# Pacific Salmon Commission Sentinel Stocks Committee Final Report 2009-2014

Pacific Commission Sentinel Stocks Committee

January 2018

## Pacific Salmon Commission Technical Report No. 39

The Pacific Salmon Commission is charged with the implementation of the Pacific Salmon Treaty, which was signed by Canada and the United States in 1985. The focus of the agreement are salmon stocks that originate in one country and are subject to interception by the other country. The objectives of the Treaty are to 1) conserve the five species of Pacific salmon to achieve optimum production, and 2) to divide the harvests so each country reaps the benefits of its investment in salmon management.

Technical Reports of the Pacific Salmon Commission present results of completed or ongoing investigations carried out by the Pacific Salmon Commission that are deemed of sufficient interest to be made available to the scientific community and the public.



Pacific Salmon Commission
600 - 1155 Robson Street
Vancouver, B.C.V6E 1B5
(604) 684-8081
www.psc.org

Pacific Salmon Commission
Technical Report No. 39

Pacific Salmon Commission
Sentinel Stocks Committee

# Pacific Salmon Commission Sentinel Stocks Committee
# Final Report 2009-2014

January 2018

Correct citation for this publication:

Pacific Salmon Commission Sentinel Stocks Committee. 2018. Pacific Salmon Commission Sentinel Stocks Committee Final Report 2009-2014. Pacific Salmon Comm. Tech. Rep. No. 39: 167 p.

**Membership of the Sentinel Stocks Committee**

| **Canadian Members:** | **United States Members:** |
|---|---|
| Mr. Chuck Parken, Co-Chair, CDFO<br>Mr. Richard Bailey, CDFO<br>Mr. Michael Chamberlain, CDFO<br>Ms. Diana Dobson, CDFO<br>Mr. Roger Dunlop, FNFC (First Nations fisheries council)<br>Dr. Brian Riddell, CDFO<br>Dr. Arlene Tompkins, CDFO<br>Mr. Ivan Winther, CDFO | Dr. Marianna Alexandersdottir, Co-Chair, NWIFC<br>Dr. Dave Bernard, Co-Chair, ADFG<br>Dr. John H. Clark, ADFG<br>Mr. Ethan Clemons, ODFW<br>Mr. Tom Cooney, NMFS<br>Mr. Dan Rawding, WDFW |
| **Canadian Associate Members:** | **United States Associate Members:** |
| Mr. Pieter Van Will, CDFO | Ms. Dani Evenson, ADFG |

# IN MEMORY OF MICHAEL CHAMBERLAIN

# 1971 – 2012

# BIOLOGIST, COLLEAGUE, AND FRIEND

# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| \ | Aggregated Abundance Based Managed |
| **ADFG** | Alaska Department of Fish and Game |
| **1999 Agreement** | June 30, 1999 PST Annex and the Related Agreement |
| **2009 Agreement** | January 2009 PST Annex and the Related Agreement |
| **AUC** | Area-Under-the-Curve |
| **BC** | British Columbia |
| **Can$** | Canadian Dollars |
| **CDFO** | Canadian Department of Fisheries and Oceans |
| **Can$** | Canadian Dollars |
| **C** | Number Salmon Caught during 2nd Event in a MR Study |
| **CI** | Confidence Interval |
| **CTC** | Chinook Technical Committee |
| **CV** | Coefficient of Variation |
| **CWT** | Coded Wire Tag |
| **DSL** | SL discounted (multiplied) by OE |
| **DSR** | Driver Stock(Ratio) |
| **E** | Spawning abundance |
| **E[ … ]** | Expected Value of Bracketed Expression |
| **ER** | Exploitation Rate |
| **FN** | First Nations |
| **FNFC** | First Nations Fisheries Caucus |
| **GAPS** | Genetic Analysis of Pacific Salmon |
| **GH** | Grease Harbour |
| **GSI** | Genetic Stock Identification |
| **GW** | Gitwinksihlkw |
| ^ | Signifies an estimate |
| **ISBM** | Individual Stock Based Managed |
| **M** | Number of Marked Salmon in a Population |
| **ML** | Maximum Likelihood |
| **MR** | Mark–Recapture |
| **MSY** | Maximum Sustained Yield |
| **n** | Sample Size |
| **NA** | Not Available |
| **NBC** | Northern British Columbia (Dixon Entrance to Kitimat including Queen Charlotte Islands) |
| **NMFS** | National Marine Fisheries Service |
| **NOC** | North Oregon Coast |
| **NR** | Not Relevant |
| **NTC** | Nuu-chah-nulth Tribal Council |
| **NWFD** | Nisga'a Lisims Government Fisheries and Wildlife Department |

| | |
|---|---|
| **NWIFC** | Northwest Indian Fisheries Commission |
| **ODFW** | Oregon Department of Fish and Wildlife |
| **OE** | Observer efficiency in detecting salmon in swim, float, or foot surveys |
| **PSC** | Pacific Salmon Commission |
| **PST** | Pacific Salmon Treaty |
| **QCI** | Queen Charlotte Island |
| **PC** | Peak (maximum) Salmon Count among repetitive counts in a survey |
| **R** | Number of Marked Salmon in C |
| **$R^2$** | Coefficient of Determination in regression |
| **RFP** | Request For Proposals |
| **rkm** | River Kilometer |
| **RT** | Radio tags |
| **SALT** | South Thompson, Lower Adams, Little and Lower Thompson rivers |
| **SD** | Standard Deviation |
| **SE** | Standard Error |
| **SEQ** | Carrying Capacity for Spawners |
| **SL** | Survey life in days |
| **SMSY** | Escapement producing MSY |
| **SEAK** | Southeast Alaska Cape Suckling to Dixon Entrance |
| **SPAS** | Stratified Populations Analysis System |
| **SRSC** | Skagit River System Cooperative |
| **SSC** | Sentinel Stocks Committee |
| **SSP** | Sentinel Stocks Program |
| **Stock** | Salmon population the subject of the main project objective |
| **tGMR** | Trans-Generational Mark Recapture |
| **UD** | Undetermined |
| **UMSY** | Exploitation Rate at MSY |
| **U.S.** | United States |
| **US$** | United States Dollars |
| **U.S. LOA** | 1998 U.S. Letter of Agreement |
| **WCVI** | West Coast Vancouver Island excluding Area 20 |
| **WDFW** | Washington Department of Fish and Wildlife |

# TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

# EXECUTIVE SUMMARY

## Background

The Sentinel Stocks Program (SSP) was an ad hoc effort negotiated by the Pacific Salmon Commission (the Commission or the PSC) in 2008 to improve information on escapements for a set of Chinook salmon *Oncorhynchus tshawytscha* stocks in the United States and Canada. Improvements were envisioned to be

- more accurate and more precise estimates from existing agency assessment programs;
- funding of new agency programs to estimate escapements; and
- funding development of new, more cost-effective methods of estimating escapements.

These improvements were to be realized through funding projects proposed by those agencies with management authority over fisheries exploiting stocks spawning in the following areas:

- Northern British Columbia (NBC);
- Fraser River Watershed;
- West Coast of Vancouver Island (WCVI);
- Puget Sound; and
- North Oregon Coast (NOC).

Chinook salmon stocks in these areas were chosen for the SSP because insufficient information on these stocks had complicated the renewal of the Pacific Salmon Treaty in 2008.

A committee of scientists representing management agencies from both countries (the Sentinel Stocks Committee or SSC) was empaneled to annually solicit, assess, coordinate, and recommend proposals to the Commission for funding, and to review and report results of those projects. The SSC was also charged with improving projects by sharing expertise among themselves and with project proponents, by fostering the development of new methods to cost-effectively estimate escapement, and by leveraging experience gained through the SSP to improve escapement estimation after the SSP had ended.

The SSP funded 67 projects at a cost of 10 million US$ from 2009 through 2014 (Table ES.1). Funds were to be drawn equally from the annual earnings of the Northern and Southern Endowment Funds. This allocation was to support projects at 2 million US$ per year from 2009–2013. However, some of the allotted 10 million US$ was unspent at the end of 2013—funds that were used to extend the SSP into 2014. Forty-one projects were Canadian and 26 U.S. although the funds spent in each nation—5,648.3 k Can$ in Canada and 4,823.9 k US$ in the U.S.—were similar, especially when currency exchange rates are considered. Preparation, evaluation, and recommendation of proposals to the Commission followed protocols and a schedule (Figure ES.1) established by the SSC during the first year of the program.

**Table ES.1**–Chinook salmon stocks studied, study objectives and methods, years funded, and costs (in thousands) for projects selected for the Sentinel Stocks Program of the Pacific Salmon Commission 2009 - 2014.

| Stock(s) | Years Funded | Total Cost | Objectives/Methods: |
|---|---|---|---|
| **CANADIAN PROJECTS:** | | | |
| Nass | 6 | $601.9 | Augment existing MR study to estimate escapement by increasing numbers marked and inspected for marks. |
| Skeena (annual) | 6 | $208.3 | Estimate terminal run size by expanding estimated escapement Kitsumkalum River using GSI of Tyee Test Fishery catch. |
| Skeena (distribution) | 1 | $417.2 | Confirm GSI from Tyee Test Fishery and describe spawner distribution in watershed with radiotelemetry. |
| Skeena (retro) | 2 | $316.0 | Estimate terminal run size 1984-2008 using methods of Skeena (annual) and genetic material from archived scales. |
| Chilko | 5 | $1,109.2 | Estimate escapement with standard MR methods. |
| S. Thompson | 6 | $804.7 | Estimate terminal run size from catches of this stock in NBC with GSI, scales and with CWTs from its ER indicator stocks. |
| Harrison | 1 | $51.5 | Determine population closure for ongoing MR study using radiotelemetry. |
| Burman | 5 | $641.8 | Estimate escapement with standard MR methods and with AUC snorkel methods using radiotelemetry (2012 only). |
| Kaouk | 3 | $755.9 | Estimate escapement counting through a weir (2009) and with standard MR methods (2010, 2011). |
| Moyeha | 2 | $172.3 | Estimate escapement with standard MR methods (2010), demonstrate ability to catch salmon (2011). |
| Marble/Tahsis/Leiner | 1 | $219.0 | Estimate escapement with AUC snorkel surveys by estimating survey life/observer efficiency using radiotelemetry. |
| Marble/Tranquil/Sarita | 1 | $180.8 | Estimate escapement with AUC snorkel surveys by estimating survey life/observer efficiency using radiotelemetry. |
| Conuma | 1 | $139.7 | Estimate abundance with standard MR methods. |
| WCVI Framework | 1 | $30.0 | Stock/assessment framework for treaty and domestic management. |
| | 41 | $5,648.3 | ←Grand Total in Can$ |
| **U.S. PROJECTS:** | | | |
| Driver Stocks | 2 | $188.2 | Estimate terminal run sizes with GSI and CWTs from ER indicator stocks recovered in SEAK fisheries and terminal areas. |
| Green | 4 | $562.9 | Estimate escapement with standard MR methods (2010) and with genetic tGMR studies funded 2011 - 2013 to produce estimates for 2010 - 2012. |
| Stillaguamish | 4 | $341.5 | Estimate current/past escapement and with genetic tGMR methods for 2007 - 2013 with funding 2011 - 2014. |
| Snohomish | 4 | $912.8 | Estimate escapement all runs with standard MR methods (2009) and with tGMR methods for Skykomish, Snoqualmie, Snohomish runs in 2011 - 2013 with funding in 2012 - 2014. |
| Skagit | 1 | $46.2 | Demonstrate ability to catch salmon. |
| Nehalem | 5 | $1,391.8 | Estimate escapement with standard MR methods and in-river creel survey. |
| Siletz | 5 | $1,195.5 | Estimate escapement with standard MR methods and in-river creel survey. |
| Siuslaw | 1 | $194.0 | Estimate escapement with standard MR methods and in-river creel survey. |
| | 26 | $4,832.9 | ←Grand Total in US$ |

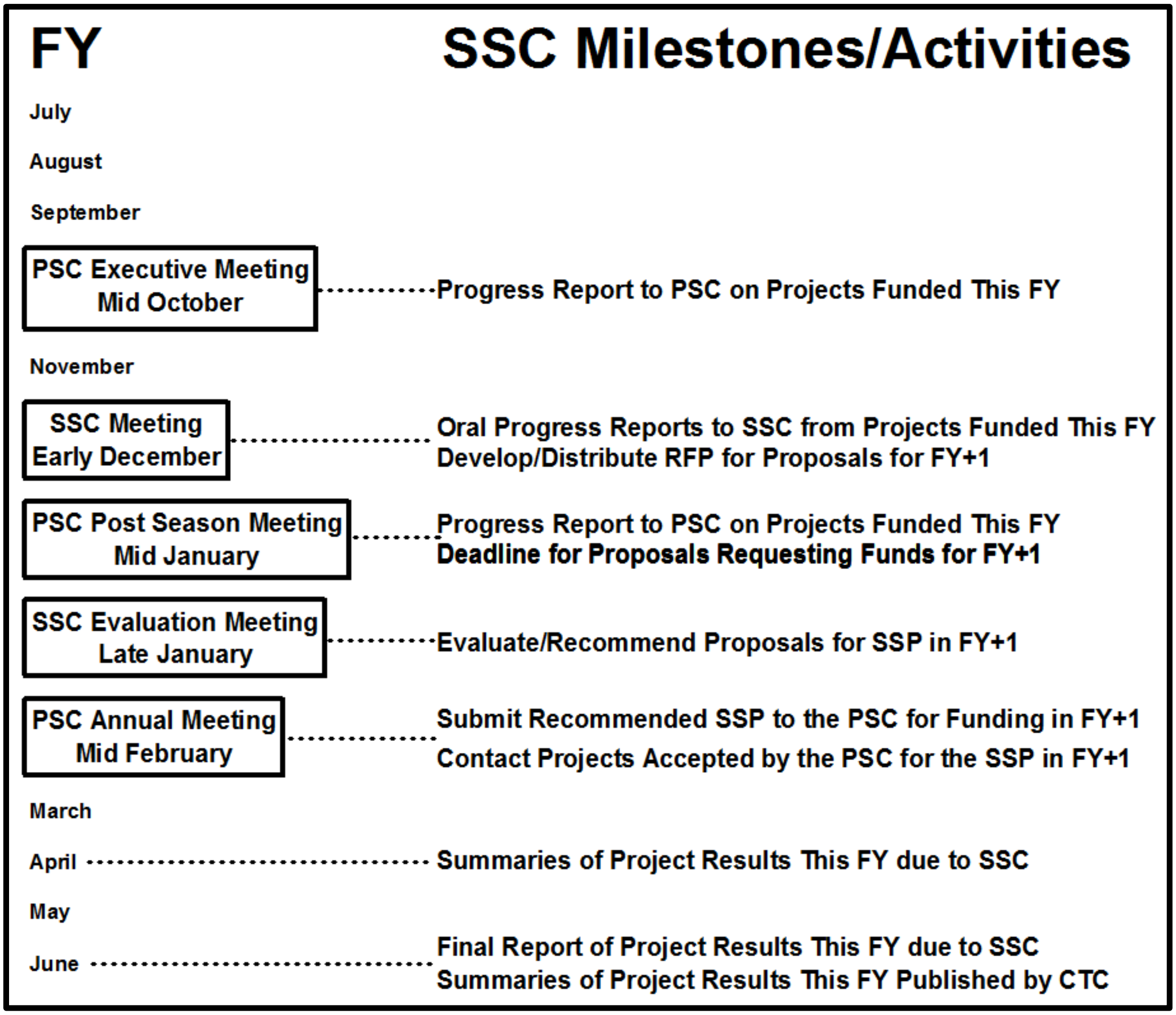



**Figure ES.1**–Schedule of annual milestones and activities of the Sentinel Stock Committee.

**Success with Objectives**

The most-frequent objective of SSP-funded projects was to support more accurate and precise estimation of abundance—usually spawning abundance—of Chinook salmon stocks from the five areas listed above. Two other objectives involved radiotelemetry—relative distribution of sub-stocks in the Skeena River Watershed and closure of the Chinook salmon population involved in a MR study on the Harrison River not funded through the SSP. A third objective involved developing a new framework for assessing spawning abundance in WCVI streams. A fourth objective was to demonstrate an ability to capture Chinook salmon on the Skagit River. The remaining projects were intended to estimate spawning abundance; methods employed in these projects were:

- Standard mark-recapture (MR) studies (all five areas);
- Trans-generational mark-recapture (tGMR) studies based on genetically identifying parents and their progeny (Puget Sound);
- Expanding genetically estimated catches in an ocean (AABM) fishery of a stock-aggregate using information from an exploitation rate indicator stock (Fraser, WCVI, NOC);

- Expanding a genetically estimated proportion of a sub-stock in a test fishery using information on the abundance of the sub-stock (NBC, Fraser);
- Expanding visual counts of Chinook salmon on spawning grounds with information on observational efficiency (OE) and survey life (SL) of spawning salmon (WCVI); and
- Weirs (WCVI).

Genetic analysis was used to estimate current spawning abundance and to retroactively estimate spawning abundance in years past by analysis of genetic material on archived scale samples (Skeena River retro). Radiotelemetry was employed to "mark" Chinook salmon in several SSP-funded MR studies and to estimate observer efficiency and survey life in AUC expansions of visual counts.

In all 111 abundance estimates were expected from SSP-funded studies, 107 were attained, and 101 have accompanying measures of precision (CVs) (see Table ES.2). Of the 101 estimates with CVs, 51 met the bilateral precision standard (CV ≤ 15%) for the Chinook Technical Committee (CTC) and another 11 were close (15% < CV ≤ 20%; Figure ES.2). The 102 abundance estimates with CVs also involved diagnostic testing to gather evidence against the accuracy of each estimate. In the few instances when evidence of bias was found, estimates were corrected or identified with limitations.

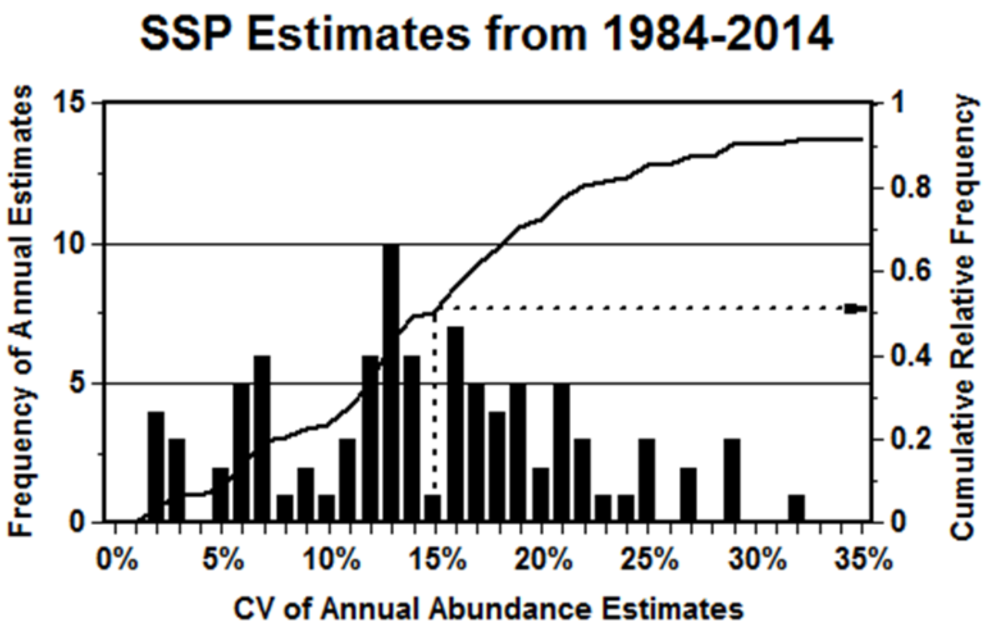



**Figure ES.2**–Frequency of estimated CVs for abundance estimates from SSP projects.

**Table ES.2**–Years funded, number abundance estimates expected, number attained, number that met the CTC bilateral standard for precision, and total funds expended (in thousands) by stock in the Sentinel Stocks Program of the Pacific Salmon Commission from 2009 – 2014. (NR not relevant; UD undetermined).

| CANADIAN PROJECTS: Stock(s) | Years Funded | Estimates Expected | Estimates Attained | Precision Standard Met | Total Cost |
|---|---|---|---|---|---|
| Nass | 6 | 6 | 6 | 5 | $601.9 |
| Skeena (annual) | 6 | 6 | 6 | 2 | $208.3 |
| Skeena (distribution) | 1 | 0 | 0 | NR | $417.2 |
| Skeena (retro) | 2 | 25 | 25 | 12 | $316.0 |
| Chilko | 5 | 5 | 5 | 5 | $1,109.2 |
| S. Thompson | 6 | 18 | 18 | 11 | $804.7 |
| Harrison | 1 | 0 | 0 | NR | $51.5 |
| Burman | 5 | 5 | 5 | 4 | $641.8 |
| Kaouk | 3 | 3 | 1 | 0 | $755.9 |
| Moyeha | 2 | 1 | 1 | 0 | $172.3 |
| Marble/Tahsis/Leiner | 1 | 3 | 3 | UD | $219.0 |
| Marble/Tranquil/Sarita | 1 | 3 | 3 | UD | $180.8 |
| Conuma | 1 | 1 | 0 | UD | $139.7 |
| WCVI Framework | 1 | 0 | 0 | NR | $30.0 |
| | | | | Grand Total in Can$ → | $5,648.3 |
| U.S. PROJECTS: | | | | | |
| Driver Stocks | 2 | 4 | 4 | 1 | $188.2 |
| Green | 4 | 3 | 3 | 3 | $562.9 |
| Stillaguamish | 4 | 7 | 7 | 4 | $341.5 |
| Snohomish | 4 | 10 | 9 | 2 | $912.8 |
| Skagit | 1 | 0 | 0 | NR | $46.2 |
| Nehalem | 5 | 5 | 5 | 2 | $1,391.8 |
| Siletz | 5 | 5 | 5 | 3 | $1,195.5 |
| Siuslaw | 1 | 1 | 1 | 0 | $194.0 |
| | | | | Grand Total in US$ → | $4,832.9 |

**Improving Estimates from Existing Agency Programs**

In the NBC area, SSP funds for improving existing agency programs were used to:

- Expand sampling power of the established stock assessment program on the Nass River run by the Nisga'a Lisims First Nation—an expansion crucial to the program in all years, but especially in the low-water, low-return year of 2010; and
- Link two existing CDFO assessment programs on the Skeena River (Tyee Test Fishery and MR studies on a tributary) through genetic analysis to estimate abundance of Chinook salmon entering the river now, and from genetic analysis of archived scales, entering the river in the past (Figure ES.3).

In the Fraser area, SSP funds for improving existing agency programs were used to:

- Test the correctness of the mathematical model used in an ongoing CDFO MR study on the Harrison River—correctness of the model was indicated;
- Produce unbiased abundance estimates for Chinook salmon spawning in three rivers to be used to expand past and future peak counts (PCs) of Chinook salmon in other, similar rivers in the CDFO stock assessment program (see Figure ES.4 for an example); and
- Expand sampling power to improve precision of MR estimates from established stock assessment programs on the Lower and Middle Shuswap rivers—resulting in CVs between 2%–3% for the Lower Shuswap stock and between 6%–16% for the Middle Shuswap stock.

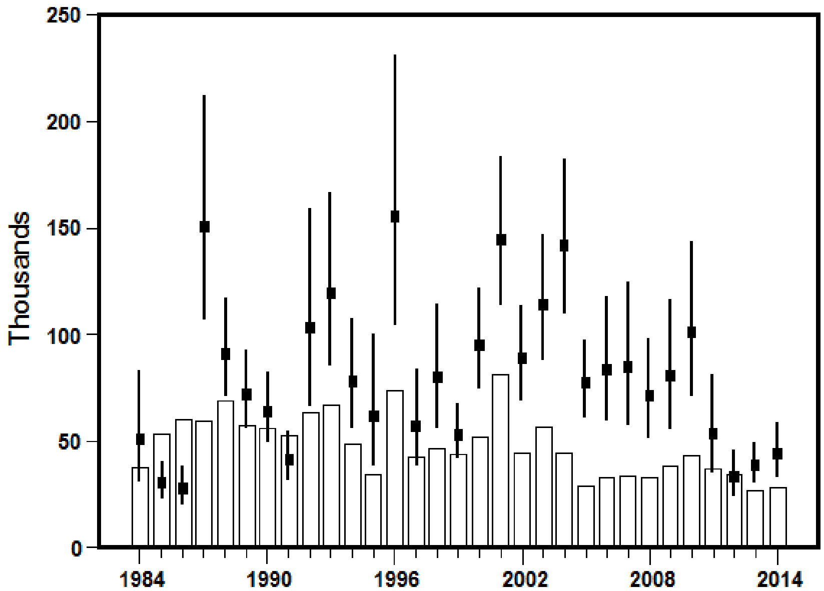



**Figure ES.3**–Comparison of the escapement indices used by the CTC to represent Chinook salmon spawning abundance in the Skeena River (bars) with escapement estimates (■) from using genetic stock identification (GSI) to expand estimated abundance of the Kitsumkalum sub-stock. Vertical lines represent lognormal 95% confidence intervals (CIs).

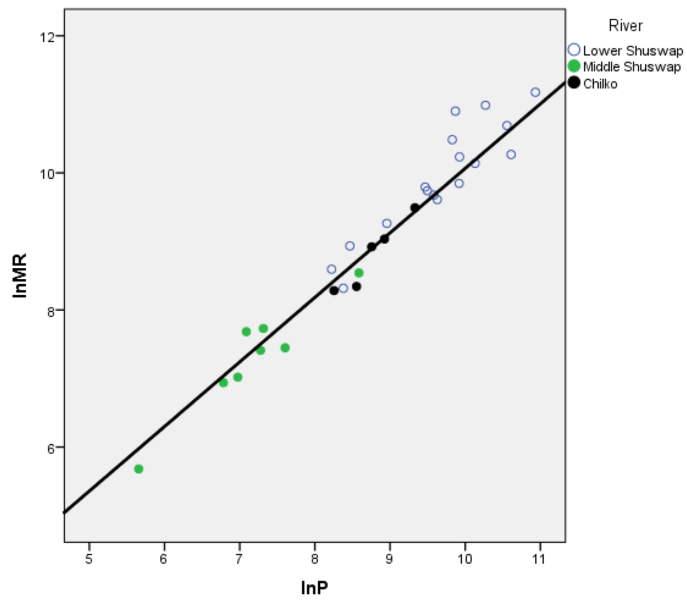



**Figure ES.4**–Natural log of escapement estimates (lnP) as calculated with peak counts from standard CDFO surveys regressed against the natural log of MR escapement estimates (lnMR) for the Lower Shuswap, Middle Shuswap, and Chilko rivers during 1983 – 2014. Similarity in fits among these three stocks indicates the slope of the common line could potentially be used to estimate abundance from PCs in other rivers with similar hydrographic features.

Funds from the SSP to improve existing stock assessment programs in WCVI were used to:

- Quantitatively estimate survey life and observer efficiency for area-under-the-curve expansions of visual counts of Chinook salmon for streams in CDFO's 6-stream and 14-stream abundance indices;
- Initiated a MR study by the Nuu-chah-nulth Tribal Council on the Burman River; and

Funds from the SSP to improve existing stock assessment programs in Puget Sound were used to:

- Develop a method to impute data for missing redd surveys in WDFW's standard stock assessment program on CTC escapement indicator stocks (see Figure ES.5; and
- Produce unbiased estimates of spawning escapement for CTC escapement indicator stocks with which to adjust biased estimates from past and future redd surveys (see Figure ES.5 for an example).

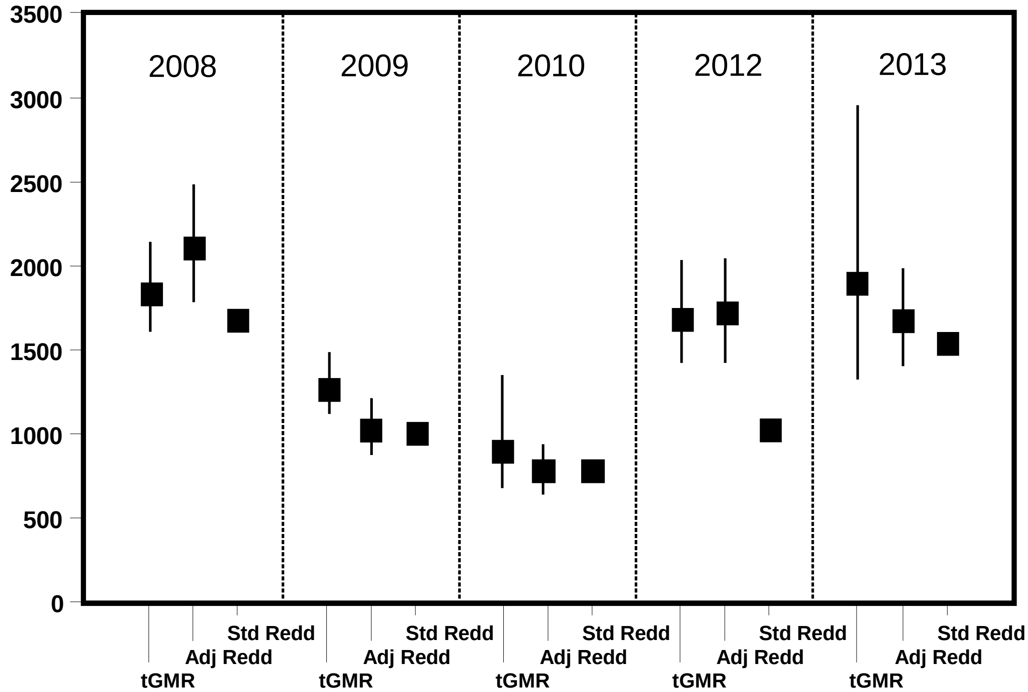



**Figure ES.5**–Abundance (escapement) estimates (■) for Chinook salmon spawning in the Stillaquamish River derived from tGMR studies alone, from redd counts adjusted for missing data and expanded by a recalculated factor of 2.39 (Adj Redd), and from the current agency method (Std Redd) of redd-count expansion (redd counts unadjusted for missing data multiplied by 2.5). Lines are 95% lognormal CIs.

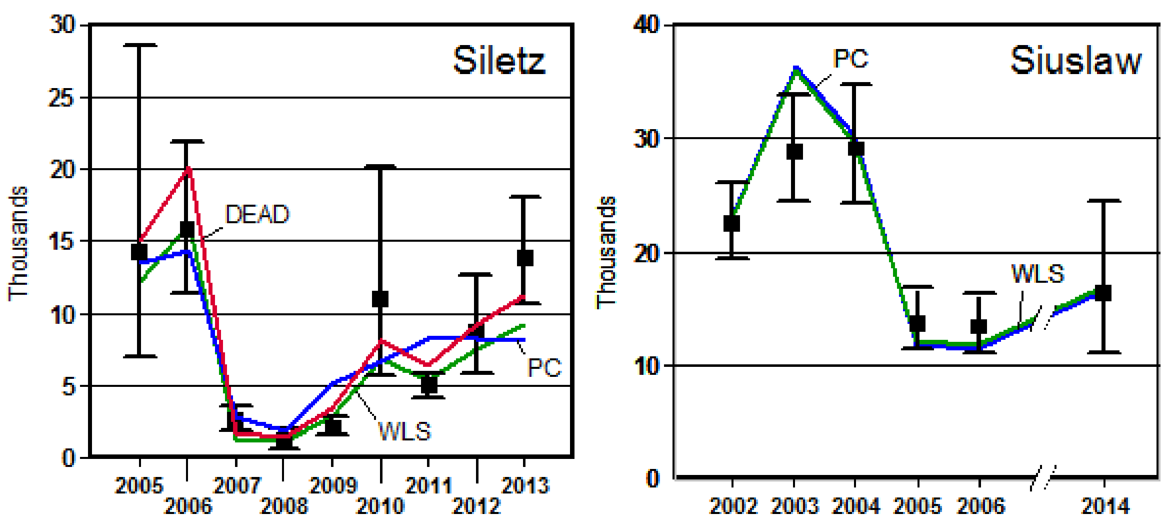



**Figure ES.6**–Predictions of spawning abundance of Chinook salmon in the Siletz and Siuslaw rivers against estimated spawning abundance from U.S. LOA and SSP-funded MR studies. Predictions (colored lines) were made from the two calibration factors based on peak counts (PCs—blue line) and on cumulative sum of DEAD salmon (red line) from standard agency surveys, and from the WLS regression (green line) using the sum of dead counts. All predictions were made with jackknife (leaving-one-out) hindcasting. Intervals are lognormal 95% CIs around MR estimates (■).

Funds from the SSP awarded to Oregon were to produce unbiased estimates of spawning escapement for CTC escapement indicator stocks with which to expand past and future counts of Chinook salmon from the agency (ODFW) stock assessment program (see Figure ES.5 for examples).

Aside from funded projects, the SSC investigated effects of imprecision and bias in estimated spawner abundance on the CTCs annual stock evaluation using synoptic plots (CTC 2015, Chapter 3, Figure 3.1). Of the two CTC bilateral data standards, violation of the accuracy standard proved more consequential than violation of the precision standard in evaluations.

### New Agency Programs

The SSP funded two new CDFO programs to estimate spawning abundance of Chinook salmon in the Chilko River and a one-time radiotelemetry project to evaluate the accuracy of GSI for the Kitsumkalum stock caught in the Tyee Test Fishery and to describe the distribution of spawners in the Skeena River Watershed. Monies for the work in the Chilko River resulted in five unbiased abundance estimates (2010–2014) with CVs ranging from 3% to 7%—well within the CTC precision standard of CV≤15%. Monies for work on the Skeena River in 2010 were used to purchase equipment (radio tags and radio receivers) as part of a one-time multi-agency study. Over 450 radio tags were successfully deployed of which 241 were tracked to spawning grounds. Information from this project improved the genetic baseline for Chinook salmon and confirmed relative stock composition as estimated with GSI at the Tyee Test Fishery.

### New, More Cost-Effective Methods

**Driver Stock (Ratio) Method.** Use of the driver stock (ratio) (DSR) method to estimate terminal run size for Chinook salmon stock aggregates inverts the process of how the CTC estimates catches of stock aggregates in ocean fisheries. In the CTC process a target stock is assumed to have the same maturation rates and suffer the same exploitation rates as a tagged indicator stock. Exploitation rates (ER) are estimated for the indicator stock with coded-wire tag (CWT) sampling programs. Independent agency estimates of terminal run size for the target stock and estimated ER for the indicator stock are used to estimate catch of the target stock in ocean (aggregate abundance based management or AABM) fisheries. In the DSR method, independent estimates of catch from the target stock in AABM fisheries and estimated ER for the indicator stock are used to estimate terminal run size of the target stock. Catch of the target stock in an AABM fishery is estimated with new programs based on genetic and scale sampling.

Results using the DSR method to estimate terminal run sizes of stock aggregates has been encouraging (Figure ES.7), however, several problems remain:

- Precision and perhaps accuracy suffer when three-year old Chinook salmon comprise a large segment of the terminal run, but are not fully recruited to AABM fisheries—lack of estimates from U.S. LOA–funded projects using the DSR method to estimate WCVI terminal run size for runs in 2012 and 2013 exemplify this problem;
- An insufficient number of genetic markers to avoid misclassification in estimating the stock composition of ocean catches—mostly a problem with the NOC aggregate stock in U.S. LOA and SSP-funded studies due to its higher misclassification error;
- Low rates of catch sampling in terminal areas for indicator stocks (such as in WCVI) decreased precision;
- Lack of a viable means of separating AABM catches into hatchery-produced and naturally-spawned Chinook salmon—not a problem with the WCVI aggregate when most hatchery-produced fish have thermally banded otoliths, but a problem with the NOC aggregate where the indicator stock is small relative to natural production; and

- Validating the core assumption of equal maturation rates and exploitation rates for the target and indicator stocks.

As to this last problem, a weak diagnostic test based on changes in relative age composition was developed that would provide evidence for the core assumption not holding, but would not provide evidence that it did. Results from applying these tests indicated differences between indicator and target stocks for the South Thompson stock and in some years the Oregon aggregate stock.

The advantage of the DSR method is its cost. With catch sampling, genetic sampling, and CWT programs in place, the only cost of the DSR method is the cost of the analysis. The approach can produce estimates for several stocks simultaneously. However, the timing of those DSR estimates is dependent on the turnaround in the GSI and CWT programs.

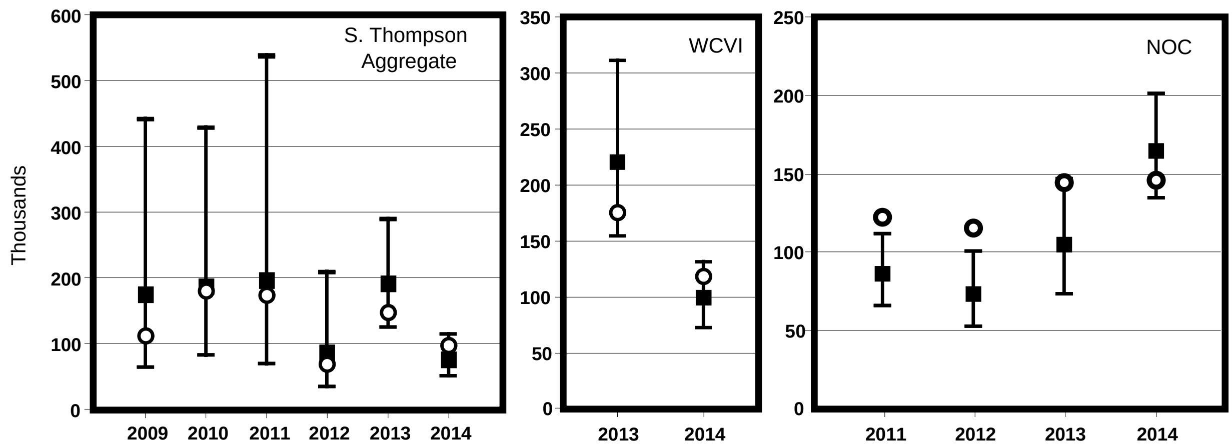



**Figure ES.7**–Estimates of terminal run size using DSR methods (■) for the South Thompson (naturals), WCVI (hatchery-produced + naturals), and NOC (naturals) aggregates of Chinook salmon stocks for combined ages 3–6. Intervals represent lognormal 95% CIs. Open circles (**o**) represent comparative statistics for terminal run size used by the CTC as reported in CTC (2016a, Appendix Table J1) directly for WCVI and Fraser Early aggregates, or in combination with information from and CTC (2015b, Table A22) containing NOC terminal catch statistics. All estimates for the South Thompson and WCVI aggregates resulted from SSP-funded projects. For the NOC aggregate estimates for 2011 and 2012 were U.S. LOA–funded while 2013 and 2014 were SSP-funded.

**Trans-Generational Mark-Recapture (tGMR) Method**. The tGMR method is a traditional mark-recapture study with two important variants—the "mark" is a genotype specific to an individual fish and the two sampling events occur in two different years. The first sampling event occurs on the spawning grounds where DNA samples are extracted from spawning, moribund, or dead Chinook salmon. The second sampling event occurs the following spring when DNA samples are taken from emigrating young. Samples from young are used to identify individual parents, some of which were sampled the previous fall and some not. Estimated spawning abundance is a function of the number of Chinook salmon sampled in the fall and the fraction of the parents identified in spring sampling that had been sampled the fall before. Accurate estimates of spawning abundance from the tGMR method requires the same conditions as does traditional two-event, closed-population MR estimates, only "all marked fish must identifiable" is always met in tGMR studies.

Trans-generational mark-recapture projects funded by the SSP were restricted to Puget Sound stocks and had very encouraging results (Figure ES.9). Available diagnostic tests provided little evidence that tGMR estimates were biased. In regard to precision, CVs for 9 of 16 estimates in Figure ES.8 met the CTC precision standard (CV≤15%) while 2 others just missed (CVs of 16% and 17%). Like MR estimates, precision of tGMR estimates depends on the numbers of adults and juveniles sampled. This "fact of life" can be seen in tGMR estimates for the Stillaguamish River. The co-managers (the Stillaquamish Tribe and WDFW) increased genetic samples from their juvenile and spawning-ground sampling beginning in 2009 with demonstrably positive results on precision (see Figure ES.8).

The tGMR method is cost effective when populations are relatively small (a few thousand spawners) and sampling programs are already established. Under these circumstances, major cost of a tGMR estimate is the cost of genotyping samples—as was the situation with the Stillaquamish stock. And as with the Stillaquamish stock, tGMR estimates can be generated for prior years with information from archived samples. For larger rivers with larger populations, the cost of processing genetic samples (about 25 US$ each) becomes prohibitive regardless of the existence of pre-established sampling programs.

An obvious "disadvantage" of the tGMR method is that there is a one-year's delay in generating the estimate. Planning fisheries for the next year as is done with calibrating the PSC Chinook model would be impossible with this one-year delay. The potential to tie tGMR estimates to timely spawning estimates (calibration) exists, which would allow for relevant estimates being utilized for both terminal and pre-terminal fisheries management.

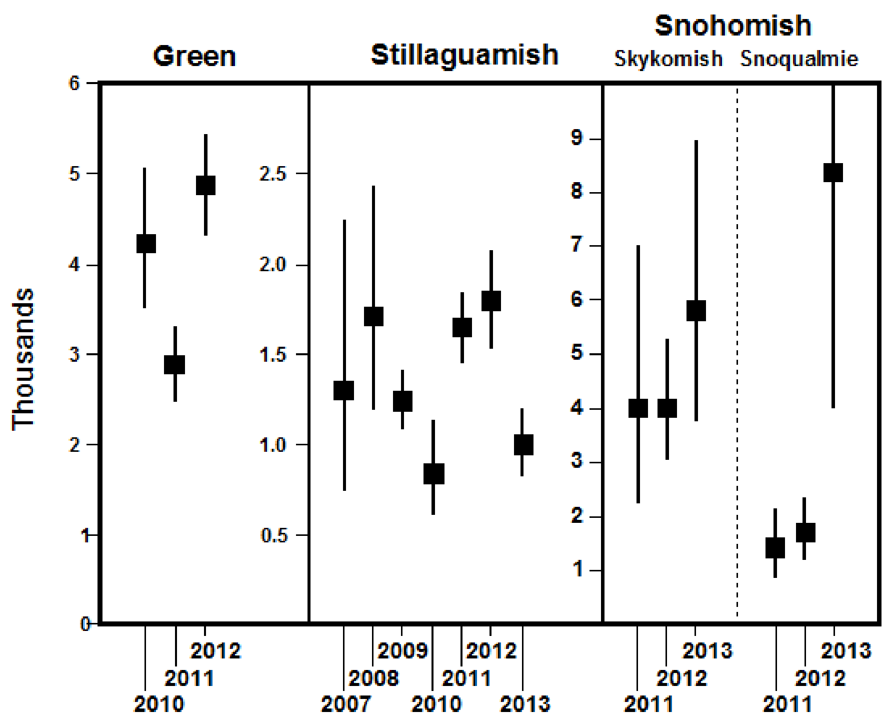



**Figure ES.8**–Estimates of pre-spawning Chinook salmon in several rivers around Puget Sound from SSP-funded tGMR/MR studies (■). Lines correspond to lognormal 95% CIs. Combined estimates for the Snohomish River were not presented because they are functions of estimates for the Snoqualmie and Skykomish rivers.

## Findings Pertinent to the 2009 Agreement

**Annual escapement for WCVI stocks in SSP-funded studies ranged from a few hundred to a few thousand Chinook salmon per river.** Estimated escapements for seven stocks in SSP-funded studies are presented in Figure ES.9. Judging from the number of Chinook salmon captured in the Kaouk and other small rivers, and the efforts expended to handle them, precise estimates of escapements for those stocks are cost prohibitive. The Burman, Kaouk, Tahsis, and Marble stocks are escapement indicator stocks under the 2009 Agreement.

**Estimates of spawning abundance for WCVI stocks funded through the SSP were similar to statistics reported by the CTC in some years, but significantly larger in others**. For 2009-2013 the estimates reported by the CTC for the Burman River were similar to mark-recapture estimates from SSP projects (89% to 116%) in three years, but substantially lower in two (23% to 30%) (Figure ES.9). The area-under-the-curve (AUC) method of estimating spawning abundance for WCVI stocks can be unreliable when surveys are infrequent and/or when parameter values are inaccurate. In contrast AUC estimates can be relied upon when surveys are relatively frequent and parameter values are accurate. An AUC estimate almost identical to the mark-recapture estimate was generated for the Burman stock in 2012 with independently estimated parameters using radiotelemetry.

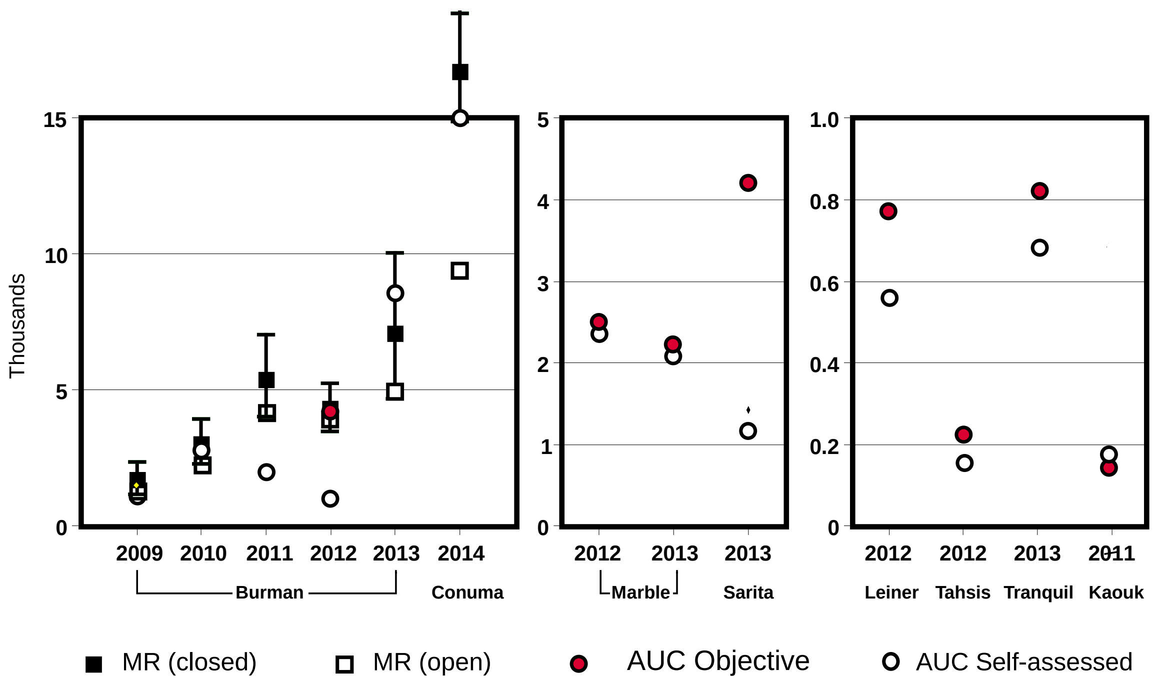



**Figure ES.9**–Abundance estimates of adult Chinook salmon in several WCVI rivers using standard, closed-population MR methods (■); open-population MR methods (□); and non-parametric area-under-the-curve (AUC) expansions with estimates of survey life (SL) and observer efficiency (OE) from radiotelemetry (●) and with self-assessed values for SL and OE, respectively (○). Intervals are lognormal 95% CIs around standard MR estimates. The SSP funded MR estimates and AUC estimates were obtained in part through radiotelemetry; estimates from AUC methods based on self-assessed parameter values are part of the CDFO standard assessment program on WCVI stocks. The same survey counts of fish-days was used in calculating both types of AUC estimates for each river-year combination regardless of the source of values of survey life and observer efficiency.

**Escapements for WCVI Chinook salmon for some of the WCVI natural indicator stocks can contain a significant component of hatchery-produced fish.**

All of the SSP-funded studies were on stocks that had escapements containing fish from hatcheries. For stocks, such as Sarita and Burman, that are directly supplemented by hatcheries, over 90% of escapement had been hatchery produced. Sampling carcasses on the spawning grounds from 2009–2014 determined that 78 to 91% of escapement to the Sarita River was hatchery-produced. Similar sampling in the Burman River during 2009–2013 showed that 93% to 97% of escapement was hatchery-produced. In comparison, only 11% of the escapement to the Marble River was of hatchery origin, although the enhancement program there is relatively modest relative others for WCVI stocks. Hatchery strays were also detected at low proportions in other rivers, such as the Kaouk River, whose stocks are not directly enhanced. The Burman, Kaouk, Tahsis, and Marble stocks are escapement indicator stocks under the 2009 Agreement. Presence of hatchery-produced Chinook salmon in escapements of these stocks diminishes their usefulness in indicating variation in natural production.

**More Chinook salmon escape to spawn in Puget Sound than indicated with standard stock assessment employed by the Washington co-managers.** Estimated escapements based on tGMR/MR studies were larger—on average twice as large—than estimates from redd-based methods in every comparison made possible by SSP funding (Figure ES.10). Relative difference was least for the Stillaguamish stock and most for the Green stock. All three stocks are escapement indicator stocks while the Stillaguamish stock is also an exploitation rate indicator.

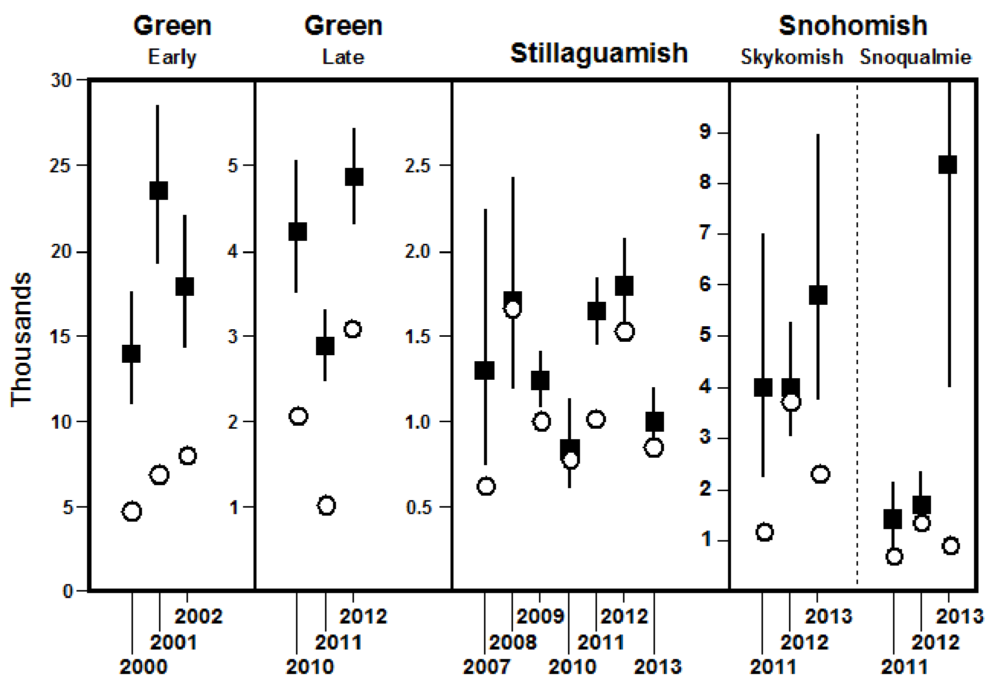



**Figure ES.10**–Comparison of estimates of pre-spawning Chinook salmon in several rivers around Puget Sound between those from tGMR/MR studies (■) and those from redd-based surveys (○). Lines correspond to lognormal 95% CIs. Early studies on the Green River were funded by the U.S. LOA and involved traditional MR studies to estimate abundance; late studies were SSP-funded and involved tGMR studies.

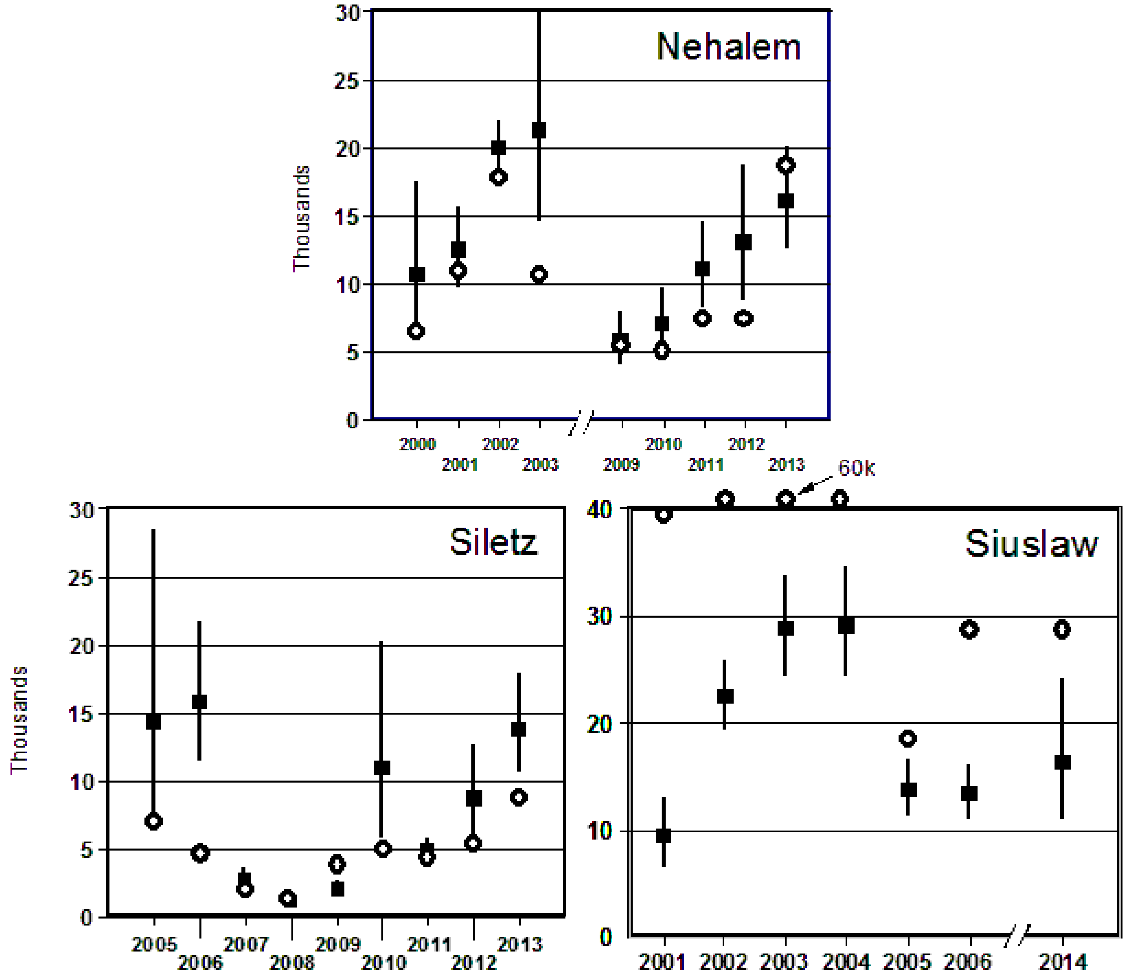



**Figure ES.11**–Estimated escapement (■) of Chinook salmon to the Nehalem, Siletz, and Siuslaw rivers from MR studies funded by the U.S. LOA prior to 2009 and by the SSP 2009–2014. Lines are lognormal 95% CIs for estimates. Circles represent estimates from annual surveys by ODFW.

**Under the 2009 Agreement, Oregon stocks of Chinook salmon have rebounded by 2014**. While this rebound should come as no surprise given events of the last few years, SSP-funded studies and earlier studies funded through the U.S. LOA provide corroboration (Figure ES.11). The Nehalem, Siletz, and Siuslaw stocks are the three escapement indicator stocks for the NOC stock aggregate under the 2009 Agreement.

**Stream surveys to estimate spawning abundance of Chinook salmon in escapement indicator stocks for the NOC aggregate have greatly improved**. Oregon has used information from U.S. LOA and SSP-funded studies to modify their standard survey designs to produce more accurate estimates of spawning abundance (see Figure ES.6). These modifications include expanding surveys and changing methods.

## Recommendations from the SSC

No committee such as ours can operate for six years, suffer through disappointments, and celebrate successes without forming some opinions as to what to do next. Now is the time and here is the place when we transform those opinions into recommendations.

**Accuracy of estimates should be given more consideration than the cost of estimates**. Sometimes agencies use a simple method of escapement estimation for expediency and cost efficiency. Relatively less funds are required to assess spawning abundance per stock which means more stocks can be assessed. Results are often called “indices” that are presumed to vary year-to-year along with escapements. The SSP supplied funds to evaluate and improve some of these indices, but more improvement is needed.

**Maintenance of a base and sustained level of funding for assessment of spawning abundance.** Implementation of the 2009 Agreement is information intensive, especially as related to knowledge of spawning abundance. Funds for getting that knowledge largely come from agencies, the Northern and Southern Endowment Funds, and U.S. LOA appropriations. Funds for the SSP were identified from the endowment funds. While dedicated funding for the SSP has ended, monies the program encumbered would be well spent on estimating escapement in the future—so long as future agreements are similar to the 2009 Agreement.

**Natural production by WCVI stocks should be estimated**. Challenges with small population sizes, highly dynamic river conditions, thin budgets, and remoteness make accurate single-river escapement assessment cost-prohibitive and impractical on WCVI. Also, the numerous stocks spawning along the WCVI create challenges for inferring overall stock status and for measuring changes in relative abundance from the few populations that can be studied, particularly for enhanced stocks. The CTC indirectly estimates annual terminal run size to WCVI, and the Driver Stock (Ratio) method funded by the SSP has shown some promise for more directly estimating terminal run size. Further development of escapement estimation approaches are necessary to meet the objectives of the Chinook management regime, via rigorous, statistically designed field and catch sampling programs to estimate natural and hatchery origin escapement.

**A multi-agency program similar to the SSP should be established to evaluate and coordinate proposed projects.** The SSC was small (at most 11 members at any one time). Its members had extensive experience in planning, designing, and implementing projects to estimate salmon escapement in both Canada and the U.S. Some members were involved with the PSC in no other way than being a member of the SSC. However, because other SSC members were involved with project evaluation for the US-LOA or for the Northern or Southern Endowment Funds, a high degree of coordination among funding sources occurred. The result was getting more escapement assessment for the available funding—a need that continues.

**Other PSC committees involved with funding decisions should adopt SSC protocols**. While this recommendation sounds a bit prideful, we repeat that many SSC members also serve on these other PSC committees. We found our iterative process of proposal development, scientific review, proposal modification, project delivery, post-season oral presentations of preliminary results and review permitted ample opportunity for committee members to interact with project leaders and agencies to improve projects. We believe our approach increased opportunities for interaction, and therefore significantly increased the quality of projects and their results.

**Acknowledgments**

We, members of the Sentinel Stocks Committee, are grateful for the opportunities of the last six years to participate in the Sentinel Stocks Program. We are thankful to commissioners past and current for giving us the chance to make a difference in the stock assessment of Chinook salmon that is so crucial to the sustainable use of this valuable resource. We especially acknowledge the efforts of David Bedford and Larry Rutter, the former an original proponent of the Sentinel Stocks Program and the latter an untiring enthusiast for its works. We are also grateful for the opportunity to have worked with Michael Chamberlain, who was an influential component on the committee and inspired us with his diligence, problem-solving abilities and enthusiasm. We thank the agencies—CDFO, ODFW, WDFW, Uu-a-thluk/Nuu-chah-nulth Tribal Council Fisheries, Mowachaht /Muchalaht First Nation, Nisga'a Lisims Government, Tulalip Tribe, Stillaguamish Tribe, and ADFG—for their cooperation and their commitment to the program. We also thank the administrative staffs of the PSC Secretariat and the U.S. Section for their efforts to make sure the hotels, meeting rooms, and plane tickets were booked, reserved, and issued. Special thanks to Dani Evenson and Amy Carroll for their help in editing and publishing this report. And lastly, we thank the many project leaders and field staff who did the challenging and sometimes uncomfortable work in the cold and rain that brought the Sentinel Stocks Program to fruition.

# 1 INTRODUCTION

The Sentinel Stocks Program (SSP) was an ad hoc effort negotiated by the Pacific Salmon Commission (the Commission or the PSC) in 2008 to improve information on escapements for a select number of Chinook salmon *Oncorhynchus tshawytscha* stocks in the Pacific Northwest of the United States and Canada. Improvements were envisioned to be

- more accurate and more precise estimates from existing agency assessment programs;
- funding of new agency programs to estimate escapements; and
- funding development of new, more cost-effective methods of estimating escapements.

These improvements were to be realized through funding projects proposed by those agencies with management authority over fisheries exploiting stocks spawning in the following areas:

- Northern British Columbia (NBC);
- Fraser River Watershed;
- West Coast of Vancouver Island (WCVI);
- Puget Sound; and
- North Oregon Coast (NOC).

Chinook salmon stocks in these areas were chosen for the SSP because lack of information on these stocks had complicated negotiations in 2008.

A committee of scientists representing management agencies from both countries (the Sentinel Stocks Committee or SSC) was empaneled to annually solicit, assess, coordinate, and recommend proposals to the Commission for funding, and to review and to report results of those projects. The SSC was also charged with improving projects by sharing expertise amongst themselves and with project proponents, by fostering the development of new methods to cost-effectively estimate escapement, and by leveraging experience gained through the SSP to improve stock assessment after the SSP had sunset.

The SSP funded 67 projects at a cost of 10 million US$ from 2009 through 2014 (Table 1.1). Through these funds the SSP fostered new methods of escapement estimation, improved information to assess stock status, and improved useful skills within agency staffs. The SSP also experienced some setbacks from floods, economic recession, equipment malfunction, and sadly, cancer.

