Nez Perce Tribe Standardized Calculations for High Level Indicators and Metrics

Ryan N. Kinzer

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Chapter 1

Preface

The Department of Fisheries Resources Management (DFRM) Research Division utilizes four technical teams to develop and standardize our analytical methodology and to guide data management. Each team consists of professional staff representing each monitoring and evaluation project and are responsible for determining how to collect, summarize and analyze fall and spring/summer Chinook Salmon and summer steelhead data using the best available science. The Adult Technical Team (ATT) examines data collected from spawning ground surveys, picket weir operations and in-stream PIT tag detection systems and focus on indicators of abundance, life history characteristics and population productivity. The Juvenile Technical Team (JTT) is responsible for summarizing data collected from rotary screw traps, beach seining, underwater snorkeling and in-hatchery monitoring. Metrics discussed by the JTT include abundance, survival and life history characteristics of various juvenile life-stages. The adult and juvenile technical teams are comprised of biologists and project leaders supervising data collection and summarization, and the calculation of performance measures for each research project. The third technical team consists of Research Division management and project leader staff who focus on the best methods for data analysis and conducting hatchery effectiveness monitoring, or implementing adaptive management. Data aquisition, storage and processing is completed by the forth team, Data Management, who is responsible for creating accurate and efficient tools to assist project staff and fish managers answer their data related questions.

The main objective of this document is to describe the methodology used to calculate high level indicators and metrics for fish populations monitored by the Nez Perce Tribe (NPT) using standardized techniques and calculations. A single, standardized and parsimonious method for all monitored areas is preferred by NPT managers and researchers to maintain transparency, reproducible and comparability across project areas and fish populations. Standardized methods and calculations for each indicator and metric were collaboratively chosen by

Research Division projects and technical teams as the best method for representing all monitored fish populations. Although all reasonable attempts to avoid different methods for indicator and metric calculations were made, in some instances multiple methods were necessary to accurately capture true population responses due to existing differences in management strategies or fish population complexity. In those cases, population differences and necessary methods used in each location are clearly identified. Additionally, different calculations and techniques are often needed to capture rare annual events that necessitate more complex methods. In these cases, annual progress reports will document and detail methodologies used to calculate indicators and metrics that differ from the standard approaches described within this document.

The contents of this document are the result of countless hours and many discussions between NPT DFRM Research Division staff during division meetings, technical team meetings, phone calls and impromptu discussions. Our staff's expertise and knowledge of salmon and steelhead data collection and analysis is endless, and without them and their contributions this work and approach would not be possible. Thank you to all those involved for being patient and helping to find a better path forward for method reproducibility and efficiency through compromise.

Chapter 2

Introduction

The Nez Perce Tribe's (NPT) Department of Fisheries Resources Management (DFRM) has the responsibility of managing, restoring and recovering fish populations in the Snake River basin. The DFRM completes these tasks with work performed under six divisions; Administration, Conservation Enforcement, Harvest Monitoring, Production, Research, and Watershed Restoration. The Tribe's fisheries activities encompass a vast geographic area, over 13 million acres, within the present-day states of Idaho, Oregon, Washington, and Montana. Data collected under the six divisions is extensive, and quantifies fisheries resource condition and response to management actions supporting 1855 Treaty rights, the Federal Columbia River Power System Biological Opinion, U.S. vs. Oregon management agreement, Snake River Basin Adjudication, Northwest Power and Conservation Council Fish and Wildlife Program, and Lower Snake River Compensation Plan mitigation.

The DFRM Research Division is tasked with monitoring and evaluating natural- and hatchery-origin anadromous fish populations throughout the Tribe's usual and accustomed areas within the Snake River basin. The Research Division's mission statement is:

> "to contribute to sound fisheries management through best available science. This involves collection of status and trends data, conduct management action effectiveness monitoring, and communication of knowledge (and uncertainties) that are unbiased, objective, collaborative, and available to the community at large."

— NPT DFRM Management Plan

To accomplish our mission the division is made up of independent monitoring and evaluation projects that contribute to the status assessments of fall Chinook Salmon, spring/summer Chinook Salmon and steelhead populations identified by the Interior Columbia Technical Recovery Team (ICTRT) (ICTRT 2003) through the collection, summarization, analysis and reporting of information. Salmonid population monitoring and evaluation is performed at multiple spatial scales (e.g., tributary, population, evolutionary significant units) and use a variety of data collection activities (e.g., spawning ground surveys, rotary screw traps). Implemented data collection activities vary across species and research division projects to answer specific population uncertainties identified through regional planning efforts and to meet data requirements for specific project objectives. Project objectives within the division include the assessment of hatchery program performance and effectiveness at individual tributary scales, hatchery program effects on natural origin populations, and the status and recovery monitoring of natural origin ICTRT populations and major population groups (MPG) (McElhany et al. 2000). Evaluation techniques at each spatial scale follow the mission statement and use the best available science to produce sound population metrics to guide fisheries management and salmon and steelhead recovery.

Research division projects evaluating hatchery program performance and the status of salmon and steelhead populations follow established monitoring and evaluation (M&E) plans (Hesse and Cramer 2000; Hesse et al. 2004; Vogel et al. 2005) using standardized fish population performance metrics. Established M&E plans identify each project's objectives and describe testable hypotheses to judge hatchery program success. Plans often suggest monitoring and evaluating similar metrics to judge performance, however, plans do not clearly state metric definitions. To aid hatchery programs and population status evaluations, and to facilitate direct comparisons of fish metrics across all Columbia Basin Salmonid populations the Ad-Hoc Supplementation Workgroup (AHSWG) defined key performance measures (Beasley et al. 2008). Sixty-two performance measures were identified and grouped into abundance, life history, survival-productivity, distribution, genetic, habitat, and in-hatchery categories.

Similar to the AHSWG, in 2008 a regional workshop of Columbia River basin fish management, regulatory and funding agencies convened to integrate existing programs into a cohesive framework to improve monitoring strategies and to allow critical uncertainties to be addressed more effectively and efficiently (CBCAMW 2010). The Coordinated Assessments (CA) project was conceptualized at the workshop and started the development on Data Exchange Standards (DES; http://www.streamnet.org/coordinated-assessments-des/) to guide regional standardization of fisheries data for the purpose of efficient, reliable calculation and transparent sharing of high level indicators of population abundance, productivity, habitat and hatchery metrics. The DES serves as metadata to the CA database which contains the regionally accepted high level population indicator and metric data stored on StreamNet (http://www.streamnet.org/data/coordinated-assessments/. CA indicators and metrics include performance measures defined by AHSWG, and others used for regional monitoring, Endangered Species Act (ESA) status reviews and viability assessments.

The DFRM Research Division projects calculate and report fish summary metrics and high level indicators following the AHSWG and CA standard definitions by using standardized estimation and analytical methods. Similar methods and approaches are possible across division projects and geographic areas because data collection protocols and repositories have been standardized across the division. Consistent and standard approaches ensure accurate hatchery program comparisons and scalability from individual tributaries to a population, and up to larger MPGs or geographic areas for Nez Perce Tribe managers and other regional decision makers.

High level indicators and metrics are shared throughout the region annually with annual progress reports, management briefings, and the CA database for all Chinook Salmon and steelhead populations monitored by the Research Division. Each individual division project is considered the main contact and reference for all data collection, summarization, analysis and reporting. Standardized data collection methods and minimum quality assurance and control procedures for data integrity can be found on http://www.monitoringresources.org for each field activity and method. Summarized data, high level indicators and metrics, and annual project reports are available for public access on the Kus web appliation (https://nptfisheries.shinyapps.io/kus-data/). Raw fisheries data are stored on Research Division servers within the DFRM's Centralized Data Management System (CDMS). Access permission to the raw data is restricted only to DFRM staff through CDMS (https://npt-cdms.nezperce.org) and Kus web applications. Raw data can be made available with a special request through the division's Data Coordinator, Ryan N. Kinzer, or Data Steward, Clark Watry.

This document provides detailed documentation of standardized Research Division methods for calculating AHSWG performance measures and CA high level indicators and metrics. Our objectives are to (1) standardize analytical methods across all division projects and monitoring locations, (2) identify common alternative methods when project or annual conditions necessitate, (3) identify uncertainty estimators, and (4) create a transparent and citable reference for interested parties when using or referencing NPT DFRM Research Division methods. The document is organized into a single introduction chapter, and three chapters grouping performance measure calculations into life stages: Adult Abundance and Life History, Juvenile Abundance and Life History, and Population Productivity. The document is not inclusive of all AHSWG and CA metrics (e.g., Distribution, Genetic and Habitat), but instead focuses on the main building blocks of population and hatchery effectiveness monitoring. The document is considered living and is subject to regular updates as missing metrics are added, and new data or methods are made available.

