Review of run size and escapement estimates for the Nass River system: Chinook, Sockeye, and Coho salmon and summer-run steelhead. Part 1 – Review of Methods

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REVIEW OF RUN SIZE AND ESCAPEMENT ESTIMATES FOR THE NASS RIVER SYSTEM: CHINOOK, SOCKEYE, AND COHO SALMON, AND SUMMER-RUN STEELHEAD PART 1 – REVIEW OF METHODS

by

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ABSTRACT

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Abundance estimates for Pacific salmon and summer-run steelhead returning to the Nass River watershed have been generated from a large-scale capture-recapture estimation program operated by the Nisg̱a'a Lisims Government Fisheries and Wildlife Department (NFWD) since 1994. Sockeye (*Oncorhynchus nerka*), Chinook (*O. tshawytscha*), and Coho (*O. kisutch*) Salmon and summer-run steelhead (*O. mykiss*) are captured and tagged at fish wheels operated in the lower Nass River. The abundance estimates generated from the fish wheels and mark and recapture programs are used to manage commercial, recreational, Nisg̱a'a Treaty, and other First Nation salmon fisheries throughout the Nass watershed and in approach waters. These abundance estimates are used for post-season accounting and are a key component for estimating aggregate net escapement, and related quantities used for domestic and international run reconstructions and harvest share agreements.

The abundance estimates for different salmon species are affected by different sources of potential bias and uncertainty. We conducted a comprehensive review of the Nass salmon capture-recapture estimation programs and annual abundance estimates. This review examines assessment and estimation procedures including a comprehensive review of key input data sources and analysis methods used to estimate abundance for each species. We identify key assumptions and sources of bias in the current program; explore the sensitivity of mark-recapture estimates to these assumptions; and identify new sources of relevant information from species-specific research projects.

To support this review, we assembled and reviewed the datasets and estimation procedures from the current capture-recapture program. This program represents over 25 years of methodical implementation, including continuously testing alternative ways of tagging and recovering fish and adapting methods to correct deficiencies. Current methods were found to produce realistic estimates for all species considered. Stratification by size or sex or time of tagging does not appear to be necessary. However, more appropriate measures of uncertainty need to be developed to incorporate uncertainty in these estimates. This report provides recommendations for operational and analytical changes to the estimation program to reduce uncertainty in abundance estimates and address data gaps, including the adoption of a Bayesian model, which can better address the uncertainties that are identified in this report.

RÉSUMÉ

Schwarz, C.J., Alexander, R., Carr-Harris, C,. Beveridge, I., Noble, C., May, C., and Warkentin, L. 2025. Review of run size and escapement estimates for the Nass River system: Chinook, Sockeye, and Coho salmon and summer-run steelhead: Part 1 – Review of Methods. Can. Tech. Rep. Fish. Aquat. Sci. 3719: xv + 161 p. https://doi.org/10.60825/eas5-q565

Les estimations de l'abondance des saumons du Pacifique et des truites steelhead estivales qui remontent vers le bassin versant de la rivière Nass ont été établies à partir d'un programme d'estimation à grande échelle par capture-recapture mené depuis 1994 par le département des pêches et de la faune sauvage du gouvernement Nisga'a Lisims (NFWD). Le saumon rouge (Oncorhynchus nerka), le saumon quinnat (O. tshawytscha), le saumon coho (O. kisutch) et la truite steelhead estivale (O. mykiss) sont capturés et marqués à l'aide de roues à poissons installées dans la partie inférieure de la rivière Nass. Les estimations d'abondance générées à partir des roues à poissons et des programmes de marquage et de recapture sont utilisées pour gérer les pêches commerciale, récréative, prévue par le traité Nisga'a et d'autres pêches au saumon des Premières Nations dans tout le bassin versant de la Nass et dans les eaux d'approche. Ces estimations d'abondance sont utilisées pour la comptabilité d'après-saison et constituent un élément clé pour estimer l'échappement net global et les quantités connexes utilisées pour les reconstructions des remontées nationales et internationales et les accords de partage des prises.

Les estimations de l'abondance des différentes espèces de saumon sont affectées par différentes sources de biais et d'incertitude potentiels. Nous avons procédé à un examen complet des programmes d'estimation par capture-recapture du saumon de la Nass et des estimations annuelles de l'abondance. Cet examen porte sur les procédures d'évaluation et d'estimation, y compris un examen complet des principales sources de données et des méthodes d'analyse utilisées pour estimer l'abondance de chaque espèce. Nous identifions les hypothèses clés et les sources de biais dans le programme actuel, explorons la sensibilité des estimations par marquage-recapture à ces hypothèses et identifions de nouvelles sources d'informations pertinentes issues de projets de recherche spécifiques à chaque espèce.

Pour étayer cet examen, nous avons rassemblé et examiné les ensembles de données et les procédures d'estimation du programme actuel de capture-recapture. Ce programme représente plus de 25 ans de mise en œuvre méthodique, y compris des tests continus de méthodes alternatives de marquage et de récupération des poissons et l'adaptation des méthodes pour corriger les lacunes. Les méthodes actuelles se sont avérées produire des estimations réalistes pour toutes les espèces considérées. La stratification par taille, sexe ou moment du marquage ne semble pas nécessaire. Cependant, des mesures d'incertitude plus appropriées doivent être développées pour intégrer l'incertitude dans ces estimations. Ce rapport fournit des recommandations pour des changements opérationnels et analytiques au programme d'estimation afin de réduire l'incertitude dans les estimations d'abondance et de combler les lacunes dans

les données, y compris l'adoption d'un modèle bayésien, qui peut mieux répondre aux incertitudes identifiées dans ce rapport.

PREFACE

Abundance estimates for Pacific salmon and summer-run steelhead returning to the Nass River watershed have been generated from a large-scale mark and recapture estimation program operated by the Nisga'a Lisims Government Fisheries and Wildlife Department (NFWD) since 1994. The abundance estimates are used to manage commercial, recreational, Nisga'a Treaty, and other First Nation fisheries for salmon and summer-run steelhead throughout the Nass watershed and in approach waters. These abundance estimates are used for post-season accounting and are a key component for estimating aggregate net escapements, total runs (TR), total returns to Canada (TRTC), terminal abundance for Nass salmon, and total allowable catch (TAC) levels for all fisheries including setting harvest shares for Nisga'a Treaty fisheries as mandated in the Nisga'a Final Agreement (NFA 2000).

Since 2000, the abundance estimates for all species of Pacific Salmon are annually reviewed by the Nisga'a-Canada-British Columbia Joint Technical Committee (JTC) and approved by the Nisga'a-Canada-British Columbia Joint Fisheries Management Committee (JFMC). However, there has not been a comprehensive review of operational or analytical procedures in recent years. There are new sources of information from species-specific research projects that have been collected over the years, such as the recent results of radio-telemetry projects and genetic stock composition, that have not yet been incorporated into abundance estimation procedures.

In May 2020, members of the Nisga'a-Canada-BC JTC initiated a review of Nass capture-recapture estimation programs. The review and subsequent analytical work was led by an expert in capture-recapture methods (Dr. Carl Schwarz) with guidance from a Technical Working Group (TWG) using datasets assembled and compiled by NFWD and LGL Limited.

Part I of this review (this document) examines the capture-recapture estimation program for Nass Sockeye, Chinook, and Coho salmon, and summer-run steelhead, reviews existing datasets and newer information sources, and makes recommendations for modifications to operational and analytical procedures. Part II of this review (in prep) implements revised estimation procedures using a Bayesian model and examines the performance of the new estimator using historical datasets.

Structure of this document

This report begins with an overview of the assessment programs that generate input data used in subsequent capture-recapture estimation procedures. Sockeye, Chinook, and Coho salmon and summer-run steelhead are captured and tagged from two fish wheels operated in the lower Nass River at Gitwinksihlkw (GW) from early June to mid-September. Additional Chinook Salmon and summer-run steelhead are marked at fish wheels operated approximately 16 km upriver of GW near Grease Harbour (GH). Marked and unmarked fish are recovered in all fish wheels, in fishery harvests below and above the fish wheels, and in several tributaries throughout the Nass watershed. Numerous methodological studies have occurred throughout the program and the current methodology can now be considered “mature”.

The subsequent sections of this report describe general examining assumptions for capture-recapture estimation methods and provide a detailed review of the specific estimation procedures, including both post-season and in-season estimation methods, for the different species of Nass salmon and steelhead considered here. The final section of this report provides detailed recommendations for improvements to the current mark and recapture estimation procedures for these populations.

As part of this review, relevant datasets spanning from 1994 to 2019 were assembled, reviewed, and organized to support revised estimation procedures that described in Part II. For this report, 2019 was selected as a focal year which was used to illustrate the generation of input data from assessment programs and estimation procedures for all species examined in this review, and specific examples from the 2019 return year are provided throughout this report.

1. Introduction

1.1 Purpose of the review

Abundance estimates for Chinook (*O. tshawytscha*), Sockeye *Oncorhynchus nerka*) and Coho (*O. kisutch*) salmon and summer-run steelhead (*O. mykiss*) returning to the Nass River watershed (Figure 1) have been generated from a large-scale mark and recapture estimation program operated by the Nisg̲a'a Lisims Government Fisheries and Wildlife Department (NFWD) since 1994 (Table 1; Table 2; Table 3; Table 4). Sockeye, Chinook, and Coho salmon and summer-run steelhead are captured and tagged mostly from fishwheels operated in the lower Nass River at Gitwinksihlkw (GW) from early June to mid-September. Additional Chinook Salmon and summer-run steelhead are marked from two to four fishwheels operated approximately 16 km upriver of the Gitwinksihlkw fishwheels near Grease Harbour (GH). Marked fish are recovered in all fishwheels, in fishery harvests below and above the fish wheels, and in several tributaries throughout the Nass watershed (Figure 1).

The abundance estimates generated from the fishwheels and mark and recapture programs are used to manage commercial, recreational, Nisg̲a'a Treaty, and other First Nation fisheries for all salmon and summer-run steelhead throughout the Nass watershed and in approach waters. These abundance estimates are used for post-season accounting and are a key component for estimating aggregate net escapements, total runs (TR), total returns to Canada (TRTC), terminal abundance for Nass salmon, and total allowable catch (TAC) levels for all fisheries including setting harvest shares for Nisg̲a'a Treaty fisheries as mandated in the Nisg̲a'a Final Agreement (NFA 2000). Abundance estimates are also used for pre- and in-season forecasting and for calculating the Annual Allowable Harvest (AAH) for Nass Sockeye Salmon captured in Alaska's District 101 gillnet and District 104 seine fisheries as defined in Chapter 2 of the Pacific Salmon Treaty. For steelhead, capture-recapture estimates are used for estimating the total number of summer-run steelhead returning to the Nass Area for estimating aggregate net escapement and reviewing annual Nisg̲a'a harvest levels to not exceed 1,000 summer-run steelhead harvested as mandated in the Nisg̲a'a Treaty.

Since 2000, abundance estimates for all species of Pacific salmon are annually reviewed by the Nisg̲a'a-Canada-British Columbia Joint Technical Committee (JTC) and approved by the Nisg̲a'a-Canada-British Columbia Joint Fisheries Management Committee (JFMC), which consists of technical and management representatives from all parties. The annual estimates and underlying datasets have capture-recapture relative standard errors (RSE) averaging between 2% and 18% for all species from 1994 to 2019. There have been many reports and studies over the years testing changes in the design of the fishwheels, different tag types, different estimation procedures, etc., and the current methodology can now be considered "mature".

However, there has not been a comprehensive review of operational or analytical procedures for capture-recapture estimates for all species in recent years, and it is not known how abundance estimates are affected by changes in environmental conditions, harvest patterns or stock composition which may have occurred over the past five years, especially during lower water level conditions in 2018. Abundance estimates for different salmon species are affected by different sources of potential bias, and there are new sources of information from species-specific research projects that have been collected over the years (including the recent results of radio-telemetry projects, genetic stock composition, etc.) that have not yet been incorporated into abundance estimation procedures.

This review examines the capture-recapture estimation programs for Nass Sockeye, Chinook, and Coho Salmon, and summer-run steelhead (defined as steelhead migrating upstream of the lower Nass River after 1 July) by using existing datasets and new information sources and makes recommendations for modifications to operational and analytical procedures.

The specific objectives of this report include:

1. Review input data sources and analysis methods used to estimate abundance of Nass Sockeye, Chinook, and Coho salmon, and summer-run steelhead;
2. Identify key assumptions, sources of bias, uncertainties, and data gaps in capture-recapture estimation programs;
3. Identify new data sources relevant to abundance estimation for all species listed in Objective 1 and explore how to incorporate this new information into abundance estimates;
4. Explore sensitivity of abundance estimates for all species to assumptions and biases identified in Objective 2; and
5. Provide recommendations for operational and analytical changes to the estimation program to reduce uncertainty in abundance estimates and future studies to address data gaps.

This report begins with a high-level review of the current tagging and estimation procedures used for the four species of interest (Section 2: 2. Overview of system and assessment programs). Then in Section 3 (3. Examining assumptions necessary for capture-recapture methods), the key assumptions for the validity of the capture-recapture estimates are discussed. Section 4 (4. Detailed review of current estimation procedures) is a detailed review of the current estimation procedures. Finally, recommendations for improvements and future work are made in Section 5 (5. Summary and Recommendations).

1.2 Limitations of the review

There are several restrictions and issues that are considered outside the scope of this review.

1.2.1 Program management

The performance and management of the fishwheel tagging program and fish recovery efforts which are assessed at regular intervals are assumed to be working as intended. Issues of data collection, data verification, and data management will not be reviewed. Genetic stock assignment is also assumed to perform as expected and will not be reviewed. Similarly, no review is done of the external studies (e.g., radio tagging studies used to estimate initial mortality).

1.2.2 Coastal Salmon

This review focuses exclusively on Chinook, Sockeye, and Coho salmon and summer-run steelhead returning to the Nass River. The coastal Nass area is known to have returns of these species of fish in multiple rivers, but these are not discussed here. Further, NFWD identifies a “coastal” stream differently than the Province of BC does via their watershed codes. Specifically, NFWD identifies Ksi Gingolx, Xnukw (Iknouk River), and Ksi Hlginx as coastal streams (and thus these populations are excluded from the mark recapture estimation procedure), whereas the Province includes these as tributaries to the Nass River.

1.2.3 Enroute mortality

The abundance estimates reviewed here are of Nass Chinook, sockeye, coho and summer run steelhead entering the river as they pass the fishwheels in the lower Nass. These estimates of terminal run, which are also referred to as “net escapement”, which are used for implementing provisions of both the Nisga’a and Pacific Salmon treaties, do not account for enroute losses as the fish migrate to their final spawning grounds resulting from fishing or other sources of mortality, or from mainstem spawning upstream of the fishwheels.

After accounting for initial handling and capture mortality for tagged fish, it is assumed that enroute losses after tagging and until spawning apply equally to tagged and untagged fish, therefore enroute mortality does not have to be considered when estimating the run sizes to the tagging sites. Causes and types of natural and fishing mortality upriver of GH are not considered here.

1.2.4 Nisga'a catches

Both Nisga'a domestic and sale gillnet fisheries may remove tagged and untagged fish at a different rate after their release at the fishwheels, especially immediately below the GW fishwheels. The current estimation procedure adjusts the number of released tagged fish to account for removals in these fisheries.

The number of fish removed in Nisga'a fisheries must be estimated. The procedures used to obtain these estimates (Mathews et al. 2012) will not be reviewed in this document and it will be assumed that estimates are unbiased. Differences in the size distribution of harvested fish and the distribution of size of tagged fish due to gillnet sizes (and other factors) will also be ignored, other than that the number of jacks will have been removed from harvest estimates used for mark recapture model adjustments.

The catch estimates used to estimate the number of tags removed in the fishery may differ from the annual total catch estimates because of timing differences between the start of fisheries and tagging programs. For example, the total catch estimates will include catch from May, but tagging at the fishwheels typically does not start until June. Consequently, only the catch from June onwards (i.e., when the fishwheels are tagging fish) is used when estimating tags removed in the Nisga’a harvest. The procedures to estimate parts of the catch are not reviewed.

From 1994 to 1999 (pre-Nisga'a Treaty), there were no in-river sale fisheries that targeted Sockeye (with the exception of a small fishwheel “Excess Salmon to Spawning

Requirements" [ESSR] harvest permitted in 1995 and1999) and Coho salmon. From 2000 to the present, there have been several years of sale fisheries for Sockeye Salmon and a few for Coho Salmon as part of the Nisga'a Treaty in-river fisheries utilizing gillnets and/or fishwheels.

1.2.5 Size cutoffs for population abundance estimates

The current system restricts tagging and estimation to certain size classes of fish as follows.

1.2.5.1 Chinook Salmon

The most common life history for Nass Chinook Salmon is stream-type, maturing after 1 to 4 years at sea (GR age classifications of 3_2, 4_2, 5_2, and 6_2). Ocean-type components of the population, which primarily occur in Lower Nass and coastal systems, are less common (GR age classifications of 2_1, 3_1, 4_1, and 5_1). For the purpose of this review, the term jack refers to Chinook Salmon with 1 ocean year (GR age 3_2 and 2_1) which are generally < 500 mm nose-fork length (NFL). NFWD uses the term "Mediums" to define Chinook Salmon between 500 and 754 mm which are predominantly age 4_2 with some age 3_1 fish. Virtually all jacks and mediums are male[1]. Large Chinook Salmon are defined as fish > 754 mm and are primarily ages 5_2, 6_2, 4_1, and 5_1.

Chinook Salmon are widely distributed in the Nass River system (Figure 2). Known spawning areas where more than 500 Chinook have been observed include the Cranberry River, Damdochax Creek, Ksi Hlginx (Ishkeenickh River), Kwinageese River, Meziadin River, Ksi Sii Aks (Tseax River), and the Nass mainstem (Koski et al. 1996a,1996b; Beveridge et al. 2020). Smaller populations are found in many other Nass tributaries.

Tagging with operculum tags (Ketchum Model No. 3, 6 mm wide by 29 mm long) has been restricted to fish ≥ 500 mm NFL since1994. This size represents medium (age 4 [some 3-year-olds]) and large Chinook (age 5 and older). There are several reasons for the size restriction: mark-recapture estimates are not estimated for jacks (small fish) below the tagging size threshold primarily due to the operculum tag not holding well for smaller fish and challenges on obtaining reliable mark rates on the spawning grounds where small fish may pass weir slats and not be counted.

1.2.5.2 Coho Salmon

The most common life history for Nass Coho Salmon is stream type, maturing after typically one year at sea, with two age classes (GR age classifications of 3_2 and 4_3) representing on average 99% of the annual returns based on ages collected from the Nass fishwheels from 1994 to 2020. Other age components of the population are less common (GR age classifications of 2_1, 2_2, 3_1, 3_3, 4_2, 4_1, 5_1, 5_3, 5_4, and 5_5). For the purpose of this review, the term jack refers to Coho Salmon with one ocean year (GR 3_2) which are generally < 400 mm fork length. NFWD uses the term "Mediums" and "Larges" to define Coho Salmon between 400 and 580 mm and > 580 mm NFL, respectively.

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[1] Genetic analysis from 2009-2019 has confirmed that the majority of fish below 754 mm are male; but in recent years, a few more females have been observed in this group (refer to the individual chinook reports for details).

Coho Salmon are found in most accessible Nass River tributaries and in many coastal streams (Figure 3). Currently, major Nass River spawning streams include Cranberry River, Kiteen River, Damdochax Creek, Kwinageese River, Meziadin River, Ksi Sii Aks (Tseax River), and Ksi Ts'oohl Ts'ap (Zolzap Creek), and tributaries to these systems.

From 1994 to 2008, tagging was restricted to fish ≥ 450 mm NFL when spaghetti tags were used. Since 2009, Coho Salmon ≥ 400 mm NFL have been tagged with either an operculum tag (2009 and 2010; Ketchum Model No. 3, 6 mm wide by 29 mm long) or an anchor tag (2011-present).