**Table 1.1**–Chinook salmon stocks studied, study objectives and methods, years funded, and costs (in thousands) for projects selected for the Sentinel Stocks Program of the Pacific Salmon Commission 2009 - 2014.

| Stock(s) | Years Funded | Total Cost | Objectives/Methods: |
|---|---|---|---|
| **CANADIAN PROJECTS:** | | | |
| Nass | 6 | $601.9 | Augment existing MR study to estimate escapement by boosting number inspected for marks. |
| Skeena (annual) | 6 | $208.3 | Estimate passage lower river by expanding estimated passage Kitsumkalum River using GSI of Tyee Test Fishery catch. |
| Skeena (distribution) | 1 | $417.2 | Estimate spawner distribution in watershed with radiotelemetry. |
| Skeena (retro) | 2 | $316.0 | Estimate passage lower river 1984-2008 by expanding passage Kitsumkalum River using GSI of Tyee Test Fishery catch. |
| Chilko | 5 | $1,109.2 | Estimate escapement with standard MR methods. |
| S. Thompson | 6 | $804.7 | Estimate terminal run size with GSI and CWTs from an ER indicator stock recovered in NBC troll and terminal area. |
| Harrison | 1 | $51.5 | Determine population closure for ongoing MR study using radiotelemetry. |
| Burman | 5 | $641.8 | Estimate escapement with standard MR methods and with AUC snorkel methods using radiotelemetry (2012 only). |
| Kaouk | 3 | $755.9 | Estimate escapement counting through a weir (2009) and with standard MR methods (2011, 2012). |
| Moyeha | 2 | $172.3 | Estimate escapement with standard MR methods (2010), demonstrate ability to catch salmon (2011). |
| Marble/Tahsis/Leiner | 1 | $219.0 | Estimate escapement with AUC snorkel surveys by estimating survey life/observer efficiency using radiotelemetry. |
| Marble/Tranquil/Sarita | 1 | $180.8 | Estimate escapement with AUC snorkel surveys by estimating survey life/observer efficiency using radiotelemetry. |
| Conuma | 1 | $139.7 | Estimate abundance with standard MR methods. |
| WCVI Framework | 1 | $30.0 | Stock/assessment framework for treaty and domestic management. |
| | 41 | $5,648.3 | ←Grand Total in Can$ |
| **U.S. PROJECTS:** | | | |
| Driver Stocks | 2 | $188.2 | Estimate terminal run sizes with GSI and CWTs from ER indicator stocks recovered in SEAK fisheries and terminal areas. |
| Green | 4 | $562.9 | Estimate escapement with standard MR methods (2010) and with genetic tGMR studies funded 2011 - 2013 to produce estimates for 2010 - 2012. |
| Stillaguamish | 4 | $341.5 | Estimate current/past escapement and with genetic tGMR methods for 2007 - 2013 with funding 2011 - 2014. |
| Snohomish | 4 | $912.8 | Estimate escapement all runs with standard MR methods (2009) and with tGMR methods for Skykomish, Snoqualmie, Snohomish runs in 2011 - 2013 with funding in 2012 - 2014. |
| Skagit | 1 | $46.2 | Demonstrate ability to catch salmon. |
| Nehalem | 5 | $1,391.8 | Estimate escapement with standard MR methods and in-river creel survey. |
| Siletz | 5 | $1,195.5 | Estimate escapement with standard MR methods and in-river creel survey. |
| Siuslaw | 1 | $194.0 | Estimate escapement with standard MR methods and in-river creel survey. |
| | 26 | $4,832.9 | ←Grand Total in US$ |

## 1.1 Origin and Mission of the Sentinel Stocks Program

Uncertainty in the size of escapements for several populations (stocks) of Chinook salmon affected negotiation of the 2009 Agreement in 2008. In a proactive attempt to reduce that uncertainty for the next negotiation 9 years hence, and for a scheduled review of the 2009 Agreement in 2014, the Commission established the Sentinel Stocks Program in Annex IV, Chapter 3, Paragraph 3 of the Pacific Salmon Treaty, 2009 Agreement:

> *3. Subject to the provision of funding by the Parties ($7.5 million ($C) from Canada and $41.5 million (U.S.) from the United States) for the specific purposes and in the amounts identified in this paragraph and paragraphs 4 and 5, below, and a commitment of $10 million (U.S.) ($2.0 million (U.S.) per year for five years, beginning in 2009) from the Northern Boundary and Transboundary Rivers Restoration and Enhancement Fund and the Southern Boundary Restoration and Enhancement Fund by the Northern Fund Committee and the Southern Fund Committee, respectively, the Parties* (U.S. and Canada) *agree:*
>
> *(a) to implement through their respective domestic management authorities a five-year research program (Sentinel Stocks Program) utilizing approximately $2.0 million (U.S.) annually provided by the Northern and Southern Funds as follows:*
>
> *(i) the purpose of the program shall be to improve the estimates of escapements of selected Chinook populations in British Columbia, Washington State and Oregon;*
>
> *(ii) the Commission shall select a bilateral body of scientists to recommend to the Commission and the Fund Committees how best to utilize these funds for the purposes identified herein;*
>
> *(iii) the program shall focus on estimating the escapements of a limited number of stocks consistent with standards to be developed by the bilateral CTC; and*
>
> *(iv) stocks shall include a limited number of escapement indicator stocks for the North Oregon coast, Puget Sound (one of which shall be the Stillaguamish River), west coast of Vancouver Island, northern British Columbia and Fraser River;*

Because Paragraph 3 of Chapter 3 provides only a general outline of the program, further direction to the program was provided by the PSC in November 2008 (see **Implementation Approach for the Chinook Sentinel Stocks Program** in Appendix 10.1). The objective of the Sentinel Stocks Program was to obtain estimates of spawning escapement for each of the specified stocks to attain a level that meets or exceeds bilateral data standards set by the Chinook Technical Committee (CTC). The approach to meeting that objective was to:

- empanel a bilateral committee of fisheries scientists, the Sentinel Stocks Committee;

- have the SSC solicit proposals from agencies to study ways to cost-effectively estimate spawning abundance of Chinook salmon to meet bilateral standards;
- work with agencies to improve proposed studies;
- recommend to the Commission which proposed studies should be funded;
- regularly report to the Commission on progress by funded studies; and
- report findings of these studies.

In the beginning, Marianna Alexandersdottir of NWIFC, Dave Bernard and John Clark of ADFG, Ethan Clemons of ODFW, Tom Cooney of NMFS, Chuck Parken of CDFO, Dan Rawding of WDFW, and Brian Riddell of CDFO were designated as members of the SSC. Additional Canadian scientists selected later included Roger Dunlop of FNFC and Richard Bailey, Michael Chamberlain, Diana Dobson, Arlene Tompkins and Ivan Winther of CDFO.

Initially, the SSC was to create a list of stocks for possible inclusion into the SSP, and the Northern and Southern Endowment Funds were to solicit proposals for studies to estimate spawning abundance for stocks on this list. The SSC was directed to improve and evaluate these proposals by considering:

- applicable bilateral data standards developed by the CTC;
- importance of the stock to be studied (the candidate stock) relative to the status of the overall Chinook salmon resource;
- similarity of the candidate stock to other stocks;
- significance of the candidate stock to PST fishery management decisions;
- opportunities for obtaining high quality estimates of spawning escapement;
- likely cost of the study; and
- total funding available for the SSP.

In their evaluations, the SSC could and did consult with other scientists, the CTC, and salmon fishery managers where needed and when appropriate. All decisions and recommendations by the SSC were to be by consensus (unanimous).

Problems with the process of soliciting and evaluating proposals as originally directed quickly became obvious. Creating a list of potential stocks for the program before the start of the SSP required a prohibitive effort by the SSC to evaluate the relative merit of stocks for inclusion on the list. Given that the SSC contained only a few scientists, extensive consultations would be required to create a stand-alone list. Better to have the scientists proposing a study present the reasons why that study was important to the SSP, so the SSC with realistic effort could evaluate the importance of the stock. So, the SSP began with the SSC soliciting proposals that covered all stocks in the five areas designated in Paragraph 3, Chapter 3 of the 2009 Agreement with the requirement that proposers list the reasons in their proposals why their study would represent a significant contribution to the SSP.

Beginning with the first year of the SSP and continuing throughout the program, the SSC recommended studies for funding to the PSC, not to the Endowment Funds. The reason for this change was largely administrative. Although monies for the SSP came from the Endowment Funds, the SSP was not an organ of the Endowment Funds. The change stream-lined the selection process for projects by removing an unnecessary step.

Over the years, most of the projects recommended by the SSC involved estimates of escapement or spawning abundance as per the objective of the SSP. In 2008 the CTC established data standards for escapement/spawning abundance estimates:

> "… *escapement estimates should be asymptotically accurate (unbiased), and, as a planning goal, escapement estimates for a stock should average a CV of 15% or less*.", page 241 in Appendix D of CTC (2013)

As directed the SSC used these accuracy and precision standards to evaluate proposals for inclusion into the SSP.

The scope of the SSP evolved beyond just estimating escapement or spawning abundance. Many projects in the SSP incorporated advances in genetics, statistical analysis, and radiotelemetry in novel ways to:

- produce new estimators of spawning abundance and escapement;
- augment information useful to those estimators already in use;
- organize agency stock assessment programs;
- expand the geographic scope of existing estimators; and
- develop estimates of escapement for years or decades before the SSP began.

A general description of the methods used in SSP projects follows in § 2 of this report. Section 3 contains summaries for projects funded in the five individual areas (NBC, WCVI, Fraser River, Puget Sound, and NOC).

## 1.2 Sentinel Stocks Committee Process

The annual SSC process consisted of building a new SSP program from previously funded and new projects. The process included two meetings of the committee and considerable work outside of those meetings. As per the 2009 Agreement the PSC staff provided administrative and logistical support for the two bilateral SSC meetings. Respective national sections covered travel costs of their SSC members to and from these meetings. Agencies supplied salaries for work by their representatives on the SSC during meetings and at other times.

After 2009 the process of building an annual SSP program settled into the fiscal-year schedule outlined in Figure 1.1. The annual process for the next fiscal year (July 1 – June 30) began the first week of December at a meeting of the SSC (usually held in Seattle). Principle investigators and/or their delegates for projects funded for the current FY reported progress made and difficulties encountered during their previous field season (see Appendix 10.2 for the presentation format). Following those presentations, the SSC wrote an RFP in memo form for the program in the next FY, sent it to the PST executive secretary (see Appendix 10.3 for an example), and distributed it to agencies through their representatives on the SSC. Proposals for the next FY in response to the RFP were to be sent to the PST Secretariat by the last day of the post-season meeting of the PSC in early to mid-January. Content of an RFP was derived mostly from deliberations within the SSC after considering information presented at the December meeting and from implications of that information.

Information from the December meeting was also reported to the PSC during the Commission's post-season meeting in January. A written progress report was prepared (usually a couple of pages) and the material was also presented orally to the PSC by a member of the SSC (usually a co-chair).

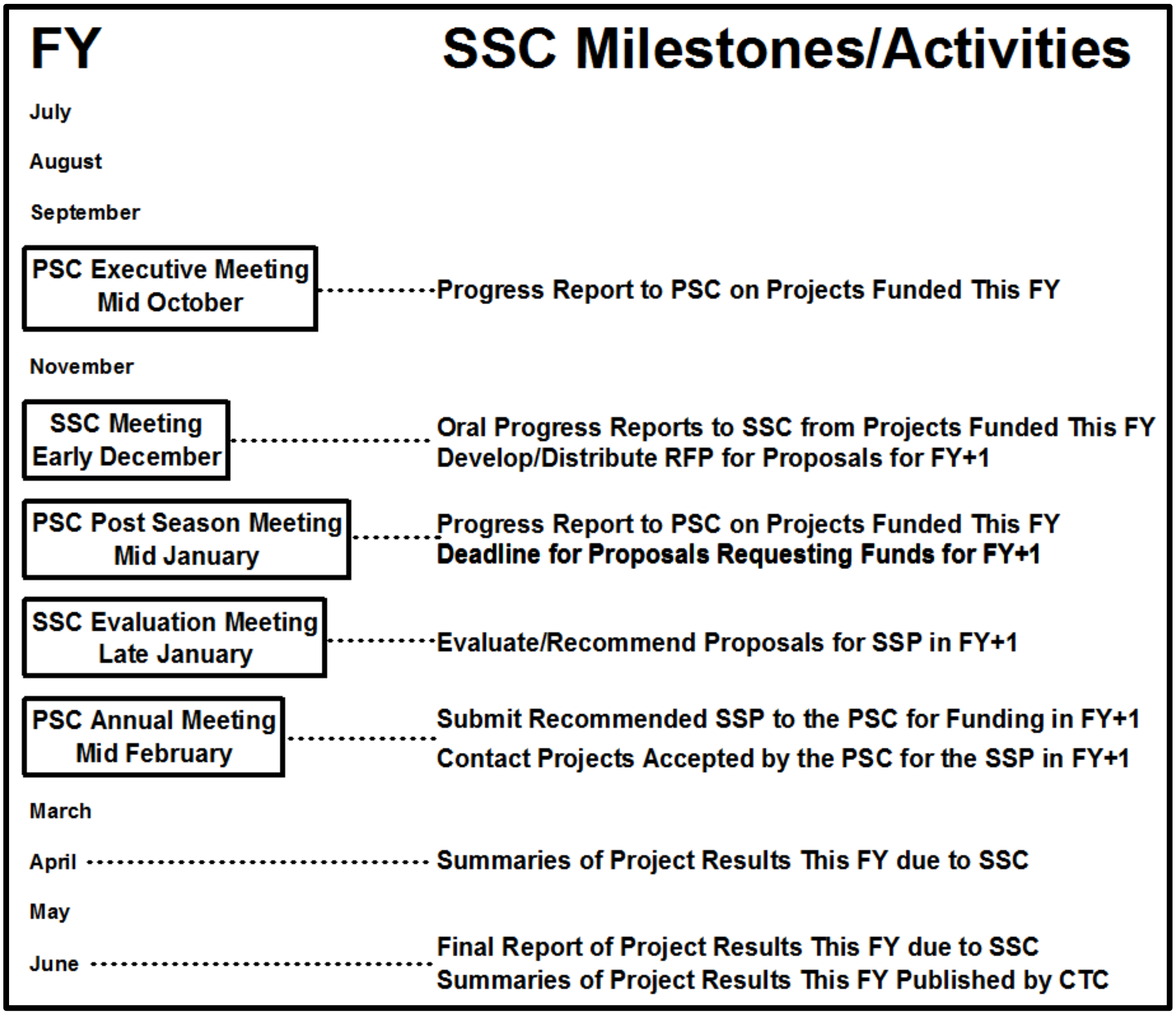



**Figure 1.1**–Schedule of annual milestones and activities of the Sentinel Stock Committee.

The RFP consisted of a cover memo with the format for project proposals and a budget spreadsheet attached (see Appendices 1.4 and 1.5 for examples). Proposals were to have:

- a cover page acting as a fact sheet about the project;
- specific project objectives with desired precision criteria;
- reasons why proponents believe their proposed work is of significance to the SSP;
- short descriptions of the experience and expertise of key project personnel;
- a detailed description of scientific methods, sample design, and techniques for conducting the project (including evidence that:
    - o sample sizes are expected to attain bilateral standards for precision; and
    - o requested resources will be sufficient to attain sample sizes);
- a timeline for progress that includes milestones against which to judge progress;
- a list of any required permits and the timing and potential impediments to securing permits;
- a list of any other projects whose outcomes affect the outcome of the proposed project; and
- a budget listed in the attached electronic spreadsheet for the first FY and for any planned continuance into subsequent fiscal years.

Reporting requirements for investigators were described in the proposal format. An oral and written progress report describing results from the prior field season was to be provided to the SSC during their meeting in early December (as described above). An executive summary for inclusion into the CTCs annual Catch and Escapement Report [i.e., CTC (2014)] was due in April of the funded FY. Final annual reports were due to the SSC and the PST Secretariat by the end of the funded FY (June 30). A specific format was required for the executive summaries (see Appendix 10.6), but not for the final report. The SSC encouraged publication of final reports in peer-reviewed outlets such as scientific journals, agency report series, and technical reports of the PSC.

The next annual meeting in the SSC schedule occurred in late January (usually held in Vancouver, BC) with the sole purpose of evaluating submitted proposals for funding in the next FY. Deliberations were free-form with the first projects listed for funding being those that by consensus best met the following criteria:

- the stock is an important stock as judged by its
    - size;
    - similarity to other stocks;
    - importance to fisheries management by both Parties;
    - role in the last negotiations; and
    - inclusion in one of the five specified areas of the SSP;
- SSP had funded the project for the current and/or previous FYs.
- likelihood of successfully producing an estimate or method was high;
    - likelihood of meeting bilateral data standards with requested funds was high;
    - amount of funds requested for the project was sufficient to meet objectives; and
    - past record of success.

Success was judged as a project having delivered its work products. Failure to do so was usually sufficient reason not to recommend the project for future funding.

As deliberations proceeded, the SSC worked with principle investigators to improve proposed methods (such as mark-recapture studies on the Burman River described in § 3.3.1), to brain storm new methods (such as t-GMR studies in Puget Sound based on genetics as described in §§ 3.4.1-3), and to develop whole new projects (such as using archived scales from the Skeena River to estimate returns of Chinook salmon back to 1984 such as described in § 3.1.2.1). Proposed budgets were altered with cooperation from proponents so as to potentially fund the maximum number of quality projects in the next FY. Available funds for the next FY consisted of

- the 2 million US$ annual allocation for the next FY (except for 2009);
- unencumbered monies from the current and previous FYs; and
- unspent funds from projects funded in the current FY.

The SSC always reached consensus in regards to the scientific merits of recommended projects, but on two occasions members disagreed as to the importance of the stocks to be studied. The PSC was informed about the disagreements.

At the conclusion of deliberations, the SSC prepared a memo with their recommendations to the PSC for projects to be funded in the next FY. A memo was also sent to each project leader with notice of the SSC decision concerning their project with reasons for that decision. Memos involving recommended projects also contained descriptions of those changes in project methods, if any, that the SSC believed would improve the chance of project success (see Appendix 10.7 for an example).

Commissioners usually received the SSC's recommendations during the first week of February and accepted or rejected those recommendations during the annual meeting in mid-February. In the history of the SSP, every project the SSC recommended by consensus was accepted and funded save one[1]. Once the PSC had accepted the recommendations for the next FY, principle investigators were informed (via memo) of the PSC's decision by their agency representative on the SSC.

The exception to the process described above occurred in 2009, the first year of the program. The difference was a requirement for an earlier round of concept proposals (see Appendix 10.8 for a format). The purpose of this extra step in the process was to solicit from the agencies what they thought were priority Chinook salmon stocks for the SSP. The proposal was to be short (no more than five pages) and dwell on concepts, not detail. Members of the SSC informed their agencies of the opportunity to submit concept proposals, and agencies were given the proposal format. Concept proposals were due to the SSC by the last day of 2008. The SSC met in early January 2009 to evaluate concept proposals, then selected those projects of interest. Principle investigators were informed as to decisions with those investigators of accepted proposals getting a request for a long (detailed) proposal (see Appendix 10.3 for the format). Long proposals were due by the end of February 2009, and the SSC met in early March to develop their recommendations to the PSC.

Executive summaries of results from SSP projects funded in the current FY were submitted to the CTC for publication in their annual catch and escapement reports (such as CTC 2014). In April SSC members solicited summaries from principle investigators according to a specific format (see Appendix 10.6). These summaries were then packaged by a single SSC member who was also a CTC member, and the package placed into the CTC report.

Final reports for the current FY were due in June. As written above, the SSC encouraged these reports to be published in some peer-reviewed outlet. Realizing that such a request might require publication at a later date, the SSC accepted "interim" final reports by the June deadline. All final reports received were archived at the CTC SharePoint site (Pacific Salmon Commission, Vancouver).

In early October, agency representatives on the SSC informally canvased currently funded projects to determine what progress had been realized partway through the field season, and this information was packaged and sent to the PSC as a progress report for the Commissioner's executive meeting in late October (see Appendix 10.9 for an example).

At this point on the calendar the annual SSC process had come full circle. In the next bilateral SSC meeting in the process, investigators again described the methods behind their projects and their results. The next section of this report provides background for six categories of methods used in SSP projects to estimate abundance.

[1] The commission's sole rejection of a recommended proposal occurred not because of problems with the proposal, but because the PSC judged that the stock to be studied was outside the five areas designated for the SSP.

# 2 GENERAL METHODOLOGIES IN FUNDED STUDIES

Sentinel Stock projects were based on methods that ranged from strictly traditional to highly innovative. General designs and significant variants are described in § 2 while project-specific summaries of methods and results are provided in § 3.

## 2.1 Traditional Mark-Recapture (MR)

Traditional mark-recapture studies are used to estimate abundance for biologically defined populations of Chinook salmon. A population so-defined can have no recruitment (increments) during a study because of salmon life history, but can suffer decrements (mortalities). Abundance estimates in the traditional MR are calculated with what are called closed-population mathematical models—no increments or decrements. Although the biologically defined salmon population is not technically closed, mortalities will not bias the subsequent abundance estimate. Model-directed sampling is divided into two general "events" each comprised of several sampling dates. In the first sampling event, a subset (sample) of Chinook salmon passing by a point in a stream on their way to the spawning grounds are caught, marked, and released to continue their migration upstream. The second sampling event occurs on the spawning grounds where a second subset is sampled and inspected for marks. Estimated abundance is a solution of the following relationship:

$$\frac{\text{Abundance (N)}}{\text{Number MARKED salmon released in the FIRST event (M)}} = E\left[\frac{\text{Catch of salmon in the SECOND event (C)}}{\text{Catch of MARKED salmon in the SECOND event (R)}}\right]$$

The naive solution of N = MC/R is predicated on large, randomly selected samples. Because sampling is not random in either event, sampling protocols must be tailored to meet conditions that ensure the estimate is consistent (unbiased). In the SSP this tailoring consisted of fishing with regular effort across sampling dates within the first sampling event, double marking fish, and completely stratifying samples by size (or age[2] or sex), and/or partially stratifying samples by sampling dates within sampling events. Other adjustments in N = MC/R were used to compensate for statistical biases from using smaller sample sizes. In the traditional MR study of migrating salmon, the abundance estimate is always germane to the site of the first sampling event. If no mortalities occur between events, the estimate is germane to the site of the second sampling event as well.

The SSP projects that successfully employed the traditional MR method or a variant of that method were projects on the Nehalem, Siuslaw, and Siletz rivers (the NOC stocks of § 3.5); on the Lower and Middle Shuswap rivers (§ 3.2.1), the Chilko River (§ 3.2.2), and the Harrison River (§ 3.2.3) in the Fraser watershed; on the Burman River of WCVI (§ 3.3.1); and on the Nass River in NBC (§ 3.1.1).

A variant of the traditional MR study based on a mathematical model for open populations—the Jolly-Seber method—was used to estimate spawning abundance on the Burman and Conuma rivers of WCVI (§ 3.3.1 and 3.3.8, respectively). In this approach, the population is spatially (not biologically) defined to be those fish resident in a specified segment of river on each sampling date. Several sampling dates are scheduled at regular intervals of one to a few days each; all sampling occurs in the same river segment. Increments (immigration) and decrements (emigration and mortalities) to the population can occur between consecutive sampling dates. A subset (sample) of Chinook salmon is captured on each sampling date, marked with individually identifiable tags, and released. Emigration and "surviving" immigration[3] between consecutive sampling dates, and abundance present on each sampling date can all be estimated from capture-recapture

[2] Age is expressed in this report as number of years or in European notation x.y in which x is the number of whole years spent in freshwater and y the number at sea. Conversion is age in number of years = x+1+y.

[3] "Surviving" immigration is comprised of immigrants that moved into the population between two consecutive sampling dates and were still in the population on the latter sampling date.

histories of individual fish. Estimated spawning abundance for the stock is the sum of estimated immigration into the river segment across sampling dates. As with traditional MR studies, captured fish are double marked, and samples can be stratified by size (or age or sex) when required to produce consistent estimates. Unlike in the traditional MR study, fishing effort need not be similar across sampling dates. However, sampling events have to be scheduled such that no or few fish could migrate through the river segment between consecutive sampling dates (transient immigrants). Improper scheduling of sampling dates or insufficient adjustment for transient immigration produces estimates of spawning abundance from this approach that are biased low.

Literature on capture-recapture and mark-recapture methods to estimate animal abundance is too extensive to cite here, however, Seber (1982) and Pollock et al. (1990) provide general references on how to conduct capture-recapture studies in general, and Schwarz et al. (1993) provides a good example of a capture-recapture study to estimate abundance of a spawning salmon population.

## 2.2 Trans-Generational Mark Recapture using GSI (tGMR)

The tGMR study is a traditional mark-recapture study with two important variants—the "mark" is a genotype specific to an individual fish and the two sampling events occur in two different years. The first sampling event occurs on the spawning grounds where DNA samples are extracted from spawning or moribund Chinook salmon. The second sampling event occurs the following spring when DNA samples are taken from emigrating young. Samples from young are used to identify individual parents, some of which were sampled the previous fall and some not. Estimated spawning abundance is a function of the number of Chinook salmon sampled in the fall and the fraction of the parents identified in spring sampling that had been sampled the fall before. Rawding et al. (2014) is a seminal work explaining in more detail the tGMR method.

The tGMR method was largely employed in the streams issuing into Puget Sound—the Green (§ 3.4.1), the Stillaguamish (§ 3.4.2), and the Snohomish rivers (§ 3.4.3).

## 2.3 Expansion using GSI of a Sub-stock

Run size into a large river can be estimated by expanding abundance estimated for a single sub-stock (usually fish spawning in a particular tributary) by the inverse fraction of the run comprised of that sub-stock. The "marked" population are those members of the run carrying a genotype unique to that sub-stock. A downstream or estuarine test fishery provides samples of Chinook salmon which can be genotyped and assigned to all upstream sub-stocks. The estimated fraction of the run comprised of the target sub-stock is the fraction of samples from the test fishery assigned to that sub-stock. Estimated run size is germane to the site of the test fishery. Again, sampling at the test fishery is not random, but can be tailored to produce consistent estimates of fractions as noted in § 2.1.

Expansions using GSI of a sub-stock can be very cost-effective. In SSP-funded studies using this technique, test fisheries and stock assessment programs in tributaries were already in place and had been so for years before the SSP came into existence. Costs to the SSP consisted of monies needed for genotyping and for conducting mixture analysis. Some of that genotyping was conducted on scales sampled in the test fishery and annually archived for decades, allowing run reconstruction over those decades. SSP projects that employed such expansions involved the Skeena and South Thompson rivers (§§ 3.1.2.1 and 3.2.1, respectively).

## 2.4 Expanding Estimated Stock-Aggregate Catch by Recoveries of an Indicator

Terminal run size of a Chinook salmon stock can be estimated by the ratio of catches to terminal run size of an exploitation rate (ER) indicator stock. Management of fisheries under the PST is accomplished by assessing indicator stocks, usually associated with hatcheries and always batch-marked with CWTs. For management, exploitation rates of ER indicator stocks are assumed to be the same as exploitation rates on a subset of other, similar, unmarked populations (collectively the target stock). Originally, the idea was to use exploitation rates on the indicator stock to estimate catch from target stocks in mixed-stock fisheries. Now that catches of target stocks can be estimated directly with GSI, exploitation rates of indicator stocks can be used to estimate escapements to terminal areas. The outline of this method was discussed during a workshop in 2005 on the future of the CWT recovery program and described in the workshop proceedings (Hankin et al. 2005, Appendix C). By leveraging information already collected by existing sampling programs, this method has the potential to be a relatively efficient and inexpensive means to simultaneously estimate terminal run sizes of both hatchery- and natural-origin fish for several stock aggregates at a time.

The method is deceptively simple being based on the expected values of two ratios with only one of the four numbers unknown:

$$E\left[\frac{\text{Terminal run size of the TARGET stock}}{\text{Catch of the TARGET stock in mixed-stock Fishery A}}\right] = E\left[\frac{\text{Terminal run size of the INDICATOR stock}}{\text{Catch of the INDICATOR stock in mixed-stock Fishery A}}\right]$$

Algebra can be used to estimate the unknown quantity—terminal run size of the target stock. Because programs are in place to estimate catch of indicator stock (CWT catch sampling), and to estimate terminal run size for indicator stocks (CWT escapement sampling), only genetic sampling of a large mixed-stock fishery is required to estimate the catch of the target stock. The genetic sample can be further divided by an additional mark (CWTs or thermally banded otoliths) to segregate hatchery and natural-origin Chinook salmon in the target stock.

Simplicity is deceptive because of simplifying assumptions. An implicit assumption is that estimates of terminal run size for the indicator stock and of catches for both target and indicator stocks are themselves all consistent (unbiased). Verifying such consistency is a formidable task. The other assumption—the "core" assumption—is that exploitation and maturation rates are the same for both target and indicator stocks. Stratifying calculations by the age of Chinook salmon largely counteracts bias due to differences in maturation rates. Other tests can provide evidence as to how much faith should be placed on the assumption of equal exploitation rates.

Two SSP projects estimated run size using this method. Genetic sampling of fisheries off NBC was used along with tagging salmon from the Shuswap rivers to estimate the terminal run size for the South Thompson River, a tributary of the Fraser River (§ 3.2.1). Objectives of the other project were to estimate terminal run size for all WCVI stocks in aggregate (§ 3.3.11) and to estimate terminal run size for all NOC stocks in aggregate (§ 3.5.4). The method was named the "ratio" method by Canadian investigators and the "driver stock" method by U.S. investigators. Hence the acronym DSR.

## 2.5 Area-under-the curve (AUC) Expansion of Multiple Counts

Annual spawning abundance in smaller streams was estimated by adjusting counts of Chinook salmon taken at regularly scheduled surveys in some SSP projects on WCVI. In any project using an AUC expansion, surveys are scheduled to occur every few days. During each survey salmon are counted from the air, from the ground, or as was the case in many SSP projects, in the water while snorkeling. Non-parametric calculations for this method follow this general outline:

1. counts are averaged between consecutive surveys to estimate the unadjusted number of Chinook salmon present during each interval between surveys;
2. each unadjusted average count is multiplied by the number of days in the relevant interval to calculate "unadjusted" count-days;
3. unadjusted count-days are summed across intervals;
4. the unadjusted count-day sum is adjusted downward by the expected survey life (SL) in days for Chinook salmon on the spawning grounds to get an unadjusted estimate of abundance; and
5. the unadjusted abundance estimate is adjusted upward by the estimated observer efficiency (OE) to get a consistent (unbiased) estimate of spawning abundance.

An alternative calculation is to adjust count days for each interval for OE and SL then sum the result across intervals (step 3 delayed to after step 5). A connected plot of unadjusted counts against the dates of surveys produces a curve for which the sum of unadjusted count-days represents the area under the curve (Figure 2.1). English et al. (1992) is a seminal work on this non-parametric approach, Irvine et al. (1993) provides detailed descriptions on its implementation, and Bue et al. (1998) provides examples.

Using the AUC method, it is difficult to achieve consistent (statistically unbiased) estimates of spawning abundance and variance estimates are often not possible (Parsons and Skalski 2010). To generate unbiased estimates, values for SL must be estimated either through tag depletion curves with daily observation or mark-recapture over the duration of the run. In addition, parameter values for OE expansions are estimated through radiotelemetry. However, for WCVI systems, annual values for SL are usually based on rudimentary information from past studies and OE is self-assessed by surveyors. AUC-type studies funded under the SSP used radio-telemetry information and other tag data to estimate SL and OE in order to generate more accurate escapement estimates for the study systems, and to evaluate the usual SL and OE assumptions used for WCVI AUC expansions.

An alternative, parametric approach to AUC expansion was developed based on the work of Hilborn et al. (1999) as a product of creating a stock assessment framework for WCVI stocks (see § 3.3.9), a framework partially funded through the SSP. A supposed advantage of this parametric model was OE and SL no longer had to be estimated independent of counts.

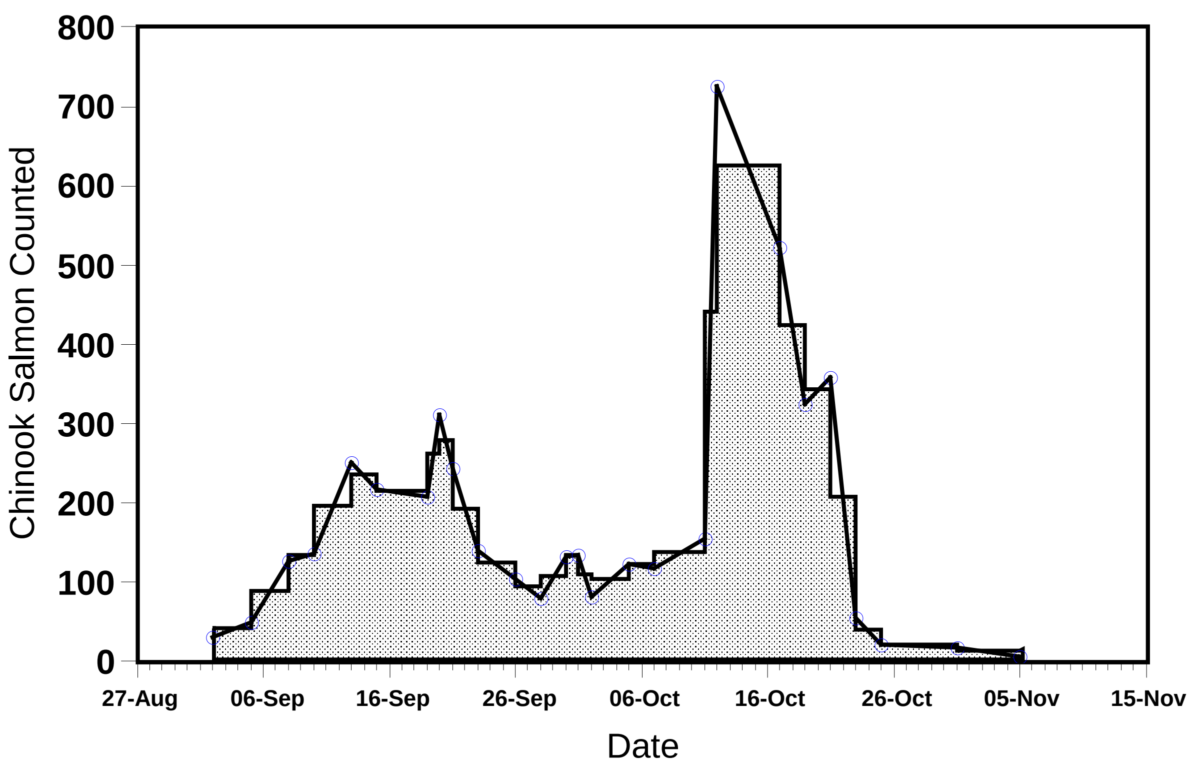



**Figure 2.1**–Generic statistics used in the non-parametric AUC expansion method for estimating Chinook salmon abundance over the spawning grounds. Counts during surveys (circles) are connected by point-to-point lines. Steps along stepped line represents counts averaged between consecutive surveys. Shaded area represents the sum of the count-days across the season and an estimate of abundance unadjusted for SL or OE.

Probability distributions describing entry and exit from the spawning grounds were combined as functions of time, SL, and OE, and the resulting model fit solely to the time series of observed counts of salmon.

Conditions needed to create a consistent (unbiased) estimate of spawning abundance with the non-parametric AUC method concern the

- coverage of surveys;
- estimating SL of salmon over the spawning grounds; and
- estimating OE.

Surveys must be conducted such that every spawner has the chance to be counted. The hiatus between surveys must be shorter than the expected SL of spawners—difficult to do when a stream has frequent freshets and flooding. Surveys must also cover all spawning grounds or there must be knowledge of the importance of the grounds that are covered. Estimates of SL and OE must themselves be consistent. Radiotelemetry is a popular if expensive means of independently estimating SL and OE, and identifying spawning grounds and their relative importance to the spawning population.

An alternative, parametric approach to AUC expansion was developed based on the work of Hilborn et al. (1999). This work was a product of creating a stock assessment framework for WCVI stocks (see § 3.3.9) and partially funded through the SSP. Spawner abundance is estimated using a maximum likelihood model that fits the observed periodic counts of spawners to a run timing curve. Although the method does not require direct estimation of the OE and SL parameters, an *a priori* assumption of arrival and departure timing of spawners is required. The uncertainty associated with this assumption creates a potential source of bias, particularly as timing varies from year to year.

Sentinel stock studies involving the AUC expansion method are described in many of the subsections of § 3.3. In most of these studies radiotelemetry information was used to adjust the "area under the curve" for SL and OE.

## 2.6 Others (Feasibility, weir, migration studies, and an assessment framework)

Not all SSP projects produced abundance or run-size estimates. One project involved investigating the feasibility of an agency to catch sufficient numbers of Chinook salmon on the Skagit River to warrant a MR study (§ 3.4.4). Another SSP study used radiotelemetry to map the distribution of spawning Chinook salmon in the Skeena River (§ 3.1.2.2). A weir (fence) was placed across the Kaouk River to count upstream passage of Chinook salmon (§ 3.3.2), and the SSP partially funded a project to improve information on WCVI Chinook salmon through organizing a new stock assessment framework (§ 3.3.10).

# 3 STUDIED SENTINEL STOCKS

Ten million US$ were dedicated to the SSP to be drawn equally from the annual earnings of the Northern and Southern Endowment Funds. This allocation was to support projects at 2 million US$ per year from 2009 - 2013. However, a recession and negative earnings for the Endowment Funds in 2008 required that funding for the SSP in 2009 come from other sources. Funds for this first year of the SSP (985k US$) were taken from the annual allocation to the U.S. CTC under the 1999 Letter of Agreement (U.S. LOA) and from CDFO (500k Can$). In subsequent years the Endowment Funds provided all monies to support the SSP. The Endowment Funds also reimbursed the U.S. CTC and CDFO and made the balance of 2 million US$ intended for 2009 available to fund projects beyond 2009. Other balances in other years accrued due to a limited number of suitable proposals in 2011 and 2013. Together these balances left some of the allotted 10 million US$ unspent at the end of 2013—funds that were subsequently used to extend the SSP into 2014.

In general, numerical terms, the 10 million US$ for the SSP funded 22 projects for a cumulative 67 project–years of work (Table 1.1). Fourteen projects were Canadian and 8 U.S. although the funds spent were similar with adjustments for currency exchange rates. In the SSP program 111 annual abundance estimates were expected, 107 were attained 101 of which had measures of precision (CVs) (Table 3.1). Of these 101 estimates 54 met the CTC bilateral standard for precision (CV ≤ 15%) and another 11 were close (15% < CV ≤ 20%; Figure 3.1).

Section 3 is a project-by-project description of new and useful information in the escapement assessment of SSP stocks. For NOC stocks the SSP program added more years of information to an already established program to develop a more cost-effective and accurate way of stock assessment. For Puget Sound stocks, the SSP program aided in developing a cost-effective, unbiased alternative to the traditional stock assessment program. The terminal run of the WCVI stock aggregate was estimated using a new method based on CWTs recovered from an ER indicator stock in Southeast Alaska (SEAK) fisheries, and new information was developed to augment the traditional escapement method used for WCVI rivers. A new method was applied to estimate escapement to the South Thompson River based on recovery of CWTs from ER indicator stocks. New methods of estimating escapement were used on the Skeena and South Thompson rivers to expand test fishery catches using genetic and CWT data. Traditional MR studies began with SSP monies on the Chilko River, and were used to augment the existing MR study on the Nass River.

## 3.1 Northern British Columbia

Significant progress had been made toward understanding Northern British Columbia (NBC) Chinook salmon populations in recent years. The SSP was preceded by a large amount of work on Chinook salmon including MR, radiotelemetry feasibility studies, and genetic baseline development. Much of the work was funded by the PSC Northern Fund. The escapement objectives within the SSP were a natural progression from the existing work and were an important step toward the development of escapement targets and management benchmarks.

**Table 3.1**–Funding (in thousands) and results for projects in the SSP by stock and year. Dollars are expressed in relevant national currency. Unless otherwise noted, results are abundance estimates and CVs (precision) for those estimates.

| CANADIAN STOCKS: | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | Total |
|---|---|---|---|---|---|---|---|
| Nass Cost → | $62.3 | $97.9 | $105.5 | $108.6 | $112.6 | $115.0 | $601.9 |
| Estimate → | 27,437 | 18,773 | 10,124 | 8,996 | 8,298 | 11,914 | |
| CV → | 13% | 25% | 9% | 6% | 8% | 13% | |
| Skeena | $29.3 | $35.8 | $35.8 | $35.8 | $35.8 | $35.8 | $208.3 |
| (annual) | 80,900 | 101,486 | 53,682 | 33,473 | 39,179 | 44,200 | |
| | 19% | 18% | 21% | 16% | 12% | 14% | |
| Skeena | | $417.2 | | | | | $417.2 |
| (distribution) | 451 radio tags successfully deployed | | | | | | |
| Skeena | | | $125.0 | $191.0 | | | $316.0 |
| (retro 1984 – 2008) | | | Some years | All years | | | |
| CV → | | | | 12% – 25% | | | |
| S. Thompson | $101.5 | $133.1 | $169.0 | $106.8 | $157.8 | $136.5 | $804.7 |
| (aggregate) | 172,485 | 188,845 | 193,884 | 86,073 | 193,152 | 77,140 | |
| | 51% | 44% | 56% | 48% | 21% | 21% | |
| (Lower Shuswap) | 25,288 | 71,353 | 18,895 | 4,091 | 28,797 | 43,952 | |
| | 2% | 2% | 2% | 3% | 2% | 3% | |
| (Middle Shuswap) | 1,717 | 5,037 | 1,031 | 293 | 2,274 | 2,170 | |
| | 7% | 6% | 15% | 16% | 7% | 8% | |
| Chilko | | $264.7 | $226.1 | $224.0 | $221.0 | $173.4 | $1,109.2 |
| | | 7,490 | 8,396 | 3,955 | 4,200 | 13,246 | |
| | | 7% | 5% | 6% | 5% | 3% | |
| Harrison | | | | $51.5 | | | $51.5 |
| | | | | Determined Population Closed | | | |
| Burman | $142.6 | $75.4 | $104.4 | $197.1 | $122.3 | | $641.8 |
| | 1,677 | 3,028 | 5,355 | 4,282 | 9,593 | | |
| | 17% | 13% | 14% | 10% | 14% | | |
| Kaouk | $321.8 | $209.1 | $225.0 | | | | $755.9 |
| | 0 caught | 150 | 0 recaptures | | | | |
| | | 27% | | | | | |
| Moyeha | | $172.3 | $0.0 | | | | $172.3 |
| | | 89 | 2 caught | | | | |
| | | 21% | | | | | |
| Marble/Tahsis/Leiner | | | | $219.0 | | | $219.0 |
| Marble Estimate → | | | | 2,509 | | | |
| Tahsis Estimate → | | | | 227 | | | |
| Leiner Estimate → | | | | 268 | | | |
| Marble/Tranquil/Sarita | | | | | $180.8 | | $180.8 |
| Marble Estimate → | | | | | 2,080 | | |
| Tranquil Estimate → | | | | | 836 | | |
| Sarita Estimate → | | | | | 4,220 | | |

–continued–

**Table 3.1**–(continued).

| CANADIAN STOCKS: (continued) | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | Total |
|---|---|---|---|---|---|---|---|
| Conuma | | | | | | $139.7 Unresolved | $139.7 |
| WCVI Framework | | | | $30.0 Canadian Science Advisory Report | | | $30.0 |
| Total Can$ | $657.5 | $1,405.5 | $990.8 | $1,163.8 | $830.3 | $600.4 | $5,648.3 |
| | | | | | | | |
| U.S. STOCKS: | | | | | | | |
| Driver Stock | | | | | $154.0 | $34.2 | $188.2 |
| WCVI Estimate → | | | | | 14,975 | 4,437 | |
| WCVI CV → | | | | | 27% | 29% | |
| NOC Estimate → | | | | | 85,636 | 156,051 | |
| NOC CV → | | | | | 18% | 11% | |
| Green | | $128.4 | $139.6 | $141.9 | $153.0 | | $562.9 |
| Estimate → | | 4,222 | 2,868 | 4,862 | | | |
| CV → | | 9% | 7% | 6% | | | |
| Stillaguamish | | | $117.3 | $71.5 | $85.0 | $67.7 | $341.5 |
| Estimate → | 1,239 | 837 | 1,637 | 1,787 | 997 | | |
| CV → | 7% | 16% | 6% | 8% | 10% | | |
| CVs (2007, 2008) → | | | 29%, 18% | | | | |
| Snohomish | $220.6 | | | $217.8 | $239.1 | $235.3 | $912.8 |
| Estimate → | 1 recapture | | 5,284 | 5,692 | 14,173 | | |
| CV → | | | 23% | 11% | 25% | | |
| Skykomish Estimate → | | | 3,986 | 4,005 | 5,813 | | |
| Skykomish CV → | | | 29% | 14% | 22% | | |
| Snoqualmie Estimate → | | | 1,298 | 1,687 | 8,360 | | |
| Snoqualmie CV → | | | 22% | 17% | 39% | | |
| Skagit | $46.2 0 caught | | | | | | $46.2 |
| Nehalem | $269.4 | $279.4 | $305.3 | $301.1 | $236.6 | | $1,391.8 |
| | 5,786 | 7,097 | 11,084 | 12,952 | 15,989 | | |
| | 17% | 16% | 14% | 19% | 12% | | |
| Siletz | $252.0 | $286.4 | $223.6 | $228.9 | $204.6 | | $1,195.5 |
| | 2,213 | 10,985 | 4,985 | 8,738 | 13,878 | | |
| | 12% | 32% | 8% | 19% | 13% | | |
| Siuslaw | | | | | | $194.0 | $194.0 |
| | | | | | | 16,395 | |
| | | | | | | 20% | |
| Total US$ | $788.2 | $694.2 | $785.8 | $961.2 | $1,072.3 | $531.2 | $4,832.9 |

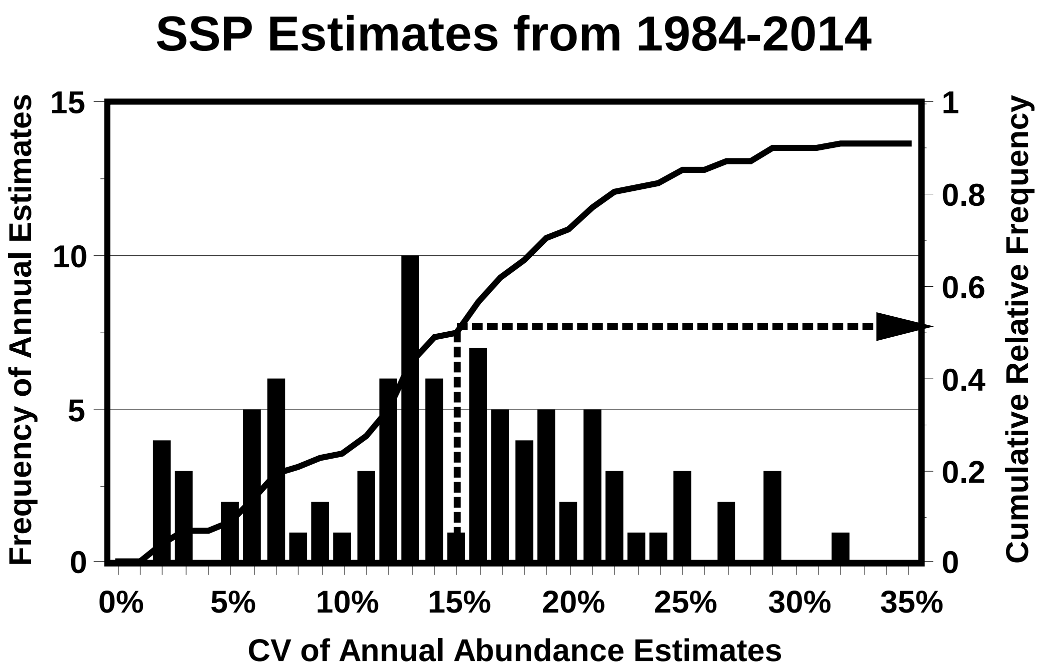



**Figure 3.1**–Frequency of estimated CVs for abundance estimates from SSP projects.

The PSC solicited proposals for the SSP in an open process. Within each geographic region there were a number of possible proponents for SSP projects on each stock group including First Nations, non-government organizations, environmental consultants, CDFO and private individuals. Soliciting proposals did not guarantee consideration of all populations appropriate as "sentinels". To ensure all possible candidate stocks had been considered, CDFO conducted a comprehensive review of all the Chinook salmon bearing streams in NBC. A stock/criteria matrix was designed to compare the 85 Chinook salmon systems to identify likely candidates with drainages between Cape Caution and the Alaska/Canada border.

Stocks were evaluated against the following criteria:

- location and accessibility;
- conservation units included in the population;
- size of the population;
- life history of the population;
- other stocks or units that this population was likely to represent;
- enhancement history;
- history of coded wire tagging;
- whether genetic baseline samples were available for the stock;
- quality of recent escapement estimates and the methods used;
- quality and quantity of biological sampling information for the stock;
- positive aspects of including the stock in the SSP (Pro's);
- negative aspects of including the stock in the SSP (Cons);
- relevance to the PST processes; and
- any other information that might be relevant when considering the population as a candidate stock for the SSP.

Candidate stocks were short listed into new projects and existing projects that required improvement to bring the estimates within the CTC data standards. Projects were considered within the priority setting exercises that occur annually for CDFO stock assessments in NBC. Projects on candidate stocks were evaluated within the existing funding opportunities that included internal CDFO sources as well as the PSC Northern Fund and SSP funds (inter alia). Attention to the specific objectives associated with each funding source was essential. Stocks were also considered with respect to their relevance to draft management plans and stock assessment frameworks.

### 3.1.1 *Nass River*

The Nass River stock was selected as a sentinel stock in 2009. The project proponent was the Nisga'a Lisims Government Fisheries and Wildlife Department (NFWD) with technical support provided from LGL Limited (Sidney, BC). The Nass River is a PST escapement indicator stock, and although Chinook salmon escapement estimation underwent significant improvements since signing of the PST, it was evident that further improvements could be realized with modest investment. The SSP funded 6 projects on the Nass River to improve annual estimates of Chinook salmon escapement from 2009 to 2014. Prior to the SSP, escapement estimates did not meet the CTC precision standard in 8 of 15 years. Estimates during the SSP bettered the precision standard in 5 of 6 years (Table 3.1 and Alexander et al. 2010–2015).

The Nass River Chinook salmon stock is large with average escapements to the upper river of 17,750 fish since 1992 (range 7,800 to 28,300; Alexander et al. 2015). The Nass River includes approximately 25 streams that drain an area of approximately 18,000 km$^2$ southwest from the British Columbia interior into Portland Inlet (Figure 3.2). The estuary is only 30 km from the Alaska/British Columbia border. A canyon at Gitwinksihlkw (GW) approximately 57 km upstream from the estuary was formed by the Tseax Volcano in 1775. Chinook salmon spawning above the canyon form a single conservation unit and there is no history of enhancement in this stock. The mainstem of the Nass River is extremely turbid with visibility near zero for most of the year. Among the major Chinook salmon producing tributaries, the Bell Irving River is glacially turbid while the Meziadin, Cranberry/Kiteen, Kwinageese and Damdochax rivers are relatively clear. Nass River Chinook salmon are primarily stream-type salmon and are far north migrating.

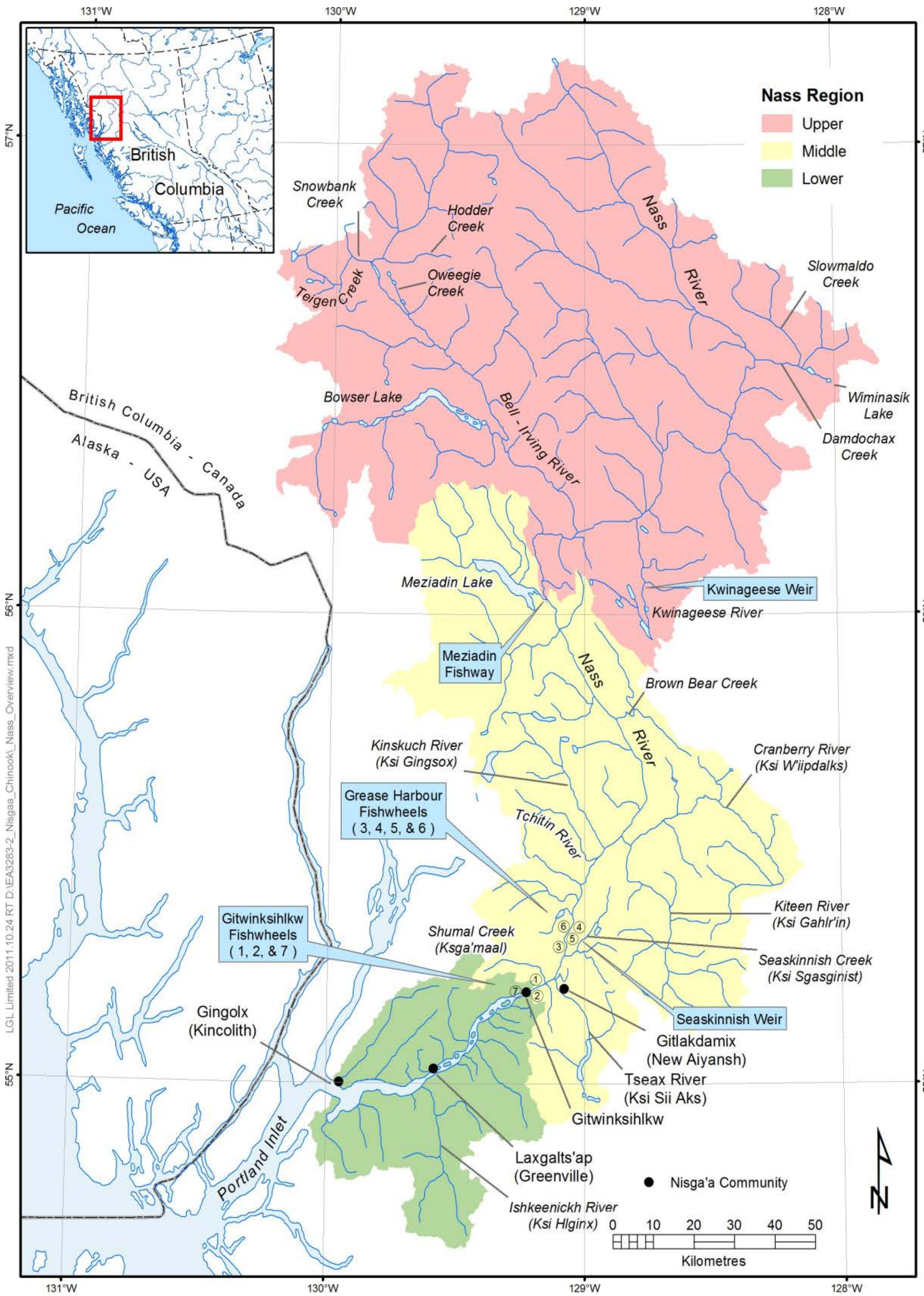



**Figure 3.2**–Nass River watershed with alternative names and sampling sites noted.

Programs using MR have been conducted since 1994 by NFWD to estimate spawning escapement in the Nass River. The Nass MR program used two fish wheels at GW in the Lower Nass canyon since 1992, and up to four fish wheels at Grease Harbour (GH) in the Upper Nass canyon from 1997, 2001–2003, and 2011–2014. Adult Chinook salmon (≥ 50 cm nose-fork length) were marked at the fish wheels by applying numbered aluminum “chick-wing” tags to the left operculum. Live fish were subsequently examined for marks at the Meziadin Fishway and both live fish and carcasses are examined for marks in other Upper Nass River tributaries. Mark-recovery locations varied over the years, but they normally included Damdochax Creek and Kwinageese River. Combined with Meziadin River, these three systems represent approximately 40% of the Upper Nass Chinook salmon aggregate stock based on radiotelemetry (1992–1993) and recent genetic (2007 and 2010–2014) data (Alexander et al. 2015). Tags were also recovered in upriver fisheries and on the spawning grounds. A modified Petersen (closed population) model was used to estimate the total population of Chinook salmon past the tagging location. Spawning escapements were calculated as the estimated Chinook salmon population past GW from the MR studies, less upriver catches in sport and FN fisheries. The average CV around annual estimates from 1994 to 2008 was 15.0% (range 7.6% to 27.8%). The main factor influencing the CV over this period was the number of marked fish examined and recovered at terminal spawning areas in the Upper Nass River watershed. Three tributaries with small Chinook salmon populations, the Kincolith, Ishkeenickh and the Iknouk, enter the Nass River below GW and are not estimated in the MR study. A small-scale enhancement facility was operated on the Kincolith River historically but was discontinued after 2009. This was the only enhancement of Chinook salmon in the Nass River watershed.

Improvements to the two event MR on the Nass River funded by the SSP included increased tag application and increased tag recovery components. In the first event, fish wheels at GH were operated to apply extra tags to Chinook salmon. In the second event a weir on the Kwinageese River was operated and additional carcass sampling was conducted on the Damdochax River to increase tag recoveries. Funds from the SSP ensured recovery operations were consistent across years rather than the sporadic operations of past years Involvement of the SSP also enabled a full review of potential MR biases (e.g., selectivity by size, sex, age, stock, and timing).

Escapement estimates were stratified by fish size where returns of large and medium sized fish were estimated rather than more traditional gender based estimates. Medium sized Chinook were more vulnerable to the fish wheels than large sized fish (average 1.53 times, range 0.93 to 2.86).

Gender identification was challenging for bright fish caught in the fish wheels, especially early in the season. Genetics were used to identify the gender of a sample (~500) of Chinook salmon caught, tagged and released at the fish wheels. Medium-sized fish (<75 cm post-orbital to hypural plate) were found to be mostly male (98%; range 91-100%). Among larger fish the gender identification error was ~30% (range 27–34%). Large males were incorrectly identified as females 50% of the time (range 38–67%) and large females were incorrectly identified as males 24% of the time (range 12–33%). Gender identification error is common in Chinook salmon observed early in their spawning migration as the dimorphic traits have not fully developed. A logistic regression morphometric model was evaluated during the SSP studies for use in predicting sex of large fish at the fishwheels based on morphological measurements and known sex from genetic samples collected from 2011–2014 (n = 1110). The model accurately predicted sex in 84.2% of cases with fair discrimination (ROC = 0.739), and on average an approximate 13% improvement over crew guesses. The morphometric model would be used in absence of genetics to improve gender estimates of large Chinook salmon. As a result of the SSP studies, sampling allowed for gender and age specific escapement estimates.

In 2010 the Nass River SSP did not achieve the CTC precision standard due to extreme environmental conditions. Insufficient marks were applied (n = 363) at the GW fish wheels and recovered (n = 15) at tag-recovery sites. The fish wheels operated under extreme low water levels that affected overall catchability and the number of marked fish released. The result was lower recoveries of marked fish at the tag-recovery sites.

The Nass River MR project provided two opportunities to investigate bias in the old study design (pre-SSP) which was associated with marking fish at another site and with using fish size-stratified escapement estimator. The relative bias could not be quantified in the old study design in its entirety because the old recovery sampling procedure at the Kwinageese River was discontinued when the SSP funded the weir operation there.

Prior to SSP funding, fishwheels captured Chinook salmon at GW and GH, but only those caught at GW were marked as part of the MR study (in most years). Those studies and a sample size power analysis found that the GW-only marking study design could produce acceptable levels of precision in the escapement estimate when more than 1,200 Chinook salmon were marked and more than 45 of them were recovered. However, in 2010 the Nass River was extremely low, which resulted in the fishwheels catching a small proportion of the migrating Chinook population. Thus, few fish were captured, marked, and recaptured in the study and the escapement estimate had low precision and too few samples to produce a size-stratified estimate. In 2011, the study design was modified and Chinook salmon were marked at GW and GH. This modification resulted in roughly three times more marked fish (mean 3.4; range 1.5-6.5) and four times more recaptured fish (mean 4.1; range 2.8-6.2; Table 3.2) over the next four years. Population estimates based on marking at both sites were generally lower than those based on the old study design (mean relative bias = -18%; range -76-39%) and they were more precise, with a mean CV of 9% for the new design compared to 18% for the old design (Table 3.2). Low river levels were experienced again in 2014 and too few (9) fish were recaptured to generate a reliable population estimate using only the GH data, but the GW data resulted in 47 additional Chinook recaptures and a reliable population estimate. In addition to increasing the resilience of the MR study to low river levels, marking at both locations increases the proportion of the escapement that is marked, increases the number of tag recaptures, and reduces bias in the population estimate.

**Table 3.2**–Summary of the Chinook salmon marked (M), recaptured (R), population estimate (N), and coefficient of variation (CV) for the study design using tags applied only at Gitwinksihlkw (GW) compared to tags applied at GW and Grease Harbour (GH).

| | GW Tags Only | | | | GW and GH Tags | | | |
|---|---|---|---|---|---|---|---|---|
| Year | M | R | N | CV | M | R | N | CV |
| 2009 | 939 | 57 | 27,437 | 13% | NA | NA | NA | NA |
| 2010 | 251 | 15 | 18,773 | 25% | NA | NA | NA | NA |
| 2011 | 445 | 44 | 11,476 | 15% | 1,145 | 123 | 10,124 | 9% |
| 2012 | 395 | 78 | 5,493 | 11% | 2,549 | 299 | 8,996 | 6% |
| 2013 | 402 | 43 | 10,083 | 15% | 1,231 | 155 | 8,298 | 8% |
| 2014 | 706 | 9 | 20,926 | 32% | 1,080 | 56 | 11,914 | 13% |

The second opportunity to investigate bias in the old study design involved generating a size-stratified escapement estimate. Link and Nass (1999) found evidence of size bias (and sex by virtue of the fact that male Chinook salmon tend to be smaller than females) in Nass River fishwheel catches in 1997. Parken and Atagi (2001, draft) found size bias in fishwheel catches of Nass River Summer-run Steelhead (*O. mykiss*) from 1997 to 1999. Size bias has also been found for Chinook salmon catches in fishwheels on the Taku River (McPherson et al. 1996, 1997; Boyce et al. 2006). Despite these findings, MR estimates for the Upper Nass River Chinook Aggregate had not been stratified by size in any years since 1994, with the exception of 1997. One of the objectives of the SPP study was to increase the numbers of marked and recaptured Chinook salmon to generate size-stratified population estimates. Size-stratified estimates and pooled estimates were calculated for all SSP years except for 2010 when too few Chinook salmon were marked (low river level). On average, the size-stratified population estimates were 5% smaller than the pooled population estimate, with relative bias ranging from -2 to -13% annually.

Two key recommendations emerged from the 2009–2014 SSP projects that emphasize the need to both apply and recover adequate marks to achieve the escapement data standard:

- mark Chinook salmon at both the GW and GH fishwheels to ensure that at least 1,300 marks are applied from four to six fish wheels that are operated each year, and
- continue mark recovery operations at Meziadin Fishway, Kwinageese River, and Damdochax Creek to ensure that sufficient marks are recovered (> 50).

### 3.1.2 ***Skeena River***

The Skeena River was selected as a sentinel stock in 2009. The Skeena River (Figure 3.3) has the second largest aggregate of Chinook salmon spawning populations in British Columbia and is one of the escapement indicator stocks defined by the PST for North/Central British Columbia. Skeena Chinook salmon are encountered in the PST Aggregate Abundance Based Management (AABM) fisheries in SEAK (all gear) and Northern British Columbia (NBC Troll and Haida Gwaii (QCI) Sport). The Skeena stock also contributes to the Individual Stock Based Management (ISBM) fisheries in Northern British Columbia including gillnet, tidal sport, non-tidal sport, tidal First Nations' (FN) and non-tidal FN fisheries. Skeena stock is north migrating so it does not contribute to the WCVI AABM fishery nor does it contribute appreciably to ISBM fisheries south of the Skeena River.