2.1 Data Collection and Management

Processing, summarizing and disseminating data and project results are as critical to the scientific process as the original collection of data itself. The data management process, however, is typically completed as an afterthought with less attention to detail being applied. As a proactive step towards thoughtful data stewardship and maintaining data integrity the Research Division follows predetermined work flows and protocols for all data activities. The standardized work flows and protocols utilize established cyber-infrastructure to efficiently support the acquisition, storage, integration, mining, and visualization of fisheries data required to meet Research Division objectives. The division acquires data from two sources; original collection by DFRM staff or through external data sharing agreements with fisheries co-managers and the original data collector. After acquisition, data collected by DFRM staff is entered and maintained in CDMS. Stored data is examined for accuracy and corrected within the online web application CDMS. External data is pulled onto servers from their source repository (e.g., Lower Snake River Compensation Plan's FINS [Fish INventory System] database) at a frequency necessary to meet management requirements. Both data sources are then merged with automated computer processing scripts to facilitate more efficient and reproducible summaries, analyses and standardized reports.

Research Division staff collects field data associated with adult picket (fixed and floating) and passive weirs, in-stream PIT tag detection systems (IPTDS), radio telemetry tracking, spawning ground surveys, juvenile rotary screw traps, beach and boat seining and in-hatchery evaluations. Depending on the field activity newly collected raw data is captured electronically (e.g., PSMFC P4, Survey123) and later uploaded to CDMS or onto hard copy datasheets for manual entry into CDMS. Each field activity uses standardized protocols developed to ensure consistent, transparent and high quality data is collected. Field activity protocols include the objectives and location of each activity, step-by-step guides for proper data collection, minimum quality assurance and control (QA/QC) standards and descriptions of how to record raw data. Field protocols are available for download on the Kus web application or from MonitoringResources.

External data originally collected by entities other than NPT is acquired through data use and sharing agreements. Currently, the Research Division consumes raw field data and summarized data collected and/or maintained by the Idaho Department of Fish and Game (IDFG), Oregon Department of Fish and Wildlife (ODFW), Washington Department of Fisha nd Wildlife (WDFW), Columbia River Inter-Tribal Fisheries Commision (CRITFC), Pacific State Marine Fisheries Commission (PSMFC), and the Data Access in Real-Time (DART, http://www.cbr.washington.edu/dart) website. External data consumed from other entities allows Research Division projects to report population performance measures that would have been unobtainable with only NPT collected data. Data citations are provided when external sources assist in performance measure calculations.

Chapter 3

Adult Abundance and Life History

The DFRM Research Division collects and summarizes adult data collected from three field methods to calculate adult abundance, and life history metrics identified by the AHSWG (Beasley et al. 2008) and described in CA DES. Data is collected for returning fall and spring/summer Chinook Salmon and steelhead using spawning ground surveys, floating and fixed panel picket weirs, Lower Granite Dam adult sampling, and instream PIT-tag detection systems (IPTDS). Detailed descriptions of field activities and data collection protocols can be found at https://www.monitoringresources.org; Spawning Ground Surveys, Picket and Floating Panel Weirs, Lower Granite Dam Adult Sampling, and Instream PIT-tag Detection Systems. Spawning ground survey data, fall Chinook Salmon run-reconstruction estimates and IPTDS abundance estimates generated from Lower Granite Dam adult sampling are stored and accessed from the Tribe's CDMS, and the weir trapping data is obtained from the LSRCP FINS database.

The summary and analysis methods used to calculate adult AHSWG performance measures and CA indicators and metrics are described below and provide a consistent and comparable approach across all NPT adult monitoring locations. In some cases, calculation methods are different for the various species or runs, or across the landscape and at different spatial scales. Necessary differences in methodology exist because of local management, available data, or to better meet monitoring objectives. For instance we may report a hatchery fraction at different spatial scales; above the weir, below the weir, total tributary, or for the entire population. In most cases the calculation method and equations are the same, however, the input variables are summarized differently and at the spatial scale meeting the objective. Any deviations in our described methods due to species, run, location or spatial scale are described in annual reports when conditions necessitate.

3.1 Index of Spawner Abundance

The sum of Chinook Salmon and steelhead redds observed in surveyed tributaries and populations provide an index of returning fish abundance. Redd counts predate other abundance estimation methods, and provide salmon managers a time-series going back to 1957 (Hassemer 1992) to track abundance trends, and they are used for a primary index of abundance in 5-year Endangered Species Act (ESA) status assessments (Matthews and Waples 1991; McClure and Cooney 2005). To meet project evaluation and population monitoring, and to provide necessary inputs for other metric calculations observed redds are enumerated into five spatial locations: (1) total population redd count (R_T), (2) an index area only redd count (R_I) (3) redds upstream of an adult monitoring site (R_U), (4) redds downstream of an adult monitoring site (R_D), and (5) redds upstream of a juvenile rotary screw trap (R_S).

3.2 Hatchery Fraction

Two variants of hatchery fraction are calculated and defined as; 1) the proportion of adult hatchery-origin fish escaping to a weir prior to any fish removals due to management actions ($pHOF$), and 2) the proportion of adult hatchery-origin fish on the spawning grounds and available to participate in natural spawning ($pHOS$).

Spring-summer Chinook Salmon $pHOF$ is estimated using weir trapping data and the maximum likelihood estimator (MLE). The MLE is then calculated as the number of hatchery-origin returns (n_H) divided by the total number of known origin returns (n_O) observed at the weir. The proportion of hatchery-origin spawners, $pHOS$, is calculated similarly as $pHOF$ but uses weir trapping data and those fish released for natural spawning, or carcasses collected during spawning ground surveys to enumerate n_H and n_O.

$$p\hat{HO}F = \frac{n_H}{n_O} \tag{3.1}$$

Uncertainty is estimated for both variants by substituting $pHOS$ for $pHOF$ within the variance estimator. Variance is estimated by assuming the number of hatchery origin fish (n_H) are independent random variables from a binomial distribution, and confidence intervals are estimated with the Wilson-Score approach (Agresti 2003).

$$Var(p\hat{HO}F) = \frac{p\hat{HO}F(1 - p\hat{HO}F)}{n_O}. \tag{3.2}$$

Fall Chinook Salmon and steelhead $pHOF$ and $pHOS$ definitions are similar to spring/summer Chinook Salmon definitions. Whereas, fall Chinook Salmon calculations use run-reconstruction data for fish escaping to Lower Granite

Dam (Young et al. 2020). Fall Chinook Salmon hatchery fraction, $pHOF$, is calculated from run-reconstruction estimates of fish returning to the dam, and $pHOS$ is determined from run-reconstruction estimates of fish released above the dam. Steelhead $pHOF$ and $pHOS$ is assumed equal because steelhead are not removed at weirs and their life-histories do not facilitate carcass collections. Both steelhead hatchery fraction variants are estimated from fish escaping to weirs.

3.3 Proportion Female

Two variants of female proportion also exist for Chinook Salmon and steelhead; 1) proportion of females escaping to a weir f^W, and proportion of females on the spawning ground f^S. To estimate both variants of female proportion we assume the number of observed females (n_f), either from weir observations or carcass collections, are an independent random variable from the binomial distribution with n_s known sex carcasses. Then, MLE, variance and confidence interval calculations for $\hat{f}$ are similar to hatchery fractions equations ((3.1), (3.2)) as follows,

$$\hat{f} = \frac{n_f}{n_s} \tag{3.3}$$

$$Var(\hat{f}) = \frac{\hat{f}(1-\hat{f})}{n_s}. \tag{3.4}$$

Both female proportion variants can be calculated for Chinook Salmon if weir trapping data (LGR run-reconstruction estimates for fall Chinook Salmon) and carcasses collection data are available. Again, due to the lack of steelhead carcasses collection and that no fish are removed at steelhead weirs we assume f^W equals f^S.

3.4 Pre-spawn Mortality

The proportion of available spawners dying before egg deposition and fertilization is calculated for female Chinook Salmon carcass collected during spawning ground surveys. Similar to hatchery fraction and proportion female, we assume the number of observed female prespawn carcasses follow a binomial distribution, then the estimated proportion of prespawn mortality ($\hat{p}$) becomes,

$$\hat{p} = \frac{n_p}{n_{f,p}}. \tag{3.5}$$

Where, n_p is the number of female carcasses with $\geq 25\%$ egg retention and $n_{f,p}$ is the total number of female carcasses with a prespawn egg retention determination.