1.2.5.3 Sockeye Salmon

Nass River Sockeye Salmon exhibit a range of life-history strategies that includes lake-type (e.g., Meziadin lake stocks), sea-type (e.g., Gingit Creek), and river-type (e.g., Brown Bear Creek; Figure 4). Lake-type stocks rear in nursery lakes (e.g., Meziadin, Fred Wright, and Bowser lakes) for one to two years before smolting and returning as adults consisting of four relatively abundant age-classes (4_2, 5_2, 5_3, and 6_3). Sea-type stocks, a subtype of river-type fish, do not require lake habitat for rearing and can therefore spawn in systems that are not proximate to large lakes (Wood et al. 2008). Sea-type fish go to sea in their first year of life and return as 0-check adults (i.e., Gilbert-Rich ages with the subscript 1; e.g., 3_1, 4_1, 5_1). These stocks are found in the lower Nass watershed, downstream of Grease Harbour, with Gingit Creek being the dominant spawning area (Beveridge et al. 2017; Alexander et al. 2023). Sea-type Sockeye Salmon are generally younger and smaller in size than lake-type sockeye returning in a given year. River-type stocks rear for one or two years in side-channel habitat, but data on these stocks are limited. A recent investigation of size trends among major age classes observed significant declines in size-at age for lake-type Nass sockeye (Freshwater et al. 2023).

The Sockeye Salmon return to the Nass River is dominated by the Meziadin run which has constituted a large majority of the return to the GW fishwheels since 2000. Other Sockeye Salmon producing areas in the Nass watershed include Bowser Lake, Damdochax and Wiminasik lakes in the Damdochax watershed, Fred Wright Lake in the Kwinageese watershed, and Gingit Creek (sea-type).

For the purpose of this review, the term jack refers to Sockeye Salmon with 1 ocean year (GR ages 2_1, 3_2, and 4_3) which are generally < 450 mm NFL. NFWD uses the term "Mediums" to define Sockeye Salmon between 450 and 580 mm NFL which likely represent three- and four-year old's (GR ages 3_1, 4_1, and 4_2). "Larges" define Sockeye Salmon > 580 mm NFL which may represent five- and six-year old's (GR ages 5_2, 5_3, and 6_3 fish).

Tagging has been restricted to fish ≥ 450 mm NFL from 1994-present with the application of spaghetti tags and excludes jacks.

1.2.5.4 Steelhead

Only summer-run steelhead are considered in this review. After spending a few months to four years (most often 1 or 2 years) feeding at sea, adult steelhead return to freshwater from June to October to spawn. Summer-run fish spend almost a year in freshwater before they spawn and are in an early stage of reproductive development when they enter freshwater. Fish entering up-river tributaries are predominantly summer-run and those entering coastal and lower Nass tributaries are winter-run. Summer-run fish move upstream to overwintering areas that are generally near their spawning locations.

A certain portion of the annual returns of summer-run steelhead are repeat spawners and return to the sea after spawning in the spring months. Some of these spawned out fish (called kelts) are caught in the fishwheels in June. Only freshly entered steelhead that are caught at the fishwheels after 1 July are tagged or adipose fin-marked. Marked summer-run steelhead are typically ≥ 450 mm NFL, with the majority > 500 mm NFL.

There are both winter- and summer-run stocks of steelhead in the Nass River watershed and the timing of these stocks returning through marine waters are defined in the Nisg̱a'a Treaty. Summer-run stocks utilize tributaries to the Nass River upstream of the canyon at Gitwinksihlkw and are assumed to enter after July 1. Winter-run stocks generally utilize tributaries to the Nass River downstream of the canyon at Grease Harbour (approximately 16 km upstream of Gitwinksihlkw) and enter between April and June. Ksi Sii Aks (Tseax River) and Ksi Sg̱asginist (Seaskinnish Creek) have been observed to have overlapping runs of both winter- and summer-run steelhead and they are referred to as sympatric steelhead populations (Bocking et al. 2005).

1.2.5.5 Contribution of smaller fish to overall abundance.

This review does not consider the contribution of small fish (defined as those smaller than species-specific minimum tagging sizes) in estimates of abundance. The NFWD catch monitoring program attempts to ensure any mark-rate examination data for harvests, recaptures, or escapements do not include small fish that are below the tagging size thresholds because that would obviously affect MR estimates. In addition, data collected on average size at age for Chinook and sockeye suggests that no changes to size boundaries are needed for medium or large fish, despite warming ocean conditions and recent trends of smaller size at age for returning fish (i.e. Beveridge et al. 2023, Freshwater et al. 2023).

2. Overview of system and assessment programs

The modern Nass River salmon/steelhead monitoring program using fishwheels in the lower Nass has been running for almost 30 years. During this time, many studies have been conducted to: improve the fishwheel design; study the performance of the tags used (anchor, operculum, spaghetti, etc.); improve adjustments for harvest, fall back, drop out, and tag loss; and choose appropriate estimators for in-season and post-season abundance. This review will not examine the historical record, much of which has already been already peer-reviewed by other groups such as the Nisg̱a'a-Canada-BC JTC, Fisheries and Oceans Canada (DFO), and Pacific Salmon Commission (PSC). These reviews are documented in various technical and manuscript reports produced since 1992 (e.g., Link and English 1996; Link and Nass 1999; Parken and Atagi 2001; Alexander and Link 2001; Alexander and Bocking 2003; Beveridge et al. 2020, 2023; Alexander et al. 2023).

Table 1 (Chinook), Table 2 (Coho), Table 3 (Sockeye), and Table 4 (steelhead) provide summary statistics and resulting estimates from 1994 to 2019. The program is quite complex, and it is helpful to review the various parts of the program and estimation procedure.

Consequently, we provide a general overview of tagging and estimation procedures used for the four species of interest, followed by a detailed example of how the system operated in 2019.

2.1 Overview

The current (post 2000) tagging and estimation procedures used for the four species of interest can be summarized as follows (Table 5):

- Fish are tagged with individually numbered physical tags (e.g., spaghetti, anchor, or operculum tags, depending on species) at GW (Table 6) with additional tagging at GH for Chinook Salmon and steelhead (Table 7). For Sockeye Salmon, the colour of the tag also varies across weeks. For Chinook, Coho, and Sockeye salmon, only fish of certain sizes are tagged (see details below); for summer-run steelhead, since 1997, all fish selected by the fishwheels are tagged (ending in 2014) or adipose fin clipped only (n = 12 years back from 2019).

- Tagged fish are also marked with a batch secondary mark (adipose hole punch at GW or adipose fin clip at GH. Operculum punches have been used on at least one occasion in 2010 when coho between 45-50 cm received a smaller operculum tag, but this is not the regular practice.

- Adjustments are made to the number of tagged fish released to account for initial handing mortality, fall back, differential harvest of tagged and untagged fish in the Nisg̱a'a Domestic Fishery, and tag loss (if fish are not fully inspected during the recapture phase) to provide a net number of tagged fish available for subsequent recapture just above GH (Tables 11 and 12). No adjustments are currently made for spawning between GW and GH. As noted later in the document, this could lead to biases in run size if the number of fish that spawn between GW and GH is large.

- Recaptures typically occur at the Meziadin Fishway (MF) (Chinook[2], Coho, and Sockeye Salmon; Table 8), Kwinageese Weir (Chinook, Coho, and Sockeye Salmon, and steelhead; Table 9) and Damdochax Creek ground (Chinook Salmon; Table 10) and aerial surveys (Sockeye Salmon; Table 10). Since 2009, other regular ground surveys have been conducted for Chinook Salmon on the Cranberry/Kiteen rivers. Three years of recoveries (2007, 2008 and 2010) have also taken place at the Ksi Sg̱asginist (Seaskinnish Creek) weir (Chinook, Coho, and Sockeye Salmon, and steelhead) in the middle Nass River between GW and GH fishwheels (no summary provided).

- Chinook Salmon are large enough that the presence/absence of a tag on the left operculum and/or the presence/absence of an adipose fin punch/clip can be determined and only fish that are “fully verified” are used in the subsequent analysis. Carcass surveys have provided recapture data from heads only where the left operculum is intact. Size group has been estimated by historical head length regression measurements. For some years and some systems, very poor carcass recovery conditions have led mark-resight from field surveys to be used instead of physically examined fish. For Sockeye and Coho salmon, the observed number of tags have been corrected for tag loss since 2004 (above) where the tag loss is estimated from a sub-sample taken at the MF and fully examined for missing tags.

- A pooled- and/or stratified (by size)-Petersen estimator is used, depending on statistical differences in either mark or recapture rates, using the estimated net number of tags available above GH and the number of inspected and recaptured fish upstream to estimate the run size just above the GH fishwheels[3]. Some care is needed in interpreting these run size estimates. For species that are only tagged at GW (Sockeye and Coho salmon), the estimate includes escapement between GW and GH and so this escapement must be subtracted to get the actual run size at GH. For species tagged at both sets of fishwheels, the estimate at GH includes part of the escapement between GW and GH.

- The estimated Nisg̲a’a harvest and sport-fish harvest between GW and GH is then added to the estimated run size at GH. This estimates the run size at GW for Chinook Salmon and steelhead.

- Additionally, escapement between GW and GH is estimated as a proportion of the run size at GH using any counts or genetic data to break out the spawning populations between GW and GH. Some caveats for the use of genetic stock identification (GSI) data for Nass Chinook are provided below. As noted later, information on escapement may also be available based on the difference in the estimated run size computed using tags from each fishwheel separately, but precision may be poor due to small sample sizes.

Fish tagged at a fishwheel and subsequently recaptured at another fishwheel are released with minimum handling; tag numbers are noted for the majority of recaptures. These recaptures are not used in the estimation procedure for Chinook Salmon because of potential non-mixing between the two fishwheel locations and “trap-happy” behavior observed for Chinook Salmon (Alexander et. al. 2023). For Sockeye and Coho salmon, the marked fraction at the GH fishwheels is used for in-season run size estimates to GW for fishery management purposes, but the GH mark-rates are not used

[3] Recovery data from Ksi Sg̲asginist (Seaskinnish Creek) weir, which is between GW and GH, was used for Coho and Chinook salmon in 2007, 2008, and 2010 (Coho only); typically, only recovery data upriver of GH are used.

in the post-season run size estimates. Post-season estimates rely on Meziadin Fishway and other mark-rate data collected on the spawning grounds to finalize run size.

Scale samples from Chinook, Coho, and Sockeye salmon and steelhead (captured after 1 July) for aging and/or genetic analyses are collected from a sub-sample of fish selected at the fishwheels in proportion to the annual fishwheel catch and based on a percentage of the previous day's catch. Both Chinook and Sockeye salmon have had regular genetic analyses conducted since 2009, but not every year for Sockeye Salmon. The genetic analyses could be used in a reverse capture-recapture estimation as outlined below, but there appear to be problems with this second approach with the accuracy of stream-specific escapement estimates. Within the Nass River, the Chinook SNP panel currently in use by DFO has been evaluated for both individual assignment (sub-stocks) and mixed stock accuracy (e.g. marine commercial fisheries). Supported reporting units within the system predominately follow the conservation unit (CU) boundaries, although the Ksi Sii Aks (Tseax River; called Tseax Slough in the genetic baseline) stock, within the Upper Nass CU, is sufficiently distinct to be resolved separately (Beacham et al. 2021; pers. comm. DFO Molecular Genetics Laboratory).

2.1.1 Detailed example: 2019 season

A detailed example of the numbers of fish captured, tagged, and the adjustments are shown in Table 11 using data from the 2019 season.

Consider the data from the 2019 season for Chinook Salmon (Table 11). As the fish enter freshwater from marine waters, a harvest occurs around Gingolx where 676 Chinook Salmon are harvested. Because Gingolx is so far downriver from the fishwheels, tagged fish are very rarely captured here and the Gingolx harvest includes fish from systems that are considered "Coastal" (i.e., non-Nass), this harvest is "ignored" when adjusting for tagged fish removed by the Nisga'a domestic and individual-sale fisheries[4]. Continuing upstream, 1,731 and 1,824 are harvested in two catch-monitoring strata below the GW fishwheels which began on 2 June 2019 (Table 12)[5].

Fish arrive at GW, at which point 727 fish are tagged from two fishwheels operated from 2 June to 13 September 2019. The Nisga'a domestic harvest and sport fishery for Chinook Salmon remove an additional 2,223 and 192 fish, respectively. Nass Chinook sub-stock proportions are available at a lower resolution for upper Nass stocks (excluding Ksi Sii Aks [Tseax River] which has a higher probability of assignment) and are currently used to estimate the escapement to Ksi Sii Aks (Tseax River) and Ksi Sgasginist. Genetic stock composition for 2019 shows that 19.4% of the tagged fish belong to the Ksi Sii Aks (Tseax River) and Ksi Sgasginist (Seaskinnish Creek) stocks (Beacham et al. 2021; Table 13).

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[4] In some years, a portion of the domestic harvest was done using the fishwheels at GH (e.g., 2001).

[5] The total Nisga'a harvest of Chinook Salmon in 2019 was 6,682 but this totals 6,445 and the difference may be associated with catch before the fishwheels started tagging on 1 June.

Upon arriving at GH, an additional 773 fish are tagged at four fishwheels for a total of 1,500 tagged Chinook Salmon released at the two tagging locations. The tagged fish also have adipose fin-marks (hole punch at GW and clip at GH as batch marks).

Adjustments are now made for tags removed in the Nisga'a domestic fishery and individual sale gillnet fishery (see details later and Table 12). Because not all tagged fish captured in the Nisga'a fisheries have their tags reported, the number of tags removed by the domestic fishery is estimated at 225 tags (based on an extrapolation of the tags reported in the individual-sale fishery to estimate the tag return rate [59%]). An adjustment for initial handing mortality and fall back (tagged fish that do not continue their migration) of -5% (75 tags) is based on radio telemetry data from 1992 and 1993 studies (Koski et al. 1996a, 1996b). No adjustment is made for tag loss for Chinook Salmon because subsequent inspection for and recovery of tags is based only on fish for which a complete inspection (for both batch marks and tags) is usually made, with the exception of infrequent application of mark-resight during stream surveys, and in when only heads can be examined unlike for other species[6]. Currently, no adjustment is made for losses of tagged fish from GW that escaped to the Ksi Sii Aks (Tseax River) and Ksi Sgasginist (Seaskinnish Creek), which would represent an additional 141 tags "lost" between GW and GH. This leaves an estimated net number of 1,201 tagged fish available for recovery at tag recovery sites above GH.

Fish are inspected for tags at the Cranberry River, the Meziadin Fishway, Kwinageese Weir, and Damdochax Creek. A total of 793 Chinook Salmon are fully inspected, of which 85 are tagged (based on tags or batch marks observed).

A Pooled-Petersen estimate of 11,097 fish (RSE 11%) represents an estimate of the run size just above GH and any spawning below. A sized-stratified Petersen estimate is 2.8% lower (10,796; RSE 11%) based on an estimate of medium (4,443; RSE 21%) and large (6,353; RSE 13%) Chinook Salmon.

Finally, the harvest of 2,223 and 192 fish from the Nisga'a Domestic Harvest and the sport fishery between GW and GH is added to this run size to estimate the run size at GW of 13,512 fish based on the pooled-Petersen estimator (or 13,211 based on the size-stratified Petersen estimator). Again, the current methodology does not add back escapement to Ksi Sii Aks (Tseax River) and Ksi Sgasginist (Seaskinnish Creek).

Table 11 provides details for other species. Note that Sockeye and Coho salmon are only tagged at the GW fishwheels.

2.2 Specific details about tagging and examination procedures

2.2.1 Marine Harvest

A marine harvest for all species occurs in most years. This marine harvest is conducted in Alaskan (commercial and sport fishery) and Canadian water (Nisga'a, other First Nations, commercial and sport harvest) in DFO statistical Areas 3 and 4.

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[6] The exception to this is for carcass surveys where often only find the head is found. The left operculum of found heads is examined for a tag or tag-loss hole and the size group estimated based on historical head size regressions for medium and large Chinook Salmon.

For most marine commercial and sport fisheries, several catch monitoring programs are in place each year to estimate the catches in the Nass marine area (Area 3). In most years since 2004, Sockeye Salmon samples are collected for stock identification in marine waters for genetic stock identification (GSI). Because this harvest occurs prior to entry of fish to freshwater, it is outside the scope of this review. However, some tagged fish have been recovered in marine commercial fisheries in both Canada and US which suggests that some non-Nass stocks may be migrating and tagged at the fishwheels, or some fish drop out after tagging, however these rare cases are accounted for by censoring tags for an assumed dropback rate.

2.2.2 Tags applied at Gitwinksihlkw fishwheels

A summary of the tag/mark types used for the four species is found in Table 15. The tag type used has changed over time in response to concerns about tag-loss, effects on fish, and operational efficiency in detecting tags.

2.2.2.1 Chinook Salmon

The current procedure is to use a uniquely numbered Kurl-lock tag (Ketchum Model No. 3, 6 mm wide by 29 mm long) on the left operculum at GW and GH fishwheels. A batch mark is added using an adipose hole punch (GW) or adipose clip (GH) depending on tagging location. This tag was chosen because other tags were actively pulled off on spawning grounds based on radio-telemetry results in 1992 and 1993[7]. The presence of the operculum tag or evidence of an operculum hole on the left operculum or batch mark is used for mark-recapture estimates.

2.2.2.2 Coho Salmon

The current procedure (since 2011) is to use uniquely numbered anchor tags plus an adipose hole punch to mark Coho Salmon at the GW fishwheels. Spaghetti tags were used to mark Coho Salmon from 1994 to 2008 and operculum tags (Ketchum Model No. 3, 6 mm wide by 29 mm long) were tried for two years (2009 and 2010). Spaghetti tag loss on spawning grounds was considered too high and operculum tags did not hold well on smaller fish. Anchor tags were chosen as the best tag type to assess tagging status on the spawning grounds, in addition to be visually counted at the Meziadin Fishway and Kwinageese Weir.

2.2.2.3 Sockeye Salmon

Sockeye Salmon are currently tagged with a uniquely numbered spaghetti tag in addition to an adipose hole punch. The colour of the spaghetti tag varies by week to enable a temporally stratified estimator to be computed.

2.2.2.4 Steelhead

Tagging has varied over time. The current procedure (since 2015) is to use an adipose hole/clip (GW/GH) for marking. Previously, spaghetti tags were used for two years (1992 and 1993), anchor tag plus adipose hole/clip for 11 years (1997-2001, 2004, 2005, 2007, 2010, 2012, and 2014) as part of capture-recapture studies, and adipose hole/clip only for six years (2002, 2006, 2008, 2009, 2011, and 2013) funded by the Province of British Columbia.

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[7] The 1993 radio tagging study also tagged some Chinook with a spaghetti tag.

2.2.3 Nisga'a harvest between GW and GH

Nisga'a harvests between GW and GH include domestic and individual-sale gillnet fisheries. In some years, selective harvesting has occurred at the GH fishwheels where some fish are sold or used for domestic fishery purposes and/or DFO's demonstration fishery program that started in 2013. Fishwheel harvest has been primarily Sockeye Salmon but also included Coho and Chinook salmon in some years. Nisga'a harvests are estimated by a catch program for both domestic and sale fisheries with catch monitors located in all four Nisga'a communities. The catch program includes boat surveys to estimate effort, or the number of nets fished, as well as interviews of all fishers in each stratum to estimate weekly catch for all species.

For Nisga'a in-river sale fisheries, fish are sold at the Nisga'a fish plant in the upper river-stratum community of Gitlaxt'aamiks. Catch estimates are tracked by permit and sales-slip by NFWD for fish sold and are matched with catch that is not sold from catch interviews.

Total annual harvest has averaged around 2,500 for Chinook Salmon; 35,000 for Sockeye Salmon; 7,000 for Coho Salmon; and 100 for steelhead (Table 16), with high year to year variation in actual numbers.

2.2.4 Sport fishery between GW and GH

Sport fishery monitoring programs have been conducted intermittently between GW and GH for a few select years (1992-2004, 2010-2017) primarily for Chinook and Coho salmon (Table 177). Sport catch tag returns for Chinook Salmon have been low since 2000 (around 10/year) as are tag returns from the Coho Salmon sport fishery (typically less than 5/year).