Two types of SSP projects were conducted on Skeena River: escapement estimation using GSI sub-stock expansion and radiotelemetry to determine sub-stock distribution.

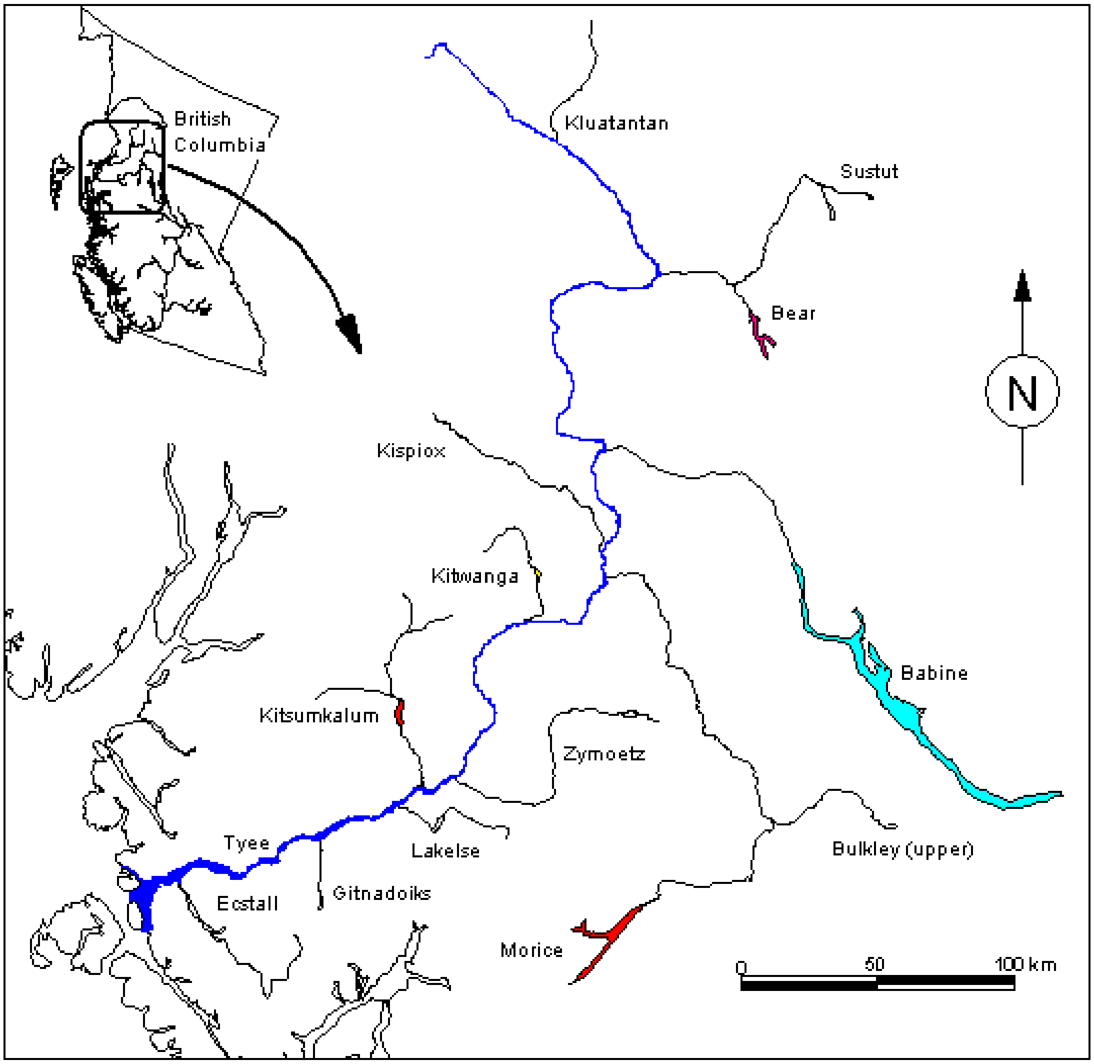



**Figure 3.3**–Skeena River watershed in northern British Columbia showing the largest tributaries and the location of Tyee.

#### 3.1.2.1 **Estimation by Expansion of a Sub-stock: 1984-2014**

The proponent for the escapement estimation project on the Skeena River was the Canadian Department of Fisheries and Oceans (CDFO). The project was made possible by a number of other projects to complete the genetic baseline information for Chinook salmon in the Skeena River. Agencies supporting the collection of baseline samples included the Skeena Fisheries Commission, Kitsumkalum Fisheries, Tahltan Fisheries, LGL Limited, the Terrace Salmonid Enhancement Society, the Toboggan Creek Hatchery, private individuals, and CDFO.

Annual projects were funded for the full duration of the SSP, and two retrospective projects were also funded that produced escapement estimates for 1984 to 2008. Eight projects were funded, and the SSP provided a total of 455,622 Can$.

Historically Skeena River Chinook salmon escapements were represented by an index that included approximately 20 populations (sub-stocks) surveyed annually using a variety of techniques. The Kitsumkalum River is the exploitation rate indicator stock for the Skeena River stock, and spawning escapements have been estimated using a MR program since 1984. Other escapement estimates that contributed to the Skeena index were based on fish weir counts, and visual observations from helicopters, fixed wing aircraft, boats and foot surveys. While the MR estimates and fish weir counts represented total fish, the visual observations were not calibrated and were known to be underestimates. Consequently, the index typically underestimated the Skeena River aggregate; MR estimates and fish weir counts were known to be over-represented in the index, and visual counts were known to be under-represented. On average the Kitsumkalum indicator stock represented approximately 30% of the index and the Bear and Morice River populations contributed 20% and 26% to the index respectively. The indices averaged about 50,000 fish for spawner abundance from 1984 to 2014 (Table 3.3).

In the SSP-funded project, the numbers of Chinook salmon returning to the Skeena River were estimated using the proportion of Kitsumkalum River fish identified from genetic samples collected at Tyee in the test fishery, and the estimates of escapement into the Kitsumkalum River from an independent MR program.

Genetic analyses of 21,550 Chinook salmon were completed from fish sampled at the Tyee Test Fishery over 36 years. The retrospective projects estimated Chinook salmon returns to the Skeena River using genetic stock identification (GSI) applied to archived scale samples. The proportions of Kitsumkalum River Chinook salmon identified in the samples were expanded to estimates for the entire Skeena-Watershed using estimates of Kitsumkalum Chinook escapement from independent MR programs. Preliminary estimates of large Chinook salmon returning to the Skeena River ranged from 28,398 in 1986 to 155,637 in 1996. Over the time series the coefficients of variation (CV) around the escapement estimates were less than the data standard of 15% in 14 years and were greater than 15% in 17 years (Table 1.1, Figure 3.4). The projects were close to the data standard (15% < CV < 20%) in 12years.

The genetic-based estimates represented an improvement over existing indices (Figure 3.4). Genetic estimates included estimates of variance which could not be produced for the indices because of the combinations of different escapement estimation techniques involved in their calculation. The data also make important contributions to our understanding of stock composition, timing, relative abundance, and age structure of the stock.

The studies provided new information regarding the components within the Skeena River stock aggregate. The Kitsumkalum River contributes 18% to the aggregate on average. Other large contributors were the Morice River at 31%, the Bear River at 7.4% and the Babine River at 6.6%. These three populations make up the Skeena Large Lake Conservation Unit. Tributaries that make up the conservation units for the Upper Skeena and the Middle Skeena River were found to contribute 9% and 17% of the total escapement to the river as a whole. The Upper and Middle Skeena River Units were poorly represented in the historic escapement index.

**Table 3.3**–Abundance indices for Skeena River Chinook salmon in aggregate, abundance estimates for the same aggregate and for Kitsumkalum River salmon, and estimated fractions of the Kitsumkalum stock at Tyee for the years 1984 to 2014. Precision statistics are given for abundance estimates and estimated fractions.

| Year | Skeena Historic CTC Escapement Index | Kitsumkalum Mark-Recapture Estimate | CV of Kitsumkalum Mark-Recapture Estimate | Weighted Proportion of Kitsumkalum at Tyee from DNA | CV of Kitsumkalum Proportion at Tyee | Skeena Chinook Escapement Estimate | CV of Skeena Chinook Escapement Estimate |
|---|---|---|---|---|---|---|---|
| 1984 | 37,598 | 12,408 | 19.9% | 20.9% | 15.1% | 51,348 | 25.0% |
| 1985 | 53,599 | 8,304 | 5.9% | 20.2% | 12.4% | 30,875 | 13.7% |
| 1986 | 59,968 | 9,109 | 5.9% | 23.3% | 14.7% | 28,398 | 15.9% |
| 1987 | 59,120 | 23,657 | 10.1% | 14.9% | 14.3% | 150,874 | 17.5% |
| 1988 | 68,705 | 22,267 | 6.9% | 21.2% | 10.5% | 91,496 | 12.6% |
| 1989 | 57,202 | 17,925 | 7.2% | 21.9% | 10.5% | 72,422 | 12.8% |
| 1990 | 55,976 | 17,406 | 6.4% | 21.2% | 11.3% | 64,188 | 13.0% |
| 1991 | 52,753 | 9,288 | 7.2% | 17.3% | 11.7% | 41,940 | 13.7% |
| 1992 | 63,392 | 12,437 | 8.1% | 10.8% | 20.7% | 103,365 | 22.3% |
| 1993 | 66,977 | 14,059 | 5.5% | 10.9% | 16.1% | 119,780 | 17.1% |
| 1994 | 48,712 | 12,629 | 9.5% | 14.6% | 13.4% | 78,228 | 16.4% |
| 1995 | 34,390 | 7,221 | 10.1% | 10.6% | 22.3% | 62,272 | 24.5% |
| 1996 | 73,684 | 12,776 | 16.7% | 8.0% | 11.8% | 155,637 | 20.4% |
| 1997 | 42,539 | 5,342 | 11.3% | 8.4% | 15.9% | 57,368 | 19.5% |
| 1998 | 46,744 | 11,065 | 6.8% | 12.2% | 16.6% | 80,677 | 17.9% |
| 1999 | 43,775 | 9,763 | 8.9% | 14.2% | 7.9% | 53,418 | 11.9% |
| 2000 | 51,804 | 14,722 | 8.2% | 13.6% | 9.5% | 95,563 | 12.5% |
| 2001 | 81,504 | 23,839 | 9.5% | 15.3% | 7.4% | 145,120 | 12.1% |
| 2002 | 44,771 | 23,849 | 11.4% | 25.0% | 5.3% | 89,235 | 12.6% |
| 2003 | 56,758 | 23,608 | 11.0% | 18.9% | 6.9% | 114,346 | 13.0% |
| 2004 | 44,243 | 25,767 | 10.2% | 16.8% | 7.8% | 142,141 | 12.8% |
| 2005 | 29,067 | 15,046 | 9.2% | 17.8% | 7.0% | 77,531 | 11.6% |
| 2006 | 33,094 | 12,368 | 14.5% | 13.7% | 9.3% | 84,199 | 17.2% |
| 2007 | 33,352 | 15,736 | 18.0% | 17.5% | 7.5% | 85,179 | 19.5% |
| 2008 | 32,963 | 10,374 | 14.2% | 13.1% | 8.2% | 71,446 | 16.4% |
| 2009 | 38,297 | 10,703 | 13.3% | 12.4% | 13.3% | 80,900 | 18.8% |
| 2010 | 43,331 | 13,712 | 14.8% | 12.7% | 10.2% | 101,486 | 18.0% |
| 2011 | 37,073 | 12,059 | 20.2% | 21.0% | 6.8% | 53,682 | 21.3% |
| 2012 | 34,024 | 9,363 | 13.9% | 26.0% | 7.8% | 33,473 | 16.0% |
| 2013 | 26,699 | 10,934 | 9.4% | 26.5% | 7.2% | 39,179 | 11.9% |
| 2014 | 28,496 | 10,308 | 11.6% | 21.6% | 8.5% | 44,200 | 14.4% |
| | | | | | | | |
| Average | 47,762 | 14,130 | | 16.9% | | 80,644 | |

In addition to the data presented for 1984 to 2014, genetic stock identifications have been completed for 1,056 samples from the Tyee Test Fishery from 1979 to 1983. Although Kitsumkalum MR estimates are not available for years prior to 1984, estimates from surveys of other systems (like Morice, Bear and Babine rivers) may be used to generate total system estimates for these early years. While the variance around these estimates will be broad (well beyond the data standard) they are important to understand as they include the base period used to compare Chinook salmon abundances coast-wide prior to the PST.

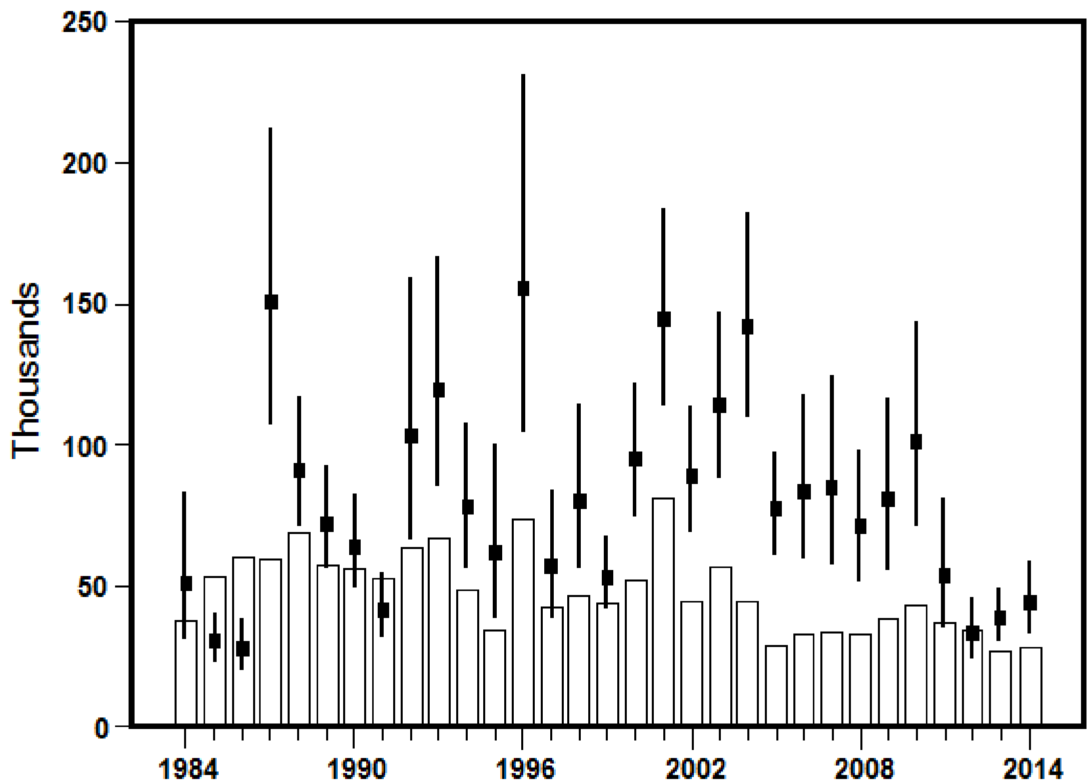



**Figure 3.4**–Comparison of the escapement indices used by the CTC to represent Chinook salmon spawning abundance in the Skeena River (bars) with escapement estimates (®) from using GSI to expand estimated abundance of the Kitsumkalum sub-stock. The vertical lines represent lognormal 95% CIs.

#### 3.1.2.2 Radiotelemetry Project: Skeena River 2010

The proponents for the Skeena River radiotelemetry project were the Skeena Fisheries Commission and LGL Limited. The Skeena Fisheries Commission (www.skeenafisheries.ca) is an aboriginal organization that includes the Tsimshian, Gitxsan, Gitanyow, Wetsuweten, and Lake Babine Nations. This project was conducted during a single year, 2010, and the SSP provided 417,195 Can$. The work was preceded by two PSC Northern Fund studies in 2008 (Plate and English 2008; Gottesfeld and Muldon 2009) to test the feasibility of catching enough Chinook salmon for the purpose of estimating distribution across the watershed with radiotelemetry.

Primary objectives for the 2010 SSP-funded study were to:

- determine the distribution of spawning radio-tagged Chinook salmon throughout the Skeena River Watershed;
- determine the DNA attribution of marked salmon based on the existing microsatellite DNA baseline and compare them to observed spawning localities;

- compare the relative abundance of Chinook salmon from the various spawning localities to the abundance as determined by analysis of the Skeena Test Fishery results from Tyee; and
- combine the above information with the best available escapement estimates for the Kitsumkalum, Morice, and Kitwanga rivers to derive a reliable estimate of the total escapement for the Skeena stock aggregate.

Secondary objectives were estimates of in-river harvest rates for the major sub-stocks, in-river migration rates, and fishery residence times for summer migrating Chinook salmon.

In their direction to the proponents for the radiotelemetry study on the Skeena River stock, the SSC identified that their primary interest was to validate the genetic approach used to generate a system-wide escapement estimate for Skeena Chinook salmon aggregate. An important component was to identify tags that entered the Kitsumkalum River relative to other tributaries, fishery removals, and losses due to mortality or other reasons. The year 2010 turned out to be an unfortunate year as the proportion of Kitsumkalum Chinook salmon in the Skeena River run that year was relatively low (12.7%) and its age structure was unusual (over 36% of the return was made up of age 1.2 males).

The Skeena River radiotelemetry study identified major Chinook salmon populations and confirmed large populations or large portions of population were not missing from the genetic baseline. Misclassification error in GSI was larger than expected suggesting difficulty in identifying individuals or fish spawning in non-natal areas were not as successful. Overall, stock contributions to the Chinook aggregate measured by the telemetry project were similar to those measured by the Tyee Test fishery (Figure 3.5) thereby validating the genetic approach of sub-stock expansion to estimating aggregate abundance to the entire watershed.

## 3.2 Fraser River

The CTC uses five stock groups to represent Chinook salmon production originating from the Fraser River: Spring-run Age 1.2, Spring-run Age 1.3, Summer-run Age 0.3, Summer-run Age 1.3, and Fraser Late. These stock groupings are based on maturation patterns, ocean distribution, and run timing at the Fraser River mouth (Candy et al. 2002; PSC 2002; Parken et al. 2008). Among the five stock groups, the SSP funded studies on Summer-run Age 0.3 (South Thompson River (6 years)), Summer-run Age 1.3 (Chilko River (5 years)) and Fraser Late (Harrison River (1 year)). Of these, only the Harrison River is identified in Attachments I-V of the 2009 Agreement because other Fraser River stocks have been reorganized into new groupings based on life history and run timing, rather than geographically aggregated. This circumstance may change since the CTC has an assignment to review Attachments I-V and recommend changes.

For Fraser stocks, the process for identifying potential Sentinel Stocks was based on information gaps and locations where experience with standard escapement methodology and environmental conditions created concern about accuracy of escapement estimates. Locations were reviewed for their suitability for studies that would meet CTC bilateral standards for escapement estimation, feasibility, cost, and partnership opportunities. During the course of the SSP, proposals were submitted for projects in four of the five stock groups.

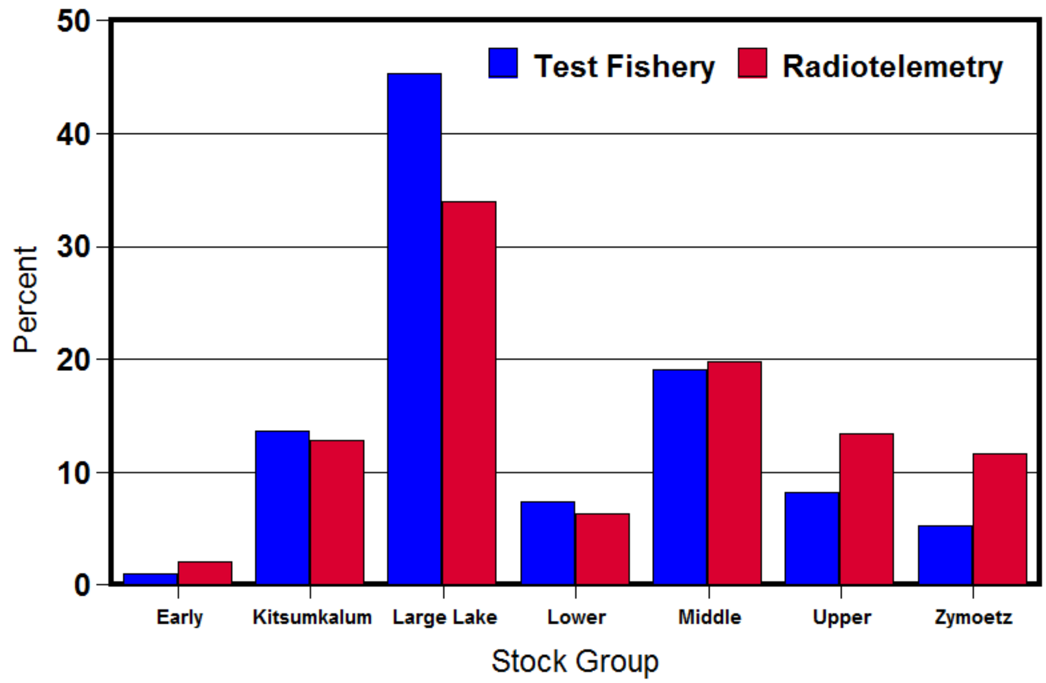



**Figure 3.5**–Distribution of Chinook salmon sampled from the Tyee Test Fishery and from test subjects in the radiotelemetry study across stock groups spawning in the Skeena River as determined through genetic analysis. Early stocks are those that spawn in the Cedar River upstream of Kitsumkalum Lake and in the upper Bulkley River (Figure 3.3)

Only the proposal for the Willow River stock (Spring-run Age 1.3 stock group) was not funded as part of the SSP; a large information gap persists in this stock group as none of the populations have escapement programs that meet CTC bilateral data standards or have escapements estimated by age. No proposals were submitted for populations in the Spring-run Age 1.2 stock group because half of the populations have escapement programs that meet the CTC standards, representing about 80% of the abundance.

Potential SSP stocks were ranked by CDFO based on several attributes including information gaps, management needs, ability to achieve the SSP objectives, feasibility, cost, partnership opportunities, opportunities for longer term funding after the end of the SSP, and the legacy of information that could be developed to improve the quality of past or future escapement data collected via low cost methods. Projects were considered within the priority-setting exercises that occur annually for CDFO stock assessments in the Fraser River. Within each stock group, only the highest priority project was proposed to the SSP for funding.

### 3.2.1 *South Thompson River*

The South Thompson River project focused on estimating abundance of spawners in the Lower Thompson, South Thompson, Little, Lower Adams, Lower Shuswap and Middle Shuswap rivers. Chinook salmon spawning in these rivers are ocean-type, mature from age-0.1 to age 0.4 with most at age 0.3, and have a far north ocean distribution. These are large, clear rivers with environmental conditions that make it challenging to estimate spawner abundance using standard methods that involve counting spawners, holders, and carcasses or redds, and multiplying the peak count by an expansion factor. Prior to the SSP, high precision traditional MR studies occurred at the Lower Shuswap River for the CTC exploitation rate indicator stock program, and at the Middle Shuswap River. Escapements estimated with MR methods were often much larger than the escapements estimated by with peak count methods at both locations. Biologists from CDFO and from First Nations have considered the feasibility of using other methods, such as MR, at locations other than Middle and Lower Shuswap rivers, but the physical conditions and fish behavior in these systems made it unrealistic to apply them. SONAR and other direct count techniques were also considered, but were deemed impractical due to the very high abundance of other salmon species co-migrating in these rivers.

Chinook salmon escapement in the South Thompson River was estimated by expanding the estimated stock-aggregate catch by recoveries of an indicator stock—the DSR method (§§ 2.3-4). The South Thompson River project examined different study designs using the expansion of an indicator stock method as well as a variation of the MR method. Both approaches required large numbers of CWT fish to be released to increase the amount of CWT recoveries and to increase the representation of the populations in the aggregate. The SSP increased CWT releases at the Middle Shuswap from 0 to 150,000 fish, whereas CWT release numbers were increased at the Lower Shuswap from 200,000 to 500,000 fish to meet joint program objectives of the CWTIP (PSC 2015) and the SSP. Tag release numbers were increased beginning in 2009 in the Middle Shuswap River, and in 2010 in the Lower Shuswap River due to delays with modifying hatchery production. Fishery recoveries of CWTs from these stocks increased noticeably by 2013 and yielded enough CWT data to evaluate different study designs and analytical methods. Estimates for 2009 through 2014 with their CVs are in Table 3.4, and several key findings occurred during the course of the SSP.

The first year of the project included an investigation to identify the assumptions required to employ the DSR method (§ 2.4) using simulation. The influential assumptions were all related to the ability of the CWT indicator stock to accurately represent maturation and exploitation rates of the aggregate. During the course of the project, the indicator stock ratio (age-specific catch based on CWT divided by catch based on GSI) was summarized for cohorts of the South Thompson stock caught in the NBC troll fishery. The analysis revealed that the indicator stock ratio declined as age increased for all cohorts; however, a similar analysis of CWTs from the Lower Shuswap escapement indicated a different pattern, with no decline in the ratio. The main finding was that there appears to be differences in the maturation schedule between the Lower Shuswap stock and the other stocks, and this was supported further by the analysis of scale age samples collected among these rivers. Generally, there appears to be a slightly older maturation schedule, as evidenced by more age-5 fish, for fish spawning in the South Thompson, Lower Adams, Little and Lower Thompson (SALT) rivers compared to Lower and Middle Shuswap rivers (which had relatively more age-3 fish). The differences in the maturation schedules reduced the utility of the NBC troll fishery data to produce an unbiased estimate of escapement to the South Thompson River with the DSR method, thus efforts were focused on expanding GSI of catches in test fisheries (§ 2.3).

**Table 3.4**–Mark-recapture (MR) estimates of Chinook salmon escapement for 2009-2014 in the South Thompson aggregate and its components spawning in the Lower Shuswap River, Middle Shuswap River, and the SALT rivers (South Thompson mainstem, Lower Adams, Little Thompson, and Lower Thompson). Statistics for the two Shuswap stocks were calculated from separate MR studies while statistics for SALT rivers were calculated in aggregate with indicator stock expansion methods.

| | Aggregate | | Lower Shuswap | | Middle Shuswap | | SALT | |
|---|---|---|---|---|---|---|---|---|
| Year | Estimate | CV | Estimate | CV | Estimate | CV | Estimate | CV |
| 2009 | 172,485 | 51% | 25,288 | 2% | 1,717 | 7% | 145,480 | 60% |
| 2010 | 188,845 | 44% | 71,353 | 2% | 5,037 | 6% | 112,455 | 74% |
| 2011 | 193,884 | 56% | 18,895 | 2% | 1,031 | 15% | 173,958 | 62% |
| 2012 | 86,073 | 48% | 4,091 | 3% | 293 | 16% | 81,689 | 51% |
| 2013 | 193,152 | 21% | 28,797 | 2% | 2,274 | 7% | 162,081 | 25% |
| 2014 | 77,140 | 21% | 43,952 | 3% | 2,170 | 8% | 31,018 | 52% |

Several test fisheries operate near the mouth of the Fraser River. One, the Albion Test Fishery operates throughout the migration of the South Thompson stock (June-September). This test fishery is standardized and begins in late April annually. Initially, an 8-inch mesh net and a multi-panel net consisting of sections of 6-, 7-, 8- and 9-inch mesh are fished on alternating days. In September, the multi-panel net is replaced by a 6¾ inch mesh net to provide estimates of the abundance of returning chum salmon (*O. keta;* Parken et al. 2008). Two test fisheries operated by the PSC are focused on other salmon species (using nets with smaller mesh); catches in these fisheries were not analyzed due to concerns about selectivity favoring smaller Chinook salmon. Another test fishery at Qualark was examined using over three years of samples, but size-selective biases were detected and samples were consequently omitted. From 2009–2014, there were large runs of pink salmon (*O. gorbuscha*) in the odd years and large returns of sockeye salmon (*O. nerka*) in 2010 and 2014 that could have saturated nets at the Albion Test Fishery. No saturation effect was detected from pink salmon, probably due to their small size relative to the mesh sizes of the Albion nets. Also, no saturation effect was detected in 2014, as late-run sockeye salmon did not migrate into the Fraser River until late September, after most of the South Thompson Chinook salmon had passed upstream. In comparison, saturation effects due to sockeye salmon were detected in 2010 for the multi-panel net when the late-run sockeye salmon migrated during late August and early September. This saturation coincided with much of the Chinook salmon migration to the South Thompson River; however saturation was only detected in the multi-panel net and was not detected in the 8-inch mesh net, which is generally too large to catch sockeye salmon. These experiences indicate that the Albion Test Fishery is a robust venue for sampling South Thompson Chinook salmon under most conditions, with the infrequent exception of years when late-run sockeye salmon are abundant and return early.

By 2013, the number of CWTs in the Fraser River test fisheries had increased greatly due to augmented CWT releases initiated by the SSP in 2009. Large numbers of CWTs enabled application of the MR method to be applied. Estimates for 2013 and 2014 were similar for the MR and indicator stock expansion methods, and confidence intervals overlapped. The MR method is conceptually simpler, but the analytical model needs more development to represent uncertainty in the CWT and GSI data. The CVs of the 2013 (21%) and 2014 (21%) escapement estimates were larger than the CTC data precision standard, but the estimates are based on asymptotically unbiased methods.

The South Thompson River project provided six years of high-precision escapement data that were used to calibrate the PC method to the Petersen MR method on the Lower and Middle Shuswap rivers (Table 3.4). In total, 18 years of calibration data are available for the Lower Shuswap sub-stock and 9 years for the

Middle Shuswap sub-stock. These data have been used to calibrate the peak count estimates to the MR estimates, and annual escapements with their measures of precision have been reported by the CTC (PSC 2015), and they are being used to improve the CTC model, as part of the base-period calibration. The calibrated time series has also been used to improve the Fraser River Chinook run reconstruction model (English et al. 2007).

Since the Lower and Middle Shuswap rivers have high quality escapement estimates based on MR or calibrated peak count methods, the peak count estimates for the S-A-L-T component were compared to their estimates derived from the indicator stock expansion method. There was a significant positive relationship between both series ($R^2 = 0.71$), and more high quality estimates can be developed after the SSP, due to the larger number of CWT fish released and recoveries expected in the future. Additional escapement estimates for 2015 and later could be useful for improving the contrast and precision of the calibration relationship, and they are necessary to increase confidence (Figure 3.6).

### 3.2.2 *Chilko River*

The Chilko River was identified as the preferred system for development as a CTC escapement and ER rate indicator stock to represent the Summer-run Age 1.3 stock group based on historical escapement data, physical characteristics of the river, importance of the stock to fisheries, and CWT data during the CTC base period. This stock group contributes to catches in AABM and ISBM fisheries from SEAK to Washington, as well as First Nations and recreational fisheries in the Fraser River. The Chilko River population is the largest of the Summer-run age 1.3 stock group, averaging 42% of the aggregate escapement during 1975–2014.

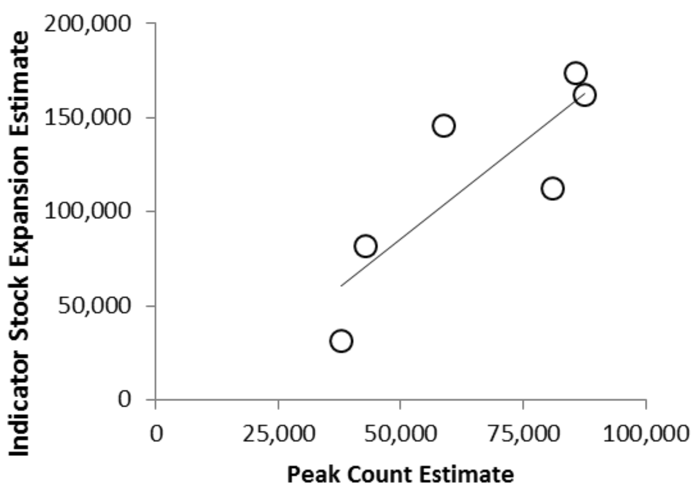



**Figure 3.6**–Comparison of the South Thompson, Lower Adams, Little, and Lower Thompson (S-A-L-T: a component of South Thompson River) Chinook salmon escapement index with escapement estimates developed using indicator stock expansion/mark-recapture methods.

This project focused on estimating escapement using two-event traditional MR methods from 2010–2014, while providing opportunities to evaluate the study design, test major assumptions, monitor age composition, investigate in-river behavior, develop a calibrated time series, and pilot a CWT program. The primary objectives were to:

- produce an estimate of spawning abundance that meets or exceeds the CTC data standards for escapement indicator stocks;
- estimate spawning abundance by age and sex; and

- produce an estimate of an annual calibration factor to correct for biases in peak count salmon escapement estimates in the Chilko River and other Fraser River tributaries that have similar visual counting conditions.

Over five years, the MR escapement estimates and associated CVs exceeded the CTC precision standard (CV≤15%; Table 3.5) and met the accuracy standard. Thus, high precision estimates of escapements by sex to the Chilko River annually can be generated and enough carcasses sampled (35%-50% of all carcasses) to use this stock as an ER indicator stock.

Due to evidence of spatial and temporal differences in capture probabilities in both the application and recovery samples, estimates were temporally and spatially stratified for females in all years and for males in two years. Therefore, the study design was modified annually to include proportional application of tags based on the spatial distribution observed in recent years to ensure sufficient samples for diagnostic bias testing and to generate unbiased stratified estimates. Although estimates using MR methods from 2010-2014 are very precise, estimates need to be accurate which will likely require the use of stratified estimation annually, at least for females. The radiotelemetry study in 2010 confirmed the assumption of population closure needed for this type of MR study.

**Table 3.5**–Estimates of Chinook salmon escapement for 2010-2014 in the Chilko River, and associated CVs based on mark recapture (MR) methods; the peak count (PC) escapement estimate; and the relative error.

| Year | MR Estimate | CV of MR Estimate | PC Estimate | Relative Error [a] |
|---|---|---|---|---|
| 2010 | 7,490 | 7% | 6,345 | -15% |
| 2011 | 8,396 | 5% | 7,526 | -10% |
| 2012 | 3,955 | 6% | 3,845 | -10% |
| 2013 | 4,200 | 5% | 5,186 | 23% |
| 2014 | 13,246 | 3% | 11,283 | -15% |

[a] Relative error = (PC Estimate – MR Estimate) / MR Estimate

Peak counts from surveys have been used to develop low precision estimates of Chinook salmon escapement for rivers in the Summer-run 1.3 stock group since 1975. To improve the accuracy and calculate precision of the historic escapement data, calibration relationships are being developed to convert lower quality, escapement indices (PCs) into higher quality estimates of total spawner escapement (see § 4.1.2.1 for more information). Peak count and MR estimates were developed concurrently during the SSP-funded study to estimate annual calibration factors and a mean factor, however additional years of concurrent estimates are needed for two reasons. First, relative error ranged from -15% to +25% and the calibration factor has not stabilized yet, which is likely due to too few measurements (n=5). Second, during the 5-year study period escapements were in the low to moderate range of the historic data. More information is needed to represent conditions with moderate to high escapements (Figure 3.7). Counting conditions at the Chilko River are close to optimal (e.g. large, clear river); therefore, annual variability in fish behavior is likely the main factor influencing the proportion of the population that is counted. Other factors—such as discharge, temperature, and densities of spawning Chinook and sockeye salmon—could be examined further. The calibration factor did not appear to vary with sockeye salmon abundance (range 250,000-2,500,000) during 2010-2014, perhaps because these species' spawning areas are isolated in the Chilko River.

This project has increased the biological knowledge for this population and the stock group. Over five years, large variations were evident in annual age compositions for males and females, which was unknown previously. Another important finding was that there are strong cohort abundance signals that become evident at age-3 (first age of maturity); this information can be valuable for forecasting the abundance of Chinook and planning fisheries if the program is continued. A pilot broodstock collection was done in 2014 to evaluate the development of a CWT program. The progeny were reared successfully to fry and will be tagged and released as smolts in the spring of 2016, with recruitment to fisheries and escapement expected from 2017 to 2020.

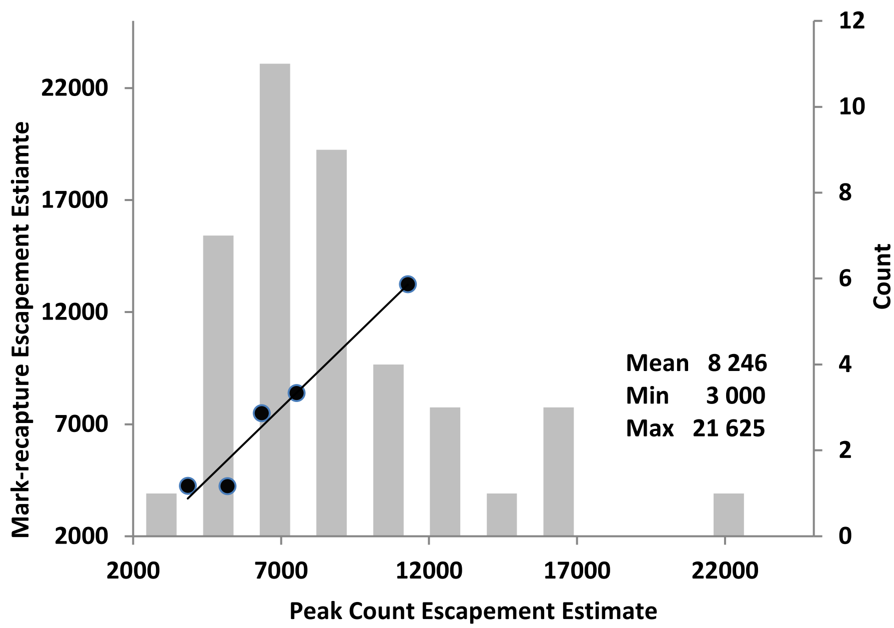



**Figure 3.7**–Peak counts of spawning abundance versus MR spawning abundance for Chilko River Chinook salmon, 2010 to 2014 (●). The histogram illustrates the frequency distribution for 40 peak counts (1975-2014) in bins of 2000 spawners. The mean, minimum and maximum values are provided for the frequency histogram.

### 3.2.3 *Harrison River*

Harrison River Chinook salmon are one of the largest natural spawning populations in British Columbia, and they are one of the most abundant stocks occurring in fishery harvests on WCVI, Coastal Washington and the Salish Sea with up to 250,000 escapement (CTC 2014). From 1984 to present, Chinook salmon escapement to the Harrison River has been estimated using MR methods (Staley 1990). Given the importance of this stock to fisheries and the PST Agreement, it was prudent to evaluate the robustness of the MR studies to the condition of population closure to ensure that the program was producing asymptotically unbiased estimates of the spawner escapement.

In 2012, a radiotelemetry study on was conducted to determine whether this two-event MR study met the condition of closure and to investigate the behavior and distribution of the spawning population. Radio tags were applied to pre-spawning Chinook salmon captured in a staging area within the downstream portion segment of the known spawning grounds in the Harrison River. Fish movements were monitored throughout residency (i.e. staging, spawning, death) using mobile receivers and receivers stationed at the upper and lower boundaries of the second sampling event (the known spawning grounds) in the MR study.

All radio tagged fish were detected and all spawned within the known spawning grounds, therefore, the condition of closure was validated for the 2012 escapement study, and presumably for the other years using the same study design. Additionally, three general behavioral patterns were recognized:

- The majority of fish dropped downstream following capture and tagging, and remained there on spawning habitat;
- Some fish were observed near the application site where there is a modest amount of spawning substrate; and
- A few fish moved downstream from the tagging site to the spawning grounds then, at a later date, moved downstream to the boundary of the Harrison River study area, only to return upstream and remain in the study area.

This last behavior was consistent with results from other studies (Bernard et al. 1999, Keefer et al. 2004).

### 3.3 West Coast of Vancouver Island

Determining escapements of Chinook salmon to WCVI streams proved challenging. Naturally produced salmon originate from about 100 streams, many of which are remote and difficult to access. All streams are short and subject to freshets. Escapement estimates are generated using the AUC method (see §2.5) which expands counts from periodic counts visual surveys of spawners by observer efficiency (OE) and survey life (SL).   Peak counts (PC) are also used by CDFO as an index of abundance for those streams in situations with few surveys

The resulting escapement estimates have inherent shortcomings with regard to scientific quality (e.g. greater uncertainty, potential biases, etc.) because of a lack of quantitative information on OE and SL specific to the stream and daily survey conditions, and because of surveys canceled due to freshets. To provide quantitative information on SL, OE, and independent estimates of escapement against which to calibrate AUC estimates, the SSP funded a suite of 17 studies across 9 WCVI streams (Figure 3.8). In many of the studies, Chinook salmon were captured near the river mouth in marine and/or fresh waters and fitted with radio tags (Table 3.6). Knowledge of subsequent locations of these radio-tagged fish was used to estimate SL (Table 3.7) and OE (Table 3.8) for individual streams in different years.

The NTC (Nuu-chah-naalth Tribal Council) and CDFO jointly proposed these 9 streams as locations for study to the SSP because these streams (stocks):

- are accessible;
- were thought to have escapements sufficiently large for evaluating escapement estimation methods;
- provide opportunities to capture large numbers of fish or to operate a weir;
- were thought relatively free of straying hatchery fish; and
- and if selected by the SSP, had potential for partnering with ongoing or new studies not funded by the SSP.

Proposals were solicited from First Nation fishery organizations, consulting firms, and CDFO.


**Figure 3.8**–Locations of field studies funded by the SSP on 9 stocks (streams) on WCVI from 2009–2014. Most of these 9 stocks were studied over several years such that together they represent 17 studies.

The SSP funded three other projects for WCVI that did not involve field studies, at least not directly. One project was funded twice (2013, 2014) with the objective of estimating terminal run size to WCVI in aggregate with the DSR method—an expansion based on GSI estimates of catch in SEAK fisheries and the return of coded-wire tags (CWTs) for the WCVI exploitation indicator stock (see § 2.4). The other project concerned the development of a stock assessment framework and an alternate AUC model (see § 2.5 for a general description of AUC methods).

### 3.3.1 ***Burman River***

The Burman River (Figure 3.9) consistently had estimated escapements in the thousands (Table 3.9), and is annually surveyed as one of six escapement indicator stocks used by the CTC and CDFO (CDFO 2012; CTC 2015). However, the population is supplemented in most years with hatchery production.

Both closed-population (traditional) MR and open-population MR methods described in § 2.1 were applied to estimate escapement to the Burman stock with SSP funding from 2009–2013. Chinook salmon were captured by beach seine in a single "stopover" pool where salmon frequently paused their upstream migration until the next freshet. Salmon caught in the pool were marked with individually numbered tags and a with a secondary batch mark, identified by sex (when obvious), measured for length, sampled for scales, and released. Live recaptures of individuals at the pool were recorded to produce individual encounter histories across sampling dates. Sampling at the stopover pool represented the first sampling event for the closed-population traditional MR study and all sampling for the open-population MR study. The second sampling event for the closed-population MR study occurred on the spawning grounds. During each sampling date carcasses not previously sampled were inspected for marks, dissected to determine sex, measured for length, and sampled for scales and otoliths. Otoliths were examined to estimate the numbers of hatchery and natural-origin fish in the escapement. Previously sampled carcasses were recognized from evidence of dissection and were not used twice in calculations.

**Table 3.6**–Elements of the SSP studies by river and year for the WCVI region.

| | | Study Element | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| System | Year | Fence | Mark-recapture | Mark-resight | Radio tags | External visible tags | Survey Life | Obs. Eff | AUC Trapezoidal | AUC MLE unimodal | AUC MLE bimodal |
| **Burman** | | | | | | | | | | | |
| | 2009 | | x | | | | x | | x | | |
| | 2010 | | x | | | | x | | x | | |
| | 2011 | | x | | | x | x | | x | | |
| | 2012 | | x | | x | x | x | x | x | | |
| | 2013 | | x | | | x | x | | x | | |
| **Moyeha** | | | | | | | | | | | |
| | 2010 | | x | | | x | | | x | | |
| | 2011 | | | | | | | | x | | |
| **Conuma** | | | | | | | | | | | |
| | 2014 | | x | | x | x | x | x | x | | |
| **Kaouk** | | | | | | | | | | | |
| | 2009 | x | x | | x | x | x | x | x | x | x |
| | 2010 | | x | | x | x | x | x | x | x | x |
| | 2011 | | x | | x | x | x | x | x | x | x |
| **Marble** | | | | | | | | | | | |
| | 2012 | | x | x | x | x | x | x | x | x | x |
| | 2013 | | x | x | x | x | x | x | x | x | x |
| **Tahsis** | | | | | | | | | | | |
| | 2012 | | | x | x | x | x | x | x | x | x |
| **Leiner** | | | | | | | | | | | |
| | 2012 | | | x | x | x | x | x | x | x | x |
| **Sarita** | | | | | | | | | | | |
| | 2013 | | | x | x | x | x | x | x | x | x |
| **Tranquil** | | | | | | | | | | | |
| | 2013 | | | x | x | x | x | x | x | x | x |

**Table 3.7**–Mean, standard deviation (SD), and coefficient of variation (CV) of estimated survey life (days) measured using radiotelemetry by stock and year from SSP-funded studies on WCVI.

| River | Year | Mean Survey Life | SD | CV | Number of Fish |
|---|---|---|---|---|---|
| Burman | 2012 | 5.0 | 4.1 | 82% | 108 |
| Conuma | 2014 | 5.3 | 4.9 | 92% | 68 |
| Kaouk | 2011 | 18.0 | 6.6 | 37% | 46 |
| Marble | 2012 | 27.4 | 14.0 | 51% | 10 |
| Marble | 2013 | 35.0 | 9.0 | 26% | 19 |
| Leiner | 2012 | 28.8 | 14.0 | 49% | 38 |
| Tahsis | 2012 | 25.4 | 15.0 | 59% | 10 |
| Tranquil | 2013 | 17.5 | 3.4 | 19% | 24 |
| Sarita | 2013 | 17.2 | 8.9 | 52% | 82 |
| Median [a] | | 17.5 | 6.9 | 39% | |

[a] Median over stream-year studies.

**Table 3.8**–Mean, standard deviation (SD), and coefficient of variation (CV) of observer efficiency measured using radiotelemetry and swim survey counts by stream and year.

| River | Year | Observer Efficiency | | | Number of Surveys |
|---|---|---|---|---|---|
| | | Mean | SD | CV | |
| Marble | 2012 | 54% | 41% | 76% | 9 |
| Marble | 2013 | 54% | 30% | 56% | 8 |
| Kaouk | 2011 | 32% | 35% | 109% | 3 |
| Burman | 2012 | 53% | 39% | 74% | 21 |
| Conuma | 2014 | 31% | 41% | 132% | 8 |
| Leiner | 2012 | 32% | 35% | 109% | 11 |
| Tahsis | 2012 | 47% | 51% | 107% | 5 |
| Tranquil | 2013 | 79% | 34% | 43% | 8 |
| Sarita | 2013 | 17% | 17% | 97% | 3 |
| Median [a] | | 49% | | | |

[a] Median over stream-year studies.

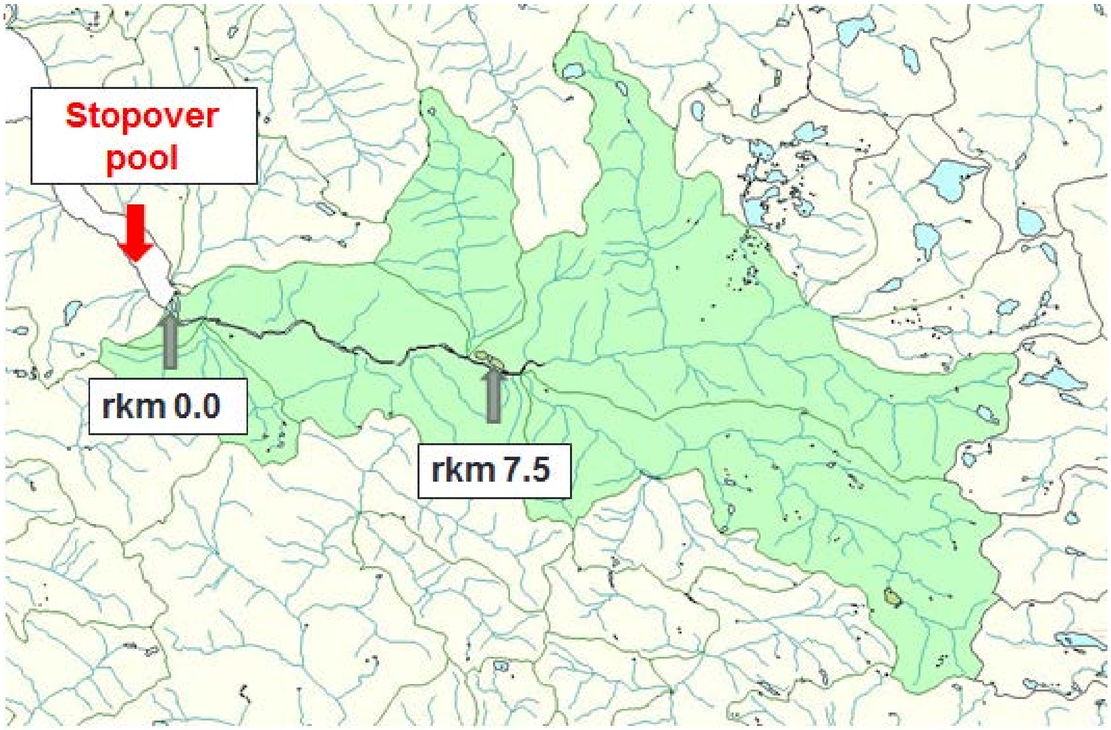



**Figure 3.9**–Locations on the Burman River where live Chinook salmon were captured, sampled, and tagged downstream in a "stopover pool" (red arrow), and the surveyed spawning grounds upstream (between the gray arrows) from 2009–2014 where dead and moribund salmon were captured and inspected.

**Table 3.9**–Abundance estimate of adult Chinook salmon in several WCVI rivers using MR methods (SSP-funded) and non-parametric (trapezoidal) AUC methods with estimates of survey life (SL) and observer efficiency (OE) from radiotelemetry (SSP-funded) and using the same AUC methods with estimated and self-assessed values for SL and OE, respectively. Studies represent the CDFO six-stock index as reported in Appendix Table B.4 in CTC (2014) and the CDFO 14-stock-index. The same number of fish-days from counts was used for each river-year combination regardless of the source of SL and OE except for the Burman stock in 2012 (see text).

| River | | Traditional MR | | Open MR | | Trapezoidal AUC | |
|---|---|---|---|---|---|---|---|
| | | Estimate | CV | Estimate | CV | Estimated SL,OE | Self-assessed SL,OE |
| Burman | 2009 | 1,677 | 17% | 1,587 | 21% | | 1,500 |
| Burman | 2010 | 3,028 | 13% | 2,453 | 11% | | 2,825 |
| Burman | 2011 | 5,355 | 14% | 4,325 | 14% | | 2,020 |
| Burman | 2012 | 4,282 | 10% | 3,966 | 7% | 4,273 | 1,003 |
| Burman | 2013 | 7,168 | 14% | 5,455 | 8% | | 8,285 |
| Conuma | 2014 | 16,242 | 10% | 9,417 | 11% | | 15,000[a] |
| Kaouk | 2009 | | | | | | 550 |
| Kaouk | 2010 | 150[b] | 27% | | | | 185 |
| Kaouk | 2011 | | | | | | 303 |
| Moyeha | 2010 | | | | | | 185 |
| Moyeha | 2011 | | | | | | 67 |
| Marble | 2012 | | | | | 2,509 | 2,364 |
| Marble | 2013 | | | | | 2,240 | 2,081 |
| Leiner | 2012 | | | | | 772 | 566 |
| Tahsis | 2012 | | | | | 227 | 163 |
| Tranquil | 2013 | | | | | 824 | 684 |
| Sarita | 2013 | | | | | 4,220 | 1,171 |

[a] Peak count

[b] Did not meet CTC standard for accuracy (<7 recaptures)

Individual encounter histories from all live encounters were assembled and tested with CloseTest (Stanley and Burnham 2005) to determine if an open population model or a closed population model was the appropriate starting model. CloseTest demonstrated additions and/or losses occurred in each year from 2009-2013 for the population in the stopover pool. In 2011, more than 50% of the fish had arrived shortly after the start of the sampling and there was no significant recruitment into the stopover study area later (Table 3.10), although losses occurred.

For the closed-population traditional MR study, annual population size was estimated independently for each sex with Chapman's modification of Peterson's model or with the maximum likelihood (ML) version of Darroch's model based on stratification by sampling date (Seber 1982) (Table 3.9, columns labeled Traditional MR). Estimates by sex were summed to produce a single estimate for adults. The program SPAS by Arnason et al. (1996) was used to check/correct calculations to meet the conditions for consistent (asymptotically unbiased) estimates. Data collected at the stopover pool and on the spawning grounds were used in calculations. A SSP-funded radiotelemetry study in 2012 (see below) indicated that 105 of 108 fish caught in the stopover pool and fitted with radio transmitters subsequently spawned in the Burman River. Three of the 105 radio-tagged fish spawned upstream of the area surveyed annually by CDFO in their standard stock assessment. The number of brood stock removed from the river by hatchery staff was subtracted from the estimates of escapement to estimate spawning abundance

For the open-population MR study, annual population size was estimated with the POPAN computer program (Schwarz and Arnason 1996) for the Jolly-Seber maximum likelihood formulation in Program MARK (White and Burnham 1999); only data collected at the stopover pool were used in these calculations (Table 3.9, columns labeled Open MR). Group capture, entry probabilities, and apparent emigration rates were modeled with time and group effects. After identifying the best starting models following the consistency tests, the best model(s) and associated population estimates were selected that had the lowest AIC (Akaike Information Criterion). The number of brood stock removed from the river by hatchery staff was subtracted from the open population estimate of escapement to estimate spawning abundance. Emigration rates and capture probabilities were assessed with RELEASE (Burnham et al. 1987), and U-CARE (Choquet et al. 2009) was used to assess and correct for effects of any capture-induced behaviour.

While diagnostic tests for the open-population MR studies showed their estimates of spawning abundance to be consistent (asymptotically unbiased), independent information showed that at least one of these estimates to be biased low. From Table 3.9 the open MR estimate for the entire year 2013 is 5,455 with a lognormal 95% CI of 4,650 to 6,416.  On September 25 of that year a CDFO survey crew estimated 6,319 Chinook salmon on the spawning grounds—a number unadjusted for OE. The survey estimate was within the 95% CI, but near the upper limit.

The cause of the apparent inaccuracy of the open-population MR estimate in 2013 was arguably the five-day hiatus in sampling that included rising waters (Figure 3.10). The hiatus provided the opportunity and rising waters the impetus for salmon to speed through the pool and onto the spawning grounds. The open-population model used on the Burman stock contained a correction for fish moving through the pool between sampling dates, yet the correction may have been insufficient. Recapture percentages on the sampling day preceding (September 19) and the day following the hiatus (September 25) are consistent with an influx of migrants through the stopover pool during the hiatus (Figure 3.10). The much higher marked percentage of fish in the stopover pool in general (16%) than over the spawning grounds (9%) (Figure 3.10) is further evidence that some migrants in 2013 were not represented in the open-population MR estimate. Because the closed-population MR estimator is based on sampling in the pool and on carcasses over the spawning grounds, the closed-population MR estimate would represent all migration. The relative stability of recapture percentages in carcasses across sampling dates was evidence in support of this conclusion (Figure 3.10).

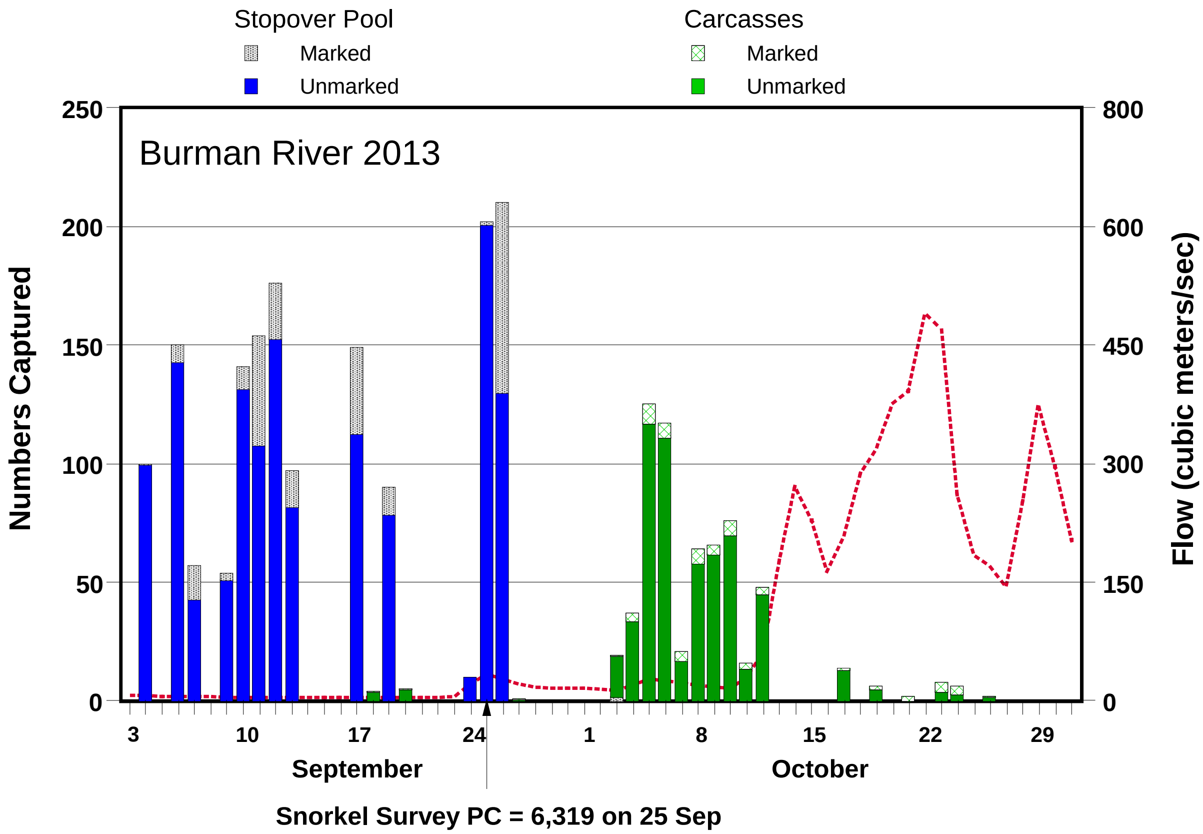



**Figure 3.10**–Numbers of live Chinook salmon captured in the downstream stopover pool, numbers of carcasses sampled on spawning grounds upstream, and probable flows for the lower Burman River in 2013. Flows were measured at gauging station 08HC001 on the Gold River approximately 10 km distant from the Burman River. Snorkel Survey PC is from a CDFO survey over the spawning grounds.

Although independent information from other years is not so instructive as information from 2013, some amount of bias is suspected in the open-population MR estimates for other years as well. Unbiased estimates from open-population MR estimators require marked and unmarked fish have the same capture probabilities (Seber 1982). That's likely not so for sampling in the stopover pool because handled Chinook salmon tend to delay their upstream migration upon release (Bernard et al. 1999; Burke et al. 2004, Keefer et al. 2004, Fryer et al. 2013, and § 3.2.3 in this report). Such delay would keep marked fish in the stopover pool and subject them to capture longer than unmarked fish. The result would be an underestimate of immigration and subsequently an underestimate of spawning abundance (Schwarz et al. 1993, see their simulation 5). The closed-population MR estimates are essentially unaffected by handling-induced behavior in the stopover pool because sampling recapture rates were determined from inspection of carcasses over the spawning grounds. Transient migration (see § 2.1) is another potential source of bias in open-population MR methods, which can be evident by fish that are captured only once. In anticipation of transient migration and handling effects such as delayed migration or seine net avoidance, the open population MR model used the time-elapsed-since-marking model.

Inspection of otoliths from carcasses in the Burman River showed that most spawners were of hatchery origin. Eggs are taken annually from the stock, hatched at Conuma Hatchery, and then reared in net pens near the mouth of the Burman River. Annually 271 to 348 carcasses were dissected and of these 64 to 97% were reared in net pens near the river mouth, 0 to 29% were strays from other hatcheries, and 3 to 7% were of natural origin. Combining the precise estimates of origin from otoliths with the MR estimates of escapement produced estimates of the natural origin Burman River spawners, in the range of a few hundred fish from 2009 to 2013.

Radiotelemetry was used in 2012 to assess emigration from the pool in the lower Burman River, to estimate survey life (SL) of individual salmon (Table 3.7), to estimate OE on the spawning grounds (Table 3.8), and to detect unsurveyed spawning grounds (Figure 3.9). Fish were caught in the downstream pool, fitted with external transmitters with dead switches, and then released. Radio-tagged fish were located subsequently with stationary recorders and mobile antenna. Three of these fish were never seen again and emigration was judged relatively minor. Whether the losses were due to emigration, mortality, tag malfunction or tag loss is unknown. Three of the 105 radio-tagged fish that entered the spawning area ascended the traditional spawner survey area, demonstrating unsurveyed spawning grounds. Radio-tagged fish remained in the stopover pool for an average of 11.2 days (SD = 9.6) before migrating upstream to the spawning after passing the stationary antennae array. No tagged fish passed permanently downstream of the pool during the study indicating closure of the population in the pool to permanent emigration downstream. Estimated SL from radio tagged fish was 5.0 d (SD = 3.1) and OE for those same fish ranged from 0 to 100% among 21 survey dates (on average 53%, SD = 39%).

Estimates of Chinook salmon spawning in the Burman River from SSP-funded closed-population, traditional MR studies were higher than estimates from agency AUC methods reported in CTC (2015) in all years of SSP funding except 2013 (Table 3.9). Agency estimates were based on subjective (self-assessed) values for SL and OE and from 6–8 survey dates annually. The SSP-funded AUC estimate in 2012 based on SL ad OE values estimated with radiotelemetry and 21 survey dates. Expansion of AUC calculations with these independently estimated values of SL and OE was within a few fish of the MR estimate for that year (4,282 vs. 4,273). The AUC estimate reported in CTC (2014) for that year was considerably lower (1,003) arguably due to the use of self-assessed values for SL and for OE, and to less frequent survey dates. Self-assessed OE values used in CDFO assessments from 2009-2013 were rarely less than 80% and were usually 90% to 100% for the Burman stock; OE estimates from radiotelemetry in all studied stocks in WCVI averaged 53% (Table 3.8) and never reached 80%.