The variance of $\hat{p}$ is approximated using the delta method because the estimator is the ratio of two random variables ($n_{f,p}$ and n_p) (Casella and Berger 2002). Using the delta method the approximate variance estimator for female prespawn mortality becomes,

$$Var(\hat{p}) = \left(\frac{\hat{p}(1-\hat{p})}{n_{f,p}}\right) + \left(\frac{n\hat{f}n_p^2(1-\hat{f})}{n_{f,p}^4}\right). \tag{3.6}$$

3.5 Adult Abundance

Estimation of adult abundance depends on a variety of factors, which include, species and run, the type of data collected, location of installed monitoring infrastructure and validity of estimator assumptions. Data collection methods used to estimate abundance of returning adult Chinook Salmon and steelhead are classified as either low or high precision (e.g., coefficient of variations less than 15%) following the CBCAMW (2010). Low precision adult monitoring refers to streams with adult abundance being derived from spawning ground survey data only, or extrapolated from other streams (e.g., using probabilistic survey designs or regressions). High precision monitoring occurs in streams with adult abundance being derived from installed fish monitoring infrastructure. Adult monitoring infrastructure includes fall Chinook Salmon run-reconstruction methods (Young et al. 2013, 2020), mark-recapture picket and floating weirs, 24-hour underwater sonar (DIDSON) and video weirs, or in-stream PIT tag detection systems.

Adult abundance is estimated as either the escapement of fish returning to a specific location (i.e., weir, IPTDS, tributary mouth) or as the spawner abundance. Escapement is defined as the sum of all returning adults to the specified location; including harvested fish, broodstock collections, adults removed for outplants or mortalities (e.g., weir mortalities, trap mortalities, prespawn mortality). Returning fish harvested in the tribal fishery is estimated by the DFRM Harvest Monitoring Program and fish harvested during state sportsman fisheries are estimated from Idaho Department of Fish and Game and Oregon Department of Fish and Wildlife creel surveys. Spawner abundance is defined as the number of fish that participated in natural spawning (i.e., minus harvested fish, broodstock, prespawn mortality, etc.).

3.5.1 Fall Chinook Salmon - High Precision Monitoring

Monitoring of adult fall Chinook Salmon returns is completed by sampling returning fish at Lower Granite Dam (Young et al. 2013). Two data streams provide adult abundance information as fish ascend the ladder at Lower Granite Dam; observational counting window, and systematic sampling at the adult trap. The counting window provides a census of fish ascending the ladder. While the trap provides origin, stock and age composition from the examination of fish for marks/tags, and collection of biological tissues samples (Young et al. 2013). Window counts require adjustments to account for biases caused by fallback and re-ascension, fallback without re-ascension, and night-time passage. Window count adjustments are made by estimating the rate of each bias using PIT tag observations at Lower Granite Dam and previous tagged fish. Age and stock composition is estimated using the trap data, collected biological samples, and the results from parental based tagging (Steele et al. 2019). The abundance of each returning age and stock group is then estimated as the product of adjusted window counts and group composition. Uncertainty is estimated through bootstrapping and described by Young et al. (2013) in more detail.

3.5.2 Spring/summer Chinook Salmon and Steelhead - High Precision Monitoring

In most high precision monitored spring/summer Chinook Salmon and steelhead populations the location of infrastructure divides tributary spawning areas into two locations, upstream and downstream. In populations with divided spawning habitat, total escapement and spawner abundance is summed across an upstream and downstream abundance estimator. Methods for estimating upstream and downstream abundance for both species is described in detail below.

3.5.2.1 Upstream Abundance

3.5.2.1.1 Mark Recapture Weir Upstream abundance of spring/summer Chinook Salmon and steelhead in streams with picket and floating weirs is estimated with a bias adjusted Lincoln-Peterson mark recapture estimator (Chapman 1951). The adjusted estimator assumes the number of recaptures are random from known values of upstream abundance, unmarked captures, and marks. The adjusted estimator accounts for the small sample size bias contained within the original Lincoln-Peterson estimator due to sampling without replacement (Chapman 1951). The adjusted estimator requires four assumptions: (1) the population is closed, (2) fish do not lose their marks or tags, (3) marks and tags are correctly enumerated, and (4) individuals have equal probabilities of detection at either the first or second occasion (Chapman 1951).

In some years or streams a violation of the equal probabilities of detection assumption occurs. When unequal probability of detection is known to exist, the adjusted Lincoln-Peterson estimator is stratified. Stratifying escapement estimates involves grouping fish based on individual characteristics (e.g., size, sex, origin) and allows for varying detection rates and yields a more precise and unbiased estimate of upstream abundance (Särndal, Swensson, and Wretman 2003). Stratification schemes are completed on a stream-by-stream and yearly basis provided recaptures sample sizes allow, and observed detection rates necessitate. Most commonly two strata are formed to better capture detection rates of smaller age 3 (i.e., jack) returns from larger adults. Following (Chapman 1951) the stratified (h) MLE for upstream abundance ($\hat{N}_{U,h}$) and its variance becomes,

$$\hat{N}_{U,h} = \frac{(m_h + 1)(c_h + h)}{(r_h + h)} - 1 \tag{3.7}$$

$$Var(\hat{N}_{U,h}) = \frac{(m_h + 1)(c_h + 1)(m_h - r_h)(c_h - r_h)}{(r_h + 1)^2(r_h + 2)}. \tag{3.8}$$

Where m_h is the number of marked or tagged (e.g., opercle punch, PIT-tag) fish released upstream of the weir, c_h is the sum of unmarked and marked spring/summer Chinook Salmon carcasses upstream of the weir, or the observed unmarked and marked steelhead moving downstream at the weir. And r_h is the number of marked spring/summer Chinook Salmon carcasses upstream of the weir, or downstream migrating steelhead observed at the weir.

Confidence intervals around $\hat{N}_U$ are provided following recommendations in Krebs (1999) and Seber and others (1982). Where, if $\geq$ 10% of fish in the second sample are marked (i.e., $\frac{r_h}{c_h}$) then a binomial distribution is used to create intervals. If the first criteria in not met, then, a Poisson distribution is used if $r_h < 50$, or a normal distribution if $r_h > 50$.

Total upstream abundance ($\hat{N}_U$) is then obtained by summing abundance and variances estimates across all H strata.

$$\hat{N}_U = \sum_{h=1}^{H} \hat{N}_{U,h}(\#eq : N_U) \tag{3.9}$$

$$Var(\hat{N}_U) = \sum_{h=1}^{H} Var(\hat{N}_{U,h})(\#eq : var - N_U) \tag{3.10}$$

A weir efficiency ($\hat{E}_h$) is obtained using $\hat{N}_{U,h}$ and the number of fish handled ($n_{w,h}$) and removed (W_h) at the weir.

$$\hat{E}_h = \frac{n_{w,h}}{\hat{N}_{U,h} + W_h} \tag{3.11}$$

Using the delta method (Casella and Berger 2002) the variance of the weir efficiency can be approximated as,

$$Var(\hat{E}_h) = \frac{n_{w,h}^2}{(\hat{N}_{U,h} + W_h)^4} Var(\hat{N}_{U,h}). \tag{3.12}$$

3.5.2.1.2 In-stream Pit Tag Detection Systems The escapement of spring/summer Chinook Salmon and steelhead upstream of an in-stream PIT tag detection system (IPTDS) is estimated using the linked model outputs of the State-space Adult Dam Escapement Model (STADEM) and the Dam Adult Branch Occupancy Model (DABOM) (See, Kinzer, and Ackerman 2016). STADEM estimates the escapement of unique fish passing Lower Granite Dam (LGD) using window counts, adult trap data and previously tagged fish detections (See, Kinzer, and Ackerman 2016). DABOM uses PIT-tags implanted in returning adult fish to LGD and later detected at IPTDS to estimate transitional probabilities to a specific location (See, Kinzer, and Ackerman 2016). The product of DABOM transition probabilities and STADEM escapement then form upstream abundance estimates ($\hat{N}_U$) for tributaries with IPTDS (See, Kinzer, and Ackerman 2016).

3.5.2.2 Downstream Abundance

Estimating spring/summer Chinook Salmon tributary or population abundance downstream of high precision monitoring locations is completed using one of five available methods: (1) fish per redd, (2) female per redd, (3) adult per redd, (4) redd expansion, or (5) carcass expansion. The single best method is chosen for each tributary or population, and adult return year is based on the validity of estimator assumptions. The five downstream abundance estimators and their implied assumptions are described below.

3.5.2.2.1 Fish per Redd Downstream abundance ($\hat{N}_D$) can be estimated by multiplying redds downstream (R_D) of the monitoring location by an estimated fish per redd value. First, fish per redd is calculated by dividing upstream abundance (N_U) by the upstream redd count (R_U) shown in section 3.8. Then, assuming redds are known without error the estimator and variance for downstream abundance becomes,

$$\hat{N}_D = R_D\left(\frac{\hat{N}_U}{R_U}\right) \tag{3.13}$$

$$Var(\hat{N}_D) = \left(\frac{R_D}{R_U}\right)^2 Var(\hat{N}_U). \tag{3.14}$$

A valid estimate of downstream abundance using the fish per redd method requires the following assumptions:

1. all redds have equal detection rates upstream and downstream,
2. fish per redd values are equal upstream and downstream, and
3. fish constructing redds downstream do not move and become counted upstream.