2.2.5 Escapement between GW and GH

The aggregate GW run size for all species is apportioned into upper and middle Nass combined spawners by subtracting any escapement estimates between GW and GH (earlier years) or using stock proportions estimated from genetic information collected at fishwheels (later years). Additionally, counts of species at selected locations have been conducted with varying consistency over time: counts of Sockeye Salmon at Gingit Creek (2000 onwards); counts of Chinook Salmon at Ksi Sii Aks (Tseax River; 2007), Ksi Sgasginist (Seaskinnish Creek; 2007, 2008, and 2010); counts of Coho Salmon at the Ksi Sgasginist (Seaskinnish Creek) weir (2007, 2008 and 2010).

2.2.5.1 Chinook Salmon

Radio tagging studies found that 24/291 (8%; Table 23) in 1992 and 24/236 (10%; Table 24) in 1993 of fish moved to the Ksi Sii Aks (Tseax River) and Ksi Sgasginist (Seaskinnish Creek) between GW and GH, which is higher than estimated based on GSI (Table 13). This portion is slightly higher than the proportion estimated using radio tagging; but includes more four-year old fish (medium) that were tagged in the genetic studies but excluded from the radio tagging studies due to the large relative size of tags available at the time. Further, as described previously, there is higher uncertainty in using GSI at the sub-stock level for Nass Chinook.

2.2.5.2 Coho and Sockeye Salmon

It is not necessary to adjust for escapement between GW and GH for Coho and Sockeye salmon because these species are only tagged at GW. It is implicitly assumed that the fishwheels select all stocks with equal capture efficiency.

2.2.5.4 Steelhead

Radio tagging studies from 1993 and 2005 showed that 4-14% of radio-tagged fish migrated to the Ksi Sii Aks (Tseax River) and Ksi Sg̲asginist (Seaskinnish Creek) systems, while habitat-capacity modelling predicts < 3% of aggregate Nass steelhead belong to these stock groups (Table 19)[8]. Given the very small numbers of tagged steelhead from GW that would belong to these stocks, the adjustment process to account for this may be moot.

2.2.6 Fishwheels at Grease Harbour

In most years, additional fishwheels operated at GH are used to increase the number of tagged fish for Chinook Salmon (e.g., 1997, 2009-present) and steelhead (e.g., 1992-1994, 1997-present). Coho and Sockeye salmon that are captured at GH are not tagged. Additional Chinook Salmon and steelhead are tagged at GH with a different batch mark on the adipose fin (adipose V-clip at GH vs adipose hole punch at GW).

Some previously tagged fish are recaptured and released. These fish are essentially handled similarly to untagged fish; however, tag numbers are read and fish are released immediately. Some fish are released without tag numbers recorded but tag presence and tag colour are noted for Sockeye Salmon.

2.2.7 Harvest above Grease Harbour

First Nation harvests occur above the GH tagging sites every year by Nisg̲a'a, Gitanyow, and sometimes other First Nations. A few economic fisheries by non-Nisg̲a'a First Nations have occurred for Sockeye Salmon since DFO's Demonstration sale fishery program began in 2013. Food fishing occurs for all species. The majority of fisheries above GH occur immediately below Meziadin Fishway (by dipnet), and on the Nass mainstem (by gillnet and fishwheel) near Kinskuch River and Brown Bear Creek. Demonstration fisheries are all conducted with selective gear (i.e., dipnet and/or fishwheel).

The Gitanyow Fisheries Authority conducts a catch monitoring program below Meziadin Fishway and other fishing areas in the Nass watershed. Catches are reported annually to DFO, and recovered tags were returned (to DFO and NFWD) from 2006-2016 in which a tag lottery was conducted for Gitanyow fishers in each of the years. Because harvest above GH is expected to be non-selective (i.e., tagged and non-tagged fish have the same harvest pressure), there is no need to adjust for the number of fish with tags removed in the upper Nass harvest when estimating abundance.

[8] The Ksi Sg̲asginist (Seaskinnish Creek) stock was not included in the genetic baseline, so this stock is missing from the GSI analyses presented in Table 19.

2.2.8 Meziadin Fishway

A summary of the number of fish that enter the Meziadin Fishway is found in Table 8. The Meziadin Fishway typically operates from the beginning of July to early October.

Tag numbers are read for all captured Chinook Salmon if an operculum tag is present. Captured fish are also examined for evidence of tag loss (i.e., adipose fin mark present but no tag present). All Chinook Salmon are classified into S/M/L size groups based on size delineations in the viewing chamber or by confirmed length if captured.

All Coho Salmon are counted during operations. A high proportion of Coho Salmon tags are also read (e.g., 88% [130/148] in 2019). Not all fish have lengths measured, but proportions by size class can be estimated from biological samples collected each day that include length, sex, tag status, and age for fish that have scales taken. In 2019, 467 Coho Salmon were sampled for biological data representing 10.8% of the total count (4,334).

All Sockeye Salmon are counted during operations. Up to 60 Sockeye Salmon tags are read per day and all tags are counted by colour so that recaptures by week of release and week of recovery can be obtained for use in a temporal stratification. Individual tag reading is still high (e.g., in 2019, 93% [1880/2021] of the Sockeye Salmon tags were read). Not all fish have lengths measured, but proportions by size class can be estimated from the biological samples. In 2019, 1,716 sockeye salmon were sampled for biological data representing 2% of the total count (88,128).

All steelhead are counted during operations. In recent years, steelhead do not have individual tags and are only batch marked with fin mark status carefully observed. The biological samples could also be used to estimate size distributions.

Because the majority of Chinook Salmon are fully examined, tag loss can be estimated where an operculum hole on the left side is used for confirmation of mark status. A sub-sample of Sockeye and Coho Salmon are selected to estimate tag loss (see 5.10 Tag loss). Steelhead are assumed not to have tag loss because of the batch mark applied.

2.2.9 Spawning Ground Surveys

Spawning ground enumeration is conducted at a number of sites upstream of the Meziadin River confluence. Generally speaking, any specific spawning area estimate where a fishway/weir is not in place (e.g., Damdochax Creek) is based on visual estimation methods (peak count and/or AUC estimation methods) and used as a relative index of spawning for estimating net escapement. Not all of these estimates are incorporated in mark and recapture estimation procedures for all species,

2.2.9.1 Meziadin River above Fishway

Chinook Salmon boat/snorkel counts have been conducted in upper Meziadin River in some years to compare with fishway counts. Three areas are surveyed between the fishway and the outlet of Meziadin Lake where Chinook Salmon spawn in relatively small count groups (i.e., <10) with good visibility to see tagged fish. Depending on water viewing conditions and counting group, observer efficiency is estimated between 50% and 80% in detecting a fish that is present. These counts are not used for generating the capture-recapture estimates because of the inability to break out the counts by size and the difficulty of detecting all marks, including those fish that have lost an operculum tag. The 1992 and 1993 radio telemetry study and some other counts that have been conducted suggest that about half the Chinook Salmon are able to jump the falls and some of the fish spawn below the fishway based on 1993 data. Interestingly, the Meziadin Fishway counts are not dominated by medium fish which are assumed to have a lower probability of jumping the falls than larger fish. For example, in 2020, 79% of the fishway counts were large fish. The higher percentage of large to medium sized fish was also observed at Kwinageese Weir (63% to 36%) where all migrating fish are counted.

2.2.9.2 Kwinageese Weir

The Kwinageese Weir (KW) was first used in 2002 and has operated annually since 2009[9]. It operates from mid-July to mid-October and it is believed to provide a complete enumeration of Chinook and Sockeye salmon passage. Several of the Chinook Salmon reports document a comparison of ground carcass counts and weir count. Fish are counted using a video system including two colour cameras. A summary of the weir counts is provided in Table 9.

Chinook Salmon counted by video are carefully examined for tag status (i.e., presence of operculum tag; tag loss; adipose batch mark) and stratified by length-class using counting marks in the viewing chamber and/or a video-analysis software (Image J). Individual tag numbers cannot be read from recorded video and fish passing the weir are not handled. Prior to 2009, Chinook Salmon carcass surveys, located above the weir site, were conducted to fully inspect fish for tag status and tag loss. With the exception of 1997, length measurement and size classification was not conducted as abundance estimates were formed using pooled Petersen estimators only.

Coho and Sockeye salmon are counted but not handled so tag numbers cannot be read. Other than defining small fish, no length stratification has occurred to date. However, length stratification would be possible for grouping counts using the delineations for Chinook (≤ 754 mm NFL for medium and > 754 mm NFL for large fish) and Sockeye, Coho, and summer-run steelhead (≤ 580 mm NFL for medium and > 580 mm NFL for large fish). The tag colour of Sockeye and Coho salmon are noted from generally very clear underwater video detections, but neither species is handled to assess tag loss. The presence of only an adipose mark has been used for estimating tag loss of the primary mark.

Steelhead are counted and inspected for the batch mark and classified to size group.

The majority of Chinook and Sockeye salmon spawn above the Kwinageese Weir, but only a portion of Coho Salmon and steelhead spawn above.

2.2.9.3 Damdochax Creek (and Wiminasik Lake for Sockeye Salmon)

NFWD have conducted salmon counts on Damdochax Creek every year since 1992. Live counts and carcass surveys are conducted for Chinook Salmon with survey areas confirmed by past telemetry studies. All Chinook Salmon carcasses are fully examined

[9] DFO operated a weir on Kwinageese in 1958 and conducted a MR study in those years.

for tag presence or tag loss on the left operculum. and these data are included in mark-recapture analyses.

Angling surveys were conducted and DNA samples collected for steelhead in BC Fisheries funded capture-recapture years (2014 was the most recent survey). Tag recaptures were included in mark-recapture analyses in these years.

Foot and aerial surveys have been conducted for Sockeye Salmon by NFWD and Gitksan Watershed Authority in some years since 2009. These surveys are focused on reaches upstream of Damdochax Lake. Some tag recoveries occur or counts by tag colour are recorded, but few carcass data are available. Due to the low number of recoveries and infrequency of ground surveys, Sockeye Salmon tag recovery data at Damdochax are not used in mark-recapture estimates.

2.2.9.4 Bell-Irving River – Oweegee/Bowser lakes (Sockeye Salmon) – Teigen/Snowbank (Chinook Salmon)

Surveys in the Bell-Irving River system are conducted on an infrequent basis because of the large area and significant poor visibility originating from glacial systems (e.g., Bowser Lake) that prevent good visual counts or finding carcasses. Data from these surveys are not incorporated into mark and recapture estimates for any species.

Aerial and ground surveys have been conducted in some years for Chinook Salmon with good information from the 1992 and 1993 radio tagging study. Aerial flights for Coho Salmon and steelhead were conducted in 2005 and aerial surveys were conducted in 2018 and 2019 for Sockeye Salmon.

Angling surveys were conducted for steelhead when releasing anchor tags and good information is available from BC Fisheries funded years (1997-2001, 2004, 2005, 2007, 2010, 2012, and 2014).

Sockeye Salmon have been documented in Teigen Creek with no nearby lakes (i.e., river-type fish) from recent mining studies (Rescan 2013). Adult Sockeye Salmon were observed in a branch of Todedada Creek, in a small tributary of Treaty Creek, and in two groundwater-fed channels near the outlets of the Bowser River and Scott Creek to Bowser Lake in 2012.

2.3 Specific features for individual species

Additional species specific surveys that do not occur in all years and do not contribute data to mark and recapture estimation programs are described below.

2.3.1 Chinook Salmon

Aerial and carcass surveys in the Cranberry-Kiteen system have been conducted annually in recent years with intensive surveys in 1992 and 1993. Recaptured marks from Cranberry-Kiteen are included in mark-recapture analyses.

2.3.2 Coho Salmon

A counting fence is operated on Ksi Ts’oohl Ts’ap (Zolzap Creek; downstream of GW) annually to enumerate returning Coho Salmon. NFWD also conducts ground surveys on Ansedagan and Diskangieq creeks in the lower Nass. No ground surveys of Coho Salmon spawning sites occur above GH.

2.3.3 Sockeye Salmon: River- and Sea-type

Annual escapement surveys are conducted by NFWD on lower Nass tributaries including Gingit and Gitzyon creeks. These are sea-type populations (which go to sea in the first year after emergence) of early returning Sockeye Salmon that make up a high proportion of the aggregate Nass run in June and early July based on age and genetic results. Typically, this population will have higher mark rates due to ideal fishwheel catchability conditions through the Gitwinksihlkw canyon due to higher water levels experienced during June. The population also tends to pass on the south side of the canyon (i.e., caught in higher abundance at FW2) based on tag recaptures on the spawning grounds. More details about the relationship between catchability and water levels throughout the season are provided in Section 4.2 (in-season estimation).

Based on radio telemetry and genetic information that are available, Sockeye Salmon that spawn in Ksi Sii Aks (Tseax River) and Ksi Ts'oohl Ts'ap (Zolzap Creek) are later-arriving populations (Alexander et al. 2022). Despite very few Sockeye Salmon being observed in Ksi Ts'oohl Ts'ap (Zolzap Creek), in 2018, the final locations of four late-arriving Sockeye Salmon were confirmed via radio tracking to be Ksi Ts'oohl Ts'ap (Alexander et al. 2022). Both are river-type populations consisting primarily of 2-year-old smolts (Alexander et al. 2023). Very few Sockeye Salmon are actually observed at Ksi Ts'oohl Ts'ap.

Brown Bear Creek, located between the Cranberry and Meziadin rivers (Figure 1), is predominantly a late-arriving river-type population consisting primarily of 2-year-old smolts. The Gitanyow Fisheries Authority conducts annual escapement surveys on Brown Bear Creek.

2.3.4 Summer-run steelhead

Steelhead captured at the fishwheels beginning 1 July are considered summer-run fish (NFA 2000). Ksi Sii Aks (Tseax River) is the boundary between summer-run steelhead where summer-run fish spawn in and upstream of Ksi Sii Aks. Most winter-run steelhead spawn in tributaries downstream of Ksi Sii Aks (e.g., Ksi Hlginx̱ [Ishkeenickh River]). Summer-run steelhead entry into the Nass River peaks in August.

Angling surveys were conducted in BC Fisheries-funded capture-recapture years.

2.4 Biological data

Biological data are collected from a sub-sample of fish captured by the fishwheels for all species (Table 20 for 2019 data). This information includes scale and tissue samples at the GW fishwheels to determine age and stock of origin. Tagged Chinook and Coho salmon, and summer-run steelhead are sexed based on external morphology, have length measured or are classified to size, and have health conditions recorded. A subsample of tagged fish is aged annually. A sample of tagged fish has stock determined using genetic stock identification methods in some years.

Due to such large tag releases each year, only a sub portion of the Sockeye Salmon that are tagged and released have biological data recorded. In 2019, 11% of the Sockeye Salmon that were tagged and released had size recorded, 16% were classified to size-class and sexed, and 14% were aged. Genetic stock identification was performed on 31% of the Chinook Salmon tagged, and most of the Chinook that were aged.

All Chinook and Coho Salmon, and summer-run steelhead marked in 2019 were size classified, sexed, and 14% (Coho Salmon) to 49% (steelhead) were aged.

Biological samples are also collected at the Meziadin Fishway (Table 21 for 2019 data). Fish lengths are collected from a subsample of each daily count; age and sex from tagged and untagged fish and size class is estimated for all fish counted. In 2019, samples collected from counts were 5% (5/110) for Chinook Salmon, 1% (1125/88,128) for Sockeye Salmon, 11% (467/4,334) for Coho Salmon, and 83% for steelhead (5/6). For biological data associated with tag recaps, 100% (5/5) for Chinook Salmon, 93% (1,880/2,021) for Sockeye Salmon were sized and sexed and 6% were aged. About 88% (130/148) of Coho Salmon were sized and sexed and 12% aged.

At the Kwinageese Weir, some lengths are collected when surveys are conducted above the weir, primarily before 2009; but in general, no biological data are collected as fish are not handled at the weir, save for size group assignment based on demarcations in the video box and from opportunistic carcasses washing up on the weir.

Length data and scale samples (for aging) are collected from intact Chinook Salmon carcasses during surveys at Damdochax Creek in most years.

Injury data are collected at the fishwheels and at the Meziadin Fishway. At the fishwheels, fish are only tagged if healthy and are from fishwheel catch with less than 10 hours of holding time. Scale loss, injury marks, and release condition are recorded for tagged fish each year.

2.5 Radio telemetry studies

There have been several studies using radio-tagged fish to estimate fall back, drop out, mortality due to tagging, movement to spawning grounds, and travel time, (Table 22). The values used for initial mortality/fallback proportions since 1994 are found in Table 31.

2.5.1 Chinook Salmon

Koski et al (1996a) and Koski et al (1996b) report on two radio-telemetry studies conducted in 1992 and 1993, respectively.

In 1992, Chinook Salmon, steelhead, and Chum Salmon (*O. keta*) were captured in the lower part of the river between Fishery Bay and Grease Harbour. Radio tagging was attempted for all healthy fish ≥ 720 mm NFL that were captured prior to 8 July; after 8 July, radio tagging was limited to a portion of the large Chinook Salmon caught to ensure that sufficient radio tags were available to mark later run fish. The radio tag was the LOTEK model CFRT-7A digitally coded tag. This tag had a 180-d life and was 16 mm in diameter, 80 mm long and weighed 44 grams in air. A total of 360 fish had radio tags implanted. The secondary mark used was an operculum tag in 1992 and spaghetti tag in 1993 for assessing tag loss. Radio-tagged fish were tracked using a combination of stationary radio tag receivers, foot, boat, and truck-based surveys, aerial surveys, and tag recoveries on the spawning areas after the fish had died.

Similar procedures were used in 1993. Fish were captured and radio-tagged between Old Aiyansh and GW. In 1993, the radio-tagging rate in the second half of the run was about one-half of the first half of the run. A total of 350 tags were applied in 1993. More of the fish were tagged from fishwheels versus tangle netting in 1992.

A summary of the fates of the radio-tagged fish is found in Table 23 and Table 24.

Key considerations and limitations for applying the results of these radio-tagging experiment are:

- Only larger Chinook Salmon (≥ 720 mm) were tagged so a lower proportion of four-year-olds were tagged;
- Tagging was not proportional to abundance over the course of the run;
- The fish entering several of the tributaries on the lower Nass River would not have been radio-tagged or they would have been tagged at a rate that was lower than their contributions to the Nass River escapement, because they were below the tagging sites;
- Difference in the results between using operculum and spaghetti tags, and fish captured by gillnet versus fishwheels. Fish tagged with spaghetti tags could experience greater tagging-related mortality due to the more invasive nature of the tag. Chinook Salmon captured with gillnets would likely experience greater stress than fish captured with fishwheels and as a result, experience greater handling-induced mortality;
- Some Chinook Salmon were confirmed to have jumped Meziadin falls, thus bypassing the counting chute.

2.5.2 Coho Salmon

Alexander and Bussanich (2006) reported on a radio-tagging study conducted in 2005 and results are also summarized in NFWD (2006).

In 2005, Coho Salmon were captured and tagged in two fishwheels operated in the middle Nass River near Gitwinksihlkw from June through September. Fish were selected after being captured by the fishwheels and implanted with a LOTEK model MCFT-3A digitally coded tag. This tag had a 335-d life, powered by 3 V batteries, was 16 mm in diameter, 46 mm long, and weighed 16 grams in air and 7 g in water. Antenna length was 460 mm. A total of 249 fish (≥ 450 mm) had radio tags implanted along with a spaghetti tag.

Radio-tagged fish were tracked using a combination of stationary radio tag receivers (n = 17; Figure 5); foot, boat and truck-based surveys; aerial surveys; and tag recoveries on the spawning areas after the fish had died. A summary of the fates of the radio-tagged fish is found in Table 25.

This was the first study to document the distribution of Coho Salmon through the Nass watershed. Key results and considerations for applying this radio-tagging experiment are:

- Five radio tags were found in small unnamed streams between Meziadin and Bell-Irving rivers;
- Many tags were tracked to streams between GW and GH (e.g., Chemainuk Creek) and below the GW tagging site. Because Coho Salmon are only tagged at

GW, escapement between GW and GH is accounted for in the estimation process.
- The study found passage into the Meziadin River after operations at the fishway had ceased.
- The study also allowed for testing of size selectivity and fate determinations based on holding time after the radio tags were applied and density in the holding tank.