In summary, the SSP-funded studies on the Burman stock have provided:

- accurate estimates of spawning abundance for five years, four of which also meet the CTC precision standard;
- evidence that estimates of spawning abundance calculated from the traditional AUC method based on self-assessed SL and OE employed by CDFO generally are underestimates of spawning abundance;
- evidence that AUC methods can produce unbiased estimates when parameters SL and OE have been quantitatively estimated, and when survey dates are frequent (a count every, or every other day);
- evidence that open-population MR models can produce significantly biased estimates of spawning abundance while appearing to produce consistent estimates; and,
- evidence that annual escapements to the Burman River are largely hatchery-origin fish.

### 3.3.2 *Kaouk River*

The Kaouk River (Figure 3.8) has been surveyed annually as one of six escapement indicator stocks used by the CTC and CDFO (CDFO 2012, CTC 2015). The traditional AUC escapement estimates ranged from 110 (in 2000) to 820 (in 1998) with the ten year (2001-2010) average being 350 fish. From 2009-2011, assumed SL was 20 or 25 days and self-assessed (subjective) OEs ranged from 79 to 100%.

With SSP funding, CDFO and Nuu-chah-nulth Tribal Council (NTC) operated a floating weir in 2009 to count passing Chinook salmon as an estimate of escapement. Because freshets are common to the Kaouk River, a coincident back-up MR study was planned in case the weir became inoperable. The weir did become inoperable due to freshets on three occasions—September 9, 18 and October 17. Unfortunately, only 13 fish had been captured below the weir and marked (marked fish were fitted with radio tags). Five of these radio-tagged fish were detected upstream of the weir site having passed during weir-topping freshets; records suggest that these fish moved upstream during the flooding events of September 18 and October 17. Three tags were detected on dead fish downstream of the weir, and five tags were never detected in the system. Swim survey counts suggest that peak escapement may have occurred after the second flooding/topping event on September 18; 427 adult Chinook salmon were counted above the weir site on September 24. Information was judged insufficient to produce a scientifically defensible estimate from weir or MR data collected in 2009.

In 2010 the SSP funded a traditional MR study proposed by M. C. Wright and Associates (Nanaimo, BC) and CDFO which resulted in an estimate of escapement of 150 Chinook salmon (CV = 27%). In anticipation of difficulties capturing fish in-river, fish were caught in the estuary with commercial gillnets and by recreational trolling from August 30 through September 10. Fish captured and judged to be in good shape were fitted with radio transmitters, tagged, and marked. Of the 87 salmon so marked, 22 entered the Kaouk River and became the marked population for the study. Of the 65 other marked fish, 5 were detected in the nearby Kauwinch River, 3 in the Tahsish River, 1 in the Leiner River, and 1 in the Conuma River, and 55 not at all.  Inside the Kaouk River 45 live fish were captured using a large beach seine; 6 were recaptures. Of five carcasses collected, otoliths were recoverable from three, and all were of wild origin (Sarga et al. 2011). A closed-population, two-sample Peterson model was used to estimate abundance of fish in the lower river using only seined fish as the second event. Diagnostic tests indicated the CTC accuracy standard had probably not been met (too few recaptures), and the estimated CV exceeded the CTC precision standard. However, the resulting estimate is consistent with the judgment that the Kaouk River annually has a small population of spawners.

In 2011 the SSP funded a MR study proposed by the Ka:'yu:'k't'h'/Che:k:tles7et'h' First Nations (KCFN) and LGL Limited (LGL) (Smith et al. 2012) which unfortunately did not produce an estimate of spawning abundance for the Kaouk River using MR methods. An AUC estimate of 256 fish (95% CI 223 to 288 fish) was generated using a parametric bootstrap model. The AUC estimate was based on a mean SL of 18.0 d estimated with information from radiotelemetry, and a self-assessed OE of 85% (Smith et al. 2012). From August 31 to October 6, 2011, 26 beach seine sets and 14 tangle net sets at five different sites from rkm 4 – 10 resulted in 66 Chinook salmon marked (63 with radio tags). Four (6.5%) of the 62 radio-tagged fish were detected subsequently upstream at locations outside of the traditional survey area—two upstream of marker 17 in the mainstem Kaouk River and two in Rowland Creek. However, attempts to recapture these or any other marked fish proved unsuccessful. Temporal and spatial overlap of the mark and recovery events, the inability to sample fish in September and October due to high water levels, and the presence of a large number of co-migrating coho (*O. kisutch*) and chum salmon are likely reasons for this failure.

In summary, the SSP-funded studies on the Kaouk stock have provided evidence that

- frequent freshets and presence of salmon other than Chinook salmon are likely to compromise assessment on the Kaouk River with weirs, AUC methods, and MR studies;
- annual escapements to the Kaouk River are likely relatively small (hundreds, not thousands),
- fitting Chinook salmon caught in the Kaouk River estuary with radio tags is not a cost-effective way to yield sufficient numbers of tagged fish in the river for a MR study; and
- some spawning occurred outside the area covered in the traditional CDFO assessment.

### 3.3.3 *Moyeha River*

The Moyeha River (Figure 3.8) was chosen for study because:

- its habitat is pristine;
- its Chinook salmon stock has not been enhanced;
- its Chinook salmon stock belongs to the 14-stock WCVI escapement ‘index’ and therefore has a time series of escapement records.

Estimates of spawning abundance have averaged 130 with a maximum of 362 between 2000 and 2009. These estimates are a mix of unexpanded PCs and AUC escapement estimates (§ 2.5).

As small stock size proved to be a problem with assessment of the Kaouk stock, so it was with assessments in the Moyeha River. In 2010 the SSP funded a MR study. Twenty four salmon were captured in seines, marked and released, and 11 carcasses were later inspected, none of which had been marked. Inspection of otoliths ostensibly from these 11 carcasses found 6 were hatchery strays from Conuma Hatchery in Nootka Sound and the others were naturally produced fish. However, this finding might have been the result of confusion of the origin of some samples by CDFO. In 2011 the SSP funded a small feasibility study on capturing Chinook salmon in the Moyeha River with angling gear; however, no Chinook salmon were captured.

Despite the failure to produce an abundance estimate, or to find a more effective sampling gear, the SSP-funded projects on the Moyeha River did provide:

- additional evidence as to the difficulty of applying MR methods to small populations of Chinook salmon on WCVI; and
- additional evidence that the spawning population in the Moyeha River is small (hundreds, not thousands).

### 3.3.4 *Marble River*

The Marble River (Figure 3.11) has also been surveyed annually as one of six escapement indicator stocks used by the CTC and CDFO (CDFO 2012, CTC 2015). Judging from PCs during these surveys, Marble River has had Chinook salmon escapements in the thousands. As such the SSP-funded studies by CDFO in 2012 and 2013 were not to estimate abundance, but to estimate parameters used in the AUC expansion method of assessment (§ 2.5). Radiotelemetry was used in both years to estimate SLand OE.

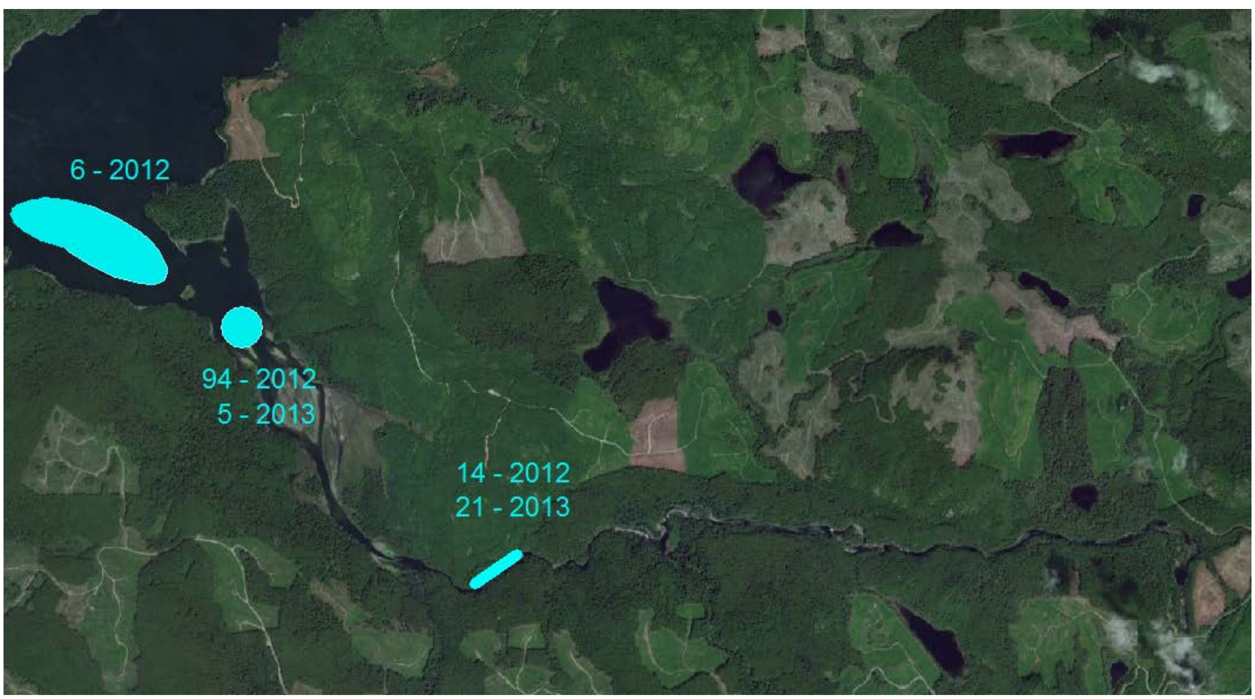



**Figure 3.11**–Varney Inlet and the Marble River in WCVI with locations where Chinook salmon were captured in 2012 and 2013, fitted with radio tags, and released (n=140).

In 2012, 114 Chinook salmon were radio tagged in Varney Bay and 14 at the mouth of the Marble River, 28 of which (21%) were later detected in the Marble River. Malfunctioning motion sensors in many radio tags compromised the ability to detect death. Subsequent review of tag position and signal strength over time allowed a determination of when individual fish most likely died. Resulting estimates of SL from those test subjects with relatively certain dates of death had a mean of 27.4 d (SD = 14, n = 10) (Table 3.7). This mean estimate was within the range of values used for traditional AUC assessments by CDFO (20 to 35 d), but less than the 30 d value used for 2012. Unlike estimating SL with radio tags, estimating SL in traditional surveys was based not on detection of death, but on the last day of visual detection of a batch-marked salmon (depletion curves, see § 2.5). Estimated OE from radio tags ranged from 13% to 100% across swims, typically lower than the self-assessed, subjective OE estimates used in the traditional assessment for 2012 (88 to 100%) (from Table 3.8 average observer efficiency estimated from radio-tagged salmon is 54%). The AUC estimate of spawning abundance (2,509) using estimated SL and estimated OE was slightly greater than the estimate with self-assessed parameter values (2,364). Approximately 11% of the escapement was comprised of fish that originated from Marble River Hatchery based on analysis of 294 otolith samples; no other hatchery stocks were detected.

In 2013, the AUC estimate of spawning abundance using estimated SL and OE from the SSP-funded study (2,240) was again slightly greater than the estimate from the traditional AUC method (2,080) with self-assessed parameter values. Seventeen days of fishing near the entrance to the Marble River and five in-river tagging sessions resulted in 26 radio-tagged salmon. About 77% (20) of these fish were later detected in the Marble River. The majority of tags were not applied until after mid-October due to very low numbers of Chinook salmon in the river throughout September and due to unsafe water levels in early October. Estimated OE ranged from 27% to 100% across swims and averaged 54% for the year (Table 3.8), while self-assessed OE that year ranged from 44 to 100%. Survey life was estimated at 35 d (SD = 9d, n = 12) (Table 3.7); the self-assessed value was 30 d. Chinook salmon abundance was similar and migration was delayed when compared to the previous year. Adverse river conditions led to only two otolith samples being collected in 2013.

Results from both years of study on the Marble River provide evidence that:

- self-assessed estimates of OE tend to be overestimates;
- AUC estimates for the Marble River stock based on self-assessed parameter values were similar to AUC estimates by CDFO based on estimated SL and OE (within 10%); and,
- capturing Chinook salmon in Varney Bay and the Marble River estuary is not a cost-effective means of obtaining test subjects for measuring OE.

### 3.3.5 *Leiner and Tahsis Rivers*

The Leiner and Tahsis rivers flow into Nootka Sound (Figure 3.12) at the head of Tahsis Inlet. Both rivers have been annually surveyed with the stock in the Tahsis River being one of six escapement indicator stocks used by the CTC and CDFO (CDFO 2012; CTC 2015). The SSP funded a project in 2012 to

- generate a mark-resight estimate of escapement to each river;
- estimate SL of Chinook salmon entering the surveyed spawning grounds; and
- estimate OE of swimmers counting fish as a means to improve traditional AUC estimates of spawner abundance.

A mark-resight study is similar to a MR study (§ 2.1) except the marked fraction of the population during the second sampling event is determined by sight at a distance during a swim in a snorkel survey, not through a physical handling of fish. Also, individual biological data are not available for tagged and untagged fish to examine for sampling bias and potential effects of such biases on the estimate of abundance. Because of conditions on both rivers in 2012, no mark-resight estimate was calculated.

Chinook salmon were radio-tagged during fishing at the head of Tahsis Inlet and marked with highly visible external spaghetti tags. River discharge and visibility data were collected to examine possible relationships between survey conditions and OE. Fixed station telemetry receivers were installed at the lower and upper extents of the surveyed spawning grounds of both rivers, and fish were also located with mobile receivers throughout the spawning period. Of the 269 Chinook salmon fitted with transmitters and released, 75 (27%) were later detected in the Leiner or Tahsis rivers. Unfortunately, motion sensors included with radio tags malfunctioned, compromising the ability to detect death. Based on position and signal strength of tags over time, a determination was made when some fish had most likely died.

The CDFO conducted 12 snorkel surveys over spawning grounds on the Leiner River and 6 over spawning grounds on the Tahsis River in 2012. The maximum number of Chinook salmon observed was 347 on the Leiner River and 109 on the Tahsis River. Crews were unable to survey for 12 to 18 days in mid to late October due to high flows on both rivers that coincided with the probable peak in migrations.

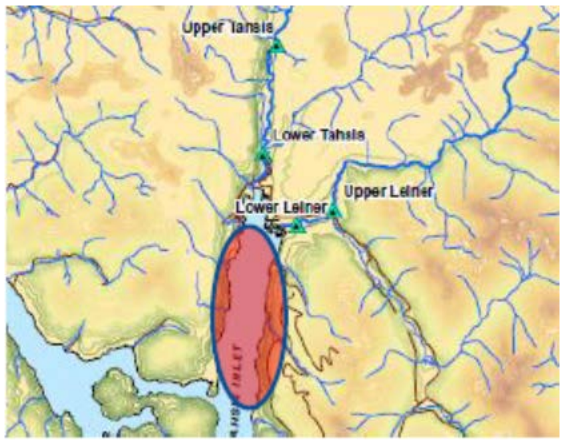



**Figure 3.12**–Tahsis Inlet and the Tahsis and the Leiner rivers in WCVI with locations where Chinook salmon were captured in 2012, fitted with radio tags, and released.

Estimated mean SL of Chinook salmon in the Leiner River was 28.8 days (SD = 14, n = 38) and 25.4 days (SD = 15, n = 10) in the Tahsis River based on radiotelemetry (Table 3.7). The traditional AUC method was applied to counts from both rivers in 2012 with an assumed stream life of 20 days. Under these circumstances the AUC estimate $\hat{E}$ based on self-assessed parameter values would tend to be greater than actual abundance ($\hat{E} > E$).

Estimated OE in 2012 was lower than self-assessed values used in AUC assessments by CDFO (e.g. 80-93% for 2012). Self-assessed OE for a swim was rarely less than 80% and was usually 90% to 100%. Observer efficiency estimated with the use of radiotelemetry averaged 32% on the Leiner River and 47% on the Tahsis River in 2012 (Table 3.8). Under these circumstances the AUC estimate $\hat{E}$ based on self-assessed parameter values would tend to be less than actual abundance ($\hat{E} < E$).

Estimates of spawning abundance from the AUC method appeared more sensitive to differences in values for OE than to differences in SL. In 2012, the AUC estimate of spawning abundance for the Leiner stock (566) based on self-assessed parameter values was less than the AUC estimate based on estimated values for SL and OE from the SSP-funded study (772) (Table 3.9). The same was true for the Tahsis stock that year (163 vs. 227 in Table 3.9).

Results from studies on the stocks in the Leiner and Tahsis rivers are that:

- self-assessed estimates of SL were under-estimates in 2012 for both the Leiner and the Tahsis stocks;
- self-assessed estimates of OE tended to be overestimates for both stocks in 2012; and
- capturing Chinook salmon in Tahsis Inlet is not a cost-effective means of obtaining test subjects for future in-river studies of Tahsis and Leiner stocks.

### 3.3.6 *Tranquil Creek*

Tranquil Creek was proposed for SSP-funding because it seemed amenable to assessment of spawning Chinook salmon with AUC methods. The creek is located in the south end of Clayoquot Sound (Figure 3.8), and flows into the head of Tranquil Inlet. The spawning area is 3.5 km long stretching downstream from an impassable falls to tidal influence. The small watershed (60 $km^2$) has clear waters with quick recovery of visibility after floods. The system has relatively good road access. Since 1995, escapement estimates from AUC methods using self-assessed parameter values (§ 2.5) have averaged about 750 Chinook salmon annually, but have not exceeded 250 recently.

The SSP funded a project on Tranquil Creek in 2013 to

- generate a mark-resight estimate of escapement,
- estimate SL of Chinook salmon entering the surveyed area of the creek; and
- estimate OE of swimmers counting fish.

Chinook salmon were captured just upstream of tidal influence, fitted with internal radio tags, and marked with external spaghetti tags. The PC of Chinook salmon observed during a swim survey was 432 (Figure 3.13), and the maximum number of fish with external spaghetti tags detected by the telemetry crew during a single survey was 17 fish. Based on radiotelemetry, the mean SL of Chinook salmon was estimated at 17.5 days (SD = 3.4 d) (Table 3.7) and the mean OE at 79% (range 29% to 100% across swims) (Table 3.8).

Four abundance estimates were generated for spawning Chinook salmon for the Tranquil stock in 2013 with the following methods:

- mark-resight (493);
- non-parametric AUC with self-assessed parameter values (684);
- non-parametric AUC with parameter values estimated with radiotelemetry (824); and
- parametric AUC with parameter values derived through maximum likelihood (ML) procedures (836).

Of these four estimates, the latter pair (824 and 836) were judged to be the most accurate estimates. Mark-resight estimates are prone to be under estimates ($\hat{E} < E$) because mark fish tend to be more detectable than unmarked fish at distance. Considering the regularity of the 11 swim surveys indicated in Figure 3.13, coverage should not have been a problem for any of the AUC methods. However, the AUC estimate based on self-assessed parameter values (SL = 20 d, OE = 100%) is probably also an underestimate, most likely due to optimistic self-assessed OEs. Similarity of abundance estimates from the non-parametric AUC method with independently estimated parameter values and the parametric AUC method (824 vs. 836) is further evidence

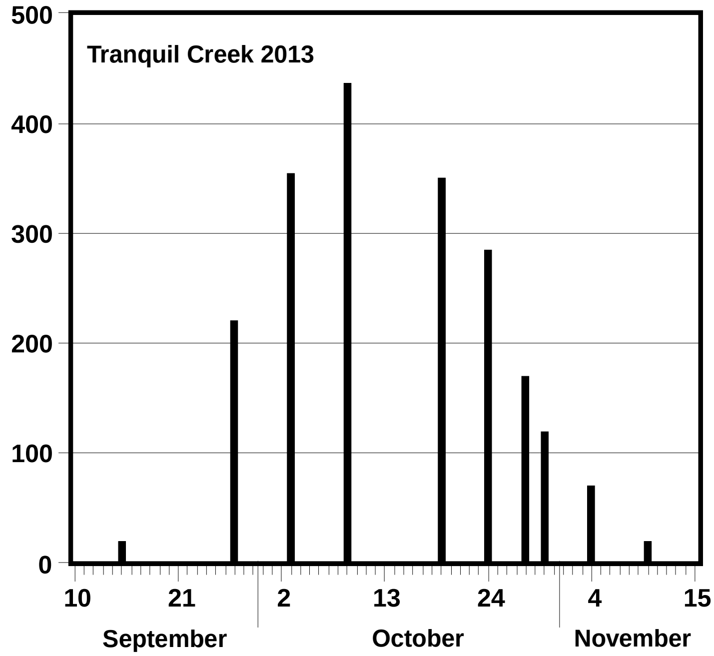



**Figure 3.13**–Counts of Chinook salmon in Tranquil Creek during swim surveys in 2013 over the spawning grounds.

that the estimate based on self-assessed parameter values (684) is biased low. The parametric AUC method is defined in more detail in § 3.3.9.

The SSP-funded study on Tranquil Creek in 2013 provided the following evidence:

- the agency abundance estimate based on self-assessed parameter values in an AUC expansion was low relative to other methods in 2013;
- the self-assessed estimates of OE tended to be overestimates;
- at least in this study, tagged test subjects probably had a higher probability of “re-sight” than did untagged subjects seen at a distance; and
- the ML abundance estimate from a parametric, unimodal run timing model was similar to the AUC estimate with parameter values estimated through radiotelemetry.

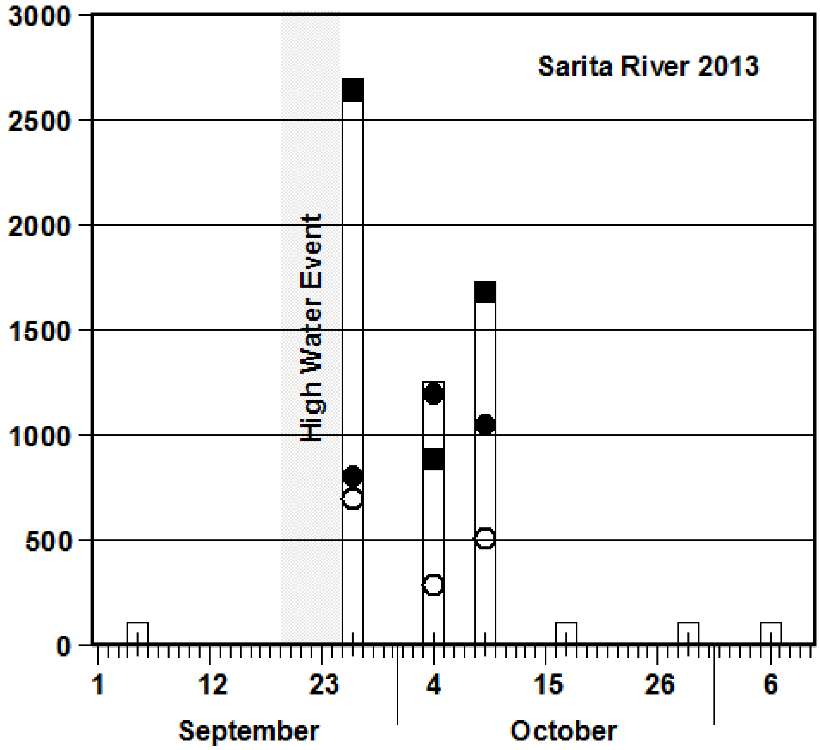



**Figure 3.14**–Raw and expanded counts of Chinook salmon from swim surveys over the spawning grounds in the Sarita River in 2013. Expanded counts are raw counts (❍) divided by OE as determined subjectively by swimmers (●) or determined with information from radiotelemetry (®).

### 3.3.7 *Sarita River*

The Sarita River on the south-east side of Barkley Sound (Figure 3.8) was chosen for the site of an SSP-funded project because, like Tranquil Creek, the physical nature of the river and expected salmon abundance seemed amenable to successful escapement estimation with AUC expansions. The watershed is small (190 $km^2$) with spawning grounds on the river that run from tidal influence upstream 6 km to an impassable falls. Survey conditions are usually favourable on the Sarita River. However, during flood events, this system takes longer to clear than other WCVI systems due to tannins flushed from an upstream lake. The river also has four fairly deep pools in the survey area (spawning grounds), the depth of which impairs visual counting of salmon. Unlike Tranquil Creek, large numbers of chum and coho salmon occur with spawning Chinook salmon. Since 1995 CDFO has estimated Chinook salmon abundance (~1,400) with AUC expansions (§ 2.5) of counts from snorkel surveys based on self-assessed parameter values for SL and OE. The SSP funded a project on the Sarita River in 2013 to

- generate a mark-resight estimate of escapement;
- estimate survey SL; and
- estimate OE of swimmers counting fish.

Chinook salmon were captured just above tidewater, fitted with radio tags, and marked with external spaghetti tags. The maximum number of Chinook salmon observed during a swim survey was 704 (Figure 3.14). A combination of high-water events and large numbers of co-migrating chum (~10,000) and coho salmon (~1,200) impaired resight efforts, and tags were only seen by swim crews on two subsequent swim surveys.

Coverage of swim surveys was poor due in part to a large freshet in mid-September (Figure 3.14). Of the 7 surveys conducted in 2013, substantial numbers of Chinook salmon were counted only during 3 with the largest count in the survey immediately following the freshet. This survey on September 26 also had the greatest discrepancy between self-assessed OE (83%) and estimated OE (27%) using information from radio tags.

Four estimates of spawning abundance were calculated with

- a parametric AUC expansion based on a bimodal model with SL estimated using ML methods to estimate SL with OE self-assessed (1,017);
- a non-parametric AUC expansion based on self-assessed values for SL and OE (1,171);
- a non-parametric AUC expansion based on values for SL and OE estimated through radiotelemetry (4,220); and
- a mark-resight method (4,776).

Self-assessed SL used in the non-parametric AUC expansion was 20 d while SL estimated through radiotelemetry was (17.2 d) (Table 3.7). Average OE estimated with radio tags was 17% (Table 3.8). The poor performance of the bimodal, parametric AUC expansion was arguably due in no small part to the poor coverage by surveys (effectively only three). This poor coverage probably affected estimates from the non-parametric AUC expansions as well, but this effect was arguably less than the effect of grossly overestimating OE in the expansion based on self-assessed parameter values (1,171 vs. 4,220). Poor coverage of swim surveys over the spawning grounds is not a critical issue for getting an unbiased estimate using the mark-resight method—all that is needed is that marked and unmarked Chinook salmon have the same probability of being seen on the spawning grounds and the marked portion is similar across surveys.

Otolith samples have been collected from Chinook salmon in the Sarita River from 2009–2014. In 2013 the SSP-funded project sampled 274 carcasses of which 79% were hatchery origin. Most of the hatchery fish (82%) were from direct supplementation of the Sarita River, the remainder was strays from other hatcheries (mostly Nitinat). In other years when otolith samples have been collected from Sarita River, hatchery origin fish have contributed between 78 and 91% of the spawning population.

Of the four estimates of spawner abundance listed above, the non-parametric AUC expansion based on independent estimates of SL and OE was considered the most accurate. On that basis, this SSP-funded study on the Sarita River in 2013 provided the following results:

- poor coverage of spawning ground surveys in the Sarita River in 2013 compromised abundance estimates from all AUC expansions;
- evidence that self-assessed estimates of OE tend to be overestimates that subsequently lead to underestimating abundance with AUC expansions;
- evidence that substantially more Chinook salmon spawned in the Sarita River in 2013 than estimated with standard AUC methods of assessment;
- that most of the salmon that escaped to spawn in Sarita River in 2013 were of hatchery origin; and
- evidence that the ML, bimodal AUC model failed to provide an accurate estimate.

### 3.3.8 *Conuma River*

The Conuma River is short and flows into Moutcha Bay of Nootka Sound along the west central coast of Vancouver Island (Figure 3.8). Spawning abundance is unusually high because the spawning grounds represent the terminal area for releases from the Conuma Hatchery. The river is easily accessible and conducive to escapement estimation with both MR and AUC methods. The agency (CDFO) estimates spawning abundance with non-parametric AUC expansions based on salmon counts from swimmers (§ 2.5).

The SSP funded a project on the Conuma River in 2014 to estimate

- survey life (SL) of Chinook salmon entering the spawning grounds;
- observer efficiency (OE) of swimmers counting fish over the spawning grounds as a means to improve AUC estimates of spawner abundance; and
- spawning abundance with a MR study.

The Conuma River stock presented an opportunity to observe the effect of large abundance on AUC expansions. With few exceptions, all other sentinel stocks on WCVI had escapements in the few hundreds or a few thousands (Table 3.9). The SSP project was awarded to the Nuu-chah-nulth Tribal Council (NTC) and the Uu-a-thluk fisheries program (Dunlop 2015).

Radiotelemetry was used to estimate SL and OE over the spawning grounds. Just over a thousand Chinook salmon (1,008) were captured in a large pool sandwiched between tidewater and the spawning grounds (Figure 3.15), and 73 were released with radio tags of which 68 passed the lower river receiver station and entered the spawning area. Only one of the 68 went on to pass the upper telemetry station at the upstream limit of the snorkelling area. Survey life (SL) for these tagged fish was relatively short at 5.3 d (SD = 4.9 d, n = 62) (Table 3.7), and OE relatively low on average at 31% (SD = 41%, n = 22) over a range of 4%–100% (Tables 3.8, 3.10).


**Figure 3.15**–Conuma River showing the tagging site and study area (between the pins) used in the SSP-funded study in 2014.

**Table 3.10**–Daily counts of Chinook salmon by two, independent swim survey crews (NTC and CDFO) in the Conuma River, 2014 along with information from radio tags and OE.

| Swim Survey Date | NTC (SSP-funded) | | | | CDFO Raw Counts |
|---|---|---|---|---|---|
| | Raw Counts | Tags Present | Tags Detected | Estimated OE | |
| Sep. 3 | 0 | 0 | | | Not surveyed |
| Sep. 13 | 19 | 0 | | | Not surveyed |
| Sep. 17 | 22 | 0 | | | 22 |
| Sep. 25 | 1,326 | 21 | 2 | 9.5% | Not surveyed |
| Sep. 26 | 6,194 | 43 | 2 | 4.6% | Not surveyed |
| Sep. 27 | 5,408 | 42 | 9 | 21.4% | Not surveyed |
| Sep. 28 | Not surveyed | | | | 21,700 |
| Sep. 29 | 5,685 | 28 | 1 | 3.6% | Not surveyed |
| Sep. 30 | 2,847 | 28 | 4 | 14.3% | Not surveyed |
| Oct. 2 | 3,949 | 7 | 7 | 100% | Not surveyed |
| Oct. 7 | 745 | 4 | 0 | 0% | 2,685 |
| Oct. 15 | 25 | 0 | | | Not surveyed |
| Nov. 7 | Not Surveyed | | | | 0 |

Among the 1,008 Chinook salmon marked in the holding pool, 87 of them were recovered among 1,512 in carcasses (Figure 3.15). The hatchery program removed several hundred fish from the river for hatchery production purposes and these fish were held in a pool to ripen for spawning. Unfortunately bears ate the first 450 fish from unprotected hatchery ponds before tags could be recorded and counted, thus a closed-population estimator required the removal of 450 fish from the calculated estimate.

The study provided insights about challenges with counting salmon under high density conditions. The combination of a relatively large population of Chinook and other salmon species (~25,000 salmon) in a small length of river (1.5 km) results in high fish densities. It can be difficult to count individual adult Chinook under high salmon densities because large numbers of salmon migrate quickly around the swim surveyors and the closest fish obscure the more distant fish. This leads to under estimating true OE. For example, the September 29 count of adult Chinook (5,685; Table 3.10) had an estimated OE that day of 4%, which results in an extremely unrealistic expanded count of nearly 160 thousand Chinook salmon. Accordingly, an AUC estimate of Chinook escapement was not developed using the radiotelemetry data.

In addition, the study provided insights about challenges with counting salmon when swim survey crews differ in their experience levels. In 2014, two independent crews, both experienced with conducting the traditional swim surveys, recorded counts that differed by 3.1 fold on October 7 and the counts differed by 3.8 fold between September 28 and 29 (Table 3.10). Furthermore, the count of 21,700 on September 28 included jacks and adults because surveyors had great difficulty separating jacks in such large schools of salmon. The high number of jacks (~25%) aligned with beach seine data during hatchery brood stock collection, although beach seines are size selective for small fish (i.e. jacks). Due to flooding in October a traditional AUC estimate was not possible because only two surveys were conducted by the CDFO contractor. Thus, the traditional estimate of adult escapement for 2014 (15,000) was based on professional judgement from hatchery staff.

As for the Burman stock (§ 3.3.1) two mark-recapture estimates were generated based on an open-population MR estimator (9,417; CV = 16%) and a closed-population estimator (16,242; CV = 10%). Sampling in the Conuma River occurred in a pool just above tidewater and on the spawning grounds just upstream (Figure 3.15). The open-population MR estimate was based solely on sampling in the pool while the closed-population MR estimate was based on sampling in the pool and over the spawning grounds. Types of data collected and diagnostic tests were the same as those taken the Burman studies. Both estimates were not adjusted for removals of brood stock for the Conuma Hatchery.

Although an early 7-day hiatus in sampling at the pool (Figure 3.16) provided opportunity for such migration, the similarity in percentages of marked fish sampled from the pool and from carcasses (both 6%) is evidence against unrepresented migration. The similarity in marked percentages is also evidence against handling-induced delay in migration. The SSP-funded study on the Conuma River in 2014 provided the following results:

- evidence consistent with the hypothesis that OE is somewhat depensatory (efficiency declines with greater abundance); and
- evidence that high salmon densities create challenging conditions to obtain counts of adult Chinook salmon.

### 3.3.9 *WCVI Stock Assessment Framework*

When the SSP began, there was a proposal to assemble existing escapement and habitat data to inform development of an improved assessment framework for WCVI Chinook salmon. The idea was to review existing data, methods, survey systems, and survey conditions through a scientific workshop, so as to identify key assessment gaps and provide recommendations for improved study design generally, and also to formulate specific studies under the SSP. This proposal was initially rejected, but was modified and subsequently funded in 2012 due to largely, but not entirely, unsuccessful attempts at implementing MR and mark-re-sight studies on WCVI populations with small escapements. The revised proposal had similar general objectives as the original proposal. That is, to review and revise statistical objectives of WCVI escapement surveys in light of current management needs and to provide recommendations to improve estimates and the overall program.

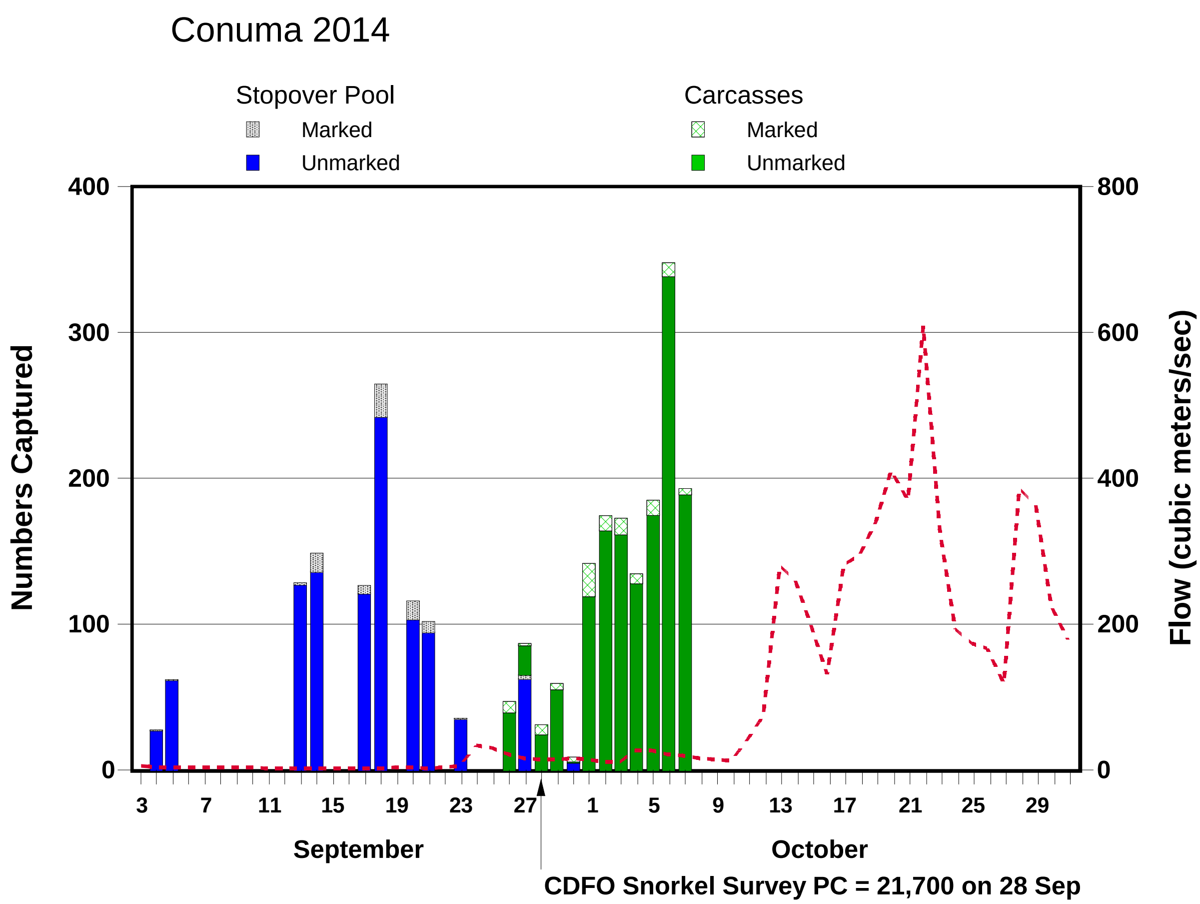



**Figure 3.16**–Numbers of live Chinook salmon captured in the downstream stopover pool, numbers of carcasses sampled on spawning grounds upstream, and probable flows for the lower Conuma River in 2014. Flows were measured at gauging station 08HC001 on the Gold River a few km distant from the Conuma River. Snorkel Survey PC is from a CDFO survey over the spawning grounds.

Similar to the initial proposal, the approach included review of data and programs through a scientific workshop. However, the review benefitted from results and insights from the WCVI SSP projects that had already been implemented. The SSP provided funds for the workshop as its direct contribution to development of the assessment framework. That workshop was held from June 18-20, 2013 in Nanaimo, BC. The workshop topics were:

- review the methodology and data currently used to estimate escapement of individual WCVI indicator stocks using periodic visual survey data (non-parametric AUC expansions, see § 2.5);
- an alternative method using a parametric AUC expansion based on a maximum likelihood (ML) approach using run timing models; and
- methods for estimating the terminal run size for the WCVI aggregate stock.

Several sources of uncertainty and bias in current methodology and data were identified, notably uncertainty arising from estimating OE and SL, uncertainty from the frequency of surveys, from missed surveys, and from when surveys missed the temporal peak of abundance. Sensitivity of abundance estimates to these uncertainties was discussed, especially sensitivity to uncertainty in estimates of OE and SL. Surveys missed due to freshets are a fact of life along the WCVI, and if frequent, can cause failure in stock assessment. In contrast, uncertainty in parameter estimates for OE and SL can be controlled, but currently only with the added, and sometimes prohibitive cost of radiotelemetry. Correlations between SL and/or OE with environmental variables (i.e., see § 4.3) will decrease uncertainty in these two crucial parameter estimates and increase repeatability in the AUC method.

The attraction of the alternative method of estimating abundance with a parametric AUC expansion based on run timing models was that OE and SL could possibly be estimated from survey counts alone. If so, there would be no need for independent parameter estimates, nor the associated cost of getting them. Although the method does not require direct estimation of the OE and SL parameters, an *a priori* assumption of arrival and departure timing of spawners is required. The uncertainty associated with this assumption creates a potential source of bias, particularly as timing varies from year to year.

Three methods to estimate terminal run size for WCVI Chinook salmon stocks in aggregate were presented, and their qualities and costs debated at the workshop:

**Expansion Across Streams**. Streams on the WCVI would be selected randomly, an AUC expansion of counts from multiple surveys would be used to estimate spawning abundance in each stream, then the spawning abundance would be expanded for the streams not sampled. Method is currently used in Canada on coho salmon.

**Expansion Across Habitats**. Streams segments in WCVI would be stratified by habitat type, segments would be selected for sampling within each habitat stratum, abundance in each randomly selected segment would be estimated with an AUC expansion of counts from multiple surveys, abundance estimates would be expanded for segments not sampled within each habitat stratum, and then summed across strata. This method is currently used by ODFW—their Generalized Random Tessellation Stratified design—to estimate abundance of spawning coho salmon.

**Driver Stock (Ratio) Method**. This is the DSR method described in § 2.4. Descriptions of its use can be found in §§ 3.2.1, 3.3.11, and 3.5.4.

The workshop proceedings and a Science Advisory Report were published that summarized the key conclusions and recommendations (CDFO 2014a, CDFO 2014b). Next steps for further development and improvement of CDFO's escapement monitoring program on WCVI were also recommended, and progress has been made on the following tasks:

- A report detailing available data from past surveys of WCVI Chinook salmon and on concomitant environmental variables; and
- Field and reporting protocols for visual surveys have been reviewed and modified based on recommendations from the Workshop.

As of the date of this report, the non-parametric AUC expansion of multiple survey counts remains the method most used by CDFO to estimate spawning abundance of Chinook salmon in WCVI streams. However, as described above, the field, reporting and analytical procedures have been updated in light of SSP study results.

### 3.3.10 *Insights from Radiotelemetry Studies on WCVI*

Radiotelemetry in SSP-funded studies on WCVI was used primarily to meet three objectives to estimate the

- average amount of time fish were alive over the spawning grounds (SL);
- fraction fish present counted by surveyors (OE); and
- proportion of a stock or population of Chinook salmon that entered a study area;

Use of radiotelemetry also provided evidence as to whether fish spawned outside surveyed areas in the Kaouk, Burman and Conuma rivers, but not in the Sarita, Tranquil, Tahsis, Leiner, or Marble rivers.

Among SSP-funded radiotelemetry studies, the average SL (16.4 d) varied considerably among the stream-year studies, ranging from 5.0 to 25.4 d (CV=42%) (see Table 3.7). The Burman and Conuma stocks had the shortest estimated SL while having the highest spawner densities, largely due to high numbers of hatchery-origin fish. Estimates of SL varied much less among the other stocks, with a mean of 19.6 d (CV=16%). In comparison, self-assessed SL values used in the AUC expansions by CDFO ranged from 10 to 30 d for the same locations and years. If OE is accurately estimated, overestimation of SL results in underestimates of spawning abundance (Ê < E), and underestimation results in overestimates (Ê > E).

Observer efficiency estimated with information from radiotelemetry was often less than the self-assessed values used by the agency. Among SSP-funded radiotelemetry studies, the average OE (45%) varied considerably across stream-years, ranging from 17 to 79% (CV=39%) (Table 3.8). In comparison, self-assessed OE efficiency ranged from 30 to 100% for the same locations and years. Overestimation of OE results in underestimation of spawning abundance, if the value of SL is accurate (Ê < E). Water clarity, river discharge and stage, abundance of Chinook salmon and other salmon, and the degree to which observers estimate fish numbers instead of counting fish can all affect OE.

While only those radio tags that reached the spawning grounds were used in SSP-funded studies to estimate SL and OE, quite a few radio tags deployed at sea were not detected (Table 3.11). Of the many undetected radio-tags applied to Chinook salmon during SSP studies in WCVI, there are four likely explanations:

- tagged fish died prior to entry into the study stream;
- fish lost their radio tag prior to entry into the study stream;
- tagged fish entered a river other than those being monitored; or
- the radio-tag malfunctioned prior to entry into the study stream.

**Table 3.11**–Summary of WCVI radio-tagging during SSP, and subsequent tag detection rates.

| Stream | Year | Location | Capture method | Radio tags type | Radio tags applied | Radio tags detected in study area | Percent detected |
|---|---|---|---|---|---|---|---|
| Marble | 2010 | River | Beach seine | Internal | 13 | 12 | 92% |
| Marble | 2011 | River | Beach seine | Internal | 5 | 4 | 80% |
| Marble | 2012 | Assumed Varney Bay | Troll and Gillnet | External | 128 | 19 | 15% |
| Marble | 2013 | Marine -Varney Bay | Troll | External | 5 | 1 | 20% |
| Marble | 2013 | River | Beach seine | External | 21 | 19 | 90% |
| Kaouk | 2009 | River | Beach seine | Internal | 13 | 5 | 38% |
| Kaouk | 2010 | Fair Harbour | Troll and Gillnet | Internal | 87 | 22 | 25% |
| Kaouk | 2011 | River | Beach seine | Internal | 63 | 62 | 98% |
| Tahsis/Liener | 2012 | Marine - Tahsis Inlet | Troll and Gillnet | External | 269 | 22 | 39% |
| Tahsis/Liener | 2012 | Marine - Tahsis Inlet | | | | 82 | |
| | | | | | total | 104 | |
| Liener | 2010 | River | Beach seine | Internal | 31 | 15 | 48% |
| Liener | 2011 | River | Beach seine | Internal | 25 | 21 | 84% |
| Burman | 2012 | River | Beach seine | External | 108 | 105 | 97% |
| Conuma | 2014 | River | Beach seine | External | 68 | 65 | 96% |
| Tranquil | 2010 | River | Beach seine | Internal | 29 | 16 | 55% |
| Tranquil | 2011 | River | Beach seine | Internal | 30 | 21 | 70% |
| Tranquil | 2012 | River | Beach seine | Internal | 25 | 22 | 88% |
| Tranquil | 2013 | River | Beach seine | Internal | 27 | 24 | 89% |
| Sarita | 2013 | River | Beach seine | External | 97 | 82 | 85% |

Chinook salmon are known to be sensitive to capture and handling in the marine environment, and reported release mortality rates vary among gear types and by the way that the fish were handled during capture and marking. Reported mortality rates vary from 15% for large Chinook salmon captured by recreational angling gear to 90% for release from gillnets (CTC 1997). Several of the SSP studies employed tangle nets or gillnets to capture fish, especially where hook and line methods failed to provide sufficient numbers of fish. Additionally, there is much debate on the impact of handling anadromous salmonids during re-acclimation to fresh water. During this period, salmon are under considerable stress as they alter their osmoregulatory functions in response to river entry. Baranski (1980) reported almost total mortality on Chinook salmon captured for hatchery broodstock by gillnetting during freshwater acclimation in the Skagit River, Washington. Baranski (1980) also reported very low mortalities (< 5%) in fully acclimated fish captured using the same gear near the spawning grounds, approximately one month after re-entry into freshwater.

Tag loss is an unlikely cause of the high rate of undetected tags applied at sea. In the WCVI studies, radio-tags were either externally secured using two Petersen tag pins backed by Petersen tags or were implanted into the esophagus of test subjects. Only recapture in nets would cause such a high loss rate in tags applied at sea, and no such evidence of recapture was found in estuarine sampling. Esophageal tags can be regurgitated; however, tags were inserted by experienced staff, and there is no evidence that such regurgitation occurred in fish tagged in freshwater.

Interception in the estuary of Chinook salmon not in the stock being studied is a more likely cause of the low rate of detection, but there is little evidence in support of this explanation. Surveys were conducted on other streams where and when feasible, however it was not possible to monitor the suite of streams that fish may have used. Further, it is not uncommon for salmon to enter the lower reaches of a river and then leave to subsequently enter another system to spawn. Should such fish have been captured and tagged in the system they entered initially, they would have been unlikely to be detected subsequently in other systems.

Tag failure is also unlikely as the cause of the low rate of detection. All tags were stored in an inactive mode, and activated immediately prior to application by removal of the magnet employed to de-activate the tag electronics. Upon application each tag was tapped gently several times to ensure activation. Additionally, tags were tested for emission of the appropriate signal prior to application to ensure tag function and that the individual frequency and code were recorded correctly. Tags that failed to activate or transmitted the wrong code at the wrong frequency were not used in the studies.

### 3.3.11 *WCVI Aggregate*

The DSR method was used to indirectly estimate terminal run size in aggregate for WCVI stocks by using a combination of harvest, genetic, age-length, otolith, and CWT information (see § 2.4 for a summary and Bernard et al. 2014 for details on the DSR method). Virtually all (90%–95%) of hatchery-origin Chinook salmon had thermally banded otoliths to distinguish them from fish of natural origin. Funding for the DSR project was provided by two sources: U.S. LOA (2011–2012) and the SSP (2013–2014). Seven SEAK fisheries were used in the application of the DSR method, including five troll and two sport fisheries (Figure 3.17). The northern outside (NO) troll quadrant was the location of four of these fisheries:

- spring commercial troll (SPR);
- first retention summer commercial troll (NO-1);
- second retention summer commercial troll (NO-2); and
- and the Sitka sport fishery (SIT).

The southern outside (SO) troll quadrant was the location of the other three fisheries:

- first retention summer commercial troll (SO-1);
- second retention summer commercial troll (SO-2); and
- the Craig sport fishery (CRG).

Because WCVI Chinook salmon are genetically distinct from all other stocks caught in these fisheries—in tests with samples of known origin taken from the GAPS data base, 97% of WCVI samples were correctly assigned (see Gilk-Baumer et al. 2013)—this aggregate stock is potentially a good candidate for the DSR method. Probability of misclassification of other stocks as the WCVI stocks has been estimated as less than 3% for all stocks in the GAPS baseline and less than 0.06% for any one stock. Because the probability of misclassification is so low with the WCVI aggregate, correction for misclassification was not included in calculations.

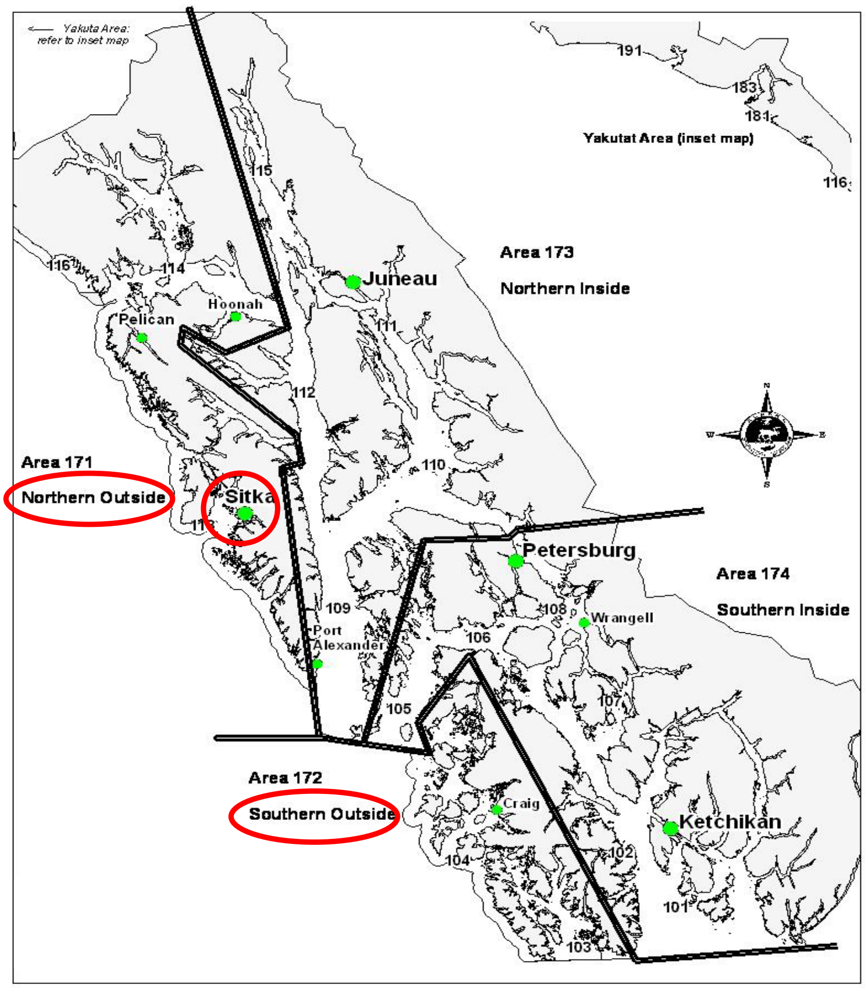



**Figure 3.17**–Locations of fishing grounds for commercial troll fisheries (Northern Outside, Southern Outside) and the home port for the Sitka sport fishery.

Age-specific estimates of terminal run size produced by the DSR method for WCVI fall Chinook salmon from both the U.S. LOA-funded and SSP-funded studies are given in Table 3.12. Hatchery-origin fish dominated the annual terminal runs (Figure 3.18), and accordingly the corresponding precision of their age-specific estimates was generally better (10% ≤ CVs ≤ 26% for ages 4–5 combined) than the precision of the natural-origin estimates (15% ≤ CVs ≤ 36% for the same age combination). Given the priority of the SSP to foster quality estimates for natural stocks, the estimates of most interest in Table 3.12 are those concerning terminal runs for the natural aggregate stock. The CTC precision standard of CV ≤ 15% was met only for the estimate of 26,249 age 4–5 fish in 2012. Note that natural-origin Chinook salmon are a subset of those Chinook salmon returning to terminal areas in WCVI.

Because size limits for retained catches in SEAK fisheries excluded most age 3 WCVI Chinook salmon from the landed catch, estimating terminal run size for this age class was problematic—estimates could be produced for 2013 and 2014, but not for 2011 and 2012. The reason can be seen in the frequency of recovering only one or no CWTs from a fishery (Table 3.13). Beside this problem with low catches of 3-year olds, the CWT fraction released from the Robertson Creek Hatchery (RBH) indicator stock has been relatively small (e.g. in calendar year 2010, the RBH releases with CWTs comprised approximately 2% of the overall hatchery production from WCVI). Bernard et al. (1998) demonstrated that precision of terminal run estimates from CWT data is directly related to the fraction of the cohort tagged.

**Table 3.12**–Estimated terminal run sizes of hatchery- and natural-origin Chinook salmon, their total, and a rough empirical approximation of that total for the WCVI Aggregate 2011–2014. Entries for Age 3s in 2011 and 2012 and Age 5s in 2011 are NA because one or fewer CWTS from the indicator stock were recovered from those cohorts in catch sampling SEAK fisheries in those years (see Table 3.13). Boxed cells represent statistics that met the CTC precision standard (CV ≤ 15%) on the natural-origin portion of the aggregate stock (1 of 8). Shaded cells contain statistics from SSP-funded studies.

| | | Hatchery | | Natural | | Total | | CTC |
|---|---|---|---|---|---|---|---|---|
| Year | Age | Point | CV | Point | CV | Point | CV | Total [a] |
| 2011 | 3 | NA | | NA | | NA | | 16,073 |
| | 4 | 61,831 | 10% | 14,064 | 18% | 75,895 | 8% | 139,226 |
| | 5 | NA | | NA | | NA | | 7,793[b] |
| | 3–5 | NA | | NA | | NA | | 163,092 |
| | 4–5 [c] | 61,831 | 10% | 14,064 | 18% | 75,895 | 8% | 147,019 |
| 2012 | 3 | NA | | NA | | NA | | 14,668 |
| | 4 | 43,684 | 18% | 19,831 | 19% | 63,515 | 13% | 38,165 |
| | 5 | 30,429 | 25% | 6,418 | 31% | 36,847 | 21% | 29,298 [b] |
| | 3–5 | NA | | NA | | NA | | 82,131 |
| | 4–5 | 74,113 | 13% | 26,249 | 15% | 100,362 | 10% | 67,463 |
| 2013 | 3 | 115,887 | 30% | 4,987 | 64% | 120,874 | 29% | 83,046 |
| | 4 | 81,735 | 29% | 4,944 | 38% | 86,679 | 27% | 74,962 |
| | 5 | 7,414 | 38% | 5,044 | 39% | 12,459 | 28% | 23.130 [b] |
| | 3–5 | 205,037 | 19% | 14,975 | 27% | 220,012 | 18% | 181,498 |
| | 4–5 | 89,150 | 26% | 9,988 | 26% | 99,137 | 24% | 98,092 |
| 2014 | 3 | 7,171 | 62% | 978 | 40% | 8,149 | 54% | 17,456 |
| | 4 | 74,279 | 16% | 1,919 | 49% | 76,198 | 16% | 92,350 |
| | 5 | 12,609 | 71% | 1,450 | 54% | 14,059 | 63% | 10.577 [b] |
| | 3–5 | 94,060 | 16% | 4,347 | 29% | 98,406 | 15% | 120,473 |
| | 4–5 | 86,888 | 16% | 3,369 | 36% | 90,257 | 16% | 102,927 |

[a] Statistics reported in CTC (2016a), Appendix Table J1 as annual post-season returns of hatchery and natural origin Chinook salmon.

[b] Ages 5 and 6 combined.

[c] Because no indicator CWTs from the Age 5 cohort were recovered in from SEAK fisheries and few from terminal areas for that indicator stock (18 expanded), the portion of the 2011 run comprised of Age 5 salmon was considered to be effectively zero for the purposes of summation.

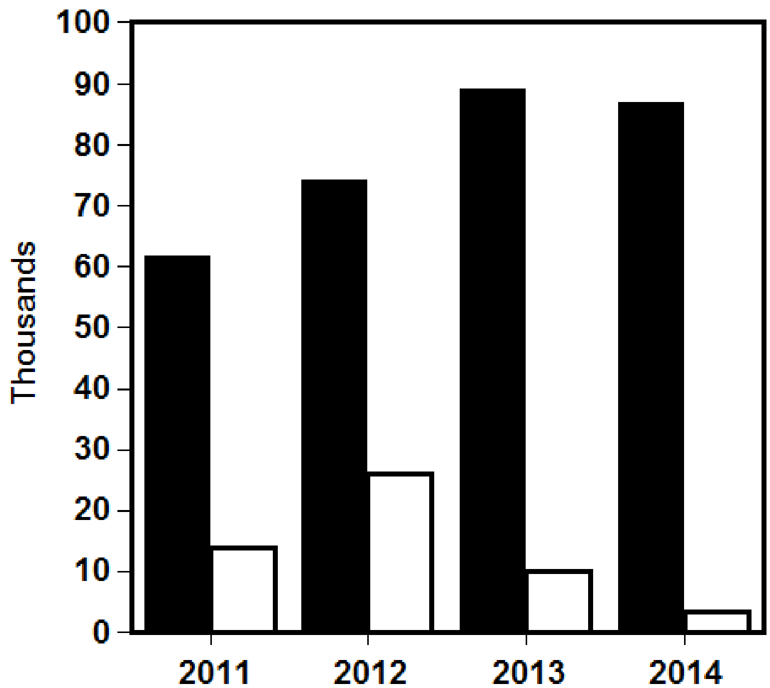



**Figure 3.18**–Terminal run size for age 4–5 fall Chinook salmon of hatchery-origin (black bars) and natural-origin (clear bars) for the WCVI stock aggregate 2011–2014 as estimated with the DSR method.

Accuracy of estimates reported herein assume a fundamental condition was met, that is, maturation and exploitation rates were equal between target and indicator stocks (the "core" assumption). Methods based on comparing age distributions among GSI samples and CWT samples from ocean fisheries and terminal runs of target and indicator stock terminal runs were developed to expose gross violations in the core assumption (see § 3.5.4 and Bernard et al. 2014). Unfortunately lack of information on the age distributions of natural-origin terminal runs prevented the use of this tool for the WCVI stocks. When not missing estimates for age 3 Chinook salmon, using the DSR method produced estimates of the WCVI aggregate abundance similar to estimates generated through traditional (run reconstruction) methods (Figure 3.19). However, the accuracy of the traditional run reconstructions is also untested.

**Table 3.13**– Expanded number of Chinook salmon with CWTs recovered in SEAK sport fisheries based out of Craig and Sitka, Alaska; in spring, commercial troll fisheries; and in summer troll fisheries in the southern and northern outside districts (first and second periods); and recovered in terminal areas for the Robertson Creek Hatchery indicator stock used to represent the WCVI stock aggregate. Shaded areas are instances where one or no CWTs were recovered. Term NA is used for years without sampling a fishery.

| | | SEAK Fisheries | | | | | | | | Terminal Area | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Age | NO-1 | NO-2 | SO-1 | SO-2 | SPR | CRG | SIT | Total | Harvest | Spawning | Total |
| 2011 | 3 | 3.4 | 0.0 | 0.0 | 0.0 | 0.0 | NA | 0.0 | 3.4 | 238.0 | 118.7 | 356.8 |
| | 4 | 88.2 | 17.2 | 21.2 | 2.9 | 90.8 | NA | 21.9 | 242.2 | 460.9 | 622.6 | 1,083.6 |
| | 5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | NA | 0.0 | 0.0 | 10.6 | 7.7 | 18.2 |
| 2012 | 3 | 0.0 | 0.0 | 0.0 | 0.0 | NA | 0.0 | 0.0 | 0.0 | 28.8 | 64.4 | 93.3 |
| | 4 | 15.5 | 24.8 | 8.7 | 0.0 | NA | 11.3 | 0.0 | 60.3 | 346.3 | 318.6 | 664.9 |
| | 5 | 10.4 | 7.1 | 4.4 | 0.0 | NA | 3.1 | 1.2 | 26.1 | 188.8 | 142.8 | 331.6 |
| 2013 | 3 | 12.9 | NA | 2.4 | NA | NA | 4.6 | 0.0 | 19.8 | 24.2 | 631.8 | 655.9 |
| | 4 | 3.2 | NA | 4.7 | NA | NA | 7.5 | 0.0 | 15.4 | 0.0 | 183.3 | 183.3 |
| | 5 | 9.7 | NA | 0.0 | NA | NA | 7.9 | 0.0 | 17.6 | 3.8 | 90.6 | 94.4 |
| 2014 | 3 | 5.2 | 0.0 | 0.0 | 0.0 | NA | 0.0 | 0.0 | 5.2 | 13.0 | 62.1 | 75.1 |
| | 4 | 68.1 | 14.8 | 10.9 | 0.0 | NA | 3.0 | 38.6 | 135.4 | 70.8 | 387.3 | 458.1 |
| | 5 | 0.0 | 0.0 | 0.0 | 0.0 | NA | 0.0 | 3.4 | 3.4 | 5.0 | 14.6 | 19.6 |

In summary, the SSP has learned the following about estimating the aggregate terminal run size of WCVI Chinook salmon with the DSR method using data from SEAK fisheries:

- Additional CWT information is needed (perhaps from an additional fishery) to consistently estimate the terminal run size of 3-year old salmon;
- Estimates of the relative age composition of Chinook salmon spawning in WCVI are needed:
    - to run diagnostics concerning the core assumption of the method; and/or
    - to consistently estimate terminal run size of 3-year olds by expanding estimates for older salmon;
- Terminal run size of natural-origin Chinook salmon to WCVI is a relatively minor portion of the overall run size;
- Precision of estimates is poor because:
    - natural-origin salmon are relatively few; and
    - the tagged ER indicator stock represents a relatively small fraction of the overall production; and

- with some of the additional information noted above, the DSR method has the potential to replace statistics for the WCVI aggregate from the traditional run reconstruction used by the CTC while providing measures of uncertainty not currently available.