3.5.2.2.2 Female per Redd A slight variant of the fish per redd method, uses estimated females per redd upstream of the monitoring location to expand redds downstream to obtain an estimated female abundance downstream ($\hat{N}_{D,F}$). This method is typically used when the proportion of females upstream is unequal to the proportion downstream.

$$\hat{N}_{D,F} = R_D \left(\frac{\hat{N}_{U,F}}{R_U} \right) \tag{3.15}$$

Where $\hat{N}_{U,F}$ is the estimate of females upstream using equation (3.7) stratified by female. Assuming the redd count is known without error, the variance for female abundance downstream becomes,

$$Var(\hat{N}_{D,F}) = \left(\frac{R_D}{R_U} \right)^2 Var(\hat{N}_{U,F}). \tag{3.16}$$

After estimating female abundance downstream we then expand by the proportion of females (f_D) in the downstream area to calculate downstream abundance (i.e., a total male and female abundance).

$$\hat{N}_D = \frac{\hat{N}_{D,F}}{\hat{f}_D} \tag{3.17}$$

Where $\hat{f}_D$ is calculated using similar methods as those shown in 3.3. Because the estimator is a ratio of random variables, the delta method is used to approximate variance,

$$Var(\hat{N}_D) = \left(\frac{1}{\hat{f}_D^2} \right) Var(\hat{N}_{D,F}) + \left(\frac{\hat{N}_{D,F}^2}{\hat{f}_D^4} \right) Var(\hat{f}_D). \tag{3.18}$$

Three assumptions need to be met for the female per redd method to be valid:

1. all redds have equal detection rates upstream and downstream,
2. female per redd values are equal upstream and downstream,
3. females constructing redds downstream and not counted upstream, and
4. all carcass have the same probability of recovery.

3.5.2.2.3 Adult per Redd Estimating abundance downstream with the adult per redd method uses another variant of the fish per redd method and the stratified adult/jack mark-recapture estimate from section 3.5.2.1.1. First, adult abundance downstream ($\hat{N}_{D,A}$) is estimated by multiplying the number redds downstream by the ratio of upstream adults ($\hat{N}_{U,A}$) to redds upstream.

$$\hat{N}_{D,A} = R_D \left(\frac{\hat{N}_{U,A}}{R_U} \right) \tag{3.19}$$

The variance estimate for adults downstream again assumes redds are known without error.

$$Var(\hat{N}_{D,A}) = \left(\frac{R_D}{R_U} \right)^2 Var(\hat{N}_{U,A}) \tag{3.20}$$

Once, an estimate of adults downstream ($N_{D,A}$) is made we estimate jacks downstream ($N_{D,J}$) using the ratio of adults to jacks observed at the weir ($\frac{n_{W,J}}{n_{A,J}}$) following,

$$\hat{N_{D,J}} = \frac{\hat{N}_{D,A}\, n_{W,J}}{n_{W,A}}. \tag{3.21}$$

The estimator of jack abundance downstream uses only one random variable $\hat{N}_{D,A}$ and the variance becomes,

$$Var(\hat{N}_{D,J}) = \left(\frac{n_{W,J}}{n_{W,A}} \right)^2 Var(\hat{N}_{D,A}). \tag{3.22}$$

Finally, to calculate total abundance downstream using the adult per redd method we sum the downstream estimates for adults $\hat{N}_{D,A}$ and jacks $\hat{N_{D,J}}$. Five assumptions need to be met in order for the adult per redd method to be valid:

1. all redds have equal detection rates upstream and downstream,
2. adult per redd values are equal upstream and downstream,
3. adults constructing redds downstream are not counted upstream,
4. an equal movement probability to the monitoring site for jacks and adults, and
5. an equal trap efficiency for jacks and adults.

3.5.2.2.4 Redd Expansion The redd expansion method estimates downstream abundance following the Chasco et al. (2014) approach using redd count and carcass information collected downstream of the monitoring site. Chasco et al. (2014) showed deterministically that redds equal the product of escapement (N), proportion of females in the population (f) and one minus prespawn mortality (p; 3.4). Then, by solving the equation $R = Nf(1-p)$ for N, and substituting in estimates of female proportion and prespawn mortality an estimate of tributary escapement is obtained using only spawning ground survey data.

Using the redd expansion method, downstream abundance is estimated by,

$$\hat{N}_D = \frac{R_D}{\hat{f_D}(1 - \hat{p_D})} \tag{3.23}$$

where R_D is the number of redds, f_D is the estimated female proportion and p_D is the estimated prespawn mortality downstream of the adult monitoring site calculated following sections 3.3 and 3.4. The redd expansion estimator is unbiased provided the following four assumptions are met:

1. all redds are enumerated without error,
2. all females build exactly one redd,
3. all carcasses are available for recovery,
4. all carcasses have the same probability of recovery, and
5. prespawn mortality is equal for males and females.

Using the delta method and assuming redds are known without error, a variance approximation for estimated escapement ($\hat{N}_D$) from only spawning ground survey data becomes (Casella and Berger 2002),

$$Var(\hat{N}_D) = \left(\frac{1}{(1 - \hat{p}_D)^2} Var(\hat{S}_D)\right) + \left(\frac{\hat{S}_D^2}{(1 - \hat{p}_D)^4} Var(\hat{p}_D)\right), \tag{3.24}$$

where $\hat{S}_D$ is the estimate of tributary spawners downstream and $Var(\hat{S}_D)$ is the variance of spawners from section 3.7.

3.5.2.2.5 Carcass Expansion The carcass expansion method requires the sum of all observed carcasses downstream of the adult monitoring site and stratified estimates of carcass recovery rates (g_l) using the upstream mark recapture data. An estimated recovery rate ($\hat{g}_l$) for fish in strata l is given by,

$$\hat{g}_l = \frac{r_l}{m_l}. \tag{3.25}$$

Where m_l is the number of marks released upstream of the monitoring location and r_l is recaptured marks. Using the same assumption for estimating upstream abundance with the adjusted Lincoln-Peterson estimator, the variance of $\hat{g}_l$ becomes,

$$Var(\hat{g}_l) = \left(\frac{1}{m_l}\right)\left(\frac{c_l}{\hat{N}_{U,l}}\right)\left(1 - \frac{c_l}{\hat{N}_{U,l}}\right)\left(\frac{\hat{N}_{U,l} - m_l}{\hat{N}_{U,l} - 1}\right). \tag{3.26}$$

Downstream abundance ($\hat{N}_{D,l}$) for strata l is then given by expanding the number of carcass $n_{D,l}$ observed downstream by the carcass recovery rate found upstream.

$$\hat{N}_{D,l} = \frac{n_{D,l}}{\hat{g}_l} \tag{3.27}$$

The delta method approximates variance of downstream abundance as,

$$Var(\hat{N}_{D,l}) = \left(\frac{n_{D,l}}{\hat{g}_l^2}\right)^2 Var(\hat{g}_l). \tag{3.28}$$

Of the five downstream estimators the carcass expansion method requires the fewest assumptions. Stratifying the recovery rate by individual fish characteristics allows for unequal detection rates and only requires one assumption be met:

1. carcass recovery rates are equal for individuals in strata l upstream and downstream of the monitoring location.

3.5.3 Spring/summer Chinook Salmon - Low Precision Monitoring

In spring/summer Chinook Salmon populations monitored only with spawning ground surveys, tributary abundance ($N_U + N_D$) is estimated using spawning ground survey data and the redd expansion method (Eq. (3.23)). Total fish in the tributary is estimated using all redds observed (R_T), and tributary estimates of female proportion (f) and prespawn mortality (p). Harvest estimates are then added in to form total tributary escapement similar to equations (3.30) and (3.31).

3.6 Tributary Escapement

Total escapement to the weir and returning to the tributary in monitored streams is estimated by summing the appropriate groups of estimated fish; upstream and downstream abundance, tributary harvest ($\hat{H}_T$), and fish removed at the picket weir (W).

Then, escapement to the weir ($\hat{N}_W$) is calculated as,

$$\hat{N}_W = \hat{N}_U + W, \tag{3.29}$$

and escapement to the tributary is calculated as,

$$\hat{N}_T = \hat{N}_U + \hat{N}_D + \hat{H}_T + W. \tag{3.30}$$

Variance of each estimated term is then summed accordingly, following Casella and Berger (2002),

$$Var(\hat{N}_T) = Var(\hat{N}_U) + Var(\hat{N}_D) + Var(\hat{H}_T), \tag{3.31}$$

where the number of fish removed at the weir (W) is assumed to be known without error.