2.5.3 Sockeye Salmon

Radio telemetry studies of Sockeye Salmon were conducted in 1995 (Link and Gurak 1997) and 2018 (Alexander et al. 2022).

In 1995, Sockeye Salmon were captured and tagged at the GW fishwheels from June through August. Fish were selected after being captured by a fishwheel and were implanted with a LOTEK model MCFT-3B digitally coded tag. The LOTEK tag had a 260-d life, powered by 3 V batteries, was 14.5 mm in diameter, 43 mm long, and weighed 4.2 g in water. A total of 118 fish (≥ 450 mm) had radio tags implanted along with spaghetti tags applied as a secondary mark.

The 2018 study used a Sigma Eight Inc. coded tags with a motion sensor (model TX-PSC-I-1200-M) to detect stationary tags. The Sigma Eight tag had programmed life capability (mean 437 d; range: 240–730 d), was 16 mm in diameter, 42 mm long, and estimated weight in water of approximately 5 g. The tagging procedures were similar to the 1995 study, with 791 fish tagged from 1 June to 15 September 2018. Of the 791 radio-tagged fish, 243 radio tags were reapplied from radio tags recovered in Nisg̱a'a gillnet fisheries, surveys at Gingit Creek, and from the Meziadin Fishway.

Radio-tagged fish were tracked using a combination of stationary radio tag receivers (n = 16); foot, boat, and truck-based surveys; aerial surveys; and tag recoveries on the spawning areas after the fish had died. The summary of the fates of the radio-tagged fish is found in Table 26 and Table 27.

The key findings of these studies, and considerations in applying the results of these radio-tagging experiments are:

- Radio-tagged Sockeye Salmon continued to enter Meziadin River after operations in 2018; 2% of tags released (n = 6) passed after operations from October 6 to 31;
- Failed transmitter rates are usually 1-3% of all radio tags released;
- Straying of fish from other rivers was noted; and
- 25% of fish that were radio-tagged in 2018, and nearly one-third of radio-tagged fish that were genotyped to Meziadin did not make it to their final destination and were last tracked in the Nass mainstem under the lowest water levels experienced since the fishwheels started operations in 1992 (Alexander et al. 2022).

2.5.4 Steelhead

Two radio tagging studies were conducted for summer-run steelhead on the Nass River. Both studies are described and summarized in Alexander et al. (2015).

In 1993 (Alexander and Koski 1995), radio transmitters were applied to 66 steelhead (≥ 500 mm NFL) caught from fishwheels and some net captures. The transmitter types were LOTEK models, CFRT-3A, CFRT-3B and CFRT-7A digitally coded tags. The CFRT-3A tag had an extremely long-life expectancy and was relatively small in dimension and weight (i.e., 750-d battery life, measured 16.2 mm in diameter and 49.5 mm in length, and weighed 16 g in air). The CFRT-3B tags had a shorter life expectancy but were slightly smaller in dimension and weight (i.e., 260-d life, measured 14.5 X 43.0 mm, and weighed 10.7 g in air). The CFRT-7A tag had a moderate life expectancy and was much larger than the CFRT-3A or CFRT-3B tags (i.e., 310-d life, measured 16.2 X 83.0 mm, and weighed 29 g in air and 12.8 g in water). The CFRT-3A or CFRT-3B tags were used to tag all steelhead longer than 50 cm NFL and had similar detection ranges. The CFRT-7A tag had a much greater detection range but could only be applied in steelhead longer than 72 cm NFL.

In 2005 (NFWD 2005; Alexander et al. 2015), similar procedures were followed for attaching radio tags by gastric insertion as was done for radio-tagged Coho Salmon. Steelhead were captured in the fishwheels from June to mid-September and radio transmitters were applied to summer-run steelhead to assess stock composition, distribution, and run-timing. A total of 106 fish above 450 mm NFL were radio-tagged along with an anchor tag applied as a secondary mark.

Radio-tagged fish were tracked using a combination of stationary radio tag receivers; foot, boat, and truck-based surveys; aerial surveys; and tag recoveries on the spawning areas after the fish had died. The summary of the fates of the radio-tagged fish is found in Table 29 and Table 30.

A similar study on the Skeena River was conducted in 1995 (Alexander et al. 1996) where 131 steelhead were radio-tagged (Table 28). Similar handling of fish occurred, but the study operated in higher water temperatures than on the Nass system so some caution may be in order in comparing results with the above studies.

The key considerations in apply the results of these radio-tagging experiment are:

- The time in the holding pen (> 10 hours) and additional handling at release (some fish where transported to calmer areas) contributed to drop back results.
- Not transporting to calmer waters resulted in improved rates of upstream migration.

2.6 Genetic information

In the current methodology, a sample of the Sockeye and Chinook salmon captured at the GW fishwheels are selected for genetic stock identification (GSI) and sampled by tissue punch or scales (Alexander et al. 2023; Beveridge et al. 2020). Scale samples from Coho Salmon are archived at the Pacific Biological Station (PBS; Nanaimo, BC) for future GSI if needed. No genetic stock identification is currently used for steelhead samples. Baseline information has been collected over the years for all species.

Genetic stock identification is also done in the marine fishery for both Sockeye (Area 3 specifically and other fisheries in both BC and Alaska) and Chinook salmon (but only from outside Troll fishery). However, marine harvest GSI data, which are used for run-reconstructions to estimate harvest rates and run size for Nass and other modelled

Sockeye Salmon stocks, are not useful for estimating the run size of Nass Sockeye Salmon at GW or GH.

2.6.1 Chinook Salmon

In previous years, GSI was based on amplification of microsatellite loci (Beacham et al. 2006). Starting in 2019, a new SNP baseline using 321 SNPs (single nucleotide polymorphisms) were used to determine GSI based on 1,145 individuals from 13 Nass Area populations (Beacham et al. 2018). The primary advantage of using SNPs is an increase in stock resolution for individual fish (note that currently there is no SNP baseline collection for Teigen Creek, a Bell-Irving stock). Sex identification was based on amplification of GH-Y, a growth hormone pseudogene linked to the sex determination locus on the Y-chromosome of several species of *Oncorhynchus* (Philips et al. 2005). Successful amplification of this sequence was considered to indicate a male Chinook Salmon. In years without genetic analyses, a logistic regression of sex vs NFL, snout length, adipose fin length, and adipose fin height was used to assign sex to large, tagged fish. Medium tagged fish were assumed to be male, unless confirmed by genetics, based on past genetic results that found that most (mean = 94%) medium fish were male.

Scales for age determination were collected at GW fishwheels from all marked Chinook Salmon and for bio-sampled jacks. From 2011 to 2019, 927 to 1,890 Chinook Salmon scales were collected at the GH fishwheels each season. Prior to 2011, GH scale collection was limited to a few years and typically <100 samples. Scale samples from Chinook Salmon captured at both locations were sent for aging to the DFO Sclerochronology Laboratory at PBS and included a portion of the marked fish. Following aging, select scale samples were transferred to the Molecular Genetics Laboratory (MGL) at PBS for genetic sex and stock identification (n = 500 in 2019). The SNP analysis was done on 448 samples (52 samples were not analyzed due to either too few loci [n = 51] or incorrect species [n = 1]).

Post-season, genetic stock identification (GSI) samples were selected on a weekly (statistical week) basis, with the number of samples determined by the weekly proportion of the run passing the GW fishwheels. Further, the number of weekly samples was stratified into medium and large fish, based on their weekly proportions. For each statistical week, the number of eligible fish (i.e., tagged, measured, scales collected, successfully aged) was determined and the required number of tags in each size-class were randomly selected.

Estimated stock proportions for years where GSI data are available are provided in Table 13. While there is greater uncertainty associated with Chinook sub-stock proportions, they provide useful trend data on the distribution of stocks within the upper Nass conservation unit. For all years, the Cranberry-Kiteen reporting group accounted for the highest proportion of sampled Chinook, with an average proportion of 35% across years. Damdochax, Kwinageese, and the Bell-Irving groups account for the next highest proportion, with a combined average proportion of 38% across all years. Minor populations include Meziadin, Seaskinnish, Tseax, and other Lower Nass stocks which on average account for 7% or less of GSI samples across years.

2.6.2 Coho Salmon

Scale samples from 552 Coho Salmon were collected at GW and aged by the DFO Sclerochronology Laboratory in 2019. At the time of writing, the genetic baseline for North Coast Coho Salmon, including Nass Coho Salmon, is under development, and GSI is not conducted on collected scale samples from Nass Coho Salmon. However, these samples are archived at PBS and may be used for GSI in the future, when the baseline is complete.

2.6.3 Sockeye Salmon

A genetic baseline that includes over 200 coast-wide stocks has been delineated using amplification of microsatellite loci (Beacham et al. 2006). Nass River Sockeye Salmon include 12 distinct stocks. Meziadin stocks account for 70-80% of the aggregate Nass sockeye return. Beveridge et al. (2017) presents a review of the stock delineation status for Sockeye Salmon with updated information presented in Alexander et al. (2022). The most recent genetic distance chart is shown in Figure 7. Genetic stock composition estimates for Nass Sockeye Salmon for years that GSI data are available are provided in Table 18.

Scales for Sockeye Salmon age determination are only collected at the GW fishwheels and in 2019, samples were collected from 1,753 tagged and untagged fish. Further, adipose fin tissue samples for GSI analysis were collected from 968 tagged and untagged Sockeye Salmon in 2019. Scale samples from all sampled Sockeye Salmon were sent to the Alaska Department of Fish and Game for aging. Following aging, scales were sent to PBS for archiving and select samples were transferred to the Molecular Genetics Laboratory (MGL) for genetic stock identification (n = 500 in 2019).

The number of weekly (statistical week) Sockeye Salmon samples selected for GSI is based on the weekly proportion of the Sockeye Salmon run passing the GW fishwheels each statistical week. Eligible fish (i.e., tagged, scales and/or adipose fin tissue collected) were randomly selected within each week with tissue samples taking precedence due to the delay in scales being shipped from Alaska. For any week with insufficient tissue samples, scale samples were randomly selected to achieve the weekly total.

2.6.4 Steelhead

Mixed stock samples for summer-run steelhead were collected in 2005, 2007, 2009, and 2010 (Table 19) from fish captured at fishwheels and during BC Fisheries studies. Six populations were delineated using amplification of microsatellite loci (Beacham et al. 2006) from 934 fish. Of note is that Ksi Sg̲asginist (Seaskinnish Creek) has not been included as a baseline genetic stock presumably because of too few genetic samples collected to date.

Scales for age determination were collected at GW fishwheels from 290 summer-run steelhead in 2019. Scale samples from marked fish were sent for aging to Birkenhead Scale Analysis (Lone Butte, BC).

Stock composition was estimated for seven years between 1998 and 2010 (Table 19). No stock composition analyses have been done since 2010, but scales have been collected each year from GW fishwheels, aged, and archived. The Nass habitat capacity model (Bocking et al. 2005) also provides estimates of productivity through the Nass system and Table 19 includes an approximate distribution by river-system based on relative amounts of habitat.

3. Examining assumptions necessary for capture-recapture methods

Uncertainty and bias in capture-recapture abundance estimation can be introduced by a number of factors. Below we describe the major assumptions for Nass assessment programs affecting the salmon species considered here, for which adjustments (described in Section 4) are made.

3.1 Tagging and inspection periods vs run period

The proportion of fish tagged will vary with the abundance of fish passing the tagging locations throughout the return, and a key assumption for capture recapture estimation programs is that tagging and recapture or resight programs cover the entirety of the run. The fishwheels are in operation for the majority of Chinook and Sockeye salmon runs, but not for Coho Salmon nor for summer-run steelhead. While we assume that the fishwheels program covers the entirety of the Chinook return, we note that Chinook are captured in downstream fisheries prior to their operation. While Sockeye Salmon are also still moving in after fishwheel operations end in mid-September, the number of fish passing the tagging locations after tagging has been completed is considered to be small.

The inspection periods upriver of GH cover the majority of the entire run for all species examined. The 2018 Sockeye Salmon telemetry study estimated 2% of Sockeye Salmon in the mainstem entered after Meziadin Fishway operations ended in the first week of October (Alexander et al. 2022). Water levels are thought to be important in determining how fast fish move to their spawning areas. In particular, very low waters occurred in 2018 that likely affected fish moving into spawning areas (Alexander et al. 2022).

Failure to tag over the entire run or to inspect the entire run can lead to positive, negative, or no bias depending on the interplay between the extent of coverage in the tagging and inspection periods and the subsequent mixing of tagged and untagged fish.

3.2 Fall-back, dropout, and initial tagging mortality

Some fish may 1) truncate their return and never resume their spawning migration (dropout), 2) fall back and try spawning elsewhere either in the Nass or another river system (fall back), or 3) die from the handling at the fishwheel (initial handling mortality). All of these causes are confounded, and typically lead to a positive bias in abundance estimates because the number of tags thought available for recapture also includes tags not available due to these factors.

A reduction in the number of tagged fish available for recapture for all of these events is made using a fixed proportion for fallback/dropout/initial tagging mortality based on radio-telemetry studies and tag type. A summary of the estimated fall back/dropout/initial tagging mortality probabilities is found in Table 31.

These probabilities are assumed to be equal for all fish regardless of sex, length, when tagged, etc., although only fish with no visible signs of injuries or health conditions are tagged, and the majority of tagged fish have been held less than 10 hours in live tanks.

The radio telemetry studies described in Section 2.5 are the primary source of information about the probabilities of fall-back, dropout, and initial tagging mortality for each species, which are described in more detail below.

3.2.1 Chinook Salmon

Koski et al. (1996a, 1996b) conducted two years of radio-telemetry tagging as described earlier. The fates of the radio tags are presented in Table 23 and Table 24. For the 1992 radio tag study, 10 radio-tags were detected as failed in transmitting (recovered and not working). Typically, 1-3% transmitter failure results have occurred in telemetry studies and therefore any Nass telemetry studies where a radio tag was not tracked at least once after operation was considered non-operational and assumed not part of the active radio-tags available for recovery.

From Table 22(a), the estimated mortality immediately following tagging is found as follows: excluding failed transmitters that were never tracked once (n = 10 in 1992; n = 9 in 1993) and fish with no final destination but considered alive (i.e., still migrating; n = 5 in 1992; n = 0 in 1993), the proportion of radio-tags lost at the tagging site are 1+11+5+5 = 22/(360-10) = 0.063 in 1992 and 1+6+3 = 10/(350-9) = 0.029 in 1993. These are considered to be losses of tagged fish due to fall-back, drop-out, and initial mortality. The fish were not tracked to a destination in the Nass were not censored from the study.

A value of 5% has been used since 1994 to adjust downwards the number of operculum tags applied at the fishwheels for Chinook Salmon, assuming that radio tagging results would have slightly higher associated handling losses due to procedures in 1992 (included applying a spaghetti tag). Non radio-tagged fish are typically handled half the time as radio-tagged fish and would be thought to have lower handling or other stress-related losses. The average handling loss over both years from radio-tags was 4.6% but the studies used two different tag types with spaghetti tags (1992) being considered more invasive and associated with higher handling mortality.

3.2.2 Coho Salmon

A 2005 study (Alexander and Bussanich 2006; NFWD 2005) is summarized in Table 25. Using the values in Table 22(b), of 249 radio tags applied with a spaghetti tag, 2+7+18 = 27/249 = 0.108 of radio-tagged fish appear to be lost to fall back/dropout/initial mortality as reported in NFWD 2005. There were an additional five tags (2.0% of tags released) that were tracked at the entry station (downstream of GW) which were considered strays from other systems including lower or coastal Nass streams.

The adjustment factor for fall back/dropout/initial mortality for spaghetti-tagged Coho Salmon was 10% from 1994 to 2008 based on Sockeye Salmon (and confirmed in the 2005 Coho Salmon radio telemetry study), 5% for 2009-2010 with the use of an operculum tag (and assumed loss from Chinook Salmon operculum tag use with less invasive tag and less handling time); and 6% since 2011 to account for use of anchor tag (based on a steelhead radiotelemetry study) from changes in the tag used and position where the fish was tagged.

3.2.3 Sockeye Salmon

Radiotelemetry studies were conducted in 1995 (Link and Gurak 1997) and 2018 (Alexander et al. 2022) and are summarized in Table 26 and Table 27.

In the 1995 study, 10% (11/118) of radio-tagged Sockeye Salmon suffered initial tagging loss plus an additional 4% (4/118) left the system. Three radio-tags were not tracked at all and are thought to have failed. Transmitters also failed after being released and tracked for a period of time (11/115 = 9.6%). The fish that were tracked leaving the system were not considered tag specific losses but were instead representative of a group of fish, including untagged fish, that entered the Nass and may have spawned below the first telemetry station. In 1995, this represented 3.4% (n = 4) of the net tags released.

Estimates of initial mortality were computed from the summary in Table 22 and Table 27. In the 2018 study, 12% (94/764) of radio-tagged Sockeye Salmon suffered tagging related losses, plus an additional 4% (28/764) of radio-tagged Sockeye Salmon left the system. A total of 17 fish with radio-tags were never tracked once and were considered transmitter failures given the total number of mobile tracking and fixed monitoring stations from June to October 2018. These transmitters also required specific activation by applicator. Reapplication of tags may also have been a factor in the tags never tracked as some antennas were frayed.

There is no evidence that this probability changed between the two studies ($p = 0.48$), and so a pooled estimate of the probability of tagging related losses would be 0.117 (SE 0.011). Estimates from 2000 to 2017 use 10% based on 1995 tag loss proportions for adjustments and 2018 and 2019 used 12%. If tags tracked as leaving the system were included, the proportion of tags initially lost between the two studies changes from 13% to 16%.

3.2.4 Summer-run steelhead

Summer-run steelhead radio telemetry studies were conducted in the Nass River in 1993 and 2005 and are summarized in Table 29 and Table 30.

In the 1993 study, spaghetti tags were used as secondary marks (Table 22). Three radio-tags were either regurgitated or the fish died near the tag sites (5.3%), and nine radio-tags were tracked downstream of GW and may not have spawned, for a total tag loss of between 0.053 and 0.190. In the 2005 study, anchor tags were used as secondary marks. Six of 106 (0.057) radio-tagged fish were estimated as mortalities near the tagging site and 11 fish were tracked below the fishwheels for a total initial tagging/handling induced mortality between 0.057 and 0.160.

The adjustment factor for fall back/dropout/initial mortality for tagged steelhead from these studies is 6% when using anchor tags and 5% when fin marking occurred. These studies estimated lower handling losses than a radio-tagging study in the Skeena River in 1995 (Alexander et al. 1996) that found 25/143 = 0.17 of radio-tagged steelhead appeared to die or fall back after tagging from fishwheels. The Skeena River handling estimate is anticipated to be much higher than in the Nass River based on higher water temperatures (12.5–15.5°C vs. 9.1–10.0°C in Nass 2005 study) that were experienced on the Skeena River during migration as well as higher holding times (>10 hours) in the live pens.

Different tag types (i.e., operculum, spaghetti, and anchor) have resulted in the use of different rates for initial handling mortality loss based on radio tagging studies. Dropout from straying has not been included as tag losses as considered representing a group of fish including untagged fish versus specific individual tagged fish that may include fish caught in fisheries or spawned below the fishwheel tagging sites.

3.3 Non-reporting of tags

Non-reporting of tags found in the inspection sample can lead to a positive bias in the estimates of abundance.

The harvest and number of tags recaptured in the Nisg̱a'a, sport, and commercial harvest are not used directly in capture-recapture analysis because of non-reporting of tags. Rather, an estimate is made of the tags removed by these harvests.

Briefly, tag returns are encouraged each year through a posted tag-lottery draw in the four Nisg̱a'a communities, at sport fishery sites including at Meziadin Lake, and on DFO's website. As well, information on tags returned in the Individual Sale fishery is used to adjust tags returned in the Nisg̱a'a domestic gillnet harvest.