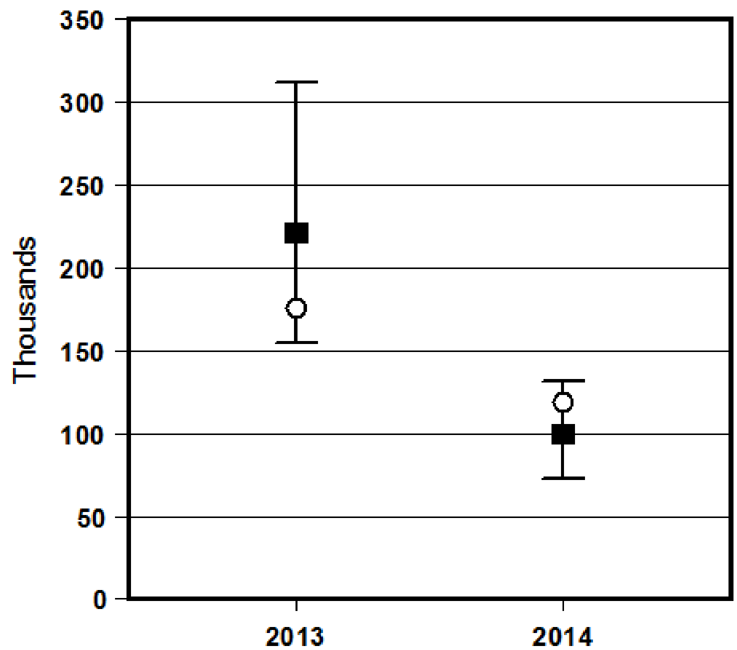



**Figure 3.19**–Estimates of terminal run size for the WCVI aggregate of Chinook salmon stocks for combined ages 3–5 for 2013–2014 hatchery and natural-origin stocks combined. Closed squares (■) represent estimates using the DSR method and intervals their lognormal 95% CIs. Open circles (**o**) represent a comparative statistic used by the CTC as reported in CTC (2016a, Appendix Table J1).

Genetic stock identification through mixture analysis was used to identify the fraction of SEAK catches composed of the WCVI aggregate. The result worked reasonably well, most likely because of the genetic uniqueness to the WCVI aggregate. The same approach was used again for n § 3.5.4 for another aggregate stock that is less unique.

## 3.4 Puget Sound

The CTC uses seven stock groups to represent Chinook salmon production originating in Puget Sound. The stock groupings are based on maturation patterns, ocean distribution, and run timing. For Puget Sound stocks, the process for identifying potential Sentinel Stocks was based on information gaps and on locations where there was believed to be a high likelihood of success in achieving the CTC standards for the accuracy and precision of escapement estimates. During the course of the SSP, proposals were received from co-managers for five stock groups. Among these proposals, the Nooksack project was not funded as part of the SSP, but a revised proposal was funded under the U.S. LOA. The SSP funded projects involved the Skagit, Stillaguamish, Snohomish, and Green rivers. Proposals were selected based on the SSP procedures described previously (§ 1.2).

To provide unbiased estimates of salmon population abundance using redd counts, the following key assumptions must be met:

- redd counts are conducted using a representative spatial and temporal sampling design that allows for expansion for unsurveyed times and areas;

- all redds are correctly identified and enumerated; and
- the expansion factor for fish or females per redd or redd life is unbiased and representative of the population.

Index redd surveys are used to estimate Chinook salmon escapement for Puget Sound populations. Using foot or boat surveys, all new redds identified are flagged to estimate the timing of redd construction and to track the number of unique redds. However, redd surveys may not cover the entire spawning distribution. Although surveys are scheduled 7 to 10 days over the spawning season, redds may be missed due to turbidity, especially later in the season. In addition, when there is lack of spatial or temporal coverage, redd counts are considered a minimum (e.g., Stillaguamish stock), and their numbers expanded to unsurveyed areas based on professional judgment. Redd-based estimates may be affected by difficulty in identifying Chinook salmon redds because of superimposition, misidentification due to overlap in spawning time with other species, potential for more than one redd per female, the presence of test digs, variation in redd characteristics, and counting errors due to experience or training of redd counters (Seamons et al 2012). For some populations (e.g. Snohomish stock), an AUC expansion is used with redd days divided by an assumed 21 day redd life. The redd AUC method is similar to the AUC method based on fish days described previously (Section 2.5). The total redd count, which is the sum of the index redd counts or estimates, is multiplied by a factor of 2.5 to estimate the total number of females, males, and jacks assumed to be associated with each redd. The estimate of abundance based on redd counts is the total number of females or fish associated with redd construction.

Success in estimating escapement of Chinook salmon in the Puget Sound area using traditional MR methods has been mixed. High flows, low abundance, crew expertise, altered fishing sites, and relatively high abundance of other fish species have affected the accuracy and precision of estimates (Musslewhite 2010, Hahn et al. 2010, Hahn et al. 2011). These factors have had detrimental effects on implementing standard methods (expanded counts of redds) and MR studies to estimate escapement. As an alternative, genetic methods originally developed to estimate abundance for wildlife populations were adapted with SSP funding to estimate salmon abundance on the spawning grounds of Puget Sound. Summaries of the genetic methods are provided in § 2.2.

Three types of abundance estimates are reported in this section on Puget Sound stocks:

1. pre-spawning abundance of all successful spawners, unsuccessful spawners, and pre-spawning mortalities, as estimated with tGMR using all carcasses recoveries on or near the spawning grounds as the first sampling event and juveniles captured at a smolt trap downstream of the spawning area as the second event;
2. abundance of all spawners as estimated with redd counts expanded by the assumption that 2.5 fish are associated with each redd; and
3. pre-spawning abundance which includes successful spawners, unsuccessful spawners, and pre-spawning mortalities as estimated with a MR study having its first sampling event considerably downstream of spawning grounds with the second event consisting of carcasses recovered from the spawning area.

Rawding et al. (2014) demonstrated that when there was negligible pre-spawning mortality and spawning surveys had complete spatial and temporal coverage, redd-based AUC expansions and MR estimates were similar. In addition, when genetic samples were representatively collected from carcasses during spawning ground surveys and juveniles during their outmigration from a smolt trap below the spawning area the trans-generational genetic mark-recapture (tGMR) and spawning ground survey estimates were similar. Therefore, if there is representative sampling and negligible pre-spawning mortality, then the above estimates should be similar when the assumptions for unbiased estimators are met. However, if there is significant, unsampled pre-spawning mortality, or if assumptions are not met, estimates could differ substantially.

### 3.4.1 *Green River*

The Green River drains 1250 $km^2$, emptying into the Green-Duwamish River before reaching saltwater in Elliott Bay in Puget Sound (Figure 3.20). Mainstem flows are regulated at Howard Hanson Dam (rkm 104) and at the City of Tacoma's municipal water supply diversion dam ("Tacoma Headworks Trap"; rkm 98). Chinook salmon spawn in the Green River from rkm 40 near Kent to the Tacoma Headworks Diversion Dam at rkm 98 and in the two larger tributaries, Soos and Newaukum creeks, which join the mainstem at rkm 54 and 66, respectively. Two salmon hatcheries operate within the Green River system, Soos Creek Hatchery (WDFW) and Keta Creek Hatchery (Muckleshoot Indian Tribe). The broodstock for these two associated programs have come from the Green River since the early 1900s. The Chinook salmon population abundance estimates for the Green River exclude spawning in Soos Creek.

In 2010, WDFW attempted an SSP-funded MR study to estimate abundance of Chinook salmon in the Green River basin with a Peterson estimator using the same study design from previous, successful MR studies (Hahn et al. 1999, 2000, 2001). The marking event consisted of beach seining between rkm 43 and 48 at the lower end of the spawning area, and the recovery event included live adult returns to the Soos Creek Hatchery, carcasses from Newaukum Creek and Soos Creek below the hatchery, and from carcasses sampled during spawning ground surveys in the mainstem between rkm 43 and 97. A section of the mainstem from rkm 77 to 90 was not surveyed due to safety concerns. Early in the season, 93 Chinook salmon were captured and tagged including 18 fitted with radio transmitters, but unfortunately, no tag marked fish were recovered in the 537 salmon carcasses examined. Of the 18 radio tagged fish, 11 returned to Soos Creek, 5 migrated up the Green River and 2 were lost after tagging. Unusually heavy rains in early September and concerns about the structural integrity of the dam (i.e., potentially catastrophic flooding from dam failure) caused an unscheduled release of water in early September coincident with the peak migration of Chinook salmon. For these reasons no MR estimate of run size was calculated. However, tissue samples from carcasses were collected in 2010 to be used to estimate spawning abundance for that year with tGMR methods. Additional details on this MR project are available in Hahn et al. (2011).

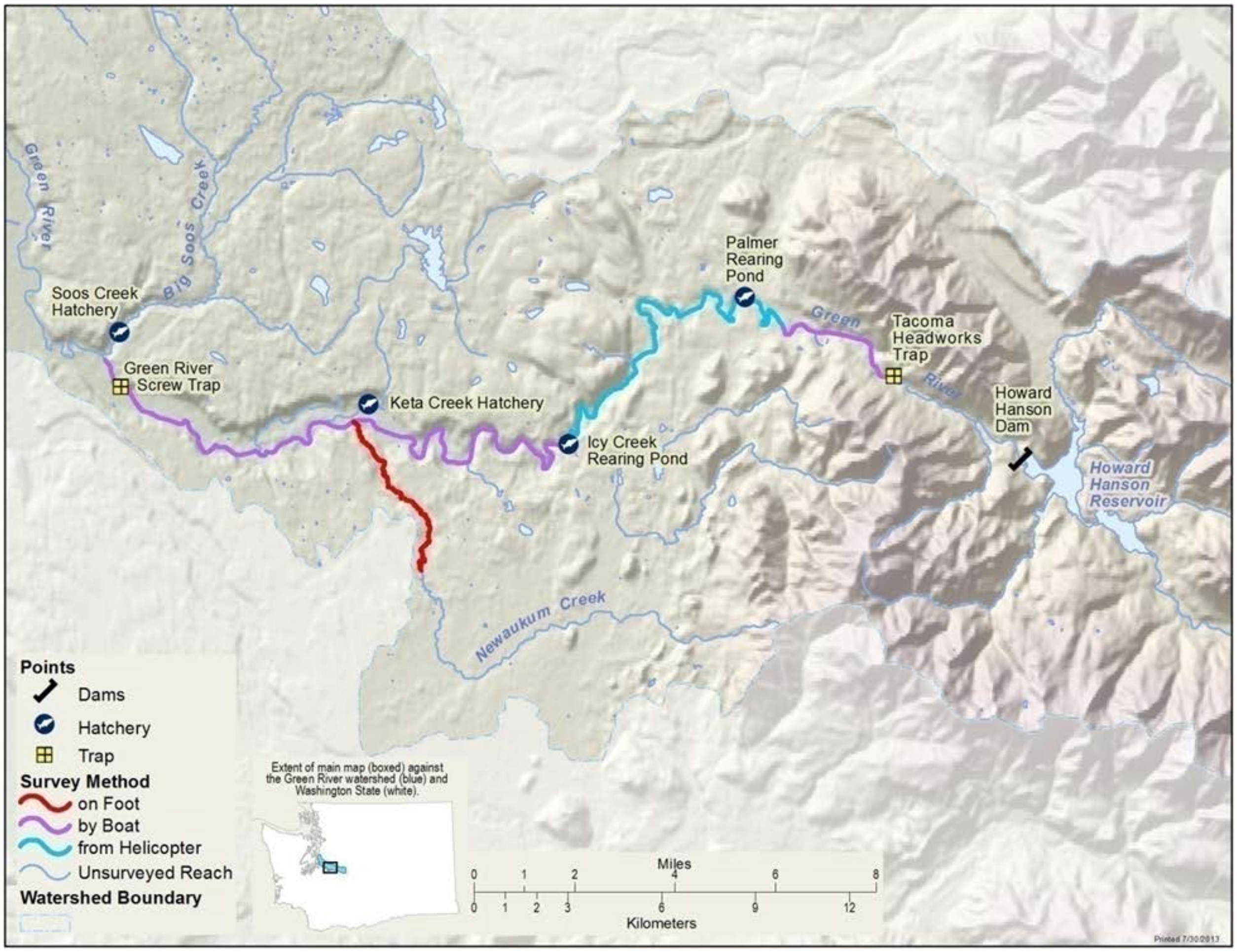



**Figure 3.20**–Locations of carcass surveys, screw traps, and hatchery facilities in the Green River. The tagging sites for the MR project in 2010 are on the mainstem below the screw trap and are not shown.

Based on the success of genetic methods to estimate salmon abundance in other basins (Rawding et al. 2014), these methods were applied to the Green River stock. The first sampling event in the tGMR concerned sampling adults on the spawning grounds, whereas the second involved sampling juveniles (progeny) in the next year. The redd-based estimates were lower than the tGMR estimates, ranging from 993 to 3,090 (Figure 3.21). The tGMR estimates based on the hypergeometric model ranged from 2,868 to 4,862 fish with a CV of less than 10%. Past MR studies funded under the U.S. LOA are also provided for reference in Figure 3.21 and Table 3.14.

In 2011 the genetic estimate of successful spawners, those that produce at least one offspring, was greater than the observed redd count. Since some spawners produce no offspring (Seamons et al. 2014), the redd–based spawner abundance in this year is biased low. Seamons et al. (2012) addressed how the closed population assumptions were tested in the tGMR study design and described methods used to adjust for possible assumption violations. Due to low escapements in recent years (Table 3.14), co-managers captured between 500 and 1,900 Chinook salmon at Soos Creek hatchery during brood years 2011 to 2013 and trucked them to the Green River to increase spawner abundance. Natural pre-spawning mortality based on female Chinook salmon carcasses ranged from 2% to 17%, the pre-spawning mortality on the trucked adult females ranged from 4% to 76%. In addition, Seamons et al. (2013, 2014) found lower numbers of offspring per spawner for the adults transported to the hatchery compared to those returning to the river. The difference in offspring per spawner for these two groups lead to tGMR estimates that are biased high (see Snohomish section for more details). Despite this bias, the tGMR estimates were consistently two times greater than the redd-based estimates, a discrepancy with traditional MR estimates that are believed to be unbiased (Figure 3.21; Hahn and Thompson 2007, Seamons et al. 2014). Developing unbiased tGMR abundance estimates when heterogeneity is present is an active area of research by WDFW. Additional details for this project are available in Seamons et al. (2012, 2013, 2014).

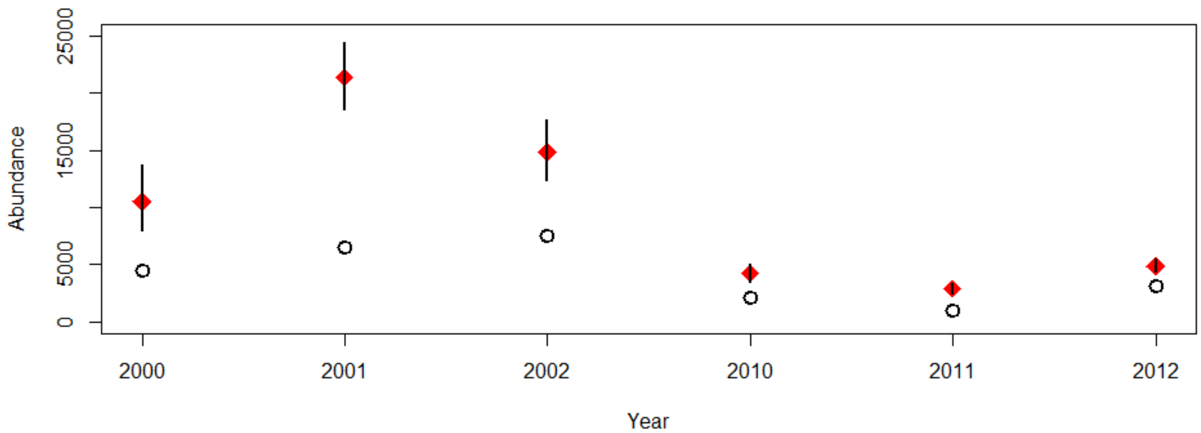



**Figure 3.21**–Comparison of redd, MR, and tGMR estimates for Green River Chinook salmon abundance (redd-based estimates are open circles, and MR and tGMR estimates are red diamonds). The black line is the 95% CI. The MR estimates for 2000–2002 are based on a traditional MR while those from 2011–2013 are based on genetic tGMR methods.

### 3.4.2 *Stillaguamish River*

The Stillaguamish River originates in the foothills of the Cascade Mountains in the northeastern portion of Puget Sound (Figure 3.22). There are two main tributaries, the North Fork (about 72 km long) and the South Fork (about 97 km long), each with numerous smaller tributaries in their basins. Two distinct native populations of Chinook salmon occur in the Stillaguamish basin. The summer-run population is more abundant and has been augmented annually by an integrated hatchery program since the 1990's. The second population is a fall-run stock which has declined and is currently at very low abundance. A hatchery program for the fall stock began in 2010.

**Table 3.14**–Abundance estimates of Chinook salmon for four Puget Sound stocks from standard mark-recapture, redd-based, and trans-generational mark-recapture study designs. All statistics in gray cells came from U.S. LOA-funded studies.

| | | Mark-Recapture | | Redd-based | | tGMR | |
|---|---|---|---|---|---|---|---|
| Stocks | Year | Pre-spawning Abundance | CV | Spawning Abundance | CV | Pre-spawning Abundance | CV |
| Green | 2000 | 13,940 | 12% | 4,942 | NA | NA | NA |
| | 2001 | 23,470 | 10% | 6,905 | NA | NA | NA |
| | 2002 | 17,840 | 11% | 7,960 | NA | NA | NA |
| | 2010 | NA | NA | 2,092 | NA | 4,222 | 9.3% |
| | 2011 | NA | NA | 993 | NA | 2,868 | 7.4% |
| | 2012 | NA | NA | 3,090 | NA | 4,862 | 5.8% |
| | | | | | | | |
| Stillaguamish | 2007 | NA | NA | 616 | NA | 1,291 | 28.8% |
| | 2008 | NA | NA | 1,671 | NA | 1,711 | 18.2% |
| | 2009 | NA | NA | 1,001 | NA | 1,239 | 6.7% |
| | 2010 | NA | NA | 783 | NA | 837 | 15.6% |
| | 2011 | NA | NA | 1,017 | NA | 1,637 | 6.2% |
| | 2012 | NA | NA | 1,534 | NA | 1,787 | 7.7% |
| | 2013 | NA | NA | 854 | NA | 997 | 9.5% |
| | | | | | | | |
| Skykomish | 2011 | NA | NA | 1,180 | NA | 3,986 | 29.4% |
| | 2012 | NA | NA | 3,745 | NA | 4,005 | 14.0% |
| | 2013 | NA | NA | 2,355 | NA | 5,813 | 22.2% |
| Snoqualmie | 2011 | NA | NA | 700 | NA | 1,398 | 22.3% |
| | 2012 | NA | NA | 1,379 | NA | 1,687 | 16.6% |
| | 2013 | NA | NA | 889 | NA | 8,360 | 38.6% |
| | | | | | | | |

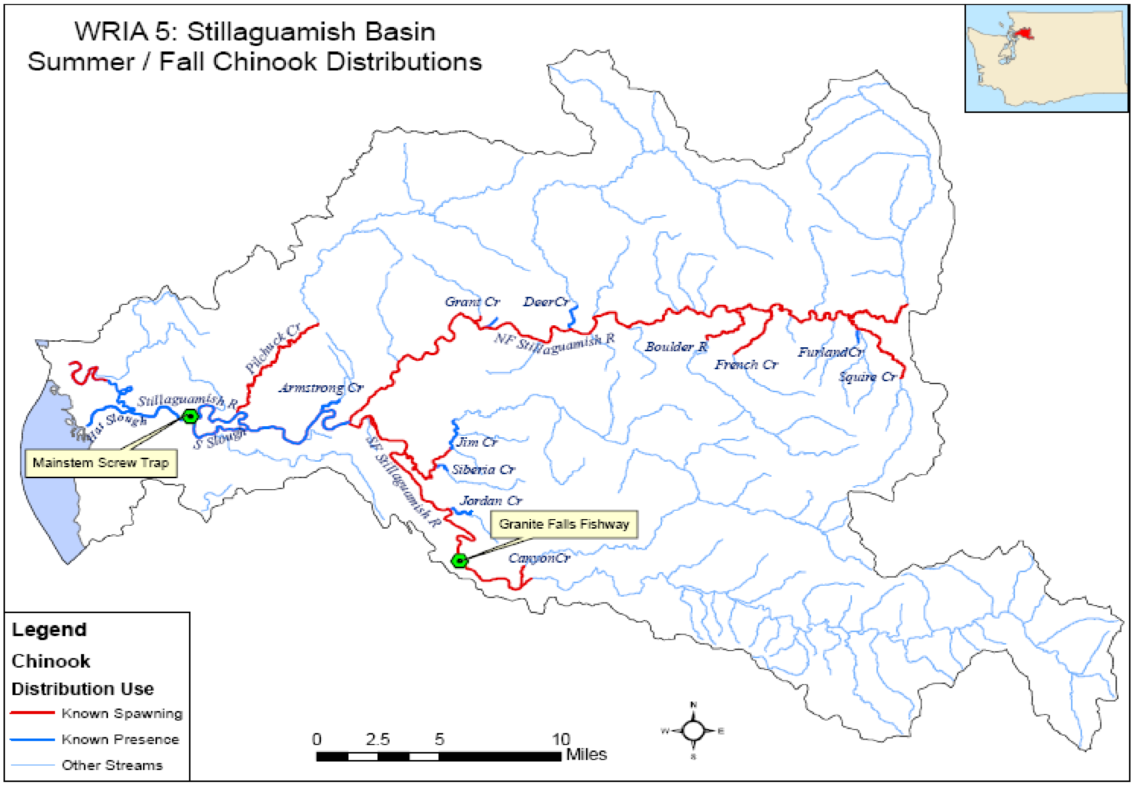



**Figure 3.22**–Spawning distribution of Chinook salmon in the Stillaguamish basin. Note a screw trap was located below the spawning area and downstream of the confluence of the north and south channels.

Based on the success of genetic studies to estimate salmon abundance in other basins, tGMR methods were applied to the Stillaguamish River, which includes both summer and fall runs. This was a cooperative project between the Stillaguamish Tribe and WDFW, where co-managers conduct spawning ground surveys, estimate spawner abundance based on redd surveys, and collect genetic samples from adult carcasses. The Stillaguamish Tribe operates the juvenile outmigrant trap and collects genetic samples from juveniles, while WDFW analyzes samples and leads the reporting effort. Genetic sampling began with brood year 2007, as part of a comprehensive genetic monitoring by the Stillaguamish Tribe; tissue samples from spawners, hatchery broodstock, and juveniles have been collected. Therefore, even though this program was not funded until 2010, salmon abundance estimates were calculated for 2007 through 2013. The traditional redd-based estimates ranged from 616 to 1,534 fish (Figure 3.23 and Table 3.14). The tGMR estimates based on the hypergeometric model ranged from 837 to 1,637 fish. Redd-based and tGMR estimates followed a similar pattern in 6 of 7 years. The 95% confidence intervals around tGMR point estimates overlapped traditional redd-based estimates in three years, but were higher in four. The CTC precision standard for abundance was met in four years, close in two (CV=0.16,0.18), but not met in 2007. The 2007 tGMR estimate was generated opportunistically since genetic samples were available but had been collected for other purposes. Based on the spatial and temporal coverage for adult and juvenile sampling, the 2007 tGMR estimate should be relatively unbiased. Since few pre-spawning mortalities were observed in any year, tGMR and redd-based estimates are both estimates of the number of salmon attempting to spawn. A redd-based expansion factor for this population is reported in § 4.1.3.1. Additional details for this project are available in Small et al. (2011, 2012, 2013, 2014, and 2015).

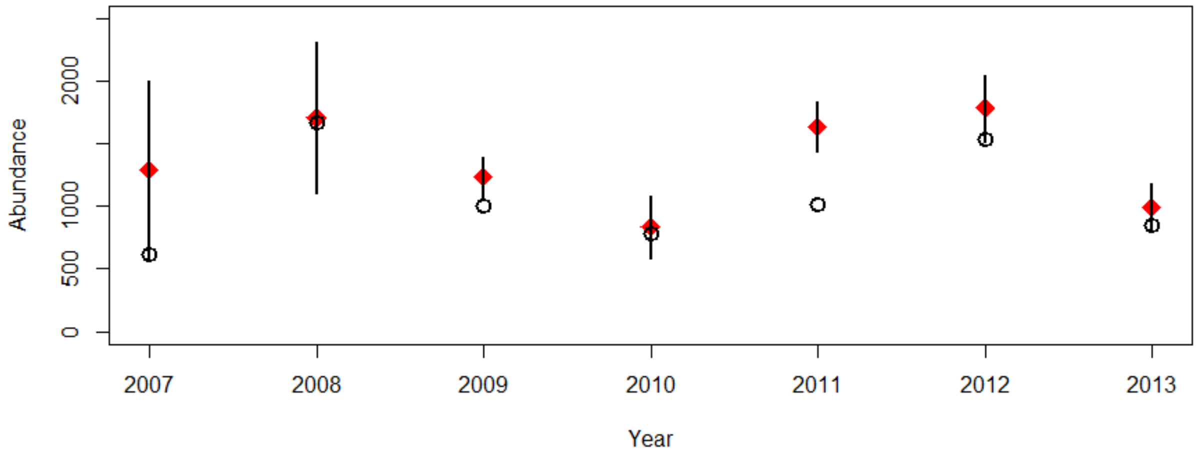



**Figure 3.23**–Comparison of estimates of escapement for Stillaguamish Chinook salmon from redd-based and tGMR estimators with the former represented by open circles and the latter by red diamonds. The black line is the 95%CI for the tGMR estimate based on the hypergeometric model.

### 3.4.3 *Snohomish River*

The Snohomish River drains 4,807 $km^2$ into Puget Sound north of Everett, WA (Figure 3.24). In the Snohomish River basin, a summer-run population spawns in the Skykomish River and a fall-run population spawns in the Snoqualmie River. The Skykomish summer-run population includes spawners in the mainstem and tributaries of the Pilchuck River, mainstem Snohomish, and the North Fork Skykomish and South Fork Skykomish rivers. Sunset Falls, located at rkm 83 on the South Fork Skykomish River just upstream of the confluence of the North and South Forks of the Skykomish River, is a natural barrier to upstream migration of anadromous salmonids. However, returning Chinook salmon (and other species) are captured in a fish trap downstream of the falls and released upstream in the South Fork Skykomish River. The Snoqualmie fall population includes spawners in the mainstem, Raging River, Tolt River, and Tokul Creek. Approximately, 523 linear stream km in the Snohomish Basin are utilized by Chinook salmon spawners, which includes 161 km of habitat upstream of Sunset Falls. Two Chinook salmon hatcheries are in the Snohomish system—Bernie Kai-Kai Gobin Salmon Hatchery located 5 km north of the mouth of the mainstem Snohomish River, and Wallace River Hatchery operated by WDFW located at the confluence of May Creek at rkm 6 of the Wallace River, which enters the mainstem Skykomish River at rkm 57. All fingerlings released from both hatcheries have their AD clipped and a portion have CWTs.

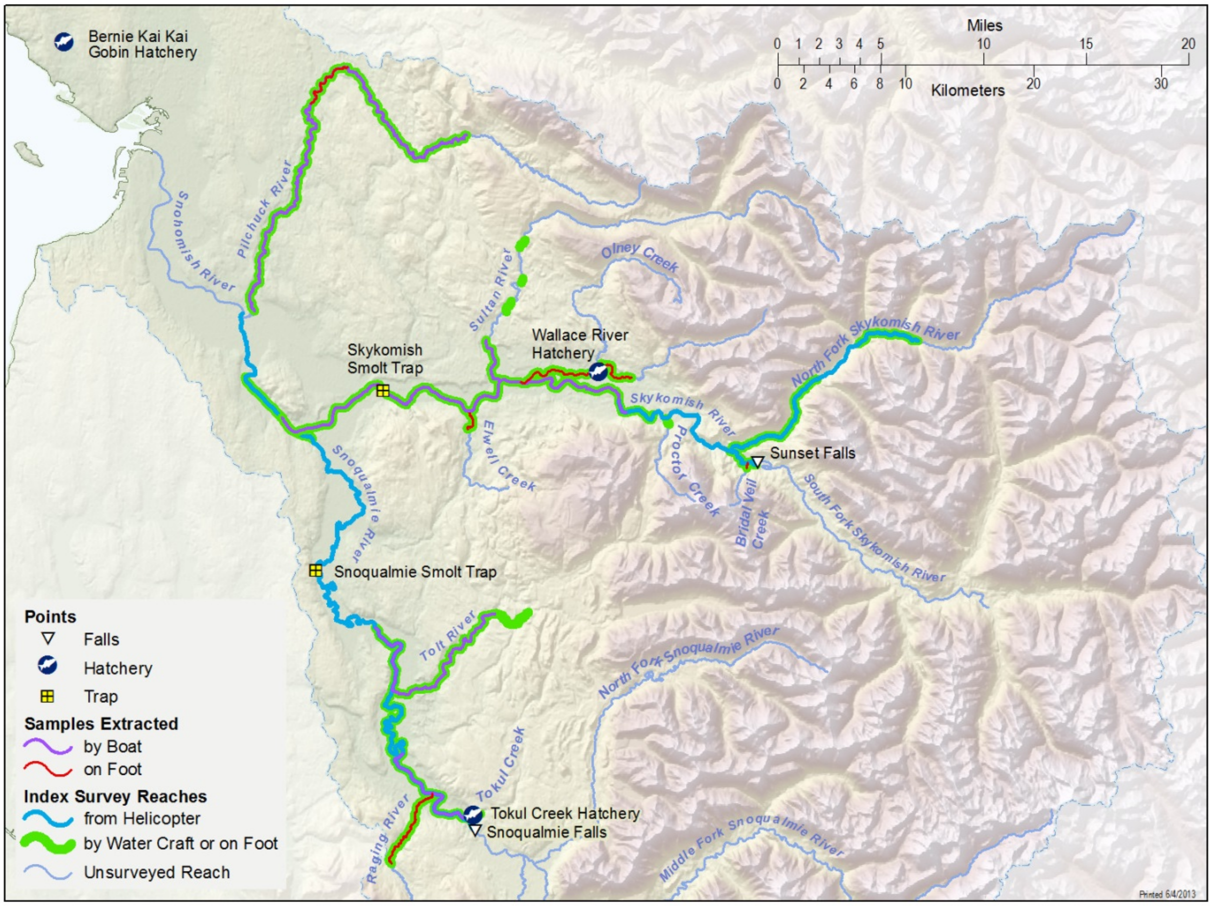



**Figure 3.24**–Locations of carcass surveys, screw trap, and hatchery facilities in the Snohomish River basin. Tagging sites for the 2009 MR study are not shown but are on the Snohomish River above the mouth of the Pilchuck River.

In 2009, WDFW attempted a MR study with SSP funding to estimate the abundance of adult Chinook salmon in the Snohomish Basin. The marking event involved beach seining and tangle netting between rkm 21 and 31 in the Snohomish River while the recovery event included adult returns to the hatcheries and to the Sunset Falls trap along with carcasses recovered during spawning ground surveys. Of the 31 Chinook salmon captured, 25 were radio tagged, but only one was recaptured at Wallace Hatchery. Radiotelemetry data showed that fish dispersed throughout the Snohomish basin and that movement was correlated with river flow pulses. A record high pink salmon run (4.2 million fish) and a record low Chinook salmon escapement to the basin coupled with early season failure to catch fish via beach seining, prevented the generation of a MR abundance estimate. Since too few Chinook salmon were caught to produce a reliable MR estimate the study was discontinued. Additional details on this project are available in Hahn et al. (2011).

Based on the success of genetic studies (i.e., tGMR) to estimate salmon abundance in other basins, tGMR methods were applied to the Snohomish Basin with SSP funding for three years starting in brood year 2011. This was a cooperative project between the Tulalip Tribes and WDFW, where co-managers worked cooperatively to conduct spawning ground surveys, estimate spawner abundance based on redd surveys, and collect genetic samples from adult carcasses. Carcasses were sampled in all spawning areas of the Skykomish and Snoqualmie basins, including areas downstream of the smolt trap on the Skykomish River (i.e., some mainstem Skykomish River, Pilchuck River, and mainstem Snohomish River). Carcasses sampled downstream of the smolt trap were excluded from genetic analysis. In 2013, some Chinook salmon were sampled live at the Sunset Falls trap; sampled fish were a fraction of those put upstream of Sunset Falls. The Tulalip Tribes operated both juvenile outmigrant traps and collected genetic samples from juveniles, and WDFW conducted genetic analyses and led the reporting effort.

From 2011 to 2013, the redd-based estimates for the Snoqualmie stock ranged from 700 to 1,379 fish (Figure 3.25 and Table 3.14). The tGMR estimates based on the hypergeometric model ranged from 1,398 to 8,360 fish. The same relative pattern was observed for the Skykomish stock except abundance estimates were generally higher. Abundance estimates based on redds in the Skykomish River ranged from 1,180 to 3,745, and the tGMR estimates ranged from 3,986 to 5,813. The CTC precision standard was only achieved for the Skykomish in 2012 and nearly so for the Snoqualmie in 2012 (CV=16.6%).

A critical assumption of the tGMR method is the probability of being tagged in the first sample and being captured in the second sample are independent or not correlated (Schwarz and Taylor 1998). Based on $\chi 2$ tests the null hypothesis that the recovery rate of genetic marks by spawning location was not different for juveniles captured at the smolt traps was rejected. Offspring of carcasses from smaller creeks and spawning locations near hatcheries were recovered at a lower recovery rate than other spawning locations. However, this alone does not indicate that tGMR abundance estimates were biased. In order for bias to occur mark rates would need to be correlated with recapture rates. Anecdotal evidence suggested that carcass recovery was more complete in smaller streams, presumably because carcasses are easier to recover from shallow water. For example, in Bridal Veil Creek, carcass recovery was thought to be close to 100%, but no Bridal Veil Creek offspring from carcasses were recaptured in two of three years at the smolt trap. In addition, fewer offspring were recovered from carcasses collected from the Wallace and Tokul watersheds where hatcheries are located. This is consistent with the observation that hatchery Chinook salmon produced fewer offspring than wild Chinook salmon (Williamson et al. 2010).

To eliminate the correlation of mark and recapture rates and reduce the bias in the tGMR abundance estimate, Seamons et al. (2015) performed a Monte Carlo (MC) sampling exercise where carcasses (marks) were subsampled from sampling site collections in proportion to their redd-count based abundance after which the tGMR estimates were calculated. Monte Carlo sampling was performed 10,000 times for each estimate each year (2011-2013) in each basin (Snoqualmie and Skykomish). The MC estimates for the Skykomish and Snoqualmie populations were lower than the original tGMR estimates. The MC approach assumes that the count of redds are an unbiased independent estimate of the true spawner abundance by spawning location. Given the assumptions required for an unbiased redd based escapement estimate (§ 2.5), the redd-based escapement estimates in Snohomish basin are biased and so are the resulting MR estimates. Despite the negative bias using the MC approach, the tGMR estimates were always larger than the redd based estimates, which was also consistently observed for other Puget Sound populations. Due to the trans-generational design of the genetic based abundance estimates, methods for addressing heterogeneity as observed in this study are not as well developed as in the traditional MR methods used in Oregon and British Columbia. Developing unbiased tGMR estimates when heterogeneity is present is an active area of research by WDFW. Additional details for tGMR projects on the Snohomish stocks are available in Seamons et al. (2013, 2014, 2015).

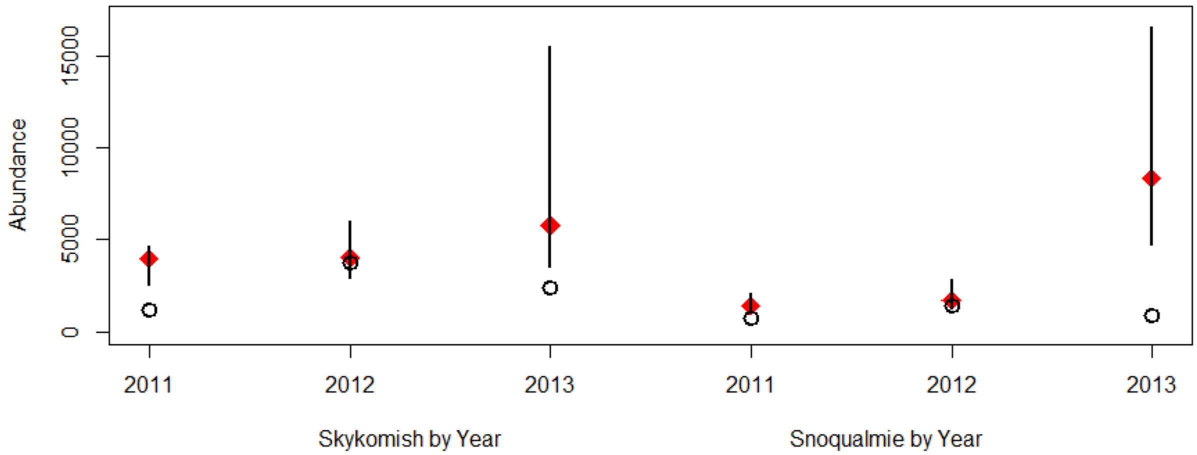



**Figure 3.25**–Comparison of estimates of escapement for Skykomish and Snoqualmie Chinook salmon from redd-based and tGMR estimators with redd based estimates represented by open circles and tGMR estimates by red diamonds. The black line is the 95%CI for the tGMR estimate based on the hypergeometric model.

### 3.4.4 *Skagit River*

The Skagit River supports what is assumed to be the largest natural spawning populations of spring, summer, and fall Chinook salmon in Puget Sound. The Skagit River System Cooperative (SRSC) proposed several options to assess escapement which included a MR study to develop, calibrate, and improve current escapement estimates based on redd counts. Although successful MR studies have been implemented for coho salmon and chum salmon using beach seines for capturing and tagging salmon in the Skagit River, the previous MR studies for Chinook salmon using fishwheels and gillnets were unsuccessful. After reviewing the initial SRSC proposal, the SSC requested the project scope to be revised into a feasibility study to test the effectiveness of the proposed trap design before considering the larger initial proposal to estimate abundance. A modified proposal was submitted and approved for funding in March 2009. Since no Chinook salmon were captured during the feasibility study, the project received no additional funding. See Musslewhite (2010) for additional information.

## 3.5 North Oregon Coast

The North Oregon Coast (NOC) aggregate of Chinook salmon stocks consist of production originating from 12 river basins bounded by the Necanicum River on the northern edge of the Oregon coast southwards to the Siuslaw River. NOC stocks are far-north migrating, with predominantly ocean-type life histories, and tend to mature at ages 4 and 5. NOC stocks contribute to both SEAK and NBC fisheries. Historically a robust and productive stock grouping, this aggregate's spawning escapement declined to historical lows during 2007 and 2008 with an estimated average of 42,765 spawners. Escapements since that time have rebounded; the most recent 5-year (2010–2014) average escapement was estimated to be 91,971 spawners. Three escapement indicator stocks represent the NOC aggregate in managing fisheries under PSC jurisdiction—the Nehalem, Siletz and Siuslaw stocks (Figure 3.26). All are annex stocks, listed in Attachments I, II and V to Chapter 3 in the 2009 Agreement.

Long standing monitoring programs for Oregon coastal fall Chinook salmon do not provide the CTC with the information required for managing fisheries on NOC stocks. ODFW has conducted standard surveys for more than 60 years to monitor stock status along coastal Oregon (Jacobs and Cooney 1997). In this monitoring program Chinook salmon are annually counted at 56 locations covering 45.8 stream miles (about

3% of the approximately 1,500 stream miles). Counting locations were not randomly selected, and the same 56 locations are surveyed each year. Although counts in these standard surveys may be sufficient to index long-term trends of spawner abundance, they are considered insufficient for deriving dependable annual estimates of spawner escapement.

Studies funded under the SSP were to provide accurate annual estimates of spawner escapement for escapement indicator stocks representing the NOC aggregate—the Nehalem, Siletz, and Siuslaw stocks. These accurate estimates were added to those from earlier studies funded under the U.S. LOA to create a time series of estimates. Two-event MR studies (see § 2.1) were used in both SSP and U.S. LOA-funded studies. Adult Chinook salmon were captured low in each river throughout the salmon migration and marked. Regularly timed samples of carcasses and moribund fish were inspected on the spawning grounds. Results from diagnostic tests indicated that MR estimates so obtained were accurate. Estimates of catch from creel surveys of the in-river sport fisheries were subtracted from MR estimates to obtain accurate estimates of spawning abundance for each river. Estimates of escapement to the Nehalem and Siletz rivers were produced with funding from the first five years of the SSP. Escapement to only the Siuslaw River was estimated in the final (extended) year of the SSP. Estimates from SSP-funded and U.S. LOA-funded studies are presented below in §§ 3.5.1 – 3.5.3.

Section 3.5.4 is a description of a different approach to estimating abundance of the NOC aggregate—directly estimating the terminal run size of the aggregate using the DSR method (see § 2.4). Sets of estimates for four years are presented, and as with the application of this method to estimate terminal run size for the WCVI aggregate, the first two sets for 2011 and 2012 were funded through the U.S. LOA while the last two sets for 2013 and 2014 were funded through the SSP.

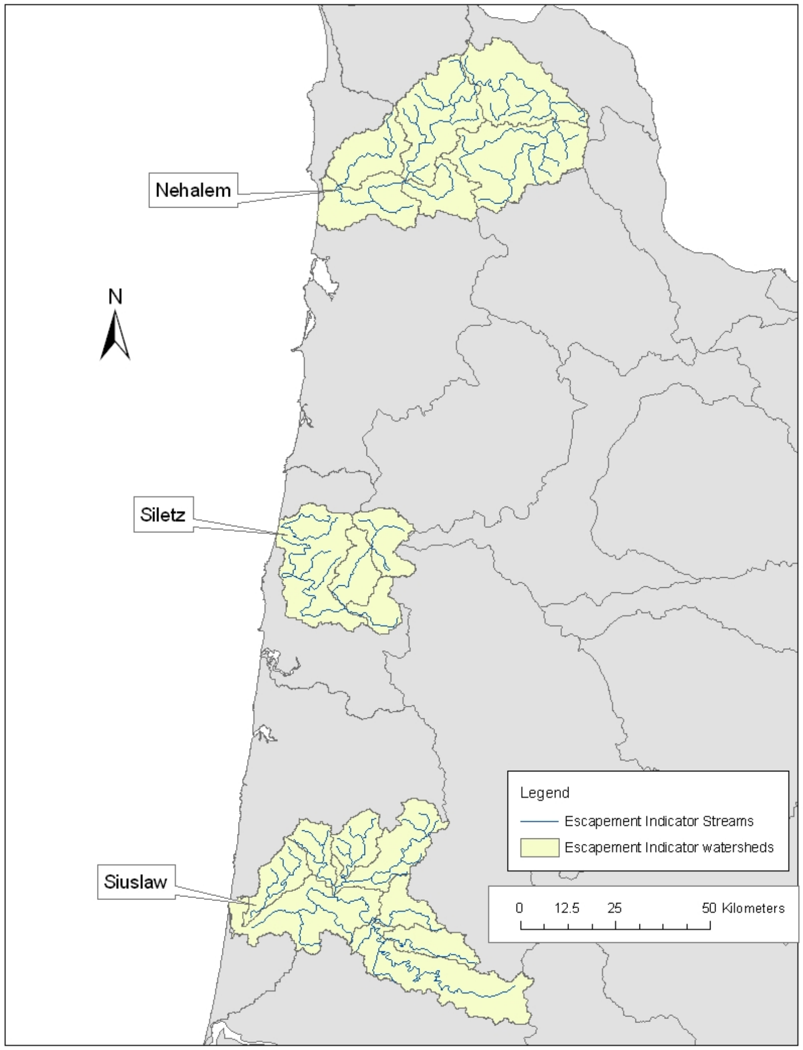



**Figure 3.26**–Indicator stocks representing the North Oregon Coast aggregate.

### 3.5.1 ***Nehalem River***

Chinook salmon from the Nehalem River are the northern-most indicator stock in the NOC aggregate (Figure 3.27). The river is located entirely in the Oregon coastal mountain range with a maximum watershed elevation of 1,070 m. Average annual river discharge is 76 $m^3$/sec and historically has ranged from 1 – 1,990 $m^3$/sec. Commercial timberlands dominate upland areas of the watershed, while floodplains are predominately pastureland.

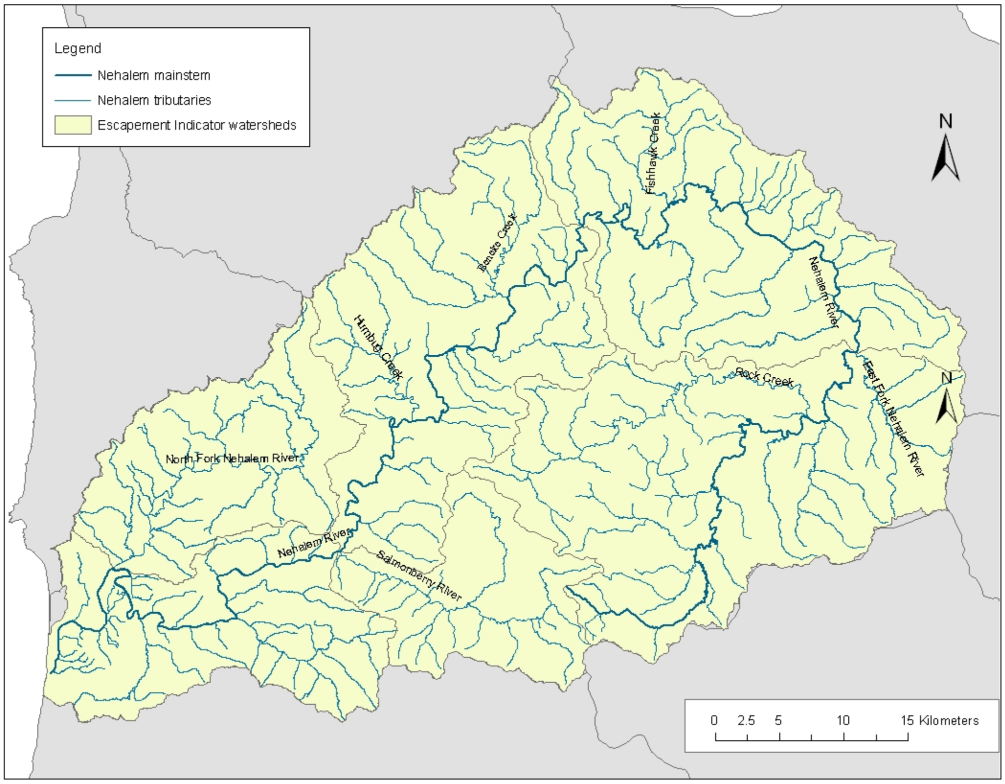



**Figure 3.27**–Watershed map of the Nehalem River basin with major tributaries depicted.

Estimated annual escapements from SSP and U.S. LOA-funded studies ranged from 5,786 spawners in 2009 to 21,283 spawners in 2003 (Table 3.15). Estimated abundance increased steadily in both the early studies and in the later studies. The low estimate occurred in 2009 in the first year of the 2009 Agreement. Of the five years of study under the SSP, two years produced MR estimates with CVs that met CTC precision standards (CV ≤ 15%) and three just missed (15% < CV < 20%).

An aspect of SSP-funded studies of the Nehalem stock was an examination of survey areas used in the long-term monitoring program. A key finding of these studies was that additional survey areas in the upper basin were/are needed to appropriately represent the spawning return of the basin's spawning population. Evidence for this expansion of the long-term monitoring program can be seen in a comparison of estimates from MR studies to estimates from the monitoring program (Figure 3.28). Estimates are similar with those from MR studies being marginally higher. In eight out of nine years MR estimates are higher—a <1% chance of happening without a systematic bias in at least one set of estimates. In response the SSC urges ODFW to continue to survey those areas specifically developed to encompass the earlier returning segment of the population so as to provide for non-biased estimates in the future. These two additional survey areas, which are in addition to the standard surveys conducted within the basin, are located in Rock Creek and an unnamed creek near to Rock Creek, are critical to adequately represent abundance of the spawning population.

**Table 3.15**–Estimated spawning abundance for the three escapement indicator stocks representing the NOC aggregative stock from MR studies. Statistics obtained through funding from the SSP are shaded in gray. All other statistics were obtained from projects funded under the U.S LOA.

| | Nehalem | | Siletz | | Siuslaw | |
|---|---|---|---|---|---|---|
| | Estimate | CV | Estimate | CV | Estimate | CV |
| 2000 | 10,678 | 26% | | | | |
| 2001 | 12,431 | 12% | | | 9,723 | 18% |
| 2002 | 19,956 | 5% | | | 22,506 | 7% |
| 2003 | 21,283 | 19% | | | 28,801 | 8% |
| 2004 | | | | | 29,119 | 9% |
| 2005 | | | 14,355 | 36% | 13,771 | 9% |
| 2006 | | | 15,891 | 16% | 13,380 | 9% |
| 2007 | | | 2,700 | 16% | | |
| 2008 | | | 1,218 | 19% | | |
| 2009 | 5,786 | 17% | 2,213 | 12% | | |
| 2010 | 7,097 | 16% | 10,985 | 32% | | |
| 2011 | 11,084 | 14% | 4,985 | 8% | | |
| 2012 | 12,952 | 19% | 8,738 | 19% | | |
| 2013 | 15,989 | 12% | 13,878 | 13% | | |
| 2014 | | | | | 16,395 | 20% |

### 3.5.2 *Siletz River*

The Siletz River has a moderately sized basin with its drainage originating in the Coast Range Mountains of the central Oregon coast (Figure 3.29). The river drains a forested watershed of over 520 $km^2$ with approximately 160 km of spawning habitat. The majority of the watershed is owned by commercial forestry companies.

In the nine consecutive years of studies funded under the SSP and the U.S. LOA, estimated escapements were relatively high (13 to 16 thousand spawners) at the start of the series (2005) and at the end (2013) (Table 3.15). Estimates dropped precipitously in 2007 and 2008, then increased. The precision standard (CV ≤ 15%) was met in three of the five SSP-funded studies and was a near miss (15% < CV < 20%) in one other.

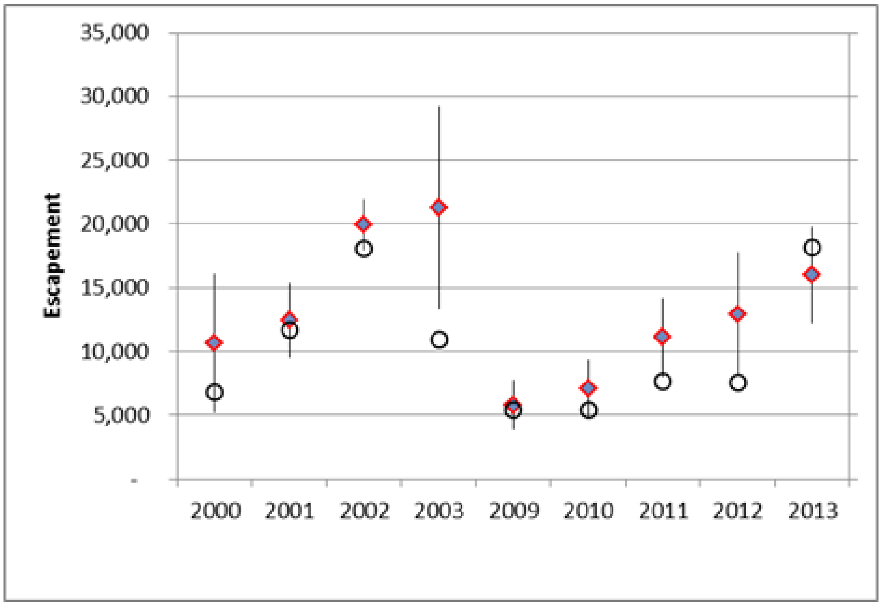



**Figure 3.28**–Estimated escapements of Chinook salmon to the Nehalem River. Circles represent estimates from annual surveys by ODFW. Diamonds and bars represent MR estimates and their symmetric 95% CIs. The U.S. LOA funded MR estimates from 2000–2003, while the SSP funded MR estimates from 2009–2013.

Similar to the case for the Nehalem stock, estimates of spawning abundance from the MR studies on the Siletz River were similar to those from the long-term monitoring program, but marginally higher (Figure 3.30). In eight out of nine years, MR estimates are higher—a <1% chance of happening without a systematic bias in at least one set of estimates. As a result, additional survey areas for the long-term monitoring program were defined that should more reliably represent the population and are important to estimation of escapements. The SSC urges ODFW to continue to survey these three areas—the upper mainstem above Sunshine Creek, Rock Creek, and Buck Creek.

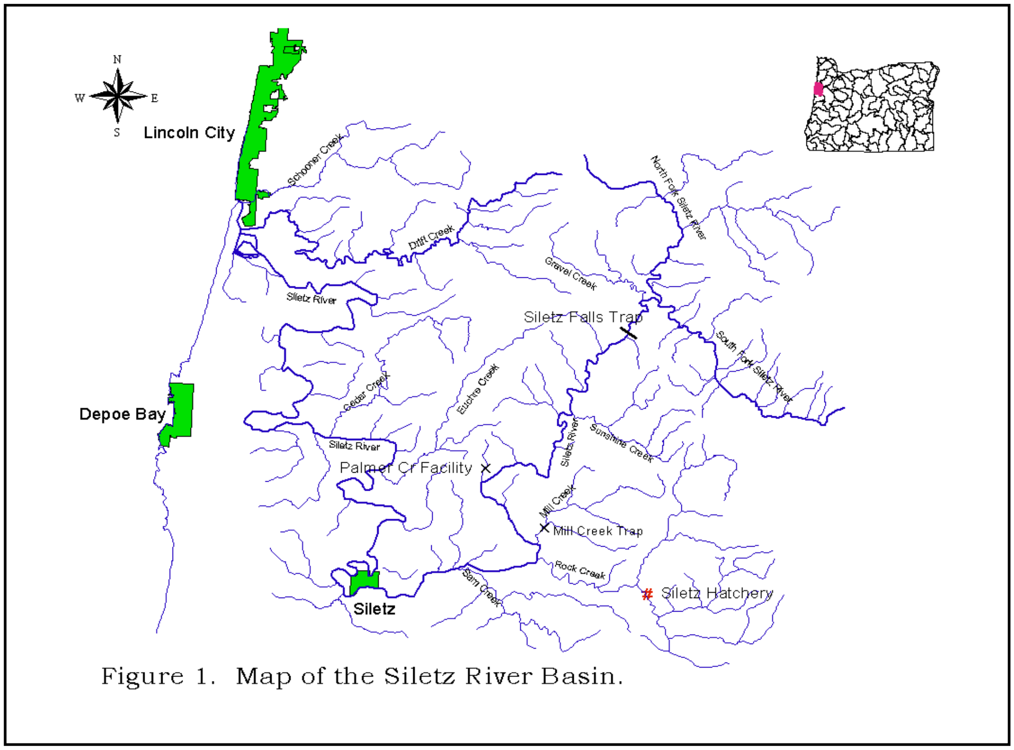



**Figure 3.29**–Siletz River basin depicting major tributaries and landmarks.

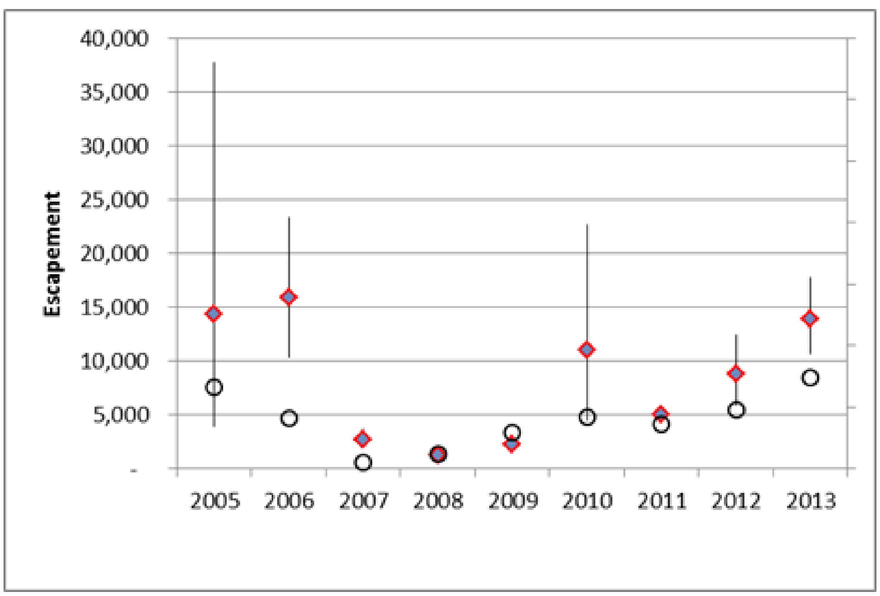



**Figure 3.30**–Estimated escapements of Chinook salmon to the Siletz River. Circles represent estimates from annual surveys by ODFW. Diamonds and bars represent MR estimates and their symmetric 95% CIs. The U.S. LOA funded MR estimates from 2005–2008, while the SSP funded MR estimates from 2009–2013.

### 3.5.3 *Siuslaw River*

The Siuslaw River is the southernmost river within the NOC aggregate and drains approximately 1,550 $km^2$ of watershed (Figure 3.31). The upper watershed has multiple owners including commercial forestry companies, the Siuslaw National Forest, and the Bureau of Land Management. Highest point in the watershed is approximately 1,990 m. Water flows average 56 $m^3$/sec and range from 1 to 1,400 $m^3$/sec.

The time series of estimated escapements for the Siuslaw stock contained a 7-year hiatus (Table 3.15) with the estimate for the last year (16,395 salmon) being the only one funded through the SSP. Precision of this last estimate (CV = 19.5%) was outside the CTC precision standard. In contrast, precision from all six estimates funded through the U.S. LOA were well within the CTC standard (CV ≤ 15%) except for the estimate in 2001 (CV = 18%).

Unlike for the Nehalem and Siletz stocks, statistics from the long-term monitoring program for the Siuslaw stock were distinctly greater than estimates from the MR studies (Figure 3.32) in all seven comparisons. For this reason no expansion of spawning ground surveys are recommended for the Siuslaw Basin. Instead, the obvious difference between sets of estimates can be accounted for with a calibration factor. Using a calibration factor can provide reasonably precise and unbiased estimates without the expenditure of any additional survey effort beyond what has been taken place in the past in the Siuslaw River (see § 4.1.1).

### 3.5.4 *NOC Aggregate*

The DSR method was used to indirectly estimate terminal run size in aggregate for NOC (North Oregon Coast) stocks by using a combination of harvest, genetic, age-length, and CWT information (see § 2.4 for a summary and Bernard et al. 2014 for details on the DSR method). Hatchery-origin Chinook salmon could be distinguished from natural-origin salmon in the NOC aggregate only through CWTs recovered in genetic samples from mixed-stock fisheries. Funding for the DSR project was provided by two sources: U.S. LOA (2011–2012) and the SSP (2013–2014). Seven SEAK fisheries were used in the application of the DSR method, including five troll and two sport fisheries (Figure 3.17). Description of fisheries can be found in § 3.3.11.

Genetic uniqueness of NOC Chinook salmon is less than that for the WCVI aggregate described in § 3.3.11. In tests with samples of known origin from the GAPS data base, 87% of NOC samples were correctly assigned (see Gilk-Baumer et al. 2013). Because GSI of catch samples from SEAK fisheries was accomplished with mixture analysis instead of individual assignment to stock, estimated relative catches of the NOC aggregate stock could only be "partially adjusted" for misclassification[4] in calculations.

---

[4] Accurate adjustment in a mixture analysis requires knowledge of the mixture in the catch—the very same knowledge that is being sought. The mixture from the GAPS data base used in the misclassification analysis was a reflection of the sample sizes used to develop a baseline. For this SSP-funded study the partial adjustment was an increase in proportion of the NOC aggregate incorrectly thought to be assigned to other stocks (13%).

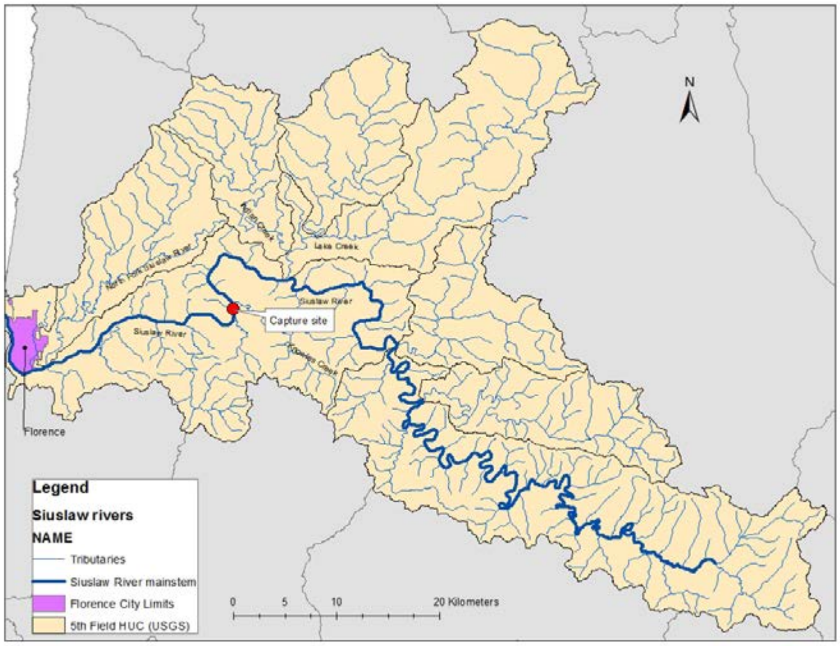



**Figure 3.31**–Siuslaw River basin with capture site depicted.

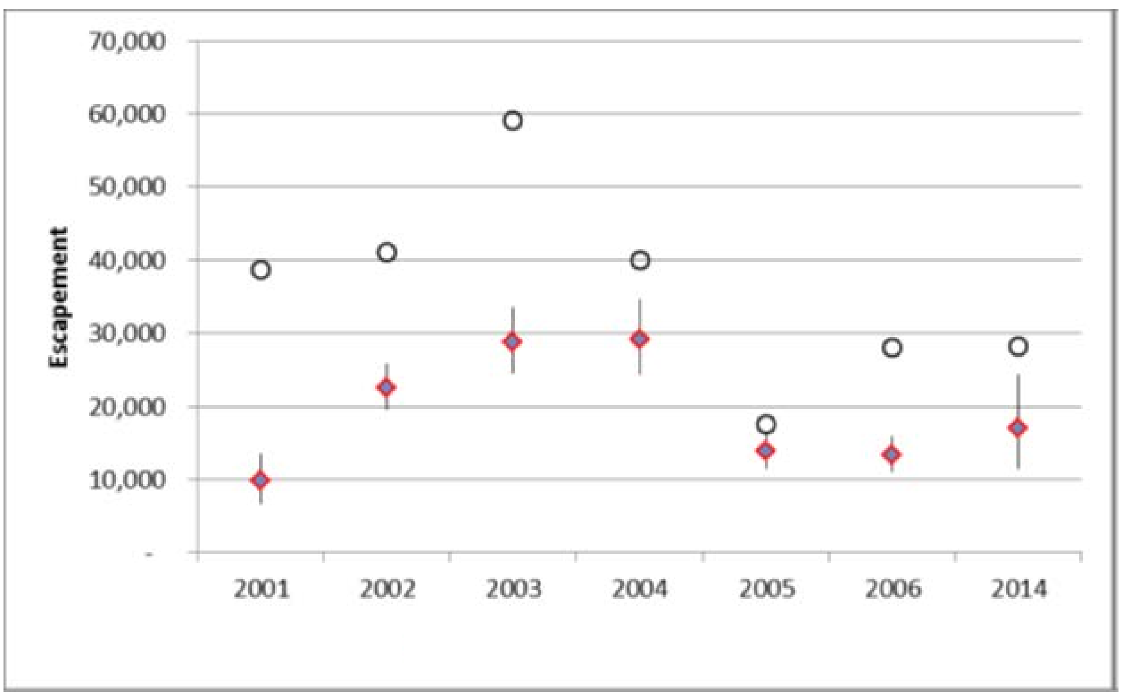



**Figure 3.32**–Estimated escapements of Chinook salmon to the Siuslaw River. Circles represent estimates from annual surveys by ODFW. Diamonds and bars represent MR estimates and their symmetric 95% CIs. The U.S. LOA funded MR estimates in all years listed above except for 2014 when funds were obtained through the SSP.