3.6.0.0.1 Female Tributary Escapement Monitored populations using high precision methods allows the point ($\hat{N}_{T,F}$) and variance ($Var(\hat{N}_{T,F})$) estimation of female tributary escapement to follow equations (3.30) and (3.31) once all terms include only females. Dividing escapement into females only is completed by stratifying the proportion of females ($\hat{f}$, Section 3.3 into upstream and downstream locations. Location specific female proportions is then multiplied with the associated upstream ($\hat{N}_U$) and downstream ($\hat{N}_U$) abundance estimates before summing with female weir removals (W_f) and female tributary harvest ($\hat{H}_{T,F}$). Female only abundance and harvest terms are calculated similarly to equations (3.32) and (3.33).

In populations with only low precision monitoring methods available, tributary female escapement and variance is estimated following,

$$\hat{N}_{T,F} = \hat{N}_T \ \hat{f} \tag{3.32}$$

$$Var(\hat{N}_{T,F}) = \hat{N}_T^2 Var(\hat{f}) + \hat{f}^2 Var(\hat{N}_{T,F}) + Var(\hat{N}_{T,F}) Var(\hat{f}). \tag{3.33}$$

3.7 Spawner Abundance

Spawner abundance represents the number of fish participating in spawning and contributing to future progeny in the tributary. The value excludes fish removed from the returning aggregate because of harvest, weir management or prespawn mortality. Spawner abundance is considered a high level indicator used for status recovery assessments, regional monitoring and evaluation and local fisheries management. Abundance is reported for both total spawners (S) and natural (S_N) only spawners. In addition, spawner abundance is partitioned to exclude jacks or returning one ocean adult fish (S_{EJ}; e.g., age 3 jacks for spring/summer Chinook Salmon).

3.7.1 Total Spawner Abundance

Total spawner abundance is estimated by summing across all l strata from upstream ($\hat{N}_{U,l}$) and downstream ($\hat{N}_{D,l}$) abundance estimates from section 3.5.2 and then removing the proportion of fish estimated to be prespawn mortalities ($\hat{p}$) from section 3.4.

$$\hat{S}_T = (1-\hat{p})\Bigg(\sum_{l=1}^{L}(\hat{N}_{U,l} + \hat{N}_{D,l})\Bigg) \tag{3.34}$$

The variance of total spawner abundance is estimated following;

$$\begin{aligned} Var(\hat{S}_T) = Var(\hat{p})(Var(\hat{N}_U) + Var(\hat{N}_D)) + \hat{p}^2(Var(\hat{N}_U) \\ + Var(\hat{N}_D)) + Var(\hat{p})(\hat{N}_U + \hat{N}_D)^2. \end{aligned} \tag{3.35}$$

3.7.1.1 Excluding Jacks

Two methods exist to estimate spawner abundance excluding jacks or one ocean adult returns. The first method subtracts out an estimated number of jacks on the spawning grounds by multiplying the estimated proportion of jacks ($\hat{A}_3$; 3.13 on the spawning grounds to total spawner abundance (assumes age samples are collected representatively).

$$\hat{S}_{T,EJ} = \hat{S}_T(1-\hat{A}_3) \tag{3.36}$$

The variance of spawners excluding jacks is given through common variance properties (Casella and Berger 2002),

$$Var(\hat{S}_{T,EJ}) = Var(\hat{S}_T)Var(\hat{A}_3)) + \hat{A}_3^2 Var(\hat{S}_T) + \hat{S}_T^2 Var(\hat{A}_3). \tag{3.37}$$

The second method follows the point and variance estimates for total spawner abundance ($\hat{S}$), but excludes the jack stratified upstream and downstream abundance estimates.

$$\hat{S}_{T,EJ} = (1-\hat{p})\Bigg(\sum_{l\neq jacks}^{L}(\hat{N}_{U,l} + \hat{N}_{D,l})\Bigg) \tag{3.38}$$

3.7.2 Natural Origin Spawner Abundance

Natural origin spawner abundance is estimated as the product of the natural origin spawner proportion ($(1-p\hat{HOS})$, 3.2) and total spawner abundance following,

$$\hat{S}_{T,N} = \hat{S}_T(1-p\hat{HOS}). \tag{3.39}$$

The estimated variance of natural origin spawner abundance follows a similar pattern as the variance of total spawners excluding jacks ((3.37)).

$$Var(\hat{S}_{T,N}) = Var(\hat{S}_T)Var(p\hat{HOS})) + p\hat{HOS}^2 Var(\hat{S}_T) + \hat{S}_T^2 Var(p\hat{HOS}). \tag{3.40}$$

3.7.2.1 Natural Origin Spawner Excluding Jacks

Using a slight modification, natural origin spawner abundance excluding jacks $\hat{S}_{T,N,EJ}$ can be estimated from total spawners excluding jacks $\hat{S}_{T,EJ}$ and stratifying the proportion of hatchery origin spawners to exclude jacks ($p\hat{HOS}_{EJ}$; 3.2).

$$\hat{S}_{T,N,EJ} = \hat{S}_{T,EJ}(1 - p\hat{HOS}_{EJ}) \tag{3.41}$$

The variance for $\hat{S}_{T,N,EJ}$ follows the same format as equation (3.40).

3.7.3 Female Spawner Abundance

To estimate total female spawners in a tributary, total spawner abundance ($\hat{S}_T$) is multiplied by the proportion of females in the population ($\hat{f}$; 3.3).

$$\hat{S}_{T,F} = \hat{S}_T \; \hat{f} \tag{3.42}$$

The approximate variance is given by the delta method,

$$Var(\hat{S}_{T,F}) = \hat{S}_T^2 \; Var(\hat{f}) + \hat{f}^2 \; Var(\hat{S}_T) + Var(\hat{S}_T) \; Var(\hat{f}). \tag{3.43}$$

3.8 Fish per Redd

Fish per redd values in monitored areas are estimated from the sum of adult upstream and downstream abundance ($\hat{N}_U$, $\hat{N}_D$; 3.5.2) divided by total redds (R_T; 3.1). The value represents the number of fish within a tributary or population needed to create one redd; including prespawn mortalities and jacks. Fish per redd ($N\hat{/}R_T$) is estimated by,

$$N\hat{/}R_T = \frac{(\hat{N}_U + \hat{N}_D)}{R_T} \tag{3.44}$$

Assuming redds are known without error, the variance of estimated fish per redd becomes,

$$Var(N\hat{/}R_T) = (\frac{1}{R_T^2}) \; (Var(\hat{N}_U) + Var(\hat{N}_D)) \tag{3.45}$$

3.9 Female Spawners per Redd

Female spawners per redd are estimated using total spawners ($\hat{S}_T$; 3.7, female proportion ($\hat{f}$; 3.9), and total redds (R_T; 3.1). The value represents the number of spawning females within a population needed to create one redd. Female spawners per redd ($S_f \hat{/} R_T$) is estimated by,

$$S_f \hat{/} R_T = \frac{\hat{S}_T \hat{f}}{R_T} \tag{3.46}$$

Assuming redds are known without error, the variance of spawners per redd becomes,

$$Var(S_f \hat{/} R_T) = (\frac{1}{R_T^2}) \; (\hat{S}_T^2 Var(\hat{f}) + \hat{f}^2 Var(\hat{S}_T) + Var(\hat{S}_T) Var(\hat{f})) \tag{3.47}$$

3.10 Size-at-Return

The size of returning Chinook Salmon and steelhead is described using data collected at Lower Granite Dam, weirs and during spawning ground surveys. Size-at-return is summarized at these different spatial scales for natural- and hatchery origin returns to examine differences that may occur between locations. Size-at-return is reported as the distribution of fork lengths collected from a random sample of individuals. Distributions are presented using common summary statistics (i.e., means, medians, standard deviation) or with graphics (e.g., histograms, boxplots) to illustrate the full range and variability in observed lengths. In addition to origin, size-at-return is often reported separately for each life stage or trapping season group, and potentially split into finer temporal scales, such as, weeks or months of capture.

3.11 Adult Run-Timing

Run-timing of Chinook Salmon and steelhead adults migrating upstream is often reported at mainstem dams (e.g., Bonneville and Lower Granite Dam), and tributary IPTDS using PIT tag observations, or with individual fish observations at weir locations. Travel time between locations is calculated as the difference in arrival timing between locations. Run-timing data is summarized with empirical cumulative distribution functions and reported as the date of passage for 1, 10, 50, 90 and 100 percent of individuals within each origin, life-stage or release group, or reported graphically.

3.12 Spawn Timing

Adult spawn timing is described for Chinook Salmon and steelhead with the proportion of total redds constructed during each survey date. However, it's recognized that the accuracy and precision of a spawn timing metric is limited due to the effort and intensity of spawning ground surveys. Ideally, to fully understand spawn timing we need to observe redd construction daily throughout the full spawning season.

