	3.17
ELA	Green	Elk Creek	0.03	0.11	0.14
ELB	Green	Elk Creek	0.03	1.11	1.14
ELC	Green	Elk Creek	1.00	3.76	4.76
ELO	Green	Elk Creek	0.97	0.14	1.11
G2A	Green	Green 2550 Trib	0.37	0.00	0.37
G2B	Green	Green 2550 Trib	0.37	1.00	1.37
G2O	Green	Green 2550 Trib	0.63	0.37	1.00
GNA	Green	Green River	1.00	3.84	4.84
GNB	Green	Green River	0.53	4.84	5.37
GNC	Green	Green River	0.31	5.84	6.15
GND	Green	Green River	0.66	6.37	7.03
GNE	Green	Green River	0.88	7.15	8.03
GNH	Green	Green River	0.29	19.32	19.61
GNI	Green	Green River	0.31	19.61	19.92
GNJ	Green	Green River	0.15	19.92	20.07
GNK	Green	Green River	0.25	20.07	20.32
GNL	Green	Green River	0.12	7.03	7.15
GNO	Green	Green River	0.47	5.37	5.84
GNP	Green	Green River	0.29	20.32	20.61
GNR	Green	Green River	0.09	20.61	20.70
GNV	Green	Green River	0.22	6.15	6.37
GNW	Green	Green River	0.22	20.70	20.92
GNY	Green	Green River	0.15	20.92	21.07
GNZ	Green	Green River	0.63	21.07	21.70

Appendix 1 e. GRTS reaches surveyed for mainstem and NF Toutle River coho salmon in 2011.

Section	Population	Stream Name	Miles	RM Start	RM Stop
S2A	NF Toutle	Silver Trib	0.77	0.66	1.43
SUB	NF Toutle	Sucker Creek	1.00	0.30	1.30
T1A	NF Toutle	Toutle Trib 1	1.00	0.00	1.00
WTA	NF Toutle	Wyant Trib 1	0.78	0.00	0.78
WTAB	NF Toutle	Wyant Trib 1	0.22	0.78	1.00
WTB	NF Toutle	Wyant Trib 1	0.78	1.00	1.78
WYA	NF Toutle	Wyant Creek	0.25	2.64	2.89
WYI	NF Toutle	Wyant Creek	1.00	5.26	6.26

Appendix 1 f. GRTS reaches surveyed for SF Toutle River coho salmon in 2011.

Section	Population	Stream Name	Miles	RM Start	RM Stop
BRC	SF Toutle	Bear Creek	1.00	1.11	2.11
JOH	SF Toutle	Johnson Creek	1.00	0.75	1.75
SFB	SF Toutle	SF Toutle	1.00	0.49	1.49
SFS	SF Toutle	SF Toutle	0.24	4.51	4.75
SFST	SF Toutle	SF Toutle	0.76	4.75	5.51
SFT	SF Toutle	SF Toutle	0.24	5.51	5.75
TSE	SF Toutle	SF Toutle	1.00	10.99	11.99
TSH	SF Toutle	SF Toutle	0.68	14.38	15.06
TSHSFF	SF Toutle	SF Toutle	0.32	15.06	15.38
SFF	SF Toutle	SF Toutle	0.68	15.38	16.06
TSN	SF Toutle	SF Toutle	1.00	19.86	20.86
TSQ	SF Toutle	SF Toutle	1.00	21.10	22.10
STS	SF Toutle	Studebaker Creek	1.00	2.04	3.04
THE	SF Toutle	Thirteen Creek	1.00	0.00	1.00

Appendix 1 g. GRTS reaches surveyed for Coweeman River coho salmon in 2011.

Section	Population	Stream Name	Miles	RM Start	RM Stop
BDB	Coweeman	Baird Creek	1.00	0.17	1.17
BDE	Coweeman	Baird Creek	1.00	1.22	2.22
C3B	Coweeman	Coweeman Trib 3	0.46	0.00	0.46
CAD	Coweeman	Coweeman River	1.00	24.28	25.28
CAL	Coweeman	Coweeman River	0.43	28.69	29.12
CALM	Coweeman	Coweeman River	0.57	29.12	29.69
CAM	Coweeman	Coweeman River	0.43	29.69	30.12
CWC	Coweeman	Coweeman River	1.00	7.54	8.54
CWM	Coweeman	Coweeman River	1.00	12.87	13.87
CWQ	Coweeman	Coweeman River	1.00	14.99	15.99
CWV	Coweeman	Coweeman River	0.12	20.70	20.82
CWVW	Coweeman	Coweeman River	0.88	20.82	21.70
CWW	Coweeman	Coweeman River	0.12	21.70	21.82
CWY	Coweeman	Coweeman River	1.00	22.46	23.46
GBC	Coweeman	Goble Creek	0.61	0.79	1.40
GBCD	Coweeman	Goble Creek	0.39	1.40	1.79
GBD	Coweeman	Goble Creek	0.61	1.79	2.40
GBF	Coweeman	Goble Creek	1.00	2.41	3.41
MUIJ	Coweeman	Mulholland Creek	1.00	3.04	4.04
NGG	Coweeman	NF Goble Creek	1.00	1.37	2.37
ONL	Coweeman	Oneil Creek	0.62	0.00	0.62
SKI	Coweeman	Skipper Creek	1.00	0.00	1.00

Appendix 1 h. GRTS reaches surveyed for Kalama River coho salmon in 2011.

Section	Population	Stream Name	Miles	RM Start	RM Stop
BRK	Kalama	Burke Creek	0.21	0.40	0.61
BUB	Kalama	Burris Creek	0.82	1.75	2.57
OWC	Kalama	Owl Creek	0.90	0.57	1.47
SCA	Kalama	Schoolhouse Creek	1.00	0.00	1.00
SPA	Kalama	Spencer Creek	1.00	0.00	1.00

Appendix 1 i. GRTS reaches surveyed for Cedar Creek coho salmon in 2011.

Section	Population	Stream Name	Miles	RM Start	RM Stop
BEA	Cedar Creek	Beaver Creek	1.00	0.22	1.22
BIA	Cedar Creek	Bitter Creek	0.69	0.20	0.89
BIAB	Cedar Creek	Bitter Creek	0.31	0.89	1.20
BIB	Cedar Creek	Bitter Creek	0.69	1.20	1.89
CEF	Cedar Creek	Cedar Creek	1.00	6.02	7.02
CEH	Cedar Creek	Cedar Creek	1.00	7.34	8.34
CEI	Cedar Creek	Cedar Creek	0.39	8.59	8.98
CEIJ	Cedar Creek	Cedar Creek	0.61	8.98	9.59
CEJ	Cedar Creek	Cedar Creek	0.39	9.59	9.98
CEK	Cedar Creek	Cedar Creek	1.00	10.07	11.07
CEL	Cedar Creek	Cedar Creek	0.40	11.30	11.70
CELM	Cedar Creek	Cedar Creek	0.60	11.70	12.30
CEM	Cedar Creek	Cedar Creek	0.39	12.30	12.69
CEMN	Cedar Creek	Cedar Creek	0.01	12.69	12.70
CEN	Cedar Creek	Cedar Creek	0.99	12.70	13.69
CEO	Cedar Creek	Cedar Creek	0.97	13.94	14.91
CEOP	Cedar Creek	Cedar Creek	0.03	14.91	14.94
CEP	Cedar Creek	Cedar Creek	0.52	14.94	15.46
CEPQ	Cedar Creek	Cedar Creek	0.45	15.46	15.91
CEQ	Cedar Creek	Cedar Creek	0.55	15.91	16.46
CER	Cedar Creek	Cedar Creek	0.32	18.11	18.43
CERS	Cedar Creek	Cedar Creek	0.68	18.43	19.11
CHA	Cedar Creek	Chelatchie Creek	1.00	0.00	1.00
CHE	Cedar Creek	Chelatchie Creek	0.12	4.42	4.54
CHEF	Cedar Creek	Chelatchie Creek	0.88	4.54	5.42
CHF	Cedar Creek	Chelatchie Creek	0.12	5.42	5.54
HIS	Cedar Creek	Cedar Creek	1.65	16.46	18.11
JOA	Cedar Creek	John Creek	0.30	0.00	0.30
JOB	Cedar Creek	John Creek	0.50	0.30	0.80
NCB	Cedar Creek	NF Chelatchie	1.00	0.47	1.47
PTR	Cedar Creek	Pup Creek Trib	1.00	0.00	1.00
PUA	Cedar Creek	Pup Creek	1.00	0.48	1.48
PZAB	Cedar Creek	Protzman Creek	1.00	0.00	1.00

Appendix 1 j. GRTS reaches surveyed for NF Lewis River coho salmon in 2011.

Section	**Population**	**Stream Name**	**Miles**	**RM Start**	**RM Stop**
GEG	Lower Lewis	Gee Creek	1.00	5.76	6.76
H1A	Lower Lewis	Hayes Trib 1	1.00	0.00	1.00
HYA	Lower Lewis	Hayes Creek	1.00	0.00	1.00
RBA	Lower Lewis	Robinson Creek	0.64	0.00	0.64
RSC	Lower Lewis	Ross Creek	1.00	0.63	1.63
STB	Lower Lewis	Staples Creek	0.49	0.20	0.69

Appendix 1 k. GRTS reaches surveyed for EF Lewis coho salmon in 2011.

Section	**Population**	**Stream Name**	**Miles**	**RM Start**	**RM Stop**
DEF	EF Lewis	Dean Creek	1.00	2.23	3.23
JEN	EF Lewis	Jenny Creek	0.23	0.00	0.23
LWA	EF Lewis	Lockwood Creek	1.00	0.00	1.00
MAA	EF Lewis	Manley Creek	1.00	0.08	1.08
MIC	EF Lewis	Mill Creek	1.00	1.20	2.20
MNE	EF Lewis	Mason Creek	1.00	2.68	3.68
MNJ	EF Lewis	Mason Creek	1.00	6.02	7.02
RCH	EF Lewis	Rock Creek	1.00	2.89	3.89
RIC	EF Lewis	Riley Creek	1.00	0.53	1.53
TSC	EF Lewis	Tsugawa Creek	1.00	0.00	1.00
ZTB	EF Lewis	Brezee Trib 27	1.00	0.00	1.00

Appendix 1 l. GRTS reaches surveyed for Washougal coho salmon in 2011.

Section	Population	Stream Name	Miles	RM Start	RM Stop
BOA	Washougal	Boulder Creek	1.00	0.00	1.00
ELA	Washougal	EF Little Washougal	1.00	0.00	1.00
HAB	Washougal	Hagen Creek	1.00	0.49	1.49
LWI	Washougal	Little Washougal	1.00	4.67	5.67
WAF	Washougal	Washougal	0.55	9.43	9.98
WAFG	Washougal	Washougal	0.45	9.98	10.43
WAG	Washougal	Washougal	0.55	10.43	10.98

Appendix 1 m. GRTS reaches surveyed for Lower Gorge coho salmon in 2011.

Section	Population	Stream Name	Miles	RM Start	RM Stop
CMP	L. Gorge	Campen Creek	1.00	0.35	1.35
HMC	L. Gorge	Hamilton Creek	1.00	1.72	2.72
HMG	L. Gorge	Hamilton Creek	0.40	3.12	3.52
HMGH	L. Gorge	Hamilton Creek	0.60	3.52	4.12
HMH	L. Gorge	Hamilton Creek	0.40	4.12	4.52
LNA	L. Gorge	Lawton Creek	1.00	0.00	1.00
WTA	L. Gorge	Walton Creek	1.00	0.34	1.34
WWB	L. Gorge	Woodward Creek	0.31	2.15	2.46
WWBC	L. Gorge	Woodward Creek	0.69	2.46	3.15
WWC	L. Gorge	Woodward Creek	0.31	3.15	3.46

Appendix 2

Appendix 2. Hatchery coho salmon smolt releases that occurred in 2010 from Brood Year (BY) 2008. The two large releases of unmarked CWT fish (e.g., CWT-NoClip) included a release of early and late stock coho salmon from the Lewis River Hatchery. These unmarked fish were all CWT and are part of the double index tag (DIT) group used to evaluate selective fisheries.

Release Site	Population	CWT AdClip	CWT NoClip	AdClip	NoClip	Total
Deep River Net Pens	Grays	25,948	0	721,052	0	747,000
Grays River Hatchery	Grays	27,726	0	125,274	0	153,000
Cowlitz Salmon Hatchery	Cowlitz	936,282	1,920	1,963,093	7,109	2,908,404
North Toutle Hatchery	Green	30,481	593	113,953	2,205	147,232
Fallert Creek Hatchery	Kalama	29,832	123	85,841	353	116,149
Kalama Falls Hatchery	Kalama	30,385	38	607,560	601	638,584
Lewis River Hatchery	NF Lewis	74,570	76,372	736,592	4,350	891,884
Lewis River Hatchery	NF Lewis	76,149	76,175	654,818	3,016	810,158
Washougal Hatchery	Washougal	30,220	244	127,783	1,030	159,277
TOTAL		1,261,593	155,465	5,135,966	18,664	6,571,688

Detection Probabilities for Passive Integrated Transponder (PIT) Tags in Adult Steelhead with Hand Held Scanners

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Final –December 2, 2015

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Abstract

Passive Integrated Transponder (PIT) tags are used throughout the Columbia River Basin for measuring survival, migration patterns, and predation rates of salmon and steelhead. The use of PIT tags for estimating salmon and steelhead harvest rates in fisheries is a potential new application for this technology. However, the efficiency with which these tags may be detected in landed catch must be known for these estimates to be unbiased. We implemented a study to evaluate PIT tag detection rates for tagged adult salmonids using a variety of tag scanner types under conditions similar to those expected in sampling of fisheries catch. Steelhead were PIT tagged and sampled prior to spawning multiple times in 14 trials with the Destron Fearing FS2001F-ISO Reader Base Unit with racquet antenna, an Allflex Model RS601-3, Destron Fearing FS2001F-ISO Reader Base Unit with Flat Plate antenna, a Destron Fearing FS2001F-ISO Reader Base Unit with 24 inch square antenna, and a Psion Workabout Pro3 Hand-Held Computer with RFID Reader. After removing one questionable trial and adjusting six others due to battery failure and RFID activation problems, a total of 3,887 PIT tags were detected out of 3,960 PIT tag samples. The data were analyzed using a general linear mixed model (GLMM) and the best model, based on Deviance Information Criteria (DIC), included a random effect for the intercept and a fixed effect for type of reader resulting in individual reader detection probabilities ranging from 96.8 to 99.7%. In contrast, the estimate of detection efficiency from the null model was 98.2%, which was not supported by DIC. Our results suggested that PIT tag detection rates with hand held PIT tag scanners were consistent with detection means above 98% when standardized protocols were implemented. Application of our detection rates to adult PIT tag fishery sampling programs allows for a bias correction due to PIT tags that are not detected, although this bias is negligible.

Introduction

Passive Integrated Transponder (PIT) tagging of salmonids in the Columbia River Basin has served a variety of purposes including estimation of juvenile and adult survival and the investigation of mechanisms affecting survival (Connor et al. 1998, Zabel and Accord 2004, Buchanan et al. 2006) such as avian and northern pikeminnow predation (Collis et al. 2001, Petersen and Barfoot 2003), and habitat characteristics (Paulsen and Fisher 2005). The number of PIT tagged salmonids released annually in the Columbia River Basin has increased from less than 20,000 tags in 1988 to over 2,000,000 in 2009. In addition, the number of returning PIT tagged adult salmonids, as measured by detections at Bonneville Dam, has exceeded 30,000 individuals. Detection systems have advanced from hand held devices (Buzby and Deegan 1999) to juvenile bypass systems to adult traps and ladders (Harmon 2003) to instream arrays capable of detecting adult and juvenile passage (Connolly et al. 2008). Almost $4,000,000 annually is dedicated to the purchase of PIT tags and millions more are spent capturing and tagging fish, recovering tags, and storing data in the PIT Tag Information System (PTAGIS), a coastwide PIT tag database. Harvested PIT tagged fish represent one of the largest sources of unaccounted mortality for PIT tagged fish in the Columbia River Basin and could provide valuable information to researchers, managers, and policy makers. This is especially true of harvest rates for groups of fish that are generally not tagged with coded-wire tags (CWT) but are often PIT tagged. These groups often include natural origin salmon and steelhead. Thus, PIT tag recoveries in fisheries may also allow managers to better estimate harvest impacts on at risk natural origin populations and to shape fisheries to reduce impacts on salmonid populations listed under the auspices of the Endangered Species Act (ESA) based on their spatial and temporal occurrence.

However, before harvest estimates can be calculated based on PIT tags, the probability of detecting a PIT tag during catch sampling of harvested adult salmon or steelhead must be estimated. While it may be convenient to assume that all PIT tagged fish sampled will be detected, violation of this assumption would result in systematic underestimates of harvest rates on PIT tagged fish. In 2010, Rawding et al. (2014) estimated PIT detection rates for tagged adult salmonids using a variety of tag scanner types under conditions similar to those expected in sampling of fisheries catch. Fall Chinook salmon, coho salmon, and summer steelhead hatchery adults were tagged with PIT tags and released into hatchery raceways. The salmon were held for seven days after tagging and the steelhead were held for 32 days after which they were sacrificed for sampling. The mean detection rate based on the 45 trails was 99.4% (95% CI = 98.5 - 100%). In 2011, the Washington Department of Fish and Wildlife (WDFW) replicated the first study to estimate the probability of detecting PIT tags in adult steelhead using readily available portable PIT tag detectors and antennae. The purpose of this study was to confirm PIT tag detection rates from 2010 and test the Psion (PS) Workabout Pro3 Hand-Held Computer with RFID Reader, which was being used as a backup PIT tag scanner and is a data logger used by WDFW for fisheries sampling.

Methods

Tagging

Adult steelhead were PIT tagged at Skamania Hatchery during the summer of 2011 to test PIT tag detection. Standard Columbia River Basin PIT tagging procedures from the Columbia Basin Fish and Wildlife Authority (CBFWA 1999) developed for juveniles were adapted for adults. Fish were briefly crowded in the hatchery raceway with seines or screens, netted, and released into an anesthetic tank containing water with a concentration of ~ 40mg of per liter of Tricaine methanesulfonate (MS-222). After fish had become docile they were tagged with a Destron Fearing TX1411SST PIT tag (12mm, 134.2 kHz), then scanned with a Destron Fearing FS2001F-ISO Reader Base Unit with a racket antenna (DF-RQ) to record the tag number, before being released back into the raceway. At the time of tagging we recorded species and sex, which was identified using morphological characteristics (Groot and Margolis 1991). PIT tagged fish were placed in a raceway with untagged fish to mimic fishery sampling conditions where the number of PIT tagged fish is unknown.

Detection Trials

Just prior to spawning in December, after being held for an average of four months, the fish were sacrificed to mimic sport and commercial sampling of dead fish. Fish were sacrificed prior to full maturation of the gonads because high rates of tag loss may occur immediately prior to spawning (Prentice et al. 1994). Carcasses were laid out in single file as one might sample a group of fish at a boat ramp or in a commercial fishery. The steelhead were placed parallel to each other in the same orientation, with the distance between the noses of adjacent fish standardized to approximately 0.75 meters to avoid potential interference between adjacent PIT tags. An initial carcass scan was conducted with a DF FS2001F-ISO Reader Base Unit a racket antenna (DF-RQ) to determine tag presence. This process was repeated with DF-RQ units, Allflex (AF) Model RS601-3 units, along with Psion (PS) Workabout Pro3 Hand-Held Computer with the built in RDIF antennae units (Figure 1). Steelhead were scanned for PIT tags using an oval shaped pattern initiated near the anterior to the gill plate, moving back toward the tail near the ventral surface, and then moving forward near the dorsal surface toward the head (Figure 2). At the end of sampling, all fish were dragged over a 12 x 26 inch flat plate detector (DF-FP) and passed through a 24 inch square (DF-SQ) antenna (Figure 1). Both were attached to a DF FS2001F-ISO Reader Base Unit with a 20-inch cable. A single trial involved scanning every individual steelhead with a particular detector unit. Using a repeated measures design each steelhead was scanned with four different DF-RQ, AF, and PS units and at the end of the day all fish were scanned once with the DF-FP and DF-SQ readers.

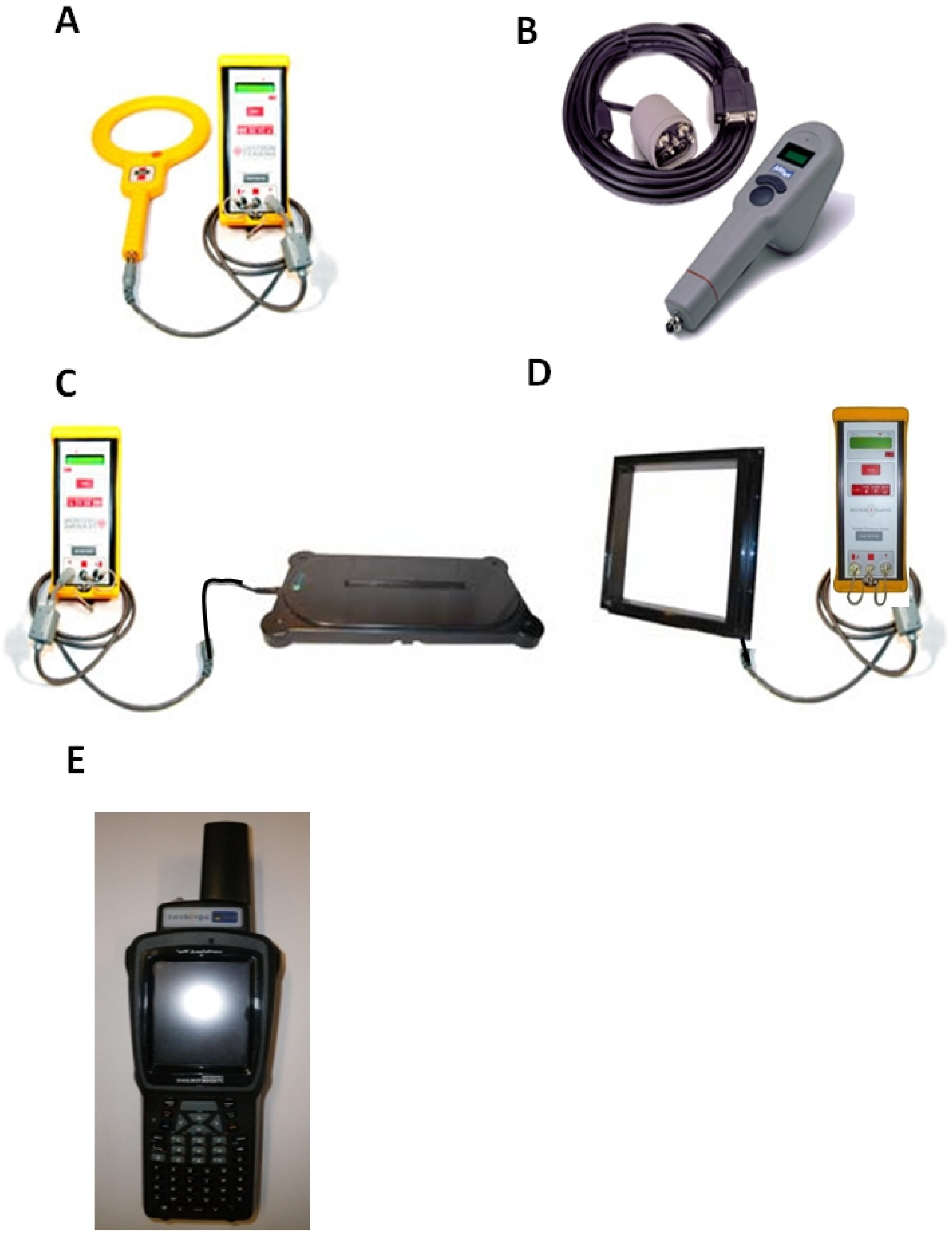

Figure 1. Pictures of PIT tag detection antennae used in this study include a) Destron Fearing FS2001F-ISO Reader Base Unit with racquet, b) Allflex Model RS601-3, c) Destron Fearing FS2001F-ISO Reader Base Unit with Flat Plat antenna, d) Destron Fearing FS2001F-ISO Reader Base Unit with 24 inch square antenna, e) Psion Teklogic data logger with RFID.

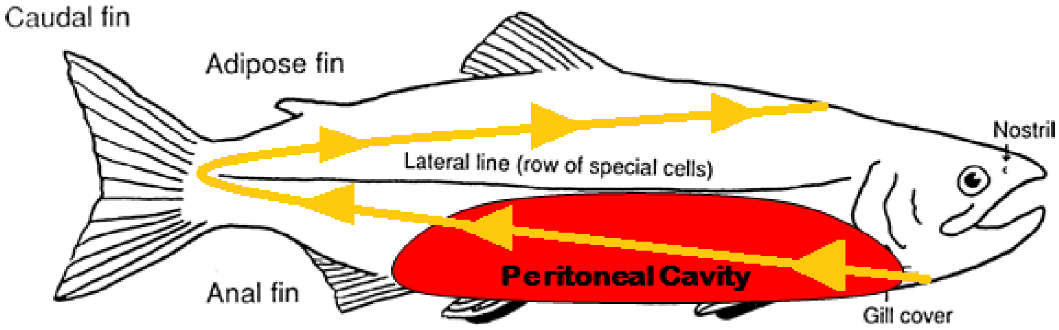

Figure 2. Pass over detection method for scanning a steelhead for PIT Tags.

Statistical Analysis

The study was designed to collect PIT tag presence/absence (binary) response data along with explanatory variables relating to the fish, samplers, and equipment. We analyzed the data using a generalized liner model (GLM) to accommodate the non-Gaussian distribution (O'Hara and Kotze 2010). The appropriate analysis for this data type is a binomial regression (Faraway 2006), which is a type of GLM that is composed of three components: 1) the binomial distribution to describe the random variation in the response, 2) the logit function is applied to the expectation of the response, and 3) a linear predictor is composed of a combination of covariates that describe the system. Both fixed and random effects were considered in the analysis. Fixed effects are traditionally used when there is interest in the studied factors or most conceivable levels of the factors are studied (Kery 2010). A fixed effect is a parameter to be estimated from the data. A random effect is often used when we do not have an interest in the factor levels in the study, or when these levels form a random sample of possible levels that could have been included within the study. Random effects are used to make generalizations about this larger population and there is a greater interest in the variation among all factor levels. However, in some cases there is a desire to estimate the random effect and use it in regression assessment.

When both fixed and random effects are included in a model it is referred to as a mixed or mixed-effects model. The data were analyzed as grouped in Table 1 based on the following equation:

$$\text{Logit}\left(\mathit{Detection/Samples}_{ij}\right) = \mu + \mathit{Trial}_i + \mathit{Type}_j \qquad (1)$$

where μ is the intercept, *Trial* is the complete sampling of the steelhead with each scanner type and serial number, *Type* is the scanner unit. The fixed effects included scanner type. PIT tag scanners were classified into five types; the DF-RQ used for portable commercial fisheries sampling, the AF used for sport fisheries sampling, the PS for back up sampling, and the DF-SQ and DF-FP for fixed site fisheries sampling. GLM analysis was conducted in WinBUGS (Lunn et al. 2000) using multi-model inference based on Deviance Information Criteria (Spiegelhalter et al. 2002), which is a Bayesian analog of Akiake Information Criteria (Burnham and Anderson 2002).

We used the methods described in Connolly et al. (2008) to estimate the probability that we missed a tag assuming independent sampling events (in our case multiple scans of individual fish with different readers).

$$x_i \sim \text{Binomial}(n_i, p.undet_i) \tag{2}$$

$$CumDet = 1 - \prod_{i=1}^{trials} (p.undet_i) \tag{3}$$

where *p.undet* = probability the fish was not detected in a trial, *x* = fish with missed PIT tags in a trial, *n* = PIT tagged fish sampled in a trial, *CumDet*= the probability of detecting a PIT tag if it was present after multiple independent trials, and *i* = trial number.

A Bayesian framework was used to estimate parameters in our analysis (Gelman et al. 1995). The goal of the Bayesian approach is to calculate the probability of a specific parameter (θ) given the data (x), written as p(θ|x). Bayes theorem is a conditional probability statement that proves the p(θ|x) is proportional to the sampling distribution for the data p(x|θ) multiplied by an independent probability distribution for the parameter, p(θ) (Gelman et al. 1995). The formula of the posterior distribution may be complex and difficult to derive. Samples from the posterior distribution can often be obtained using Markov chain Monte Carlo (MCMC) simulations (Gilks et al. 1995). WinBUGS is a software package that implements MCMC simulations using a Metropolis within Gibbs sampling algorithm (Spiegelhalter et al. 2002) and has been used in salmonid studies (Rivot and Prevost 2002, Link and Barker 2010).

One of the most controversial aspects of the Bayesian approach is the specification of priors. We used vague priors for this analysis with the intent that the posterior distribution be dominated by the observed data. When this occurs the results obtained from Bayesian and maximum likelihood methods yield similar results (Kery 2010). Priors for the intercept and regression coefficients were a Normal $(0,10^2)$. Convergence was tested using the Brook-Gelman-Rubin (BGR) diagnostic (Ntzoufras 2009) and precision was assessed by monitoring MC % error. The BGR diagnosis compares the between and within sample variability. Although convergence cannot be assured, a BGR value of less than 1.1 is generally acceptable and indicates that the MCMC simulations have stabilized (Kery 2010). The MC % error measures the variation of a parameter due to simulation, and to obtain precise parameter estimates it is recommended that the MC% error divided by the standard deviation be less than 5% (Lunn et al. 2000).

Results

Data Censoring

A total of 590 tagged and untagged adult steelhead were examined for PIT tags, with a maximum of 335 tags detected in the 14 trials. However, during the study we had some problems with equipment malfunction which necessitated censoring data collected during these trials (Table 1). Trial 14 with a DF-RQ was censored due to poor data resulting from a broken antenna. In trials 4 & 5, fish were sampled with the DF-SQ and DF-FP at the end of the day; PIT tags were not detected due to rundown batteries in these units. For the PS to detect PIT tags, the Wedge 2.1' (RFID antenna) needs to be initialized. This did not occur during the initial phase of the sampling. In addition, the wedge was accidentally turned off in PS/4 during the middle portion of the study resulting in only 102 fish sampled with this unit.

Table 1. Detections, samples, and detection probability estimates for 14 PIT tag trials.