Non-reporting of tags in the sport fishery is currently not estimated except in some cases where returns have been used to estimate overall catch in an area. Few tags are typically returned each year for each species. The number of fish removed overall by the sport fishery is currently small in recent years, but they are concentrated in a few select tributaries.

3.4 Tag loss

A key assumption for a capture-recapture estimate is that there is no tag loss. Tag loss leads to positive biases in capture-recapture estimates of abundance.

Tag-retention can be estimated if fish are double tagged. In NFWD studies, tagged fish are also given a batch mark – typically an adipose punch or fin clip. It is assumed that the batch-mark cannot be lost (e.g., regrowth or complete loss of adipose fin due to an injury to the fish). Fish are examined for primary tags at the Meziadin Fishway, Kwinageese Weir, and in some spawning ground surveys. The hole punch or clip can be clearly seen during random fish inspections at Meziadin Fishway for estimating primary tag loss.

Video camera resolution is excellent at the Kwinageese Weir. The colour of tags cannot always be determined, but tag type and adipose mark are seen well for Chinook Salmon and summer-run steelhead. Spaghetti- and anchor-tags are highly visible for Sockeye and Coho Salmon but adipose fin marks are harder to observe for these species.

Stream walks (e.g., carcass surveys) are useful for counting fish. While carcass surveys are used as a primary mark recovery method for Chinook, obtaining accurate enumeration of live tags is challenging due to cryptic tags that are not easily seen in the field. Estimates of tag loss for all species are not possible for live fish observed during stream walks. In addition, the breakout of medium and large fish cannot be determined reliably in visual ground counts.

3.4.1 Chinook Salmon

All Chinook Salmon are tagged with an aluminum tag through the left operculum and a batch fin-clip that differs if the fish is tagged at the first (GW) or second (GH) set of fishwheel locations. Fish are carefully inspected upriver, and only those fish which are fully inspected for an operculum mark (either the tag or a clearly visible hole) and a fin-clip are used in estimation procedures, so the issue of tag loss is irrelevant for estimation procedures (assuming that the batch clip cannot be "lost"). An exception is for in-stream examinations at Damdochax Creek, where in many cases only the head is examined, and a fish with an intact head and no evidence of an operculum tag hole would be considered unmarked.

Estimates of tag loss for Chinook Salmon are presented in Table 32. Estimated tag loss is generally low at Meziadin Fishway with high uncertainty due to small sample. Observation of operculum tags missing at Kwinageese Weir are higher than at Meziadin Fishway that is likely caused from longer migration distance and passing over terrain that could dislodge the operculum tag. However, operculum tag losses are not used in the capture-recapture method as only confirmed marks detected from adipose fin and/or operculum marks being present are used for tag recoveries when estimating population estimates.

3.4.2 Coho Salmon

Since 2011, all Coho Salmon are tagged with anchor tags and batch marked with an adipose fin punch. In earlier years, spaghetti tags were used and in two years, operculum tags were used (Table 15). A sub-sample of fish that pass the Meziadin Fishway without tags are carefully examined for missing tags (Table 33). For example, in 2019, over 4,334 Coho Salmon were counted at the Meziadin Fishway of which 148 were observed to have tags. A subsample of 419 fish without tags was selected. One fish was found to have lost its tag because it had an adipose punch and evidence of a dorsal hole where the anchor tag was placed. A simple moment-estimator for the number of fish with lost tags in the entire sample is found as (4334-148) x 1 / (420-1) = 10. The estimated tag loss proportion is then 10/(10 + 148) = 6.3%.

If no tag loss is observed in the subsample (e.g., 2017, 2018, or 2020), then the mean tag loss of previous years is used. In many cases, the number of fish with lost tags in the subsample is very small (Table 33) implying that the estimates of tag loss have very poor precision. A Bayesian hierarchical model could handle years of zero counts in a much more direct fashion.

Additional information on tag loss has been collected at the Kwinageese Weir since 2009 (Table 33) but data are not used in capture-recapture estimates as fish are not handled to confirm adipose marking status like they are at the Meziadin Fishway. The tag loss proportion appears to be higher at the Kwinageese Weir than at the Meziadin Fishway with distance travelled and passing terrain that could dislodge the primary mark. However, to confirm actual tag loss of the anchor tag would require a sub sample of untagged Coho Salmon to be physically examined to confirm adipose marking status.

Additional studies have been done on tag loss using operculum tags in earlier years for review of using this type of tag application. Mark rates decreased with distance from GW and could be interpreted as increasing primary mark loss over distance. However, operculum tag loss rates cannot be assumed to parallel spaghetti tag loss rates. The Ketchum # 1 crimp lock operculum tags used for Coho Salmon in 2008 locked poorly (Alexander et al. 2009), and a similar problem was observed for the small National Brand tags used on Coho Salmon less than 500 mm NFL in 2010. Coho Salmon with obviously loose tags due to operculum damage were observed at both the Ksi Sg̲asginist (Seaskinnish Creek) weir and the Meziadin Fishway in 2010. High operculum tag loss rates are typically not observed for Nass River Chinook Salmon marked with operculum tags at the Gitwinksihlkw fishwheels (e.g., 13% at Meziadin Fishway and 7% at Kwinageese Weir in 2009; Alexander et al. 2010). The higher operculum tag loss rates observed for Coho Salmon relative to Chinook Salmon may be related to the less robust nature of the operculum of Coho Salmon (i.e., thin and light) and possible behavioural differences. High operculum tag loss combined with limited visibility from an overhead viewpoint (i.e., Meziadin Fishway) was one of the reasons to discontinue the use of operculum tags for Coho Salmon. For current mark-recapture estimates, estimates of primary tag loss is based on untagged salmon being sampled and physically examined for loss of the primary mark at Meziadin Fishway for Chinook, Sockeye, and Coho salmon.

3.4.3 Sockeye Salmon

All Sockeye Salmon are tagged with a spaghetti tag and are batch marked with an adipose fin hole punch. A sub-sample of fish that pass the Meziadin Fishway without tags are carefully examined for missing tags (Table 34). In 2019, over 88,128 Sockeye Salmon were counted at the Meziadin Fishway of which 2,021 were observed to have tags. A subsample of 1,708 fish without a tag was selected and two fish were found to have lost their tag because they had an adipose punch and evidence of a dorsal hole where the spaghetti tag was placed. A simple moment-estimator for the number of lost tags in the entire sample is found as (88,128-2,021) x 2 / (1,708-2) = 101. The estimated tag loss proportion is then 101/(101+2,021) = 4.7%.

As with Coho Salmon, if the number of fish observed with lost tags is 0, a mean tag loss value based on previous years will be needed as there were no years where there were no Sockeye Salmon observed with lost tags. In many cases, the number of lost tags in the subsample is very small (Table 34) implying that the estimates of tag loss have very poor precision.

Additional information on spaghetti-tag loss is also available from Kwinageese Weir but these tag losses are not used in the capture-recapture estimates. The estimated tag loss at Kwinageese Weir appears to be generally lower than the estimated tag loss at Meziadin Fishway, but fish are not handled to confirm tag status and adipose fins are difficult to see in the video counts. Currently, tag loss of the primary spaghetti tag is estimated from the Meziadin Fishway sampling.

3.4.4 Summer-run steelhead

Tag loss cannot occur because currently all steelhead are batched marked with an adipose fin punch/clip since 2014. Information on tag loss for years where tags are applied is shown in Table 35 and is of historical interest only. Estimated tag loss proportions are generally low, but sample sizes are small and so the uncertainty in these estimates is large.

3.5 Immigration

A key assumption of the capture-recapture estimators is that fish are not entering or exiting the system between tagging and recovery sites. Immigration leads to a positive bias in the estimate of fish passing the fishwheels. There are no other sources of fish from other entrances to the Nass River above Grease Harbour, so immigration is assumed to be zero.

3.6 Emigration

Emigration (like mortality) that does not depend on the tagging status of the fish does not result in biases to the estimates of abundance at the location of tagging. However, if emigration is different for tagged vs non-tagged fish, estimates of abundance can exhibit bias.

Not all spawning grounds are measured for escapement. This is not an issue assuming that tagging at the fishwheels is proportional to the run over time. Escapement will “look like” mortality so that capture-recapture estimates will refer back to the run size passing GH. Potential spawning occurring in systems below the fishwheels include Chinook Salmon at Ksi Hlginx̱ (Ishkeenickh River), Sockeye Salmon at Ksi Ts’oohl Ts’ap (Zolzap Creek), Coho Salmon at Ksi Ts’oohl Ts’ap (Zolzap Creek), Anudol Creek and in lower Nass mainstem areas based on radio telemetry studies.

3.7 Enroute mortality

An important assumption of the current program which warrants further study is that natural enroute mortality affects tagged and untagged fish equally. Mortality that does not depend on the tagging status of the fish, does not result in biases to the estimates of abundance at the location of tagging.

While it is assumed that enroute natural mortality is the same for tagged/untagged fish if fish have moved upstream of the tagging fishwheels, it is not known how the handling-related physiological stress or injuries for tagged fish in the Nass may interact with higher water temperatures or abnormally high or low flows to increase fish mortality and enroute losses due to disease or exhaustion as has been observed in other systems (Teffer et al. 2017). (Teffer et al. 2017). Based on reports from the fishwheels, there appear to be low injury incidences for most years with gillnet, lamprey, and sea lice injuries noted. Water temperatures are fairly cool compared to other systems which helps in the handling of fish. Most injuries reported at Meziadin Fishway are head wounds from jumping the falls and predatory wounds.

3.8 Heterogeneity in probability of capture

There are many types of heterogeneity in the probability of capture which can lead to different types of bias:

- Pure heterogeneity occurs when fish consistently differ in catchability at both tagging and recapture locations. For example, larger fish could be more catchable at both locations. This will lead to a negative bias in estimates of abundance.
- Varying heterogeneity occurs when, for example, certain fish are more catchable at the tagging location and less catchable at the recapture locations (trap shyness; positive bias), or vice versa (trap happiness, negative bias).

Seber (1982) shows that bias in estimates of abundance is related to the negative of the correlation in catchability between the tagging and recapture locations across fish (See Section 4.3.1.2). A positive correlation (pure heterogeneity, trap happiness) leads to negative bias in estimates of abundance; a negative correlation leads to positive bias. Note that a correlation of 0 leads to no bias, and a correlation of 0 can occur in many ways such as a constant probability of capture at either location; complete mixing; etc.

3.8.1 Testing for simple heterogeneity

Stratification is a common method for reducing the bias caused by heterogeneity. There are two common statistical tests to determine if stratification may be needed.

In the first test, a 2 x *k* contingency table is created to examine if the recapture proportions are equal across release strata. The release strata could be biological (e.g., sex, length classes) or spatial (the two fishwheel locations), or temporal (early vs late releases).

	Rel stratum 1	Rel stratum 2	…	Rel stratum *k*
Recovered	$n_{r,1}$	$n_{r,2}$		$n_{r,k}$
Not recovered	$n_{n,1}$	$n_{n,2}$		$n_{n,k}$

A Pearson chi-square test (or Fisher Exact test if sample sizes are small) is used. An example of this analysis is found in Table 36. The raw number of tags released is used without adjustments for initial tagging mortality, tag loss, or removals in the Nisga'a domestic harvest. Presumably, the initial tagging mortality is the same for both size classes (medium and large) and because Chinook Salmon are fully inspected upriver, tag loss is not an issue; no adjustment has been made for the Nisga'a harvest (see Table 38 and Table 39). Failure of these implicit assumptions could lead to evidence of heterogeneity that is an artefact. Because the number of tags removed due to these causes are only estimates, it is not advisable to use the adjusted number of tags because this would not account for uncertainty in the number of tags removed.

In the second test, a 2 x *k* contingency table is created to examine if the marked proportions (marked fractions) are equal across the recapture strata:

	Rec stratum 1	Rec stratum 2	…	Rec stratum *k*

Marked	$n_{m,1}$	$n_{m,2}$		$n_{m,k}$
Not marked	$n_{n,1}$	$n_{n,2}$		$n_{n,k}$

Again, a Pearson chi-square test (or Fisher Exact test if sample sizes are small) is used. An example of this comparison is found in Table 37. This test implicitly assumes that initial tagging mortality, tag-loss, and the selectivity in the Nisga'a harvest is the same for all size categories. Tag-loss is not an issue for Chinook Salmon comparisons because all fish are fully inspected. Difference in the marked fraction could be a byproduct of differential initial tagging mortality or differential selectivity in the Nisga'a harvest.

Note that rejection of the null hypothesis in either test is only suggestive that stratification is needed because equal tagging or equal recapture probabilities are sufficient to ensure that estimates remain unbiased because this leads to a correlation of 0 between the capture and recapture probabilities. Similarly, failure to reject the null hypothesis does not imply that stratification is not needed because small sample sizes may provide tests with little power. It appears that a common practice in the Nass system is to use a stratified estimator only if BOTH hypothesis tests show evidence of heterogeneity. This rule has been used since the mid-1990s when Chinook stratification was reviewed following Bernard and Hansen (1992). For example, a previous Sockeye and Coho salmon report found, "A significant difference between size stratified (232,877) and pooled (242,213) population estimates to GH fishwheels in 2018 was observed based on the above two conditions being significant. Size stratified estimate was chosen." Abundance for Chinook Salmon has been estimated using a stratified estimator since 2009 because the larger sizes may have lower mark rates with more large fish able to avoid the fishwheel. In most years, estimates of abundance for Sockeye and Coho salmon have not used a stratified estimator, but in recent years testing of homogeneity has occurred.

If the sample sizes are large, quite small differences in subsequent recovery or in the marked fraction can be detected which would seem to call for stratification, but the impact could be small. Note that the Bayesian fish-stratified models described in Part 2 of this report do not make a binary selection between a pooled or fully stratified estimate, but fit models where the data determine how far apart the marked fraction in the fish-strata are allowed to be.

If individual covariate measurements are available (e.g., fish length), a finer test of heterogeneity can be constructed using a two-sample Kolmogorov–Smirnov (KS) test[10] of equal distribution of the covariates in different tagging locations, different recovery location, release vs. recovery, etc. There is no simple way to estimate the size of the bias that may occur if there is a difference in the distribution of covariate based on the two samples. Results of this test may indicate that a stratified estimator based on 2 or 3 classes may be useful. The current classes were defined by general age delineations by size.

[10] The K-S test comparing size distributions has been done for Chinook Salmon for many years and selected years for Sockeye and Coho salmon using Meziadin Fishway data compared to the tagging data.

Note that the KS-test is most sensitive to differences in the middle of the distribution. A related test, the Anderson-Darling (AD) test is most sensitive to differences in the tails of the distributions. It is not clear which test is preferred in this context. Multi-sample extensions of the AD-test are available, but not for the KS-test.

3.8.1.1 Chinook Salmon

Extensive testing for homogeneity in capture and recapture probabilities has been done for Chinook Salmon (e.g., Table 20 and Appendix E of the 2019 report (Beveridge et al. 2020) using size (medium vs large), sex, ocean age, period of tagging/recapture, where tagged (upper or lower fishwheels), and where recaptured (different tributaries). The 2019 report reviewed bias testing from 2009 to 2019 (Table 20 of Beveridge et al. 2020) when sufficient marks were released and recovered for analyses and determined that potential heterogeneity was detected in about half of the tests but there was no regular pattern.

There appears to be heterogeneity in catchability at GW, particularly in low water conditions where more medium Chinook Salmon would be caught than larger fish and so more age 4 and more males (genetics suggest that 98% of fish less than 755 mm are males) are captured. The analysis at the GH fishwheels shows these fishwheels are less selective than those at GW fishwheels given the fishing area in the canyons.

For example, consider the following data from 2019 for Chinook Salmon, ignoring the issues of tag adjustments.

	GW	GH	Both
(Adjusted) Tags released	566	614	1,200
Total inspected at MF, KW, DC, CR			793
Recaptured	26	59	85
Recapture probability	0.046	0.093	Chi-square p-value 0.002

There is evidence of a differential recapture probability between the two fishwheel locations, which could be attributable in part to escapement between GW and GH and/or underestimation of harvest. Two fishwheel sites are operated at GW and up to four individual sites are operated at GH.

A Petersen estimator using data from each tagging area would expand the total inspected by the recapture probability, i.e., abundance is estimated as 793/0.046 or 793/0.093 assuming that the capture probability for the untagged fish to be 0.045 or 0.093, respectively. However, there is no way to know what the proper expansion factor is. Both estimates will be biased in unknown ways.

However, the number of tags released at the two sites is approximately equal implying that the initial tagging probabilities are roughly equal which is one of the conditions under which the pooled-Petersen (over both tagging areas) will be unbiased, so the pooled-Petersen may be the best estimator.

In cases where the tagging probabilities differ along with the recapture probabilities, then perhaps the cause is related to a factor such as size, i.e., the two sites differentially catch fish of different sizes. In this case, the proper solution is to stratify by size everywhere and use the size-stratified estimators.

Differences in the estimates of abundance between size stratified estimators and unstratified estimators were small for Chinook Salmon (averaging about 2-3%) (Table 40). The size of the bias is comparable to the estimated standard error so stratification may not be needed because the actual uncertainty is certainly larger than the estimated standard error due to other assumption violations and steps taken to estimates tags removed, etc.

3.8.1.2 Sockeye and Coho Salmon

Similar testing for homogeneity in capture and recapture probabilities has been done for Coho and Sockeye salmon based on size (medium vs large) as shown in the NFWD annual reports. For most years, size selectivity has not been detected when the size distribution is compared using the KS-test from Meziadin Fishway recoveries vs. releases. If evidence of a difference in both the recovery probability or the marked fraction is found, then a stratified estimator (by size) is used; otherwise the pooled estimator is used.

Table 40b and Table 40c compare estimates of run-size from a size-stratified estimate and the pooled-Petersen estimate and found difference on the order of 5-10% but there are only a small number of years where stratification has been done for Coho Salmon.

3.8.1.3 Summer-run Steelhead

Similar testing for homogeneity is done for steelhead (Alexander et al. 2015) for size, marine age, sex, capture-period, and recapture location. Any marked fish observed during Kwinageese Weir video counts where tag numbers could not be read were not included in age or sex analyses. There was little evidence of heterogeneity.

Results from BC Fisheries funded capture-recapture studies found that the difference in the estimates of abundance between size-stratified estimators and unstratified estimators (Table 40d) were small for Nass summer-run steelhead (average <1%).

3.8.2 Test for heterogeneity in tag removal probabilities in domestic fishery

A third test is often done to see if there is evidence of heterogeneity in Nisg̲a'a Domestic Fishery removals by size class:

	Removed	Not removed
Size Class 1	$n_{s1,r}$	$n_{s1,nr}$
Size Class 2	$n_{s2,r}$	$n_{s2,nr}$

The utility of this test is primarily to determine if the number of tags removed after release at the fishwheels to account for the Nisg̲a'a Domestic harvest needs to be done for each size class separately. However, the results of this test do not impact bias in the estimates of abundance.

Some care is needed when conducting these tests. For example, Table 38 and Table 39 are examples of such a comparison. If the expanded removals are used (Table 38), then the ordinary chi-square tests and p-values will not be valid because the expanded counts are uncertain, and this uncertainty has not been included in the analysis. A bootstrapping or Bayesian approach may be needed to account for this variability in the expanded removals. If the raw removals are used (Table 39), then no account has been made of the reporting probability for removals, and so any estimate of the recapture probability (and comparison of the recapture probabilities) is confounded with differences in the reporting probability.

4. Detailed review of current estimation procedures

There are several features of the system that preclude a straightforward use of standard capture-recapture methods such as the unstratified/stratified Petersen/Chapman estimators or temporally stratified Darroch/SPAS/BTSPAS estimators. Rather than developing a custom estimator, the current practice is to adjust the number of tagged fish released for various factors that differentially affect tagged fish, and to use these adjusted values in unstratified/stratified Petersen/Chapman estimators.

4.1 Adjusting number of released tags

Not all tagged fish are available for subsequent recapture upstream of GH. As noted in the summary, various adjustment factors are used to adjust the number of tagged fish (from one or both sets of fishwheel sites) to provide an estimate of the number of tagged fish available for recapture just above GH.