3.13 Age Structure

Age structure is calculated separately for natural- and hatchery-origin Chinook Salmon and steelhead adults. Age structure is reported as a proportion, and represents the composition of total tributary escapement assigned to each age class for a given return year. Proportions are estimated from a sub-sample of total adults returning to the tributary or population, and collected at a weir or during carcass surveys. Sub-sampled fish are assigned an age from either a known mark/tag, or estimated from a genetic parentage, dorsal fin ray or scale analysis. In some instances multiple methods are available to estimate age of an individual fish. In these cases, the assigned age is determined by method accuracy; mark/tag first, genetic assignment, dorsal fin ray, and finally scale analysis. Fish length (i.e., fork length) is not used to determine age. Once sampled individuals are aged, estimation of age class proportions are made using two analytical approaches; (1) direct estimation, and (2) length-at-age key.

3.13.1 Direct Estimation

The first method assumes a sub-sample of aged fish were collected representatively with equal rates of sampling. If equal rates of sampling are met for all age groups, proportions are calculated using a multinomial distribution following,

$$\hat{A}_a = \frac{n_a}{\sum_{a=1}^{A} n_a} \tag{3.48}$$

where $\hat{A}_a$ is the estimated proportion of fish in age group a within the total tributary escapement, and n_a is the number of individuals sampled in group a (Casella and Berger 2002). The variance equation for multinomial probabilities is similar to that of the binomial probability parameter,

$$Var(\hat{A}_a) = \frac{\hat{A}_a(1-\hat{A}_a)}{\sum_{a=1}^{A} n_a}. \tag{3.49}$$

3.13.2 Length-at-Age Key

Weir detection and carcass recovery rates are often un-equal for individuals of different sizes or age classes. If un-equal sampling is suspected to have occurred after examining weir efficiencies ($hatE_l$) and carcass recovery rates ($\hat{g}_l$) from section 3.5.2.1.1 and 3.5.2.2.5. Length-at-age keys are developed by weighting age proportions based on estimated abundance ($\hat{N}_{T,l}$) of fish in each length based strata or age group. Length-at-age keys are developed by first estimating the conditional probability ($\hat{A_{a|l}}$) of sub-sampled fish being in age group (a) given it is in length interval (l).

$$\hat{A}_{a|l} = \frac{n_{a,l}}{\sum_{a=1}^{A} n_{a,l}} \tag{3.50}$$

Next, conditional probabilities are multiplied by estimated tributary escapement of fish in similar length intervals or strata.

$$\hat{N}_{T,a,l} = \hat{N}_{T,l}\ \hat{A}_{a|l} \tag{3.51}$$

The variance of multiplying two random variables becomes,

$$Var(\hat{N}_{T,a,l}) = \hat{N}_{T,l}^2\ Var(\hat{A}_{a|l}) + \hat{A}_{a|l}^2\ Var(\hat{N}_{T,l}) + Var(\hat{N}_{T,l})\ Var(\hat{A}_{a|l}). \tag{3.52}$$

Lastly, summing across length interval abundance estimates for an age class and dividing by total escapement yields weighted proportions to represent the total return year age structure.

$$\begin{aligned}\hat{A}_a &= \frac{\sum_{l=1}^{L} \hat{N}_{T,a,l}}{\sum_{a=1}^{A}\sum_{l=1}^{L} \hat{N}_{T,a,l}} \\ &= \frac{\hat{N}_{T,i\cdot}}{\hat{N}_{T,\cdot\cdot}}\end{aligned} \tag{3.53}$$

The delta method is used to approximate the variance of age proportions as,

$$Var(\hat{A}_i) = \left(\frac{1}{\hat{N}_{T,\cdot\cdot}^2}\right) Var(\hat{N}_{T,i\cdot}) + \left(\frac{\hat{N}_{T,i\cdot}^2}{\hat{N}_{T,\cdot\cdot}^4}\right) Var(\hat{N}_{T,\cdot\cdot}) \tag{3.54}$$

3.14 Age-at-Return

Brood year based adult returns are reported in two ways; (1) as the estimated tributary escapement of brood year returns for each age group, and (2) as female only brood year returns. Estimating run year tributary escapement belonging to each age group allows for run-reconstruction and cohort based smolt-to-adult (5.1), progeny-per-parent (5.2), and recruit-per-spawner (5.3) estimates.

3.14.1 Brood Year Return

The calculation of brood year (BY) adult returns requires the summation of tributary escapement estimates ($\hat{N}_T$; 3.5.2) multiplied by age structure proportions (A_a; 3.13) from multiple return years (RY). Where a single age class brood year return ($\hat{N}_{BY,a}$) is calculated as,

$$\hat{N}_{BY,a} = \hat{N}_{T,RY=BY+a} \ \hat{A}_{a,RY=BY+a}, \tag{3.55}$$

and total brood year returns ($\hat{N}_{BY}$) is given by the summation,

$$\hat{N}_{BY} = \sum_{a=1}^{A} (\hat{N}_{T,RY=BY+a} \ \hat{A}_{a,RY=BY+a}). \tag{3.56}$$

.

The variance of total brood year return again requires the summation of individual age class returns.

$$Var(\hat{N}_{BY}) = \sum_{a=1}^{A} \Big[(\hat{N}^2_{T,RY=BY+a} \ Var(\hat{A}_{a,RY=BY+a})) + \tag{3.57}$$

$$(\hat{A}^2_{a,RY=BY+a} \ Var(\hat{N}_{T,RY=BY+a})) + \tag{3.58}$$

$$(Var(\hat{N}_{T,RY=BY+a}) \ Var(\hat{A}_{a,RY=BY+a})) \Big].$$

.

Estimates of adult brood year returns, excluding jacks, requires the same summation as equation #ref(eq:broodreturn) but excludes the jack age class.

$$\hat{N}_{BY,EJ} = \sum_{a \neq jacks}^{A} (\hat{N}_{T,RY=(BY+a)} \ \hat{A}_{a,RY=(BY+a)}). \tag{3.59}$$

.

The associated variance for brood year returns ($Var(\hat{N}_{BY,EJ})$) excluding jacks follows equation (3.57) without the jack age class.

Female only adult brood year returns ($\hat{N}_{BY,F}$) is calculated by summing female stratified run year estimates of tributary escapement ($\hat{N}_{T,F}$; 3.5.2) and age structure ($\hat{A}_{a,F}$; 3.13) following equation (3.56). The variance of female brood year returns follows equation (3.57).

Chapter 4

Juvenile Abundance and Life History

The DFRM Research Division collects and summarizes juvenile data collected from two field methods to calculate juvenile abundance, and life history metrics identified by the AHSWG (Beasley et al. 2008) and described in CA DES. Data is collected from outmigrating juvenile Chinook Salmon and steelhead using rotary screw trap methods and beach seining techniques. Detailed descriptions of field activities and data collection protocols can be found at https://www.monitoringresources.org; Rotary Screw Traps and Beach Seining. Rotary screw trap and seining data are stored and accessed from the Tribe's CDMS, and the regional PIT-tag data repository maintained by Pacific States Marine Fisheries Commission, PIT Tag Information Systems (PTAGIS).

The summary and analysis methods used to calculate juvenile AHSWG performance measures and CA indicators and metrics are described below and provide a consistent and comparable approach across all NPT juvenile monitoring locations. In some cases, calculation methods are different for the various species or runs, or across the landscape and at different spatial scales. Necessary differences in methodology exist because of local management, available data, or to better meet monitoring objectives. In most cases the calculation method and equations are the same, however, the input variables are summarized differently and at the spatial scale meeting the objective. Any deviations in our described methods due to species, run, location or spatial scale are described in annual reports when conditions necessitate.

4.1 Juvenile Emigrant Abundance

Juvenile abundance is estimated from data collected at rotary screw traps (Volkhardt et al. 2007) based on brood year for emigrating natural-origin spring/summer Chinook Salmon and migration year for natural-origin steelhead. Abundance estimates for spring/summer Chinook Salmon are made at four life-stages or trapping seasons and then combined for a brood year total. The four spring/summer Chinook Salmon life stages include (1) young of the year (YOY), (2) parr, (3) presmolt, and (4) smolt. Spring/summer Chinook Salmon life-stages are designated by age and seasonal trapping dates; YOY are newly emerged juveniles collected from January 1 - June 30, parr are collected from July 1 - August 31, presmolt are collected from September 1 - December 31, and smolt are collected from January 1 - June 30 at age 1. Estimates for YOY are often unavailabe due to low trapping numbers; when YOY catch is low the captured fish are included in the parr life-stage. Trapped steelhead vary in fresh-water age when migrating downstream precluding brood year abundance estimates similar to spring/summer Chinook Salmon. Steelhead abundance instead is organized into assumed year of migration to Lower Granite Dam and split into fall and spring trapping seasons.