Trial	Type	Detections	Samples	mean	sd	2.5%CI	median	95%CI
1	DF-RQ/1	335	335	0.999	0.002	0.993	0.999	1.000
2	DF-RQ/2	315	335	0.939	0.013	0.911	0.940	0.962
3	DF-RQ/4	329	335	0.981	0.007	0.964	0.982	0.992
4	DF-FP	300	309*	0.969	0.010	0.947	0.971	0.985
5	DF-SQ	307	309*	0.992	0.005	0.980	0.993	0.999
6	AF/1	332	334	0.993	0.005	0.981	0.994	0.999
7	AF/2	334	334	0.999	0.002	0.992	0.999	1.000
8	AF/3	333	334	0.996	0.004	0.986	0.997	1.000
9	AF/4	333	334	0.996	0.004	0.986	0.996	1.000
10	PS/1	298	301*	0.988	0.006	0.973	0.990	0.997
11	PS/2	284	300*	0.945	0.013	0.917	0.946	0.968
12	PS/3	287	298*	0.962	0.011	0.937	0.963	0.980
13	PS/4	100	102*	0.976	0.015	0.936	0.979	0.996
14*	DF-RQ/3	242	335	0.722	0.024	0.672	0.723	0.768

* Indicates potential problem in the trial, red lines with grey shading were adjusted or censored.

Results after Data Censoring

After removing the questionable trial (14) and correcting for battery loss and initialization of the RFID reader (trials 4, 5, 10, 11, 12, & 13), a total of 3,887 PIT tags (98.2%) were detected out of 3,960 PIT tags. The sample mean detection rate for these trials was 97.9%. Graphical examination of the data displays overlapping 95% CI for most readers, which implies similar detection rates between tag reader types (Figure 3).

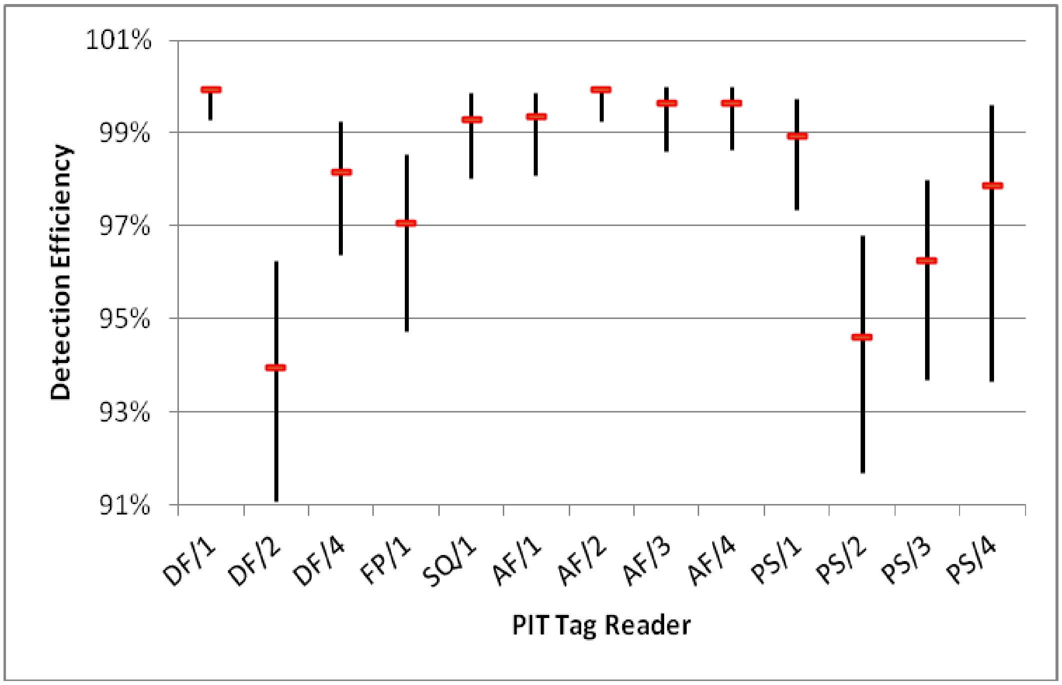

Figure 3. Detection efficiency of known PIT tagged fish in 12 trials using DF-RQ, AF, DF-FP, and DF-SQ readers. The red bar is the median for the 95% CI.

Detection Probabilities

The estimated probability of detecting a PIT tag (equation 2) in the 14 trials was equal to 100%. Detection rates were analyzed using a general linear mixed model (GLMM) based on equation 1, which is the full model. The results from the full model support high detection probabilities using all readers (Table 2) with the AF detecting PIT tags at a slightly higher detection rate (median = 99.7%) than the DF-RQ (median = 97.5%). The data logger (PS) had a slightly lower detection rate (median = 96.8%). The DF-SQ and DF-FP had median detection probabilities of 99.4% and 97.2%, respectively. The null model had a detection efficiency of 98.2% (SD=0.002).

Table 2. Estimates of detection probability from the full model by scanner type from the different PIT tag detection models (DF-RQ=DF with racquet, DF-FP=Flat Plate, DF-SQ=Square Antenna, AF=Allflex, and PS=Psion Data Logger).

Type	mean	sd	2.5% CI	median	95% CI
DF-RQ	0.974	0.005	0.964	0.975	0.983
DF-FP	0.971	0.010	0.949	0.972	0.987
DF-SQ	0.993	0.005	0.982	0.994	0.999
AF	0.997	0.002	0.994	0.997	0.999
PS	0.968	0.006	0.956	0.968	0.978

The best model based on Deviance Information Criteria (DIC) was the full model (intercept, trial, and type) with a value of 89.4 followed by the null model (intercept and trial) with a value of 124.4. The two models have ΔDIC of greater than 25, which indicates negligible support for the null model.

Discussion

Our results suggested that individual PIT tag detection rates with hand held PIT tag detectors were greater than 98% and were consistent between scanner types. Rawding et al. (2014) found similar results. However, they found slightly higher detection rates with the DF-RQ (99.8%) compared to this study (97.4%). The difference is likely due to one of the three DF-RQ readers in this study having much lower detection efficiency (93%) compared to the other DF-RQ readers (98% and 100%). We were unable to determine the cause of the lower detection rate for the one DF-RQ reader but it was likely that an operator did not follow protocols as they hurried to complete the sampling.

Our estimates of AF detection rates were similar between both studies; the detection rate was 99.7% in this study compared to 99.2% in 2010. Rawding et al. (2014) estimated detection rates for a PS of 98.4% with a single sample of 198 Chinook salmon; however in this study we estimated a slightly lower detection efficiency of 96.8% for steelhead. Difference may be due to the use of different PS models. In addition, we used an external antenna in 2010 and an internal antenna in 2011. The lower detection rate for the PS is not a concern since this unit is only used to collect PIT tag data after the PIT tag had been identified using an AF unit while sport sampling (Appendix 2, page 25). Detection rates in this study were 97.2% and 99.4% for the DF-FP and DF-SQ compared to detection rates near 99% for the DF-SQ and DF-FP in 2010 (Rawding et al. 2014).

Using the same PIT tag type with AF and DF-RQ readers, Hauser (2003) examined PIT tag detection rates in Pacific Halibut that were PIT tagged in the cheek and found each PIT tag reader had detection rates greater than 96%, and no significant difference between readers ($P > 0.05$) in 19 trials. Although tag location in that study was different from ours (cheek for halibut versus body for steelhead), both yielded similar results, although our study had more trials and a slightly better detection rate. Since our detection rate approached 100%, using the assumption of perfect detection efficiency for salmon and steelhead would lead to only a slight negative bias in sampled PIT tags. Our results support that PIT tag detection rates in commercial and recreational fisheries can be high if thoughtful, well-designed protocols are developed and implemented. We only observed lower detection rates when there were equipment problems or possible lack of protocol implementation. This underscores the importance of properly maintaining testing equipment, proper training of staff, and quality assurance/quality control (QA/QC) programs.

Our scanning protocols (Figure 2) call for the use of the pass over method. However, many samplers using the DF-RQ use the pass through method, where fish are passed through the open racquet (Charlie Cochran, WDFW per. comm.). It is probable that the pass through method has detection rates based on read ranges in Table 3. We implemented the pass over methods because we wanted a consistent detection method in order to compare among reader types, and because we wanted our results to be applicable to real catch sampling, which sometimes does not allow for pass through detection. For example, large Chinook salmon cannot fit through the opening in the racquet, eliminating the possibility of consistent use of the pass through method for all adult salmon with the DF-RQ. In addition, the pass through method cannot be implemented for the smaller hand held detectors like the AF. We chose the pass over method because it can be consistently implemented under all hand held adult fishery sampling situations. WDFW adult PIT tag sampling protocols for commercial and sport fisheries are listed in Appendix 1 and 2, respectively.

Table 3. Read ranges in inches for PIT tag detectors used in this study with two different tags.

Model	Read Range (12.5mm, 125 kHz)	Read Range (12.5mm, 134.2 kHz)
FS2001F-ISO Reader with a racket antenna	5.0 - 8.5	9.0 - 14.5
FS2001F-ISO Reader with a flat plate	9.0 -12.5	12.0-16.5
FS2001F-ISO Reader with a 24” square	12.0	18.5
Allflex Model RS601-3	2.0	3.2
Psion Teklogix Workabout Pro 7527C-G2 w/Agrident AIRE 200 RFID	NA	6.7

During efficiency trials in 2010, most Chinook and coho salmon retrieved from the holding raceway contained PIT tags (Rawding et al. 2014). This resulted in few untagged coho and Chinook salmon in the scan sample, potentially conditioning samplers to expect tagged fish. This could have resulted in a tendency for samplers to use scanners in a manner ensuring high detection efficiency since most fish were known to contain tags, whereas similar scan patterns would be less likely in the field where tag rates would be substantially lower. To counteract this tendency, samplers used the protocols described in the appendix and were limited to one reader pass to sample each fish, preventing them from repeatedly scanning fish that they believed had tags that were undetected during a first pass. To test for this possible bias we tested PIT tag detection efficiency when only a portion of the fish were tagged. During the 2010 and 2011 steelhead studies only 43% and 57% of the samples was PIT tagged, respectively. The PIT tag detection rates were similar for steelhead compared to the other species. This suggests the proportion of tagged fish had little influence on our detection rates and is likely explained by following standard protocols.

Study Limitations

Bolker et al. (2009) in a review of GLMM noted that there are accurate techniques to estimate parameters in simple cases, but complex GLMM are challenging to fit and model selection and hypothesis testing remains difficult. Our original study design was set up as a repeated measures design with each fish as a random effect along with individual fish covariates such as length, girth, sex, and species and was analyzed using logistic regression based on the binary data (Hilbe 2009). However, we had challenges in estimating mixed effects with the logistic regression packages in R and WinBUGS. Venables and Ripley (2002) noted the Hauk-Donner phenomenon can cause convergence problems when the fitted probabilities are close to 1, which occurred in our data set. We were unable to get reasonable results using various packages in R including the glmer in the lme4 package or in the glmmPQL in the MASS package for the binary data. To address this problem we analyzed the data by blocking each trial as a random effect, but this led to a loss of individual data such as length, girth, sex, and tag location. Bolker et al. (2009) indicated that Bayesian methods might offer a solution in challenging cases in this study for binary data and we are currently exploring this approach.

One of the major limitations in this study was our use of fish PIT tagged as adults rather than as juveniles, which is when the majority of fish are tagged in the Columbia River. However, seeding PIT tags to estimate efficiency is an accepted practice for hand held detectors (Hauser 2003) and for flat plate detectors (Evans et al. 2012). We chose seeding as a practical solution to ensure sufficient sample sizes. A key assumption in seeding tags is that the tag location and orientation in newly tagged adults is similar to returning adults or that if tag placement and orientation are different the read range in the detectors allows for the same detection rate for sown adults and juvenile-tagged fish. The read range is the manufacturers' estimate of the distance from which a tag can be detected. Many factors contribute to the read range including the tag type, operation frequency, antenna power, tag orientation, and interference from other devices. The read range table from the manufacturers is presented for the 125 kHz and 134 kHz tags (Table 3). Read range for the 134 kHz tag used in this study with the DF-RQ, DF-SQ, and DF-FP is greater than nine inches which is much further than the 2.0-6.7 inches for the lighter and more portable handheld units (AF and PS). Therefore, the DF-RQ, DF-SQ, and DF-FP should provide higher detection efficiencies. For this reason, and based on the results of this study, WDFW uses the DF-RQ for all commercial sampling. The read range of the AF units was listed at 3.2 inches, which suggests it may have a lower probability of detecting tags in larger fish such as Chinook salmon. However, field observations suggest the AF read range may be an underestimate (Steve VanderPloeg WDFW pers. comm.). WDFW sport samplers use the AF because samplers cannot carry the heavy and larger DF-RQ units and these DF-RQ units are substantially (six times) more expensive than the AF units. Based model selection in this study and Rawding et al. (2014) separate detection rates are appropriate for sampling type (AF and DF-RQ) and species (Chinook, coho, and steelhead).

A second concern could be our approach to estimating PIT tag loss, which was based on multiple independent detections of the same fish. However, PIT tag location, orientation, and other factors could lead to some PIT tags not being detected. If this occurred, than our assumption about independence may have been violated.

Conclusions and Recommendations

This analysis indicates that applying our detection rates to PIT tag fishery sampling programs, where our protocols are followed, is appropriate. However, it should be noted that some fish are dressed (cleaned) after they are caught but before they can be sampled. Since these fish have likely expelled tags inserted into the peritoneal cavity, this leads to fewer fishery samples for PIT tags than for CWTs because CWT placement is in the snout and tag loss is not an issue for dressed fish. Samplers need to exclude dressed fish from samples they scan for PIT tags.

We make the following recommendations: 1) samplers should continue to implement protocols developed during this study that led to consistent and high PIT tag detection rates, 2) a quality control and quality assurance program is needed to ensure implementation of sampling protocols, 3) continued periodic tagging of hatchery fish and replication of this study (or one similar) to update detection rates should be conducted as needed, 4) sampling should be expanded to adult hatchery salmon tagged as juveniles to address the concern mentioned above, and 5) since we had a significant fixed effect for species using DIC for model selection it makes sense to expand sampling to include sockeye salmon and other races of Chinook salmon.

Acknowledgements

Many WDFW staff contributed to the success of this study. We would like to thank Charlie Cochran for assistance with the initial tagging of the fish. For assistance in the scan detection study, we thank Tiffany Loper, Charlie Cochran, and Lisa Brown. Bryce Glaser, Mark Johnson and Eric Kinne helped coordinate with samplers and WDFW hatchery staff. A special thanks goes out to Skamania Hatchery supervisor John Allen and his staff for use of their fish and facilities. In addition, NOAA-NWFSC staff Michelle Rub and Lyle Gilbreath assisted in the PIT tagging of steelhead. Thomas Buehrens provide very useful comments on an earlier draft. We thank Rick Golden (BPA) for his support of this project.

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Appendix One: Procedures/Protocol for PIT sampling in the Columbia River Commercial/Treaty Fisheries

It is essential to follow the protocols and procedures below. Failure to follow these will lead to undetected PIT tagged fish, which will provide biased estimates of harvest and stock composition. Therefore, all staff will follow these procedures and protocols daily. If you have any questions please contact: Ben Warren @ Cell: (360) 635-2318, Office: (360) 906-6700 Ex: 6844 and/or E-mail Benjmin.Warren@dfw.wa.gov or your supervisor.

PIT tag units will be assigned to crews and are available for crew leaders to take on the table in the PIT station / CWT/DNA data summary cubicle (or in the cubical of crew leaders). The unit will be ready to sample and fully charged.

On occasions where units are not specifically assigned to crew leaders due to time constraints or lack of sufficient PIT readers to allow for daily downloads, the PIT tag coordinator will notify crew leaders and assign PIT readers for the entire week. During these peak weeks, it will be the crew leaders' responsibility to insure that the unit they have been assigned is charged and ready to sample with each sampling day unless otherwise notified.

Commercial sampling using the Destron Fearing FS2001 (Cheese Block)

I – Parts of the FS2001 (Cheese Block) PIT tag reader

The primary PIT tag sampling unit that crews will use for the detection of PIT tagged fish is the Destron Fearing FS2001, “lovingly” known as the Cheese Block.

App. 1 - Figure 1: Complete kit for Commercial PIT tag sampling

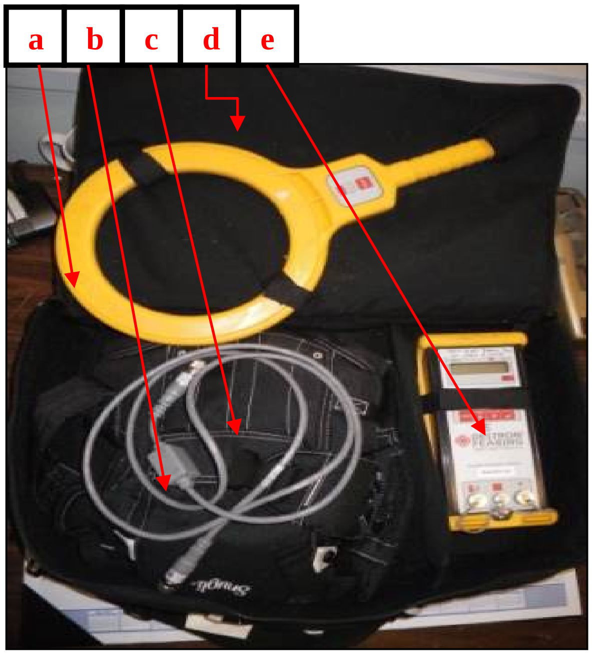
a) Antenna Racket

b) Cable

c) Snuggly-chest equipment holder*

d) Bag (which should have a dummy tag and protocol in the front pocket)

e) Cheese Block



App. 1 - Figure 2: Correct assembly of the FS2001-ISO "Cheese Block"

In order to connect the antenna racket to the Cheese Block in the correct configuration, the end with the ferrite choke box (circled) goes to the transceiver (Cheese Block).

Please be careful when attaching and detaching these cables. The best method is to gently wiggle the cable as you screw the connectors on and off. Please be sure that the cables are tightly secured, and when not in use, all caps are screwed on tightly.

II – Using the FS2001 (Cheese Block) PIT tag reader correctly while sampling

1. **Select the PIT detector unit number into the header comments of each sampling form** – This number is found on the front and base of the Cheese Block units – use the dropdown menu to select the correct unit type and number combination.

2. **Scan the test tag at the beginning and end of each session!!!** (Each Cheese Block bag has a test tag kept in front zipper pocket) ***A session*** changes when you start a new day or switch sampling locations (i.e. a new byer on the same day). It is very important to scan the test tag at the beginning and end of the sampling session, because it shows that the PIT tag unit is working both before and after sampling and the times that it was tested. **It is mandatory to scan the test tag at the beginning and end of the sampling session**.

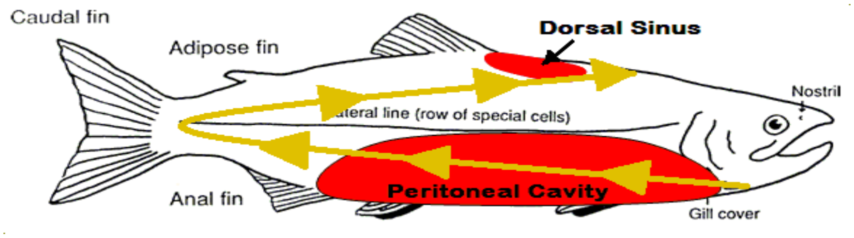
3. The preferred location for PIT tagging is the peritoneal cavity; gutted salmon **should not** be PIT tag scanned because it is unknown if PIT tag loss has occurred. It is very important that gutted fish be sampled on a separate, CWT-Only sample form.

4. **The Cheese Block is not waterproof!!!** Unfortunately, the Cheese Block units are not waterproof and are not very water resistant. To combat this equipment shortfall, please try to keep the Cheese Block unit in hand and away from water. If it is raining (or may rain), please wrap both ends of the antenna cable in a plastic SNID bag, and use the zip ties located in the Cheese Block front zipper pocket to make the connections as water-tight as possible.

5. **The Cheese Block is not rugged!!!** Unfortunately, the Cheese Block units are not completely rugged. To combat this equipment shortfall, please try to keep the Cheese Block unit in hand and avoid placing the unit in any position where it may fall onto a hard surface. **Be AWARE of your surroundings.**

6. We will be using the **Pass-Over method** for scanning salmonids as illustrated below. The Cheese block is set to require the racquet antenna "scan" button to be pressed and held to scan for a PIT tag. Hold the button for five seconds, and *touching* the antenna parallel to the fish's lateral line, pass the antenna in an oval pattern over the fish as illustrated. Speed can affect the detection rate, so try to scan at a consistent medium speed, taking the full five seconds to complete the oval.

App. 1 - Figure 3: Correct application of the Pass-Over Method using the Cheese Block unit.



7. **Look at the Cheese Block screen!!!** There are many sources of noise while PIT tag sampling in a commercial or treaty fishery setting. The only way to insure that all PIT tags are accounted for is to look at the Cheese Block screen **for every fish scanned, every time.**

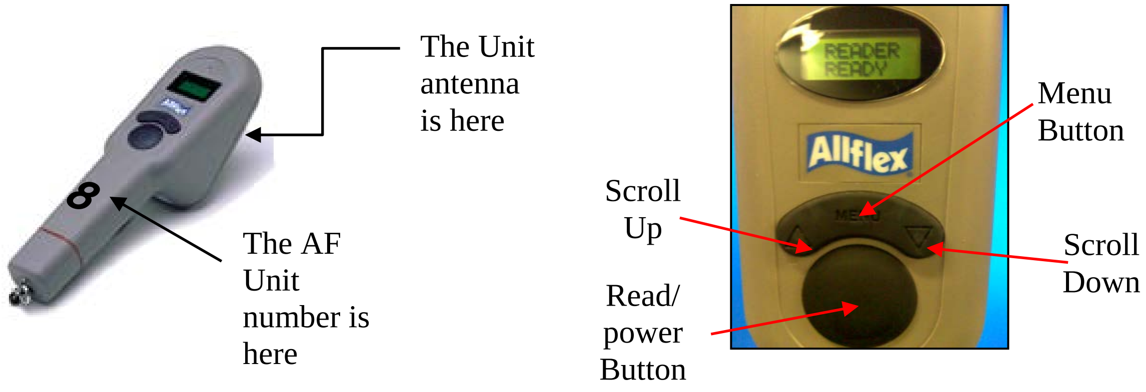
II – Using the R601-3 (Allflex) PIT tag reader correctly while sampling

Along with an assigned Cheese Block, each crew leader should have their sport-assigned R601-3 PIT tag reader, known as an Allflex. It is each crew leader's responsibility to make sure they have their Allflex as a backup in case of damage or malfunction to the Cheese Block during sampling.

Due to the hectic nature of Commercial and Tribal fishery sampling, it is even more important to follow strict adherence to protocol if samplers need to resort to using the Allflex unit for primary PIT tag scanning.

As covered above (Section II, 6) the **Pass-Over method** will be used for scanning salmonids. The Allflex units are set to scan for five seconds. **You must** utilize the entire five seconds to scan the fish, and you must have the Allflex antenna physically pressing on the lateral side of the fish being scanned.

App. 1 - Figure 4: All Flex unit components and input controls.



III - PIT tag recovery in a Commercial/Treaty fishery

1. During sampling, PIT tagged fish are treated the same as CWT fish. In most cases, they will be set aside to work up for bio data later – or given to the samplers working the board. *Make sure* that you keep track of fish that have PIT tags to maintain accurate data.

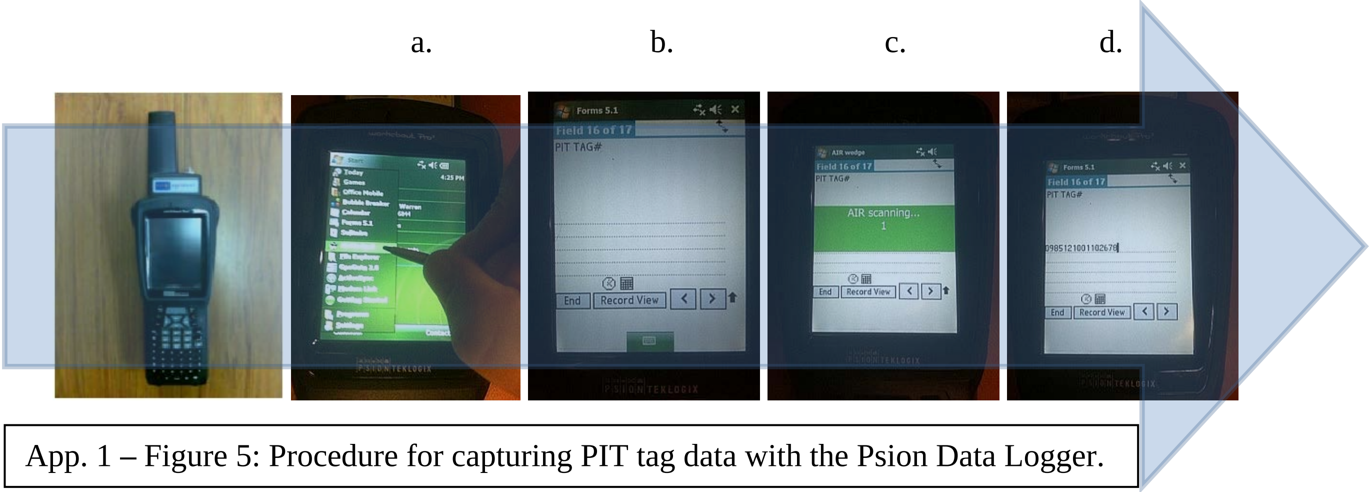
2. To use the Psion Data Logger to populate the PIT Tag # field:

    a. Ensure that the program AirWedge2 has been activated (you only need to check this at the beginning of the sampling period – not every time you scan a PIT tag)

    b. Ensure that the PIT Tag # field is selected

    c. Press the ⌃ button on the Psion to begin scanning for the PIT tag

    d. When the PIT Tag has been successfully interrogated, the PIT Tag # field will populate with a 14 digit decimal number.



PIT TAG# 0985121001102678

App. 1 – Figure 5: Procedure for capturing PIT tag data with the Psion Data Logger.

IV – Cleaning and returning the PIT tag reader

When a sampling session has been completed for the day, and *the test tag has been scanned to end the session* it is expected that samplers will clean the Cheese Block unit as best as they are able. Please follow these simple instructions to avoid damaging the Cheese Block while cleaning and returning the unit.

1. Detach each component
2. Cap each post on the cheese block before cleaning with water
3. Tightly cover the antenna racquet post with a hand before washing with water – do not let any water near the post.
4. Wash each component with light water - *please do not spray forcefully*.
5. Use the scrubbing wipes included in the Cheese Block bag to remove any fish blood/scales etc. still attached to the equipment.
6. Leave the Cheese Block bag partially open on one side for the trip back to the office to allow for air to circulate and dry the equipment.
7. Be sure to leave the Cheese Block bag and equipment on the sampling table in the CWT/PIT tag sampling area for downloading.

Appendix Two: Procedures/Protocol for PIT sampling in the Columbia River Sport Fishery

It is essential to follow the protocols and procedures below. Failure to follow these will lead to undetected PIT tagged fish, which will provide biased estimates of harvest and stock composition. Therefore, all staff will follow these procedures and protocols daily. If you have any questions please contact: Ben Warren @ Cell: (360) 635-2318, Office: (360) 906-6700 Ex: 6844 and/or E-mail Benjmin.Warren@dfw.wa.gov or your supervisor.

PIT tag units will be assigned to individual samplers at the beginning of their sampling season.

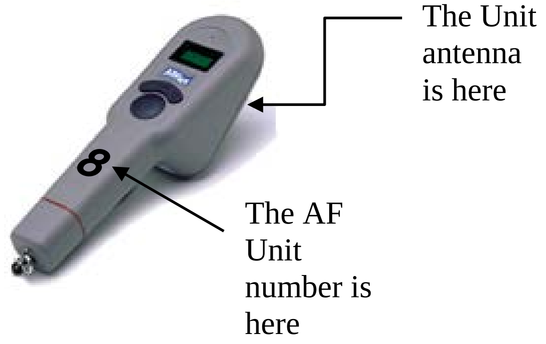
On occasions where units are not specifically assigned to samplers due to time constraints or last minute need, the PIT tag coordinator should be notified that a unit will be in use; crew leaders should ensure that this occurs. It will be the sampler's responsibility to ensure that the unit they have been assigned is charged and ready to sample with each sampling day, and to notify the PIT tag coordinator or their supervisor if any problems arise.

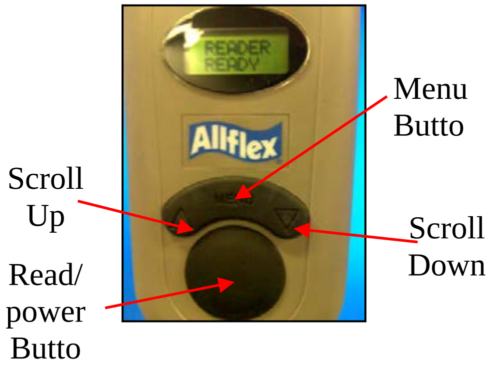
I – Parts of the R501-3 (Allflex) PIT tag reader

The primary PIT tag sampling unit that will be used for the detection of PIT tagged fish in Sports fisheries is the Biomark R501-3 reader, “lovingly” known as the Allflex.

As seen in Figure 1 below, a complete kit for Sport PIT tag sampling will include:

App. 2 - Figure 1: Complete kit for Sport PIT tag sampling





Blue “Start” Test Tag
Red “Stop” Test Tag

4 Rechargeable AA batteries
(usually installed in All Flex)

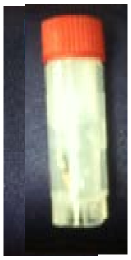
4 Alkaline AA batteries
(reserved for emergencies)

II – Using the R601-3 (Allflex) PIT tag reader correctly while sampling

1. **Select the PIT detector unit number into the header comments of each sampling form** – This number is found on the front handle of the Allflex units – use the dropdown menu to select the correct unit type and number combination.

2. **Scan the Blue test tag at the beginning of each session!!!** Each sampler will be given a blue "start" test tag.

3. **Scan the Red test tag at the end of each session!!!** Each sampler will be given a red "stop" test tag.



A session changes when you start a new sampling day or sampling type (i.e. – moving from a CREEL survey to a stream survey on the same day). It is very important to scan the blue test tag at the beginning of the session, and the red test tag at the end of the sampling session, because it shows that the PIT tag unit is working both before and after sampling, and the times that it was tested. **It is mandatory to scan the start test tag at the beginning of the sampling session, and the stop test tag at the end of the sampling session**.