Age-specific estimates of terminal run size produced by the DSR method for NOC Chinook salmon from both the U.S. LOA-funded and SSP-funded studies are given in Table 3.16. Estimates for age 6 salmon were zero in all years except 2011. Natural-origin fish dominated the annual terminal runs (Figure 3.33), and accordingly the corresponding precision of their age-specific estimates was generally better (11% ≤ CVs ≤ 18% for ages 3–5 combined) than the precision of the hatchery-origin estimates (29% ≤ CVs ≤ 81% for ages 4–5). Given the priority of the SSP to foster quality estimates for natural stocks, the estimates of most interest in Table 3.16 are those concerning terminal runs for the natural aggregate stock ages 3–6 and 4–6. The standard (CV ≤ 15%) was met for both age groupings in 5 of 8 instances and was just outside the standard (15% < CV ≤ 20%) in the rest (Table 3.16). A problem occurred for estimating terminal run size for 3-year olds, but not from a lack of CWTs in catch samples from SEAK fisheries (Table 3.17). Very few catch samples from the established sampling program for catches in SEAK fisheries consisted of no or only one recovered CWT. The problem is that except in 2011 genetic samples contained no CWTs from 3-year olds. Because hatchery production from Oregon was not otolith marked, hatchery-origin salmon could not be distinguished from natural-origin salmon without recovering CWTs in genetic samples. The result is that the estimate of “natural-origin” NOC aggregate represents both hatchery-origin and natural-origin 3-year olds.

Accuracy of estimates reported herein require the “core” assumption was met, that is, maturation and exploitation rates were equal between target and indicator stocks. A diagnostic method based on comparing age distributions among GSI samples and CWT samples from ocean fisheries and terminal runs of target and indicator stocks was developed to expose gross violations in the core assumption (see Bernard et al. 2014). The diagnostic method is based on a change in relative age compositions for the target (driver) stock between ocean and terminal fisheries and for the indicator stock. If the core assumption has not been met, change in relative age distributions will differ between both driver and target stocks. Note however that a lack of difference is not evidence that the core assumption has been met. In each year except 2011 the shifts in relative age compositions between ocean fishery and terminal area were essentially the same for driver and indicator stocks (Figure 3.34). In 2011 relative age composition of the indicator stock shifted slightly towards 4-year old fish from the SEAK fishery to terminal fisheries. The same shift occurred with the driver (target) stock, only more so, indicating that the core condition of equal maturation and equal exploitation rates had not strictly been met in 2011. No such evidence was forthcoming for the years 2012–2014 (Figure 3.34). As of the writing of this report, the diagnostic test is still under development.

The CTC’s post-season estimates of terminal run size for the NOC aggregate are within the 95% confidence intervals surrounding the combined hatchery and natural-origin estimates for the aggregate from the DSR method in 2013 and 2014, but not in 2011 and 2012 (Figure 3.35). The CTC’s post season estimate here is the sum of the post season return (escapement) in Appendix Table J1 in CTC (2015) and the total mortality from sport fishing in the Oregon Coastal Inside as reported in Table A22 in CTC (2016). These sources do not report measures of uncertainty for their statistics.

**Table 3.16**–Estimated terminal run sizes of hatchery-origin, natural-origin Chinook salmon separately and combined for the NOC aggregate 2011 to 2014. Entries for age-3 hatchery fish in 2012 – 2014 are labeled NA because no CWTS from the indicator stock were recovered in GSI samples from those cohorts in SEAK fisheries. Shaded cells represent statistics from SSP-funded projects. Boxed cells contain estimates that met the CTC precision standard (CV ≤ 15%) for the natural-origin portion of the aggregate stock (5 of 8).

| | | Hatchery | | Natural | | Total | | CTC |
|---|---|---|---|---|---|---|---|---|
| Year | Age | Point | CV | Point | CV | Point | CV | Total [a] |
| 2011 | 3 | 7,213 | 40% | 10,771 | 68% | 17,984 | 44% | |
| | 4 | 5,539 | 88% | 35,800 | 13% | 41,339 | 16% | |
| | 5 | 1,890 | 78% | 24,301 | 21% | 26,191 | 20% | |
| | 6 | 0 | 0 | 775 | 62% | 775 | 62% | |
| | 3–6 | 14,642 | 40% | 71,648 | 14% | 86,290 | 13% | 123,048 |
| | 4–6 | 7,429 | 69% | 60,876 | 11% | 68,305 | 12% | |
| 2012 | 3 | NA | | 21,747 | 48% | 21,747 | 48% | |
| | 4 | 2,532 | 91% | 12,368 | 25% | 14,901 | 26% | |
| | 5 | 318 | 76% | 36,600 | 17% | 36,918 | 17% | |
| | 3–5 | 2,851 | 81% | 70,716 | 16% | 73,567 | 16% | 115,625 |
| | 4–5 | 2,851 | 81% | 48,969 | 13% | 51,819 | 13% | |
| 2013 | 3 | NA | | 11,927 | 79% | 11,927 | 79% | |
| | 4 | 17,772 | 48% | 54,976 | 22% | 72,748 | 20% | |
| | 5 | 220 | 101% | 18,733 | 33% | 18,953 | 33% | |
| | 3–5 | 17,992 | 48% | 86,068 | 18% | 104,060 | 17% | 145,032 |
| | 4–5 | 17,992 | 48% | 73,709 | 17% | 91,700 | 16% | |
| 2014 | 3 | NA | | 4,492 | 79% | 4,492 | | |
| | 4 | 6,046 | 35% | 90,551 | 17% | 96,957 | 16% | |
| | 5 | 2,765 | 54% | 61,007 | 23% | 63,772 | 22% | |
| | 3–5 | 9,171 | 29% | 156,051 | 11% | 165,222 | 10% | 146,428 |
| | 4–5 | 9,171 | 29% | 151,558 | 11% | 160,729 | 10% | |

[a] Sum of estimates reported in CTC (2015), Appendix Table J1 as annual post-season escapement of hatchery and natural origin Chinook salmon and estimates of total mortality from sport fishing Oregon Coastal Inside in Table A22, CTC (2016).

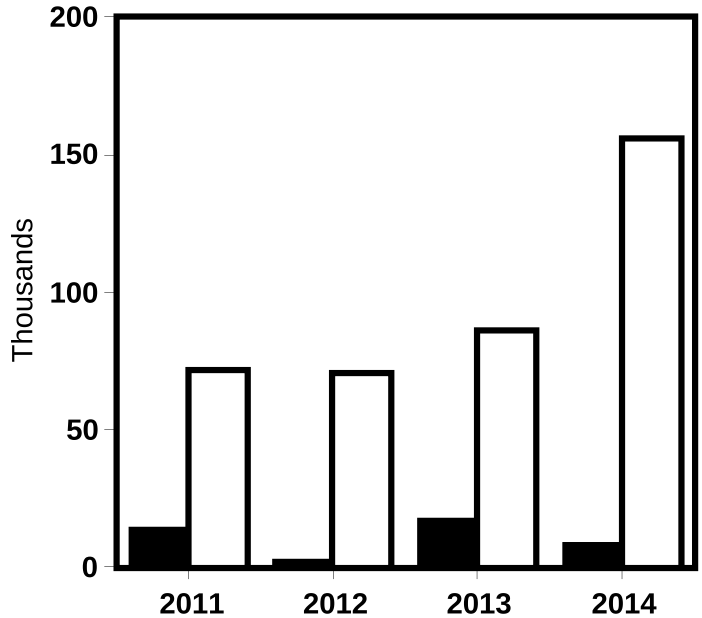



**Figure 3.33**–Terminal run size for Age 3–5 fall Chinook salmon of hatchery-origin (black bars) and natural-origin (clear bars) for the NOC stock aggregate 2011–2014 as estimated with the DSR method.

**Table 3.17**–Expanded number of Chinook salmon with CWTs recovered in SEAK sport fisheries based out of Craig and Sitka, Alaska; in spring commercial troll fisheries; and in summer troll fisheries in the southern and northern outside districts (first and second periods); and recovered from terminal areas for the Salmon River Hatchery indicator stock used to represent the NOC driver stock aggregate. NA represents years when genetic samples were not taken from a fishery. Shaded areas are instances where one or no CWTs were recovered.

| | | SEAK Fisheries | | | | | | | | Terminal Areas | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Age | NO-1 | NO-2 | SO-1 | SO-2 | SPR | CRG | SIT | Total | Harvest | Spawning | Total |
| 2011 | 3 | 17.0 | 15.1 | 0.0 | 8.8 | 1.3 | NA | 1.9 | 44.1 | 779.2 | 751.6 | 1,587.0 |
| | 4 | 207.4 | 40.9 | 46.5 | 23.5 | 8.7 | NA | 18.2 | 345.2 | 533.4 | 1,044.5 | 1,973.4 |
| | 5 | 61.2 | 8.6 | 12.7 | 8.8 | 3.2 | NA | 9.3 | 103.8 | 136.7 | 174.8 | 436.6 |
| 2012 | 3 | 0.0 | 46.0 | 0.0 | 3.1 | NA | 0.0 | 0.0 | 49.1 | 324.6 | 621.0 | 997.7 |
| | 4 | 64.8 | 205.3 | 47.9 | 39.8 | NA | 10.1 | 1.1 | 368.9 | 394.9 | 540.7 | 1,355.4 |
| | 5 | 31.1 | 28.3 | 30.5 | 6.1 | NA | 4.6 | 1.2 | 101.7 | 133.4 | 257.5 | 504.5 |
| 2013 | 3 | 9.7 | NA | 0.0 | NA | NA | 0.0 | 0.0 | 9.7 | 518.6 | 1,437.4 | 1,965.7 |
| | 4 | 196.4 | NA | 89.3 | NA | NA | 30.1 | 5.0 | 320.9 | 1,171.9 | 2,784.5 | 4,312.5 |
| | 5 | 25.8 | NA | 4.7 | NA | NA | 7.0 | 1.0 | 38.4 | 83.6 | 163.7 | 293.6 |
| 2014 | 3 | 0.0 | 11.1 | 5.4 | 2.6 | NA | 0.0 | 0.0 | 19.4 | 572.6 | 1,376.0 | 1,948.6 |
| | 4 | 461.1 | 81.4 | 54.4 | 44.4 | NA | 3.2 | 48.8 | 693.3 | 1,096.2 | 3,464.5 | 4,560.7 |
| | 5 | 125.8 | 14.8 | 21.8 | 23.5 | NA | 0.0 | 16.6 | 202.5 | 528.1 | 1,363.6 | 1,891.7 |

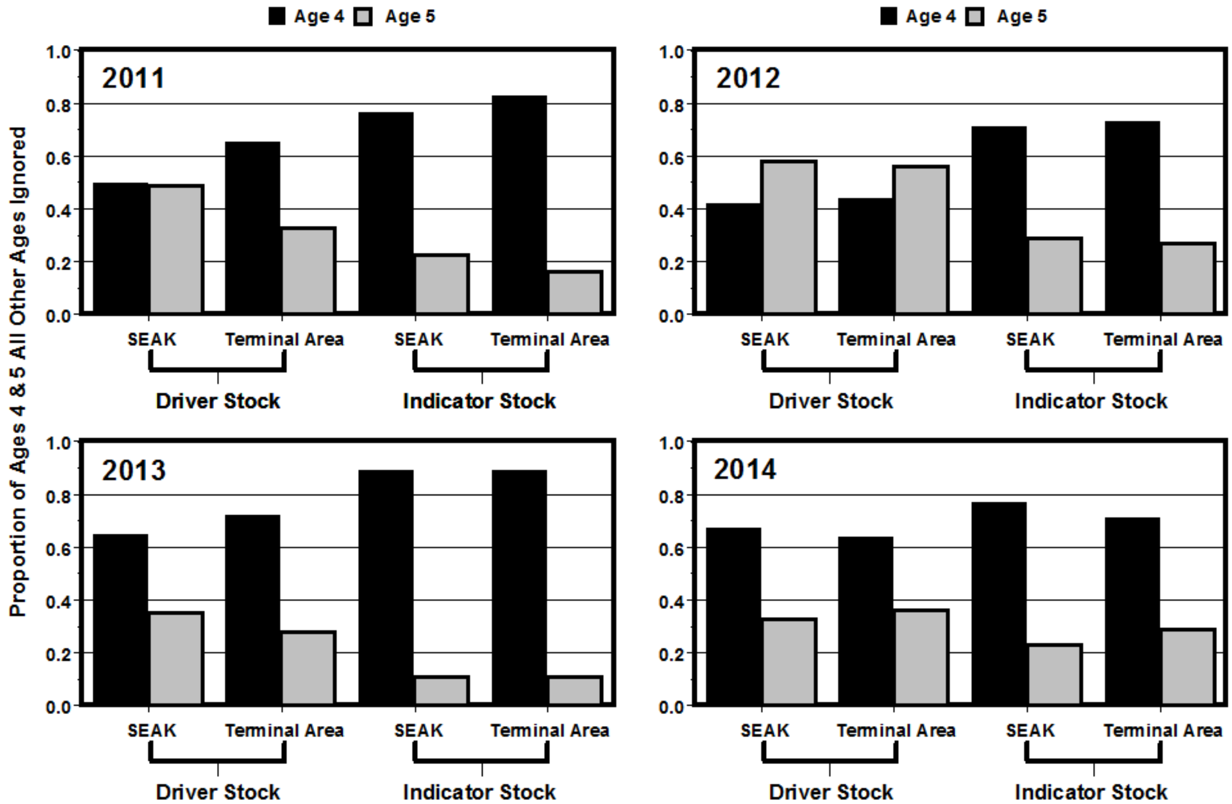



**Figure 3.34**–Relative age compositions of four and five-year old, natural-origin NOC Chinook salmon comprising driver and indicator stocks in 2011 and 2012 as estimated in SEAK fisheries and in terminal areas in 2011 and 2012.

In summary, the SSP has learned the following about estimating the aggregate terminal run size of NOC Chinook salmon with the DSR method using data from SEAK fisheries:

- Salmon tagging in hatcheries outside of the Salmon River Hatchery is insufficient in many years to segregate hatchery-origin 3-year olds from the total run;
- Catch sampling and escapement sampling programs are:
  - sufficient to produce estimates of terminal run size with a precision that meets or almost meets the CTC standard for precision; and
  - sufficient to apply diagnostic tests to find evidence of violating the core assumption of the method; Accuracy of estimates could be improved by analyzing enough genetic markers to assign a stock origin to individual salmon taken in genetic sampling in lieu of a mixture analysis;
- Estimates of NOC terminal run size from the DSR method are:
  - consistent with terminal run size of hatchery-origin Chinook salmon being a relatively minor portion of the overall run size to the north Oregon Coast; and
  - comparable to terminal run sizes used by the CTC in most years; and
- Estimates from the DSR method are consistent with the NOC aggregate having rebounded from its low in 2008–2009.

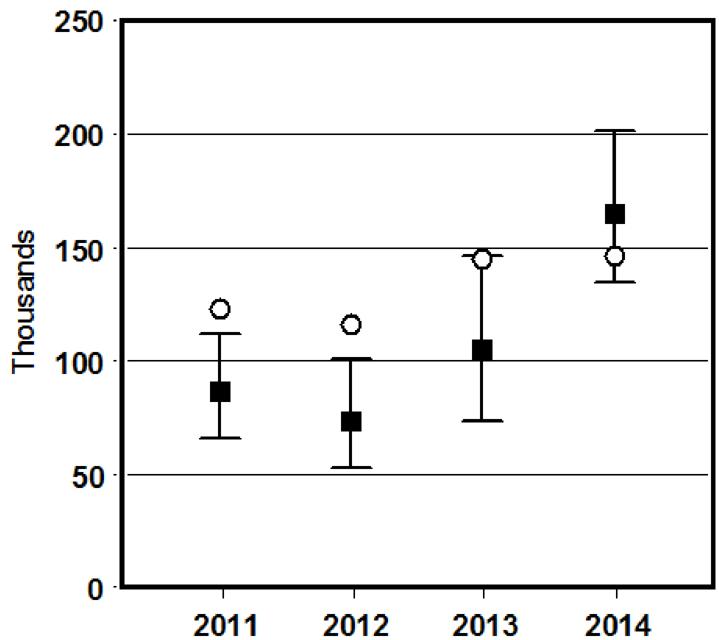



**Figure 3.35**–Estimates of terminal run size for the NOC aggregate (hatchery plus natural) of Chinook salmon stocks for combined ages 3–5 for 2011–2014 hatchery and natural-origin stocks combined from the DSR method. Closed squares (■) represent estimates using the DSR method and intervals their 95% confidence intervals. Open circles (**o**) represent a comparative statistic on terminal run size used by the CTC as reported in Appendix Table J1 of CTC (2015) and Table A22 of CTC (2016). Confidence intervals were derived as lognormal approximations.

# 4 LEVERAGING RESULTS

## 4.1 Calibration with Indices

The SSP developed many high quality escapement estimates for several rivers coast-wide that can be compared to escapements estimated with standard agency methods. Often agency "standard" methods—typically a visual count of an unknown portion of an adult population—were used to calculate escapement indices that were biased, of unknown quality, but were relatively cheap to generate. Because of their low cost, standard methods will likely be used in the future regardless of their unknown bias and unknown precision. Fortunately, a few relatively high-cost abundance estimates can be used to leverage many low-cost indices to improve the cost effectiveness of stock assessment. Conversion of visual indices into higher quality or known-quality estimates is called calibration, and is the process of finding statistical relationships between those visual indices that an agency may generate and more costly independent escapement estimates (e.g., from MR studies). In the future such a statistical relationship would be used produce a relatively unbiased abundance estimate from a low-cost visual index.

Section 4 provides examples of calibrations for Chinook salmon stocks of the Oregon Coast, Fraser River, and Puget Sound. These calibrations are based not only on results from SSP-funded projects, but also on results from other special PSC-funded projects including those funded through the U.S. LOA for work conducted in Puget Sound and Oregon. Additional years represented by non-SSP funded studies widened the range of conditions upon which statistical relationships were derived making those relationships better predictors.

### 4.1.1 *The Oregon Experience*

Oregon has been conducting standardized Chinook salmon surveys (visual counts) throughout its coastal basins for over the past 60 years. Annual escapement estimates and currently-adopted CTC escapement goals are based on expansions of counts from those visual surveys (Zhou and Williams 1999, 2000). Beginning in 1999, the U.S. LOA process funded MR studies to produce unbiased, precise abundance estimates of spawning Chinook salmon in Oregon streams. At first, these MR studies were initiated in the Nehalem and Siuslaw basins with subsequent studies throughout coastal Oregon. In 2009, funding was procured through the SSP to continue ongoing MR studies. Results from both U.S. LOA and SSP-funded studies together were used to construct a new expansion of visual counts through calibration.

Construction of this new expansion had two goals. The first was to determine the appropriate visual index from spawning ground surveys that best correlates with true spawner abundance as determined from MR studies. Traditional agency indices have relied on static, unchanging sections or rivers that have been consistently surveyed, and exploration beyond these areas was needed to confirm that indices derived from these areas could provide represented escapements. This approach initially focused on utilizing "peak counts" (PCs) of both live and dead fish surveyed at regular intervals to provide a metric to compare to MR estimates, as well as other visual metrics (e.g. numbers of redds). However, the focus of investigation was not limited to peak counts, and this broader approach proved to be valuable in later analysis.

The second goal was the determination of a statistical relationship between the appropriate visual index and abundance estimates from MR studies. The relationship would be used not only to estimate spawning abundance in the future, but also to adjust past expansions to improve the time series of past estimates.

#### 4.1.1.1 **Siletz: A Case Study in Improvement through Time**

Indices of Chinook salmon abundance derived from the historically conducted survey areas on the Siletz River didn't seem to track with MR estimates. Years of study prior to SSP funding had shown that traditional survey areas had not encompassed the diversity of habitat that Chinook salmon are known to use during spawning. Historical survey areas were exclusively in tributaries. Initial calibrations using PCs from these traditional areas looked similar to what is represented in Figure 4.1.

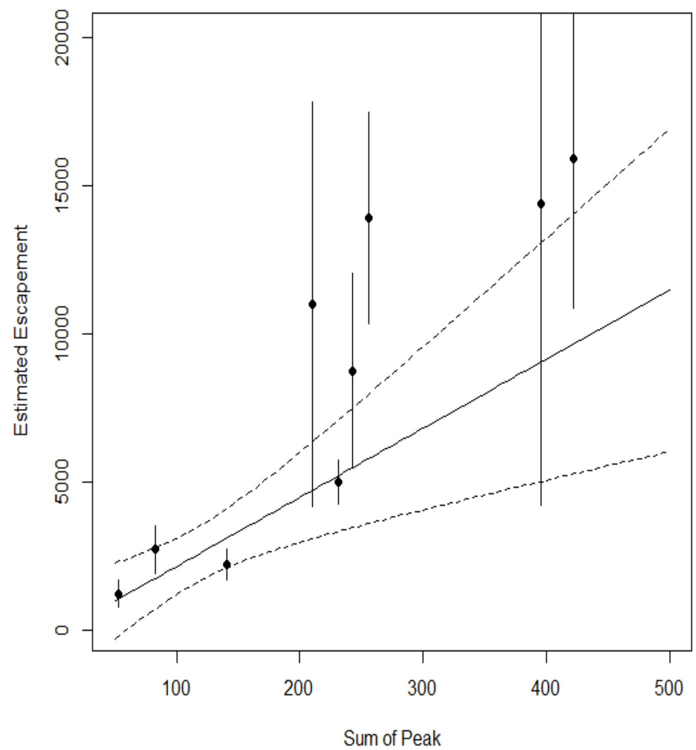



**Figure 4.1**–A WLS regression between the sum of peak counts of all (live and dead) Chinook salmon observed among multiple surveys each year in standard survey areas (X) and the MR estimated escapement for the Siletz River (Y). The regression has an adjusted $R^2$ of 0.65. Solid lines represent 95% CIs for MR estimates; dashed lines the 95% CIs for the regression.

Without any survey areas in the mainstem Siletz River, a sizeable portion of the population had not been represented in surveys. With additional survey areas in the mainstem added to the calibration, the revised WLS regression between PCs and MR-estimated spawning escapement was improved, as seen in Figure 4.2. Not quite satisfied as yet with the strength of the relationship, ODFW analysts (Brian Riggers) continued to search for an index that more closely followed the MR estimates of escapement. A third WLS regression was calculated using sums of cumulative counts of carcasses in traditional and mainstem survey areas (Figure 4.3). Table 4.1 contains the data used in the calibrations.

A calibration approach simpler than WLS regression was also employed—a calibration factor determined as the mean of ratios of survey counts to MR estimates (Table 4.1). Using PCs from traditional and the new mainstem survey areas, the mean expansion factor is 34.4 (CV=45%). Using cumulative counts of Chinook salmon carcasses in the same survey areas, mean expansion factor is 48.0 (CV=35%). Calculation of CVs include both process error across years and measurement error in MR estimates.

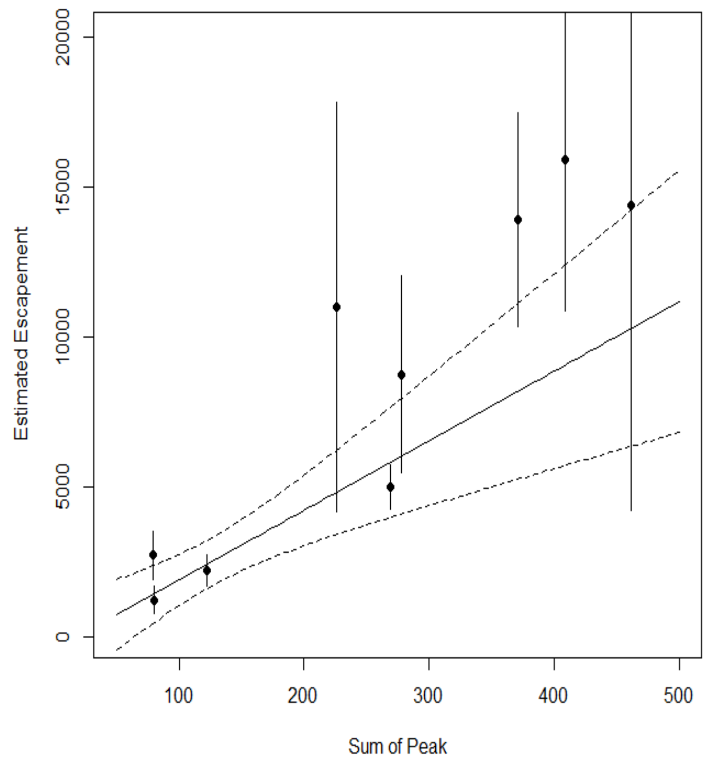



**Figure 4.2**–A WLS regression between peak counts of all (live and dead) Chinook salmon observed among multiple surveys each year in both standard and additional survey areas (X) and MR estimated escapement for the Siletz River (Y). The regression has an adjusted $R^2$ of 0.73. Solid lines represent 95% CIs for MR estimates; dashed lines the 95% CIs for the regression.

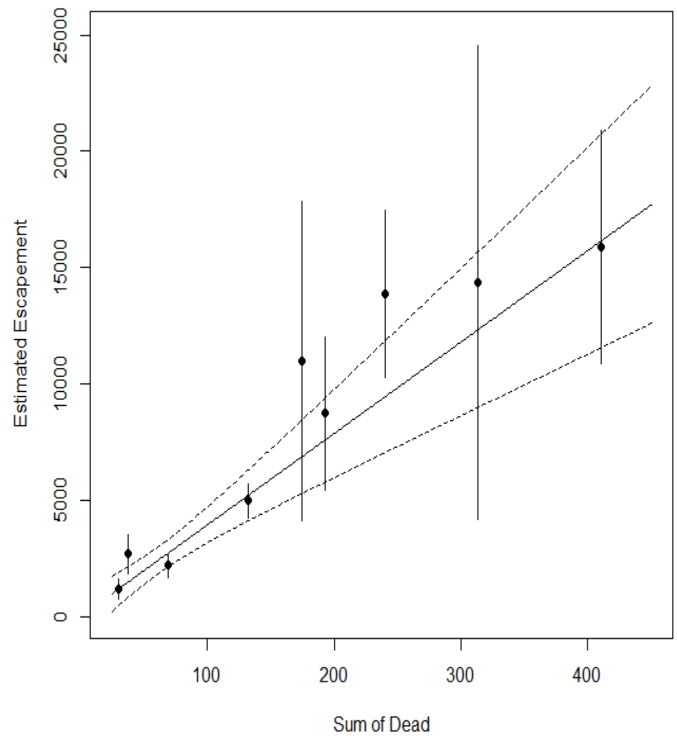



**Figure 4.3**–A WLS regression between the cumulative sum of dead Chinook salmon observed over multiple surveys each year in both standard and additional survey areas (X) and MR estimated escapement for the Siletz River (Y). The relationship has an adjusted $R^2$ of 0.86. Solid lines represent 95% CIs for MR estimates while dashed lines the 95% CIs for the regression.

**Table 4.1**–Mean calibration factors to transform Chinook salmon counts into unbiased estimates of spawning abundance on the Siletz River. Factors are based on multiple surveys per year over traditional and newly added survey areas. MR estimates are described in § 3.5.2.

| Year | Peak Counts (All Salmon) | Calibration Factor (MR Est/Peak Counts) | Cumulative Dead Counts | Calibration Factor (MR Est/Cumulative Dead Counts) | MR Estimate | SE |
|---|---|---|---|---|---|---|
| 2005 | 396 | 36.25 | 313 | 45.9 | 14,355 | 5,188 |
| 2006 | 422 | 37.66 | 410 | 38.8 | 15,891 | 2,564 |
| 2007 | 83 | 32.53 | 38 | 71.1 | 2,700 | 419 |
| 2008 | 53 | 22.96 | 30 | 40.6 | 1,218 | 227 |
| 2009 | 141 | 15.70 | 69 | 32.1 | 2,213 | 268 |
| 2010 | 210 | 52.31 | 175 | 62.8 | 10,985 | 3,488 |
| 2011 | 231 | 21.58 | 132 | 37.8 | 4,985 | 382 |
| 2012 | 243 | 35.96 | 193 | 45.3 | 8,738 | 1,676 |
| 2013 | 256 | 54.21 | 240 | 57.8 | 13,878 | 1,822 |
| Mean Factor | | **34.4** | | **48.0** | | |
| CV | | 45.3% | CV | 35.2% | | |

Predictability of spawning abundance in the Siletz River was arguably good regardless of the approach used in making the prediction (Figure 4.4). Three predictions were made for each year with a MR estimate—one prediction using a mean calibration factor involving PCs (Table 4.1), another a mean calibration factor involving carcass counts (Table 4.1), and a third the WLS regression described in Figure 4.3. All predictions were based on data from the same survey areas, and all predictions were made with jackknife (leaving-one-out) hindcasting. Of the 9 years for comparison, the two methods based on calibration factors put 6 predictions within the 95% CIs around MR estimates; 7 of 9 hits were recorded using the WLS regression. In the four years with the tightest CIs (2007–2009 and 2011), only one hit occurred for the calibration factor based on dead fish, two hits with the calibration factor based on PCs, and three hits with the WLS regression. While the WLS regression appears to do slightly better than the calibration factors, all three methods picked up the drop in spawning abundance between 2006 and 2007 and the steady increase in the following years.

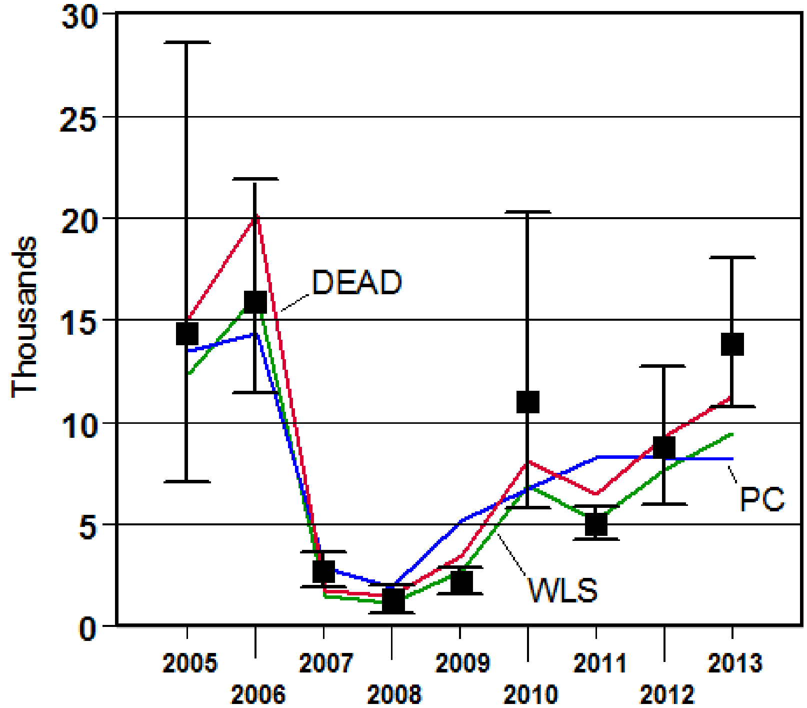



**Figure 4.4**––Predictions of spawning abundance of Chinook salmon in the Siletz and Siuslaw rivers against estimated spawning abundance from U.S. LOA and SSP-funded MR studies. Predictions (colored lines) were made from the two calibration factors based on peak counts (PCs—blue line) and on cumulative sum of DEAD salmon (red line) from standard agency surveys, and from the WLS regression (green line) using the sum of dead counts. All predictions were made with jackknife (leaving-one-out) hindcasting. Intervals are lognormal 95% CIs around MR estimates (■).

#### 4.1.1.2 **Siuslaw: Another Successful Calibration**

Initial analysis showed that no additional survey areas needed to be considered in calibrating results from standard surveys to MR estimates for the Siuslaw River stock of Chinook salmon (see Table 4.2 for data). Weighted least squares regression of MR estimates against PCs for six years proved to be exceedingly precise (Figure 4.5). Also, a mean of the ratios MR estimates/PCs over the same six years was also precise (19.9 with a CV=16%). Calculation of CVs for this mean calibration factor included both process error across years and measurement error in MR estimates within years.

Predictability of spawning abundance in the Siuslaw River was good regardless of the approach used to make predictions (Figure 4.6). Two predictions were made for each year with an MR estimate—one prediction using a mean calibration factor involving PCs (Table 4.2), and a second the WLS regression described in Figure 4.5. All predictions were based on data from the same survey areas, and all predictions were made with jackknife (leaving-one-out) hindcasting. Both approaches to calibration gave almost identical predictions. Of the 6 years for comparison, both approaches put 5 predictions within the 95% CIs around MR estimates. The only exception was 2003 for which predictions were higher than the 28,801 MR estimate. Interestingly, predictions were "spot on" the MR estimate for the following year with a similar 29,119. Such a dichotomy is consistent with the over prediction for 2003 being due to random chance as opposed to depensatory counts in the traditional survey.

**Table 4.2**–Mean calibration factors to transform Chinook salmon counts into unbiased estimates of spawning abundance on the Siuslaw River. Factors are based on multiple surveys per year over traditional survey areas. MR estimates are described in § 3.5.3.

| Year | Peak Counts (All Salmon) | Calibration Factor (MR Est/Peak Counts) | MR Estimate | SE |
|---|---|---|---|---|
| 2002 | 1,180 | 19.07 | 22,506 | 1,600 |
| 2003 | 1,764 | 16.33 | 28,801 | 2,341 |
| 2004 | 1,510 | 19.28 | 29,119 | 2,598 |
| 2005 | 614 | 22.43 | 13,771 | 1,302 |
| 2006 | 594 | 22.53 | 13,380 | 1,249 |
| 2014 | 836 | 19.61 | 16,395 | 3,291 |
| Mean Factor | | **19.9** | | |
| CV | | 16.4% | | |

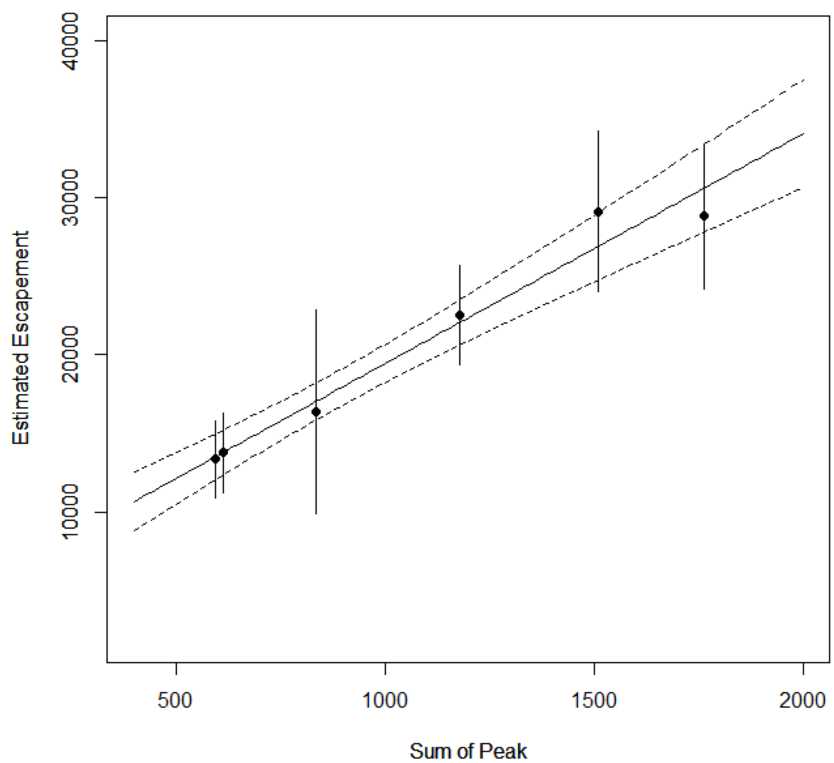



**Figure 4.5**–A WLS regression between the sum of peak counts of all (live and dead) Chinook salmon observed among multiple surveys each year in standard survey areas (X) and the MR estimated escapement for the Siuslaw River (Y). The regression has an adjusted $R^2$ of 0.97. Solid lines represent 95% CIs for MR estimates; dashed lines the 95% CIs for the regression.

### 4.1.2 *The Fraser River Experience*

The PC method is the most frequent way that escapements of Fraser River Chinook salmon have been estimated since 1975. Generally, rivers are surveyed, often by helicopter, two or three times during the peak of spawning activity and then the date with the highest combined count of spawners, holders, and carcasses is multiplied by an expansion (calibration) factor (Bailey et al. 2000; Parken et al. 2003). However, some of the historic estimates can be based on a variation of the PC method, e.g. inclusion of empty redds. The PC expansion factor is based on studies conducted during the 1980s at two Fraser River tributaries (Farwell et al. 1999). Since then, several studies have examined the calibration of escapement estimates generated with PC and more accurate methods when opportunities arose, as they did with the SSP-funded South Thompson project on the Middle and Lower Shuswap rivers.

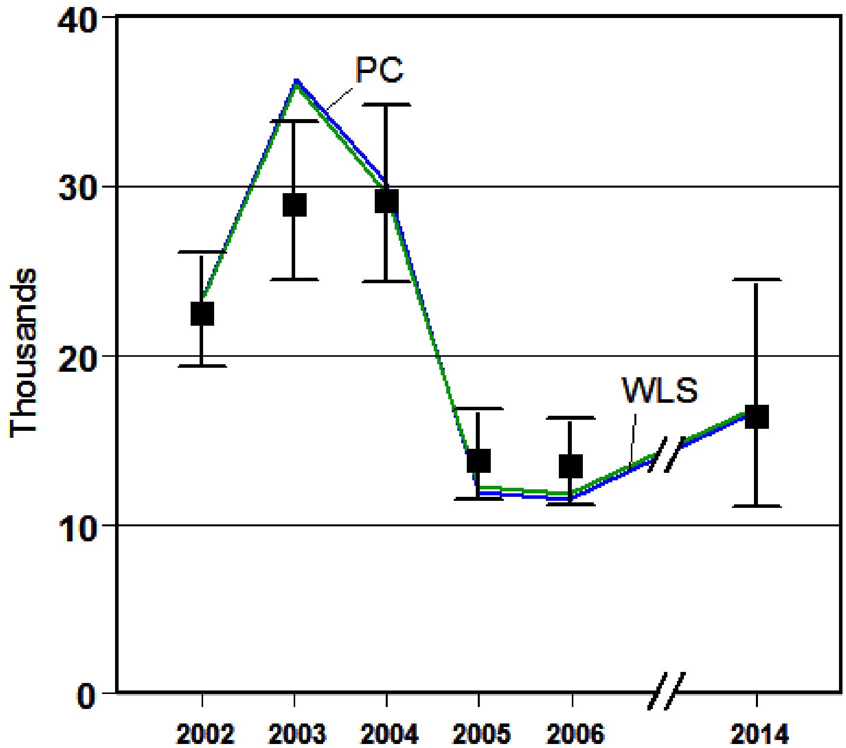



**Figure 4.6**–Predictions of spawning abundance of Chinook salmon in the Siuslaw River against estimated spawning abundance (®) from U.S. LOA and SSP-funded MR studies. Predictions were made from the calibration factor in Table 4.2 (PC) and from the WLS regression as per Figure 4.5. All predictions are based on peak counts from traditional survey areas. All predictions were made with jackknife (leaving-one-out) hindcasting. Bands are lognormal 95% confidence intervals around MR estimates.

#### 4.1.2.1 <u>Shuswap Rivers</u>

At present the data from the Middle Shuswap River is judged insufficient to reliably calibrate PCs to MR estimates. Concurrent PC and MR methods have occurred for nine years 2006-2014 on the Middle Shuswap River with eight having normal environmental conditions and one with unusually high river levels and low water clarity. Under the usual environmental conditions there was a strong relationship between the natural log PC and natural log MR estimates ($R^2 = 0.91$; Figure 4.7). However, most of the calibration data are for small escapements (only one year had a large escapement). Thus, additional years of concurrent estimates of large escapements are needed to produce a reliable calibration for the Middle Shuswap stock.

Distribution of escapement sizes was more comprehensive for the Lower Shuswap stock and was better suited to calibration. Seventeen years of concurrent PC and MR escapement data beginning in 1983 is available for the Lower Shuswap River. Because MR estimates have similar CVs, both PC and MR estimates were natural log-transformed and regressed to estimate an expansion factor. However, a pattern persisted in the residuals that indicated a change in the counting technique beginning in 2007. When these data were coded for the time period from 1983-2006 and 2007-2014, time series patterns were more evident (Figure 4.8), and the calibration relationships differed significantly. The MR estimates were always greater than the PC estimates from 1983–2006, whereas, in the 2007-2014 period, half of the MR estimates were greater than the PC estimates. Therefore, multiple regression was used to generate the calibration relationship, since the slopes of the relationships were similar (ANCOVA: $P = 0.429$), but intercepts differed (ANCOVA: $P < 0.001$). The revised the time series of escapement estimates consist of MR estimates and calibrated PC estimates (Figure 4.9).

#### 4.1.2.2 **Meta-analysis Calibration**

One potential benefit of the SSP-funded studies in the Fraser River Watershed is that results can be leveraged to have application beyond the stocks studied. Counting conditions are common to the Middle Shuswap, Lower Shuswap, and Chilko rivers—broad rivers and clear waters. Meta-analysis of the results from the SSP studies and corresponding PCs indicates there is a common calibration relationship across all three rivers (Figure 4.10). This common relationship could be used to expand PCs in other rivers with similar counting conditions but without independent abundance estimates, rivers like the Nechako, Clearwater, Quesnel, Cariboo, Stuart, Little, South Thompson, and the Lower Adams. Such a “general” calibration could be used to expand past and future PCs from these rivers to produce estimates of spawning abundance. Another benefit of the hierarchical modelling technique used in this meta-analyses is that river-specific calibration relationships can be strengthened by borrowing information among the rivers.

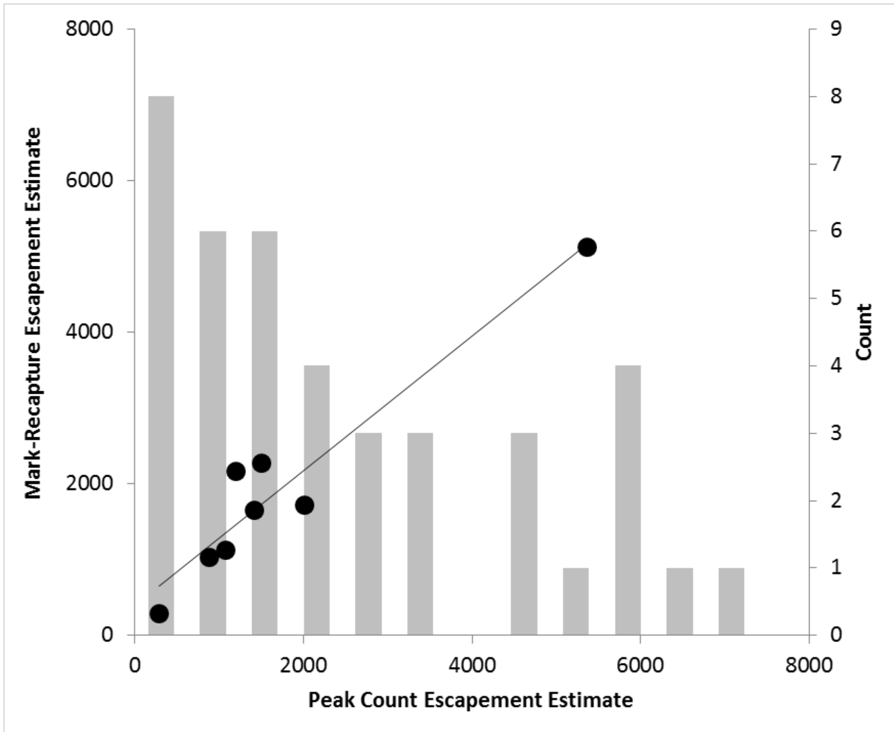



**Figure 4.7**–PC escapement estimates versus MR estimates of escapement for Chinook salmon in the Middle Shuswap River, 2006 to 2014 (circles), with 2010 excluded due to unusual environmental conditions. The histogram illustrates the frequency distribution for 40 peak counts (1975–2014) in bins of 500 spawners. The PC escapement estimate is a PC expanded with information from Farwell et al. 1999.

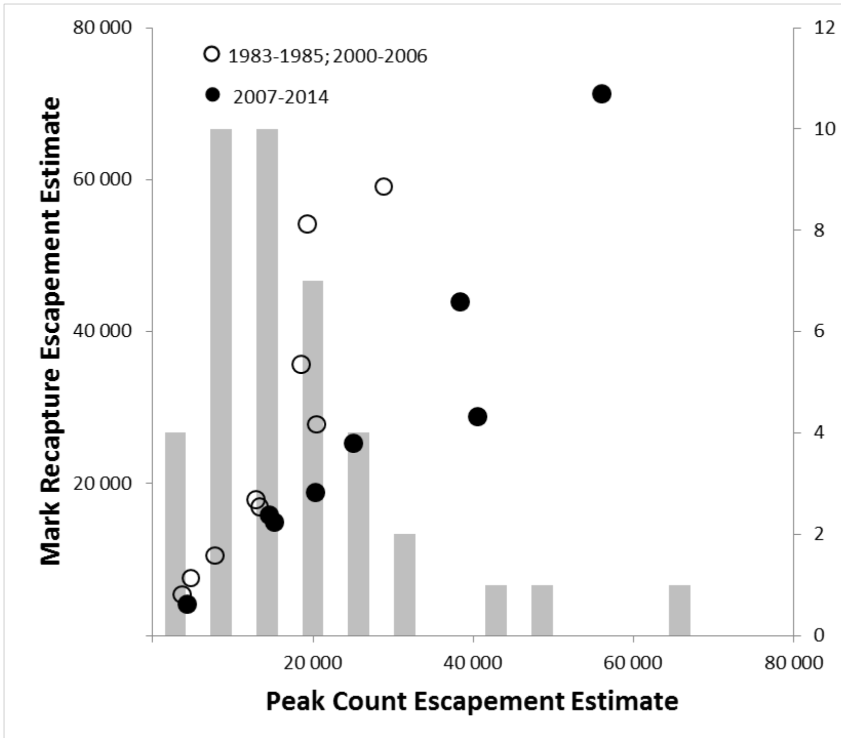



**Figure 4.8**–Peak count escapement estimates and the mark-recapture escapement estimates for the Lower Shuswap River during 1983-2006 (open circles) and 2007-2014 (solid circle). The histogram illustrates the frequency distribution for 40 peak count escapement estimates (1975-2014) in bins of 5000 spawners. The PC escapement estimate is a PC expanded with information from Farwell et al. 1999.

### 4.1.3 *The Puget Sound Experience: Stillaguamish River*

Since redd counts are the most common method of monitoring Chinook salmon populations in Washington, developing an improved expansion factor for redd counts (see Murdoch et al. 2009 and Rawding et al. 2014 for details) may have broad application across Puget Sound and the state. In the Stillaguamish Basin, redd surveys were conducted by both the Stillaguamish Tribe and WDFW. Surveys were scheduled over the spawning period from late August through late October and covered the entire spawning distribution. To provide a total abundance estimate, all observed redds are summed and multiplied by an expansion factor of 2.5 to account for the number of fish associated with a redd.

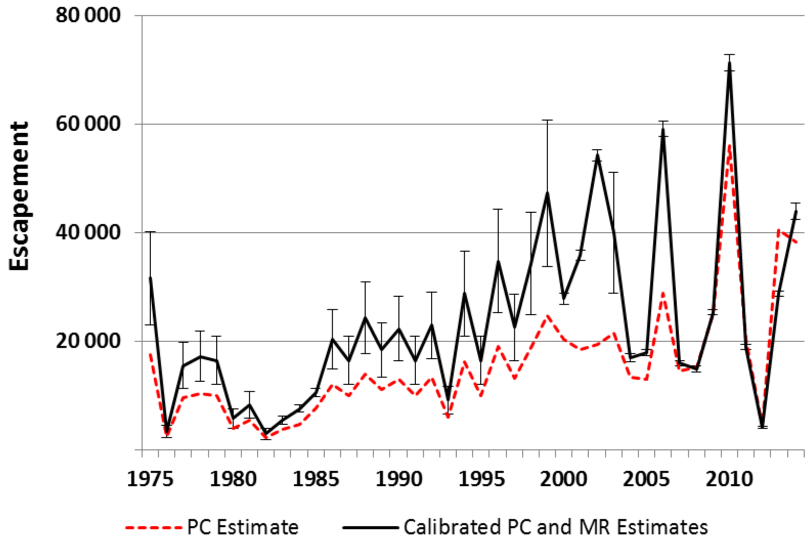



**Figure 4.9**–Comparison of PCs of Chinook salmon in the Lower Shuswap River and the revised time series of calibrated PC and MR estimates. Bars represent 95% CIs. The PC estimate is a PC expanded with information from Farwell et al. 1999.

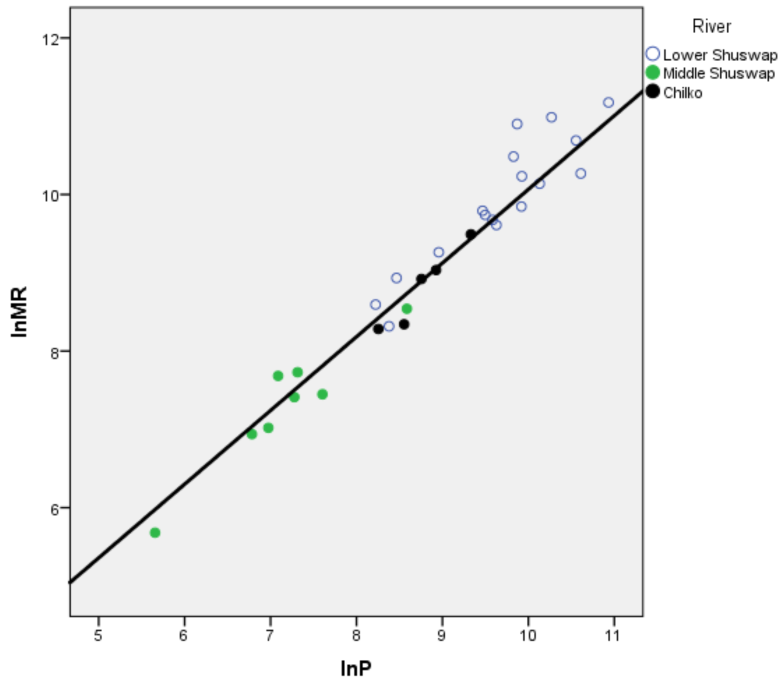



**Figure 4.10**–The natural log of PCs of escapement (lnP) and the natural log of MR escapement estimates (lnMR) for the Lower Shuswap, Middle Shuswap, and Chilko rivers during 1983 - 2014. The calibration relationship line was estimated using a hierarchical Bayesian model (code developed by Kery 2010).

Redd surveys are prone to have missing data. Although weekly surveys were planned for the Stillaguamish River over the entire known spawning distribution for 2007–2013, only 37% to 56% of the scheduled surveys could be implemented (Rawding et al. 2015). Most missed surveys were missed due to high-flow turbidity in the mainstem index areas and to insufficient resources to survey all tributary index areas.

Rawding et al. (2015) proposed a two-step approach to develop a better way to handle missing data and an improved redd-expansion factor using tGMR estimates. First, redd counts were adjusted for missed surveys with a modified hierarchical Bayesian model developed by Su et al. (2001) to account for missed surveys. This model had the following assumptions:

- weekly pattern of redd construction (e.g. spawning) in each surveyed reach was normally distributed (Hill 1997, Hilborn et al. 1999);
- mean spawning date and the standard deviation of the normal distribution for all reaches within a year was from a common mean spawning date and standard deviation for the entire population (Su et al. 2001); and
- redd counts in each surveyed reach had a normal error structure (Hilborn et al. 1999).

The second step involved regressing the tGMR estimates against the redd counts adjusted for missed surveys for brood years 2008 to 2012[5] (Figure 4.11). The new expansion factor was 2.39 (SD=0.21) fish per redd, not far from the traditional 2.5.

Abundance estimates from tGMR studies and from adjusted redd were not surprisingly very similar for all years and larger than the traditional redd based estimates (Figure 4.12). The similarity is understandable once redd counts have been adjusted for missing data in that tGMR estimates were used to create both estimates. Since the tGMR-generated expansion factor (2.39) is similar to the traditional factor (2.5), the major cause behind the lower abundance in traditional redd-based estimates is due mostly to missed surveys. That difference is minor in all years except for 2012 (see Figure 4.12)

In summary, the SSP-funded studies on the Stillaguamish River have provided a new and improved expansion factor for redd counts for that stock. Along with adjustments for missing counts proposed by Rawding et al. (2015), the expansion factor can be used to cheaply provide relatively unbiased estimates of spawning abundance along with measures of uncertainty. However, the parametric imputation of data for missing surveys has its limits, as can be seen for the parametric AUC expansions for stream counts developed as part of the WCVI Assessment Framework (§§ 3.3.9, 3.3.6, and 3.3.7).

[5] Data from 2007 were excluded from the analysis because redd counting methods were standardized after that year.

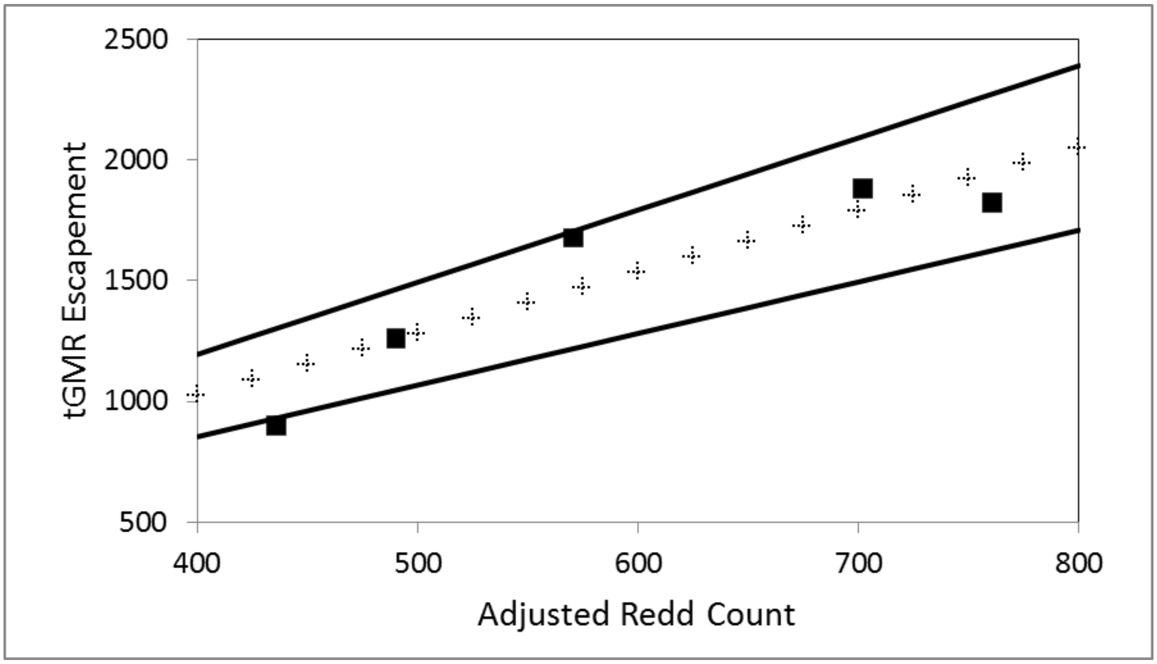



**Figure 4.11**–tGMR escapement (abundance) estimates regressed against redd counts adjusted for missing data for brood years 2008–2012 of the Stillaguamish stock. Solid back lines are 95% CIs, grey +'s represent the predicted fit, and black squares the data.

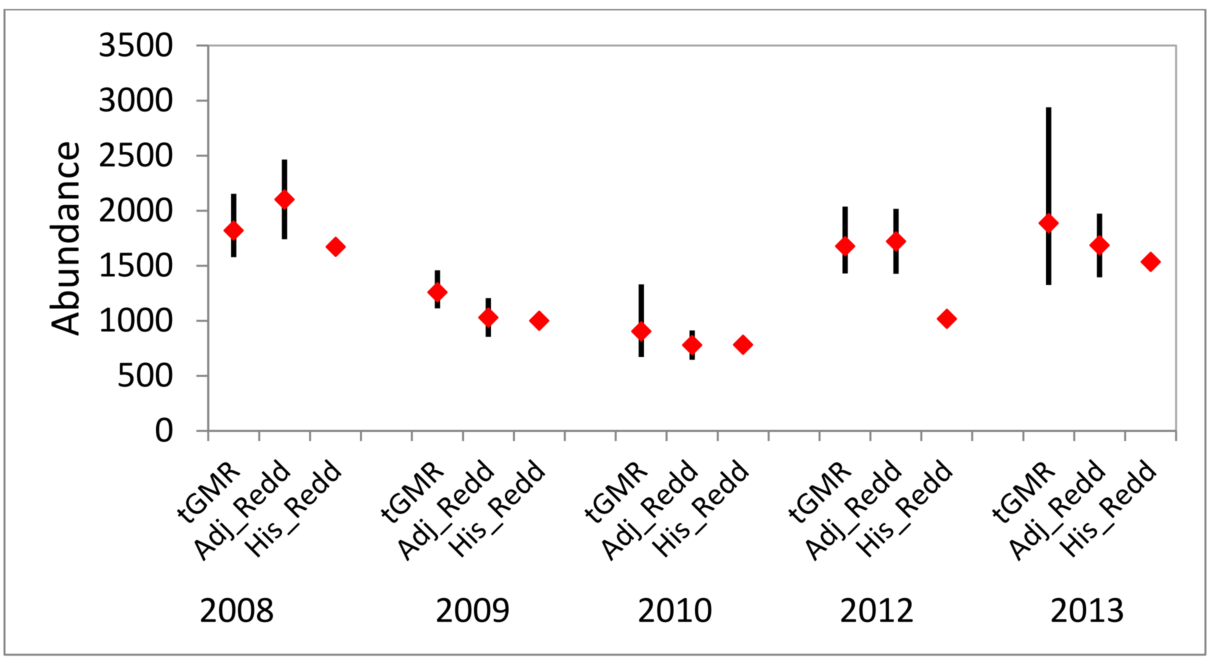



**Figure 4.12**–Abundance (escapement) estimates for Chinook salmon spawning in the Stillaquamish River derived from tGMR studies alone, from adjusted redd counts expanded by a factor of 2.39 (Adj_Redd), and from the historical method (Hist_Redd) of redd-count expansion (redd counts unadjusted for missing data multiplied by 2.5). Black lines are 95% CIs.

## 4.2 Use of Historical Records

Successful SSP projects sometimes provided opportunities to expand our knowledge well beyond expectations—sometimes even back in time. The project involving expansion of the abundance estimate for the Kitsumkalum sub-stock to an estimate for the entire Skeena River is just such an example (§ 3.1.2.1). Studies on the Kitsumkalum River and the Tyee Test Fishery have involved sampling Chinook salmon for decades with sampled scales used to determine age of individual fish. These scales were fortuitously archived when collected without full knowledge of the future uses of these collections. The SSP provided the funds to genetically determine the sub-stocks from these scales years later, and as a result, a time series of estimated terminal run sizes now exists stretching back decades before the inception of the SSP (Table 3.3 and Figure 3.4). While scales were being collected in the Skeena River, they were also collected in ocean fisheries in SEAK and NBC. These scales were also archived and await genetic analysis, and once analyzed, there could be a complete reconstruction of the Skeena River run for the past 30 some years. Such a time series will produce considerable insights into the productivity of this important stock of Chinook salmon.

Perhaps more important than the advances made in estimating annual run size to the Skeena River is the template this project provides for understanding the productivity of many other Chinook salmon stocks. Archiving scales is a common practice. Provided that good documentation and scientific design practices were followed for the sample collection, all that is often required are the funds to do the genetic analysis. Such funding of genetic analysis funded by the SSP for the Skeena River project showed how to proceed.

Historical data records and archived scale collections from Skeena River Chinook salmon were used successfully to generate escapement estimates from 1984 to 2014. The availability of the historic sample data and archived scale samples were essential to the project. Three sets of data informed the estimation procedure:

- Tyee Test Fishery capture and sample information;
- scale sample archives; and
- Kitsumkalum River Chinook mark-recapture information.

Beneficial attributes of the historic test fishery data were that they existed in formats that were readily available for analyses. Beneficial attributes of the scale samples were that they were archived in a manner[6] such that they could be recovered and matched to the capture data. While these connections seem obvious it is exceedingly common for the links between historic records to be eroded over time, either through error or by changes in technology. In the case of the Skeena River project, the strengths were a well-designed test fishery, a well maintained database of capture information from the test fishery, and a highly effective database and archival system for the preservation and recovery of scale samples. The extraction of genetic material from scales was a relatively recent development and would not have been possible if not for the forethought by those that created the scale archival system. Accessibility was a key feature of that scale archival system.