Emigrant abundance is estimated similarly for each spring/summer Chinook Salmon life-stage and fall or spring steelhead trapping season. Abundance is estimated using a stratified Bailey mark-recapture model (Bailey 1951) with precision estimates calculated using bootstrapping methods (Mooney et al. 1993) developed by Steinhorst et al. (2004). Stratifying the abundance estimator allows for heterogeneous capture probabilities across life-stages or trapping seasons. Trapping seasons are stratified into seven day periods to account for changing fish behavior and environmental trapping conditions. Steinhorst et al. (2004) recommended at least seven recaptures in each strata, if this condition is not met for each seven day period, adjacent strata, or additionals days are included until at least seven recaptures are achieved. The Bailey estimator uses three inputs for each 7-day weekly strata (w) to estimate life-stage (j) juvenile abundance ($\hat{N}_j$); (1) unmarked captures (c_w), (2) marked releases (m_w), and (3) marked recaptures (r_w) (Steinhorst et al. 2004).

$$\hat{N}_j = \sum_{w=1}^{W} \frac{c_w(m_w + 1)}{(r_w + 1)} \tag{4.1}$$

Variance estimates and confidence intervals for juvenile abundance are given using bootstrap techniques; assuming unmarked capture and recaptures are independent random variables from binomial distributions (Steinhorst et al. 2004).

$$c_w \sim Binomial(\hat{N}_w, \hat{p}_w) \tag{4.2}$$

$$r_w \sim Binomial(m_w, \hat{p}_w) \tag{4.3}$$

Where estimates of strata abundance ($\hat{N}_w$) and capture probabilities ($\hat{p}_w = \frac{r_w}{m_w}$) are substituted for the binomial parameters (Steinhorst et al. 2004). Total juvenile abundance ($\hat{N}_J$) emigrating past the rotary screw trap is given by summing weekly (w) strata across all juvenile life stages.

4.2 Juvenile Survival

Survival of migrating Chinook Salmon and steelhead from release (i.e., rotary screw trap, beach seining, or hatchery release) to Lower Granite Dam is estimated using the Survival Under Proportional Hazards (SURPH) juvenile survival program (Smith et al. 1994; Skalski et al. 1998). The SURPH program estimates survival probabilities (ϕ_j) and detection probabilities (ρ_j) using a Cormack, Jolly and Seber (CJS) model (Cormack 1964; Jolly 1965; Seber and others 1982). Survival estimates to Lower Granite Dam are reported for each natural- and hatchery-origin release group. Natural-origin release groups include all PIT tagged fish within a single life-stage/trapping season and migration year, in order to pair with juvenile abundance estimates (4.1). Survival is estimated from subsequent tag detections at hydrosystem and other in-river facilities obtained from the online database PTAGIS. SURPH's companion program PITPRO (Westhagen and Skalski 2007) is used to develop capture history files with the four Lower Snake River and four Lower Columbia River dams, and the estuary towed array as potential tag detection locations. The PITPRO capture history file output is then input into SURPH to generated CJS estimates with associated 95% profile likelihood confidence intervals (Smith et al. 1994; Skalski et al. 1998).

4.3 Smolts Equivalents

Estimated smolt equivalents ($\hat{N}_S$) represent the abundance of fish surviving to Lower Granite Dam (LGD) from the total brood year or migratory year abundance estimate or hatchery release number. Smolt equivalents are derived by multiplying each life stage specific survival from release location to LGD ($\hat{\phi}_j$; 4.2) by the life stage abundance estimate ($\hat{N}_j$; 4.1). Life-stage specific smolts reaching LGD is then summed across all life-stages (J) to estimate a total brood year (spring/summer Chinook Salmon) or migration year abundance (steelhead) of smolts at LGD.

$$\hat{N}_S = \sum_{j=1}^{J} \hat{N}_j * \hat{\phi}_j \tag{4.4}$$

Using common variance properties (Casella and Berger 2002) precision for total smolts at LGD becomes;

$$Var(\hat{N}_S) = \sum_{j=1}^{J} (\hat{N}_j^2 Var(\hat{\phi}_j) + \hat{\phi}_j^2 Var(\hat{N}_j) + Var(\hat{N}_j) Var(\hat{\phi}_j)). \tag{4.5}$$

4.4 Age-at-Emigration

The age of juveniles migrating past rotary screws is estimated differently for spring/summer Chinook Salmon and steelhead. Generally, emigration age and the proportion of spring/summer Chinook Salmon migrating past rotary screw traps is determined solely from the abundance of fish within each life-stage or trapping season, and non-overlapping age and size classes. In contrast, steelhead migrants passing rotary screw traps are often comprised of different age groups with overlapping size classes.

Spring/summer Chinook Salmon age-at-emigration is reported as the proportion of the total brood year abundance migrating as age 0 YOY, age 1 parr, age 1 presmolt, and age 1 smolt. Each life-stage and age proportion is calculated by dividing life-stage abundance by the total brood year abundance. Additionally, age 2 juveniles determined from fork length and captured after the smolt season ends (i.e., June 30th) are included in brood year summaries when they are observed in the trap catch.

Steelhead age-at-emigration is reported as the proportion of age groups caught during each fall and spring trapping season. Seasonal age proportions are estimated from scales collected from a random sample of trapped fish. Scales are collected from between the posterior edge of the dorsal fin and anterior edge of the anal fin directly above the lateral line (Scarnecchia 1979; Knudsen and Davis 1985). Collected scales are then prepared and read following procedures outlined in Seelbach and Beyerle (1984) and Davis and Light (1985). Scales are read by multiple readers with a final age determination and error rate calculated using methods described by Beamish and Fournier (1981) and Beamish and McFarlane (1983).

4.5 Size-at-Emigration

The size at emigration for Chinook Salmon, and steelhead is described by reporting the distribution of fork lengths collected from a random sample of individuals. Distributions are presented using common summary statistics (i.e., means, medians, standard deviation) or with graphics (e.g., histograms, boxplots) to illustrate the full range and variability in fork lengths. Size-at-emigration is reported separately for each life stage or trapping season group, or split into finer temporal scales, such as, weeks or months.

Growth rates during a trapping season, or across the full migratory year are determined with a Von Bertalanffy (1938) growth model. Growth models are fit following the Beverton and Holt (1957) parameterization to better assess size-at-emigration, and growth of juvenile spring/summer Chinook Salmon and steelhead captured at rotary screw traps. Growth model coefficients are estimated with a non-linear least squares method and is represented as,

$$l_t = L_\infty(1 - e^{(-K(t-t_0))}). \tag{4.6}$$

Where l_t is the length of individuals at time t, L_∞ is the asymptotic length or mean length at emigration, K is a growth coefficient and t_0 is a coefficient for time when length equals zero. Time is typically represented as the number of months that occur between egg deposition and capture at the rotary screw trap.

4.6 Condition of Juveniles at Emigration

The mean condition factor ($\bar{K}$) is calculated for each life-stage and trap season migrant group released at rotary screw traps, and hatchery release groups using Fulton's condition factor (Anderson and Neumann 1996).

$$K_i = (w_i/l_i^3) * 100,000 \tag{4.7}$$

Where K_i is the condition factor for individual i, w_i is weight, and l_i is length measured from a random sample of juveniles collected from each release group. Weight is measured to the nearest 0.1 g and length is measured to the nearest 1.0 mm from the snout tip to the fork in the tail.

4.7 Emigration Timing

Juvenile emigration timing is described for spring/summer Chinook Salmon and steelhead using empirical cumulative distribution functions and rotary screw trap data. Emigration timing is summarized and then reported as the date of passage for 1, 10, 50, 90 and 100 percent of individuals within each life-stage or trap season, or reported graphically. Daily emigration numbers and timing are calculated by expanding unmarked trap catch with the weekly trap efficiency estimated during juvenile abundance estimation (4.1).

4.8 Mainstem Arrival

Mainstem arrival timing at LGR is calculated using PIT tag interrogation data queried from PTAGIS for fall and spring/summer Chinook Salmon and steelhead individuals PIT-tagged during beach seining, rotary screw trapping, and hatchery marking activities. Arrival timing is described similarly to emigration timing with graphical displays of the empirical cumulative distribution functions, and the dates of 1, 10, 50, 90 and 100 percent of individuals arriving to LGR. Summaries are provided for each natural-origin life stage or trapping season, and hatchery-origin release groups.

Additionally, we report the proportion of emigrants passing Lower Granite Dam prior to the start of fish collections at juvenile by-pass facilities for transportation, and increased spring and summer spill operations. Collections for transportation (i.e., barging or trucking) at juvenile bypass facilities located on the lower Snake River dams typically begin during April. We assume fish arriving prior to the transportation period are not transported, and those fish arriving on the start date or later would be transported if observed in by-pass facilities at any of the transport dams (Lower Granite Dam, Little Goose Dam and Lower Monumental Dam), unless the observed PIT tag is designated for return-to-river.