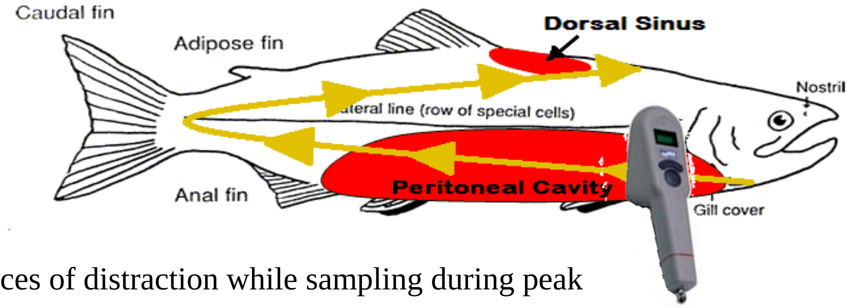
4. The preferred location for PIT tagging is the peritoneal cavity; gutted salmon **should not** be PIT tag scanned because it is unknown if PIT tag-loss has occurred. It is very important that gutted fish be sampled on a separate, CWT-Only sample form.

5. **The Allflex is not waterproof!!!** Unfortunately, the Allflex units are not waterproof – only water resistant. To combat this equipment shortfall, please do not submerge the Allflex units. If it is raining extremely hard, samplers should wrap the Allflex unit in a SNID plastic bag to protect the unit.

6. **The Allflex is not indestructible!!!** Unfortunately, the Allflex units are not extremely rugged. To combat this equipment shortfall, please try to keep the Allflex unit in hand or in your vest, and avoid placing the unit in any position where it may fall onto a hard surface / get crushed / get damaged. **Be AWARE of your surroundings.**

7. We will be using the **Pass-Over method** for scanning salmonids as illustrated below. The Allflex is set to turn on after pressing and holding the middle read button for one second. When the Allflex unit is powered on, *touch* the unit antenna perpendicular to the fish's lateral line. Press the center button once, and the unit will begin to scan for a PIT tag, and pass the antenna in an oval pattern over the fish as illustrated. Speed can affect the detection rate, so try to scan at a consistent medium speed, taking the full 5 seconds to complete the oval.

App. 2 - Figure 2: Correct application of the Pass-Over Method using the All Flex unit.



8. **Look at the Allflex screen!!!** There are many sources of distraction while sampling during peak times in a sport fishery. The only way to ensure that all PIT tags are accounted for is to look at the Allflex screen **for every fish scanned, every time.**

App. 2 - Figure 3: Common All Flex display messages

III READING **overy II** PIT Tag found No Tag Found

9. During sampling, PIT tagged fish will be recorded in the Psion Data logger. To use the Psion Data Logger to populate the PIT Tag # field:

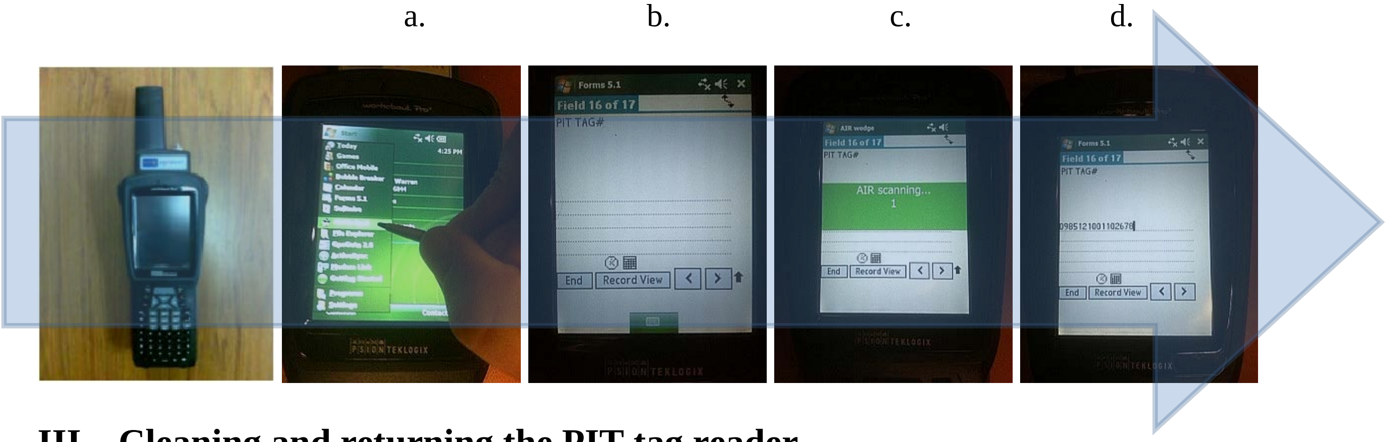
a. Ensure that the program AirWedge2 has been activated (you only need to check this at the beginning of the sampling period – not every time you scan a PIT tag)

b. Ensure that the PIT Tag # field is selected

c. Press the ⌃ button on the Psion to begin scanning for the PIT tag

d. When the PIT Tag has been successfully interrogated, the <u>PIT Tag #</u> field will populate with a 14 digit decimal number.

App. 2 – Figure 4: Procedure for capturing a PIT tag with the Psion Data Logger.



III – Cleaning and returning the PIT tag reader

When a sampling session has been completed for the day, and *the blue test tags have been scanned to end the session,* it is expected that samplers will clean the Allflex unit as best as they are able.

- Do not spray the Allflex unit directly with strong jets of water
- Clean with a wet cloth – or cleaning wipes are available in the PIT/CWT samplers area

At the end of each sampling week, it is expected that samplers will turn-in their Allflex to be downloaded, checked, and batteries replaced if needed. Samplers must leave their Allflex unit in the PIT Tag downloading area, labeled “PIT Tag units to download”.

Each sampler will have the Allflex unit that they have been assigned returned after it has been downloaded. Allflex units will be returned to each individual sampler’s mailbox – unless samplers have a more obvious alternative (i.e. cubical desk for crew leaders).

Estimates of Columbia River Salmon and Steelhead Harvest Rates for 2011 Sport, Commercial, and Treaty Fisheries based on Passive Integrated Transponder (PIT) Tags

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Extended Abstract

In 2010, the Washington Department of Fish and Wildlife (WDFW) and the Pacific States Marine Fisheries Commission (PSMFC) added Passive Integrated Transponder (PIT) tag sampling to the existing mainstem Columbia River fishery sampling program that collects biological data and recovers Coded Wire Tags (CWT) from sport and commercially harvested salmon and steelhead for use in salmon recovery and fisheries management decisions. We conducted a study to determine the feasibility of using PIT tags recovered from fisheries to estimate harvest rates for Columbia River salmon and steelhead. In our study, we estimated PIT tag detection rates using handheld scanners and expanded PIT tags recovered in fall fisheries based on these detection rates and sample rates of fisheries. Expanded tag recoveries from fisheries sampling were divided by total PIT tagged adult returns to Bonneville Dam (BON) to estimate harvest rates for PIT tagged upriver (above BON) populations (Rawding et al. 2014a). This harvest study was opportunistic in that it took advantage of the existing juvenile PIT tagging program throughout the Columbia River Basin to estimate harvest rates.

In 2011 we expanded sampling for PIT tags to the spring, summer, and fall sport and commercial fisheries below BON and the summer and fall treaty fisheries above BON. As expected, harvest rates were variable and imprecise when adult PIT tag returns to BON were low or when there were only a few tag recoveries in the fishery. Estimates of harvest rates below BON in the commercial fisheries, and particularly in the sport fisheries, were less precise than above BON due to lower tagging rates and smaller numbers of tag recoveries. To address this concern, we calculated harvest rates at a range of population scales including individual release groups and major tributaries, Evolutionary Significant Units (ESU)/Distinct Population Segments (DPS), and for larger population aggregates. Pooled tag groups used to estimate harvest rates were supported both by life history attributes and 2011 run timing graphs for each species at BON.

Harvest rate estimates based on PIT tags were very similar to estimates made by the US v Oregon Technical Advisory Committee (TAC) for several stocks including spring Chinook salmon during the spring commercial fishery, coho salmon during the fall commercial fishery, sockeye salmon during the treaty summer fishery, Bonneville Pool Hatchery Chinook salmon during the fall treaty fishery, and upriver spring Chinook in the sport fishery. In contrast, PIT tag harvest estimates diverged substantially from TAC estimates for summer commercial and treaty catches of Upper Columbia summer Chinook and treaty catches of B-run steelhead. Differences between TAC and PIT tag harvest estimates may be explained in part by the criteria used to estimate harvest rates by TAC, which in some cases depend on counts, timing, and length of returning adults at BON that do not necessarily correspond to the designated populations for which PIT tag estimates were made. Additionally, we detected age or size selectivity of the catch in several fisheries relative to the escapement. Therefore, our harvest rate estimates, which were not stratified by age, were likely biased low for adults and larger fish and biased high for jacks and smaller fish due to higher catch rates of larger fish in net fisheries.

In addition, for our harvest rate estimates we used PIT tag returns and counts at BON to populate a mixture model to estimate the abundance of early and late upriver coho stocks and the harvest rates for these groups in the Zone 6 treaty fishery. We also used timing information based on PIT tag detections at BON in conjunction with information on tagging rates of adults to estimate

sockeye run timing and stock composition at BON for the Snake, Wenatchee, and Okanogan populations.

We recommend the continued recovery of PIT tags as part of the fishery sampling program as well as the development of age or size structured harvest estimates using PIT tag data. Since this was a feasibility study, final salmon and steelhead Columbia River harvest estimates by reporting group are available in WDFW and ODFW (2012).

Introduction

Passive Integrated Transponder (PIT) tagging of salmonids in the Columbia River Basin has served a variety of purposes including estimation of juvenile and adult survival and the investigation of mechanisms affecting survival (Connor et al. 1998, Zabel and Accord 2004, Buchanan et al. 2006) such as avian and northern pikeminnow predation (Collis et al. 2001, Petersen and Barfoot 2003), and habitat characteristics (Paulsen and Fisher 2005). According to the Columbia Basin PIT Tag Information System (PTAGIS), a database operated by the Pacific States Marine Fisheries Commission (PSMFC), the number of salmonids PIT tagged annually in the Columbia River Basin has increased from less than 20,000 in 1988 to over 2,000,000 in 2009. In addition, the number of returning PIT tagged adults, as measured by detections at Bonneville Dam (BON), has recently exceeded 30,000 individuals. Over the last thirty years, detection systems have advanced from hand held devices (Buzby and Deegan 1999) to detectors located in juvenile bypass systems and adult traps and ladders (Harmon 2003), and instream arrays capable of passively detecting tagged adult and juvenile fish as they migrate (Connolly et al. 2008). Almost $4,000,000 annually is dedicated to the purchase of PIT tags and millions more are spent capturing and tagging fish, recovering tags, and storing data in PTAGIS. Harvested PIT tagged fish represent one of the largest sources of unaccounted mortality for PIT tagged fish in the Columbia Basin and could provide valuable information to researchers, managers, and policy makers. This is especially true of harvest rates for groups of fish that are generally not tagged with coded-wire tags (CWT) but are often PIT tagged. These groups often include natural origin (hereafter “wild”) salmon and steelhead that belong to populations listed as threatened or endangered under Endangered Species Act (ESA). Thus, PIT tag recoveries in fisheries may also allow managers to better estimate harvest impacts on at-risk wild populations and to shape fisheries to reduce impacts on ESA listed fish based on their spatial and temporal occurrence. Estimates of fishery harvest rates based on PIT tag recoveries were first made by Rawding et al. (2014a), but were limited to fall commercial and treaty fisheries. The purpose of this study was to estimate the harvest rate of salmon and steelhead based on PIT tags recovered in below BON sport and commercial, and above BON treaty mainstem Columbia River fisheries sampled in the spring, summer, and fall 2011 fishery seasons.

Methods

Overview of Fisheries and Data Collection

Columbia River mainstem fisheries above and below BON were sampled through a coordinated effort between the Washington Department of Fish and Wildlife (WDFW), the Oregon Department of Fish and Wildlife (ODFW), and PSMFC (Figure 1). All catch that is sold commercially from the Zones 1-5 below BON commercial fishery and the Zone 6 above BON treaty fishery is recorded in pounds (lbs.) on fish tickets and this information is reported to WDFW and ODFW by commercial buyers. This total represents the total reported commercial catch in Zones 1-5 below BON, however some treaty catch in Zone 6 is instead sold “over the bank” to the public or is retained for personal use. This catch, not sold to commercial buyers, is reported by treaty tribes as non-ticketed catch (number of fish by species).

Commercial and treaty fishery catches that are sold to buyers are sampled for CWT and PIT tags. A systematic sample of weights of undressed harvested salmon and steelhead are taken to convert the landed pounds of fish on the fish tickets into an estimate of the total number of fish harvested by species and period. The original purpose of the fishery sampling program was to estimate the individual stock contributions to the overall catch using CWT groups primarily from hatchery production. However, this same CWT sampling program has been used to collect data for mixed stock genetic fishery analysis (Kassler et al. 2002) and in this project WDFW and PSMFC sampling was expanded to include scanning of harvested adult salmon and steelhead for PIT tags. In Zones 1-5 the commercial fishery catches that are landed in Oregon are primarily sampled by ODFW, with WDFW and PSMFC sampling the Washington landings. In Zone 6, PSMFC and WDFW sample the majority of the treaty catch sold to commercial buyers in both Oregon and Washington. Sport fisheries are sampled through a creel of anglers to estimate catch and collect biological data including CWT and PIT tags. Creel data is expanded to estimates of total sport catch through the use of effort expansions based on aerial effort counts.

Commercial fisheries targeting salmon occur below BON in Zones 1-5 throughout much of the year and are managed as discrete seasonal fishery periods corresponding to their seasonal timing. These fishery periods are described in WDFW and ODFW (2012) and are briefly summarized below:

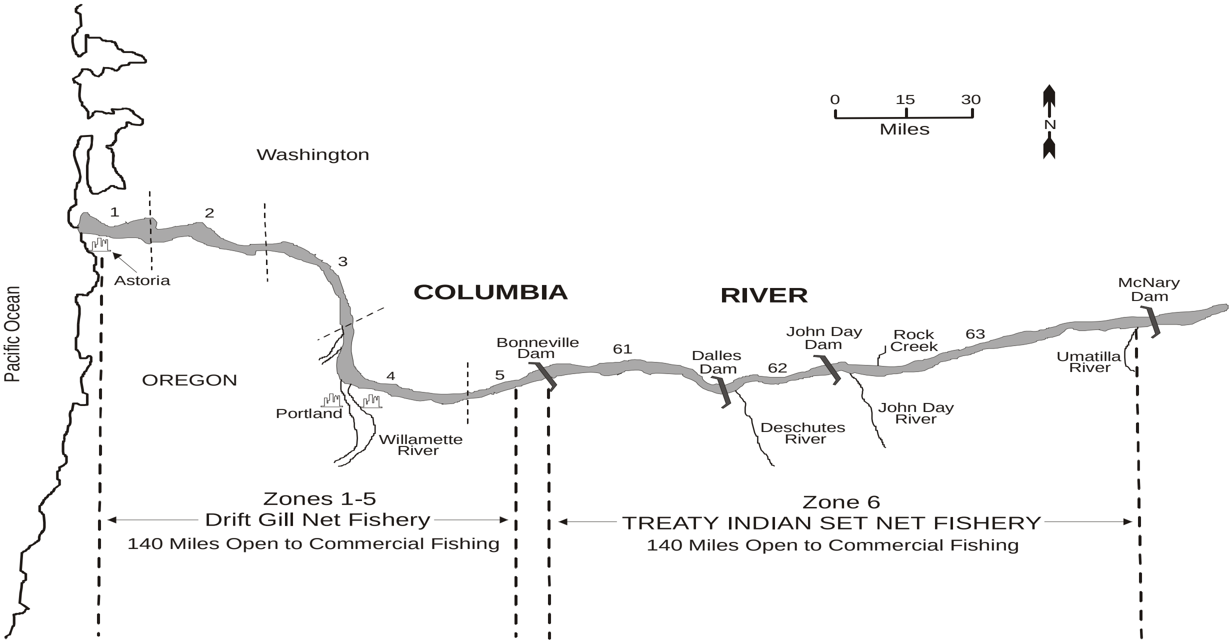
- A spring (January 1-June 15) fishery which retained only hatchery Chinook. Openings occurred on March 29 and April 6 and operated with a maximum of 4.25 inch mesh tangle net gear and on May 12-13 and May 18-19 with 8 inch minimum drift gillnet gear.
- A summer (June 15-July 31) fishery which retained wild and hatchery Chinook and a small number of sockeye salmon. Openings occurred on June 16-17 and June 22-23 and operated with 8 inch minimum mesh.
- A fall fishery was a drift gillnet fishery with the following mesh restrictions: 9 to 9.75 inches in August with openings nightly on August 4-5, 18-26, and 28-31, 8-9.75 inches from September 18 to Oct 20 with nightly openings September 18-21, 28-29, and October 5-6, October 13-14, and 18-20. There were also daytime openings with 6 inch maximum mesh on October 13 and 19.

Treaty fisheries retaining salmon occurred above BON in Zone 6 throughout much of the year and were managed as discrete seasonal fishery periods corresponding to their seasonal timing. Gear types include set gillnets, hook and line angling, and platform dip nets. Treaty fisheries are non-mark selective and thus retain both wild and hatchery origin salmon and steelhead. The 2011 fishery periods included:

- A spring fishery which used primarily platform dip net and hook and line gears and operated from May 10 – June 15; this fishery was not sampled for PIT tags and therefore harvest estimates are not reported for this fishery.
- A summer fishery which included set nets and platform dip net and hook and line gears and operated from June 20-July 31. There were no set net mesh restrictions until July 11 when a 7.25 inch minimum was required for the rest of the season.
- A fall fishery which included set nets and platform dip net and hook and line gears and operated from August 1-October 6.

Sport fisheries targeting salmon occur below BON in Zones 1-5 throughout much of the year, and although regulations change according to time period, catch is estimated only by calendar month. Regulations for open sport fisheries are briefly described below:

- Jan 1-April 19: Hatchery Chinook and hatchery steelhead retention.
- May 15-June 15: Hatchery Chinook, sockeye, and hatchery steelhead retention.
- June 15-July 18: Hatchery Chinook, sockeye, and hatchery steelhead retention.
- July 18-July 31: Sockeye and hatchery steelhead retention.
- August 1-Dec 31: Hatchery steelhead, hatchery coho retention, and hatchery and wild Chinook retention, with periodic area closures for Chinook.



Commercial Fishing Zones on the Columbia River Below McNary Dam.

Figure 1. Map of commercial fishing zones sampled in the 2011 sport, commercial, and treaty fisheries.

Juvenile salmon and steelhead throughout the Columbia River are tagged using standard Columbia Basin PIT tagging procedures from the Columbia Basin Fish and Wildlife Authority (CBFWA, 1999). In 2010, adult salmon and steelhead in the fall fisheries that were not dressed (gutted) were sampled by WDFW and PSMFC samplers for CWT and PIT tags. Sampling for PIT tags was conducted with a Destron Fearing (DF) FS2001F-ISO Reader Base Unit with racquet antenna. More details on the fishery sampling can be found in Nandor et al (2011). Adult salmon were scanned for PIT tags using the pass over method (Rawding et al. 2014b). The PIT tag number and date/time of each detection were recorded on the scanner and later downloaded at the office. If a sampler observed that a PIT tag was detected as indicated by the scanner LCD screen, the last four digits of the PIT tag number along with biological information including species, date, length, sex, and fin marks were recorded on a data form. This was done to link the PIT tag to the related biological information. However, because samplers work in a noisy environment and sample a high volume of fish, many times the beep was not heard and only the PIT tag number and date stamp were recorded on the scanner. For these fish, biological information at the time they were tagged was obtained from PTAGIS, however biological information at the time of detection was not available. In addition to PIT tag detections, samplers maintained a count of the number of each species of fish sampled for PIT tags at each location for a specific time period called a session. At the end of the season, all fish detected with PIT tags were uploaded to PTAGIS.

Unlike the intent of the CWT program, which is to estimate harvest, PIT tagging of salmon and steelhead occurs for reasons other than evaluating harvest. Therefore, using PIT tags to estimate harvest rates is opportunistic, much like studies of bird predation on juvenile salmonids (Collis et al. 2001). Owing to its different primary objectives, PIT tagging in the Columbia River Basin lacks a study design phase similar to that which is implemented for the CWT program involving power analysis to ensure that tagging and sampling programs release and recover enough tags to meet management precision goals (Bernard and Clark 1996, Bernard et al. 1998). As a result, some small juvenile PIT tag release groups have a low probability of surviving to the adult stage and an even lower chance of being sampled in fisheries. Reporting harvest rates for these small individual tag groups may lead to imprecise harvest estimates. Although there are no exact guidelines for the minimum number of tags needed to estimate harvest rates per group, Hankin et al. (2005) suggest about 10 recoveries per stratum, which is similar to the range of 5-10 tag recoveries for mark-recapture studies (Seber 1982, Schwarz and Taylor 1998). Therefore, we reported harvest for groups with a minimum of one recovered tag but we also pooled tag groups into larger aggregates by river, management group, and Evolutionary Significant Units (ESU) or Distinct Population Segments (DPS) for reporting purposes to address the potential bias in harvest rates caused by the low number of recoveries.

The catch or landings data were obtained from a variety of sources including: 1) WDFW and ODFW (2012), 2) landings for 2011 Columbia River Mainstem Fisheries available at from ODFW (http://www.dfw.state.or.us/fish/OSCRP/CRM/comm_fishery_updates_11.asp). Individual fish weights were based on sampling these fisheries and provided by ODFW. The PIT tag sampling rate was provided by PSMFC (Bryant Spellman, PSMFC, unpublished data) and all PIT tag information including fishery catch, mainstem dam, and other detections were queried from PTAGIS.

Harvest Reporting Groups

Arbitrary pooling of returning individuals from various release sites or populations can lead to aggregate groups of fish that may not experience homogenous harvest rates. However, the population structure of Columbia River salmon and steelhead has been summarized by Weitkamp et al. (1996), Busby et al. (1996), Myers et al. (1998), and McClure et al. (2003). These authors suggest that salmon and steelhead populations are hierarchically organized into major population groups and then ESU or DPS.

We hypothesized that ESU or DPS membership would be a suitable surrogate for susceptibility of individuals and populations to harvest. Individuals and populations comprising an ESU or DPS share similar life history attributes, such as size and age at maturity and migratory timing, both of which are known to affect susceptibility to harvest (Kendall et al. 2009). Therefore, in order to estimate harvest rates we needed to group individuals by run timing and other population membership information. We decided upon three kinds of harvest reporting groups organized around ESUs and DPSs at hierarchical spatial scales: 1) a series of "ESU/DPS" groups which included all returning PIT tagged fish that could be assigned to an "ESU/DPS" group based on their release site, species, and run type or in the cases of unlisted populations (e.g., coho salmon above the White Salmon and Hood rivers) to spatial groups organized to mimic existing ESUs for other species; 2) a series of smaller spatial scale "Rivers" groups which included all releases in individual major rivers or other subpopulation aggregates comprising the various "ESU/DPS" groups; and 3) a series of "Large Aggregates" groups which pooled harvest rates at varying spatial scales greater than the "ESU/DPS" groups. At each of these levels, we also estimated harvest rates for hatchery and wild origin fish separately, as well as pooled. We restricted our dataset to only PIT tagged returns with release sites, species, rear types, and run types that could unambiguously be assigned to one of our categories. For example, all fish tagged at BON as jacks or adults were excluded; all Chinook with an unknown run type were excluded, steelhead tagged as smolts at mainstem Columbia River dams below the Snake were excluded since they could not be assigned to "ESU/DPS" groups and we did not calculate an overall "Above BON" harvest rate for steelhead.

In order to determine whether pooling of our harvest groups was appropriate, we developed a graphical analysis to determine whether candidate members of a potential group shared similar run timing at BON. We plotted the cumulative run timing of candidate groupings of returning PIT tagged salmon and steelhead. We compared the timing of fish from each "ESU/DPS" as well as each major tributary or subpopulation "Rivers" group contributing to each "ESU/DPS" group with at least 10 returning adults detected at BON. Steelhead were further divided in the Snake River into Snake River A and B runs based on Busby et al. (1996). Chinook salmon were subdivided beyond the ESU level in a few cases based on traditional harvest accounting in the Columbia River (e.g., Lower Columbia Chinook were split into "Bright" and "Tule" groups, and Hanford Reach Chinook were separated from Upper Columbia and Middle Columbia River stocks). Based on the graphical analysis we developed groups with similar timings for harvest analysis.

Statistical Analysis

A Bayesian framework was used to estimate parameters in our analysis (Gelman et al. 1995). The goal of the Bayesian approach is to calculate the probability of a specific parameter (θ) given the data (x), written as p(θ|x). Bayes theorem is a conditional probability statement that proves the p(θ|x) is proportional to the sampling distribution for the data p(x|θ) multiplied by an independent probability distribution for the parameter, p(θ) (Gelman et al. 1995). The formula of the posterior distribution may be complex and difficult to derive. Samples from the posterior distribution can often be obtained using Markov chain Monte Carlo (MCMC) simulations (Gilks et al. 1996). WinBUGS is a software package that implements MCMC simulations using a

Metropolis within Gibbs sampling algorithm (Spiegelhalter et al. 2003) and has been used in salmonid studies (Rivot and Prevost 2002, Link and Barker 2010).

One of the most controversial aspects of the Bayesian approach is the specification of priors. We used vague priors for this analysis with the intent that the posterior distribution be dominated by the observed data. When this occurs the results obtained from Bayesian and maximum likelihood methods yield similar results (Kery 2010). The priors are specified below and are standard vague priors which allow the data to form the posterior distribution. Convergence was tested using the Brook-Gelman-Rubin (BGR) diagnostic (Ntzoufras 2009) and precision was assessed by monitoring MC % error. The BGR diagnosis compares the between and within sample variability. Although convergence cannot be assured, a BGR value of less than 1.1 is generally acceptable, and indicates that the MCMC simulations have stabilized (Kery 2010). The MC % error measures the variation of a parameter due to simulation, and to obtain precise parameter estimates it is recommended that the MC% error divided by the standard deviation be less than 5% (Lunn et al. 2002).

Detection Study

A study was performed by Rawding et al. (2014b) in order to determine the efficiency of handheld readers in detecting PIT tags in adult salmon and steelhead during the sampling of fisheries catch. Estimates of detection efficiency from this study were used to expand tag detections during fisheries sampling in order to account for missed tags. In order to propagate the uncertainty in detection rates into the uncertainty associated with the harvest estimates the estimates of detection rate and associated uncertainty reported by Rawding et al. (2014b) were incorporated into our harvest model (Table 1). Allflex readers were used for sport fishery sampling, while Destron Fearing readers were used for commercial and treaty fishery sampling.

Table 1. Estimates of detection probability by species and scanner type from the two different PIT tag detection models (AF=Allflex, DF=Destron Fearing) from Rawding et al. (2014b).

Species	Scanner	detection rate	detection rate (sd)	2.50%	median	97.50%
Chinook	AF	98.79%	0.42%	97.85%	98.84%	99.47%
Chinook	DF	99.52%	0.22%	98.99%	99.55%	99.85%
coho	AF	99.74%	0.10%	99.50%	99.75%	99.90%
coho	DF	99.89%	0.07%	99.71%	99.90%	99.98%
steelhead	AF	99.80%	0.10%	99.56%	99.82%	99.95%
steelhead	DF	99.92%	0.06%	99.75%	99.93%	99.99%

Harvest Model Components

The estimate of total catch in the treaty fishery is estimated through a creel program operated by the treaty tribes and is reported to the TAC. The catch from this fishery can be split into ticketed catch (i.e. sold to large buyers/processors) reported in pounds of fish by species, and non-ticketed catch reported as counts of fish by species. It should be noted that a variance for the total catch and the non-ticketed portion is currently not available (Marianna McClure, CRITFC, pers.

comm.). Since the non-ticketed portion of the treaty catch is not sampled by WDFW, ODFW or PSMFC, we estimated it by subtracting the ticketed catch, which includes variance from uncertainty in the average weights, from the total catch reported by the treaty tribes. Total counts of fish are determined in the non-tribal commercially caught salmon and the ticketed portion of the treaty catch in Washington and Oregon. To do this, total pounds by species, which are reported to the states in pounds on fish tickets, were converted to counts of fish through dividing by the average weight of each species collected from a subsample of commercially sold fish (treaty or non-tribal commercial origin) in each fishery period. In a small number of fishery periods, few enough of a particular species were caught that none were sampled, so weights from adjacent fishery periods were used to estimate catch. Mainstem sport catch is estimated for each month through a creel program below BON; however, variance estimates are not currently available. The posterior probability distributions of stochastic and derived parameters in our harvest model were estimated in a Bayesian framework based on following equations:

The mean weight for commercially sold catch of a particular species can be estimated by

$$weight_{ji} \sim Normal(wt\_mu_j, wt\_tau_j) \qquad (1)$$

where i is an individual $weight_i$ in period j, wt_mu_j is the estimated mean weight, and wt_tau_j is 1/variance for each period j. The ticketed catch (count of fish) is estimated by

$$T\_catch_j = (lbs_j / wt\_mu_j) \qquad (2)$$

where lbs_j are the pounds of fish. The total reported catch for a period, $catch_j$ is the sum of the ticketed catch and the non-ticketed catch (only Zone 6 treaty fishery), which is used for ceremonial and subsistence purposes or sold directly to the public and is estimated by

$$catch_j = T\_catch_j + NT\_catch_j \qquad (3)$$

where NT_catch_j is the non-ticketed catch. This method was used to account for uncertainty in the weekly ticketed catch in the Zone 6 treaty fishery, whereas $catch_j$ was exactly equal to T_catch_j in the commercial fishery. For the sport fishery equations 2 and 3 were not used since total harvest was provided as fish rather than weights, and consequently, $catch_j$ was treated as data for this fishery, with no estimates of uncertainty. A subsample of ticketed catch is inspected for PIT tags as described in the sampling section and was assumed to be representative of the non-ticketed catch with respect to population composition within a fishery period:

$$samp_j \sim Binomial(p\_samp_j, catch_j) \qquad (4)$$

where $samp_j$ is the weekly number of fish landed that were sampled, and p_samp_j is the proportion of the weekly catch that was sampled. The expanded number of tags by group k is estimated by

$$x\_tag_{jk} = (tag_{jk} / p\_samp_j) / h\_\mathrm{det}) \qquad (5)$$

where k denotes the harvest reporting group, x_tag_{jk} is the expanded number of weekly tags, tag_{jk} is the number of sampled tags in the fishery, and h_det is the PIT tag detection rate using handheld detectors. The total tags by group in the fishery is estimated by

$$sum\_tag_k = \sum_{k=1}^{K} (x\_tag_{jk}) \qquad (6)$$

which is the sum of the weekly expanded tags by group. Since not all PIT tags are detected at BON we estimated the PIT tag detection rate at BON by

$$B\_tags \sim Binomial(pBON\_\mathrm{det}, M\_tags) \qquad (7)$$

where *pBON_det* is the probability of being detected at BON, based on the number of unique PIT tags detected at McNary Dam (MCN) plus those missed at BON (*M_tags*), and *B_tags* the number of PIT tags detected at BON. The expanded number of tags by group passing BON is estimated by

$$xBON\_tag_k = BON\_tag_k \,/\, pBON\_\mathrm{det} \qquad (8)$$

where $xBON\_tag_k$ is the expanded number of tags per group. The harvest rate in the Zone 6 treaty fishery was estimated by

$$sum\_tag_k \sim Binomial(HarvRate_k, x\_BON\_tag_k) \qquad (9)$$

based on the expanded tags in the fishery and those passing BON, whereas harvest rates in fisheries below BON were estimated by

$$sum\_tag_k \sim Binomial(HarvRate_k, x\_BON\_tag_k + sum\_tag_k) \qquad (10)$$

in order for the denominator in below BON harvest rates to include fishery removals between BON and the river mouth as previously described, by adding the expanded PIT tag catch to the expanded BON estimate of tags. To complete the Bayesian analysis, we specified vague priors so the posterior distribution would be dominated by the data. We used the following vague priors for the weights and proportions

$$mu_j \sim Normal(0,0.001) \qquad (11)$$

$$tau_j \sim Gamma(0.001,0.001) \qquad (12)$$

$$p\_samp_j \sim Beta(0.5,0.5) \qquad (13)$$

$$pBON\_\mathrm{det} \sim Beta(0.5,0.5) \qquad (14)$$

$$HarvRate_k \sim Beta(0.5,0.5) \qquad (15)$$

for equations 1, 2, 4, 7, 9, and 10.