Mark-recapture data for the Kitsumkalum sub-stock were readily available, but not so for the data from the Tyee Test Fishery (i.e. the data were not in a common format). Data from most of the years prior to 1999 had to be captured from the raw data sheets. Individual tag identification was not available for data from 1987. Revisiting the data revealed some errors and a common problem was the incorrect assignment of fish attributes in the tag application sample and the tag recovery sample. For example, a fish encountered during tag application may have been assigned a different gender than when that fish was subsequently recovered.

[6] The process of determining ages from scales included making acetate impressions, maintaining a database, archiving the scales and the acetate impressions. Pressing the scales to produce acetate impressions appeared to help preserve the DNA in the scales (John Candy, personal communication).

Significant efforts were made to standardize the historical Kitsumkalum data records, and this work was still underway at the time of this writing.

The success of the Skeena SSP project demonstrates the value of good sampling design coupled with sample preservation and data maintenance. These attributes allowed for analyses and results well beyond the initial intent of the programs involved.

# 5 UNCERTAINTY

The CTC bilateral standards for estimating annual escapements for stocks or stock groups acknowledges two general components of uncertainty:

- relative error induced by random sampling (imprecision); and
- directional error as either negative or positive bias.

Each of these sources of uncertainty can have negative impacts on management of Chinook salmon fisheries under PSC jurisdiction. A simple cohort-based model was developed to illustrate such potential impacts from a representative range of imprecision and bias in estimated spawner abundance on selected management applications. Analyses with this model were designed to provide insights on a particular management question:

> *How might different combinations of environmental and sampling variability affect annual status evaluations and estimation of stock/recruit reference points?*

"Annual status evaluations" are those used by the CTC in their synoptic plots published annually in their catch and escapement reports (see CTC 2015). "Estimation of stock/recruit reference points" involves generating short-series of "estimated" spawner abundance through simulation using known reference points, then fitting a stock/recruit function to those series to estimate "virtual" reference points influenced by imprecision and bias. Errors in estimating spawner abundance can have impacts on other key management applications as well, such as pre-season forecasts and exploitation rate calculations, however, the analyses described in § 5 are limited to CTC status evaluations and to reference points.

## 5.1 Simulation Model

The simulation model used here is heuristic in that it does not specifically represent any one particular population. The model incorporates a Ricker stock-recruit production function populated with productivity, capacity, and age structure parameters that reflect values within the ranges estimated for stock groups covered in CTC annual reports (Table 5.1). The stock-recruit function contains a random (lognormal) variable "ε" representing environmental influence on production, the values of which reflect the EV indices reported by the CTC (2015) (Table 5.1). Production by a brood year is divided according to average maturation rates (Table 5.1) to mimic average age-at-return patterns typical of Chinook salmon populations in the Pacific Northwest. These age-at-return patterns define age composition of an annual run. Spawning abundance for the next generation of salmon is calculated by applying annual exploitation rates to each annual run. Such calculations are based on the condition that annual exploitation rates are measured without error even though random sampling errors in estimating annual escapement do accumulate and impact estimates of total recruitment and annual exploitation rates. All simulations assume a target exploitation rate (U) equal to 80% of the UMSY for the hypothetical stock.

Basic analysis consists of 45 scenarios for which the simulation model is used to generate 500, 30-year time series of escapements (spawning abundance) for each scenario (see Figure 5.1).

**Table 5.1**–Simulation model parameter and scenario summary. Ricker function includes lognormal environmental error term.

## Simulation Model: Parameters and Scenarios

**Ricker SR function:**

$$R = exp^{(a)} * S * exp^{\left(-\frac{a}{SEQ} * S\right)} * \varepsilon^{(0,SD)}$$

| | | Age prop. | Mat. Rate |
|---|---|---|---|
| a=2.0 | 3 | 0.25 | 0.13 |
| SEQ=25,000 | 4 | 0.5 | 0.53 |
| SMSY=9,000 | 5 | 0.25 | 1 |
| $\mu_{msy}$=.72 | | | |

Simulation input Management U = 0.8*UMSY

**Scenarios**

| ***Environmental var.*** | ***Spawner Abundance estimation error*** | |
|---|---|---|
| ***lognormal SD*** | ***Lognorm SD*** | ***Bias*** |
| 0.15 | 0 | 0 |
| 0.50 | 0.15 | 0.67 1 in 10 years |
| 1.00 | 0.3 | 0.67 1 in 5 years |
| | | 0.67 Every year |
| | | 1.5 Every year |

Each scenario has a unique combination of three factors: environmental variation, sampling error (imprecision) in spawning abundance estimates, and bias in spawning abundance estimates (Table 5.1). Sampling error was modeled by random draws from a lognormal distribution under three alternative standard deviations: 0.0, 0.15, and 0.30. The middle level (0.15) represents the CTC bilateral precision standard. The higher level is simply twice the CTC standard and is intended to illustrate the effect of relatively high imprecision. Estimating annual escapement abundance with no error is unlikely in most situations; the scenario was included in this analysis to serve as a benchmark for evaluating the relative impacts of sampling errors.

The types of bias in scenarios are based on a review of comparative results across the SSP-funded studies (Table 5.1). In some cases, comparisons among standard methods in place at the time of SSP studies indicated a consistent directional bias, usually (but not always) resulting in systematic underestimates. Such bias might be the result of index areas not being representative of all spawning habitat, observation error, or not meeting conditions for a consistent (unbiased) estimate. Other studies indicated the potential for a more complex pattern, with substantial directional bias in some but not all years. Possible mechanisms that could result in underestimation in some years would include annual variations in environmental conditions that affect counts, either across a spawning season or at critical (e.g., peak) times. At least in one SSP study, methods historically used to estimate annual spawning abundance were chronically overestimating abundance. Approaches for addressing the results of each SSP study are described in the § 3.

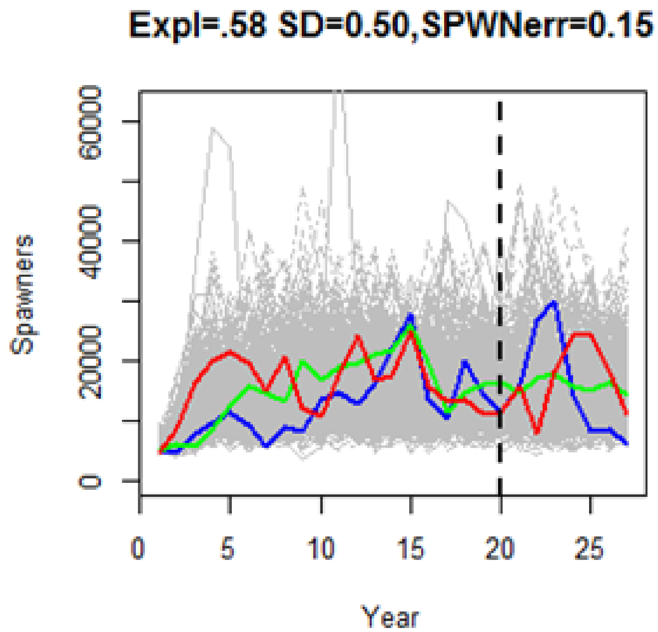



**Figure 5.1**–Example of outputs from simulations for a single scenario—500 Monte Carlo simulations with three randomly chosen runs highlighted in color.

## 5.2 Annual Evaluation Status

The CTC has used synoptic plots (Figure 5.2) to annually assess status of Chinook salmon stocks under PSC jurisdiction as part of the PSCs commitment to precautionary management. Plot axes are estimated spawner abundance (vertical) and estimated annual exploitation rates (horizontal). Zones on the plot represent risk of recruitment overfishing as defined by management objectives, usually SMSY and UMSY. A time-series of annual paired estimates (spawner abundance, brood-year exploitation rate) is plotted with the most recent point in the series representing the current stock status relative to risk. Risk levels associated with green or red zones in the plot are obvious; points in the yellow zones are considered to reflect the possibility of "falling into conservation concern" (CTC, 2015 section 3).

Synoptic plots were generated by the SSC for each scenario based on the projected escapement in year 20 in each of the 500 simulated 30-year time series (Figure 5.3). The simulated escapement was changed to an "estimated" escapement according to a random draw from a lognormal distribution with sampling-error parameter values specified in Table 5.1 for that scenario. Calculation of the annual exploitation rate was based on that "estimated" escapement in each simulation and the annual catch. A summary of the distribution of estimates in the three categories other than 'Safe' is shown in Figure 5.4. The 'Safe' category was not included in the summary figure to highlight the relative change in assignments to the remaining categories under the various combinations of background environmental 'noise' and abundance estimation error. Detailed summaries of synoptic plots in the form of pie charts that include points in the "Safe Zone" are in Figure 5.8 at the end of § 5.

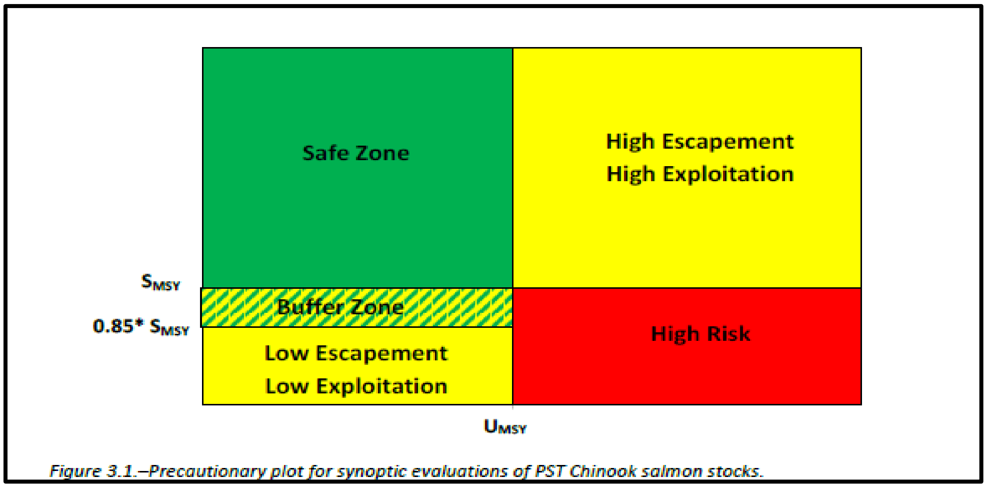



**Figure 5.2**–Excerpted from CTC (2015) Chapter 3 fig. 3.1.

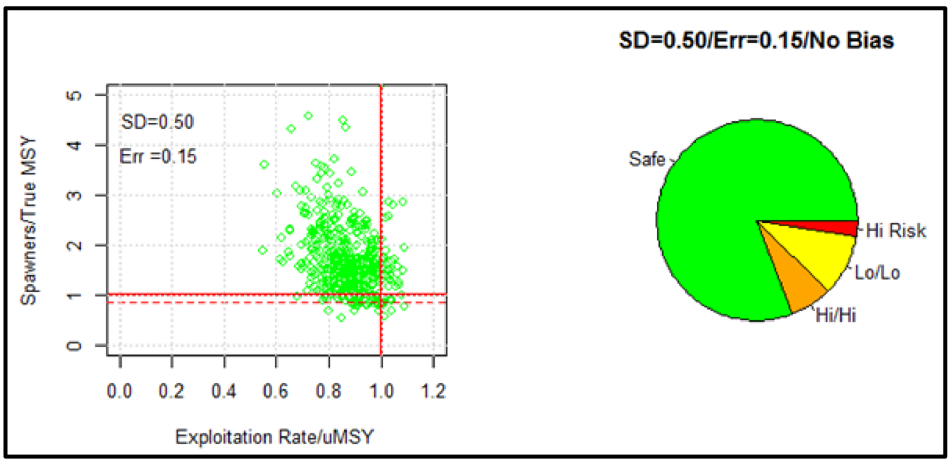



**Figure 5.3**–Example of outputs from simulations for a single scenario—synoptic plot of escapement-exploitation rate pairs for year 20 in 500 simulations with random sampling error included and pie chart with risk distributions.

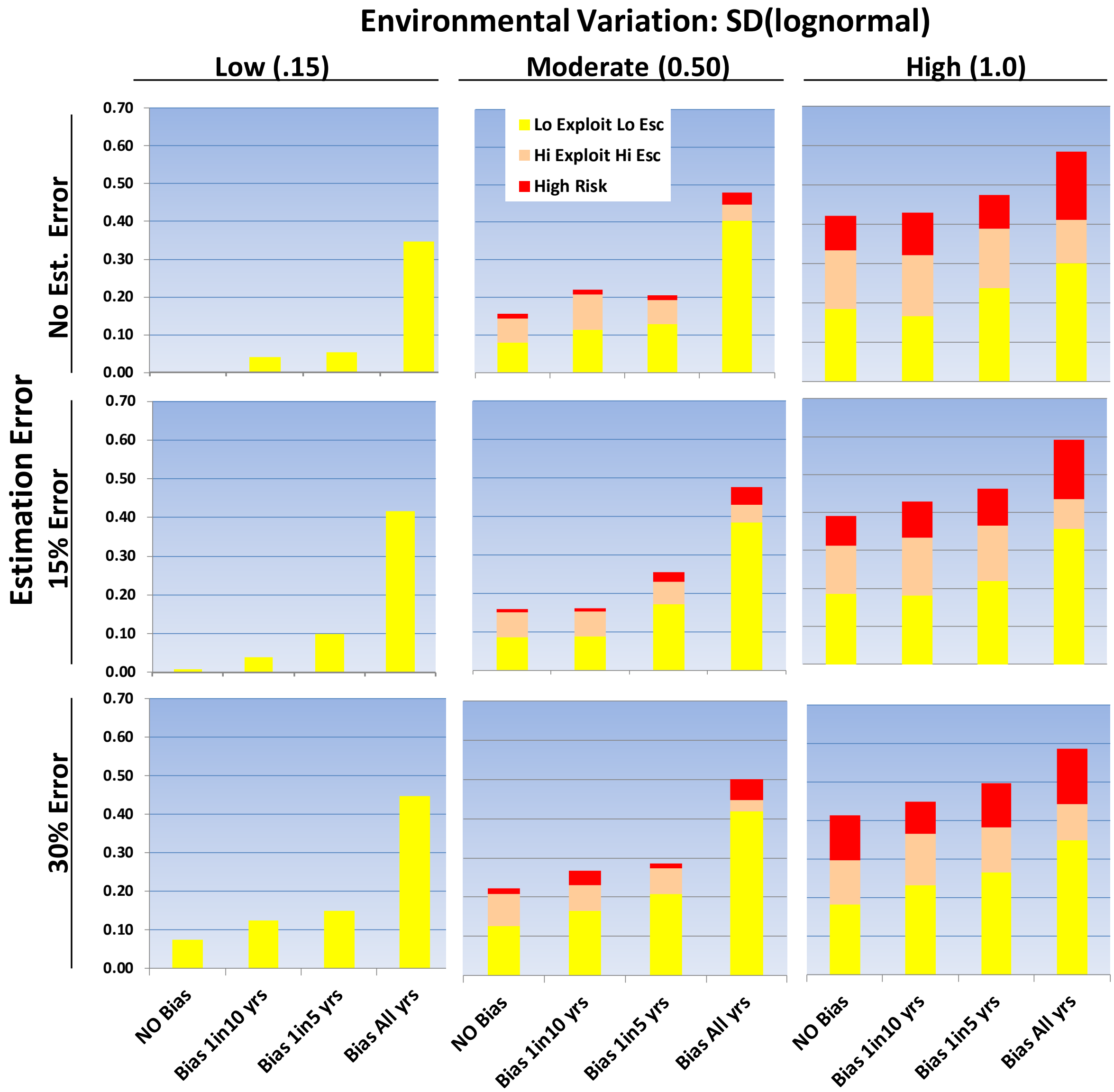



**Figure 5.4**– Proportion of simulations under each scenario that were in the CTCs synoptic graph categories other than 'Safe' (below SMSY,UMSY ). Panel columns represent levels of environmental variability in survival. Panel rows represent alternative levels of imprecision in estimated spawning abundance.

Level of environmental variation, imprecision in estimated spawner abundance, and bias in estimated spawner abundance all affected the distribution of perceived risk in the assessment. The level of environmental 'noise' had the most impact on differences across the runs within each scenario. As expected, variations in directional bias had higher influence on the projected results than did the level of imprecision estimates of annual abundance. The level of imprecision increased the rate of misclassification under all three levels of environmental variability, although the proportional impact was dampened at higher levels of environmental variation (Figure 5.4).

The effect of different levels of imprecision was most pronounced in the set of scenarios with low (SD = 0.15) annual environmental variation. The number of years misclassified as below both SMSY and UMSY was higher under the No Bias and both periodic bias scenarios. The range of imprecision modeled had little impact on the relatively high misclassification rate associated with the constant bias scenario.

In one of the SSP-funded studies, estimates of spawner abundance generated with the agency standard methodology had a positive bias. A positive bias scenario to represent this situation (assessment Oregon's Siuslaw stock) was added to the analysis under the assumption that annual estimates were, on average, overestimated actual escapement by 50%. As would be expected, the positive bias scenarios had a tendency to erroneously assign some years that would have actually fallen into higher risk categories to the 'Safe' category (Figure 5.5).

Results from this simple set of simulations give a general indication of the effects on annual assessment status from bias and imprecision in escapement estimates. This simulation exercise assumed that exploitation rate estimates are independent of error in estimating spawner abundance. For some populations, uncertianty in escapement could affect the translation of CWT indicator stock exploitation rates to a naturally spawning stock, especially if terminal area harvest rates on CWT indicator groups are calculated using imprecise or biased escapement estimates for the indicator stocks. Such an impact would be stock-specific and would be beyond the scope of the simple simulations conducted for this analysis.

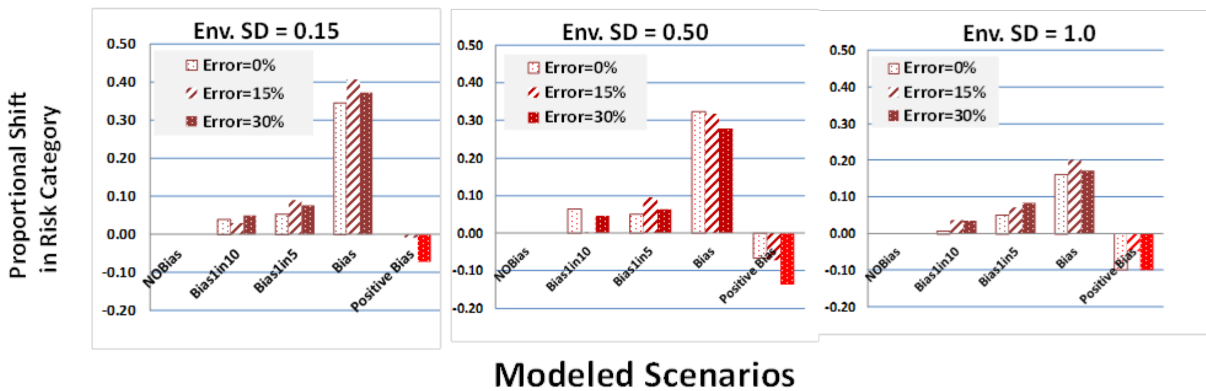



**Figure 5.5**–Summary of relative misclassification proportions among CTC categories from the "Safe Zone" to higher-risk categories by scenario with specific levels of environmental variability, of imprecision in estimated spawner abundance, and of bias in estimated spawner abundance. Positive bias scenarios involved a bias of 50%.

## 5.3 Estimation of Stock Recruit Reference Points

Imprecision and bias in "estimates" of spawner abundance from the simulations also affect imprecision and bias in "estimated" reference points (SMSY and UMSY). Reference points were derived from fitting a Ricker function to "estimated" spawner escapement $S_y$ and "estimated" recruitment $R_y$ $\{= \sum_i[S_{y+i}/(1-U_{y+i})]\}$ with the subscript on R and S specifying a brood year. The fitted portion of each time series ran from brood years 6 through 25. The first five brood years were excluded to avoid effects of initial conditions of each simulation. The result was a distribution of "estimated" values of SMSY over the 500 simulations for each scenario (see Figure 5.6 for an example). The overall patterns in results from the simulations (Figure 5.7) were consistent with the conclusions reported by Kehler et al. (2002). In general, increased environmental variation or imprecision in estimates of spawner abundance led to consistent underestimates of SMSY. Simulations with low environmental variability tended to result in lower SMSY estimates relative to actual values of SMSY than did simulations with higher environmental variability for scenarios with negative bias or no directional bias in estimated spawner abundance. Simulations with a consistent positive bias showed increasing deviations from actual SMSY as imprecision in estimated spawner abundance increased. There was substantial variation in estimates of UMSY within the 500 simulations for each scenario, but median values of USMY across each scenario were close to the 'true' underlying value. The relatively simple mechanism for simulating harvest and for extrapolating to total brood year production from estimated escapements using a constant exploitation rate likely contributed to this pattern.

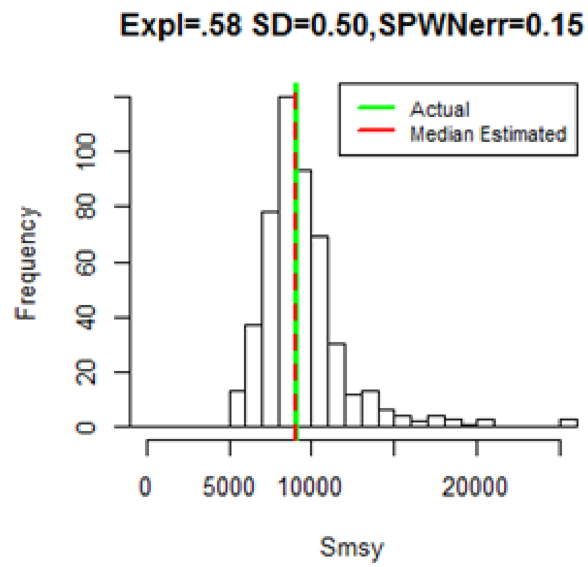



**Figure 5.6**–Example of outputs from simulations for a single scenario—frequency distribution of "estimated" SMSY estimates for 500 simulations.

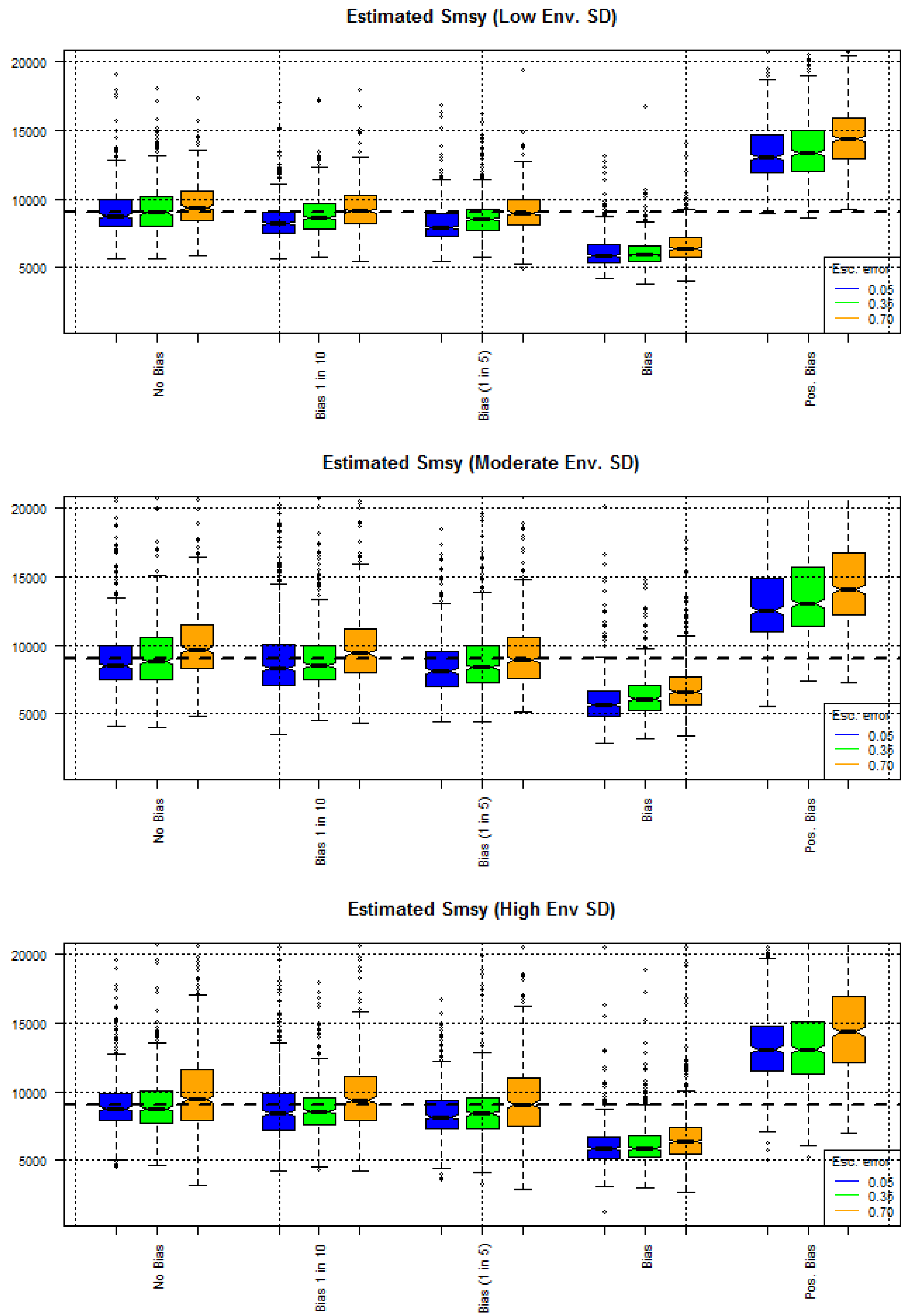
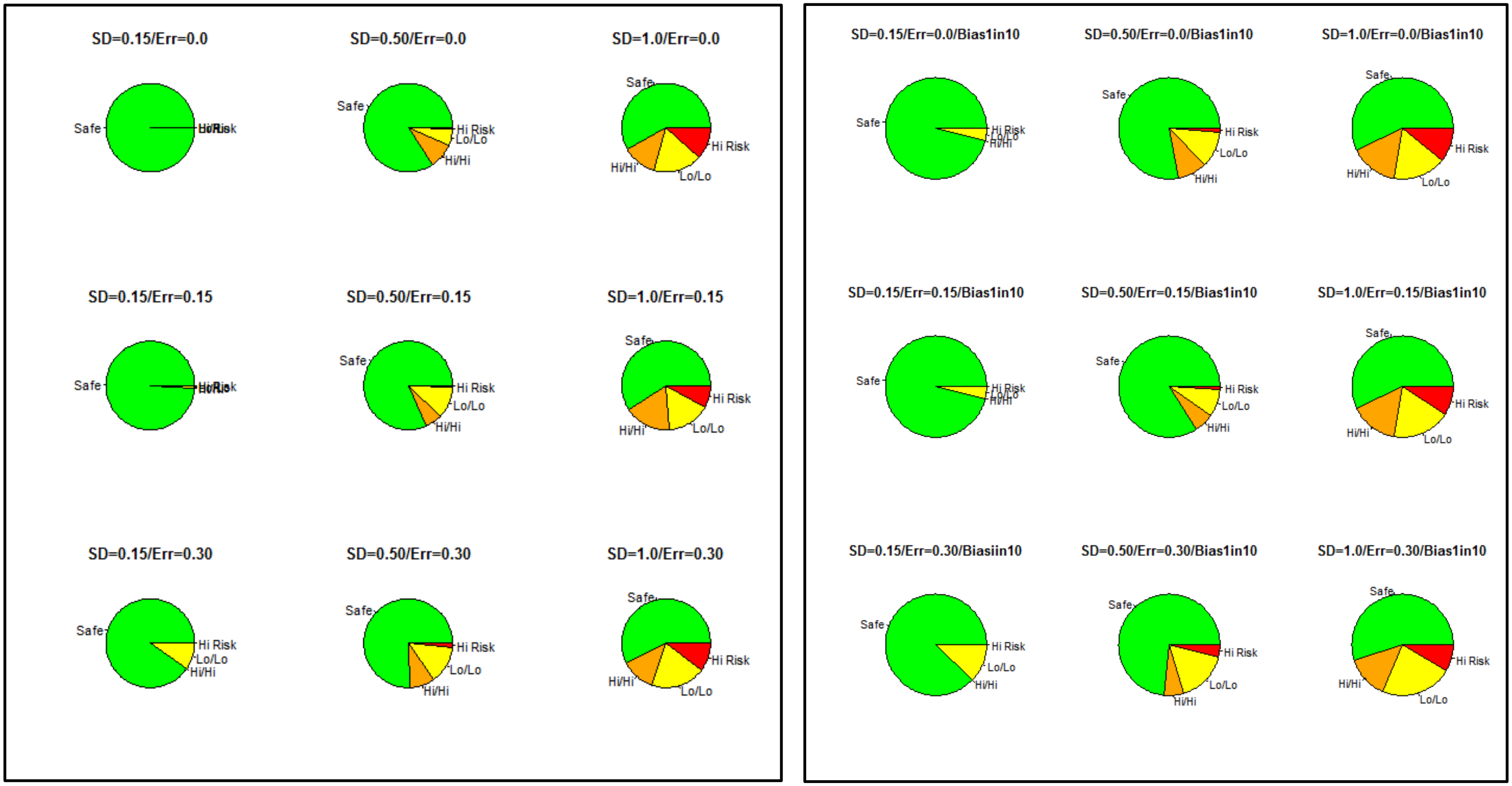
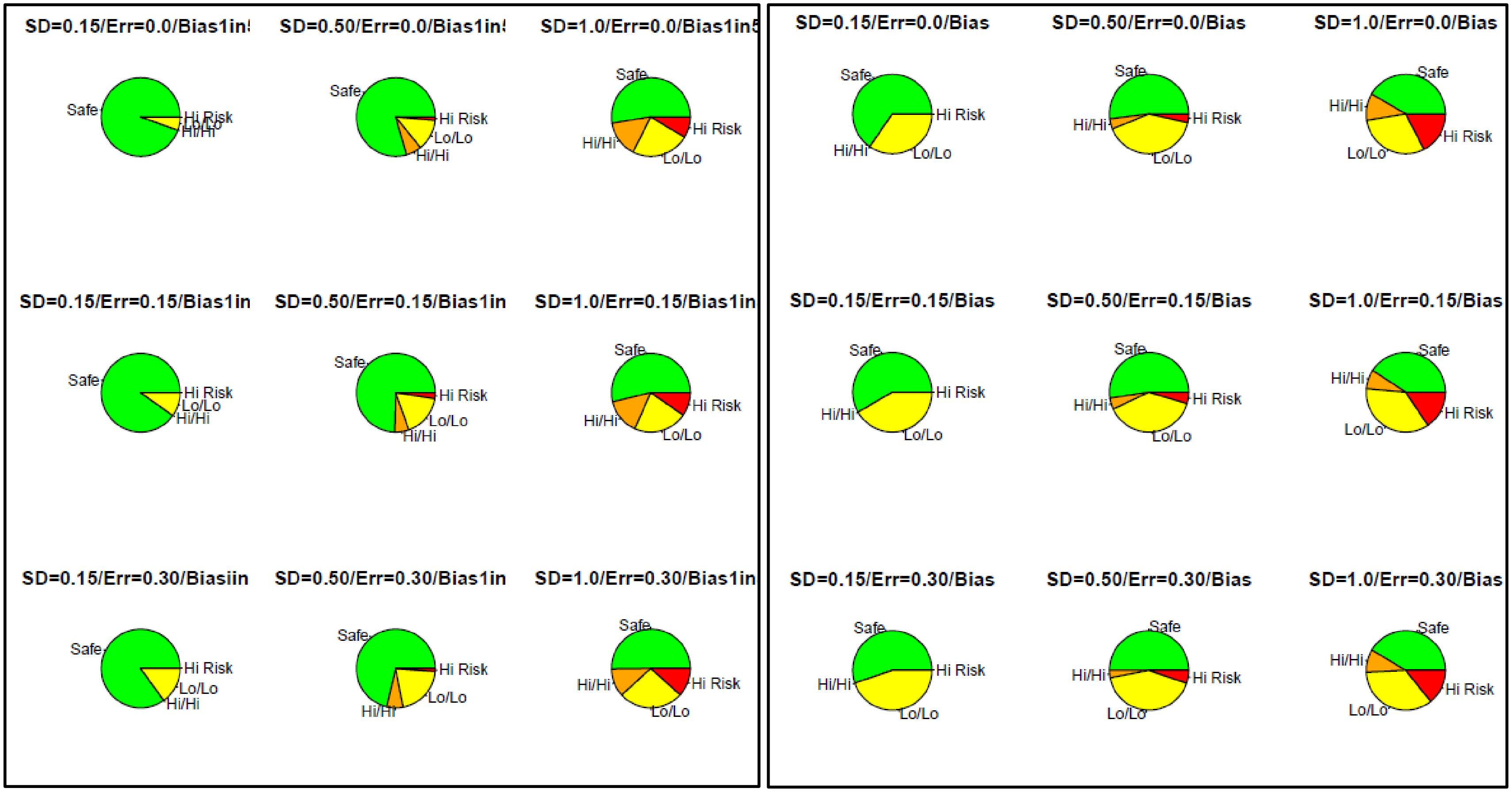



**Figure 5.7**–"Estimated" SMSY values for each scenario against actual value of SMSY (dashed line). Scenarios are defined by levels of environmental variability, of imprecision in "estimated" spawner abundance, and of type of bias in "estimated" spawner abundance used in simulations.




No Bias Bias (1 in 10 Years)

**Figure 5.8**–Fraction of 500 simulations for each of the CTC risk categories used in their annual assessments of stock status. Each pie chart corresponds to a different scenario involving levels of environmental variability (columns) and imprecision in estimates of spawner abundance (rows). Panels represent scenarios by type of bias (0.67 of actual) in estimated spawner abundance. Green represents a "Safe Zone" of negligible risk of recruitment overfishing, red a zone of high risk, and orange and yellow zones of possible risk. See Figure 5.2 for an example of CTC risk categories.




Bias (1 out of 5 Years) Bias (All Years)

**Figure 5.8**–(Continued).

# 6 ADDED BENEFITS

An important legacy of the SSP is the benefit beyond immediate success. These benefits include, but are not limited to:

**New or improved information to implement Chapter 3 of the 2009 Agreement**. Assessments specified in Chapter 3 crucial to implementing the 2009 Agreement rely on escapement estimates. Such estimates from SSP-funded studies can be used to

- calibrate the PSC Chinook salmon model, and subsequently, to plan fisheries and evaluate management performance;
- forecast stock abundance from age-specific estimates of escapement;
- compare escapement estimates to escapement objectives as described in ¶13 in Chapter 3 of the 2009 Agreement;
- determine escapement and exploitation rate objectives from stock-recruitment analysis; and
- expand CWT recoveries and subsequently estimate maturation and exploitation rates for naturally spawned exploitation rate indicator stocks, such as the Middle and Lower Shuswap stocks.

**Development and application of state-of-the-art methodologies and analytical tools**. Estimating escapement can be difficult, and often cannot be successfully done with the usual methods. When faced with difficulty, the SSC used collaborative problem solving to develop and adapt new, state-of-the-art methods rarely used to estimate escapement of Pacific salmon.

For Puget Sound stocks, genetic mark-recapture—tGMR—methods of estimating spawning abundance (§ 2.2) proved to be highly successful and cost-effective when more traditional methods—traditional MR—proved to be expensive and often unsuccessful. The tGMR method had been recently used to estimate Chinook salmon escapement in the lower Columbia River Basin (Rawding et al. 2014). The SSP funded studies in Puget Sound based on tGMR methods took advantage of ongoing spawning ground and smolt survey programs funded by agencies. Due to the success of these SSP-funded studies on the Green, Stillaguamish, and Snohomish rivers, tGMR methods were adopted by other studies funded by sources other than the SSP, such as estimating spawning abundance of spring Chinook salmon in the Nooksack River—a U.S. LOA-funded study.

The driver stock (ratio)—DSR—method (§ 2.4) was developed with SSP (and U.S. LOA) funding to estimate terminal run sizes for large stock aggregates with widely dispersed, numerous spawning grounds. The idea was to leverage existing coast-wide CWT programs and newly established genetic catch sampling in ocean fisheries to cost-effectively estimate terminal run size. Estimating terminal run size to the South Thompson aggregate stock was the first DSR study the SSP funded; the next project so funded concerned the NOC and WCVI aggregate stocks. Although SSP funding was restricted to these three aggregates and to genetic catch sampling in NBC and SEAK fisheries, the DSR method can potentially be applied simultaneously to all stock aggregates (including the Washington Coastal, Puget Sound, and Columbia River aggregates) at very little additional cost.

**Capacity building in PSC technical committees and agencies**. The annual review process and collaboration of the SSC and project proponents facilitated a substantial improvement in knowledge and technical capacity for the purpose of salmon escapement estimation within the PSC technical committees and agencies. Each annual iteration of the review process enabled problems and solutions to be identified which were tried and reported back to the SSC and agency staff via annual post season workshops. Thus, new knowledge was disseminated which benefited other escapement estimation programs beyond those funded by the SSP.

Projects funded by the SSP also provided numerous opportunities to increase capacity of management agencies. Obviously, agencies can use equipment purchased for SSP studies to support their stock assessment after the SSP studies have been completed. However, building capacity is more than new equipment. For instance, there's the SSC facilitated collaborative effort between ODFW and CDFO-Fraser Group to exchange best field practices and methods. Representatives from CDFO toured ODFW mark-recapture operations on the Oregon coast to share expertise and develop methodologies common to all SSP projects. Both agencies realized a fruitful exchange of information and expertise which is having a lasting, positive effect on escapement assessment in both countries.

# 7 KEY FINDINGS

## 7.1 Puget Sound

1. In general, the redd survey design was not completely covering spawning grounds, thus escapement was underestimated and by an inconsistent fraction. On the Stillaguamish River for example, the traditional escapement program surveyed only about half of the possible spawning reaches, in space and time, due to unfavorable river conditions and lack of resources. No adjustments had been made to account for the unsurveyed strata in the traditional escapement program, which caused the historic redd-based abundance estimates to be biased low.
2. After adjusting for missed surveys and unsurveyed areas on the Stillaguamish River, there were on average 2.3 fish per redd (SD=0.21) in the spawning population based on the concurrent escapements estimated from the tGMR method. If redd counts had been done in prior years consistent with the way they were done during the SSP, those estimates could be adjusted, however, further work is needed to evaluate whether an unbiased escapement estimate could be developed for historic redd-based estimates. A study design was developed to produce unbiased estimates for future surveys.
3. The tGMR method generates an abundance estimate of the number of carcasses for the time the carcasses are sampled, which is akin to the time of tagging in a MR program. Thus, the spawner estimate can be derived from the tGMR estimate using an estimate of the unspawned carcass rate.
4. Representative sampling of carcasses is important in the first sampling event to generate an unbiased carcass estimate with tGMR. Some individual spawners produce many offspring, and spawning success was correlated inversely with stream size (i.e. wetted area). Thus, the study design must include stratification by stream size in the carcass survey event to achieve representative sampling.
5. There is potential to go back and correct the historic data, which requires estimates of the unspawned carcass rate, and there is potential for future programs to produce unbiased estimates of carcass abundance using a new study design for the redd survey method.

## 7.2 WCVI

1. It was difficult to generate accurate and precise escapement estimates for many of the WCVI streams because of highly dynamic river flows, small population size, and remoteness. There were not enough SSP financial resources to generate high quality escapement estimates on these rivers, with a few exceptions. Those exceptions occurred where there were abundant hatchery-origin populations. It was not cost-effective to develop high quality estimates of escapement for individual rivers with low Chinook salmon abundance.
2. The SSP studies found considerable inter-annual and inter-river variability in survey life which affects the reliability of estimates from using AUC methods that do not have annual survey life estimates.
3. The SSP studies found that observer efficiency was also variable, often in the range of 40-60%. Self-assessed observer efficiencies were consistently overestimates, especially during periods with high river discharge. Self-assessed observer efficiencies were more accurate in smaller, clear-water streams. These conditions affect negatively the reliability of the AUC methodology to provide accurate estimates of spawning abundance.
4. Hatchery-origin spawners were detected at nearly all the PSC stock indicator streams studied. For those stocks with relatively high levels of direct enhancement, typically over 80% of the spawners

were hatchery-origin fish. For the WCVI stock group, hatchery-origin fish ranged from about 70 to 90% of fish sampled in the SEAK troll fishery and identified as WCVI-origin using genetics.

5. Using the timing of freshets to cost-effectively estimate discounted survey life for use in AUC methods was investigated for the Burman stock. The work to date shows promise, but is in need of more development before application.

## 7.3 North Oregon Coast

1. The SSP studies developed a calibration approach that could be used to improve the quality of historic escapement estimates and a new method to use the index counts under a modified study design to produce more accurate escapement estimates. In this way, the SSP has contributed a legacy of improved escapement data for North Oregon Coast stocks.

## 7.4 Northern BC

1. For the Nass River, the traditional MR study design was overestimating escapement and was at risk of being unable to generate an escapement estimate under low river levels. Accordingly, the study design has been modified, however resources are necessary to ensure adequate tag recovery sampling in the future.
2. A cost-effective approach was developed to improve estimates of escapement for the Skeena River aggregate stock using test fishery data. With access to over 30 years of genetic material from a test fishery, a time series of over 30 estimates of in-river abundance was developed. Three decades of standardized test fishing resulting in a cross-referenced archive of scales—the source of genetic material—made this time series possible. Such standardized test fishing and such rigorous archiving of samples for other rivers and other stocks can produce similar time series of estimated in-river abundance.

## 7.5 Fraser River

1. A novel method was developed iteratively during the SSP to estimate escapement for components of the South Thompson stock. The method depends critically on large amounts of coded wire tagging, high precision escapement estimation, and sampling of the CWT indicator stocks, and representative sampling of mature fish at a river-mouth test fishery. Sampling of mature fish at the Fraser River mouth was necessary as maturity patterns differed between components of the stock, which meant that ocean fishery sampling on fish of mixed maturity violated the key assumption of the indicator stock expansion method. The SSP results indicate that the traditional PC method underestimated escapement and additional years of paired estimates are necessary to develop a calibration relationship and correct for any biases.
2. The escapement at Chilko River can be accurately estimated with precision using traditional MR methods and unbiased estimators. The assumption of population closure was verified using radiotelemetry.
3. The assumption of closure—a condition for accurate use of the traditional MR method—was verified at the Harrison River using radiotelemetry.
4. Known underestimates of spawning abundance using the traditional PC method for large, clear rivers in the Fraser River can be adjusted based on results from three rivers studied with SSP funds. Calibration information can be borrowed from other large, clear rivers with calibration data to correct biases in PC escapement estimates for rivers that have little or no calibration data. This approach has the potential to be applied for other types of rivers where escapements are likely underestimated via the standard PC method that relies on counts from index reaches.

## 7.6 Uncertainty

1. Meeting the CTC data standard for accuracy in spawning escapement estimates is generally more efficacious than meeting the data standard for precision.

# 8 RECOMMENDATIONS

No committee such as ours can operate for six years, suffer through disappointments, and celebrate successes without forming some opinions as to what to do next. Now is the time and here is the place when we transform those opinions into recommendations.

**Accuracy of estimates should be given more consideration than the cost of estimates**. Sometimes agencies use a simple method of escapement estimation for expediency and cost efficiency. Relatively less funds are required to assess spawning abundance per stock which means more stocks can be assessed. Results are often called “indices” that are presumed to vary year-to-year along with escapements. The SSP supplied funds to evaluate and improve some of these indices, but more improvement is needed. What is also needed is for agencies to embrace these improvements.

**Maintenance of a base and sustained level of funding for assessment of spawning abundance.** Implementation of the 2009 Agreement is information intensive, especially as related to knowledge of spawning abundance. Funds for getting that knowledge largely come from agencies, the Northern and Southern Endowment Funds, and U.S. LOA appropriations. Funds for the SSP were identified from the endowment funds. While dedicated funding has ended, the monies it entailed would be well spent on estimating escapement—so long as future agreements are similar to the 2009 Agreement.

**Natural production by WCVI stocks should be estimated**. Challenges with small population sizes, highly dynamic river conditions, thin budgets, and remoteness make accurate single-river escapement assessment cost-prohibitive and impractical on WCVI. Also, the numerous stocks spawning along the WCVI create challenges for inferring overall stock status and for measuring changes in relative abundance from the few populations that can be studied. The CTC indirectly estimates annual terminal run size to WCVI, and the Driver Stock (Ratio) method funded by the SSP has shown some promise for more directly estimating terminal run size. What’s missing is a rigorous, statistically designed field study to estimate the hatchery composition of spawners for the WCVI aggregate population. Information from such a program could be used to provide estimates of natural production for the aggregate and perhaps for domestic conservation units on WCVI as well.

**A multi-agency program similar to the SSP should be established to evaluate and coordinate proposed projects.** The SSC was small (at most 11 members at any one time). Its members had extensive experience in planning, designing, and implementing projects to estimate salmon escapement in both Canada and the U.S. Some members were involved with the PSC in no other way than being a member of the SSC. However, because other SSC members were involved with project evaluation for the US-LOA or for the Northern or Southern Endowment Funds, a high degree of coordination among funding sources occurred. The result was getting more escapement assessment for the available funding—a need that continues.

**Other PSC committees involved with funding decisions should adopt SSC protocols**. While this recommendation sounds a bit prideful, we repeat that many SSC members also serve on these other PSC committees. We found our iterative process of proposal development, scientific review, proposal modification, project delivery, post-season oral presentations of preliminary results and review permitted ample opportunity for committee members to interact with project leaders and agencies to improve projects. We believe our approach increased opportunities for interaction, and therefore significantly increased the quality of projects and their results.

# 9 LITERATURE CITED

Alexander, R. F., R. C. Bocking, W. J. Gazey, R. J. Bussanich, and S. C. Kingshott. 2010. Estimating the abundance of adult Chinook Salmon returning to the Nass River, BC, using mark-recapture techniques, 2009. Report prepared by LGL Limited, Sidney, BC, for the Pacific Salmon Commission, Vancouver, BC, and the Nisga'a Lisims Government Fisheries and Wildlife Department, New Aiyansh, BC. Nisga'a Fisheries Report #09-22: viii + 103 p.

Alexander, R. F., J. J. Smith, W. D. Duguid, S. C. Kingshott, and R. C. Bocking. 2011. Estimating the abundance of adult Chinook Salmon returning to the Nass River, BC, using mark-recapture techniques, 2010. Report prepared by LGL Limited, Sidney, BC, for the Pacific Salmon Commission, Vancouver, BC, and the Nisga'a Lisims Government Fisheries and Wildlife Department, New Aiyansh, BC. Nisga'a Fisheries Report #10-22: x + 131 p.

Alexander, R. F., W. D. Duguid, and S. C. Kingshott. 2012. Estimating the abundance of adult Chinook Salmon returning to the Nass River, BC, using mark-recapture techniques, 2011. Report prepared by LGL Limited, Sidney, BC, for the Pacific Salmon Commission, Vancouver, BC, and the Nisga'a Lisims Government Fisheries and Wildlife Department, New Aiyansh, BC. Nisga'a Fisheries Report #11-22: ix + 117 p.

Alexander, R. F., W. D. Duguid, and S. C. Kingshott. 2013. Estimating the abundance of adult Chinook Salmon returning to the Nass River, BC, using mark-recapture techniques, 2012. Report prepared by LGL Limited, Sidney, BC, for the Pacific Salmon Commission, Vancouver, BC, and the Nisga'a Lisims Government Fisheries and Wildlife Department, New Aiyansh, BC. Nisga'a Fisheries Report #12-22: ix + 112 p.

Alexander, R. F., I. A. Beveridge, S. C. Kingshott, and D. Robichaud. 2014. Estimating the abundance of adult Chinook Salmon returning to the Nass River, BC, using mark-recapture techniques, 2013. Report prepared by LGL Limited, Sidney, BC, for the Pacific Salmon Commission, Vancouver, BC, and the Nisga'a Lisims Government Fisheries and Wildlife Department, New Aiyansh, BC. Nisga'a Fisheries Report #13-22: xii + 113 p.

Alexander R. F., I. A. Beveridge, S. C. Kingshott, and D. Robichaud. 2015. Estimating the abundance of adult Chinook Salmon returning to the Nass River, BC, using mark-recapture techniques, 2014. Prepared by LGL Limited, Sidney, BC, for the Pacific Salmon Commission, Vancouver, BC, and the Nisga'a Lisims Government Fisheries and Wildlife Department, New Aiyansh, BC. Nisga'a Fisheries Report #14-22: xii + 115 p.

Arnason, A. N., C. W. Kirby, C. J. Schwarz, and J. R Irvine. 1996. Computer analysis of data from stratified mark-recovery experiments for estimation of salmon escapements and other populations. Canadian Technical Report of Fisheries and Aquatic Sciences. 2106: 37p.

Bailey, R. E., C. K. Parken, J. R. Irvine, B. Rosenberger, and M. K. Farwell. 2000. Evaluation of the utility of aerial overflight based estimates versus mark–recapture estimates of chinook salmon escapement to the Nicola River, British Columbia. Canadian Stock Assessment Secretariat, Research Document 2000/152, Ottawa.

Baranski, C. 1980. Skagit summer broodstock collection program, 1975-1979. Washington Department of Fisheries Progress Report 104. 21pp.

Bernard, D. R., R. P. Marshall, and J. E. Clark. 1998. Planning sampling programs to estimate salmon harvest with coded-wire tags. Canadian Journal of Fisheries and Aquatic Sciences 55:1983-1995.

Bernard, D. R., S. Gilk-Baumer, D. Evenson, W. D. Templin, R. L. Peterson, and R. Briscoe. 2014. Feasibility of estimating the 2011 terminal run sizes for Chinook salmon driver stocks harvested in Southeast Alaska troll and sport fisheries. Alaska Department of Fish and Game, Fishery Manuscript No. 14-09, Anchorage.

Bernard, D. R., J. J. Hasbrouck, and S. J. Fleischman. 1999. Handling-induced delay and downstream movement of adult chinook salmon in rivers. Fisheries Research 44:37-46.

Boyce, I.M., S.A. McPherson, D.R. Bernard, and E.L. Jones III. 2006. Spawning abundance of Chinook salmon in the Taku River in 2003. Alaska Department of Fish and Game, Fishery Data Series No. 06-16, Anchorage.

Bue, B.G., S.M. Fried, S. Sharr, O.G. Sharp, J.A. Wilcock, and H.J. Geiger. 1998. Estimating salmon escapement using area-under-the-curve, aerial observer efficiency, and stream-life estimates: The Prince William Sound pink salmon example. North Pacific Anadromous Fish Commission Bulletin 1: 240-250.

Burke, B. J., T. J. Bohn, S. L. Downing, M. A. Jepson, and C. Peery. 2004. Dam passage and fallback by Chinook salmon and steelhead as determined by passive integrated transponder tags and radio tags. Report by National Marine Fisheries Service to the U.S. Army Corps of Engineers Walla Walla and Portland District, Seattle, WA. Project No. ADS-00-14, 64 pages.

Burnham, K.P., D.R. Anderson, G.C. White, C. Brownie, and K.H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society Monograph 5.

Candy, J.R., J.R. Irvine, C.K. Parken, S.L. Lemke, R.E. Bailey, M. Wetklo, and K. Jonsen. 2002. A discussion paper on possible new stock groupings (conservation units) for Fraser River Chinook salmon. DFO Canadian Stock Assessment Secretariat Research Document 2002/085.

CDFO (Canadian Department of Fisheries and Oceans). 2012. Assessment of West Coast Vancouver Island Chinook and 2010 forecast. Canadian Science Advisory Secretariat, Science Advisory Report 2012/032.

CDFO 2014a. West Coast Vancouver Island Chinook Salmon Escapement Estimation and Stock Aggregation Procedures. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/038.

CDFO 2014b. Proceedings of the Regional Peer Review on the West Coast Vancouver Island Chinook Salmon Escapement Estimation and Stock Aggregation Procedures; June 18-20, 2013. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2014/025.

Choquet, R., Lebreton, J.-D., Gimenez, O., Reboulet, A.-M. and Pradel, R. 2009. U-CARE: Utilities for performing goodness of fit tests and manipulating Capture-Recapture data. Ecography 32: 1071-1074 (Version 2.3).

Coulthard, B., and D.J. Smith. 2015. A 477-year dendrohydrological assessment of drought severity for Tsable River, Vancouver Island, British Columbia, Canada. Hydrological Processes article first published online 14 Dec 2015. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/hyp.10726/pdf.

CTC (Chinook Technical Committee) 1997. Incidental fishing mortality of Chinook salmon: Mortality rates applicable to Pacific Salmon Commission fisheries. Report TCCHINOOK (97)-1. Vancouver, BC.

CTC (Chinook Technical Committee). 2002. Catch and escapement of Chinook salmon under Pacific Salmon Commission jurisdiction 2001. Pacific Salmon Commission, Report TCCHINOOK (02)1-1. Vancouver, BC.

CTC (Chinook Technical Committee). 2013. Catch and escapement of Chinook salmon under Pacific Salmon Commission jurisdiction 2012. Pacific Salmon Commission, Report TCCHINOOK (13)-1. Vancouver, BC.

CTC (Chinook Technical Committee). 2014. Catch and escapement of Chinook salmon under Pacific Salmon Commission jurisdiction 2013. Pacific Salmon Commission, Report TCCHINOOK (14)-2. Vancouver, BC.

CTC (Chinook Technical Committee). 2015. Catch and escapement of Chinook salmon under Pacific Salmon Commission jurisdiction 2014. Report TCCHINOOK (15)-2. Vancouver, BC.

CTC (Chinook Technical Committee). 2016. Catch and escapement of Chinook salmon under Pacific Salmon Commission jurisdiction 2015. Pacific Salmon Commission, Report TCCHINOOK (16)-2. Vancouver, BC.

Dunlop, Roger H. 2015. Open population mark-recapture estimation of ocean-type Chinook salmon (*Oncorhynchus tshawytscha*) spawning escapements at stopover sites on the west coast of Vancouver Island. Report of Nuu-chah-nulth Tribal Council to the Pacific Salmon Commission Sentinel Stocks and Southern Boundary & Enhancement Fund.

English, K. K., R. C. Bocking, and J. R. Irvine. 1992. A robust procedure for estimating salmon escapement based on the area-under-the-curve method. Canadian Journal of Fisheries and Aquatic Sciences. 49: 1982-1989.

English, K. K., R. E. Bailey, and D. Robichaud. 2007. Assessment of Chinook salmon returns to the Fraser River using run reconstruction techniques, 1984–02. Canadian Science Advisory Secretariat, Research Document 2007/020.

Farwell, M. K., R. E. Bailey, and B. Rosenberger. 1999. Enumeration of the 1995 Nicola River chinook salmon escapement. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2491.

Fryer, J. K., J. Whiteaker, and D. Kelsey. 2013. Upstream migration timing of Columbia Basin Chinook salmon, sockeye salmon, and steelhead, 2011. Columbia River Inter-Tribal Fish Commission Technical Report 13–04. 98 pages.

Gargett, A. and M. Abbott. 2005. Scientifically speaking: tips for preparing and delivering scientific talks and using visual aids. The Oceanography Society Council. http://www.tos.org/resources/publications/sci_speaking.html

Gilk-Baumer, S., W. D. Templin, and L. W. Seeb. 2013. Mixed stock analysis of Chinook salmon harvested in Southeast Alaska commercial troll fisheries, 2004–2009. Alaska Department of Fish and Game, Fishery Data Series No. 13-26, Anchorage.

Gottesfeld, A.S. and C. Muldon. 2009. Live Capture and Tagging of Skeena Chinook Feasibility Study (SFC Component). Prepared by the Skeena Fisheries Commission for the Pacific Salmon Commission file NF-2008-I-19A.

Hahn, P.K.J., C. Ashbrook, T. Cropp, G. Vander Haegen, and M.C. Mizell. 1999. Assessment of Chinook salmon spawning escapement in the Green-Duwamish River, 1999. Completion Report, NMFS Contract #NA97FP0383, updated March 19, 2003. Wash. Dept. of Fish and Wildlife, Olympia, WA 98501-1091. 60 p.

Hahn, P.K.J., M.C. Mizell, and T. Cropp. 2000. Assessment of Chinook salmon spawning escapement in the Green-Duwamish River, 2000. Completion Report, NMFS Contract #NA07FP0375, updated June 6, 2003. Wash. Dept. of Fish and Wildlife, Olympia, WA 98501-1091. 73 p.

Hahn, P.K.J., M.C. Mizell, and T. Cropp. 2001. Assessment of Chinook salmon spawning escapement in the Green-Duwamish River, 2001. Completion Report, NMFS Contract #NA17FP1278, updated Sept. 5, 2003. Wash. Dept. of Fish and Wildlife, Olympia, WA 98501-1091. 95 p.

Hahn, P.K.J., and B. Thompson. 2007. Investigation of possible undercounting of Chinook salmon redds in the Green-Duwamish River, Washington: 2006. Completion Report, NMFS Contract #NA06BNF4380171, Nov. 21, 2007. Wash. Dept. of Fish and Wildlife, Olympia, WA 98501-1091. 95 p.

Hahn, P.K.J., D. Lowry, and M. Mizell. 2010. Abundance estimation of Snohomish system Chinook salmon via mark-recapture, 2009-10 Sentinel Stock monitoring. Project completion report to Sentinel Stocks Committee of the Pacific Salmon Commission.

Hahn, P.K.J., D. Lowery, M. Mizell, and Y-W Lee. 2011. Abundance estimation of Green River system Chinook salmon via mark-recapture. Project completion report to Sentinel Stocks Committee of the Pacific Salmon Commission.

Hankin, D. G., J. H. Clark, R. B. Deriso, J. C. Garza, G. S. Morishima, B. E. Riddell, C. Schwarz, and J. B. Scott. 2005. Report of the expert panel on the future of the coded wire tag recovery program for Pacific salmon. Pacific Salmon Commission Technical Report 18, Vancouver, British Columbia. Report available at: www.psc.org/pubs/CWT/EPfinalreport.pdf.

Hilborn, R., B.G. Bue, and S. Sharr. 1999. Estimating spawning escapement from periodic counts: comparison of methods. Canadian Journal Fisheries Aquatic Sciences 56:888-896.

Hill, R.A. 1997. Optimizing aerial count frequency for the area-under-the-curve method of estimating escapement. North American Journal of Fisheries Management 14:461-466.

Irvine, J. R., J.F.T. Morris, and L.M. Cobb. 1993. Area-under-the curve salmon escapement estimation manual. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1932.

Jantz, L., R. Kadowaki and B. Spilsted. 1990. Skeena River Salmon Test fishery, 1987. Canadian Data Report of Fisheries and Aquatic Sciences No. 804, 151 p.

Jacobs, S. E. and C. X. Cooney. 1997. Oregon coastal spawning surveys, 1994 and 1995. Oregon Department of Fish and Wildlife, Information Report 97-5. Portland, OR.

Keefer, M. L., C. A. Peery, T. C. Bjornn, M. A. Jepson, and L. C. Steuhrenberg. 2004. Hydrosystem, dam, and reservoir passage rates of adult Chinook salmon and steelhead in the Columbia and Snake river. Transactions of the American Fisheries Society 133:1413–1439.

Kehler, D.G., R.A. Myers and C.A. Field. 2002. Measurement error and bias in the maximum reproductive rate for the Ricker model. Can. J. Fish. Aquat. Sci. 59:854-864.

Kery, M. 2010. Introduction to WinBUGS for ecologists. Academic Press, Burlington.

Link, M.R., and B.L. Nass. 1999. Estimated abundance of Chinook salmon returning to the Nass River, B.C., 1997. Can. Manuscr. Rep. Fish. Aquat. Sci. 2475: x + 64 p.

Manske, M. and C.J. Schwarz. 2000. Estimates of stream residence time and escapement based on capture-recapture data. Canadian Journal of Fisheries and Aquatic Sciences 57:241-246.

McPherson, S.A., D.R. Bernard, M.S. Kelley, P.A. Milligan, and P. Timpany. 1996. Spawning abundance of Chinook salmon in the Taku River, 1995. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 96-36, Anchorage.

McPherson, S.A., D.R. Bernard, M.S. Kelley, P.A. Milligan, and P. Timpany. 1997. Spawning abundance of Chinook salmon in the Taku River, 1996. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 97-14, Anchorage.

Murdoch, A. R., T. N. Pearsons, and T. W. Maitland. 2009. The number of redds constructed per female spring Chinook salmon in the Wenatchee River basin. North American Journal of Fisheries Management 29:441–446.

Musslewhite, J. 2010. The feasibility of capturing sufficient Skagit Chinook to do a mark-recovery population estimate. Report to the Sentinel Stock Committee. Skagit River System Cooperative.

Parken, C.K. and D.Y. Atagi. 2001 (draft). Evaluation of sampling selectivity at the Nass River fishwheels pertaining to Summer-run Steelhead. Draft Skeena Fisheries Report: vii + 59 p.

Parken, C.K., R.E. Bailey, and J.R. Irvine. 2003. Incorporating uncertainty into area-under-the-curve and peak count salmon escapement estimation. North American Journal of Fisheries Management 23:78-90.

Parken, C.K. Candy, J.R., Irvine, J.R and Beacham, T.D. 2008. Genetic and coded wire results combine to allow more-precise management of a complex Chinook salmon aggregate. North American Journal of Fisheries Management 28:328-340.

Parsons, A.L. and J.R. Skalski. 2010. Quantitative Assessment of Salmonid Escapement Techniques. Reviews in Fisheries Science Vol. 18, Iss. 4.

Plate, E.M. and K.K. English. 2008. Lower Skeena Chinook Tagging Feasibility Study, 2008. Prepared by LGL Limited, Sidney, BC, for the Pacific Salmon Commission, Vancouver, BC, and Kitsumkalum Fisheries, Kitsumkalum, BC file NF-2008-I-19B.

Pollock, K. H., J. D. Nichols, C. Brownie, and J. E. Hines. 1990. Statistical inference for capture-recapture experiments. Wildlife Monographs No. 107, p. 3–97.

PSC (Pacific Salmon Commission). 2002. Catch and escapement of Chinook salmon under Pacific Salmon Commission Jurisdiction. Pacific Salmon Commission Joint Chinook Technical Report (02)-1.

PSC (Pacific Salmon Commission). 2015. Five-year synthesis report of the PSC Coded Wire Tag (CWT) Improvement Program. Pacific Salmon Commission Technical Report No. 33.