4.1.1 Fallback/dropout/initial mortality of tagged fish

Not all tagged fish continue their journey upstream. Some fish may truncate their return and never resume their spawning migration (dropout), fall back and attempt to spawn elsewhere (fall back); are non-Nass spawners (included in fallback), or die from the handling at the fishwheel (initial handling mortality). All of these causes are completely confounded, and a single adjustment is made for all of these events based on past telemetry studies and assumed tag types.

The adjustment factor is typically based on radio tagging studies as noted earlier and summarized in Table 22. The uncertainty of the current abundance estimators does not include contributions from the uncertainty of the initial mortality probability.

4.1.2 Adjustments for tag loss

A key assumption for a capture-recapture estimate is that there is no tag loss. Adjustments for tag loss can be made in two (mathematically equivalent) ways. The number of available tags can be reduced by the estimated tag-retention probability. Or, the number of observed tagged fish recaptured can be inflated by the inverse of the tag-retention probability. For example, let θ represent the tag retention probability. Then the adjusted Petersen estimator can be written as:

$$\widehat{N} = \frac{M\theta C}{R} = \frac{MC}{R/\theta}$$

where M is the (unadjusted) number of tags released; C is the number of fish inspected; and R is the number of tags recovered. Currently, when adjustments for tag loss are made, they are made by reducing the number of tagged fish to account for subsequent tag loss.

Tag-retention can be estimated if fish are double tagged. In these studies, tagged fish are also given a batch mark – typically an adipose punch or fin clip. It is assumed that the batch-mark cannot be lost (e.g., regrowth or complete loss of adipose fin due to an injury to the fish). In the case of steelhead kelts, evidence of adipose mark still exists for fish that entered from previous year (e.g., July-Sep), spawned in April and May, and emigrated late May to June in following year (Richard Alexander, pers. comm.).

The uncertainty of the current abundance estimators does not include contributions from the uncertainty of the tag loss probability.

4.1.2.1 Chinook Salmon

No adjustment for tag loss is made because only fish that can be fully examined for the presence of the batch mark are used in the estimation procedures, i.e., only those fish for which the tag is read (if present) and the status of the left operculum hole and/or fin clips are established are used to account for recoveries of heads only during carcass surveys. The number of Chinook Salmon that are examined is sufficiently small and the fish are large enough that all fish can be examined, and the presence of a batch mark can generally be determined even on a video monitor. Consequently, it is unlikely that a fish that lost its tag would not be recognized as being tagged at the Kwinageese and Meziadin facilities. For carcass surveys, the left operculum is key to identifying mark status as many fish are often missing the caudal area to determine adipose fin mark status.

Consequently, there is no need for an adjustment for tag loss. Unfortunately, this also implies that data from recovery locations where a full inspection for tags and tag loss was not made cannot be used (e.g., from stream walks or aerial surveys using visual live counts). If records are kept at the video monitoring station on tag loss, then it may be possible to incorporate these other sources if no further tag loss is expected (which may be a dubious assumption).

4.1.2.2 Coho and Sockeye Salmon

Tag loss for Coho and Sockeye salmon is estimated in each year based on a sub-sample of fish selected at the Meziadin Fishway that are carefully examined (Table 33; Table 34). If no tag loss is observed in the subsample, the mean of previous years is used.

Estimates of tag loss for anchor tagged Coho Salmon has varied across years ranging from 4% to 16% from 2011 onwards with a few years affected by non-beveled tag used that caught on nets.

Estimates of tag loss for Sockeye Salmon in 1994-1999 were back-computed based on radio-telemetry studies in 1995 and 2018; no estimates of tag loss were made from

2000-2007 and Meziadin sub-sampling started in 2008 to estimate tag loss. Estimates of spaghetti tag loss for Sockeye Salmon have ranged from 4% to 12% from 2012 onwards.

This tag loss is used to adjust the number of tags released and the adjusted number of tags is used in all further abundance estimates. The same tag loss proportion is used for all fish-strata if a stratified estimate is formed. Unfortunately, the data used for tag loss (Table 33; Table 34) is too sparse to allow for an examination if tag loss varies by size category in any one year, but there may be sufficient data with multiple years to see the tag loss varies by size category.

In many systems, the tag loss may increase with the time/distance after tagging, so the tag loss proportion could be larger for recovery locations further upriver from the Meziadin Fishway, especially for spaghetti tags that can be removed by aggressive fish on spawning grounds or during migration. Duguid et al (2011) reported on a three-year study to examine tag loss for Coho Salmon at three sites (Ksi Sgasginist [Seaskinnish Creek], Meziadin Fishway, and Kwinageese Weir). They found no evidence of a difference in the mark rate at the three sites but found that the loss of the primary (operculum tag) mark in 2010 increased with distance from the Gitwinksihlkw fishwheels with 15% (14/87) operculum tag loss at Ksi Sgasginist (Seaskinnish Creek) weir, 28% (45/163) at Meziadin Fishway, and 50% (4/8) at Kwinageese Weir.

Currently, the Coho Salmon estimate of abundance is based on recoveries from both the Meziadin Fishway and Kwinageese Weir using anchor tags. Table 33 shows that anchor tag loss at the Kwinageese Weir may be substantially larger than at the Meziadin Fishway, so that the adjustment for tag loss using only Meziadin Fishway data may be inadequate. About half of the recaptures of Coho Salmon come from the Kwinageese Weir and so if the tag loss is underestimated, this could introduce a positive bias because the number of tagged fish at the weir will be undercounted. However, Coho Salmon are not handled at Kwinageese Weir to confirm loss of the primary mark and likely the tag loss observations from the Kwinageese video counts are underestimated as adipose fins are difficult to observe from the video imagery.

Only fish collected at the Meziadin Fishway were used for our review of Sockeye Salmon abundance estimates using spaghetti tags from 1994 to 2019 as Kwinageese Weir operations started much later, after 2009, in the time series of capture-recovery data. However, like Coho Salmon, estimates of loss of the primary mark for Sockeye Salmon passing the Kwinageese Weir would not be reliably confirmed as fish are not handled and adiposes are too small to estimate total losses from the video imagery.

A Bayesian hierarchical model could be of use in this situation of estimating the loss of primary marks, particularly when the data are so sparse (in some years no fish are observed without tags in the sub-sample) and data from prior years could inform the missing value for the year where the tag loss cannot be estimated directly. The relationship between the tag loss proportions for the two species may also be informative when one species' tag loss cannot be estimated, however this would assume that tag loss for different species covaries in a given year, which has not been tested.

4.1.2.3 Summer-run Steelhead

Currently (since 2015), summer-run steelhead are only marked with a batch mark (fin clips) and tag loss is not an issue. For the primary steelhead assessment years (1997-2001, 2004, 2005, 2007, 2010, 2012, and 2014), anchor tags were used, thus similar findings for Coho Salmon since 2011 are applicable to steelhead. However, past studies did not adjust for tag loss and used secondary batch marks as confirmation of marking status during angling surveys which attempted to collect data from all spawning systems.

4.1.3 Tags removed by harvesters

Tag removals primarily occur in four in-river fisheries, including:

1. Nisga'a gillnet harvest (domestic fishery and individual sale) which are thought to be selective towards tagged fish because much of the harvest occurs below the fishwheels (at both GW and GH fishwheel locations) as fish recover from tagging;
2. Recreational harvest (generally small near the tagging sites);
3. Economic demonstration harvests at the fishwheels which have occurred in only a few years since 2013 and tag recoveries were recorded for all fish harvested; and
4. Upper Nass First Nations (UFN) harvest (domestic food and economic opportunity) which primarily take place in the Nass mainstem upstream of GH, and in Meziadin River below the fishway.

Of these, the first three are of higher priority to the present review. It is assumed that harvest upstream of GH (e.g., UFN harvest) is non-specific (i.e., tagged and untagged fish have the same harvest probabilities) and so the impact on upstream harvest on the capture-recapture estimates has been ignored. There is some possibility that this may not be true for some species and some mainstem harvests in some years are from size selective gillnets or fishwheels. The extent of bias introduced by these issues is unknown.

The Nisga'a gillnet fishery and recreational harvest occur downriver of GH. Demonstration harvests occur at the GH fishwheels only. Afternoon tagging at GW on a sale fishery day is not conducted until after the sale fishery closes (i.e., tagging occurs after 6 pm). The Nisga'a gillnet harvest represents the largest of these harvests and the most complex component of the estimation procedure due to the large number of tags removed, relative to the number recovered. In theory, any harvest downriver of GW would only be untagged fish and only affects the run size at GW. However, some fish, after being tagged, may temporarily move back downriver from the fishwheel and be harvested. Consequently, the number of tagged fish available for recapture above GH needs to be adjusted.

A key issue is that tagged fish appear to be more vulnerable to nets below the GW fishwheels while recovering than untagged fish (Link and English 1996). If harvest between GW and GH was non-specific (i.e., tagged and untagged fish have the same harvest probabilities), it could also be ignored. However, harvest between GW and GH primarily occurs around the fishwheels and recently released tagged fish may have a higher harvest probability (Link and English 1996) especially for marked Chinook Salmon that after recovering may experience higher harvests from sale fisheries than initial untagged group. For these reasons, the number of tags removed by fisheries between GW and GH must also be estimated.

Similar concerns lie with the recreational fishery below GW, between GW and GH, and above GH. However, the recreational harvest for all species of Nass salmon in these strata is thought to be very small. Sport harvest is not an issue for Sockeye and Coho salmon or for steelhead, but may be more of a concern for Chinook Salmon, especially at the Ksi Sg̱asginist (Seaskinnish Creek) and Ksi Sii Aks (Tseax River) systems. Sport catch is expected to be less than 500 Chinook Salmon each year and the number of tags removed is expected to be very small.

Lastly, Nisg̱a'a Demonstration or Nisg̱a'a Treaty selective fisheries have occurred at the GH fishwheels with implications for the tagging and mark and recapture estimation program. When these fisheries are permitted, tagged fish are also removed as part of the catch and not counted in the number of tagged fish released. Only Sockeye and Coho salmon have been removed in these fisheries in most years, and for years where Chinook Salmon were harvested in the fishwheels (e.g., 2001), marking did not occur at the GH fishwheels.

Nisga'a gillnet harvest

Matthews et al. (2012) provide a detailed explanation of how the Nisga'a gillnet fishery is monitored. In general, estimates are made of the total harvest (tagged and untagged fish) based on surveys. However, not all harvested tagged fish are reported and this unreported component must also be estimated. The same procedure is used for all species.

The lower Nass is divided into four zones (or river-strata; Gingolx [near Portland Inlet], Laxgalts'ap [a.k.a. Lower Stratum] below GW, Gitwinksihlkw (a.k.a. Middle Stratum below and including GW), and Gitlaxt'aamiks (a.k.a. Upper Stratum between GW and GH). Because the harvest near Gingolx is quite far downriver from the fishwheels, tagged fish are seldom harvested and the harvest from this zone is not used in the adjustment process.

There are two types of gillnet harvest – a domestic fishery and individual sales. Data on the domestic fishery and individual sales fishery are recorded at the zone (strata) level. Details on the survey procedures to obtain these catch estimates are discussed in Mathews et al. (2012).

Based on net counts and effort, the actual reported harvest in the domestic fishery is adjusted for non-reporting to give an estimate of total gillnet harvest (along with a measure of precision). The tags harvested by the domestic fishery are supposed to be returned to catch monitors in each of the communities from June to September but are underestimated due to harvesters not seeing the tags or harvesters not complying with the requirement to return tags.

The number of tagged fish harvested by the individual sale fishery is known exactly through observations by catch monitoring staff on the river and at a fish plant where fish are sold. The catch monitors use a counting slip when interviews are conducted to ensure that each fisher that sold fish has been interviewed. A simple expansion factor then estimates the total number of tagged fish removed in the domestic harvest based on the ratio of tagged fish seen in the individual sales fishery. This is conducted for each zone and then added over the zones.

For example, consider the data on the Nisga'a gillnet harvest for 2019 in Table 12. An estimated total of 2,223 (SE 157) Chinook Salmon were harvested in the Upper stratum. This consists of an estimated 1,733 (SE 157) harvested in the domestic fishery (DF) and 490 (SE 0) from the individual-sale fishery (ISF)[11]. A total of 52 tags were observed from the DF, and 40 from the 490 in the ISF. The value of 490 refers only to the portion of the ISF that is fully monitored which is usually quite a high proportion (typically 90%+) of the total ISF. Assuming that the ISF was completely observed on river and when Chinook Salmon was sold at the fish plant, the estimated total number of tags in the combined DF and ISF is 2,223 * 40/490 = 181 tags from the Upper stratum. A similar computation is done for the other strata. The estimated total number of Chinook Salmon tags removed is 181 + 43 + 1 = 225 fish. This represents 225/1,500 = 15% of tagged fish at both fishwheels.

The tag compliance rate is computed as the total number of tags returned / estimated total tags removed = 132/225 = 59%.

The tag return rates (Table 14) have averaged 83% (61-100%), 59% (23-84%), and 86% (62-99%) for Sockeye, Chinook, and Coho Salmon from 2000 to 2019 for estimating total removals in Nisg̲a'a fisheries. In other words, on average, 17%, 41%, and 14% additional tags are estimated to be removed in Nisg̲a'a fisheries for Sockeye, Chinook, and Coho Salmon, which corresponds to an average of 205 Chinook Salmon (36-610), 1,023 Sockeye Salmon (524-2,507), 103 Coho Salmon (0-383), and 25 (13-46) steelhead. Three tag lottery draws ($250 each) were conducted in most years to encourage tag returns by species.

If no ISF occurs (e.g., Coho Salmon in 2018), then the mean compliance rate (86%) from years 2000-2007, 2009-2017 is used. For steelhead in 2019, 347 fish were captured in the ISF with NO tagged fish present. Consequently, the estimated tagged fish lost to the Nisg̲a'a Domestic Harvest would be 0 fish. The actual number of tagged fish removed in the Nisg̲a'a Domestic Fishery is 16 and is obtained using the mean harvest rate (3.0%) based on years of observed catches from capture-recapture studies (2000, 2001, 2004, 2005, 2007, and 2010).

Note that the total catch used to expand the tag-fraction in the ISF may differ in earlier years from the total catch reported in harvest monitoring due to timing issues. For example, harvest monitoring may measure harvest starting in May, but fishwheels may not start operating until June and so only the harvest from June onwards (when the fishwheels are operating and tagging fish) is used. In most cases, the difference in estimates of catch is small except for Sockeye Salmon from 2000-2006.

For years when a low number of ISFs occur for a given species, the mark rate encountered in these fisheries may differ substantially from the mark rates integrated over the longer domestic fishing period. An alternative approach to combining information from the DF and ISF compliance rates, would be to apply a mean compliance rate to the voluntary (domestic fishery) component, which may produce a more conservative estimate of the number of tags removed in this fishery.

Harvest of steelhead occurs alongside the domestic salmon catch monitoring program and an average value around 3% is used to estimate number of tagged summer-run steelhead removed in the Nisg̲a'a domestic harvest.

Nisg̲a'a harvest at fishwheels

These harvests include Nisg̲a'a Treaty and DFO's permitted *Demonstration Harvest fisheries.* It has been mostly Sockeye Salmon but there have been a few years of other species (Table 16). A full inspection of all fish harvested is made so the number of tags removed by the fishwheel harvest are known with little uncertainty. Tagged fish are removed along with any fish harvested. Three sources of verification occur at the fishwheels, at the landing site on the river, and at the fish-processing plant. No harvest at the fishwheels has occurred for several years so no adjustment has been made for these years.

Sport fishery between GW and GH

Sport fishery catches are estimated each year from either creel programs or using average harvest rates to estimate catches. Tag returns are used in adjustments when available (Table 17).

The impact of these adjustments on the estimation procedure have not been well investigated. For example, Link and English (1996, p. 18) found that selective removal in the harvest would bias estimates of Sockeye Salmon abundance by less than 1%. Selective removal estimates have been compared periodically with GW specific generated estimates and have offered more conservative estimates given the concerns raised by Link and English (1996). The sport fishery would impact Chinook Salmon population more than the other species.

4.1.4 Tags in escapement between GW and GH

In the current methodology, no adjustment is made for tagged fish (from the fishwheels at GW) that move to spawning areas between GW and GH. No adjustment has been made for spawning escapement above GH assuming that tagged fish and untagged fish have the same escapement probabilities, i.e., fishwheels tag equally in all escapement stocks and tagged fish mix with untagged fish.

Not adjusting for escapement between GW and GH is problematic because it complicates interpretation of the abundance estimates (and for species tagged at both fishwheel locations, introduces potential bias in the estimates).

For species that are only tagged at GW, the number of tagged fish released at GW is adjusted for harvest between GW and GH, but not for escapement. Consequently, the estimated number of available tags at GH is biased upwards, and the capture-recapture estimators estimate the run size at GH plus escapement between GW and GH, and not simply the run size at GH. Only the harvest between GW and GH needs to be added back to the estimate. This occurs for Sockeye and Coho salmon. So, while that estimation procedure “works”, the wording used in annual reports is confusing because the estimate is often simply called the run size at GH (which it is not).

For species tagged at both GW and GH, it is mostly tagged fish released at GW that could spawn between GW and GH; and it is assumed that fish tagged and released at GH mostly do not spawn between GW and GH. While GH fishwheels have caught CWT Coho Salmon which most likely are destined to Ksi Ts’oohl Ts’ap (Zolzap Creek) between GW and GH, this is assumed to represent a very small proportion of the run. The estimated number of tags above GH consists of estimated net tags released at GW (biased upwards because escapement not accounted for), plus the net tags from GH. Thus, the capture-recapture estimate does not estimate the run size at GH, nor at GW, nor at GH plus escapement between GW and GH. This problem occurs for Chinook Salmon and steelhead (see Appendix B).

Current estimation methods should be modified (see below) by also adjusting the number of fish tagged at GW based on the proportion that may belong to spawning areas between GW and GH estimated from the genetic stock information collected.

Estimates of escapement between GW and GH are not available for all years for Chinook Salmon and steelhead and so a simple adjustment (like that for harvest) may be difficult. Rather, yearly genetic stock identification (e.g., for Chinook Salmon) can be used to estimate the proportion of the run at GW that spawned between GW and GH and an adjustment to the tags applied could be made which would remove the bias. However, genetic stock identification is only available for a small number of years for steelhead, and so an “average” adjustment that accounts for the year-to-year variability in the proportion that spawn between GW and GH will have to be done.

It would be theoretically possible to compute estimates of escapement using separate data from each set of fishwheels, e.g., a Petersen estimate based on tag returns from tags applied at GW and a Petersen estimate based on tag returns from tags applied at GH. The former would estimate the run size at GW and the latter the run size at GH. Some care is needed if adjustments are made to the number of tags released at GW for harvest between GW and GH, in which case the difference in estimates is the sum of escapement and harvest.

If no information about escapement between GW and GH is available (and no adjustment to tags applied at GW for escapement), then there is no simple way to “combine” information from the two estimates.

For Chinook Salmon and steelhead, an analysis of the separate abundance estimates based on each fishwheel could also estimate the number of fish that spawn between GW and GH. For example, consider the following data from 2019 for Chinook Salmon, ignoring the issues of tag adjustments.

	GW	GH	Both
(Adjusted)Tags released	566	614	1,200
Total inspected at MF, KW, DC, CR	793	793	793
Recaptured	26	59	85
Petersen estimate of run size	17,263	8,252	11,087

This would seem to indicate the escapement between GW and GH is about 9,000 fish but this estimate has very poor precision. The estimated run sizes at GW and GH also have poor precision because they are each based on a small number of tags released and recaptured. Without information about escapement between GW and GH, there is no way to combine information from tags at both fishwheels.

Here is where a Bayesian solution would be very helpful because even weak prior information about escapement between GW and GH would enable sharing of information on run sizes based on tags released at both fishwheels. Information would need to be available on releases and recaptures by fishwheel location (e.g., available from the tag number for Chinook Salmon and from the type of adipose fin clip for steelhead). For example, if prior information indicated that the average escapement between GW and GH is about 5% of the run (or about 1000 fish), the large difference above is “shrunk” towards the prior (presumably caused by small sample sizes) and information from both wheels is automatically “shared”.