Coho Salmon Mixture Model

Graphical examination of the daily BON coho salmon count data indicated two peaks and suggested there may be two run timing components to the above BON coho salmon population. Weitkamp et al. (1996) indicated that there are early and late timed salmon populations in the Columbia River. Further inspection of the data indicated that only the early portion of the run was PIT tagged. Using our approach detailed above we can only estimate the harvest rate for the early run. However, the harvest rate of the late coho salmon population is of interest to fishery and hatchery managers to assess the contribution of these fish to fisheries. Our basic approach was to use mixture models to estimate the proportion and total number of early and late coho salmon passing BON. We estimated the harvest rate for the early group based on PIT tags as described above and estimated the catch of early coho salmon by multiplying the early coho harvest rate by the number of early coho salmon passing the dam. The number of late fish harvested was estimated by subtracting the early coho catch from the total harvest, the late coho salmon harvest rate is a function of the number of late coho salmon caught in the fishery and passing BON.

Mixture models are a class of models used to estimate subpopulations within the overall population using a different probability distribution to represent each subpopulation (Marin and Robert 2007). Finite mixture models have a specified number of subpopulations that sum to 100%. We used the PIT tag abundance and timing of the early coho salmon along with the BON count data to help define mixture components. This is referred to as the incomplete data model because not all early coho salmon are PIT tagged. Typical fishery application for mixture models include estimating ages based on length frequency data or timing of fish runs (Macdonald and Pitcher 1979; Flynn et al. 2006, Holt 2006, Anderson and Beer 2009). For coho salmon, we observed a bimodal migration pattern at BON and noticed the tags were only detected from the first mode. Therefore, we pursued the use of mixture models in conjunction with the harvest estimates to estimate harvest for the second mode. We assumed the mixture was comprised of two normally distributed run components for:

$$Nj_t = Pj\left[\frac{1}{\sqrt{2\pi\sigma_j^2}}\exp\left(-\frac{day_t-\mu_j}{2\sigma_j^2}-\right)\right] \tag{16}$$

j=1,2 for the first two components, Nj_t is the predicted count of salmon for each of the components at time t, day_t is Julian day , μ_j is the mean date of passage, and σ_j is the standard deviation of the day of arrival. The predicted number of fish present on each day is;

$$NT_t = (N1_t + N2_t)Total \tag{17}$$

where *Total* is the count of coho salmon passing the BON fish ladder. The statistical model allows normal process error in the counts is:

$$CT_t \sim Normal(NT_t, prec) \tag{18}$$

where CT_t is the daily count at BON and *prec* (e.g., 1/variance) allows a normal error structure in the counts and the number of coho salmon in each component is:

$$coho_j = P_j Total\ . \tag{19}$$

To allow better mixing the second mean date of passage is estimated as;

$$\mu_2 = \mu_1 + K \tag{20}$$

where K is the difference between the mean dates of arrival. The early catch is estimated by:

$$E\_catch = e\_HarvRate * coho_1$$

where $coho_1$ is the abundance estimate for early coho and *e_HarvRate* is the harvest rate based on PIT tags for the early component calculated from equation 11. The catch for the late period is estimated by:

$$L\_catch = \sum_{i=1}^{periods} catch - E\_catch. \tag{21}$$

where catch is estimated as from equation 4. The harvest rate for the late component is estimated by:

$$L\_HarvRate = L\_catch / coho_2 \tag{22}$$

where the $coho_2$ is the abundance for the second component. To finish specifying the model, we placed a prior on the proportions of the first components and estimate the second component by subtraction:

$$P_1 \sim Beta(1,1) \text{ and } P_2 \sim 1 - P_1 \qquad (23, 24)$$

And used a vague prior for both *K* and *prec*:

$$K \sim dgamma(0.001, 0.001),\ prec \sim dgamma(0.001, 0.001) \qquad (25, 26)$$

and for the standard deviation of the second component, a vague uniform prior was used:

$$\sigma_2 \sim dunif(1,15). \tag{27}$$

We used PIT tagged jack and adult coho salmon to estimate the prior for the first mixture component:

$$day_j \sim Normal(\mu_1, tau_1) \tag{28}$$

where day is the date for each PIT tag coho salmon passing BON, μ_1 is the estimated mean date of passage, and tau_1 is the 1/variance for the first period.

Sockeye stock composition and Okanogan harvest rate

Sockeye salmon in the Columbia River almost exclusively belong to three populations: the Wenatchee, Snake, and Okanogan rivers. However, only the Wenatchee and Snake populations are PIT tagged as juveniles, allowing direct estimation of harvest rates based on PIT tags. We developed an alternate method, termed the “subtraction method”, to estimate Okanogan sockeye abundance at BON, Zone 6 catch, and harvest rate. When using the subtraction method, we assumed all non-Snake or non-Wenatchee sockeye belonged to the Okanogan population, which is generally consistent with the present understanding of Columbia River sockeye. In future years, this method may need to be modified to account for growing sockeye populations in the Yakima and Deschutes rivers.

We estimated the proportion of the Wenatchee and Snake adult sockeye salmon that were PIT tagged based on the ratio of PIT tagged to total counted sockeye in the Wenatchee and Snake basins. For Snake River populations we used Lower Granite Dam ladder counts. For the Wenatchee population we used Tumwater Dam ladder counts, located below Lake Wenatchee on the Wenatchee River, and below all known spawning areas. We made the following assumptions:

1) Counts of sockeye at Tumwater and Lower Granite Dam were censuses and all fish were accurately identified and enumerated;
2) Adults PIT tagged as juveniles accurately represented the timing of adults passing BON;
3) Survival of adults tagged as juveniles to upstream dams were the same as untagged adults;
4) All adult sockeye salmon with PIT tags were detected at Tumwater and Lower Granite dams.

The proportion of the tagged population is estimated by

$$Tsk_i \sim Bin(p\_skT_i, SkDam\_Ct_i) \tag{29}$$

$$p\_skT_i \sim Beta(0.5,0.5) \tag{30}$$

where "i" is the population index with 1 denoting Wenatchee and 2 denoting Snake, Tsk_i is the number of PIT tag sockeye detected at Tumwater and Lower Granite dams, $SkDam\_Ct_i$ is the number of sockeye passing these dams, and p_skT_i is the proportion of sockeye passing these dams that were PIT tagged.

The number of Wenatchee and Snake PIT tags is summed by statistical week and divided by the proportion of each population that is PIT tagged and is estimated by

$$BONsk_{wi} = Tsk_{wi} / p\_skT_i \tag{31}$$

where "w" is the statistical week, the $BONsk_{wi}$ is the number of sockeye from the Wenatchee and Snake populations detected at BON, and Tsk_{wi} and the number of PIT tagged sockeye from each population by week.

The weekly estimate of Okanogan sockeye passing BON is estimated by

$$BONsk_{w3} = BON\_Ct_w - \sum_{i}^{2} BONsk_{wi} \tag{32}$$

where "3" is a population index denoting Okanogan and BON_Ct_w is the weekly count of BON sockeye salmon.

The total number of Wenatchee and Snake River fish harvested is the harvest rate of these groups calculated from PIT tags times the estimated number of these fish passing BON and estimated by

$$Sk\_Harv_i = BONsk_i * Z6\_skHR_i \tag{33}$$

where the Sk_Harv$_i$ is the number of sockeye harvested from the Wenatchee and Snake populations and $BONsk_i$ is the seasonal estimate of these sockeye populations passing BON dam, and $Z6\_skHR_i$ is the seasonal harvest rate for these populations.

The number of Okanogan sockeye salmon harvested in the Zone 6 fishery is calculated by subtracting the number of Wenatchee and Okanogan sockeye from the total Zone 6 catch and is estimated by

$$Sk\_Harv_3 = HarvTot - \sum_i^2 Sk\_Harv_i \tag{34}$$

where Sk_Harv_3 is the total number of Okanogan sockeye salmon harvested and *HarvTot* is the total number of sockeye salmon harvested in Zone 6.

The Okanogan sockeye salmon harvest rate is the number of Okanogan harvest in Zone 6 divided by the BON estimate of Okanogan origin sockeye salmon and is estimated by

$$Z6\_SkHR_3 = Sk\_Harv_3 / BONsk_3 \tag{35}$$

where $Z6\_SkHR_3$ is the Okanogan harvest rate, Sk_Harv_3 is the total number of Okanogan sockeye salmon harvested in the Zone 6 fishery, and $BONsk_3$ is the seasonal estimate of Okanogan sockeye salmon passing BON dam.

Size Selectivity

Assigning catch to specific age classes is an important aspect of estimating fishery exploitation rates and is necessary for accurate run reconstruction. It also allows for measurement of potential age-based fishery selection (Kendall et al. 2009). We evaluated age selectivity by comparing the catch to the run before fisheries in Zone 6. For lower river sport and commercial fisheries, we compared the catch of upriver stocks to the run at BON. Fishery removals may have influenced our estimates of selectivity for lower river fisheries, however these effects were likely minimal where harvest rates were low.

To evaluate selectivity we developed methods to compare the age distribution in the catch relative to the run. Our assignment of ages was based on PIT tags which were implanted in fish as juveniles and later interrogated at BON, as well as in fisheries catch. PIT tags are implanted in juvenile salmonids at a variety of sizes and ages and specific freshwater ages are not always available. However, adult size in salmonids is predominantly explained by the amount of time spent at sea (e.g., Quinn 2005), which is a variable we can measure with PIT tags based on release dates and return dates. Since age selectivity principally operates through selectivity on different ocean age classes of differing sizes, we compared the ocean age of catch relative to the run as a whole.

We developed a set of criteria to assign steelhead, coho and Chinook salmon to ocean ages based on the time of year at which they were tagged as juveniles, the duration between tagging and return to BON (travel times), and in the case of steelhead, their juvenile size and time of year at tagging. First, frequency histograms of travel times were plotted to identify modes in the data. Second, tag histories were examined for fish near and within each of the modes to confirm that they were of the same ocean age (e.g., out-migrated the same spring). If tag histories confirmed that each mode represented only one age class, a threshold was identified that would correctly classify fish to one of the ocean age modes. For coho, Chinook, and sockeye salmon, which have shorter and less plastic life histories in freshwater than steelhead, identification of thresholds was possible for all PIT tagged fish. For steelhead, more variable ages at tagging and release, and the ability of some steelhead to remain in freshwater after tagging for another year or more, necessitated that we censor our dataset in order to accurately classify ocean age for only a subset of individuals. In order to confidently assign ocean ages to steelhead, we excluded all fish tagged as adults (during a previous spawning run), as well as all fish tagged during summer/fall as parr. We further censored our dataset to remove steelhead <140 mm that may have smolted in a subsequent year. We then used Chi-Square tests to compare the relative proportion of age classes among the catch and overall run for each species.

Model Selection and Validation

In our harvest study, tag recovery data was sparse and formal model selection techniques may not be very informative. Therefore, model development relied more on our knowledge of salmon biology and harvest rather than formal model selection (Mäntyniemi and Romakkaniemi 2002). Formal model selection and validation with Bayesian mixture models is difficult and model validation therefore relied on visual comparison of the model fit to the data and was supported by the results of Rawding et al. (2014b). They developed an *ad hoc* model validation approach for the coho run timing mixture model that involved comparing the proportions of early and late timed coho jacks and adults at BON based on dam counts, with the estimated number of early- and late-timed hatchery coho salmon smolts released above BON in corresponding years. These proportions should be similar if the smolt to adult return rate to BON is similar for the two groups. Their results suggested that early and late timed coho smolt release numbers closely matched returning adult early and late proportions estimated by the mixture model.

Results

Our harvest models were estimated in WinBUGS with two MCMC chains. After the burn-in period and thinning to reduce autocorrelation we saved 10,000 independent samples of the posterior distribution for estimates. The MCMC output was monitored for convergence and yielded BGR values of less than 1.1. The MC % error was also less than the recommended 5% needed to obtain precise estimate (Lunn et al. 2002).

Timing Analysis

Graphical analysis of the run timing of PIT tagged fall Chinook salmon, coho salmon, and summer steelhead at BON supported grouping of individuals for harvest analyses at hierarchical spatial scales developed around ESUs and DPSs (Figures 2-5).

Chinook salmon from 11 “ESU/DPS” reporting groups were sampled in fisheries in 2011. Timing of all “ESU/DPS” groups and their contributing “Rivers” groups was generally very similar (Figure 2). This was particularly true for fall Chinook stocks, where timing of passage at BON was temporally compressed and “Rivers” groups were very similar to “ESU/DPS” groups (Figure 2; panels b, c, e, h, and j). Although there was generally strong correspondence between the timing of spring and summer “Rivers” groups and their corresponding “ESU/DPS” groups, these runs had a more protracted passage period at BON and there was more variability, except for Lower Columbia River (LCR) spring Chinook stocks and Mid Columbia River (MCR) summer Chinook, for which there was only one “Rivers” group (Figure 2; panels d, f, g, i, k, l). Part of this variability and the protracted run timing may be explained by the incorporation in these timing graphs of jacks and mini-jacks, which are known to migrate later than older adults and comprise varying proportions of populations.

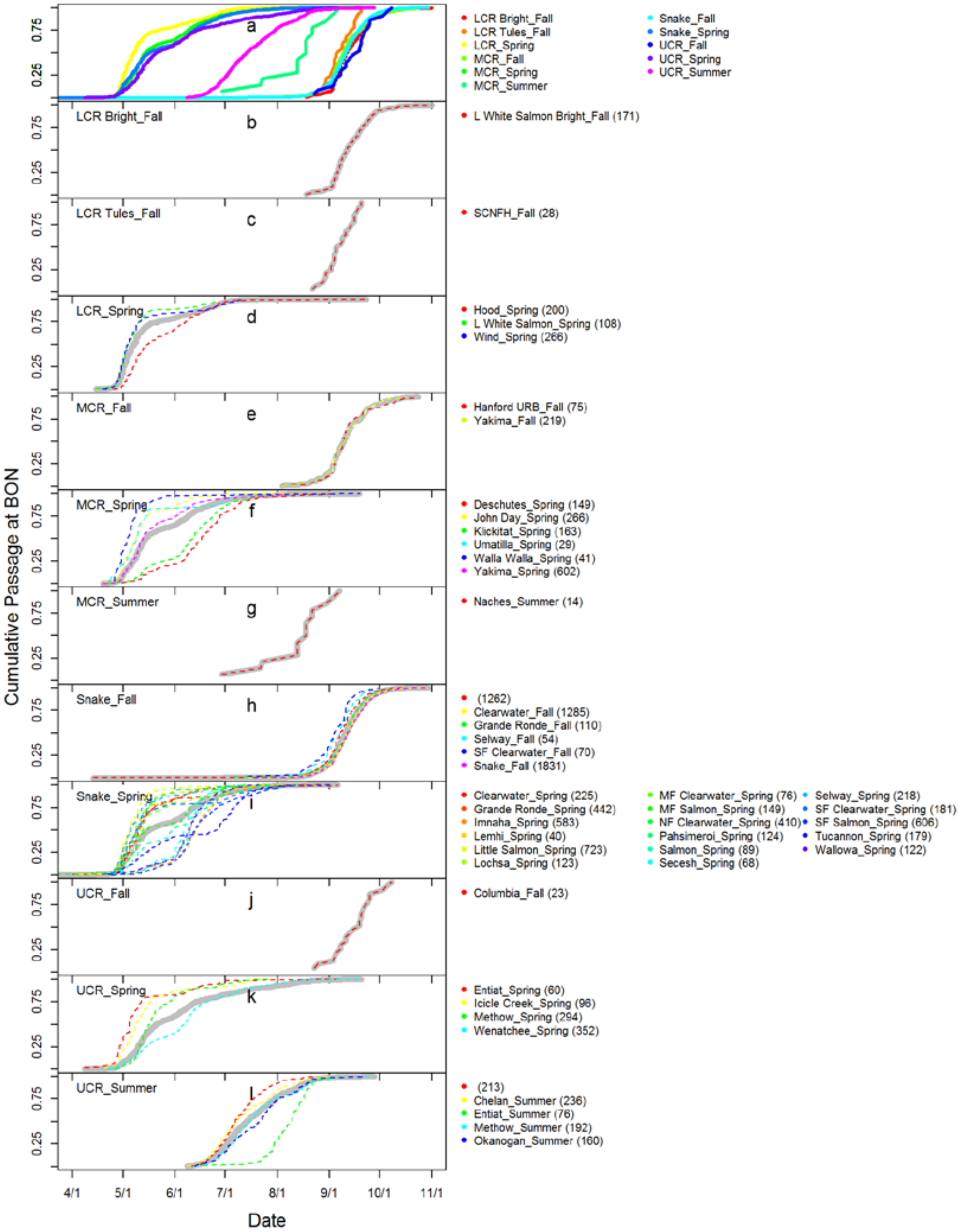


Figure 2. Cumulative passage of PIT tagged Chinook salmon at BON that belonged to release groups detected in sampled 2011 mainstem Columbia fisheries sampled for PIT tags and other release groups belonging to the same “ESU/DPS” harvest reporting groups . Continuous colored lines (panel a), and grey lines (panels b-l) are timing by “ESU/DPS” groups whereas dotted lines are timing of groups by “Rivers” groups contributing to “ESU/DPS” groups. Dotted lines with no name are fish assigned to an “ESU/DPS” group but not a specific “Rivers” group. Sample sizes at BON are reported in parentheses. Only data series with >10 tagged adults returning to BON were plotted.

Coho salmon were sampled from three “ESU/DPS” reporting groups in 2011 and these ESUs and their contributing rivers exhibited similar run timing at BON, passing BON primarily between the last week in August and the middle of September, though Mid-Columbia (Yakima River) coho were slightly later timed than other populations (Figure 4).

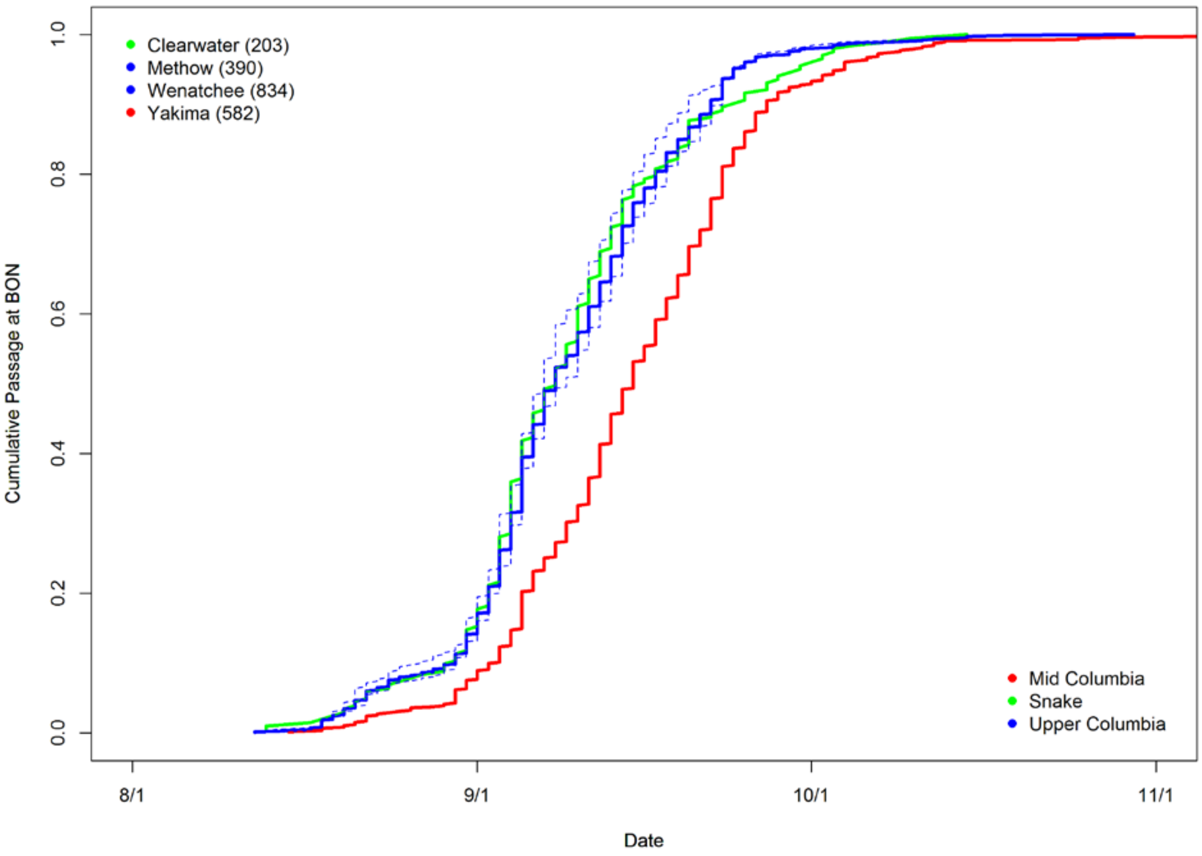


Figure 3. Cumulative passage of PIT tagged coho salmon at BON that belonged to release groups sampled in 2011 fisheries and other release groups belonging to the same ‘ESU’ grouping. Continuous lines are timing groups by “ESU/DPS” whereas dotted lines are timing of groups by “Rivers” contributing to “ESU/DPS” groups of the same corresponding color. Sample sizes at BON are reported in parentheses. Only data series with >10 tagged adults returning to BON were plotted.

Sockeye salmon were sampled from two “ESU/DPS” reporting groups in 2011, passing BON primarily between the middle of June and the middle of July (Figure 4).

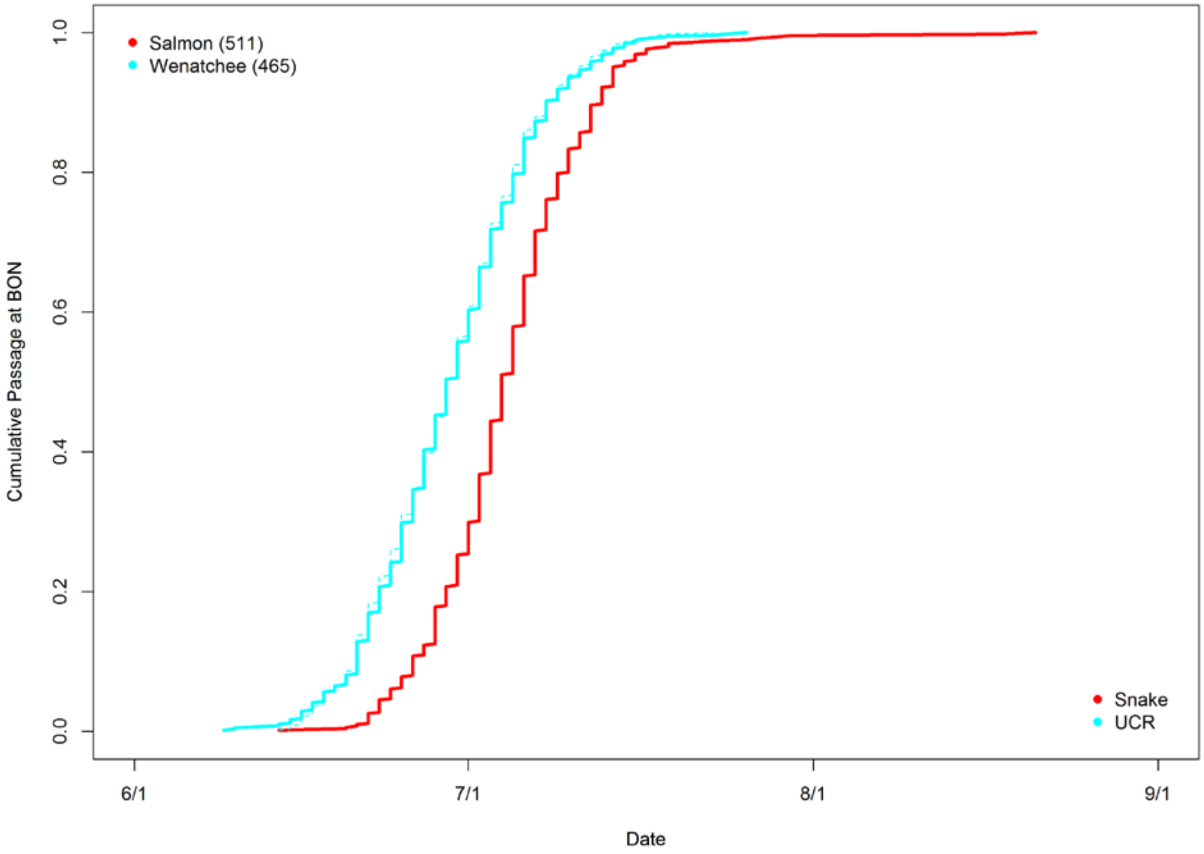


Figure 4. Cumulative passage of PIT tagged sockeye salmon at BON that belonged to release groups sampled in 2011 fisheries and other release groups belonging to the same “ESU/DPS” harvest reporting groups. Continuous lines are timing groups by “ESU/DPS” whereas dotted lines are timing of groups by “Rivers” groups contributing to “ESU/DPS” groups of the same corresponding color. Sample sizes at BON are reported in parentheses. Only data series with >10 tagged adults returning to BON were plotted. Summer steelhead were sampled from five “ESU/DPS” reporting groups in 2011. Run timing varied considerably among these groups (Figure 5; panel a): Lower Columbia summer steelhead displayed a more protracted run which began much earlier than other groups (Figure 5; panel b); Middle Columbia (MCR), Upper Columbia (UCR), and Snake River A-run (SNA) all had similar run timing with most passage occurring in July and August (Figure 5; panels c, d, and f); Snake River B-run steelhead were considerably later to arrive at BON, with most fish passing after August (Figure 5; panel e). The individual “Rivers” groups comprising these “ESU/DPS” groups exhibited similar run timing at BON, suggesting that using these “ESU/DPS” groups for pooling harvest rates was appropriate.

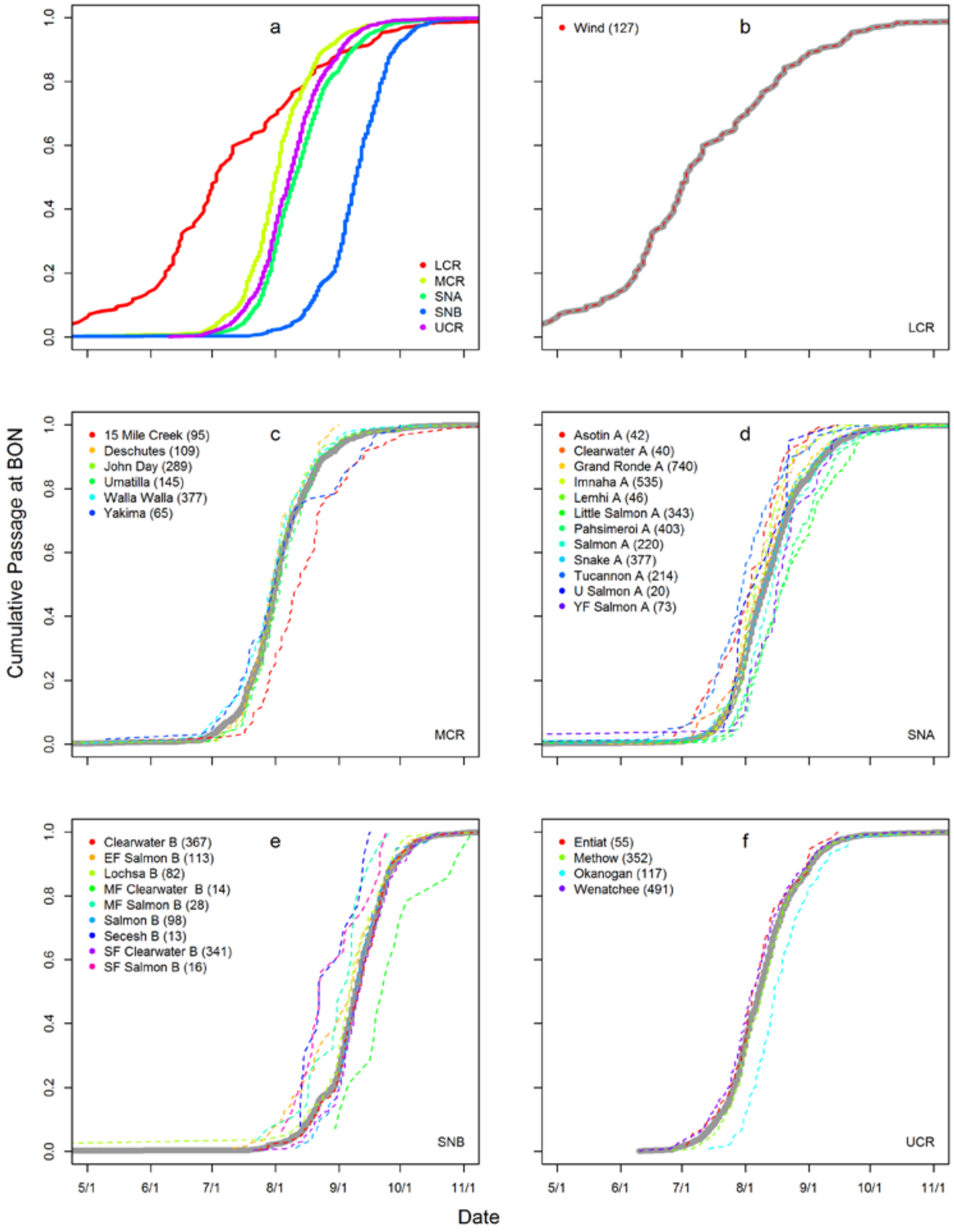


Figure 5. Cumulative passage timing of PIT tagged summer steelhead at BON that belonged to release groups sampled in 2011 fisheries and other release groups belonging to the same "ESU/DPS" groups. Timing is shown by for all "ESU/DPS" reporting groups (a), as well as comparing each "ESU/DPS" group with its contributing "Rivers" groups; Lower Columbia (b), Middle Columbia (c), Snake A-run (d), Snake B-run (e), and Upper Columbia (f). In panels b-f continuous gray lines depict the timing of "ESU/DPS" groups, whereas dotted lines show the timing of "Rivers" groups contributing to those "ESU/DPS" groups. Only data series with >10 tagged adults returning to BON were plotted. Sample sizes at BON are reported in parentheses.