Chapter 5

Productivity

The DFRM Research Division calculates Chinook salmon and steelhead productivity metrics identified by the AHSWG (Beasley et al. 2008) and described in CA DES. To calculate productivity metrics a combination of adult and juvenile abundance metrics described in chapters @ref(#chap:adult) and @ref(#chap:juvenile) are used. Adult and juvenile metrics include variations (e.g., including and excluding jacks, females only) of total brood year returns, return year spawner abundance, juvenile abundance and smolt equivalents.

The summary and analysis methods used to calculate productivity metrics are described below and provide a consistent and comparable approach across all NPT monitoring locations. In some cases, calculation methods are different for the various species or runs, or across the landscape and at different spatial scales. Necessary differences in methodology exist because of local management, available data, or to better meet monitoring objectives. In most cases the calculation method and equations are the same, however, the input variables are summarized differently and at the spatial scale meeting the objective. Any deviations in our described methods due to species, run, location or spatial scale are described in annual reports when conditions necessitate.

5.1 Smolt-to-Adult Return Rates

Smolt to adult return (SAR) ratios are calculated four different ways: (1) tributary emigrant to tributary escapement, (2) LGD smolts to tributary escapement, (3) LGD smolts to LGD escapement, and (4) tributary emigrants to LGD escapement. A similar point and variance estimator is used for each SAR variant.

$$(1) \qquad S\hat{A}R_1 = \frac{\hat{N}_{BY}}{\hat{N}_{J,BY}} \tag{5.1}$$

$$(2) \qquad S\hat{A}R_2 = \frac{\hat{N}_{BY}}{\hat{N}_{S,BY}} \tag{5.2}$$

$$(3) \qquad S\hat{A}R_3 = \frac{\hat{N}_{LGD,BY}}{\hat{N}_{S,BY}} \tag{5.3}$$

$$(4) \qquad S\hat{A}R_4 = \frac{\hat{N}_{LGD,BY}}{\hat{N}_{J,BY}} \tag{5.4}$$

Where $\hat{N}_{BY}$ is the total brood year return (3.14), $\hat{N}_{LGD,BY}$ is brood year return to Lower Granite Dam, $\hat{N}_{J,BY}$ is brood year juvenile emigrant abundance (4.1), and $\hat{N}_{S,BY}$ is the brood year juvenile smolt equivalent estimate at Lower Granite Dam (@ref(#sec:smolts)).

The approximate variance of each SAR variant uses the delta methods and follows,

$$Var(S\hat{A}R_1) = \left(\frac{1}{\hat{N}^2_{J,BY}}\right) Var(\hat{N}_{BY}) + \left(\frac{\hat{N}^2_{BY}}{\hat{N}^4_{J,BY}}\right) Var(\hat{N}_{J,BY}). \tag{5.5}$$

5.2 Progeny-per-Parent Ratio

Four variants of progeny-per-parent (P/P) ratios are calculated to estimate trends in adult to adult productivity. The four variants include (1) total recruits per total spawner, (2) adult recruits per adult spawner, (3) total recruits per adult spawner, and (4) female recruits per female spawner. Estimation of each progeny-per-parent (P/P) follows a similar format using total recruits ($\hat{N}_{BY}$), adult recruits ($\hat{N}_{BY,EJ}$) and female recruits ($\hat{N}_{BY,F}$) from section 3.14 in the numerator, and total spawner ($\hat{S}_T$), adult spawner ($\hat{S}_{T,EJ}$) and female spawners ($\hat{S}_{T,F}$; 3.7.2) in the denominator.

$$(1) \qquad \hat{P/P}_1 = \frac{\hat{N}_{BY}}{\hat{S}_T} \tag{5.6}$$

$$(2) \qquad \hat{P/P}_2 = \frac{\hat{N}_{BY,EJ}}{\hat{S}_{T,EJ}} \tag{5.7}$$

$$(3) \qquad \hat{P/P}_3 = \frac{\hat{N}_{BY}}{\hat{S}_{T,EJ}} \tag{5.8}$$

$$(4) \qquad \hat{P/P}_4 = \frac{\hat{N}_{BY,F}}{\hat{S}_{T,F}} \tag{5.9}$$

The variance approximation, using the delta method, for the four variations of progeny-per-parent follows the same format.

$$Var(\hat{P/P}_1) = \left(\frac{1}{\hat{S}_T^2}\right) Var(\hat{N}_{BY}) + \left(\frac{\hat{N}_{BY}^2}{\hat{S}_T^4}\right) Var(\hat{S}_T) \tag{5.10}$$

5.3 Recruit per Spawner

5.3.1 Spawners Above Juvenile Trap

Calculating juvenile recruits per spawner requires an estimation of fish spawning above a juvenile emigrant trap. The inclusion of all tributary spawners in recruit per spawner values biases the productivity estimate low. To avoid the bias, the spatial location of tributary spawners is assumed equal to redd location. As such, the proportion of redds above a juvenile trap ((R_J/R_T); 3.1) is applied to tributary spawners ($\hat{S}_T$; 3.7) to estimate spawners above emigrant traps ($\hat{S}_J$).

$$\hat{S}_J = \hat{S}_T \left(\frac{R_J}{R_T}\right) \tag{5.11}$$

Assuming redds are known without error the variance becomes (Casella and Berger 2002),

$$Var(\hat{S}_J) = \left(\frac{R_J}{R_T}\right)^2 Var(\hat{S}_T) \tag{5.12}$$

In some streams, weir management and brood stock removal can influence spawner per redd values upstream and downstream of the weir site violating the assumption of spawner and redd distribution being equal. If the juvenile trap is located upstream of the weir, spawners above the juvenile trap and it's associated variance is calculated similarly to equations (5.11) and (5.12) but using spawners ($\hat{S}_U$) and redds (R_U) upstream instead of totals.

$$\hat{S}_J = \hat{S}_U \left(\frac{R_J}{R_U} \right) \tag{5.13}$$

If juvenile traps are located downstream of the adult weir spawners between the weir and juvenile emigrant trap need to be estimated. To estimate spawners between the two locations, we can expand the number of redds between the weir and trap by the downstream spawner per redd value. Estimated spawners above the juvenile emigrant trap then becomes the sum of spawners upstream of the weir ($\hat{S}_U$) with the estimated spawners between the weir and trap.

$$\hat{S}_J = \hat{S}_U + \left(\frac{R_J - R_U}{R_D} \right) \hat{S}_D \tag{5.14}$$

Again, assuming redds are known without error the variance is,

$$Var(\hat{S}_J) = Var(\hat{S}_U) + \left(\frac{R_J - R_U}{R_D} \right)^2 Var(\hat{S}_D). \tag{5.15}$$

5.3.2 Recruit per Spawners

Six variants of juvenile recruit per spawner values are calculated to show productivity trends. The six recruit per spawner variants include (1) emigrant per total spawner, (2) emigrant per adult spawner, (3) emigrant per female spawner, (4) smolt per total spawner, (5) smolt per adult spawner, and (6) smolt per female spawner.

$$(1) \qquad \hat{R/S}_1 = \frac{\hat{N}_J}{\hat{S}_J} \tag{5.16}$$

$$(2) \qquad \hat{R/S}_2 = \frac{\hat{N}_J}{\hat{S}_{J,EJ}} \tag{5.17}$$

$$(3) \qquad \hat{R/S}_3 = \frac{\hat{N}_J}{\hat{S}_{J,F}} \tag{5.18}$$

$$(4) \qquad \hat{R/S}_4 = \frac{\hat{N}_S}{\hat{S}_J} \tag{5.19}$$

$$(5) \qquad \hat{R/S}_5 = \frac{\hat{N}_S}{\hat{S}_{J,EJ}} \tag{5.20}$$

$$(6) \qquad \hat{R/S}_6 = \frac{\hat{N}_S}{\hat{S}_{J,F}} \tag{5.21}$$

Where the numerator $\hat{N}_J$ is the total emigrant abundance at the trap (4.1) or $\hat{N}_S$, the estimated number of smolts at Lower Granite Dam (4.3). And the denominator consists of all spawners ($\hat{S}_J$), spawners excluding jacks ($\hat{S}_{J,EJ}$) or female spawners ($\hat{S}_{J,F}$) above the juvenile trap. Where the three types of spawners above the trap are calculated following method outlined in section 5.3.1. The variance approximation for the six variations of recruits per spawner uses the delta method and follows the same format.

$$Var(\hat{R/S_1}) = \left(\frac{1}{\hat{S}_J^2}\right) Var(\hat{N}_J) + \left(\frac{\hat{N}_J^2}{\hat{S}_J^4}\right) Var(\hat{S}_J) \tag{5.22}$$

Chapter 6

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