4.1.5 Total adjustment for all sources

The total censoring of all initial tag losses (handling, loss of primary mark, and removal in Nisga’a fisheries) has averaged 25% for Chinook Salmon, 23% for Coho Salmon, 28% for Sockeye Salmon, and 8% for summer-run steelhead from 1994-2019 (Table 1; Table 2; Table 3; Table 4).

4.1.6 Accounting for uncertainty in adjustment factors

The uncertainty in these adjustment factors has not been incorporated into the uncertainty of the abundance estimates (see section 4.2 Estimation). There are two levels of uncertainty that need to be incorporated. First is sampling uncertainty. Estimates of the various adjustment factors are based on a sample of fish. Second is year-to-year variation. The adjustment factors likely vary among years due to local conditions in each year. If multiple years of data are unavailable, estimates of uncertainty based on expert opinion can be used. Both types of uncertainty can be incorporated either by using a "synthetic" distribution for the adjustment factor as illustrated for the estimate of fallback/dropout for the Taku River (Pestal et al. 2020), or by using a hierarchical Bayesian model where uncertainties due to sampling and variation across years are explicitly modelled. A hierarchical Bayesian model will automatically shrink estimates based on sparse data to the overall mean and use the overall mean if no data are available.

4.2 Estimation

This section provides an overview of current estimation procedures using the adjusted tag numbers described above. Section 4.2.1 reviews the equations that are used to estimate abundance and uncertainty using unstratified and different options for stratified estimates. Section 4.2.2 reviews the index methods that are currently used to generate estimates for steelhead, for which insufficient tag recoveries preclude using regular estimation procedures in some years. Section 4.2.3 describes the estimated harvest and escapement for Chinook Salmon and steelhead between GH and GW to obtain the run size at GW when tagging occurs at both GW and GH fishwheels.

4.2.1 Capture-recapture estimates

The current capture-recapture methodology uses either a pooled-Petersen or stratified-Petersen estimator (by length) to estimate the run-size at GH. Because of the tag adjustments, use of estimation methods that require individual tag histories (e.g., SPAS/BTSPAS) will be problematic because these alternate methods typically do not allow for the adjustments made in the current methodology (except fall back/initial handling mortality adjustment that is included in the BTSPAS models). A temporally stratified-Darroch estimator (SPAS) has been used for Sockeye Salmon each year based on batch colour and tag recovery data to provide weekly estimates of catchability.

4.2.1.1 Pooled Petersen estimators

The Chapman-adjusted estimator for the Petersen-estimators is used for this system. Let M, C, and R be the number of tagged fish available below GH (this is the number tagged after adjustments for initial handling mortality, fallback, differential harvest, tag loss[12], escapement between GW and GH etc.), the number of fish inspected, and the number of tagged fish observed, respectively.

The Chapman-adjusted pooled-Petersen estimator is:

$$\widehat{N}_{PP} = \frac{(M+1)(C+1)}{(R+1)} - 1$$

with an estimated standard error of

$$se\left(\widehat{N}_{PP}\right) = \sqrt{\frac{(M+1)^2(C+1)(C-R)}{(R+1)^2(R+2)}}$$

A 95% confidence interval for the abundance can be found in the usual way as

$$\widehat{N} \pm z \times se$$

The sampling distribution of R often has a right skew, so there are two common modifications in finding the confidence interval. The first is to transform the estimate and standard error to the logarithmic scale, find the confidence interval on the logarithmic scale, and then back-transform the endpoints of the confidence interval. Or the method described in Lockwood and Schneider (2000) based on a Poisson distribution for the number of recaptures can be used as shown in Beveridge et al (2020, p. 11). A 95% interval for the number of recaptures is found, assuming that they follow a Poisson distribution as:

$$CI = R_i + 1.92 \pm 1.96\sqrt{R_i + 1.0}.$$

and then the upper and lower limits on *R* are substituted into the Chapman estimator.

Profile confidence intervals can also be used, but these will be of little use here because of the need to account for the uncertainty in the number of tags available for recapture. Alternatively, the Bayesian credible interval is obtained directly from the output of the MCMC procedure, and the Bayesian methods will be able to easily incorporate other sources of uncertainty. With large number of recaptures, both methods will give similar results.

4.2.1.2 Stratified-Petersen estimators

One assumption commonly made in Petersen-like estimators of abundance is homogeneity of the probability of capture either at the tagging events, or in the

[12] For some species, a tag loss adjustment is made to estimate the number of tagged fish at GH that will retain their tags over the course of the return upstream, i.e., even though tag loss occurs upstream of GH, the adjustment is made as if the tag loss occurred just after tagging and the observed number of tagged fish captured is used (without adjustment for fish that would have been recaptured with missing tags). This is a computational shortcut and is mathematically correct.

recapture events, or both. This assumption implies that the probability of capture or the probability of recapture is equal for all fish. Failure of this assumption can lead to bias in the estimates.

Notice that if homogeneity occurs EITHER during the capture event or during the recapture event, then the estimates remain unbiased even if heterogeneity exists in the other event.

While heterogeneity can cause bias in the estimates, the situation is more nuanced. Seber (1982) showed that the relative bias in a Petersen-type estimator can be approximated by:

$$RelativeBias \cong -C(p_1, p_2)\frac{\sqrt{V(p_1)V(p_2)}}{E[p_1 \times p_2]}$$

where *C()* is the correlation between the capture probabilities at the two event; *V()* is the variance in capture probabilities at each event; and *E[]* refers to the expectation of the product of the probability of capture in the two events. Here the correlation, variance, and expectation are taken over the probability of capture for the individual fish.

If the probability of capture at either event is equal for all fish, then both the *C()* and *V()* terms are 0 and there is no bias regardless if the probability of capture is heterogeneous at the other event. Similarly, if there is no correlation in the probability of capture across the two events, then the *C()* term is zero and there is again no bias. Complete mixing will lead to a correlation of 0 and no bias. There are many other ways in which the bias could also be zero.

Pure heterogeneity in catchability (e.g., larger fish are more catchable at both events) leads to negative biases in estimates of abundance because the correlation in the probability of capture across events is positive. Heterogeneity that is related to temporal or geographical stratification can lead to positive or negative biases in the estimates depending upon the correlation of the probability of capture between the two sampling occasions. For example, if fishwheels become saturated, then the probability of capture is reduced when there is pulse of fish passing the fishwheels. If this pulse also saturates the fishway at Meziadin and reduces the probability of capture at the fishway, then a positive correlation exists between the two capture probabilities and negative bias is again introduced.

Stratification can be used to reduce the bias caused by heterogeneity. In the Nass River system, stratification by length (size) is commonly used. Stratified estimators by time of tagging and time of recapture could be used if fish can be identified by the time of release and recapture (e.g., via individual numbered tags, or via batch marks that change with time). Stratification by time has been used in the Nass system for Sockeye Salmon using different tag colours to indicate the week of tagging but has not been used for other species because of tag loss (e.g., fin clips are used to indicate tagging status) and because tag numbers are not easily read in the fishway or video-counting weir.

4.2.1.2a Fish cannot change strata between release and recovery

The simplest case occurs when fish cannot change strata between release and recovery (e.g., stratification based on sex or length class). In this case, separate estimates are formed for each stratum using stratum-specific statistics and then rolled up to form the estimate for the entire population in the usual way.

Note that to reduce costs, stratified (e.g., by length) data are not fully collected and often the number of fish in a stratum is an estimate based on a sub-sample of fish. For example, rather than size-stratifying over 100,000 Sockeye Salmon at Meziadin Fishway, a sample (typically around 1,000 fish) of Sockeye Salmon are measured and size stratified, and then the size proportions are used to impute the actual number of fish in each stratum. A similar procedure is used for the number of fish in each size strata at tagging. The procedure for obtaining estimates of tagged fish removed in the Nisg̱a'a Domestic Harvest also relies on a sub-sample and further assumptions. The uncertainty in the allocation to the strata has not been accounted for in the analysis.

Suppose that two strata are used (e.g., based on length classes of medium and large fish). The stratified-Petersen estimator would first divide the values of M, C, and R by the stratum variable. Let M_m, C_m, and R_m and M_L, C_L, and R_L represent the stratified versions of the statistics. A Chapman-adjusted pooled-Petersen estimator is found for each stratum:

$$\widehat{N}_{PP,M} = \frac{(M_m + 1)(C_m + 1)}{(R_m + 1)} - 1$$

$$\widehat{N}_{PP,L} = \frac{(M_L + 1)(C_L + 1)}{(R_L + 1)} - 1$$

The estimate of the combined run at GH is found by adding the individual estimates from the size strata:

$$\widehat{N}_{SP} = \widehat{N}_{PP,M} + \widehat{N}_{PP,L}$$

and the estimated standard error is found as:

$$se(\widehat{N}_{SP}) = \sqrt{se(\widehat{N}_{PP.M})^2 + se(\widehat{N}_{PP,L})^2}$$

Confidence intervals are found as discussed earlier.

In some cases, the sample size for some of the strata may be too small to be useful. For example, in the 2018 Chinook Salmon report (Beveridge et al. 2019), there were only two recoveries for medium sized Chinook Salmon. It is well known that the Petersen estimator is severely biased when computed using a small number of recoveries and it is recommended that at least 7-10 recaptures be available before computing an estimate. As noted in Appendix A of this report, the ad hoc method used in these cases is equivalent to using the marked fraction based on the other strata for the stratum with small sample sizes. Consequently, as a rule of thumb, stratification should have at least 7-10 recaptures in each stratum.

Stratification can come with a price of increased uncertainty in the estimate of abundance. For example, in a population that is stratified into two equal groups where the probability of capture and recapture vary by a factor of 2 in both groups at both events (e.g., large fish have twice the probability of capture at the fish wheels and at the recovery locations), the unstratified estimator has a 10% negative bias, but the stratified estimator has a standard error that is approximately 25% larger. The overall accuracy (combination of bias and precision) depends on the population size and the actual capture probabilities. In general, estimate accuracy is better for the stratified estimator in larger populations because the bias scales linearly with population size but the standard error declines roughly by the square of the number of recaptures. In the case of smaller populations, both estimators have approximately the same accuracy.

There are also additional costs associated with tagging and recovery to enable stratification. For example, for size stratification, all fish must now be measured when both tagging and after recovery. Adjustments for the Domestic Harvest, Sport Harvest, and Demonstration Harvest must be collected by size category (it is assumed that initial mortality and tag loss do not depend on size). Sufficient tags need to be applied and recovered in each stratum to enable estimates to be made and avoid small sample biases. If the abundance is small in a stratum, then simple proportional tagging across the run may have sufficient tags applied and recovered. This is a reason that size stratified estimates were not made in most years for Chinook Salmon in the early years of the program and why additional marking at the GH fishwheels must be done in order to apply and recover enough tags in all strata.

The stratified results can be compared to the pooled-Petersen (ignoring stratification) to determine if the reduction in bias from stratification is biologically important relative to the precision of the estimate. Cochran (1977; Section 1.8) suggests that the effect of bias on the accuracy of an estimate is negligible if the absolute value of the bias is less than 1/5 of the standard error of the estimate.

Table 40 compares the estimates of run size from the pooled-Petersen estimator and the size-stratified estimator. For Chinook Salmon, the average difference was about 4% (size-stratified lower); for Coho Salmon, the average difference was 9% (stratified larger); for Sockeye Salmon, the average difference was very close to 0%; for steelhead, the average difference was about 1.1% (size-stratified larger).

While the computations appear to be straightforward, it assumes that sufficient tags are applied and recovered in each stratum to enable estimates to be made and avoid small sample biases. Again, a Bayesian solution may be helpful. If you assume a hierarchical model where the recapture probability varies by stratum around an “average” value for the year, and the average yearly values comes from a suitable distribution, then in cases where the data for a stratum in a year are large, it provides sufficient information to estimate a separate capture-probability for each stratum; in cases where the number of recaptures is small, the estimate of the capture-probability for that stratum will automatically be shrunk towards a value informed by other years. It is not necessary to make a formal decision between the two estimators.

Note that currently, the number of tags available to capture is adjusted to account for tag loss, fall back/drop out, removals by the Nisg̲a'a Domestic fishery, etc. Currently, many of these adjustments are not stratum specific because the strata-specific data are very sparse. As noted elsewhere, the uncertainty in the estimated number of tags available has not been accounted for in the current estimation procedures.

In the case of a continuous covariate such as length that can be measured for all tagged and recapture fish, a Petersen-type estimator that uses the individual value of the covariate can be formed using the methods of Huggins (1989). In this method, a model for the relationship between the capture probability and the covariate is assumed (e.g., quadratic). Chen and Lloyd (2000) developed a method that fits a non-parametric relationship between the covariate and the capture-probability that may be more suitable. These methods will require the use of individually numbered tags that can be read at all recapture occasions and will need additional development when the number of tags removed must also be estimated at each covariate value (!). These methods could be used for Chinook Salmon without major changes to the program. Some modifications are needed for Coho and Sockeye salmon as not all fish recaptured have the tag numbers read. A well-designed PIT tagging program would provide automated reading of individual tags for these species, however there would still be a need to count and sample unmarked fish, and for double tagging to assess tag loss.

4.2.1.2b Fish can change strata membership between release and recapture

In some cases, fish can change membership between release and recapture. For example, in temporal stratification where the strata are defined as “early” or “late”, fish tagged in the early stratum, could be recaptured in either the “early” or “late” recovery stratum. But fish released in the “late” stratum presumably cannot be recaptured in the “early” stratum.

This type of stratification will require individually numbered tags or batch marks that identify the stratum of release so that the stratum membership for each fish can be identified. If tag loss is substantial, then this type of stratification becomes difficult to implement. Currently, fin clips are used as secondary marks and fish are carefully inspected for both tags and secondary marks, so tag loss is accounted for, but the secondary marks do not allow for temporal stratification. In all years, different coloured tags were used for Sockeye Salmon to indicate the week of release; Coho Salmon have a large number of individual tags numbers read at Meziadin Fishway. In these cases, temporal stratification may be possible.

The theory for this type of stratification has been outlined in Schwarz and Taylor (1998) and implemented in the *SPAS R* package (Schwarz 2019) in the case of general geographic and temporal stratification, and by Bonner and Schwarz (2011) and implemented in the *BTSPAS R* package (Bonner and Schwarz 2020) in the case of temporal stratification.

Releases are stratified into *s* temporal groups, e.g., weeks. Similar adjustments can be made to the number of released fish to account for dropout, fall back, tag loss, harvest, etc. Recoveries of untagged fish are also stratified into *t* temporal groups, e.g., weeks. The number of strata of releases should less than or equal the number of recovery strata (i.e., $s \leq t$), if estimates of abundance are wanted at the release location. Recaptures of tagged fish can then be classified by the stratum of release and recovery into an $s \times t$ matrix. If $s = t$, then an analytical estimator is available as outlined by Darroch (1961). In all other cases, the estimator is found numerically using maximum likelihood as shown in Schwarz and Taylor (1998).

Note that in many cases, the stratified estimator fails to be computed using the initial stratification and some pooling of rows or columns will be needed as outlined in Schwarz and Taylor (1998). The use of the Schaeffer estimator is discouraged as it has been shown to be asymptotically equivalent to a pooled-Petersen estimator (Schwarz, unpublished report).

Temporal stratification has been done for Sockeye Salmon (different coloured tags indicate the week of release). It may be possible to compute temporally-stratified estimates for Coho Salmon because there are large number of individually identified fish at the Meziadin Fishway.

A key issue with the current methods used for temporal-stratification is that the uncertainty from estimating tags removed in the Nisga'a harvest, due to tag loss and initial mortality estimates, has not been incorporated and so the final uncertainty in the run size has been underestimated.

Consider an example of a temporally-stratified estimator for Sockeye Salmon for the 2019 season. A total of 8,240 fish were tagged and released with different coloured tags into 15 statistical weeks (Table 41). Adjustments for fall back, drop out, tag loss, etc. are made at the week level resulting in an adjusted total of 6,071 tags available just upriver of GH (Table 41) with the adjustment ranging from 16% to 50% across the weeks.

A total of 88,128 fish were examined and stratified also in 15 temporal strata (Table 42) and the (adjusted) releases were classified by the week of release and recapture (Table 42). The completely pooled-Petersen estimate (ignoring stratification) is 264,603 (SE 4,748).

The program SPAS was used to estimate the abundance after some rows and columns were pooled (Table 43). The Schaefer estimate is 264,835 (no SE available) which is very close to the pooled-Petersen estimator but as shown by Schwarz (pers comm), the Schaefer estimator is asymptotically equivalent to the pooled-Petersen, provides no new information, and should not be used. These data were also analyzed using the *R* version of SPAS (Table 44). Estimated run size at GH (including escapement between GW and GH) is 288,528 (SE 14,444) respectively which is substantially larger than the pooled-Petersen estimate. However, the reported standard error is most certainly an underestimate of the actual uncertainty.

A key issue with the use of SPAS is that decisions often are made about pooling rows and/or columns when the estimate fails. There is no objective way to determine which rows/columns need to be pooled. The reason for the poor performance of SPAS is that this program is designed for geographical stratification where movement between all release and all recovery strata is possible. However, in the case of temporal stratification, fish cannot be recovered before they are released and so much of the recovery matrix (lower triangle) is zero.

Bonner and Schwarz (2009) developed a theory for the analysis of temporally stratified data and the program BTSPAS is available to fit these models. Selected output from BTSPAS is found in Table 45. The estimated run size just upriver of GH from BTSPAS is 280,072 (SD 12,705), similar to the estimate from SPAS. Again, the reported uncertainty is under-reported because no accounting is made for the uncertainty in the adjustments to the number of tagged fish released.

If the weekly adjustments made to account for tagged fish removed between GW and GH is approximately proportional over time, then a variant of BTSPAS can also account for this dropout and incorporate additional uncertainty. From Table 41, the average removal proportion was 1 – 6,071/8,240 = 26%, but removal proportions ranged from 16% to 39%. BTSPAS allows the user to specify a tagged availability (1 – removal proportion) that is applied to all release strata and the method of specification also (implicitly) gives a measure of uncertainty of this adjustment. Two values are specified to BTSPAS whose ratio is the average tagged availability. For example, a 25% fallback proportion could be expressed as 3 in 4, 30 in 40, or 300 in 400 (etc.) for the tagged availability, with the latter being a more precise specification of the available proportion. Here some guidance is needed on choosing appropriate values, and Table 46 shows the results with various levels of certainty in the availability proportion.

The estimated run size is unaffected by the specification of the (x, n) pair that specifies the availability of tags after release and the standard error declines as the specification for the tag availability becomes more precise. With “perfect” knowledge of the proportion of tags available, the uncertainty will match that seen earlier.

4.2.1.3 Multiple recapture locations

Fish can be recovered and inspected in multiple locations upriver of the fishwheels and by several different groups. For example, Chinook Salmon are captured (and examined) as the Meziadin Fishway, the Kwinageese Weir, and during carcass surveys at Damdochax Creek and Cranberry River.

In theory, a multiple recapture capture-recapture method could be used, but this would require the use of individually numbered tags (or PIT tags) to construct the capture-history for each fish. Unfortunately, removals of tagged fish in the adjustment process is not recorded at the individual fish level and so these methods would require considerable methodological development to account for these adjustments. Additionally, very few fish are recaptured on multiple occasions.

The current methodology first tests if the marked fractions are equal at all recovery locations (e.g., Table E-12 of the 2019 Chinook Salmon report [Beveridge et al. 2020]). These tests may have poor power because of small sample sizes. Then, assuming that the statistical test fails to reject the hypothesis of equal marked fractions, all recoveries and recaptures from the multiple recovery locations are pooled together for use in stratified- or pooled-Petersen estimators (e.g., Table 4 of the 2019 Chinook Salmon report [Beveridge et al. 2020]).