PIT Tag Recoveries and Harvest Reporting Groups
We were able to assign a total of 13,367 jack and adult Chinook salmon detected at BON dam in 2011 that were released from various sites within the Columbia River Basin to harvest reporting groups. PIT tagged Chinook salmon returning to BON in 2011 were assigned to 11 "ESU/DPS" harvest reporting groups which generally followed formal NOAA ESU boundaries with some modifications as previously described. These "ESU/DPS" harvest groups consisted of 178 unique combinations of release site, run type, and rear type (Figure 6; Appendix Table 1).

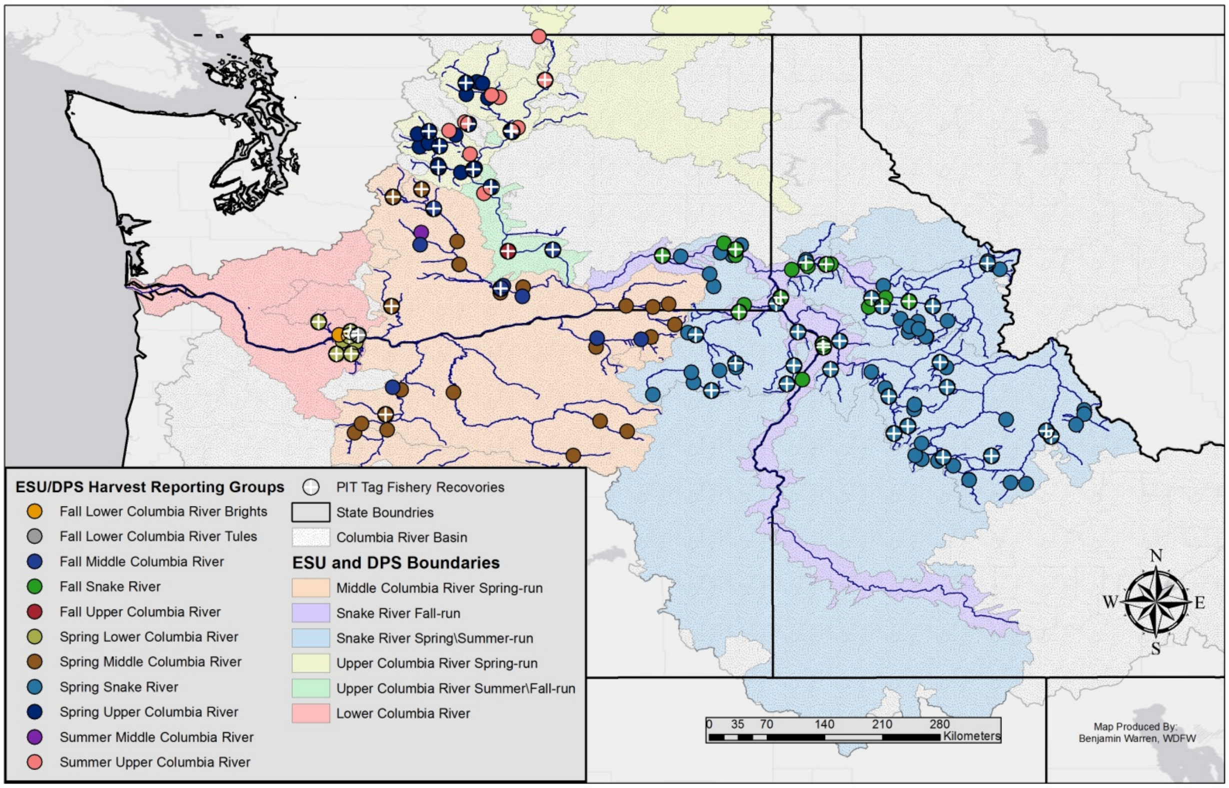


Figure 6. Map of the Columbia River Basin showing NOAA ESU boundaries for Chinook salmon, as well as the locations where PIT tagged jack and adult Chinook salmon that were used in generating harvest estimates in 2011 were released as juveniles. Colored circles show juvenile release locations for all returning adult fish (harvest + escapement) that were used to estimate harvest rates in 2011, colored according to the "ESU/DPS" harvest reporting groups they were assigned to, while white crosshatches represent the subset of those release sites for which harvested PIT tagged adults were sampled in fisheries.

We were able to assign a total of 2,030 jack and adult coho salmon detected at BON dam in 2011 that were released from various sites within the Columbia River Basin to harvest reporting groups. PIT tagged coho salmon returning to BON in 2011 were assigned to 3 "ESU/DPS" harvest reporting groups which generally followed NOAA ESU boundaries of steelhead and Chinook since coho salmon populations above the White Salmon River (WA) and Hood River (OR) do not have formally defined ESUs. These "ESU/DPS" harvest groups consisted of 24 unique combinations of release sites and rear types (Figure 7, Appendix Table 2).

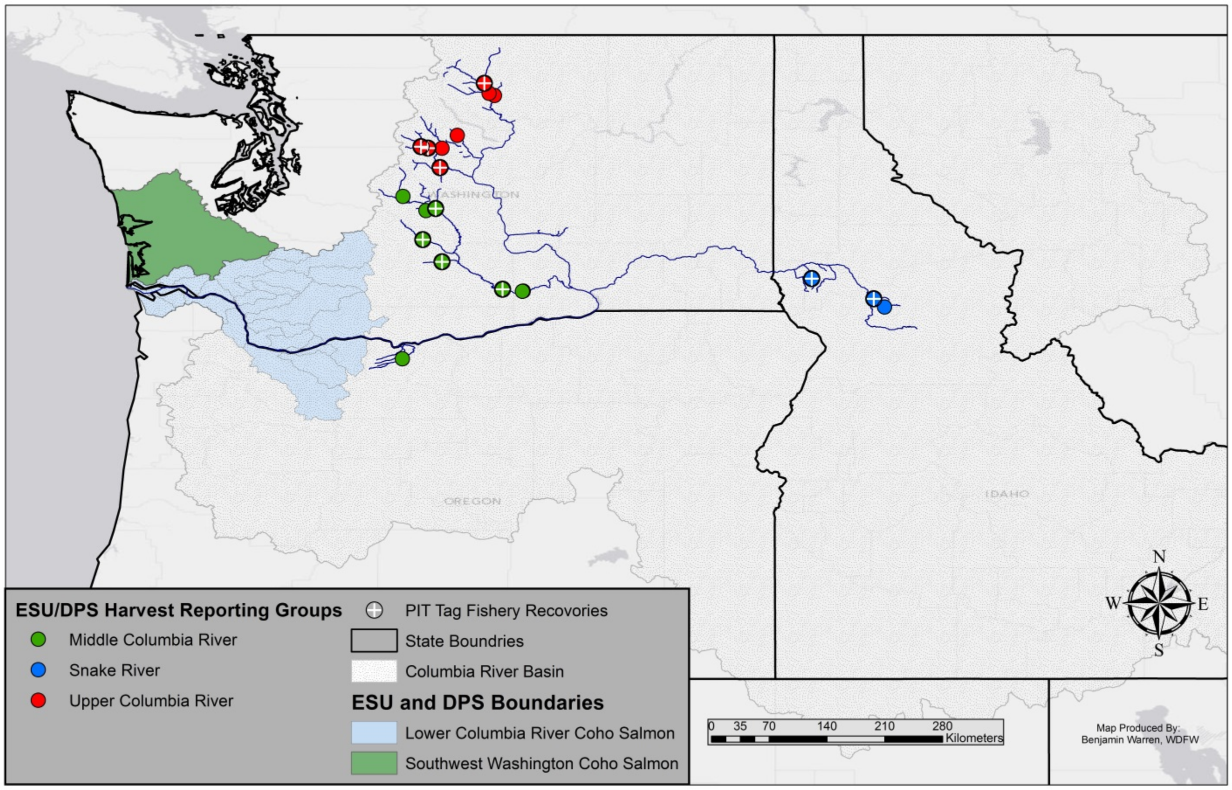


Figure 7. Map of the Columbia River Basin showing NOAA ESU boundaries for coho salmon, as well as the locations where PIT tagged jack and adult coho salmon that were used in generating harvest estimates in 2011 were released as juveniles. Colored circles show juvenile release locations for all returning adult fish (harvest + escapement) that were used to estimate harvest rates in 2011, colored according to the ESU harvest reporting group they were assigned to, while white crosshatches represent the subset of those release sites for which harvested PIT tagged adults were sampled in fisheries.

We were able to assign a total of 1,914 sockeye salmon detected at BON dam in 2011 that were released from various sites within the Columbia Basin to harvest reporting groups. PIT tagged sockeye salmon returning to BON in 2011 were assigned to two “ESU/DPS” harvest reporting groups. The Snake River group followed NOAA ESU boundaries. The Upper Columbia River group included both Okanogan and Wenatchee fish, however independent “Rivers” estimates were made for both populations. These “ESU/DPS” harvest groups consisted of 18 unique combinations of release sites and rear types (Figure 8, Appendix Table 3).

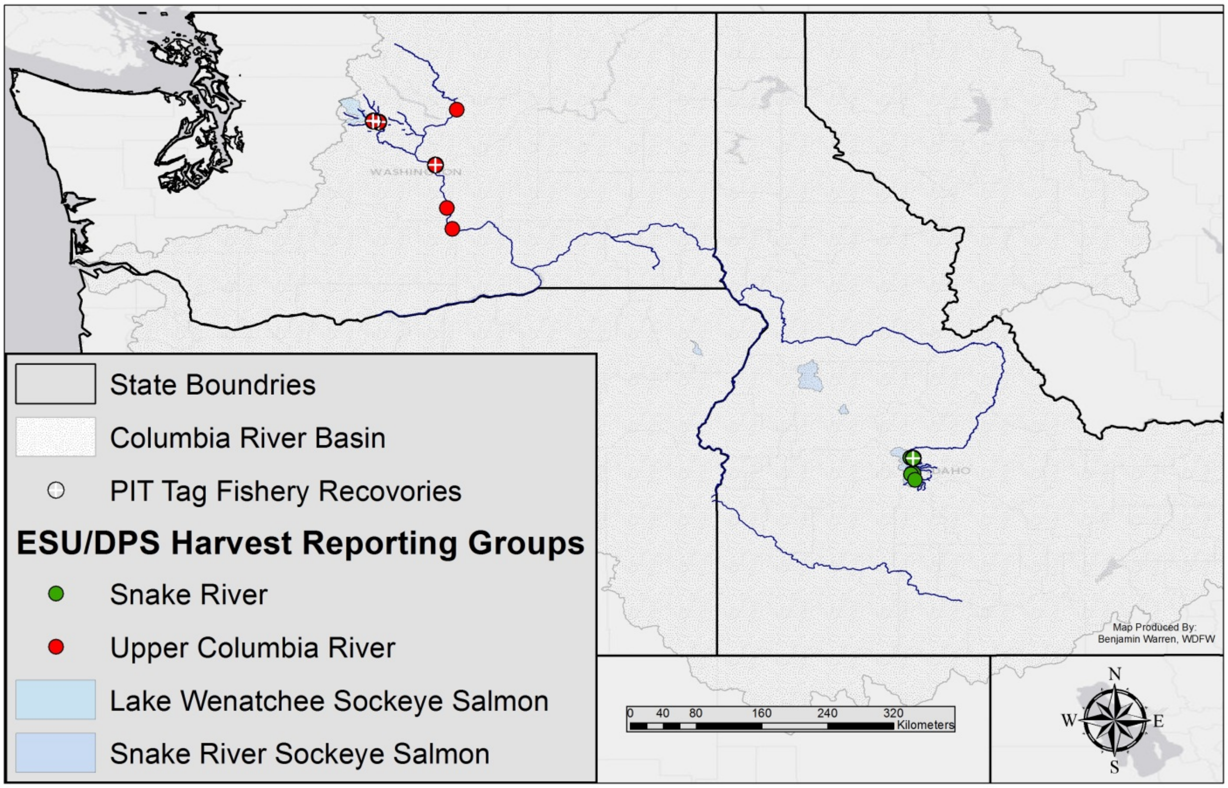


Figure 8. Map of the Columbia River Basin showing NOAA ESU boundaries for sockeye salmon, as well as the locations where PIT tagged jack and adult sockeye salmon that were used in generating harvest estimates in 2011 were released as juveniles. Colored circles show juvenile release locations for all returning adult fish (harvest + escapement) that were used to estimate harvest rates in 2011 colored according to the ESU harvest reporting group they were assigned to, while white crosshatches represent the subset of those release sites for which harvested PIT tagged adults were sampled in fisheries.

We were able to assign a total of 7,883 steelhead detected at BON dam in 2011 between April 1st and November 1st (7,721 detected between July 1st and November 1st) that were released from various sites within the Columbia River Basin to harvest reporting groups. PIT tagged steelhead returning to BON in 2011 were assigned to five “ESU/DPS” harvest reporting groups which generally followed formal NOAA DPS boundaries for steelhead except for in the Snake River where A and B run steelhead were separated for harvest rate estimation. These “ESU/DPS” harvest groups consisted of 176 unique combinations of release sites and rear types (Figure 9 Appendix Table 4).

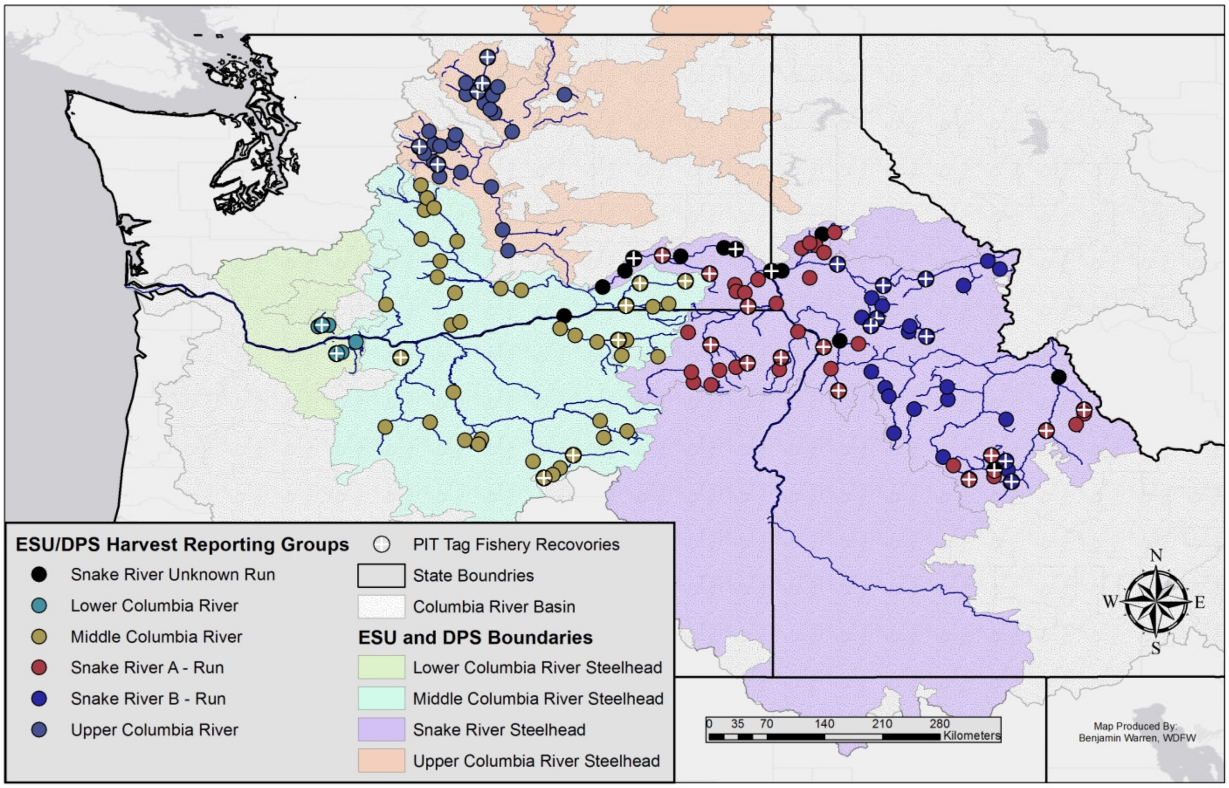


Figure 9. Map of the Columbia River Basin showing NOAA DPS boundaries for steelhead, as well as the locations where PIT tagged steelhead that were used in generating harvest estimates in 2011 were released as juveniles. Colored circles show juvenile release locations for all returning adult fish (harvest + escapement) that were used to estimate harvest rates in 2011, colored according to the "ESU/DPS" harvest reporting group they were assigned to, while white crosshatches represent the subset of those release sites for which harvested PIT tagged adults were sampled in fisheries. Snake River Unknown Run fish belonged to both Snake A and B run DPS reporting groups.

PIT tag detection Rates at BON

We calculated species-specific and fishery period-specific estimates of adult salmonid PIT tag detection probability at BON and used chi-square tests to assess whether fishery-specific estimates of efficiency differed. These tests revealed no significant differences except for steelhead, so species-specific salmon detection efficiency data were pooled to generate annual estimates of detection efficiency at BON. For steelhead, estimated detection efficiency based on the proportion of fish previously detected within the same year at BON and at MCN was lower in spring months than the remainder of the year. Examination of detection data from 2011 revealed that this was due to the overwintering and kelting behavior of steelhead, which may pass BON in one year and MCN the following year. To accurately estimate detection efficiency of adult steelhead at BON, we censored our dataset to fish passing MCN after July 1st to eliminate steelhead which had ascended BON in a previous year. Detection efficiencies were consistently high (98-99%) for all species (Table 2).

Table 2. Detection probabilities of adult salmonids passing through BON by species in 2011.

Species	Parameter	mean	sd	2.50%	50%	97.50%
Chinook	pB_det[1]	0.986	0.001	0.983	0.986	0.988
Coho	pB_det[2]	0.979	0.004	0.970	0.980	0.987
Steelhead	pB_det[3]	0.987	0.001	0.984	0.987	0.990
Sockeye	pB_det[4]	0.992	0.003	0.987	0.993	0.996

Fisheries Sampling and Harvest Rates

Few salmon and steelhead are PIT tagged below BON and we were unable to estimate the uncaught proportion of these release groups. Consequently, lower river harvest rates were only estimated for PIT tagged groups originating from releases above BON. In addition, lower river fisheries for steelhead, spring Chinook, summer Chinook, and coho salmon are mark selective, thus all wild fish are released precluding harvest estimates from these groups. Harvest of natural origin Chinook salmon occurred after July 31 due to healthy wild populations (e.g. Hanford Reach fall Chinook) but few wild fall Chinook are PIT tagged. Therefore, estimates of upriver wild fall Chinook salmon are unavailable due to the lack of tagging.

Below Bonneville Sport Fishery (February-October 2011)

We sampled sport fisheries on the mainstem Columbia River below Bonneville Dam from February-October 2011. Chinook salmon, coho salmon, sockeye salmon, and steelhead were sampled for CWT and PIT tags, while tissue samples were collected for genetic mixed stock fishery analysis. There were no PIT tags recovered from sockeye and coho salmon, and thus we were unable to develop harvest rate estimates for these species.

Chinook

Over 55,000 Chinook were caught by sport fishermen in the mainstem Columbia River below BON between February and October in 2011. Estimated catch and the proportion of the catch sampled for PIT tags are found in Table 3. The sample rate was variable, but generally did not achieve the 20% guideline (Nandor et al. 2011) for fishery sampling (Table 3). The estimated harvest rate varied between 1% and 6% for various “ESU/DPS” groups, but was as high as 14% for “Rivers” groups (e.g., Lochsa spring Chinook)(Table 4).

Table 3. Catch and estimated PIT tag sample rates of Chinook salmon by month during sport fisheries below BON from February-October 2011. Catch is the total catch of fish in a period reported by ODFW and WDFW (2012), and p_samp is the proportion of the catch sampled for PIT tags.

month	catch	p_samp	p_samp sd
2	280	0.08	0.01674
3	3349	0.17	0.00652
4	4128	0.15	0.00565
5	5029	0.08	0.00379
6	10064	0.10	0.00297
7	1976	0.13	0.00762
8	6815	0.10	0.00365
9	22066	0.09	0.00186
10	1843	0.04	0.00459

Table 4. Sampled and expanded PIT tags and harvest rates (hr) of Chinook salmon during mainstem Columbia River sport fisheries below BON in 2011. Tags and ex_tags are the unexpanded and expanded number of PIT tags sampled in fisheries, respectively. Only hatchery origin (H) groups were detected during sampling. Run types are noted by season.

Reporting Group	tags	ex_tags	hr	sd	2.5%	median	97.5%
Hatchery ESU/DPS Groups							
LCR_Spring H	4	35.73	0.059	0.010	0.042	0.059	0.080
MCR_Spring H	3	36.66	0.043	0.007	0.030	0.042	0.058
Snake_Spring H	17	154.60	0.042	0.003	0.035	0.042	0.049
UCR_Spring H	1	12.22	0.019	0.005	0.010	0.019	0.031
MCR_Fall H	1	11.13	0.050	0.014	0.025	0.048	0.080
Snake_Fall H	4	42.30	0.009	0.001	0.007	0.009	0.012
Hatchery Rivers Groups							
Hood_Spring H	3	28.98	0.129	0.022	0.089	0.128	0.176
Imnaha_Spring H	4	40.03	0.097	0.015	0.070	0.096	0.128
L White Salmon_Spring H	1	6.83	0.063	0.023	0.027	0.060	0.115
Little Salmon_Spring H	3	19.63	0.027	0.006	0.017	0.027	0.040
Lochsa_Spring H	2	18.36	0.140	0.030	0.086	0.138	0.203
MF Clearwater_Spring H	1	6.83	0.087	0.031	0.037	0.084	0.155
NF Clearwater_Spring H	1	12.22	0.030	0.008	0.016	0.029	0.048
SF Salmon_Spring H	4	37.60	0.068	0.011	0.049	0.067	0.090
Wallowa_Spring H	1	10.01	0.108	0.031	0.054	0.106	0.175
Wenatchee_Spring H	1	12.22	0.057	0.015	0.031	0.055	0.090
Yakima_Spring H	3	36.66	0.070	0.011	0.050	0.070	0.094
Clearwater_Fall H	1	9.92	0.008	0.002	0.004	0.008	0.014
Snake_Fall H	1	11.13	0.006	0.002	0.003	0.006	0.011
Yakima_Fall H	1	11.13	0.052	0.015	0.027	0.051	0.085

Steelhead

Over 26,000 steelhead were caught by sport fishermen in the mainstem Columbia River below BON between February and October in 2011. We estimated harvest rates only for summer steelhead stocks and limited our PIT tagged based harvest rate estimates to steelhead passing BON after April 1, 2011. Estimated catch, and the proportion of the catch sampled for PIT tags by month are found in Table 5. The sample rate was variable, and was higher from June-October than during the spring, but did not achieve the 20% guideline (Nandor et al. 2011) for fishery sampling (Table 5). The estimated harvest rate generally varied between 2% and 4% for various "ESU/DPS" groups, (Table 6), although the LCR steelhead harvest rate, which only included Hood River steelhead, was 14%.

Table 5. Catch and estimated PIT tag sample rate by month during the mainstem steelhead sport fisheries below BON from February-October 2011. Catch is the total catch of fish in a period reported by WDFW and ODFW (2012), and p_samp is the proportion of the catch sampled for PIT tags.

month	catch	p_samp	p_samp sd
2	24	0.06	0.05
3	458	0.06	0.01
4	583	0.05	0.01
5	1076	0.04	0.01
6	3296	0.11	0.01
7	8549	0.19	0.00
8	11161	0.16	0.00
9	848	0.10	0.01
10	45	0.12	0.05

Table 6. Sampled and expanded PIT tags and harvest rates (hr) during mainstem Columbia River steelhead fisheries below BON in 2011. Tags and ex_tags are the unexpanded and expanded number of PIT tags sampled in fisheries, respectively. Only hatchery-origin (H) groups were detected during sampling. Snake River steelhead estimates are reported in divided A and B run management groups as well as combined in AB groups.

Reporting Group	tags	ex_tags	hr	sd	2.5%	median	97.5%
Large Aggregates Groups							
SNK AB H	20	118.50	0.028	0.023	0.028	0.033	0.028
Hatchery ESU/DPS Groups							
LCR H	2	14.26	0.142	0.082	0.140	0.215	0.142
MCR H	2	11.78	0.036	0.018	0.035	0.058	0.036
SNA H	15	86.79	0.032	0.025	0.032	0.039	0.032
SNB H	3	18.98	0.020	0.012	0.020	0.030	0.020
UCR H	6	39.41	0.042	0.030	0.041	0.056	0.042
Rivers Groups							
Clearwater B H	2	12.73	0.034	0.034	0.018	0.033	0.055
Grand Ronde A H	4	23.26	0.035	0.035	0.023	0.034	0.050
Hood Summer H	2	14.26	0.142	0.142	0.082	0.140	0.213
Imnaha A H	1	6.09	0.016	0.016	0.006	0.016	0.031
Little Salmon A H	3	17.98	0.052	0.052	0.032	0.051	0.078
Methow H	2	12.73	0.039	0.039	0.021	0.038	0.063
Salmon A H	3	17.98	0.080	0.080	0.048	0.078	0.117
Salmon AB H	1	6.09	0.028	0.028	0.011	0.027	0.053
Salmon B H	1	6.09	0.062	0.062	0.024	0.059	0.115
Snake A H	4	21.23	0.054	0.054	0.035	0.053	0.078
Umatilla H	1	6.09	0.092	0.092	0.037	0.088	0.167
Walla Walla H	1	5.06	0.021	0.021	0.007	0.019	0.041
Wenatchee H	4	26.74	0.059	0.059	0.039	0.059	0.083

Zone 1-5 Commercial Fisheries

Spring (weeks 14, 15, 20, 21)

Chinook Salmon

Over 4,500 Chinook were caught in the Zone 1-5 spring commercial fishery. Mean weights, total catch, and the PIT tag sample rate are reported in Table 7. The sample rate was variable, but consistently very high, surpassing the 20% guideline (Nandor et al. 2011) for fishery sampling (Table 7). The estimated harvest rates varied substantially from <1-10% for “Rivers” groups with “ESU/DPS” groups estimates between ~1% and 2% (Table 8).

Table 7. Weights, catch, and PIT tag sample rates of Chinook salmon during the spring commercial fishery in Zones 1-5 in 2011. Periods are fishery weeks, weights (wt) are mean weights in pounds, catch is the total catch of fish in a period, and p_samp is the proportion the catch sampled for PIT tags.

week	wt	wt se	catch	catch se	p_samp	p_samp se
14	13.64	0.2338	1290.0	22.17	0.3729	0.01457
15	13.70	0.1825	790.1	10.51	0.6392	0.01987
20	14.36	0.2466	1633.0	28.11	0.2326	0.01047
21	14.72	0.2699	820.7	15.04	0.4983	0.01963

Table 8. Sampled and expanded PIT tags and harvest rates (hr) of Chinook salmon during the spring commercial fishery in Zones 1-5 in 2011. Tags and ex_tags are the unexpanded and expanded number of PIT tags sampled in fisheries, respectively. Only hatchery (H) PIT tags were observed in catch in this fishery. "River" and "ESU/DPS" harvest estimates were computed for Zones 1-5 Chinook salmon.

Reporting Group	tags	ex_tags	hr	sd	2.50%	median	97.50%
ESU/DPS Groups							
LCR_Spring H	2	4.02	0.008	0.004	0.002	0.007	0.017
MCR_Spring H	5	18.38	0.022	0.005	0.013	0.022	0.033
Snake_Spring H	16	41.08	0.012	0.002	0.008	0.011	0.015
UCR_Spring H	1	4.16	0.007	0.003	0.002	0.007	0.016
Rivers Groups							
Clearwater_Spring H	1	1.92	0.011	0.007	0.002	0.009	0.029
Deschutes_Spring H	4	15.69	0.100	0.024	0.059	0.098	0.152
Grande Ronde_Spring H	3	8.66	0.029	0.010	0.014	0.028	0.051
Imnaha_Spring H	1	4.16	0.012	0.006	0.004	0.011	0.025
Little Salmon_Spring H	4	9.00	0.013	0.004	0.006	0.012	0.022
Lochsa_Spring H	1	1.92	0.021	0.013	0.003	0.018	0.055
Methow_Spring H	1	4.16	0.017	0.008	0.005	0.016	0.035
MF Clearwater_Spring H	2	4.02	0.055	0.025	0.017	0.052	0.115
NF Clearwater_Spring H	3	7.35	0.019	0.007	0.008	0.018	0.033
SF Salmon_Spring H	1	4.16	0.009	0.004	0.003	0.008	0.019
Wind_Spring H	2	4.02	0.016	0.008	0.005	0.015	0.035
Yakima_Spring H	1	2.97	0.007	0.004	0.002	0.006	0.016

Summer (weeks 25-26)

Chinook Salmon

Over 5,000 Chinook were caught in the Zone 1-5 summer commercial fishery. Mean weights, total catch, and the PIT tag sample rate are reported in Table 9. The sample rate was close to its target the first week, and was higher in the second week, surpassing the 20% guideline (Nandor et al. 2011) for fishery sampling (Table 9). The estimated harvest rates varied substantially from <1-15% for "Rivers" groups where tag recoveries were low, with "ESU/DPS" groups estimates all close to 1% (Table 10). Although the fishery was termed the “summer” fishery, most PIT tags recovered belonged to spring rather than summer Chinook stocks.