Rawding, D. J., C. S. Sharpe, and S. M. Blankenship. 2014. Genetic-based estimates of adult Chinook salmon spawner abundance from carcass surveys and juvenile out-migrant traps. Transactions of the American Fisheries Society 143:55-67.

Rawding, D., and co-authors. 2015. Development of expansion factors to estimate Stillaguamish Chinook salmon spawning abundance from redd survey and genetic estimates of salmon abundance. Working Draft. Washington Dept. of Fish and Wildlife, Olympia, WA.

Sarga, R., M.C. Wright, and A. Velez-Espino. 2011. Mark-recapture estimation of the 2010 Chinook salmon (*Oncorhynchus tshawtscha*) escapement in the Kaouk River, British Columbia. Prepared for the Pacific Salmon Commission, Vancouver, B.C.

Schwarz, C. J., and A. N. Arnason. 1996. A general methodology for the analysis of capture-recapture experiments in open populations. Biometrics 52: 860-873.

Schwarz, C. J., R. E. Bailey, J. R. Irvine, F. C. Dalziel. 1993. Estimating salmon spawning escapement using capture-recapture methods. Canadian Journal of Fisheries and Aquatic Sciences 50:1181-1191.

Seamons, T. R., and coauthors. 2012. Spawner abundance estimates for Green River Chinook salmon. Washington Dept. of Fish and Wildlife, Olympia, WA.

Seamons, T. R., and coauthors. 2013. Spawner abundance estimates for Green River Chinook salmon. Washington Dept. of Fish and Wildlife, Olympia, WA.

Seamons, T. R., and coauthors. 2014. Spawner abundance estimates for Green River Chinook salmon. Washington Dept. of Fish and Wildlife, Olympia, WA.

Seamons, T. R., and coauthors. 2015. Genetic-based abundance estimates for Snohomish River Chinook Salmon. Washington Dept. of Fish and Wildlife, Olympia, WA.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters, 2nd ed., pp. 200 and 214, Edward Arnold, London.

Shortreed, K.S., and J.G. Stockner. 1983. Periphyton biomass and species composition in a coastal rainforest stream in British Columbia: effects of environmental changes caused by logging. Canadian Journal of Fisheries and Aquatic Sciences 40:1887-1895.

Small, M. P., D. Rawding, T. Seamons, A. Spidle, C. Scofield, J. Griffith, E. Martinez, and P. Verhey. 2011. Estimating spawner abundance for Stillaguamish Chinook salmon using genetic mark-recapture for brood years 2007, 2008 and 2009. Report to the Sentinel Stocks Committee

Small, M. P., and coauthors. 2012. 2010 Progress Report: Chinook salmon abundance in the Stillaguamish River estimated using genetic mark-recapture analyses Washington Department of Fish and Wildlife, Olympia, WA.

Small, M. P., and coauthors. 2013. 2011 Progress Report: Chinook salmon abundance in the Stillaguamish River estimated using genetic mark-recapture analyses Washington Department of Fish and Wildlife, Olympia, WA.

Small, M. P., and coauthors. 2014. 2012 Progress Report: Chinook salmon abundance in the Stillaguamish River estimated using genetic mark-recapture analyses Washington Department of Fish and Wildlife, Olympia, WA.

Smith, J. J., R. C. Bocking, W. Kennedy, and T. Hansen. 2012. Estimating the escapement of Kaouk River Chinook salmon, 2011. Prepared by the Ka:'yu:'k't'h'/Che:k'tles7et'h' First Nations, Kyuquot, B.C., and LGL Limited, Sidney, B.C., for the Pacific Salmon Commission, Vancouver, B.C.

Staley, M.J. 1990. Abundance, age, size, sex and coded wire tag recoveries for Chinook salmon escapements of the Harrison River, 1984-1988. Can. Manuscr. Rep. Fish. Aquat. Sci. 2066: 42p.

Su, Z., M. D. Atkinson, and B. W. Van Alen. 2001. A hierarchical Bayesian model for estimating historical salmon escapement and timing. Canadian Journal of Fisheries and Aquatic Sciences 58:1648-1662.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study, 46 (Supplement 1): S120–S139.

Williamson, K. S., A. R. Murdoch, T. N. Pearsons, E. J. Ward, and M. J. Ford. 2010. Factors influencing the relative fitness of hatchery and wild spring Chinook salmon (*Oncorhynchus tshawytscha*) in the Wenatchee River, Washington, USA. Canadian Journal of Fisheries and Aquatic Sciences 67(11):1840-1851.

Zhou, S., and R. Williams. 1999. Stock and recruitment analysis and escapement goals for Nehalem River fall Chinook. ODFW Information Report Series No. 99-04.

Zhou, S., and R. Williams. 2000. Escapement goals for Siletz and Siuslaw River Fall Chinook Based on Stock Recruitment Analysis. ODFW Information Report Series No. 2000-04.

# 10 APPENDICES

### Guidance from the Commission on Implementation

### Implementation Approach for the Chinook Sentinel Stocks Program

**Background.** During recent negotiations within the Pacific Salmon Commission to amend the current Chinook regime under Chapter 3, Annex IV of the Pacific Salmon Treaty, it became apparent that the accuracy and precision of spawning escapement estimates for important natural stocks of Chinook salmon should be improved in order to support implementation of the Chinook annex. Reliable estimates of spawning escapements for a large number of natural Chinook stocks over time are critical to assessing the status of the resource throughout the Treaty area and are necessary to assess the long term conservation and production goals of the Treaty.

Recognizing the importance of better estimates of Chinook spawning escapements, the Commission conceived of the five year Sentinel Stock Program (SSP) and included it as a specific requirement in the revised Chinook regime (see Paragraph 3(a) of Chapter 3, Annex IV). The SSP is intended to focus on improving spawning escapement estimates for a select subset of natural Chinook populations for which estimates of spawning escapement are critical to fishery management decisions required to implement the Chinook annex. Improving these estimates will strengthen the biological basis of the Chinook regime, increase confidence in management, and better inform the development of future regimes.

Paragraph 3 of Chapter 3 provides only the general parameters of the program (i.e., study regions), and leaves the development and overall management of the program to a bilateral scientific committee (Sentinel Stocks Committee or SSC). It further provides that funding for the SSP should derive in equal amounts from the two funds created by the 1999 Agreement, i.e., the Northern and Southern Funds. It is the expectation of the Commission that the SSC will maximize the benefits derived from the short term, intensive studies made possible by the SSP.

The Chinook Technical Committee (CTC) is tasked with recommending bilateral standards for the assessment program required to effectively implement the annex. This includes data standards for escapement estimates. Because the SSP is to be implemented beginning in 2009, it is expected that the CTC will give high priority to the development of data standards that will apply to escapement estimates provided by the SSP, per paragraph 8 of Appendix A to Chapter 3.

**Objective of the Sentinel Stock Program.** The objective of the Sentinel Stock Program is to obtain estimates of the spawning escapement for each of the included stocks to attain a level that meets or exceeds bilateral data standards.

**Purpose.** This document describes in greater detail how the SSP will be implemented. Specifically, it identifies the role of the bilateral scientific committee, the SSC, and its interactions with the Commission, the management agencies who will oversee and/or implement the studies, and the Northern and Southern Fund Committees.

**The Sentinel Stocks Committee.** The Commission appoints the following individuals to the SSC:
U.S. members: Dave Bernard and John Clark (ADFG); Dan Rawding (WDFW); Tom Cooney (NMFS); Marianna Alexandersdottir (NWIFC); Ethan Clemons (ODFW)
Canadian Members: Brian Riddell (DFO); Chuck Parken (DFO); other Canadian representatives TBD

**Approach.** Consulting with other scientists, the CTC, salmon fishery managers and other officials of either Party as necessary and appropriate, the SSC will provide scientific advice as to how best to attain the objective of the SSP. All decisions and recommendations made by the SSC will be by consensus. The SSC will proceed as follows:

1. The SSC will identify which specific spawning stocks in the five-named regions (North Oregon Coast, Puget Sound, Fraser River, west coast of Vancouver Island, and northern British Columbia) as identified in Paragraph 3(a) IV) should be studied to best accomplish the objective of the SSP, taking into account, among other considerations, any applicable bilateral data standards developed by the CTC, the importance of a candidate stock relative to the status of the overall Chinook salmon resource, its similarity to other stocks, its significance to PST fishery management decisions, the opportunities for enumerating or obtaining high quality estimates of spawning escapement for that stock, the likely cost of the study, and the total funding available for the SSP (i.e., averaging $2 million per year but not less than $10M over five years).
2. The SSC will identify potentially acceptable escapement enumeration or escapement estimation methodologies that are consistent with meeting or exceeding bilateral data standards for each of the identified stocks.

**Proposal (Study) Development and Implementation.**

3. The Fund Committees will solicit proposals for each stock identified by the SSC (see number 1 above). Proposals submitted and considered by the SSC will be fully detailed scientific proposals to conduct a spawning escapement enumeration or spawning escapement estimation study. The duration of the proposed work will be one to five years. The proposals will describe the preferred methodology for accomplishing the expressed objective of the SSP and provide a basis for concluding how the escapement enumeration or escapement estimation studies will produce estimates that meet or exceed bilateral data standards for precision and accuracy. The format for proposals will be designed to facilitate full scientific review by the SSC (e.g., similar to the current U.S. LOA process) and external reviewers, as required. The proposals will: link requested budgets to expected levels of effort and the resulting precision and accuracy for estimates of escapement; include explicit plans for monitoring both compliance and effectiveness; and provide a schedule with milestones upon which the extent of progress can be judged (including explicit plans for monitoring both compliance and effectiveness).
4. The SSC will review the proposals and, in consultation with the study sponsors, identify acceptable ways to address any identified concerns for incorporation into the study design and implementation plan. After the SSC completes its review and approves (by consensus) the study/implementation plan, the proposals will be passed on to the Fund Committees and reformatted as necessary to accommodate the Fund Committees' decision making and contract administration procedures.
5. An annual report detailing the results of each study will be submitted by the project sponsors to the SSC, the CTC, and the Fund Committees for their information. The SSC will review the conduct of the study with the sponsor and recommend adjustments to the study design, when appropriate.
6. The SSC will prepare an annual progress report to the Commission and Fund Committees based on the individual study reports, with a particular focus on any modifications of any of the studies that may be necessary. At the conclusion of the five year SSP, the SSC will provide a summary report and any recommendations they deem appropriate to the Commission and Fund Committees.

**Schedule.** The new Chinook agreement requires the SSP to begin in 2009. Thus, identification of study stocks and development/approval of the study proposals should be completed no later than March 16, 2009 to accommodate funding processes of the Northern and Southern Fund Committees and provide for projects to be implemented for the 2009 field season. Thereafter, annual reports will be provided to the SSC, with preliminary reports submitted in time to accommodate the review necessary for the SSC to report to the Commission at the February Annual meeting. Final reports will be submitted no later than June 1, in order to allow sufficient time to incorporate any necessary changes in the studies for the ensuing field season and to allow annual review by the fund committees as needed to authorize continued funding.

**Administrative Details.**

- The travel costs of SSC members will be covered by their respective national sections.
- If required by his/her employing agency, reasonable salary costs of SSC members while working on the SSP program may be reimbursed by the Funds using funding available for the SSP (i.e., part of the $2 million per year). Reimbursement of these costs from the Funds will not exceed 3% of the amount provided annually from each fund.
- The PSC staff will provide administrative and logistical support for bilateral meetings of the SSC.
- On the direction of the Fund Committees, the PSC staff will set aside the annual funding obligated by each Committee (i.e., $1 million each) to cover the costs of the studies without regard to the location of the studies.

## 10.1 Presentation Format for Project Progress Reports

October 16, 2011
To: Project Leaders
From: Sentinel Stock Committee
Subject: SSP Presentation Recommendations

**Overview:** The primary purpose of your scientific presentation is to inform the SSC on the progress and results of your study to meet the SSP Chinook salmon monitoring goal, which is to provide an unbiased estimate of Chinook salmon abundance with an average precision, as measured by the Coefficient of Variation (CV) of less than 15%. Secondary objectives may include the development of calibration factors, or recommendations to improve a subsequent effort if funded. A successful scientific talk is well organized, logically structured, and uses concise language. It should have an introduction, a body, and a conclusion.

The PowerPoint is the primary tool used to enhance the understanding of your presentation. The following are some general recommendations regarding the use of PowerPoint for presentations (Gargett and Abbott 2005).

- Each slide shown must enhance, support, exemplify, and/or facilitate understanding of material covered in your talk.
- All information presented on each slide should be brief and concise. Remember do not place too much material on a slide.
- Slides must be legible and clearly visible to the entire audience. Use color for emphasis, distinction, and clarity.
- Be aware of the "life span" of each slide and rehearse your talk. A rule of thumb is that two or three bullets per image are best; six are considered the absolute maximum.
- Finally, do not read your slides to the audience instead of giving a talk.

One website with advice on good scientific talks is the University of Indiana-Resources for Graduate Students and Post-Docs: A Compilation (http://www.indiana.edu/~halllab/grad_resources.html ).

**SSC Presentation Recommendations:** Your talk should have a clear logic path, given your primary objective of informing the SSC on the progress and results of your study to meet the CTC Chinook salmon abundance goals. Since many funded SSP projects are based on a mark-recapture study design, we will use this topic to highlight the key points for a successful presentation. Other projects can adapt their methods to this format.

**Title.** This slide contains project title submitted to SSP and presenter but may contain co-investigators not presented. It should also indicate the number of years the SSC has funded the project.

**Talk Outline:** This slide contains the logical structure of the talk. Please tell us what you plan to talk about and the order you plan to discuss these topics. An outline should include: 1) study design, key assumptions for your study design, results, and next steps/recommendations.

**Study Design:** These slides should 1) describe the study population (abundance at the time of tagging or recovery, (Chinook $\geq$ age 3, Chinook above the tagging site, etc.), 2) describe the proposed method to estimate abundance (Darroch or Petersen Estimator), and 3) provide a map of the study area including tagging sites, recovery sites, radio tag antennae.

**Assumptions:** These slides list the assumptions required for an unbiased estimator, the additional experiments used to test these assumptions, or if the assumptions were not tested, what information was used to support that the hypothesis was met. For closed population estimates the slides must address closure, tagging effects, and equal catchability.

**Selectivity:** The equal catchability assumption may not be met when there is sex, length, or age bias in the tagging and recovery events. These slides address the methods for testing for sex, length, or age selectivity in the first or second sample event.

**Results:** These slides must report on: 1) the number of tagged fish, the number of recaptured fish, and the number of captured fish in the second sample, 2) the results of assumptions tests including: spatial and temporal chi-square tests for stratification, tag loss assessed through double tagging, radio tags to assess mortality and closure, etc., and 3) results of selectivity tests.

**Abundance Estimate:** This slide should report the homogeneous groups that were used to estimate abundance, (females and large males may need to be estimated separately due to selectivity tests), the method used to estimate abundance (Darroch, hypergeometric, or binomial), and the final abundance estimate and the CV.

**Calibration:** These slides should report on concurrent monitoring efforts and the calibration factors. For example, what are the annual peak count expansion, apparent residence time, or females per redd estimates?

**Recommendations/Next Steps:** These slides should provide recommendations for future years, if concurrent work is important such as models to identify sex, radio tagged fish determined distribution, if there is carry over funding, or other information you believe is important to the SSC.

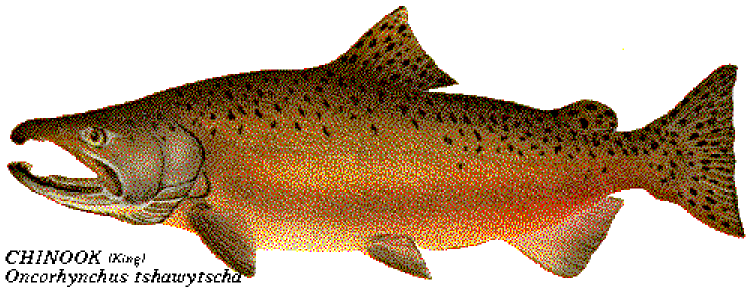
**Summary:** The purpose of this last slide is to end the presentation with a summary table for SSP population. It should be noted that not all proposals include concurrent Peak Count Expansion (PCE), residence time (RT), and Females per Redd (FpR). When not applicable, these cells can be omitted.

| Year | MR Estimate | MR CV | PCE w/SD | RT w/SD | FpR w/SD |
|---|---|---|---|---|---|
| 2008 | | | | | |
| 2009 | | | | | |
| 2010 | | | | | |
| 2011 | | | | | |

**References:**

Gargett, A. and M. Abbott. 2005. Scientifically speaking: tips for preparing and delivering scientific talks and using visual aids. The Oceanography Society Council. http://www.tos.org/resources/publications/sci_speaking.html

## 10.2 Example of a Request for Proposals (RFP): 2013




**Sentinel Stocks Committee**

**TO:** John Field, PSC Executive Secretary
**FROM:** Sentinel Stocks Committee
David R. Bernard, U.S. co-chair SSC
Chuck Parken, Canadian co-chair SSC
Marianna Alexandersdottir, U.S. co-chair SSC
**DATE:** December 4, 2012
**SUBJECT:** Request for Proposals for the Sentinel Stocks Program, 2013

The Sentinel Stocks Committee (SSC) met on 27–28 November to review projects funded in FY2012, and to generate a formal request for proposals for funds in FY2013 under the Sentinel Stock Program. Projects funded last year for which the committee will request proposals for funding next year are identified in the table on the next page as "continuing projects". The table also contains comments to proponents about changes and recommendations by the committee. While the committee does not know the dollars that these projects in aggregate will request, we anticipate the amount will be near 984k $US and 772k $Can based on information provided last year. Based on preliminary budget information, we anticipate that substantial funding will be available for new projects.

Therefore, the committee will also request proposals for new projects as identified in the table on page 3. Addition of new projects will be contingent on objectives of the proposed projects being consistent with the goals and mission of the program and on available funding.

cc.: Richard Bailey, DFO; John H. Clark, ADFG; Ethan Clemons, ODFW; Tom Cooney, NOAA Fisheries; Roger Dunlop, Uu-a-thluk/NTC Fisheries; Dan Rawding, WDFW; Arlene Tompkins, DFO; Ivan Winther, DFO; Pieter Van Will, DFO; Angus MacKay, PSC

| Continuing Projects by Stock: | |
|---|---|
| Siletz | Oregon Department of Fish and Wildlife<br>ATTN: Ethan Clemons |
| Nehalem | Oregon Department of Fish and Wildlife<br>ATTN: Ethan Clemons<br>COMMENTS: Should exclude work to provide a separate estimate for the North Fork. |
| Snohomish | WASHINGTON DEPARTMENT OF FISH AND WILDLIFE<br>ATTN: Dan Rawding<br>COMMENTS: Should determining feasibility of sampling at Sunset Falls, and if feasible, should sample at Sunset Falls. |
| Stilliguamish | WASHINGTON DEPARTMENT OF FISH AND WILDLIFE<br>ATTN: Dan Rawding |
| Green | WASHINGTON DEPARTMENT OF FISH AND WILDLIFE<br>ATTN: Dan Rawding |
| Burman | UU-A-THLUK (NUU-CHAH-NULTH TRIBAL COUNCIL)<br>ATTN: Roger Dunlop<br>COMMENTS: Should continue capture-recapture study only without radio telemetry. |
| Marble, Leiner, Tashis | DEPARTMENT OF FISHERIES AND OCEANS<br>ATTN: Pieter Van Will<br>COMMENTS: Should exclude the cost of radio tags from the budget; should use currently owned tags and tags replaced by vendor; should select test subjects inriver (not in estuary) with a frequency sufficient to avoid bias in estimated survey life. |
| South Thompson | DEPARTMENT OF FISHERIES AND OCEANS<br>ATTN: Richard Bailey |
| Chilko | DEPARTMENT OF FISHERIES AND OCEANS<br>ATTN: Richard Bailey |
| Skeena | DEPARTMENT OF FISHERIES AND OCEANS<br>ATTN: Ivan Winther<br>COMMENT: GSI for Tyee test fishery to estimate run size into the Skeena River in 2013. |
| Nass | DEPARTMENT OF FISHERIES AND OCEANS<br>ATTN: Ivan Winther<br>COMMENTS: Should determine feasibility of PIT tags as marks in capture-recapture study, and if feasible, use PIT tags in study. |

| New Projects: | |
|---|---|
| NOC/WCVI Aggregates | ALASKA DEPARTMENT OF FISH AND GAME<br>ATTN: David Bernard<br>COMMENTS: Should estimate terminal run size for each aggregate using a method based on GSI in SEAK fisheries and the recovery of CWTs, and when necessary, otoliths from exploitation-rate indicator stocks. Project should be prosecuted in active cooperation with ODFW and DFO. Should investigate feasibility of using additional fisheries beyond SEAK, and if feasible, use information from these fisheries in conjunction with SEAK fisheries. |

| | |
|---|---|
| WCVI Aggregate | UU-A-THLUK (NUU-CHAH-NULTH TRIBAL COUNCIL)/DFO<br>ATTN: Diana Dobson/Pieter Van Will<br>COMMENTS: Should sample a suite of rivers/streams, preferably escapement indicator stocks under the PST, to estimate fraction of spawning abundance composed of F1 hatchery-produced strays in each stream. |

Members of the committee associated with the relevant agencies as identified in the table will directly contact investigators for continuing projects and potential investigators on new projects. Each contact will include a proposal format and a budget sheet (see the two files attached to this communication). Proposals will be submitted via e-mail to Angus MacKay before 1700 hrs. PST, Friday, January 18, 2013.

Attachments**:** Sentinel_Stocks_2013_Budget_Form.xls;
Sentinel_Stocks_2013_Proposal_ Format.doc

## 10.3 Format for Annual Proposals

**FORMAT FOR PROPOSALS SUBMITTED TO
THE PACIFIC SALMON COMMISSION'S SENTINEL STOCKS PROGRAM**

**Cover Page**

Provide a *cover page* that identifies the following:

1. Project Title
2. Chinook Population Involved
   a. Region
   b. Stock Type and Name
   c. River System
3. Period Covered
4. Total Funding Requested
5. Requesting Agency
6. Principal Investigator (s)
   a. Name (s)
   b. Position (s)
   c. E-mail Address (s)
   d. Phone Number (s)

Proposals must be emailed to Angus MacKay (mackay@psc.org) no later than 1700 hrs. on January 17, 2014.

**Project Objectives**

Provide a concise statement of project objectives. Objectives should include statements concerning planned relative precision for estimates. The objectives should clearly identify what the project is intended to estimate, i.e., total return to river or spawning escapement stratified by age and/or sex, and/or by hatchery versus wild production.

**Significance to the Pacific Salmon Commission's Sentinel Stocks Program**

*Please note that the* ***objective*** *stated for the Sentinel Stocks Program is to attain estimates of the spawning escapement for each of the included stocks to a level that meets or exceeds bilateral data standards. Also, please note that the Pacific Salmon Commission provided direction to the Sentinel Stocks Committee concerning stocks included in the Sentinel Stocks Program. The Commission directed that stocks in the program are to be important relative to the overall coast-wide Chinook salmon resource. Further, stocks in the program should be similar to other stocks within the same region, should be significant to fishery management decisions by the Commission, and should have the potential to be cost-effectively studied. As per these criteria the Sentinel Stocks Committee has selected a suite of stocks proffered in concept proposals previously solicited from your agency, and from other agencies.*

Although a suite of stocks has been selected for the Sentinel Stocks Program (SSP), some stocks may not be studied because of insufficient monies to fund projects on all of them. As an aid to the Sentinel Stocks Committee in recommending funding this fiscal year, please succinctly illustrate why your proposed project would make a significant contribution to the Sentinel Stocks Program.

- For the stock being proposed for study, what is its distribution across fisheries managed under the Pacific Salmon Treaty?
- What exploitation rate indicator stock used by the Chinook Technical Committee most closely represents the study population? Describe how well the study population is represented by the exploitation rate indicator stock (i.e. fishery distribution, maturation, and other biological characteristics).
- What is the relevance of the study population to the assessment of the overall abundance of Chinook salmon coast-wide?
- What is the significance of the study population to management decisions by the Pacific Salmon Commission?
- How similar is the study population to other stocks in the region?
- Do the study population and a hatchery share a natal stream? Do Chinook salmon of hatchery origin stray onto the spawning grounds of the study population? Has there been past monitoring of the ratio between hatchery and natural production? How does the proposed study intend to monitor hatchery recruitment to spawning areas? What is the extent of hatchery production (e.g. hatchery contribution to spawning escapement)?
- Explain what you are doing in this project that will improve your monitoring of escapement in years following SSP funding (i.e. after 2014). **NOTE: if your project is funded in FY2014, you will be asked to elaborate on this point in your final report.**

**Experience and Expertise of Key Project Personnel**

Provide relevant vitae of key personnel who would be responsible for conducting the project. If persons have experience in the monitoring and enumeration of anadromous stocks, please provide a list of publications relevant to the proposed study.

**Supporting Person/Agencies**

Individuals and/or agencies that were contacted and/or involved in developing your proposal should be identified.

**Methodology and Project Design**

Describe methods, sample design, and techniques for conducting the project. Provide adequate detail so reviewers have a full appreciation of how the project is to be conducted and can thus provide an adequate technical review of the proposal. Describe in detail the statistical methodology for analysis and demonstrate that the expected sample sizes are adequate for the precision of estimates that are being proposed. Statements of the expected precision of estimates should be given within objective statements. Identify how estimates will be developed by sex, age, and/or origin (hatchery or wild). Also provide evidence that resources will be sufficient to attain sample sizes (e.g. information from previous studies). Identify significant risks to success (e.g. environmental, methodological, human capacity, in-kind financial, etc.)? An objective assessment of risks to success will improve the chances of a successful proposal.

The applicable bilateral data standards for estimating escapement are:

*1) Estimates of spawning escapement should on average attain an estimated coefficient of variation (CV) of 15% or less; and*
*2) Specific estimates shall be demonstrable consistent estimates, that is, methods used to produce them are asymptotically unbiased*.
Successful proposals must provide a basis for concluding how the escapement assessment being proposed will meet or exceed the data standards (e.g. evidence of precision levels in past programs on the study system or an assessment of needed sample sizes to provide the desired levels of precision, descriptions of how key assumptions pertaining to sampling biases will be evaluated). Successful proposals must link requested budgets to expected levels of effort and the resulting precision and accuracy, as well as include explicit plans for monitoring both compliance and effectiveness.

**Timeline**

Provide a timeline for project tasks that include the expected beginning and duration of the project as well as the preparation of progress reports and final reports. The Sentinel Stocks Committee will require principle investigators to participate in an annual workshop to be scheduled in concurrence with the Pacific Salmon Commission post-season review meeting in January wherein the submitted progress report and initial plans for the coming field season can be discussed in person with the Sentinel Stocks Committee.

**Permits**

Identify any required permits, those already obtained, and the timing and potential impediments to securing necessary permits to conduct the project. Have required permits been obtained?

**Project Coordination**

If the outcome of the proposed project is dependent on the funding/completion of a related project:

- Is this project to be coordinated with other projects in the Sentinel Stocks Program? Which ones? Is it to be coordinated with projects outside the SSP?
- Describe the relationships among projects.

**Reporting Schedule/Outlet**

Annual progress reports describing results from the prior field season are to be provided to the Sentinel Stocks Committee by January 1st of each year. Final annual reports are to be submitted to the Sentinel Stocks Committee, the Chinook Technical Committee, and the Northern and Southern Fund Committees by May 1st of the year following applicable field work. Specify where the final report will be published. Publication in peer-reviewed outlets is mandatory with preference for publishing in scientific journals, in agency report series, and in technical reports of the Pacific Salmon Commission.

**Proposed Budget**

Provide a detailed assessment of anticipated funding needs for FY2014, and if appropriate FY2014, by filling out the attached electronic file *Sentinel_Stock_2014_Budget_Form.xls*. If matching funds are to be secured, or have been secured, provide appropriate details.

**Additional Comments**:(NOT to exceed one page)

Are there additional attributes of the proposed project that you wish to emphasize? For example, new knowledge will be applicable to other surveys or methodologies of estimating escapement, the proposed study will provide inferences relevant to surrounding Chinook populations, or partnerships involved with the proposal will provide additional funds or other in-kind contributions.

## 10.4 Project Budget Sheet

Below on the next two pages find an abbreviated example of a budget sheet (form) required of each proposed project prior to their evaluation by the SSC.

# Project Budget Form



**Name of Project:**
**Siletz River Escapement Indicator Stock Chinook Enumeration and Spawner Survey Calibration**

**ELIGIBLE COSTS**

## Labour - Wages & Salaries

| Position | # of crew | # of work days | hrs per day | rate per hour | YEAR 1 BUDGET (+ In-kind + cash) | YEAR 1 OTHER FUNDING (In-Kind & Cash) | YEAR 1 CONTRIBUTION FUNDING (SSP Amount) |
|---|---|---|---|---|---|---|---|
| PEMD | 1 | 20 | 8 | $40.38 | $6,461 | $6,461 | $0.00 |
| SFWB | 1 | 122 | 8 | $27.24 | $26,689 | $13,344 | $13,344 |
| NRS-2 | 1 | 125 | 8 | $20.30 | $20,297 | $10,149 | $10,149 |
| NRS-1 | 1 | 260 | 8 | $17.00 | $35,340 | $0.00 | $35,340 |
| EBA | 6 | 67 | 10 | $11.88 | $47,496 | $0.00 | $47,496 |
| | | | | | | | |
| | | | | sub total | $136,282 | $29,954 | $106,329 |

## Labour - Employer Costs ( percent of wages subtotal amount )

| Position | rate | amount | BUDGET | OTHER FUNDING | CONTRIBUTION FUNDING |
|---|---|---|---|---|---|
| PEMD | 47.8% | $ 3,088 | | $3,088 | $0 |
| SFWB | 52.1% | $ 13,905 | | $6,952 | $6,952 |
| NRS-2 | 62.1% | $ 12,596 | | $6,298 | $6,298 |
| NRS-1 | 67.4% | $ 23,819 | | $0 | $23,819 |
| EBA | 72.4% | $ 34,387 | | $0 | $34,387 |
| | | sub total | $87,796 | $16,339 | $71,457 |

## Subcontractors & Consultants

| | # of crew | # of workdays | hrs per day | rate per hour | BUDGET | OTHER FUNDING | CONTRIBUTION FUNDING |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| Insurance if applicable | | | | | | | |
| | | | | sub total | $0 | $0 | $0 |

## Volunteer Labour

| | # of crew | # of workdays | hrs per day | BUDGET | OTHER FUNDING | CONTRIBUTION FUNDING |
|---|---|---|---|---|---|---|
| Skilled | | | | | | |
| Unskilled | | | | | | |
| Insurance if applicable | | | | | | |
| | | | sub total | $0 | $0 | $0 |
| | | | **Total Labour Costs** | **$224,078** | **$46,292** | **$177,786** |

## Site / Project Costs

**Provide details in the space below. Use additional page if needed.**

| Item | Details | BUDGET | OTHER FUNDING | CONTRIBUTION FUNDING |
|---|---|---|---|---|
| Travel (do not include to & from work) | Vehicles, mileage and per diem | $10,000 | | $10,000 |
| Small Tools & Equipment | | | | $0 |
| Site Supplies & Materials | nets and accessories | $2,000 | | $2,000 |
| Equipment Rental | | | | $0 |
| Work & Safety Gear | Field supplies (waders, rain gear, marking supplies, etc.) | $2,000 | | $2,000 |
| Repairs & Maintenace | Supplies and maintenance (Boats, Weir, Nets) | $1,200 | | $1,200 |
| Permits | | | | $0 |
| Technical Monitoring | | | | $0 |
| Other site costs | Cell phone | $1,000 | | $1,000 |
| | **Total Site / Project Costs** | **$16,200** | **$0** | **$16,200** |

Page 2 of 2

| ELIGIBLE COSTS | | | | BUDGET (YEAR 1) | OTHER FUNDING (YEAR 1) | CONTRIBUTION FUNDING (YEAR 1) |
|---|---|---|---|---|---|---|
| **Training (e.g Swiftwater, bear aware, electrofishing, etc).** | | | | + In-kind + cash) | In-Kind & Cash | PSC Amount |
| Name of course | # of crew | # of days | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | **Total Training Costs** | **$0** | **$0** | **$0** |
| **Administrative Costs** | | | | | | |
| Office space; including utilities, etc. | | | | | | |
| Office supplies | | | | | | |
| Telephone & Long Distance | | | | | | |
| Photocopies & printing | | | | | | |
| Insurance | | | | | | |
| Indirect/overhead costs (27%) | | | | $60,501 | $12,499 | $48,002 |
| Other overhead costs (give details) | | | | $4,374 | $0 | $4,374 |
| | | | | | | |
| | | | | | | |
| | | | **Total Administrative Costs** | **$64,875** | **$12,499** | **$52,376** |
| **Capital Costs / Ass** (Items that have an initial cost of $250 CAN or more that can be readily misappropriated for personal use or gain or will not be fully consumed by the project.) **Provide details in the space below. Use additional page if needed.** | | | | | | |
| | | | | | | |
| Boat Motor | | | | $10,000 | $0 | $10,000 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | **Total Capital Costs** | **$10,000** | **$0** | **$10,000** |
| | | | **Project Total Costs** | **$315,153** | **$58,791** | **$256,362** |

**Budget Summary** 3% COL/Inflation

**SSC Contribution Only**

| | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Total Labour Costs** | **$177,786** | **$183,119** | **$188,613** | **$194,271** | **$200,099** |
| **Total Site / Project Costs** | **$16,200** | **$16,686** | **$17,187** | **$17,702** | **$18,233** |
| **Total Training Costs** | **$0** | **$0** | **$0** | **$0** | **$0** |
| **Total Overhead Costs** | **$52,376** | **$53,947** | **$55,566** | **$57,233** | **$58,950** |
| **Total Capital Costs** | **$10,000** | **$0** | **$0** | **$0** | **$0** |
| **Project Total** | **$256,362** | **$253,753** | **$261,365** | **$269,206** | **$277,282** |
| **5 Year Project Total** | **$1,317,968** | | | | |

The form was sent to agencies along with the annual request for proposals as the spreadsheet "Sentinel_Stocks_2009_Budget_Form.xls". The example is abbreviated in that the spreadsheet covers budgets for not only the upcoming fiscal year, but for all subsequent fiscal years for which the agency plans to propose continuing the project. The part of the spreadsheet covering the detail on all subsequent fiscal years beyond the year in question was excluded from the example simply to save space.

## 10.5 Reporting Format for Executive Summaries

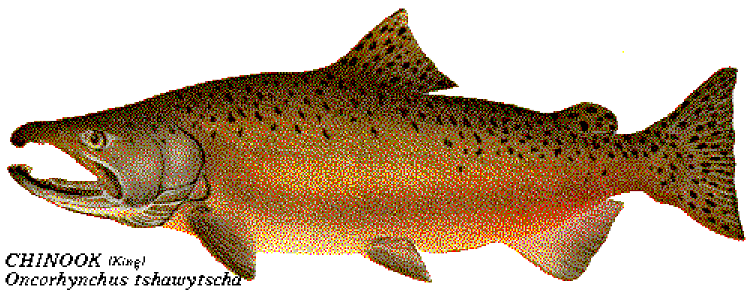
### Sentinel Stock Reporting Format

The PSC commission has identified that the CTC will report on the SSP projects in their annual escapement report. In accordance with this task, the SSC requests the proponents of each of the funded studies to supply a brief executive summary to be included in their final report which includes the following elements:
Please limit the response to 2 pages maximum.

**Executive summary**

- Please describe the stock, it’s relation to the stock group and its most recent 10-year average estimated escapement prior to the Sentinel Stock Study.
- Methods used to derive the escapement estimate (a brief summary only, please). If there have been major revisions to the approach, please highlight these changes.
- If historic estimates are available, please provide a comparison table between historically derived estimates and newly estimated escapements.
- Summarize the results of the study to include the escapement estimate, CV around the estimate and performance relative to CTC standards.
- If unsuccessful to performance standards, provide a brief statement explaining reasons why these standards were not met.
- If applicable, provide estimates of CV around calibration and or expansion factors derived between SSP projects and alternative indices.
- Describe methods being explored to provide accurate estimates of escapement beyond the sunset of the SSP program.
- Final monetary amount allocated to the study from the SSC (e.g., the SSP provided XX dollars in 2011).

10.6 **Example of SSC Recommendations to Commissioners: 2009**




**Sentinel Stocks Committee**

**TO:** PSC Commission Co-Chairs
**FROM:** Sentinel Stocks Committee
**DATE:** March 12, 2009
**SUBJECT:** Sentinel Stocks Projects

The Sentinel Stocks Committee (SSC) met in Seattle 10-12 March to review and recommend projects for funding in 2009 and in subsequent years under the Sentinel Stocks Program (SSP). Fourteen proposals were reviewed and 10 are recommended for funding in 2009. Table 1 below shows the recommended projects and funding levels.

Funds requested by recommended projects require a nearly complete expenditure of available Sentinel Stock Program funds in 2009 ($500k in Can$ and $985k in US$). Expenditure of U.S. funds includes a transfer of $195.6k US$ to Canada. At a currency exchange rate of 0.77, this transfer will cover the $254k Can$ shortfall in the Canadian portion of the program.

The proposals above were chosen by consensus as per the approach outlined in the directive from the Commission to the SSC entitled *Implementation Approach for the Chinook Sentinel Stocks Program, October 2008* and the *Sentinel Stocks Program Second Stage Proposal Evaluation, February 2009*. Recommended proposals represent stocks in all five regions specified in the directive (North Oregon Coast, Puget Sound, Fraser River, west coast of Vancouver Island, and northern British Columbia). The recommended sentinel stocks are of significant importance to the management of fisheries for Chinook salmon under the Pacific Salmon Treaty. These stocks are either large in their own right, or represent many stocks over a wide area. Proposed methods were judged to be cost effective and would likely result in estimates of spawning abundance that meet bilateral standards for accuracy and precision.

**Table 1.**Recommended projects and funding levels for the Sentinel Stocks Program in 2009.

| Stock Group | Stock | Title | 2009 Funding Level ($1000s) |
|---|---|---|---|
| WCVI | Kaouk | Kaouk River Escapement Estimation | 321.8 |
| WCVI | Burman | Burman River Escapement Estimation | 142.6 |
| Fraser | S. Thompson | Abundance Estimates South Thompson Aggregate | 101.5 |
| NBC | Atnarko | Atnarko River Escapement Estimation Project | 95.6 |
| NBC | Nass | Estimates Aggregate Population Upper Nass | 63.2 |
| NBC | Skeena | Escapement Estimation Skeena River w/ GSI | 29.3 |
| | | Total Costs of Canadian Projects in Can$-----> | 754.0 |
| | | Available Funds in Can$ ----> | 500.0 |
| | | Difference in Can$ ----> | -254.0 |
| Oregon Coast | Nehalem | Nehalem Escapement Indicator Stock Enumeration | 269.4 |
| Oregon Coast | Siletz | Siletz River Escapement Indicator Stock Enumeration | 252.0 |
| Puget Sound | Snohomish | Abundance Estimate Snohomish System | 220.6 |
| Puget Sound | Skagit | Feasibility of Capturing Chinook Salmon | 46.4 |
| | | Total Costs of U.S. Projects in US$-----> | 788.4 |
| | | Transfer to Canada of Funds in US$ ----> | 195.6 |
| | | Proposed Expenditure of US Funds in US$ ----> | 984.0 |
| | | Available Funds in US$ ----> | 985.0 |

In its deliberations the SSC considered issues related to funding beyond 2009. Evidence of success will be required to secure funding beyond 2009 along with resubmittal of an updated proposal. Most proponents with recommended projects anticipate similar annual requests for four more years (Nehalem, Burman, Snohomish, S. Thompson, Atnarko, Nass, Skeena) while others do not (i.e. the Siletz was proposed for a 3-year duration). Some proponents anticipate substantially lower funding requests after 2009 due to expenditure of capital costs in 2009 (e.g. Kaouk), while others anticipate an increase depending on results in 2009 (Skagit). Four of the proposals are not recommended for funding in 2009. Specific reasons for not recommending are:

*WCVI Stock Assessment Framework*. The SSC did not believe this proposal was consistent with the directive in that no specific stock was identified for escapement estimation in 2009. Instead the proposal centered around several approaches to improve precision and accuracy in methods used to estimate total spawner abundance, but without providing any evidence of the magnitude of the gain in precision or accuracy.

*Kitwanga River Chinook Salmon Enumeration*. The Kitwanga stock is a small component of the Skeena River escapement indicator stock. Although estimates of escapement to the Kitwanga River would be very accurate, precise, and valuable, this information would be subsumed by estimates of escapement to the whole Skeena River obtained from a recommended project (the “Escapement Estimation Skeena River w/ GSI”).

*Escapement Estimation to the Kwinamass & Khutzeymateen Rivers*. The stock proposed for 2009 is actually the Kateen stock associated with the Kateen River, a tributary of the Khutzeymateen River. Although estimates of escapement to the Kateen River would be valuable to represent the small coastal spawning populations, the Kateen stock represents a small component of the Nass escapement indicator stock.

*Improving Stillaguamish Chinook Escapement Methodologies.* The Stillaguamish stock is identified as a sentinel stock in the Agreement. However, the SSC judged that relative to the recommended projects, proposed methods in this project ran a high risk of not meeting bilateral standards for accuracy in estimates. Planned sampling in the river would not result in information sufficient to correct bias in estimates from the proposed capture-recapture study if presumptions about migratory behavior within the river proved to be wrong. The SSC will consider a revised proposal next year.

The SSC proposes to hold a meeting in Seattle this December 2009 to review progress in projects funded for 2009 and begin the process of soliciting proposals for 2010. Proposals for 2010 would be requested in time for SSC review during the January 2010 PSC meeting, such that recommended projects will be identified to the Commission during the February PSC meeting.

## 10.7 Format for Concept Proposals

Pacific Salmon Commission
Chinook Salmon Sentinel Stocks Program

**Preliminary Project Outline and Justification**

The Sentinel Stock Committee (SSC) has prepared this short-form project outline to identify priority Chinook populations that agencies propose for consideration under this new PSC initiative. The objective stated for the Sentinel Stock Program is to attain estimates of the spawning escapement for each of the included stocks to a level that meets or exceeds bilateral data standards (see attached CTC letter commenting on bilateral data standards). Also attached is a document which provides more background on the Sentinel Stocks program and the SSC. This proposal will be used by the SSC to prepare a recommended work plan to be presented to the PSC in January 2009. The proposal is to be a SHORT, concept-type description of the populations of interest to the agency and of proposed methods for estimating spawning escapement. Each outline cannot exceed five pages in length and must contain the following information:

**Contact Name and Agency**: (name of person submitting, position, e-mail, and phone)

**Supporting person/agencies**: (those contacted and/or involved in developing this submission)

**1) Description of the Chinook population involved (*1 proposal per combination of Region, stock, and river systems*)**:

a) Region: describe geographic location (a map would be useful)
b) Stock type and name
c) River system: identify the river for full system estimates or tributaries for specific population estimates
d) Distribution of populations in PSC fisheries: What CTC exploitation rate indicator would most closely represent the distribution of this population?
e) Relevance of the candidate stock to the assessment of the overall Chinook salmon resource (e.g., significance to PST fishery management decisions, similarity to other stocks within the region)
f) Extent of hatchery production: hatchery in system, strays, etc.; has there been past monitoring of the ratio between hatchery and natural production?

**2) Extent of Project**: clearly identify what the project is intended to estimate, i.e., total return to river or spawning escapement; (age & sex composition, and hatchery versus wild proportions). Is the project to run one year or several? Is this project to be coordinated with other projects in the SSP? Which ones? Is it to be coordinated with projects outside the SSP?

**3) Brief description of methods**:

a) Recommended methodology and why: *An essential component of the proposal is your justification of the methodology*.
b) Risks to success: An objective assessment will improve the chances of a successful proposal.
c) Preliminary Budget by major items: Please include a preliminary estimate of the needed costs to capital and construction, equipment, operating costs, labour and all other costs to be requested from the SSC. If matching funds are to be secured or have been, please make a note of these as well.
d) Please provide a timeline of the expected beginning, duration and reporting of operations.
e) What evidence is there that the requested monies should be sufficient to attain estimates meeting bilateral standards?

**5) Long-term intention for project**: The Sentinel Stocks program is limited under the 2008 Agreement to a five year period. Comment on your expectation of continuance beyond these five years if your project is successful.

## 10.8 Example of Progress Report to Commissioners: 2012

Sentinel Stocks Committee

**Progress Report for Projects funded through the Sentinel Stocks Program, 2012**

Report to the Pacific Salmon Commission during their Executive Work Session, 2012

16-18 October 2012

Vancouver, B.C. Canada

Please find below a description of progress for the 14 projects that comprise the Sentinel Stocks Program in 2012. Allocated funds, schedules, main objectives, and status of fieldwork are also listed for each project. Information given below reflects the latest information available to the Sentinel Stocks Committee in early October 2012.

| | |
|---|---|
| **Northern BC – Nass Stock** | **Cost in 2012: 108.57 $Can** |
| **Nass River Escapement Estimate Improvement** | **Progress through 25 September** |
| Fisheries and Oceans Canada | **Fieldwork Completed as of 12 October** |

The objective is to augment an existing mark-recapture study to estimate the escapement to the Upper Nass River by increasing the number of adult Chinook salmon marked and subsequently inspected for marks. The goal was to improve precision in the estimate to meet the CTC standard. Funds were to mark at three to four fishwheels at Grease Harbour in addition to the two fishwheels at Gitwinksihlkw, survey carcasses on the Damdochax River and elsewhere, and operate a weir (fence) on the Kwinageese River for the full migration period of the Chinook run. Operations began on schedule and tagging at Grease Harbour fishwheels occurred as planned. A preliminary estimate of 10,562 (SE=461; CV%=5.8) large Chinook adults (>49 cm NFL) was computed to Gitwinksihlkw. The estimate was based on 3,081 marks applied from 4,059 fish captured at the fishwheels, 1,053 fish examined for marks from three Upper Nass tributaries, and 292 marks recovered by the recovery efforts. The CTC standard was fully achieved in 2012 due to the additional funding received to support tagging and recovery efforts. The additional funding also helped monitor fish passage from the 2011 in-stream habitat work that enabled passage of salmon on the Kwinageese River that were blocked from a recent rock slide.

| | |
|---|---|
| **Northern BC – Skeena Stock** | **Cost in for 2012: 35.8 $Can** |
| **Escapement Estimation Skeena River w/ GSI** | **Progress through September 26** |
| Fisheries and Oceans Canada | **Field work Completed as of 29 September** |

The objective is to estimate escapement of Chinook salmon to the Skeena River by expanding an estimate for the Kitsumkalum River using the genetic composition of catches in the Tyee Test Fishery. The SSP funds are used to analyze genetic samples collected in the test fishery. The test fishery itself and the project to estimate abundance in the Kitsumkalum River are funded independently. The Tyee Test fishery is conducted with a fixed level of effort and all fish caught are sampled. As such, Chinook abundance directly influences catch levels. The project began on schedule and approximately 500 fish were sampled. Genetic extractions have been completed and genotyping is underway for the samples. Funding was based on a maximum of 1500 fish sampled. The sampling shortfall (500 versus 1500) will reduce precision in estimated abundance by a moderate amount, but should not affect the accuracy of the estimate. The variance around the spawner estimate of Kitsumkalum Chinook salmon has had the most significant effect on whether the estimate for the aggregate meets the data standard based on the analysis of previous years. The Kitsumkalum mark-recapture project is underway but suffered a minor setback due to a relatively low return in 2012. A relatively small number (677) of tags were applied to age 3+ fish. Excellent weather conditions in September had positive effects on the number of carcasses encountered and examined for marks in the dead pitch program. To date over 800 carcasses have been examined for marks and the preliminary estimate for the Kitsumkalum Chinook return is 9,300 fish with a CV of 14%. Carcass recovery continues on the Kitsumkalum River. Actual costs for this SSP project will be approximately $16K.

| | |
|---|---|
| **Northern BC – Skeena Stock** | **Cost in 2012: 191 $Can** |
| **Historic Escapement Estimation Skeena River w/ GSI (New)** | **Progress through September 29** |
| Fisheries and Oceans Canada | **Field work Completed (historic)** |

The objective of this project is to use archived scale samples from Chinook salmon from the Tyee Test fishery to generate escapement estimates for the Skeena aggregate. Genetic analyses are used to determine the proportion of the catch originating from the Kitsumkalum River. The estimates of escapement to the Kitsumkalum River are known from mark-recapture programs conducted since 1984. This Kitsumkalum proportion is expanded to generate escapement estimates for the aggregate. A total of 11,228 samples from 15 years were selected for genetic analyses to complete the time series from 1979 to 2008. Years 2009 through 2012 have been completed through annual SSP projects. The samples from years 1979 to 1983, 1994-1996, and 2006-2008 have been genotyped (8,442 fish) and the extractions are underway for the 2001-2003 samples (2,786 fish). The stock identification results have not been completed using the new baseline samples collected from the Bear River in 2012. The Kitsumkalum escapement estimates from 1984 to 2008 were very precise, with CV's averaging around 10%, so many of the aggregate escapement estimates in the historic time series should meet the CTC data standard (CV=15%).

| | |
|---|---|
| **WCVI – Marble, Tahsis, and Leiner Stocks** | **Cost in 2012: 219.0 $Can** |
| **Improving the parameter estimates of survey life and observer efficiency required for the AUC method of spawning abundance on key Chinook populations of the West Coast of Vancouver Island, 2012 (new)** | **Progress through September 24** |
| DFO South Coast Division, WCVI Salmon Assessment Unit | **Field work Ongoing as of 24 September** |

The objectives of the program are to estimate the survey life (SL) of Chinook salmon entering the freshwater survey areas, assess temporal and spatial variation in SL, estimate observer efficiency, and develop AUC escapement estimates. The project uses radio tagging of salmon near the river mouth and snorkel and telemetry surveys in the rivers. Radio-tagged fish are tracked in each river using two methods: fixed-station receiver sites at the top and bottom of the index survey section and mobile-tracking during swims with an H-antenna. At the Marble River, tagging began on 26 August and after 21 days of sampling 102 adult Chinook salmon had been radio-tagged (as of Sept 18). Marble River snorkel surveys began in late August, and the peak count of adult Chinook to date was on 14 September at 722 fish (4 tagged, 718 not tagged). Five tags have been tracked into the survey section as of September 14. Tagging operations continue, but have slowed. Tagging began in Tahsis Inlet on August 29 and has continued for two days a week, ending in the last week of September. Two hundred fifty tags were applied as of September 20. Snorkel surveys in the Tahsis and Leiner rivers began in early September. Peak counts as of Sept ember 24 are 15 Chinook salmon (2 tagged, 13 not tagged) in the Tahsis River on September 15 and 147 Chinook salmon (10 tagged, 147 not tagged) in the Leiner River by September 16. Paired swims and telemetry will continue through October. River levels were extremely low at these locations during August and September. Problems have been identified with the functioning of the motion sensors for some of the Lotek radio tags, which causes some tags to identify a 'dead' fish when it is alive. The manufacturing problem may reduce the effective sample size of radio tags, and the net effect on the study is unclear at this point.

**WCVI - Burman Stock** Cost in 2012: 197.1 $Can
**Burman River Chinook Salmon Mark Recapture** Progress through 4 October
Uu-a-thluk/Nuu-chah-nulth Tribal Council Field work Ongoing as of 4 October

The primary objective is to estimate escapement of adult Chinook salmon with closed-population and open-population mark-recapture experiments. Marking began on September 10. Chinook salmon have accumulated in the lower river staging area and tagging site as low flows have effectively delayed migration to other parts of the river. About 1000 adult salmon have been marked of which 90 carry radio tags. Over 240 live recaptures and another 20 radio tagged fish have been recorded at the lower river site. A large number (300) of jacks have been marked. Carcass surveys have sampled about 80 carcasses of which 9 were marked and another 3 carried radio tags. The population in the staging area is well marked, and the project is well situated for the carcass recovery phase. Fixed telemetry stations were established at the limits visual survey sections within the river. Mobile telemetry surveys conducted during snorkel surveys to enumerate Chinook salmon and radio tagged fish are occurring every second or third day. Sampling targets to meet program standards and results were: to mark 1000 fish and examine 100 carcasses for marks (as above). Sampling targets for otoliths used to determine origin and for scales have been achieved. Preliminary data suggests the precision and accuracy goals will be achieved. Problems have been identified with the functioning of the motion sensor for some of the Lotek radio tags, which causes some tags to identify a 'dead' fish when it is alive. The manufacturing problem may reduce the effective sample size of radio tags, and the net effect on the study is unclear at this point.

**WCVI – Statistical Framework for Stock Assessment** **Cost in 2012: 30.0 $Can**
DFO South Coast Division, WCVI Salmon Assessment Unit **Progress through 5 October**
**Ongoing as of 5 October**

A Canadian Science Advisory Process workshop has been scheduled for May 7 to 9, 2013. The workshop is an open process and SSC members will be invited along with others in the PSC organization such as CTC members. The workshop products are intended to be scientific and reflect the results of rigorous peer review and be published. The goal is to produce two key outputs, including (1) a peer reviewed Chinook Escapement Monitoring Framework for the WCVI Management Unit, including an estimation model for AUC analysis (i.e. a research paper), and (2) a Workshop Proceedings reviewing and recommending methods for estimation of the total escapement within the larger unit depending on the objective (e.g. CTC model stocks both hatchery and natural, CDFO Conservation Units).

**Fraser – South Thompson Stock** **Cost in 2012: 160.8 $Can**
**Abundance Estimate South Thompson Aggregate** **Progress through October 3**
Fisheries and Oceans Canada **Field work Ongoing as of 3 October**

The objective is to estimate system-wide escapement to the Fraser Summer-run 0.3 aggregate and component populations. The method estimates stock contribution rates from scale, GSI and CWT data collected in the NBC troll fishery and in the Lower Fraser Albion test fishery, which are then applied to CWT data collected on the spawning grounds for the Lower and Middle Shuswap indicator stocks. The method requires application of CWTs to juveniles from the indicator stocks, and mark-recapture studies in Middle and Lower Shuswap rivers to estimate the returns of CWTs to both systems and to achieve target sample sizes of CWT recoveries in the NBC troll and Albion test fishery. Targets for numbers of CWTs to be applied and released (150k from Middle Shuswap and 500K from Lower Shuswap) were achieved. Fishery sampling for GSI and scales occurred on the North coast, as well as for CWTs (in prep), and subsequent data are being processed. At Albion, GSI, scale and CWT samples await analysis. Capture-recapture studies are ongoing at both systems. Marking has finished at Middle Shuswap and recovery sampling has just started, whereas marking is still underway at Lower Shuswap. Escapements to both systems appear much lower than observed in recent years. At Middle Shuswap, approximately 60 Chinook salmon were marked and released back to the river, and approximately 600 salmon have been marked to date at Lower Shuswap. Mark recovery is just starting at Lower Shuswap.

**Fraser – Chilko Stock**
**Chilko River Chinook Salmon Mark-Recapture**
Fisheries and Oceans Canada

**Cost in 2012: 224.0 $Can**
**Progress through October 3**
**Field work just completed as of 3 October.**

The objective is to estimate spawning abundance in the Chilko River, using a two-event mark-recapture study. A total of 680 fish were captured in the Chilko River, marked with Petersen disk tags and released back into the river of which 307 fish were captured by beach seines and 373 by angling. Carcass sampling was completed by early October; approximately 1530 carcasses were examined for marks, of which about 270 were marked. Based on those recoveries, a preliminary estimate of 4100 has been developed (CV $\cong$ 5%), however, no assessments of bias have been conducted at this time.

**Fraser – Harrison Stock**
**Telemetry Study For Closure, Harrison River**
Fisheries and Oceans Canada

**Cost in 2012: 51.1 $Can**
**Progress through October 3**
**Field work Ongoing as of 3 October**

The objective is to apply radio tags to returning Chinook salmon captured in the Harrison River to assess subsequent behavior and evaluate compliance with assumptions of closure associated with the annual Petersen mark-recapture estimate of escapement to the Harrison River. To date, telemetric monitoring stations have been installed at the upper and lower limits of the study area, close to the middle of the spawning area on the Harrison, and immediately upstream of the mouth of the Chilliwack River. The Chilliwack station is intended to detect migration of fish that were captured and tagged in the Harrison that subsequently entered into the Chilliwack River. Eighty-eight radio tags were purchased, and will be applied to returning Chinook salmon during October. Seining operations started at the beginning of October and two tags have been applied to date.

**Puget Sound – Stillaguamish Stock**
**Escapement Estimation w/PBI Genotyping**
Washington Department of Fish and Wildlife

**Cost in 2012: 71.5 $US**
**Progress through September 27**
**Field Work Completed by 9 October**

The SSP funded a project to estimate escapement of Chinook salmon in the Stillaguamish River using a genetic mark-recapture study based parental genotyping from carcasses collected in the fall and outmigrants captured via smolt trapping during the following winter and spring. This is a cooperative effort between WDFW and the Stillaguamish Tribe. We provided escapement estimates using this method for BY 2007 to 2010 in our recent annual report. Progress for BY 2011 is presented in Table 1. A total of 225 and 2797 tissue samples were collected from adults and juveniles, respectively. The WDFW Molecular Genetics Lab has successfully genotyped 141 adult tissue samples; genotyping of some carcass tissue failed due to the deteriorated condition of some specimens. Genotyping adult scale samples and juvenile samples is ongoing.

**Table 1**. Tissue samples (adult samples include tissues and scales) and genotyped Stillaguamish River Chinook salmon for BY 2011 GMR project.

| Spawn Year | Outmigration Year | | Carcasses Sampled | Carcasses Successfully Genotyped | | Juveniles Sampled | Juveniles Successfully Genotyped |
|---|---|---|---|---|---|---|---|
| 2011 | 2012 | | 225 | 114 successes<br>84 in progress | | 2797 | In progress |

**Puget Sound – Green Stock**
**Escapement Estimation w/PBI Genotyping**
Washington Department of Fish and Wildlife

**Cost in 2012: 141.9 $US**
**Progress through September 27**
**Field Work Completed by 9 October**

The SSP funded a project to estimate spawning escapement of Chinook salmon in the Green River using a genetic mark-recapture study based on parental genotyping from carcasses collected in the fall and outmigrants captured via smolt trapping during the following winter and spring. The WDFW provided escapement estimates using this method for BY 2010 in our recent annual report. The WDFW Molecular Genetics Lab is currently processing the salmon carcasses collected by Region 4 staff. Progress for BY 2011 is presented in Table 2. A total of 382 and 2548 tissue samples were collected from adults and juveniles, respectively. A total of 1996 juveniles have been subsampled for genotyping. Genotyping of adult and juvenile samples is in progress at the WDFW Molecular Genetics Lab.

**Table 2.** Tissue samples and genotyped fish for Green River Chinook salmon for BY 2011.

| Spawn Year | Outmigration Year | | Carcasses Sampled | Carcasses Successfully Genotyped | | Juveniles Sampled | Juveniles subsampled | Juveniles Successfully Genotyped |
|---|---|---|---|---|---|---|---|---|
| 2011 | 2012 | | 382 | In progress | | 2548 | 1996 | In progress |

**Puget Sound – Snohomish Stock**
**Escapement Estimation w/PBI Genotyping**
Washington Department of Fish and Wildlife

**Cost in 2012: 217.8 $US**
**Progress through September 27**
**Field Work Completed by 9 October**

The SSP funded a project to estimate escapement of Chinook salmon in the Snohomish River basin using a genetic mark-recapture study based parental genotyping from carcasses collected in the fall and outmigrants captured via smolt trapping during the following winter and spring. This is a cooperative effort between WDFW and the Tulalip Tribe. This is the first year of the project. The Tulalip tribe successfully operated two outmigrant traps on the Skykomish River (RM 26.5) and one on the mainstem Snoqualmie River (RM 12.2). These traps are located below most of the spawning in the basin. Progress for BY 2011 is presented in Table 3. A total of 221 and 149 tissue samples were collected from BY11 adults on the Snoqualmie and Snohomish rivers, respectively. A total of 376 and 1268 juveniles were collected from the Snoqualmie and Skykomish, respectively. There was no need to sub-sample juvenile collections prior to genotyping since the number sampled was below our target number. Proportional sub-sampling will occur after genotyping using a bootstrap analysis. Genotyping of adult and juvenile samples is in progress at the WDFW Molecular Genetics Lab.

**Table 3**. Tissue samples and genotyped fish for Snoqualmie and Skykomish River Chinook salmon for BY 2011.

| River | Spawn Year | Outmigration Year | | Carcasses Sampled | Carcasses Successfully Genotyped | | Juveniles Sampled | Juveniles Successfully Genotyped |
|---|---|---|---|---|---|---|---|---|
| Snoqualmie | 2011 | 2012 | | 221 | In progress | | 376 | In progress |
| Skykomish | 2011 | 2012 | | 149 | In progress | | 1268 | In progress |

**Oregon Coast– Nehalem Stock**
**Nehalem Escapement Indicator Stock Enumeration**
Oregon Department of Fish and Wildlife

**Cost in 2012: 301.1 $US**
**Progress through 4 October**
**Field work Ongoing as of 4 October**

The objective is to estimate terminal escapement with a mark-recapture study and an in-river creel survey. Fish began entering the river in early August and by the October 4, 470 had been captured in the first event (425 adults and 45 jacks tagged). The target is 4% of an expected 8700 spawning fish return or 350 fish tagged. So far the majority of tagged fish are presumed to represent the summer run; the fall run has yet to be discerned. Concurrent to incoming Chinook being tagged, efforts to recover tags in the river began the week of September 24. To date (October 4), one marked fish has been captured and sampled in the riverine creel survey. Expanded estimates to the expected recruitment from the study group of fish to the fishery are not currently available. Netting for Chinook salmon in the North Fork of the Nehalem River has begun the week of September 17.

**Oregon Coast– Siletz Stock**
**Siletz River Escapement Indicator Stock Enumeration**
Oregon Department of Fish and Wildlife

**Cost in 2012: 228.9 $US**
**Progress through 4 October**
**Field work Ongoing as of 4 October**

The objective is to estimate terminal escapement with a mark-recapture study and an in-river creel survey. Tagging began in August 22 and so far 217 fish have been captured in the first event (185 adults and 32 jacks tagged). The target is 5% of an expected 4400 spawning fish return or 220 fish tagged. Tagging efforts continue and are anticipated to peak later this month with a transition from an unusually dry fall to a more active rainy season. Spawning ground surveys have been initiated, but results from these have yet to be compiled. To date (October 4), two marked fish have been observed in the creel survey in the Siletz River.

One additional development of note is the collaborative effort between ODFW and CDFO-Fraser group to exchange best field practices and methods. Representatives from CDFO are touring ODFW mark-recapture operations on the Oregon coast during the week of October 15 to share and develop methodologies common to all SSP projects. Both agencies anticipate a fruitful and lasting positive impact on escapement enumeration coastwide.