Table 9. Weights, catch, and PIT tag sample rates of Chinook salmon during the summer commercial fishery in Zones 1-5 in 2011. Periods are fishery weeks, weights (wt) are mean weights in pounds, catch is the total catch of fish in a period, and p_samp is the proportion the catch sampled for PIT tags.

week	wt	mu_wt	catch	catch_se	p_samp	p_samp se
25	17.28	0.31	2506.00	44.51	0.19	0.01
26	17.56	0.38	2504.00	53.67	0.47	0.01

Table 10. Sampled and expanded PIT tags and harvest rates (hr) of Chinook salmon during the summer commercial fishery in Zones 1-5 in 2011. Tags and ex_tags are the unexpanded and expanded number of PIT tags sampled in fisheries, respectively. H, W, and HW refer to hatchery, wild, and combined hatchery and wild groups. “River” and “ESU/DPS” harvest estimates were computed for Zones 1-5 Chinook salmon.

Reporting Group	tags	ex_tags	hr	sd	2.50%	median	97.50%
ESU/DPS Groups							
Snake_Spring H	8	33.41	0.009	0.002	0.006	0.009	0.013
UCR_Spring H	1	5.293	0.009	0.004	0.003	0.008	0.018
UCR_Summer H	3	6.279	0.006	0.002	0.002	0.006	0.011
Snake_Spring W	3	9.742	0.012	0.004	0.006	0.011	0.020
Combined Hatchery and Wild ESU/DPS Groups							
Snake_Spring HW	11	43.09	0.010	0.001	0.007	0.010	0.013
UCR_Spring HW	1	5.293	0.007	0.003	0.002	0.006	0.013
UCR_Summer HW	3	6.279	0.006	0.002	0.002	0.006	0.011
Rivers Groups							
Chelan_Summer H	2	4.037	0.018	0.009	0.006	0.017	0.039
Imnaha_Spring H	6	25.89	0.065	0.012	0.043	0.065	0.091
SF Salmon_Spring	2	7.54	0.015	0.006	0.006	0.015	0.028
Wenatchee_Spring H	1	5.293	0.026	0.011	0.010	0.025	0.051
Imnaha_Spring W	2	4.037	0.021	0.010	0.006	0.019	0.046
Salmon_Spring W	1	5.293	0.155	0.060	0.060	0.148	0.293

Fall (weeks 32-36, 39, and 40-43)

Chinook Salmon

Over 50,000 Chinook were caught in the Zone 1-5 fall commercial fishery. Mean weights, total catch, and the PIT tag sample rate are reported in Table 11. The sample rate was consistently slightly below the 20% guideline (Nandor et al. 2011) for fishery sampling during the first six weeks of the fishery but exceeded this guideline during the last three weeks (Table 11). The estimated harvest rates varied primarily between ~5% and 10% for "Rivers" and "ESU/DPS" groups (Table 12).

Table 11. Weights, catch, and PIT tag sample rates of Chinook salmon during the fall commercial fishery in Zones 1-5 in 2011. Periods are fishery weeks, weights (wt) are mean weights in pounds, catch is the total catch of fish in a period, and p_samp is the proportion the catch sampled for PIT tags.

week	wt_se	wt_se	catch	catch se	p_samp	p_samp se
32	21.00	0.43	994.80	20.27	0.14	0.01
34	20.63	0.26	3222.00	41.12	0.15	0.01
35	20.01	0.21	8459.00	87.70	0.17	0.00
36	19.81	0.24	12350.00	146.70	0.11	0.00
39	15.68	0.22	20670.00	293.80	0.15	0.00
40	15.55	0.27	2308.00	39.89	0.17	0.01
41	15.04	0.28	1566.00	29.44	0.28	0.01
42	14.05	0.36	789.40	20.52	0.34	0.02
43	14.59	0.29	906.70	18.13	0.32	0.02

Table 12. Sampled and expanded PIT tags and harvest rates (hr) of Chinook salmon during the fall commercial fishery in Zones 1-5 in 2011. Tags and ex_tags are the unexpanded and expanded number of PIT tags sampled in fisheries, respectively. H, W, and HW refer to hatchery, wild, and combined hatchery and wild groups. “River” and “ESU/DPS” harvest estimates were computed for Zones 1-5 Chinook salmon.

Reporting Group	tags	ex_tags	hr	sd	2.50%	median	97.50%
ESU/DPS Groups							
LCR Bright_Fall H	2	13.78	0.077	0.020	0.077	0.020	0.119
Snake_Fall H	30	206.20	0.043	0.003	0.043	0.003	0.049
MCR_Fall W	2	7.18	0.084	0.031	0.084	0.031	0.153
LCR Bright_Fall H	2	13.78	0.077	0.020	0.077	0.020	0.120
Combined H/W ESU/DPS Groups							
MCR_Fall HW	2	7.18	0.024	0.009	0.024	0.009	0.045
Snake_Fall HW	30	206.20	0.043	0.003	0.043	0.003	0.049
Rivers Groups							
Clearwater_Fall H	8	55.35	0.041	0.006	0.041	0.006	0.053
Grande Ronde_Fall H	1	6.85	0.062	0.021	0.062	0.021	0.111
L. White Sal. Bright_Fall H	2	13.78	0.076	0.019	0.076	0.019	0.117
Selway_Fall H	1	6.85	0.119	0.041	0.119	0.041	0.214
Snake_Fall H	10	72.18	0.038	0.004	0.038	0.004	0.047
Hanford URB_Fall W	2	7.18	0.092	0.031	0.092	0.031	0.157

Coho Salmon

Over 13,000 coho salmon were caught in the fall Zones 1-5 fishery. Mean weights, total catch, and the PIT tag sample rate are reported in Table 13. The sample rate was generally below the 20% guideline during the first six weeks of the fishery but exceeded the goal during the last three weeks. Coho harvests rates were approximately 3-4% for “ESU/DPS” groups, which for coho were developed based on spatial structure used to delineate ESUs of other species (Table 14).

Table 13. Weights, catch, and PIT tag sample rates of coho salmon during the fall commercial fishery in Zones 1-5 in 2011. Periods are fishery weeks, weights (wt) are mean weights in pounds, catch is the total catch of fish in a period, and p_samp is the proportion the catch sampled for PIT tags.

week	wt	wt se	catch	catch se	p_samp	p_samp se
32.00	5.10	0.95	4.06	0.98	0.10	0.12
34.00	6.97	0.33	110.30	5.28	0.21	0.04
35.00	6.92	0.17	277.80	6.67	0.14	0.02
36.00	7.76	0.12	1259.00	19.88	0.11	0.01
39.00	10.00	0.12	7310.00	89.98	0.12	0.00
40.00	10.01	0.21	819.80	17.12	0.23	0.02
41.00	10.38	0.22	814.70	17.05	0.33	0.02
42.00	9.39	0.21	2151.00	48.02	0.36	0.01
43.00	9.35	0.31	545.80	18.13	0.40	0.02

Table 14. Sampled and expanded PIT tags and harvest rates (hr) of coho salmon during the fall commercial fishery in Zones 1-5 in 2011. Tags and ex_tags are the unexpanded and expanded number of PIT tags sampled in fisheries, respectively. Only hatchery (H) coho salmon were recovered during fishery sampling. Only “Rivers” and “Large Aggregates” harvest estimates were computed for Zones 1-5 coho salmon.

Reporting Group	tag	ex_tag	hr	sd	2.50%	median	97.50%
Large Aggregates Groups							
Above BON H	9	74.89	0.035	0.004	0.028	0.035	0.044
Rivers Groups							
Clearwater H	1	8.132	0.040	0.013	0.018	0.039	0.070
Methow H	2	17.49	0.043	0.010	0.026	0.043	0.064
Wenatchee H	3	24.6	0.029	0.006	0.019	0.029	0.041
Yakima H	3	24.6	0.043	0.009	0.028	0.043	0.062

Zone 6 Treaty Fisheries

Summer (weeks 5-31)

Steelhead

The summer treaty fishery caught approximately 4,000 steelhead in 2011. We estimated harvest rates only for summer steelhead stocks and limited our PIT tagged based harvest rate estimates to steelhead passing BON after April 1, 2011. Estimated catch and the proportion of the catch sampled for PIT tags by month are found in Table 15. The sample rate was below the 20% guideline (Nandor et al. 2011) in all periods and was below 10% in several periods, potentially owing to a large portion of the tribal catch being used for ceremonial and subsistence purposes or for sale directly to the public (Table 15). The estimated harvest rate generally varied between

2% and 3% for various “ESU/DPS” groups, though estimates were more variable for “Rivers” groups where tag recoveries were fewer (Table 16).

Table 15. Weights, catch, and estimated PIT tag sample rates of steelhead by week during summer treaty fisheries in Zone 6. Periods are fishery weeks, weights (wt) are mean weights in pounds, catch is the total catch of fish in a period, and p_samp is the proportion of the catch sampled for PIT tags. Catch includes ticketed sales and over the bank sales, reported by WDFW and ODFW (2012).

week	wt	wt se	catch	catch se	p_samp	p_samp se
25	9.31	2.98	138.00	19.50	0.03	0.01
26	4.76	1.27	177.30	189.50	0.02	0.02
27	6.68	0.40	245.40	8.85	0.12	0.02
28	5.07	0.40	430.50	18.53	0.05	0.01
29	6.75	0.28	589.50	15.88	0.07	0.01
30	6.85	0.33	754.50	29.48	0.18	0.02
31	7.35	0.17	1667.00	36.81	0.12	0.01

Table 16. Sampled and expanded PIT tags and harvest rates (hr) of steelhead during summer treaty fisheries in Zone 6 in 2011. Tags and ex_tags are the unexpanded and expanded number of PIT tags sampled in fisheries, respectively. Harvest rate estimates are made for wild (W), hatchery-origin (H), and combined (HW) groups and Snake River steelhead estimates are divided into A and B run management groups as well as combined in AB groups.

Reporting Group	tags	ex_tags	hr	hr se	0.025	median	0.975
Large Aggregates Groups							
SNK AB H	5	56.55	0.014	0.003	0.009	0.013	0.020
SNK AB W	5	36.65	0.028	0.005	0.019	0.028	0.038
Combined Hatchery and Wild Large Aggregates Groups							
SNK AB HW	10	93.22	0.017	0.002	0.012	0.017	0.022
Combined Hatchery and Wild ESU/DPS Groups							
MCR HW	3	25.52	0.024	0.005	0.015	0.024	0.035
SNA HW	7	70.62	0.023	0.004	0.017	0.023	0.032
UCR HW	3	19.63	0.017	0.004	0.011	0.017	0.026
ESU/DPS Groups							
MCR H	1	8.486	0.027	0.009	0.012	0.026	0.047
SNA H	5	56.55	0.022	0.004	0.014	0.021	0.031
UCR H	3	19.63	0.022	0.005	0.013	0.022	0.033
MCR W	2	17.03	0.023	0.006	0.013	0.022	0.036
SNA W	2	14.06	0.033	0.009	0.018	0.033	0.054
Rivers Groups							
Grand Ronde A H	2	11.12	0.017	0.005	0.008	0.017	0.029
Imnaha A H	1	19.96	0.052	0.017	0.026	0.050	0.090
Methow H	2	11.12	0.036	0.011	0.018	0.035	0.060
Snake A H	1	19.96	0.054	0.017	0.025	0.052	0.091
Tucannon A H	1	5.531	0.036	0.015	0.013	0.034	0.071
Walla Walla H	1	8.486	0.033	0.011	0.015	0.032	0.058
Wenatchee H	1	8.486	0.021	0.007	0.008	0.020	0.037
John Day W	1	8.486	0.031	0.010	0.015	0.030	0.054
Lemhi A W	1	5.531	0.123	0.048	0.047	0.119	0.235
Tucannon A W	1	8.486	0.173	0.052	0.088	0.169	0.289
Walla Walla W	1	8.486	0.077	0.025	0.035	0.074	0.131

Chinook Salmon
Almost 23,000 Chinook were caught in the summer Zone 6 treaty fishery in 2011. Estimated catch and the proportion of the catch sampled for PIT tags by month are found in Table 17. The sample rate was below the 20% guideline (Nandor et al. 2011) in all periods and was below 10% in several periods, potentially owing to a large portion of the tribal catch being used for ceremonial and subsistence purposes or for sale directly to the public (Table 17). The estimated harvest rate generally varied between 2% and 3% for various "ESU/DPS" groups, though estimates were more variable for "Rivers" groups where tag recoveries were fewer (Table 18).

Table 17. Weights, catch, and estimated PIT tag sample rates of Chinook by week during summer treaty fisheries in Zone 6. Periods are fishery weeks, weights (wt) are mean weights in pounds, catch is the total catch of fish in a period, and p_samp is the proportion of the catch sampled for PIT tags. Catch includes ticketed sales and over the bank sales, reported by WDFW and ODFW (2012).

week	wt	wt se	catch	catch se	p_samp	p_samp se
25	14.39	0.43	4385.00	166.70	0.10	0.01
26	15.86	0.41	3849.00	120.60	0.15	0.01
27	16.64	0.34	3832.00	84.02	0.25	0.01
28	17.31	0.49	3469.00	84.06	0.16	0.01
29	17.08	0.29	3191.00	36.31	0.16	0.01
30	17.36	0.40	1942.00	31.37	0.18	0.01
31	17.63	0.45	2068.00	43.41	0.07	0.01

Table 18. Sampled and expanded PIT tags and harvest rates (hr) of Chinook during summer treaty fisheries in Zone 6 in 2011. Tags and ex_tags are the unexpanded and expanded number of PIT tags sampled in fisheries, respectively. Harvest rate estimates are made for wild (W), hatchery-origin (H), and combined (HW) groups.

Reporting Group	tags	ex_tags	hr	hr se	2.50%	median	97.50%
ESU/DPS Groups							
Snake_Spring H	23	159.00	0.045	0.004	0.038	0.045	0.053
UCR_Spring H	1	6.81	0.011	0.004	0.005	0.011	0.021
UCR_Summer H	4	30.74	0.027	0.005	0.019	0.027	0.038
Snake_Spring W	11	76.57	0.090	0.010	0.071	0.089	0.110
UCR_Spring W	1	6.81	0.032	0.012	0.012	0.031	0.060
Combined Hatchery and Wild ESU/DPS							
Snake_Spring HW	34	235.50	0.053	0.004	0.046	0.053	0.061
UCR_Spring HW	2	13.59	0.016	0.004	0.009	0.016	0.026
UCR_Summer HW	4	30.74	0.027	0.005	0.018	0.027	0.038
Rivers Groups							
Chelan_Summer H	3	16.46	0.071	0.017	0.040	0.070	0.107
Imnaha_Spring H	8	47.84	0.128	0.017	0.096	0.127	0.164
NF Clearwater_Spring H	1	10.30	0.026	0.008	0.013	0.025	0.044
Pahsimeroi_Spring H	2	8.13	0.076	0.025	0.034	0.074	0.131
Selway_Spring H	1	10.30	0.054	0.017	0.027	0.052	0.091
SF Salmon_Spring H	8	55.47	0.108	0.014	0.082	0.107	0.137
Wallowa_Spring H	2	20.59	0.241	0.046	0.155	0.241	0.335
Wenatchee_Spring H	1	6.81	0.034	0.012	0.015	0.032	0.063
YF Salmon_Spring H	1	6.27	0.753	0.143	0.427	0.770	0.970
Grande Ronde_Spring W	1	4.00	0.033	0.016	0.009	0.031	0.069
Imnaha_Spring W	3	20.60	0.100	0.020	0.065	0.099	0.143
MF Salmon_Spring W	4	27.97	0.188	0.032	0.131	0.187	0.256
Pahsimeroi_Spring W	1	6.81	0.610	0.139	0.331	0.612	0.857
Secesh_Spring W	1	10.30	0.157	0.045	0.083	0.153	0.255
SF Salmon_Spring W	1	6.81	0.086	0.031	0.034	0.084	0.158
Wenatchee_Spring W	1	6.81	0.051	0.018	0.021	0.049	0.091

Sockeye Salmon

The treaty fishery in Zone 6 caught almost 13,000 sockeye in 2011. The sample rate varied between weeks but was well below the recommended 20% guideline in all periods, resulting in few tag recoveries (Table 19). Despite the low sampling rate, harvest rates were consistently 6-7% for all groups (Table 20).

Table 19. Weights, catch, and estimated PIT tag sample rates of sockeye salmon by week during summer treaty fisheries in Zone 6 in 2011. Periods are fishery weeks, weights (wt) are mean weights in pounds, catch is the total catch of fish in a period, and p_samp is the proportion the catch sampled for PIT tags. Catch includes ticketed sales and over the bank sales, reported by WDFW and ODFW (2012).

week	wt	wt se	catch	catch se	p_samp	p_samp se
25	4.27	0.86	601.40	6.45	0.00	0.00
26	3.48	0.13	1678.00	94.27	0.05	0.01
27	3.62	0.08	4521.00	103.40	0.08	0.00
28	3.48	0.08	4695.00	76.66	0.08	0.00
29	4.26	1.14	1019.00	24.65	0.00	0.00
30	4.29	1.29	284.40	8.18	0.00	0.00
31	4.31	0.94	61.45	32.10	0.01	0.01

Table 20. Sampled and expanded PIT tags and harvest rates (hr) of sockeye salmon during summer treaty fisheries in Zone 6 in 2011. Tags and ex_tags are the unexpanded and expanded number of PIT tags sampled in fisheries, respectively. Harvest rate estimates are made for wild (W), hatchery-origin (H), and combined (HW) groups. Okanogan sockeye harvest rates were made using the “subtraction method” (see methods), therefore tag data are not reported.

Reporting Group	tags	ex_tags	hr	hr se	2.50%	median	97.50%
Combined Hatchery and Wild Large Aggregates							
Above BON HW	9	128.900	0.067	0.007	0.055	0.067	0.081
Rivers Groups							
Salmon H	3	36.880	0.072	0.011	0.051	0.071	0.095
Wenatchee H	1	21.410	0.062	0.015	0.037	0.061	0.095
Wenatchee W	1	12.260	0.071	0.019	0.038	0.070	0.112
Combined Hatchery and Wild Rivers Groups							
Wenatchee HW	3	36.880	0.072	0.012	0.049	0.071	0.096
Okanogan HW	NA	NA	0.070	0.003	0.064	0.070	0.076

Fall (weeks 32-41)

Steelhead

Over 27,000 steelhead were caught in this fishery (Table 21). Weights increased through the fishery period, presumably as more large B-run fish became available. Sample rates were below the 20% guideline in most periods. Harvest rates were variable and ranged from >10% to <2%, possibly a function of few tag recoveries for some stocks as well as differing susceptibility to fisheries as a function of size and timing. Pooling release groups into DPSs decreased the variability of the harvest rate estimates (Table 22).

Table 21. Weights, catch, and PIT tag sample rates of steelhead during the fall treaty fishery in Zone 6 in 2011. Periods are fishery weeks, weights (wt) are mean weights in pounds, catch is the total catch of fish in a period, and p_samp is the proportion the catch sampled for PIT tags. Catch includes ticketed sales and over the bank sales, reported by WDFW and ODFW (2012).

week	wt	wt se	catch	catch se	p_samp	p_samp se
32^{+}	7.00	0.22	600.10	15.21	0.23	0.02
33^{+}	5.82	0.33	1103.00	49.86	0.02	0.00
34	6.33	0.38	595.70	29.26	0.27	0.02
35	7.09	0.25	2676.00	65.66	0.11	0.01
36	7.69	0.24	2872.00	37.15	0.14	0.01
37	8.82	0.27	2888.00	61.44	0.14	0.01
38	9.83	0.21	3657.00	53.61	0.22	0.01
39	10.00	0.26	7537.00	62.40	0.08	0.00
40	9.66	0.28	2881.00	52.72	0.16	0.01
41^{+}	9.03	0.39	2740.00	52.41	0.14	0.01

$^{+}$ Fish in this period include hook and line and platform caught fish late in the season and after week 41.

Table 22. Sampled and expanded PIT tags and harvest rates of steelhead during the fall treaty fishery in Zone 6 in 2011. Tags and ex_tags are the unexpanded and expanded number of PIT tags sampled in fisheries, respectively. Estimates are separated for hatchery (H) and wild (W) fish in each group. For Snake River populations, A, B, and AB refer to A run, B run, and combined A and B run estimates, respectively.

Reporting Group	tags	ex_tags	hr	hr se	2.50%	median	97.50%
Large Aggregates Groups							
SNK AB H	33	231.30	0.055	0.004	0.049	0.055	0.063
SNK AB W	6	54.24	0.042	0.006	0.031	0.041	0.054
Combined Hatchery and Wild Large Aggregates Groups							
SNK AB HW	39	285.50	0.052	0.003	0.046	0.052	0.058
Combined Hatchery and Wild ESU/DPS Groups							
LCR HW	2	14.56	0.070	0.018	0.039	0.068	0.108
MCR HW	4	29.52	0.027	0.005	0.018	0.027	0.038
SNA HW	15	100.50	0.033	0.003	0.027	0.033	0.040
SNB HW	9	66.49	0.062	0.008	0.048	0.062	0.078
UCR HW	2	14.56	0.013	0.003	0.007	0.013	0.021
ESU/DPS Groups							
MCR H	1	7.29	0.023	0.008	0.010	0.023	0.042
SNA H	15	100.50	0.038	0.004	0.031	0.038	0.046
SNB H	8	60.05	0.064	0.008	0.049	0.064	0.083
UCR H	2	14.56	0.016	0.004	0.009	0.016	0.026
LCR W	2	14.56	0.120	0.030	0.068	0.118	0.188
MCR W	3	22.19	0.030	0.006	0.019	0.029	0.044
SNB W	1	6.42	0.049	0.019	0.019	0.047	0.093
Rivers Groups							
Clearwater B H	3	21.82	0.060	0.012	0.038	0.059	0.087
EF Salmon B H	1	12.76	0.115	0.030	0.064	0.113	0.182
Grand Ronde A H	4	26.30	0.041	0.008	0.027	0.041	0.058
Imnaha A H	1	7.20	0.019	0.007	0.008	0.018	0.034
Methow H	2	14.56	0.047	0.012	0.027	0.046	0.073
Pahsimeroi A H	1	7.20	0.020	0.007	0.008	0.019	0.035
Salmon A H	1	4.57	0.024	0.011	0.008	0.022	0.049
SF Clearwater B H	4	25.45	0.075	0.014	0.050	0.075	0.106
Snake A H	6	41.75	0.111	0.017	0.080	0.110	0.145
Tucannon A H	1	8.87	0.057	0.018	0.026	0.055	0.097
Walla Walla H	1	7.29	0.029	0.011	0.012	0.028	0.053
YF Salmon A H	1	4.57	0.071	0.032	0.022	0.067	0.147
15 Mile Creek W	1	7.41	0.083	0.029	0.035	0.080	0.148
John Day W	2	14.78	0.053	0.013	0.030	0.052	0.081
Lochsa B W	1	6.42	0.083	0.030	0.033	0.079	0.152
Wind W	2	14.56	0.121	0.029	0.070	0.119	0.184

Chinook Salmon

The treaty fall Zone 6 fishery caught ~136,000 Chinook salmon in 2011, which was more than the total below BON sport and commercial Chinook catches from all seasons combined. Sample rates exceeded the 20% guideline in 5 of 10 weeks and were lower in the remaining weeks (Table 23). The harvest rate for Chinook was highly variable, ranging from <1% for summer and spring Chinook stocks encountered in this fishery to 40% for LCR Tule Chinook from the Spring Creek National Fish Hatchery and 57% for UCR Chinook, though tag recoveries for this stock were few (Tables 23 and 24).

Table 23. Weights, catch, and the PIT tag sample rate of Chinook salmon during the fall treaty fishery in Zone 6 in 2011. Periods are fishery weeks, weights (wt) are mean weights in pounds, catch is the total catch of fish in a period, and p_samp is the proportion the catch sampled for PIT tags. Catch includes ticketed sales and over the bank sales, reported by WDFW and ODFW (2012).

week	wt	wt SE	catch	catch SE	p_samp	p_samp SE
32+	14.15	2.96	62.91	50.87	0.19	0.07
33+	14.46	2.33	99.14	26.09	0.08	0.03
34	14.25	2.37	81.94	24.97	0.12	0.04
35	18.26	0.39	5867.00	110.80	0.18	0.01
36	17.51	0.27	12220.00	144.80	0.22	0.00
37	17.42	0.22	39990.00	415.60	0.24	0.00
38	17.14	0.20	33380.00	353.30	0.29	0.00
39	16.17	0.32	26620.00	434.30	0.19	0.00
40	14.83	0.28	11580.00	212.00	0.20	0.01
41+	14.67	0.33	6086.00	116.50	0.24	0.01

+ Fish in this period include hook and line and platform caught fish late in the season and after week 41.

Table 24. Sampled and expanded PIT tags and harvest rates of Chinook salmon during the fall fishery in Zone 6 in 2011. Tags and ex_tags are the unexpanded and expanded number of PIT tags sampled in fisheries, respectively. Harvest rates (hr) are reported for “Rivers” groups and “ESU/DPS” groups; W refers to wild groups, H refers to hatchery groups, HW refers to combined hatchery and wild groups, and U to unknown origin groups.

Reporting Group	tags	ex_tags	hr	hr SE	2.50%	median	97.50%
Separate H/W ESU/DPS Groups							
LCR Bright_Fall H	6	26.600	0.157	0.028	0.105	0.157	0.218
LCR Tules_Fall H	3	11.140	0.400	0.091	0.232	0.396	0.583
LCR_Spring H	1	4.598	0.009	0.004	0.003	0.008	0.018
MCR_Fall H	5	22.000	0.101	0.020	0.066	0.099	0.145
Snake_Fall H	101	436.200	0.094	0.004	0.086	0.094	0.103
UCR_Fall H	3	13.140	0.571	0.098	0.374	0.574	0.755
UCR_Summer H	1	5.755	0.005	0.002	0.002	0.005	0.010
MCR_Fall W	1	4.598	0.059	0.026	0.018	0.056	0.119
Combined H/W ESU/DPS Groups							
LCR Bright_Fall HW	6	26.600	0.156	0.027	0.108	0.155	0.210
LCR Tules_Fall HW	3	11.140	0.400	0.090	0.232	0.399	0.578
LCR_Spring HW	1	4.598	0.009	0.004	0.003	0.008	0.019
MCR_Fall HW	6	26.490	0.087	0.016	0.057	0.086	0.120
Snake_Fall HW	101	436.200	0.094	0.004	0.086	0.094	0.103
UCR_Fall HW	3	13.140	0.565	0.101	0.361	0.565	0.757
UCR_Summer HW	1	5.755	0.006	0.002	0.002	0.005	0.010
Rivers Groups							
Clearwater_Fall H	27	120.000	0.094	0.008	0.078	0.093	0.111
Columbia_Fall H	3	13.140	0.568	0.099	0.361	0.570	0.746
Grande Ronde_Fall H	1	3.025	0.031	0.016	0.007	0.028	0.069
Hood_Spring H	1	4.598	0.025	0.011	0.008	0.024	0.052
L White Salmon Bright_Fall H	6	26.600	0.158	0.028	0.106	0.157	0.217
Okanogan_Summer H	1	5.755	0.039	0.015	0.015	0.037	0.071
SCNFH_Fall H	3	11.140	0.399	0.090	0.229	0.398	0.582
Snake_Fall H	41	180.700	0.098	0.007	0.085	0.098	0.113
Yakima_Fall H	5	22.000	0.107	0.022	0.068	0.106	0.153
Hanford URB_Fall W	1	4.598	0.066	0.029	0.022	0.062	0.134

Coho Salmon

Approximately 26,000 coho salmon were harvested in the fall Zone 6 fishery. Sample rates were generally below the 20% guideline (Table 25). Individual hatchery harvest rates ranged from 16 to 25% and the aggregate harvest rate for this group was 19.7% (Table 26).

Table 25. Weights, catch, and the PIT tag sample rate of coho salmon during the fall treaty fishery in Zone 6 in 2011. Periods are fishery weeks, weights (wt) are mean weights in pounds, catch is the total catch of fish in a period, and p_samp is the proportion the catch sampled for PIT tags. Catch includes ticketed sales and over the bank sales, reported by ODFW and WDFW (2012).

week	wt	wt se	catch	catch se	p_samp	p_samp se
32⁺	5.38	1.53	3.86	1.51	0.11	0.15
33⁺	5.39	1.54	3.88	1.84	0.11	0.14
34	5.55	1.33	22.71	6.60	0.24	0.10
35	6.77	0.23	1489.00	14.88	0.06	0.01
36	7.41	0.20	982.70	19.65	0.16	0.01
37	8.88	0.14	4025.00	51.19	0.17	0.01
38	8.58	0.13	5055.00	73.21	0.16	0.01
39	9.02	0.12	5393.00	85.86	0.14	0.01
40	9.09	0.13	3781.00	52.88	0.12	0.01
41⁺	9.04	0.15	5237.00	57.28	0.09	0.00

⁺ Fish in this period include hook and line and platform caught fish late in the season and after week 41.

Table 26. Sampled and expanded PIT tags and harvest rates for coho salmon "Rivers" and "Large Aggregates" groups during the fall treaty fishery in Zones 6 in 2011. Tags and ex_tags are the unexpanded and expanded number of PIT tags sampled in fisheries, respectively. H refers to hatchery groups and HW refers to combined hatchery and wild groups. CMW is a combined Clearwater, Methow, and Wenatchee estimate since these stocks had similar run timing.

Reporting Group	tags	ex_tags	hr	hr se	2.50%	median	97.50%
Large Aggregates Groups							
Above BON HW	50	405.000	0.197	0.010	0.178	0.197	0.217
CMW H	39	307.100	0.213	0.012	0.190	0.213	0.236
Rivers Groups							
Clearwater H	7	51.570	0.252	0.030	0.195	0.251	0.313
Methow H	9	63.880	0.163	0.019	0.128	0.162	0.201
Wenatchee H	23	191.600	0.227	0.015	0.198	0.227	0.258
Yakima H	10	89.850	0.162	0.017	0.130	0.161	0.197

Sockeye Salmon Stock Composition, Proportions of Tagged Adults, and Total Catch by Population

The proportions of Snake and Wenatchee sockeye that were PIT tagged in 2011 were 0.014 and 0.221, respectively, based on counts of tagged and untagged sockeye at Lower Granite and Tumwater dams, respectively (Table 27). We estimated that 2,338 and 37,680 Snake and Wenatchee sockeye passed BON, respectively, based on an expansion of tagged sockeye counts at BON using our tagging rate estimates (Table 27). Using the subtraction method, the Okanogan sockeye run size at BON was 145,800. We also used PIT tag expansion and the subtraction method to estimate run timing of sockeye at BON (Figure 10). The Okanogan salmon run peaked one week earlier than Wenatchee run and two weeks earlier than Snake River run (Figure 10). Finally, we estimated Okanogan sockeye total catch (10,260) based on the subtraction method.

Table 27. Estimated proportions of sockeye that were PIT tagged, their run sizes at BON, and their harvest rates in Zone 6 treaty fisheries in 2011. Very few Okanogan sockeye were PIT tagged in 2011 and their tagging rate was thus excluded. HW indicates that these estimates included both hatchery and wild individuals.

Population	Mean	SE	2.50%	median	97.50%
Proportion PIT Tagged					
Wenatchee HW	0.014	0.001	0.012	0.014	0.016
Snake HW	0.221	0.011	0.201	0.221	0.242
Run size at BON					
Wenatchee HW	37680	2368	33320	37590	42600
Snake HW	2338	113	2134	2331	2568
Okanogan HW	145800	2367	140900	145900	150200
Total Catch					
Wenatchee HW	2437	462	1608	2403	3414
Snake HW	168	29	114	166	229
Okanogan HW	10260	472	9266	10290	11120

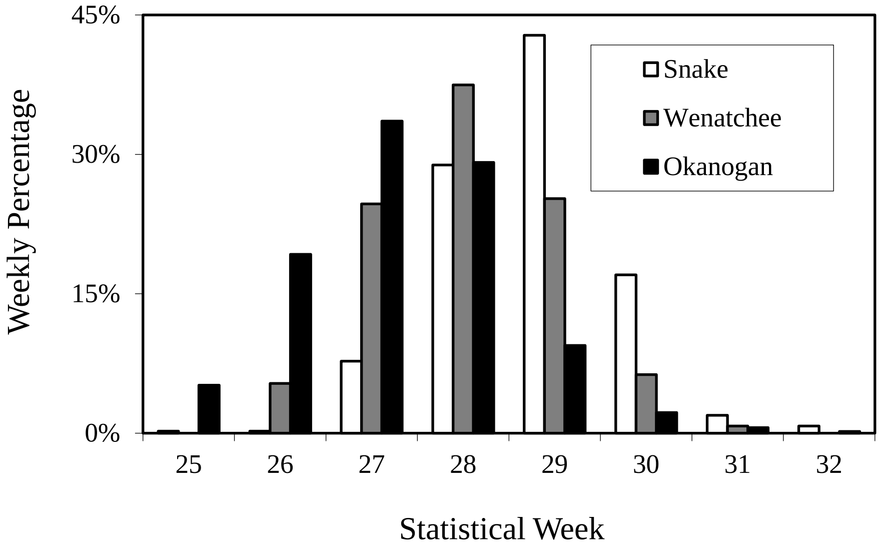


Figure 10. Weekly timing of sockeye salmon passing BON in 2011. The Wenatchee and Snake River fish were estimated based on PIT tag timing and the proportion of the population tagged. Okanogan fish were estimated based on the subtraction method.

Coho Salmon Mixture Model

The normal mixture model suggested that the mean dates of passage for the early and late coho components was separated by about 28 days and occurred on days of the year (DOY) 254 and 282, respectively. The width of the normal curve (SD) was greater for the second component. The abundance estimates for the early and late components were 125,100 and 24,740 fish, respectively. The estimated catches were 24,660 and 1,331 fish for the early and late components, respectively. These correspond to harvest rates of 20% and 5%, respectively (Table 28).

Table 28. Parameter estimates for the early and late components of coho salmon passing BON using a normal mixture model and harvest rates for these components in the Zone 6 treaty fishery.

Parameter	Mean	SD	2.50%	median	97.50%
Early Run Mean Passage (Day of Year)	253.80	0.19	253.40	253.80	254.10
Late Run Mean Passage (Day of Year)	282.30	0.67	281.00	282.30	283.60
Early Run Passage SD (days)	10.60	0.16	10.29	10.60	10.90
Late Run Passage SD (days)	6.12	0.71	4.89	6.07	7.68
Diff. Between Early and Late (days)	28.54	0.66	27.25	28.54	29.85
Early Run Size (fish)	125100	2052	121000	125200	129100
Late Run Size (fish)	24740	2052	20800	24700	28870
Early Run Catch (fish)	24660	1309	22150	24660	27280
LateRun Catch (fish)	1331	1301	-1267	1341	3833
Early Run Harvest Rate	0.197	0.010	0.178	0.197	0.217
Late Run Harvest Rate	0.053	0.052	-0.054	0.054	0.151
Early Run Proportion of Total Run	0.835	0.014	0.807	0.835	0.861
Late Run Proportion of Total Run	0.165	0.014	0.139	0.165	0.193
Total Run Passage SD (days)	397.80	14.90	369.80	397.60	427.90

Two validation measures suggested the mixture model adequately fit the data; graphical visualization suggested the mixture model was consistent with the data (Figure 11) and was supported by comparison of the ratio of early to late smolt releases, which produced a similar estimate. The mixture compositions from our analysis suggested the early and late components comprised 83.5% (95% CI 80.7% to 86.1%) and 16.5% (95% CI 13.9% to 19.3%) of the run, respectively. These compared favorably to the TAC estimates of the early and late coho run components (81% and 19%, respectively) based on an October 1st cutoff at BON.

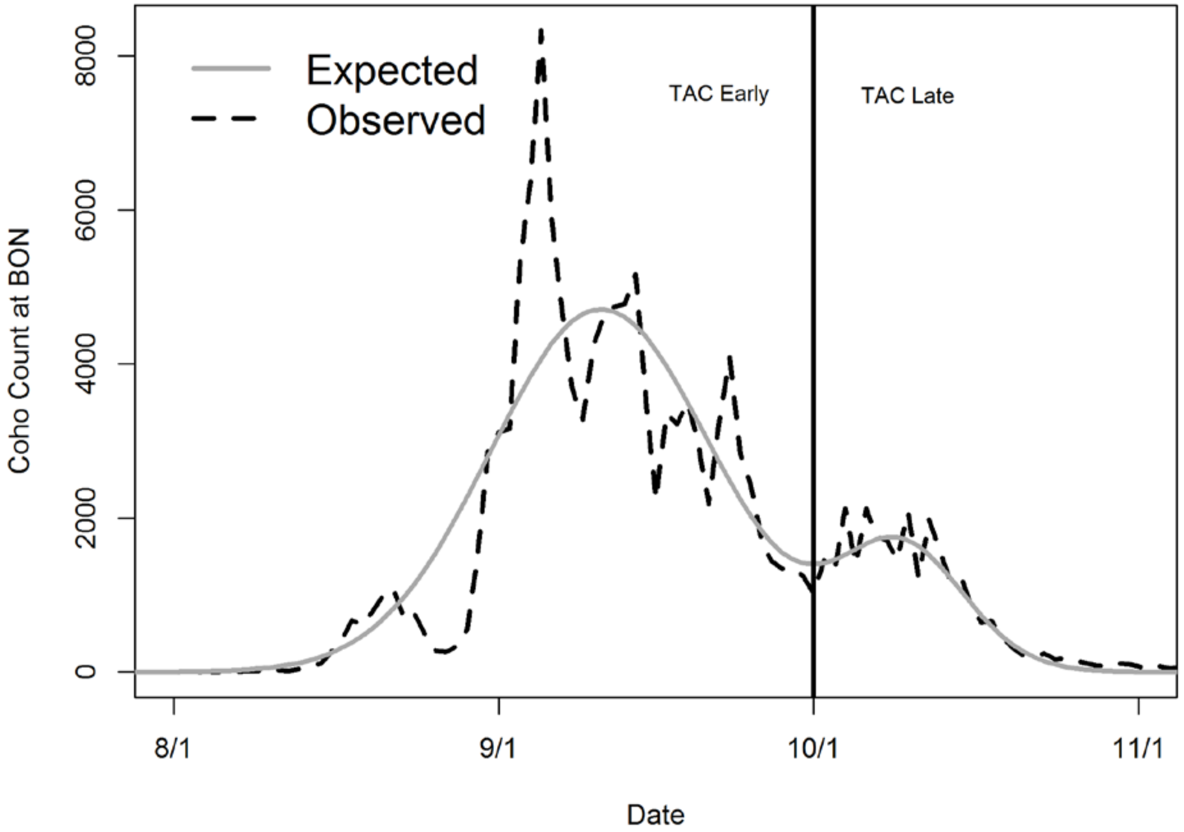


Figure 11. Fit of the expected counts (gray) based on the mixture model relative to observed counts (black) of coho salmon at BON in 2011. These results suggest the early proportion of the jack and adult return comprised 83.5% of the total return. TAC traditional early and late counting periods based on an October 1st cutoff date at BON are shown for reference.

Assigning ages to PIT tagged adult salmon and steelhead

Visual analysis of travel days (days between release as juveniles and detection as adults at BON) histograms revealed multimodal travel durations for all species, indicative of multiple ocean age classes of adult salmon and steelhead (Figure 12). Based on these multiple distinct modes in these histograms, and examination of individual tag histories to corroborate observed patterns, ocean ages were assigned to adult salmon and steelhead (Table 29).

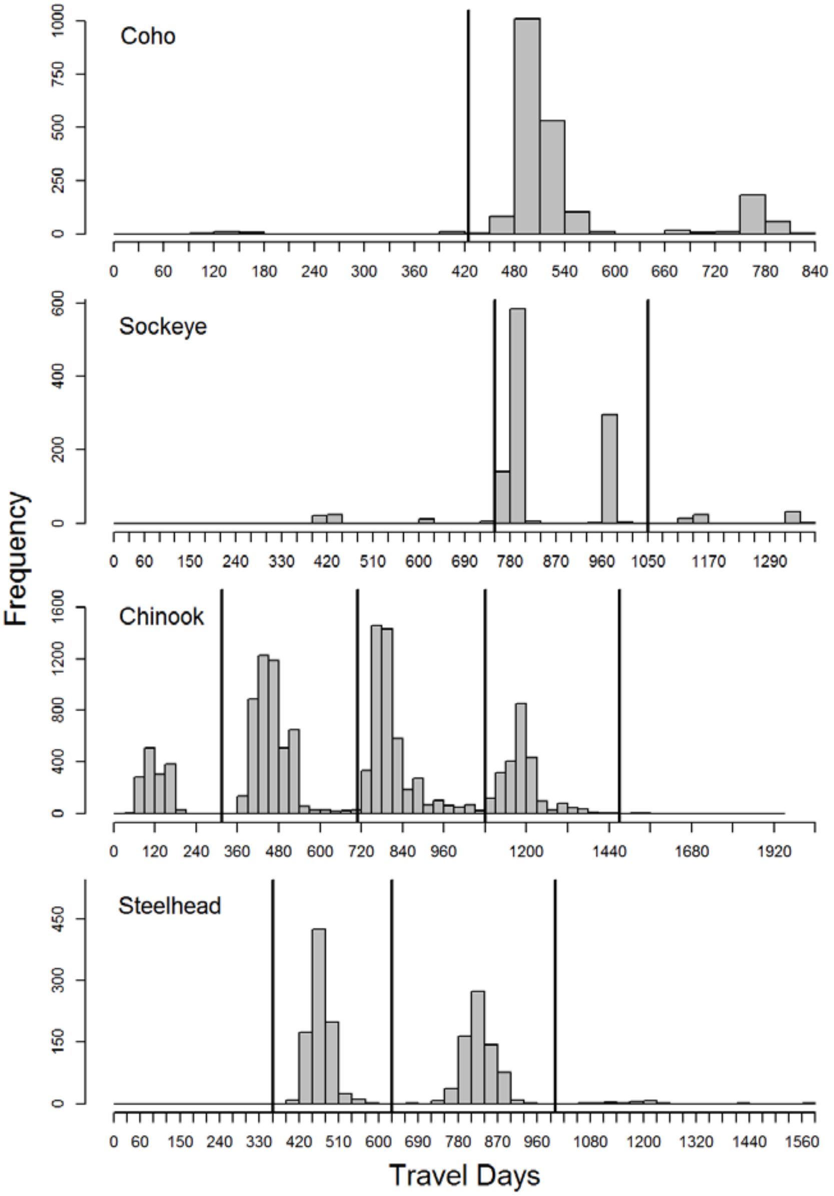


Figure 12. The frequency of travel days for PIT tagged adult salmon and steelhead returning to BON in 2011 that were used for harvest analysis. Vertical lines depict ocean age cutoffs developed based on visual analysis of histograms and confirmed by individual tag histories; coho were either ocean age 0 or 1, steelhead and sockeye were age 1, 2, or 3, and Chinook were either age 0, 1, 2, 3, or 4. Coho, sockeye, and Chinook graphs include all individuals detected at BON. Steelhead data were subsetted in order to permit accurate ocean age assignments, and included only fish tagged between January 1st and June 1st, and were between 140 and 350 mm in length, and were therefore thought to be smolting and less likely to remain for additional years after release.

Table 29. The number of travel days used to define ocean age classes of salmon and steelhead. Steelhead data only included fish released between January 1st and June 30th that were between 140 and 350 mm in length at tagging and were therefore thought to smolt in the same year of tagging.

Species	Age 0	Age 1	Age 2	Age 3	Age 4
Coho	< 425	> 425	NA	NA	NA
Sockeye	NA	< 700	> 700 & < 1,050	> 1,050	NA
Chinook	< 314	>314 & < 710	> 710 & < 1,070	> 1,070 & < 1,470	> 1470
Steelhead	NA	> 360 & < 630	> 630 & < 1,000	> 1,000	NA

Fishery Size Selectivity

Tests used to compare the ocean age composition of the catch relative to the whole run at BON based on PIT tags revealed significant differences with catches mostly including greater proportions of older age classes. All fisheries on summer Chinook, treaty fisheries for spring Chinook, and treaty and commercial fisheries for fall Chinook were significantly age-selective (Chi-Square, $P < 0.05$). Although other fisheries were not significantly age-selective, sample sizes of the catch were limited, leading to low power to detect such selectivity. Consequently, qualitative comparisons were made between the age composition of the catch and run (Table 30). Treaty fisheries for all species caught greater proportions of older fish than the run at BON. Sport fisheries below BON caught greater proportions of younger spring Chinook (jacks), and greater proportions of older (hatchery) steelhead. Commercial fisheries below BON caught older summer and fall Chinook.

Table 30. Numbers and proportions of PIT tagged upriver salmon and steelhead by ocean age class at BON and catches below BON in commercial and sport fisheries and the Zone 6 treaty

fishery. Catches are pooled across all seasons. Bold typeface indicates sport, treaty, and commercial catches that differed significantly in their age composition from the run at BON. Steelhead data are a subset for which it was possible to assign ocean age classes, whereas ages were assigned to all individuals of other species.

		BON		Treaty		Sport		Commercial	
Species	Ocean Age	Run	%	Catch	%	Catch	%	Catch	%
Coho	0	25	1	0	0	NA	NA	0	0
	1	2,003	99	50	100	NA	NA	9	100
Sockeye	1	59	5	0	0	NA	NA	NA	NA
	2	1,040	89	6	100	NA	NA	NA	NA
	3	73	6	0	0	NA	NA	NA	NA
Spring Chinook	0	505	8	**0**	**0**	0	0	0	0
	1	1,827	30	**3**	**15**	10	48	6	21
	2	3,013	50	**12**	**60**	7	33	21	75
	3	654	11	**5**	**25**	4	19	1	4
	4	1	0	**0**	**0**	0	0	0	0
Summer Chinook	0	532	24	**0**	**0**	**0**	**0**	**0**	**0**
	1	890	40	**3**	**14**	**0**	**0**	**0**	**0**
	2	610	27	**14**	**67**	**4**	**100**	**7**	**88**
	3	189	9	**4**	**19**	**0**	**0**	**1**	**13**
	4	1	0	**0**	**0**	**0**	**0**	**0**	**0**
Fall Chinook	0	477	9	**2**	**2**	0	0	**1**	**3**
	1	2,036	40	**12**	**10**	2	40	**1**	**3**
	2	1,021	20	**32**	**27**	1	20	**8**	**24**
	3	1,597	31	**73**	**61**	2	40	**23**	**68**
	4	11	0	**0**	**0**		0	**1**	**3**
Steelhead	1	842	53	11	39	4	50	NA	NA
	2	714	45	17	61	4	50	NA	NA
	3	21	1	0	0	0	0	NA	NA

Discussion

Efficacy of PIT tags for harvest estimation and associated assumptions

Since this was a feasibility study, the official estimates of total harvest and harvest rates in 2011 Columbia River mainstem fisheries are available from TAC. Our harvest rate estimates rely on a number of untested assumptions regarding reported or estimated catch, and random or representative sampling: 1) All commercial buyers in both states are required to report commercially sold catch by species and weight. This study assumed the reporting by weight was accurate for all species; 2) Estimates of total catch based on a creel of the Zone 6 treaty fisheries are provided by tribal fisheries managers and are used in estimating non-ticketed catch. We assume their methods are unbiased but we have not incorporated the uncertainty in non-ticketed catch into our harvest rate estimates because this is unknown; 3) Within each fishery area, harvest rates based on PIT tagged fish were made from PIT tag recoveries at commercial buyers for treaty and below BON for commercial fisheries, and from sampling sport fisheries catch landed in Washington below BON. Sampling rates were calculated based on total reported catch for a zone, so if PIT tagged fish from all populations are equally susceptible to being caught regardless of net or angler location within a zone, our harvest estimates should remain unbiased. However, if PIT tagged fish from certain populations during commercial fisheries tend to be sold at a higher rate to Washington or Oregon buyers, our sampling of only the catch landed in Washington from lower Columbia River sport fisheries could lead to biased harvest estimates.

We aggregated fishery catch by statistical week for commercial and treaty fisheries, by month for sport fisheries, and combined catch across spatial strata: Zones 1-5 were combined into a below BON group and Zones 61, 62, and 63 were combined into an above BON group . We did this because it was difficult to obtain daily data, some catch sampled at buyers came from a mixture of zones, and PIT tagged fish recoveries were few, necessitating pooling. Furthermore, we assumed that fish sampled for PIT tags and weights were a representative sample of the catch. Representative fisheries sampling from buyers is difficult to ensure because we cannot predict how many commercial buyers are present for any fishery. To best address this situation, we concentrated our sampling effort on known larger buyers with lesser effort on smaller buyers. However, when we sampled at a buyer we sampled all available undressed fish for PIT tags, and used a systematic sample to collect weights and other biological information. Although random sampling is a better option, systematic sampling is used because it is easier to consistently implement in the field.

We were hopeful of developing portable PIT tag interrogation stations for commercial sampling, but we ran into some challenges with electrical interference causing variable detection rates. Furthermore, we found it difficult to set up the portable stations in most confined fish buying areas. Alternatively, additional PIT tag recoveries could be obtained by working with fish buyers to set up similar detector stations as fish move through a facility, or as fish are cleaned, because most PIT tags will come out with the body cavity contents. However, it would be difficult to expand these numbers at fish buyers because the number of fish sampled for tags is unknown and a study to estimate detection rates would be needed at each facility. If regional fish managers decide it is important to obtain more adult detections, additional funds should be set aside to work with larger stationary buyers.

Comparison of Selected Harvest Estimates

Sport Fisheries Below BON

Comparisons of harvest rate estimates using PIT tags with those developed by TAC was difficult for sport fisheries because many sport fisheries are mark-selective and PIT tag estimates for these fisheries were specific to hatchery stocks. In addition, low PIT tag sample sizes limited precision of many sport fishery harvest rate estimates because the recovery rate of tags was below the lower limit recommended by Seber (1982). TAC estimated a lower mainstem sport spring Chinook harvest rate of 4.29% (9,606 fish harvested out of a runsize at the river mouth of 221,157; WDFW and ODFW 2012—Table 7). This was very similar to the harvest rate based on PIT tags for Snake "ESU/DPS" spring Chinook of 4.2% (95% CI 3.5-4.9%) which had a substantial number of PIT recoveries (n =19), and overlapped the 95% CIs for other stocks for which PIT tag estimates were based on few recoveries (Table 4). TAC estimated a harvest rate of 5.1% for Up-River Bright (URB) fall Chinook, and 1.7% for Wild Snake River fall Chinook in below BON sport fisheries. The PIT tag harvest rate estimated for hatchery Snake fall Chinook was 1% (95% CI 0.6-1.2%), which is lower than both estimates, but it was based on only four tag recoveries (Table 4). We did not recover any summer Chinook, sockeye or coho salmon PIT tags from sport fisheries so we did not make harvest estimates for these species. Steelhead sport fisheries are mark-selective and are therefore not directly comparable to TAC estimates of wild stock non-retention impact rates in sport fisheries.

Zones 1-5 Commercial Fisheries

TAC estimated a below BON commercial fishery harvest rate of 1.5% (3,410 caught out of an upriver run of 221,157; WDFW and ODFW 2012—Table 7) on upriver spring Chinook during the spring fishery. PIT tag based estimates were 0.7, 2.2, and 1.2%, respectively, for hatchery LCR (BON pool) (tag recoveries = 2), MCR (n = 5), and Snake spring Chinook (n = 16), and were similar to TAC's estimates (Table 8). TAC estimated a harvest rate of 6.2% (catch of 5,576 from a run of 80,574) on Upper Columbia summer Chinook during the below BON summer commercial fishery (WDFW and ODFW 2012—Table 10). The PIT tag estimate was 0.6% based on three tag recoveries. Interestingly, PIT tag recoveries revealed that in addition to Upper Columbia summer Chinook, Upper Columbia Snake spring Chinook were caught in the summer commercial fishery, with respective harvest rates of 0.7 and 1.0% (Table 10). TAC estimated a Wild Snake River fall Chinook harvest rate of 6.6% which was slightly higher than the PIT based estimate of 4.3% (95% CI 4.3-4.8%) based on 30 recovered tags. For coho, TAC estimated lower river harvest rates of 2.6% and 6.9%, on early and late coho (including lower river coho stocks), respectively. This compared to the PIT based estimate of 3.5% (95% CI 2.8-4.4%) for coho, which mixture model analysis suggested were early timed. No PIT tags were recovered from coho salmon in lower river commercial catches.

Zone 6 Treaty Fisheries

TAC estimated a harvest rate of 29.5% for Upper Columbia summer Chinook in the summer treaty fishery (catch of 20,645 from a run of 69,994 based on June 15-July 31st timing at BON; WDFW and ODFW 2012—Table 10). PIT tag harvest estimates for this fishery included many more stocks including several spring Chinook stocks. Harvest rates were 4.5% for hatchery Snake spring Chinook and 9.0% for wild Snake spring Chinook, and 2.7% for hatchery Upper Columbia summer Chinook (Table 18). TAC estimated a harvest rate of 6.9% for Snake River sockeye in the Zone 6 treaty summer fishery (catch of 132 from a run of 1,919; WDFW and ODFW 2012—Table 16), which was very similar to the PIT based harvest rate of 7.2 (95% CI 4.9-9.6%) for Snake River sockeye based on three tag recoveries and to the total upriver sockeye harvest rate 6.7% (95% CI 5.4-8.0%) based on nine tag recoveries (Table 20). TAC estimated a steelhead harvest rate of 0.84% (2,683 caught out of the A-run abundance of 318,125; WDFW and ODFW 2012—Table 28) for A-runs during for Zone 6 summer treaty fisheries, which compared with PIT based estimates that were closer to 2.0% for MCR, Snake, and UCR hatchery and wild steelhead encountered during this fishery (Table 16).

For the fall fishery period, TAC estimated a Zone 6 treaty harvest rate of 53.7% (catch of 28,801 from a run at BON of 53,660; WDFW and ODFW 2012 Fall Report—Table 17) for Bonneville Pool Hatchery (BPH) Chinook (the naming convention used by TAC referring to Lower Columbia River Tule Chinook originating from Spring Creek National Fish Hatchery and other Tule releases in the Bonneville Pool). The PIT based estimate was 40% (95% CI 23-58%) based on three tag recoveries and was not statistically different from the TAC estimate. The TAC harvest rate estimate for the Snake River Wild URB grouping in Zone 6 was 24.9% (WDFW and ODFW 2012 Fall Report—Table 18), which was higher than the PIT based estimates for hatchery Snake fall Chinook (9.5%; 95% CI 8.6-10.3%) based on a large sample size including 101 tag recoveries. The TAC estimate for the Pool Upriver Brights (PUB), which include Hatchery bright Chinook stocks returning to hatcheries in the BON pool, was 39.0%, which was higher than the PIT based estimate of 15.7% (95% CI 10.5-21.8%) (Table 24). TAC manages fisheries in the Columbia River for impacts to steelhead for the Skamania Group (before 7/1 at BON), Group A (after 7/1 at BON and < 78 mm) and Group B (after 7/1 and > 78 mm). However, these management groups do not correspond to steelhead recovery populations or other management needs. TAC reported a 7.2% impact for wild Group A steelhead and a 21.1% impact for Group B steelhead (WDFW and ODFW 2012; Tables 18 and 21). PIT based estimates for the fall fishery to steelhead included a harvest rate of 3.8% (95% CI 3.1-4.6%) based on 15 tag recoveries for Snake hatchery stocks belonging to biological A-run populations, and 6.2% (95% CI 6.2-7.8%) for Snake steelhead belonging to biological B-run populations (see Appendix for biologically-based population A- and B-run designations). Interestingly, LCR wild steelhead from the Wind River were also caught in the fall fishery, yielding a harvest rate of 12.1% (95% CI 7.0-18.4%) in this fishery, despite their management by TAC within the Skamania aggregate, thought to pass BON by June 31, and presumably clear the fishery area shortly thereafter (Table 24).

Size Selectivity

Size selectivity in many fisheries should be the expected and not the exception (Bernard and Clark 1996, Kendall et al. 2009). The results of our selectivity tests suggest that for most commercial and treaty fisheries, our reported harvest estimates were biased high for jacks and younger adults, which were caught at low rates, and were biased low for older fish, which were caught at relatively higher rates. This was less of a problem for sport fisheries, which appeared to be less size- and age-biased. Our analysis suggested age structured models are a more defensible approach for estimating harvest rates in mainstem Columbia River fisheries. Attempts to use travel days to assign ocean age were very successful for sockeye, coho, and Chinook salmon, but were less successful and required data sub-setting for steelhead. Since some of the juveniles that are PIT tagged are not actively migrating smolts and may rear in freshwater for an extended period before emigrating to the ocean, estimates of ocean ages are not straightforward with PIT tags. The denominators in our harvest estimates are the numbers of PIT tagged adult fish detected at BON, so we must be able to assign ages to these fish (for which we have no data other than their tagging information) as well as the catch (for which we have lengths and weights). Validation of travel days-based ocean age assignments should be completed for all species and efforts should be made to make age structured harvest estimates, or at least, jack/mini-jack and adult only harvest estimates.

Data sharing

All PIT tags sampled in fisheries were uploaded to PTAGIS after the season. Therefore, this fishery mortality information is available to fishery managers and researchers. In this report, we purposely provided estimates of the fishery sample rate, PIT tag scanner detection probabilities, the PIT tag detection rate at BON, and the species-specific release site-rear/run types used (Appendices 1-3) to make harvest estimates in this paper. Interested parties may query PTAGIS to obtain the number of adults and jacks detected at BON along with the PIT tags sampled in the fishery belonging to our harvest groups. With this information, interested parties can estimate harvest rates for their own tag release groups. However, when estimating harvest rates they should be aware of the uncertainty caused by the few PIT tag recoveries in fisheries and deal with it appropriately via discrete error distributions (e.g., Poisson or binomial). Despite these caveats we have demonstrated that PIT tag sampling can provide reasonable harvest estimates, finer scale population harvest estimates, and provide estimates of uncertainty, which are not available using current harvest estimation methods in the Columbia River.

Mixture Models

The use of mixture models to estimate harvest rates for coho salmon was necessary because of the bimodal return timing of early and late coho populations (Weitkamp et al. 1996). Inference using mixture models is difficult because there is often no data regarding the number of subpopulations, their timing, or whether the variance in Gaussian mixture models should be equal for both subpopulations (Carlin and Louis 2009). However, Figure 11 suggested our PIT tag recoveries contained information on the mean date of passage and the variance for the early population, since these recoveries substantially overlapped the early mode of the adult coho salmon run at BON, which we used as a prior in the mixture model. Since the different subpopulations were well defined due to timing differences, a vague prior provided similar results for the estimate of the late harvest rate. More work is needed in mixture model selection and goodness of fit tests.

Sockeye Salmon Population Composition Based on PIT Tags

We were able to successfully estimate the timing and abundance of upriver sockeye stocks at BON based on PIT tags in returning adults detected at BON and tagging rates of adults determined from tributary dam census counts and tag detections. We were additionally able to estimate the abundance and timing at BON of the minimally tagged yet abundant Okanogan population based on subtracting counts of Wenatchee and Snake sockeye. In future years if reintroduction efforts in the Deschutes and Yakima Rivers are successful, it may be increasingly difficult to identify timing and abundance of Okanogan sockeye if they and the newly reintroduced stocks are not also tagged at sufficient rates. Such information may be invaluable to fishery managers to structure fisheries to increase interceptions of abundant stocks while attempting to minimize impacts on stocks of conservation concern. For example, in 2011 Snake River sockeye were later arriving than Okanogan sockeye at BON by two weeks. Fisheries could have been constructed to harvest abundant Okanogan sockeye early in the season with reduced impacts on later returning Snake River sockeye.

Our analysis of the timing and abundance of sockeye salmon at BON was limited to the use of fish PIT tagged as juveniles. With some additional assumptions, it may be possible to use the adult sockeye salmon PIT tagged at BON if they were tagged proportional to the run. However, based on weekly timing in 2011, tagging at BON Adult Fish Facility was not representative of the run as a whole. No adults were PIT tagged from the early portion of the run, weeks 19 to 24, when few fish were available. During the peak of the run, weekly tagging rates increased from 0.25% in week 25 to 2.03% in week 30. During the later part of the run few fish were tagged. Due to the lack of proportional tagging, we did not incorporate BON adult tagging into our analysis. However, stratified population estimates (Schwarz and Taylor 1998) may be used to estimate the abundance of the different stocks passing BON when tagging is not proportional. However, this is beyond the scope of this report.

Conclusions

In this study we extend the method of estimating salmon and steelhead harvest rates based on PIT tags in the Columbia River that was developed by Rawding et al. (2014a). It is a natural extension to recover these PIT tags given the small incremental cost to fisheries sampling because fisheries are already sampled (e.g., for CWT and genetic samples) and PIT tags provide fishery managers finer scale harvest estimates along with harvest estimates for wild populations, which are currently not directly available for most populations.

Harvest estimates compared favorably with those developed by Columbia River fishery managers in some cases, particularly where sample sizes were large (“Large Aggregate” estimates), and where TAC defined stocks based on criteria that correspond to populations identified by PIT tags, but differed in others. In addition, we provided fine scale harvest estimates at the “River”, “ESU/DPS”, and management group scales. These fine scale estimates are not available with traditional sampling programs, but ESU level estimates are available through genetic sampling (Kassler et al. 2002). These fine scale estimates allow fishery managers greater flexibility in managing for weaker stocks or populations at high risk. However, our estimates were only made possible where there was sufficient juvenile PIT tagging of populations or ESUs of interest. It appears that many populations of steelhead and spring Chinook in each Columbia River DPS are PIT tagged, but fewer populations of fall Chinook and coho salmon are PIT tagged. Therefore, making an inference about harvest for these population using PIT tags requires assumptions about the susceptibility to harvest of tagged and untagged populations. However, harvest rates for hatchery populations of Chinook and coho salmon are still available based on CWT.

We calculated harvest rates specific to each fishery, as opposed to exploitation rates. For example, in the Zone 1-5 and sport fishery, harvest rates are based on the abundance of fish entering Zone 1; and in the Zone 6 fishery the harvest rate is based on the abundance at BON. This differs from the TAC, which in many cases calculates harvest rates for fisheries based on fish entering the Columbia River. We did not standardize harvest estimates to the mouth of the Columbia River because the number of PIT tags detected below BON was small and the fishery sampling was incomplete; this should be considered in future years.

Recommendations

We recommend the following improvements to PIT tag-based harvest estimates:

1) Develop statistical methods to estimate “over the bank” or non-ticketed catch in Zone 6 treaty fisheries
2) Obtain numbers of dressed and whole fish when sampling and explicitly use this information in adjustment of ticketed catch based on different weights
3) Stratify Zone 6 sampling by pool especially for summer steelhead due to their holding behavior, which may be pool-specific for certain populations
4) Explore the feasibility of reporting fish numbers instead of pounds on fish tickets, which would eliminate the uncertainty in the derived catch estimate
5) Increase sampling of PIT tagged fish in the Oregon commercial and treaty landings and begin sampling sport catch landed in Oregon
6) Pursue further development of statistical methods that combine harvest information from multiple sources such as PIT tags, CWT tags, and genetic markers using maximum likelihood or Bayesian approaches to provide a single harvest estimate
7) Consider the use of hierarchical modeling of harvest estimates as an alternative to pooled/aggregate estimates
8) Consider a power analysis for important fishery management groups to ensure sufficient PIT tagging and sampling to meet managers precision goals
9) Develop methods for age structured harvest rates based on PIT tags
10) Recommend juvenile tagging of Okanogan sockeye
11) Increase PIT tag fishery sampling rates to meet 20% guideline
12) Work with managers to develop estimates of indirect fishery mortality (net drop-out rate; non-retention mortality)

Acknowledgements

Many WDFW and PSMFC staff contributed to the success of this study, through their hard work in developing protocols, coordinating logistics, and sampling fisheries. We thank the various PIT tag coordinators who allowed WDFW to use their PIT tag data for this study. Bob Woodard and the Region 5 data management team provided assistance in PIT tag and fishery database development and management. We thank Rick Golden (BPA) for his support of this project.

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Appendix

Appendix Table 1. The number of PIT tagged Chinook salmon detected passing upstream through Bonneville Dam used in harvest estimates by hierarchical reporting groups “Rivers” and “ESU/DPS” reporting levels. Release Site refers to the release site code from PTAGIS. Rear types include hatchery (H), wild (W), and unknown (U).

ESU/DPS	River	Release Site	Rear Type	Number of Tags 1/1—12/31
LCR Bright_Fall	L White Salmon Bright_Fall	LWSH	H	171
LCR Tules_Fall	SCNFH_Fall	SPRC	H	28
LCR_Spring	Hood_Spring	BLKBAS	H	84
LCR_Spring	Hood_Spring	HOODR	W	1
LCR_Spring	Hood_Spring	PARK	H	72
LCR_Spring	Hood_Spring	WILL	H	43
LCR_Spring	L White Salmon_Spring	LWSH	H	108
LCR_Spring	Wind_Spring	CARS	H	266
MCR_Fall	Deschutes_Fall	DESCH1	W	1
MCR_Fall	Hanford URB_Fall	COLR6	W	75
MCR_Fall	Natches_Fall	NATCHR	H	6
MCR_Fall	Umatilla_Fall	THOP	H	2
MCR_Fall	Umatilla_Fall	UMAR	H	5
MCR_Fall	Yakima_Fall	CHANDL	W	5
MCR_Fall	Yakima_Fall	YAKIM1	H	205
MCR_Fall	Yakima_Fall	YAKIM1	U	1
MCR_Fall	Yakima_Fall	YAKIM1	W	4
MCR_Fall	Yakima_Fall	YAKIM2	H	4
MCR_Spring	Deschutes_Spring	DESCH1	W	2
MCR_Spring	Deschutes_Spring	METOLR	W	1
MCR_Spring	Deschutes_Spring	PELTON	H	118
MCR_Spring	Deschutes_Spring	SHTIKC	W	2
MCR_Spring	Deschutes_Spring	WSPH	H	26
MCR_Spring	John Day_Spring	GRBLDC	W	1
MCR_Spring	John Day_Spring	JDAR1	W	136
MCR_Spring	John Day_Spring	JDAR2	W	34
MCR_Spring	John Day_Spring	JDARMF	W	95
MCR_Spring	Klickitat_Spring	KLIH	H	163
MCR_Spring	Umatilla_Spring	IMQP	H	24
MCR_Spring	Umatilla_Spring	THOP	H	1
MCR_Spring	Umatilla_Spring	UMAR	H	4
MCR_Spring	Walla Walla_Spring	MILLC	U	5
MCR_Spring	Walla Walla_Spring	MILLC	W	1
MCR_Spring	Walla Walla_Spring	WALLAR	U	25

MCR_Spring	Walla Walla_Spring	WALLAR	W	3
MCR_Spring	Walla Walla_Spring	WALLSF	H	5
MCR_Spring	Walla Walla_Spring	YELHKC	U	2

Appendix Table 1 continued.

ESU/DPS	River	Release Site	Rear Type	Number of Tags 1/1—12/31
MCR_Spring	Yakima_Spring	AMERR	W	1
MCR_Spring	Yakima_Spring	CHANDL	W	21
MCR_Spring	Yakima_Spring	CLARFP	H	183
MCR_Spring	Yakima_Spring	EASTOP	H	141
MCR_Spring	Yakima_Spring	JACKCP	H	128
MCR_Spring	Yakima_Spring	ROZBYP	H	4
MCR_Spring	Yakima_Spring	ROZTAL	H	23
MCR_Spring	Yakima_Spring	ROZTAL	W	49
MCR_Spring	Yakima_Spring	SSDTAL	H	4
MCR_Spring	Yakima_Spring	SSIDEC	H	4
MCR_Spring	Yakima_Spring	YAKIM1	H	1
MCR_Spring	Yakima_Spring	YAKIM1	W	43
MCR_Summer	Naches_Summer	NATCHR	H	14
Snake_Fall		LGRRRR	H	4
Snake_Fall		LGRRRR	U	1
Snake_Fall		LGRRTR	H	5
Snake_Fall		LGRRTR	U	1
Snake_Fall		SNAKE3	H	888
Snake_Fall		SNAKE3	U	8
Snake_Fall		SNAKE4	H	355
Snake_Fall	Clearwater_Fall	BCCAP	H	1,254
Snake_Fall	Clearwater_Fall	CLWR	W	6
Snake_Fall	Clearwater_Fall	NLVP	H	13
Snake_Fall	Clearwater_Fall	NPTH	H	12
Snake_Fall	Grande Ronde_Fall	GRAND1	H	110
Snake_Fall	Selway_Fall	CEFLAF	H	54
Snake_Fall	SF Clearwater_Fall	LUGUAF	H	70
Snake_Fall	Snake_Fall	CJRAP	H	659
Snake_Fall	Snake_Fall	LYFE	H	642
Snake_Fall	Snake_Fall	PLAP	H	530
Snake_Spring		LGRRBR	U	1
Snake_Spring		LGRRRR	H	4
Snake_Spring		LGSTAL	H	1
Snake_Spring		SNAKE2	H	1
Snake_Spring		LGRRBR	H	4
Snake_Spring	Clearwater_Spring	CLEARC	H	194

Snake_Spring	Clearwater_Spring	LOLOC	H	12
Snake_Spring	Clearwater_Spring	LOLOC	W	8
Snake_Spring	Clearwater_Spring	NPTH	H	11
Snake_Spring	EF Salmon_Spring	SALEFT	W	6
Snake_Spring	Grande Ronde_Spring	CATHEC	W	23
Snake_Spring	Grande Ronde_Spring	CATHEP	H	225

Appendix Table 1 continued.

ESU/DPS	River	Release Site	Rear Type	Number of Tags 1/1—12/31
Snake_Spring	Grande Ronde_Spring	GRAND2	W	7
Snake_Spring	Grande Ronde_Spring	GRANDP	H	13
Snake_Spring	Grande Ronde_Spring	GRNTRP	H	31
Snake_Spring	Grande Ronde_Spring	GRNTRP	W	77
Snake_Spring	Grande Ronde_Spring	LOOH	H	35
Snake_Spring	Grande Ronde_Spring	LOOKGC	W	16
Snake_Spring	Grande Ronde_Spring	MINAMR	W	15
Snake_Spring	Imnaha_Spring	IMNAHR	H	26
Snake_Spring	Imnaha_Spring	IMNAHR	W	10
Snake_Spring	Imnaha_Spring	IMNAHW	H	349
Snake_Spring	Imnaha_Spring	IMNTRP	W	198
Snake_Spring	Lemhi_Spring	HAYDNC	W	8
Snake_Spring	Lemhi_Spring	LEMHIR	W	21
Snake_Spring	Lemhi_Spring	LEMHIW	W	11
Snake_Spring	Little Salmon_Spring	RAPH	H	723
Snake_Spring	Lochsa_Spring	CFCTRP	W	8
Snake_Spring	Lochsa_Spring	COLTKC	W	1
Snake_Spring	Lochsa_Spring	POWP	H	114
Snake_Spring	MF Clearwater_Spring	KOOS	H	76
Snake_Spring	MF Salmon_Spring	BEARVC	W	1
Snake_Spring	MF Salmon_Spring	BIG2C	W	83
Snake_Spring	MF Salmon_Spring	CAMASC	W	3
Snake_Spring	MF Salmon_Spring	CAPEHC	W	1
Snake_Spring	MF Salmon_Spring	ELKC	W	3
Snake_Spring	MF Salmon_Spring	MARTRP	W	54
Snake_Spring	MF Salmon_Spring	SULFUC	W	4
Snake_Spring	NF Clearwater_Spring	DWORNF	H	410
Snake_Spring	Pahsimeroi_Spring	PAHP	H	113
Snake_Spring	Pahsimeroi_Spring	PAHTRP	W	11
Snake_Spring	Salmon_Spring	CHAMBC	W	1
Snake_Spring	Salmon_Spring	CHAMWF	W	1
Snake_Spring	Salmon_Spring	SALTRP	H	1
Snake_Spring	Salmon_Spring	SAWT	H	57

Snake_Spring	Salmon_Spring	SAWTRP	W	29
Snake_Spring	Secesh_Spring	LAKEC	W	23
Snake_Spring	Secesh_Spring	SECESR	W	16
Snake_Spring	Secesh_Spring	SECTRP	W	29
Snake_Spring	Selway_Spring	MEADOC	H	13
Snake_Spring	Selway_Spring	MEADOC	W	17
Snake_Spring	Selway_Spring	SELWY1	H	188
Snake_Spring	SF Clearwater_Spring	CROOKR	H	52
Snake_Spring	SF Clearwater_Spring	CROTRP	H	11

Appendix Table 1 continued.

ESU/DPS	River	Release Site	Rear Type	Number of Tags 1/1—12/31
Snake_Spring	SF Clearwater_Spring	CROTRP	W	2
Snake_Spring	SF Clearwater_Spring	NEWSOC	H	11
Snake_Spring	SF Clearwater_Spring	NEWSOC	W	1
Snake_Spring	SF Clearwater_Spring	REDP	H	76
Snake_Spring	SF Clearwater_Spring	REDR	H	24
Snake_Spring	SF Clearwater_Spring	REDTRP	W	4
Snake_Spring	SF Salmon_Spring	JOHNSC	H	13
Snake_Spring	SF Salmon_Spring	JOHNSC	U	1
Snake_Spring	SF Salmon_Spring	JOHTRP	W	39
Snake_Spring	SF Salmon_Spring	KNOXB	H	506
Snake_Spring	SF Salmon_Spring	KNOXB	W	42
Snake_Spring	SF Salmon_Spring	LSFTRP	U	1
Snake_Spring	SF Salmon_Spring	LSFTRP	W	3
Snake_Spring	SF Salmon_Spring	SAEFSF	U	1
Snake_Spring	Tucannon_Spring	CURP	H	147
Snake_Spring	Tucannon_Spring	TUCR	W	32
Snake_Spring	U Salmon_Spring	HERDC	W	2
Snake_Spring	U Salmon_Spring	VALEYC	W	4
Snake_Spring	Wallowa_Spring	LOSTIP	H	82
Snake_Spring	Wallowa_Spring	LOSTIR	H	4
Snake_Spring	Wallowa_Spring	LOSTIR	W	36
Snake_Spring	YF Salmon_Spring	YANKFK	H	8
UCR_Fall	Columbia_Fall	PRDH	H	23
UCR_Spring		RI2BYP	U	2
UCR_Spring		TURO	H	57
UCR_Spring		WELLD2	H	1
UCR_Spring	Chelan_Spring	CHELAR	H	1
UCR_Spring	Entiat_Spring	ENTIAR	W	60
UCR_Spring	Icicle Creek_Spring	LEAV	H	96
UCR_Spring	Methow_Spring	BIDDLP	H	9

UCR_Spring	Methow_Spring	METH	H	94
UCR_Spring	Methow_Spring	METHR	H	2
UCR_Spring	Methow_Spring	METHR	W	4
UCR_Spring	Methow_Spring	TWISPR	H	5
UCR_Spring	Methow_Spring	TWISPR	W	20
UCR_Spring	Methow_Spring	WINT	H	41
UCR_Spring	Methow_Spring	WOLFC	H	119
UCR_Spring	Wenatchee_Spring	CHIP	H	209
UCR_Spring	Wenatchee_Spring	CHIWAR	W	29
UCR_Spring	Wenatchee_Spring	CHIWAT	W	86
UCR_Spring	Wenatchee_Spring	NASONC	W	16
UCR_Spring	Wenatchee_Spring	WENATL	H	2

Appendix Table 1 continued.

ESU/DPS	River	Release Site	Rear Type	Number of Tags 1/1—12/31
UCR_Spring	Wenatchee_Spring	WENATR	W	3
UCR_Spring	Wenatchee_Spring	WENATT	W	5
UCR_Spring	Wenatchee_Spring	WHITER	H	1
UCR_Spring	Wenatchee_Spring	WHITER	W	1
UCR_Summer		RI2BYP	U	5
UCR_Summer		WELH	H	30
UCR_Summer		WELTAL	H	183
UCR_Summer	Chelan_Summer	CHELAR	H	236
UCR_Summer	Entiat_Summer	ENTH	H	74
UCR_Summer	Entiat_Summer	ENTIAR	W	2
UCR_Summer	Methow_Summer	CARP	H	78
UCR_Summer	Methow_Summer	METHR	H	114
UCR_Summer	Okanogan_Summer	OKANR	H	148
UCR_Summer	Okanogan_Summer	SIMILR	H	12
UCR_Summer	Wenatchee_Summer	DRYP	H	253
Total				**13,367**

Appendix Table 2. The number of PIT tagged coho salmon detected passing upstream through Bonneville Dam used in harvest estimates by hierarchical reporting groups including “Large Aggregates, “Rivers” and “ESU/DPS” reporting levels. Release Site refers to the release site code from PTAGIS. Rear types include hatchery (H), wild (W), and unknown (U).

Large Aggregates	ESU/DPS	River	RelSite	Rear Type	Number of Tags 1/1—12/31
Above BON			MCNGWL	H	4
Above BON			MCNGWL	W	13
Above BON	Mid Columbia	15 Mile Creek	15MILC	W	1
Above BON	Mid Columbia	Yakima	AHTANC	H	17
Above BON	Mid Columbia	Yakima	CHANDL	H	7
Above BON	Mid Columbia	Yakima	CHANDL	W	9
Above BON	Mid Columbia	Yakima	NATCHR	H	340
Above BON	Mid Columbia	Yakima	NATCHR	W	2
Above BON	Mid Columbia	Yakima	PROTAL	U	1
Above BON	Mid Columbia	Yakima	TANEUC	W	19
Above BON	Mid Columbia	Yakima	YAKIM1	H	31
Above BON	Mid Columbia	Yakima	YAKIM1	W	2
Above BON	Mid Columbia	Yakima	YAKIM2	H	156
Above BON	Snake	Clearwater	KOOS	H	135
Above BON	Snake	Clearwater	LAPC	H	68
Above BON	Upper Columbia	Entiat	ENTIAR	W	1
Above BON	Upper Columbia	Methow	TWIS2P	H	4
Above BON	Upper Columbia	Methow	WINT	H	230
Above BON	Upper Columbia	Methow	WINTBC	H	156
Above BON	Upper Columbia	Wenatchee	BEAV3P	H	2
Above BON	Upper Columbia	Wenatchee	BUTCHP	H	137
Above BON	Upper Columbia	Wenatchee	LEAV	H	504
Above BON	Upper Columbia	Wenatchee	NASONC	H	3
Above BON	Upper Columbia	Wenatchee	ROLFIP	H	188
Total					**2,030**

Appendix Table 3. The number of PIT tagged sockeye salmon detected passing upstream through Bonneville Dam used in harvest estimates by hierarchical reporting groups including “Large Aggregates, “Rivers” and “ESU/DPS” reporting levels. Release Site refers to the release site code from PTAGIS. Rear types include hatchery (H), wild (W), and unknown (U).

Large_Aggregates	ESU_DPS	River	RelSite	Rear_Type	Number of Tags 1/1--12/31
Above BON			BONAFF	U	698
Above BON			MCNGWL	W	5
Above BON	Snake	Salmon	ALTULC	H	1
Above BON	Snake	Salmon	ALTULC	W	2
Above BON	Snake	Salmon	PETTL	H	1
Above BON	Snake	Salmon	PETTLC	H	1
Above BON	Snake	Salmon	RLCTRP	H	82
Above BON	Snake	Salmon	RLCTRP	W	1
Above BON	Snake	Salmon	SAWTRP	H	428
Above BON	UCR		PRDGWL	U	1
Above BON	UCR		RI2BYP	U	111
Above BON	UCR		RI2BYP	W	10
Above BON	UCR		RISTAL	U	4
Above BON	UCR		WANGWL	U	1
Above BON	UCR		WANTAL	U	1
Above BON	UCR		WELLD2	U	44
Above BON	UCR	Wenatchee	WENA2T	W	176
Above BON	UCR	Wenatchee	WENATL	H	347
Total					**1,914**

Appendix Table 4. The number of PIT tagged steelhead detected passing upstream through Bonneville Dam used in harvest estimates by hierarchical reporting groups including "Large Aggregates, "Rivers" and "ESU/DPS" reporting levels. Release Site refers to the release site code from PTAGIS. Rear types include hatchery (H), wild (W), and unknown (U). Run management designations A, B, and combined (unknown run) AB are listed for all Snake River stocks.

Large Aggregates	ESU/ DPS	River	Release Site	Rear Type	4/1-10/31	7/1-10/31
	LCR	Hood Summer	BLKBAS	H	81	68
	LCR	Hood Summer	HOODR	H	6	5
	LCR	Hood Summer	HOODWF	H	1	0
	LCR	Wind	PANT2C	W	6	2
	LCR	Wind	TROUTC	W	37	14
	LCR	Wind	WIND2R	W	80	51
	MCR	15 Mile Creek	15MILC	W	94	93
	MCR	Deschutes	PERTAL	W	4	4
	MCR	Deschutes	TROU2C	W	105	105
	MCR	John Day	BEAR2C	W	1	1
	MCR	John Day	BRIDGC	W	31	31
	MCR	John Day	CAMP2C	W	5	5
	MCR	John Day	JDAR1	H	0	0
	MCR	John Day	JDAR1	W	1	1
	MCR	John Day	JDAR2	W	79	79
	MCR	John Day	JDARMF	W	47	47
	MCR	John Day	JDARSF	W	95	95
	MCR	John Day	JSFBC	W	5	5
	MCR	John Day	JSFMC	W	23	23
	MCR	Klickitat	KLICKR	W	1	1
	MCR	Rock Creek	ROCK2C	W	1	1
	MCR	Rock Creek	SQAW3C	W	2	2
	MCR	Umatilla	MEACHC	H	7	7
	MCR	Umatilla	MEACHC	W	19	19
	MCR	Umatilla	MINP	H	16	16
	MCR	Umatilla	PENP	H	19	19
	MCR	Umatilla	UMAR	H	22	22
	MCR	Umatilla	UMAR	W	62	61
	MCR	Walla Walla	DAYP	H	98	87
	MCR	Walla Walla	DAYP	W	2	1
	MCR	Walla Walla	MILLC	W	18	17
	MCR	Walla Walla	TOUCHR	H	60	60
	MCR	Walla Walla	TOUCHR	W	19	18
	MCR	Walla Walla	WALLAR	H	104	97
	MCR	Walla Walla	WALLAR	W	72	69
	MCR	Walla Walla	YELHKC	W	4	4
	MCR	Yakima	CHANDL	W	2	2
	MCR	Yakima	NATCHR	W	1	1
	MCR	Yakima	NFTEAN	W	4	3

	MCR	Yakima	ROZTAL	W	12	12
	MCR	Yakima	SATUSC	W	5	5
	MCR	Yakima	TANEUC	W	3	3
	MCR	Yakima	TEANAR	W	1	1
	MCR	Yakima	TOPPEC	W	21	21
	MCR	Yakima	YAKIM1	U	4	3
	MCR	Yakima	YAKIM1	W	12	12
	UCR		PRDGWL	U	1	1
	UCR		PRDLD1	H	1	0
	UCR		PRDLD1	U	5	5
	UCR		PRDLD1	W	6	6
	UCR		PRDTAL	U	18	17
	UCR		RI2BYP	H	43	42
	UCR		RI2BYP	U	5	5
	UCR		RI2BYP	W	26	26
	UCR		RISTAL	U	5	5
	UCR		WANTAL	U	12	12
	UCR		WELFBY	H	1	1
	UCR		WELLD1	H	2	2
	UCR	Entiat	ENTIAR	W	54	54
	UCR	Entiat	MADRVR	W	1	1
	UCR	Methow	BEAV2C	W	5	5
	UCR	Methow	CHEWUR	H	25	25
	UCR	Methow	CHEWUR	W	9	9
	UCR	Methow	GOLD2C	W	1	1
	UCR	Methow	LIBBYC	W	1	1
	UCR	Methow	METHR	H	29	29
	UCR	Methow	METHR	W	2	2
	UCR	Methow	PESHAR	W	1	1
	UCR	Methow	TWISPR	H	5	4
	UCR	Methow	TWISPR	W	12	12
	UCR	Methow	TWISPW	H	29	29
	UCR	Methow	WINT	H	230	230
	UCR	Methow	WOLFC	W	2	2
	UCR	Okanogan	OMAKC	H	117	117
	UCR	Wenatchee	CHIWAR	H	50	49
	UCR	Wenatchee	CHIWAT	W	9	9
	UCR	Wenatchee	NASONC	H	156	156
	UCR	Wenatchee	NASONC	W	8	8
	UCR	Wenatchee	ROLFIP	H	3	3
	UCR	Wenatchee	TUMFBY	H	7	6
	UCR	Wenatchee	TUMFBY	W	13	13
	UCR	Wenatchee	WENA2T	W	1	1
	UCR	Wenatchee	WENATR	H	211	201
	UCR	Wenatchee	WENATR	W	28	25
	UCR	Wenatchee	WENATT	W	4	4
SNK AB			IHRBYP	H	3	2
SNK AB			IHRBYP	W	1	1

SNK AB			LGRLDR	H	1	1
SNK AB			LGRLDR	W	55	51
SNK AB			LGRRBR	H	91	90
SNK AB			LGRRBR	W	424	418
SNK AB			LGRRRR	H	218	212
SNK AB			LGRRRR	W	196	195
SNK AB			LGRTAL	W	5	5
SNK AB			LGSTAL	H	3	3
SNK AB			LMNBYP	H	16	15
SNK AB			LMNBYP	U	1	1
SNK AB			LMNBYP	W	10	9
SNK AB			SNAKE1	H	1	1
SNK AB			SNAKE2	H	2	2
SNK AB			SNKTRP	H	40	40
SNK AB			SNKTRP	W	32	32
SNK AB		Clearwater AB	CLWTRP	W	9	9
SNK AB		Salmon AB	LSFTRP	W	1	1
SNK AB		Salmon AB	SALR3	H	139	139
SNK AB		Salmon AB	SALR4	H	67	67
SNK AB		Salmon AB	SALTRP	H	17	17
SNK AB		Salmon AB	SALTRP	W	3	3
SNK AB	SNA	Asotin A	ASOTIC	W	36	35
SNK AB	SNA	Asotin A	ASOTNF	W	1	1
SNK AB	SNA	Asotin A	ASOTSF	W	4	3
SNK AB	SNA	Asotin A	CHARLC	W	1	1
SNK AB	SNA	Clearwater A	BIGBEC	W	31	31
SNK AB	SNA	Clearwater A	CORRAC	W	1	1
SNK AB	SNA	Clearwater A	LAPC	W	2	2
SNK AB	SNA	Clearwater A	LBEARC	W	2	2
SNK AB	SNA	Clearwater A	PINE2C	W	5	5
SNK AB	SNA	Grand Ronde A	BCANF	H	195	195
SNK AB	SNA	Grand Ronde A	CATHEC	W	16	16
SNK AB	SNA	Grand Ronde A	CEDA2C	W	1	1
SNK AB	SNA	Grand Ronde A	COTP	H	173	172
SNK AB	SNA	Grand Ronde A	GRAND2	W	9	9
SNK AB	SNA	Grand Ronde A	GRNTRP	H	55	55
SNK AB	SNA	Grand Ronde A	GRNTRP	W	22	22
SNK AB	SNA	Grand Ronde A	LOOKGC	W	4	4
SNK AB	SNA	Grand Ronde A	LOSTIR	W	23	23
SNK AB	SNA	Grand Ronde A	MINAMR	W	11	11
SNK AB	SNA	Grand Ronde A	WALH	H	230	229
SNK AB	SNA	Imnaha A	BSHEEC	H	126	126
SNK AB	SNA	Imnaha A	IMNTRP	W	143	143
SNK AB	SNA	Imnaha A	LSHEEF	H	265	264
SNK AB	SNA	L Salmon A	SLATEC	H	2	2
SNK AB	SNA	Lemhi A	HAYDNC	W	11	11
SNK AB	SNA	Lemhi A	LEMHIR	W	30	30
SNK AB	SNA	Lemhi A	LEMHIW	W	6	6

SNK AB	SNA	Little Salmon A	LSALR	H	332	331
SNK AB	SNA	Little Salmon A	RPDTRP	W	8	8
SNK AB	SNA	Pahsimeroi A	PAHSIW	H	2	2
SNK AB	SNA	Pahsimeroi A	PAHTRP	H	393	393
SNK AB	SNA	Pahsimeroi A	PAHTRP	W	5	5
SNK AB	SNA	Potlatch A	POTREF	W	8	8
SNK AB	SNA	Salmon A	SAWT	H	188	188
SNK AB	SNA	Salmon A	SAWTRP	H	24	24
SNK AB	SNA	Salmon A	SAWTRP	W	4	4
SNK AB	SNA	Snake A	LYFE	H	59	55
SNK AB	SNA	Snake A	SNAKE4	H	318	318
SNK AB	SNA	Tucannon A	TUCR	H	164	155
SNK AB	SNA	Tucannon A	TUCR	W	50	48
SNK AB	SNA	U Salmon A	SLAT2C	H	12	12
SNK AB	SNA	U Salmon A	VALEYC	H	6	6
SNK AB	SNA	YF Salmon A	YANKFK	H	70	70
SNK AB	SNA	YF Salmon A	YANKFK	W	1	1
SNK AB	SNB	Clearwater B	CLEARC	H	78	78
SNK AB	SNB	Clearwater B	DWORMS	H	274	274
SNK AB	SNB	Clearwater B	LOLOC	H	14	14
SNK AB	SNB	EF Salmon B	SALEFT	H	1	1
SNK AB	SNB	EF Salmon B	SALREF	H	112	112
SNK AB	SNB	Lochsa B	CFCTRP	W	26	26
SNK AB	SNB	Lochsa B	COLTKC	W	6	6
SNK AB	SNB	Lochsa B	FISTRP	W	49	47
SNK AB	SNB	MF Clearwater B	KOOS	H	13	13
SNK AB	SNB	MF Salmon B	BIG2C	W	23	23
SNK AB	SNB	MF Salmon B	MARTRP	W	4	4
SNK AB	SNB	MF Salmon B	MONUMC	W	1	1
SNK AB	SNB	Salmon B	SQAW2C	H	98	98
SNK AB	SNB	Secesh B	LAKEC	W	1	1
SNK AB	SNB	Secesh B	SECESR	W	1	1
SNK AB	SNB	Secesh B	SECTRP	W	11	11
SNK AB	SNB	SF Clearwater B	CLWRSF	H	276	276
SNK AB	SNB	SF Clearwater B	CROOKR	H	17	17
SNK AB	SNB	SF Clearwater B	CROTRP	W	1	1
SNK AB	SNB	SF Clearwater B	MEAD2C	H	3	3
SNK AB	SNB	SF Clearwater B	REDP	H	39	39
SNK AB	SNB	SF Clearwater B	REDR	H	5	5
SNK AB	SNB	SF Salmon B	JOHTRP	W	3	3
SNK AB	SNB	SF Salmon B	KNOXB	W	13	13
		Totals			**7,883**	**7,721**