An estimate of the marked fraction is estimated using a ratio estimator pooling over all recovery locations as:

$$\widehat{MF} = \frac{Total\ recaptures}{Total\ recoveries}$$

and an estimate of the overall abundance is found as

$$\widehat{N} = \frac{Tags\ available}{\widehat{MF}} = \frac{Tags\ available\ \times\ Total\ recoveries}{Total\ recaptures}$$

which is similar in form to a pooled-Petersen. Because no new tagged fish are being introduced, the multiple recapture locations can be modelled using the Bailey (1951, 1952) binomial model which leads to the same estimator as the pooled-Petersen model. The standard error is computed slightly differently in the two models but the differences in the estimated standard error are not consequential.

A more serious problem arises if the test for equal marked fraction among the recovery locations indicates evidence of a difference in the marked fraction among recovery locations. For example, suppose that the marked fraction at location A was 10% and at location B, it was 2%. This may be an indication that the fishwheels are not tagging in a uniform fashion. For example, early in the run the tagging probability was 10% and these were primarily location A fish, while later in the run, the fishwheels were saturated and so only 2% of fish were tagged and this was primarily fish that move to location B. A temporal (for tagging) x location (for recovery) stratification may be needed, but this may require information from individually tagged fish which may not be available. This apparently occurred in the 2012 Chinook Salmon report results (Table 5 of the 2012 Chinook Salmon report; Alexander et al. 2013), but an examination of Table 6 of the 2012 Chinook Salmon report shows that this result occurred because of the very large sample sizes at the recovery locations had large power to detect small (unimportant) differences in the marked fraction.

Analogous methods could be used to assess the selectivity of the fishwheels among multiple stocks within the same species. When these statistical tests were done, no evidence of a differential marked fraction among stocks was obtained.

4.2.1.4 Uncertainty in the estimates

The current procedure uses the estimates for uncertainty (e.g., the standard error) based on a known number of tags released.

The adjustments made to the number of tags applied to calculate the “net” number of tagged fish available above GH leads to unbiased estimates of the run-size at GH assuming that the estimated adjustments are unbiased, but the additional uncertainty introduced by these adjustments has NOT been accounted for in the current estimates of uncertainty (i.e., the current reported standard errors are too small). This additional uncertainty in the adjustment arises because some of the adjustments are based on samples of fish themselves (e.g., tags lost to harvest below GH) and some are based on average values that do not account for year-to-year variation (e.g., fallback adjustments).

It will be a formidable problem to find analytical equations to account for this additional uncertainty. A bootstrap approach may be useful. However, we recommend a Bayesian approach as it can easily account for multiple sources of uncertainty.

4.2.1.5 Specific comments about capture-recapture estimates for Chinook Salmon

Table 12 of the 2019 Chinook Salmon report (Beveridge et al. 2020), footnote (b) states that any escapement between GW and GH is included in the run size at GH. This is incorrect (see Appendix B) and it is necessary to both adjust for tags applied at GW that are "removed" by fish that spawn between GW and GH, and then to add back escapement between GW and GH to the estimated run size at GH.

For example, consider the following data from 2019 for Chinook Salmon comparing the estimates computed using the current methodology and a proposed modification to account for escapement between GW and GH:

	Current	Corrected
Tags released at GW	727	727
Tags released at GH	773	773
Adjustment for Nisga'a Harvest	- 224	- 224
Adjustment for initial mortality	- 75	- 75
Adjustment for tag loss	Not needed	Not needed
Adjustment for escapement between GW and GH (19.4% of GW tags)	Not done	- 141
Net tags available above GH (M)	1,201	1,060
Examined at CR, MF, KW, DC	793	793
Tags recaptured	85	85
Run size at GH (Chapman estimator)	11,097	9,795
Add back Nisga'a harvest between GW and GH	+2,223	+2,223
Add back sport harvest between GW and GH	+ 192	+ 192
Add back escapement between GW and GH (19.4%)	Not done	+2,938
Run size at GW	13,512	15,148

As noted previously, the estimate of run size at GH is higher using the current methodology compared to the corrected methodology. However, the additions back to the run at GH that ignore the escapement leads to a run size estimate at GW that is lower than the corrected methodology. A similar correction will be needed for any stratified estimator.

Note that the method outlined on page 22 of the 2018 report (Beveridge et al. 2019) for dealing with small number of recaptures (i.e., in the medium stratum) is "equivalent" to pooled-Petersen estimator using the large Chinook Salmon to estimate the mark fraction. Notice that the equation (9) in the report needs to be reformatted because the current equation (9) does not appear to be correct.

4.2.1.6 Specific comments about capture-recapture estimates for steelhead

We will also need to estimate the number of fish that spawn between GW and GH and make a similar adjustment to the estimation methods for summer-run steelhead. An additional complication is that genetic information is not collected on a regular basis for summer-run steelhead.

4.2.2 Index methods for summer-run steelhead

In some years, the capture-recapture estimate for summer-run steelhead “fails” because of inadequate recaptures (e.g., in 2018 there were no recaptures of tagged steelhead). An index of the run size was constructed in a multistep process using estimated fishwheel capture probabilities of Sockeye or Coho salmon to expand observed captures of steelhead. This index is then calibrated using the relationship between the index and the capture-recapture estimates of summer-run steelhead from 11 years where the capture-recapture estimator for steelhead can be computed. There are some (minor) errors in the description in how the index is computed. The current calibration method can be improved, and the uncertainty of the calibrated estimate is underestimated and needs to recomputed. We provide a revised method for calibration.

This process is described in Alexander et al (2015) and detailed computations are available in Appendix B. The procedures using the catches of Sockeye Salmon are similar to the procedure using Coho Salmon catches.

There are several steps in constructing the index of escapement:

Step 1. Compute an expansion factor for each fishwheel using the ratio of the fishwheel hours expended to the hours expended in an (arbitrary) reference year of 1999. Notice that Equation (8) in Alexander et al (2015) is inverted. For example, in 2019, fishwheel 1 ran from 2 June to 13 September for a total of 1,742 hours. In the reference year (1999), fishwheel 1 ran from 7 June to 30 September for a total of 2,180 hours. Hence, the expansion factor for fishwheel 1 is 2,180/1,744 = 1.25 rather than 1,744/2,180 as given in Equation (8). A similar computation is done for fishwheel 2.

Step 2. Expand the observed catch of steelhead using the expansion factor from step 1. This is Equation 9 of Alexander et al. (2015). For example, in 2019, 57 steelhead were captured, and this is expanded by the factor of 1.25 to give an adjusted number of steelhead captured of 71 fish.

Step 3. The proportion of the Coho Salmon run captured at fishwheel 1 is computed and used to expand the adjusted count from step 2 (Equation 10 from Alexander et al. 2015). For example, in 2019, 1,893 Coho Salmon were captured from 2 June to 13 September from the estimated run of 82,319. The estimated capture efficiency of fishwheel 1 is 1,893/82,319 = 2.3%. Assuming the same capture efficiency for steelhead, the estimated run size of steelhead based on fishwheel 1 catch is 71/0.023 = 3,087.

Similar steps occur for fishwheel 2 catches and the estimated run sizes based on fishwheel 2 catches is 10,269.

Step 4. We now have two independent estimates of run size (one from each fishwheel). The average of the two is used as the uncalibrated index of run size (Equation 11 in

Alexander et al. 2015) and its standard error is computed using the formula for the standard error of a mean from a sample of size 2 (Equation 13 in Alexander et al. 2015). The uncalibrated estimated run size for steelhead is 6,678 (SE 3,591).

This index may be biased because many assumptions were made that cannot be verified. For example:

- An arbitrary choice of 1999 to create a baseline for hours of operation of the fishwheels. The year 1999 was chosen because water levels in that year were quite high for the entire run and so the hours of operation were extensive. The choice of year has no impact on the index as the calibration process corrects for the choice of index year.
- Expanding the observed catch of steelhead by the expansion factor based on an arbitrary year of 1999 assumes that fish arrive uniformly over the hours of operation and that the hours expended in 1999 covered the entire run. The latter assumption was likely satisfied as the fishwheel at GW ran to the end of September.
- Capture efficiency of the fishwheels is assumed equal for all species of fish, i.e., all species are equally catchable by the fishwheel.
- Catches at the two fishwheels are independent.

Because of these potential biases, a last step (calibration) is required.

Calibration

To convert the index into an estimate of abundance, it is calibrated against 11 years (1997-2001; 2004-2005; 2007, 2010, 2012, and 2014) where both a capture-recapture estimate and the steelhead index of abundance are available. It is implicitly assumed that the capture-recapture estimates are unbiased for the true abundance. A plot of the index and capture-recapture estimates for the 11 years is found in Figure 8. The steelhead abundance index based on Coho Salmon captures are typically smaller than the capture-recapture estimates of steelhead abundance.

There are many ways to find the calibration factor:

(a) Mean of ratios (MOR)

$$MOR_{mr:index} = \frac{\sum \frac{MR_i}{index_i}}{n}$$

or

$$MOR_{index:mr} = \frac{\sum \frac{index_i}{MR_i}}{n}$$

(b) Ratio of means (ROM)

$$MOR_{index:mr} = \frac{\sum \frac{index_i}{MR_i}}{n}$$

or

$$MOR_{mr:index} = \frac{\sum \frac{MR_i}{index_i}}{n}$$

Ratio of geometric means (ROGM) $ROGM_{index:mr} = \frac{\sqrt[n]{\prod index_i}}{\sqrt[n]{\prod MR_i}}$

or

$$ROGM_{mr:index} = \frac{\sqrt[n]{\prod MR_i}}{\sqrt[n]{\prod index_i}}$$

where *n* is the number of pairs of estimates (in this case *n* = 11), $index_i$ is the value of the steelhead index to abundance, and MR_i is the value of the capture-recapture estimate of abundance in the i^{th} pair of estimates.

The current methodology uses a MOR calibration factor. The disadvantage of the MOR calibration factors is that they are not "symmetrical", i.e., $MOR_{index:mr} = 0.778$ is not equal to $1/MOR_{mr:index} = \frac{1}{1.143} = 0.702$. The ROM and ROGM calibration factor are "symmetrical" and so it does not matter which value is chosen as the final calibrated estimate will still be the same (after appropriate adjustments).

A plot of the calibration factors is also shown in Figure 8. Fortunately, the calibration factors are all similar and so the calibrated estimates will not change dramatically when the different calibration factors are used.

The steelhead index is then corrected by the calibration factors. However, Equation (15) of Alexander et al (2015) is incorrect. It states:

$$\hat{N}_{CI}m = \frac{OBSescGW}{\left(\frac{\sum \frac{\widehat{N_{mr}}}{OBSescGW} \times 100}{n_{mr}}\right)} \quad \text{(Equation 15)}$$

where *OBSescGW* is the steelhead index value and n_{mr} is the number of years where both the index and capture-recapture estimate are available (11 years). It is necessary to expand the steelhead index by the ratio of the steelhead index to the capture-recapture estimates and so equation (15) should be written either as

$$\hat{N}_{CI,m} = \frac{OBSescGW}{\frac{\sum \frac{OBSescGW}{\hat{N}_{mr}}}{n_{mr}}} = \frac{OBSescGW}{MOR_{index:mr}}$$

or

$$\widehat{N}_{CI,m} = OBSescGW \times \frac{\sum \frac{\widehat{N}_{mr}}{OBSescGW}}{n_{mr}} = OBSescGW \times MOR_{mr:index}$$

Unfortunately, this results in two different calibrated estimates because of the lack of symmetry as noted before and there is no objective way to select which is "better".

The ROM or ROGM calibration factors are recommended because they are "symmetrical" and so a recommended calibrated estimate is found as:

$$\widehat{N}_{CI,m} = \frac{OBSescGW}{ROM_{index:mr}} = OBSescGW \times ROM_{mr:index}$$

or

$$\widehat{N}_{CI,m} = \frac{OBSescGW}{ROGM_{index:mr}} = OBSescGW \times ROGM_{mr:index}$$

The ROGM is further preferred because the ROM calibration factor may be heavily influenced by a year with large steelhead or capture-recapture estimate, while the ROGM is less influenced (geometric means are less than or equal to arithmetic means).

Equations (16), (17), and (18) of Alexander et al. (2015) propose methods to compute the standard error of the calibrated values. These are incorrect because:

- Equation (16) includes the value of 1.96 used in computing 95% confidence intervals which should not be included.
- Even if Equation (16) is modified to drop the value of 1.96, it ignores the two levels of uncertainty in the uncalibrated index and in the MOR value.
- The computed SE in the spreadsheets are unrealistically small – for example, the estimated steelhead index for 2019 is 6,678 (SE 3,591) for a RSE of 53%, but the estimated calibrated abundance in the spreadsheets for 2019 is 8,588 (SE 1,313) for a RSE of 15%. If the calibration factor were known exactly, i.e., had a standard error of 0, both the index value and its standard error would be multiplied by the same value and the RSE would not change (i.e., would remain at 53%). The uncertainty after calibration must increase when you multiply the index by a calibration factor that is also uncertain.

To compute the uncertainty of the calibrated value, the variance of a product of two (independent) random variables is used[13]:

$$\mathrm{Var}(XY) = (\sigma_X^2 + \mu_X^2)(\sigma_Y^2 + \mu_Y^2) - \mu_X^2\mu_Y^2$$

[13] https://en.wikipedia.org/wiki/Product_distribution

where X and Y are two random variables with means and standard deviations ,
respectively. We let X be the steelhead index value with its computed standard error seen previously, i.e., 6,678 (SE 3,591) and Y be the ROGM calibration factor.

To compute the standard error of the ROGM estimator, we first use the fact that:

$$\mathrm{Var}(XY) = (\sigma_X^2 + \mu_X^2)(\sigma_Y^2 + \mu_Y^2) - \mu_X^2 \mu_Y^2$$

where X and Y are two random variables with means μ and standard deviations σ, respectively. We let X be the steelhead index value with its computed standard error seen previously, i.e., 6,678 (SE 3,591) and Y be the ROGM calibration factor.

To compute the standard error of the ROGM estimator, we first use the fact that:

$$\log(ROGM_{mr:index}) = \frac{\sum \log\left(\frac{mr_i}{index_i}\right)}{n}$$

i.e., a simple mean on the log(ratio) scale. The standard error of $\log(ROGM_{mr:index})$ is found in the usual way:

$$\mathrm{se}(\log(ROGM_{mr:index})) = \frac{\mathrm{sd}\left(\log\left(\frac{mr_i}{index_i}\right)\right)}{\sqrt{n}}$$

For the 2019 data, we have $\log(ROGM_{mr:index}) = 0.302\ (SE\ 0.101)$.

Then because $ROGM_{mr:index} = \exp(\log(ROGM_{mr:index}))$ the standard error is found as:

$$\mathrm{SE}(ROGM_{mr:index}) = ROGM_{mr:index} \times \mathrm{SE}(\log(ROGM_{mr:index}))$$

For the 2019 data, we have $ROGM_{mr:index}$= 1.35 (SE 0.136). The calibrated estimate of abundance of steelhead for 2019 is then:

$$\widehat{N}_{calibrated} = \mathrm{OBSescGW} \times \mathrm{ROGM}_{mr:index} = 6{,}678 \times 1.35 = 9{,}015.$$

The standard error is found as:

$$SE\left(\widehat{N}_{calibrated}\right) = \sqrt{\left(SE(\mathrm{OBSescGW})^2 + \mathrm{OBSescGW}^2\right)\left(SE(\mathrm{ROGM})^2 + \mathrm{ROGM}^2\right) - \mathrm{OBSescGW}^2\,\mathrm{ROGM}^2}$$

$$= \sqrt{\left(3{,}591^2 + 6{,}678^2\right)\left(0.136^2 + 1.35^2\right) - 6{,}678^2\ 1.35^2} = 4{,}966$$

The final calibrated estimate of abundance of steelhead for 2019 is 9,015 (SE 4,966; RSE = 55%) and so the RSE has increased slightly (as it must) to account for the uncertainty in the calibration factor.

4.2.3 Adjusting for harvest and escapement between GH and GW

Once the run size at GH is estimated, this is augmented by the estimated harvest and escapement (for Chinook Salmon and steelhead) between GH and GW to obtain the run size at GW. Notice that for species where tagging only occurs at the GW fishwheels, the estimated run size from the capture-recapture surveys already includes the escapement between GW and GH and no further adjustment needs to be done. But as noted earlier, the existing reports need to be worded carefully as it is often implied that the estimate obtained refers to the run size at GH.

Catch data from the Nisg̲a'a Domestic Fishery are available with enough resolution to obtain the harvest between GH and GW. There is a relatively small recreational fishery between GW and GH for Chinook Salmon (<500 fish) currently; it is assumed that no Sockeye Salmon are harvested in the sport fishery in this harvest stratum and that most Coho Salmon sport harvest occurs after the fishwheels cease operation in September, however it is not known what portion of the fish that are harvested migrate past the fishwheels during operation.

If estimates of escapement are available (e.g., based on genetic stock information on fish captured at the GW fishwheels), then an adjustment to the tags released at GW can be made similar to the adjustments for harvest. The estimated run size at GH would then be adjusted for escapement between GW and GH in a similar way as the adjustment for harvest.

Conversely, in order to estimate the run size at GW, adjustments are made to the run size just upriver from GH. The order and focus of the harvest relative to escapement can affect the way the adjustment is made.

We assume almost all the harvesting of Chinook Salmon by Nisg̲a'a fisheries occurs before these fish enter spawning locations as fishing occurs on the mainstem of the Nass River. This implies that the Nisg̲a'a Domestic harvest is a mixture from stocks that spawn at GH or higher and those that spawn between GH and GW. The majority of recreational harvest occurs primarily at the mouths of Ksi Sii Aks (Tseax River) and Ksi Sg̲asginist (Seaskinnish Creek) and could also be a mixture of stocks. Collection of DNA data from the harvest would verify these assumptions. The other assumption is that middle Nass Chinook spawners travel above GH; however small numbers of middle Nass Chinook are present in individual DNA samples collected at the Meziadin Fishway.

As a first approximation, we assume that the order of events is:

- Fish arrive at GW
- Fish may be harvested at the GW fishwheels.
- Escapement to spawning areas between GW and GH
- Domestic harvest between GW and GH
- Sport harvest between GW and GH simultaneous to the Domestic Harvest
- Fish arrive at GH
- Fish may be harvested at the GH fishwheels.

Consequently, to obtain the estimated run size at GW from the run size just upriver of GH, the reverse steps must be followed, i.e.:

$$N_{GW} = \frac{N_{GH} + FWH_{GH} + NH_{GW-GH} + SportH_{GW-GH}}{1 - p_{escapeGW-GH}} + FWH_{GW}$$

where

- *FWH* is the fishwheel harvest at GH or GW
- *NH* is the Nisg̲a'a Domestic Harvest between GW and GH
- *SportH* is the sport harvest between GW and GH
- is the proportion of the run at GW that spawns between GW and GH.

For example, if the run size at GW was 20,000 fish, 10% spawned between GW and GH, 1,500 was harvested in the Nisg̲a'a Harvest, 500 was harvested in the sport fishery, and 1,000 was harvested at the GH fishwheel, then the run size just upriver of GH is found as:

$$N_{GH} = (20{,}000 - 0) \times 0.9 - 1500 - 500 - 1000 = 15{,}000$$

and in reverse we get:

$$N_{GW} = \frac{15{,}000 + 1500 + 500 + 1000}{0.9} + 0 = 20{,}000$$

This estimator is only an approximation because the actual dynamics are far more complex.

4.4 In-season estimation

There are two types of in-season estimates for Nass salmon species. First are "run-to-date" estimates (i.e., estimated cumulative number of fish that have passed GW since the start of the run). Second are future (i.e., end of the current season) "total-run" estimates based on an expansion of the "run-to-date" estimates by historical run-percentages to-date.

In-season "run-to-date" population point estimates for Nass Sockeye and Coho salmon and summer-run steelhead in 2019 were derived during GW fishwheel operations, using one to three of the different methods described below. Typically, one of the Method 1 or 2 estimates are used to the last week of June until sufficient tag recaptures are captured at the GH fishwheels to estimate run sizes based on mark-rate data as in Method 3. The selection of the appropriate estimate to use before Method 3 is based on water levels experienced during operation.

The "run-to-date" point estimate is then used to generate a "total-run" forecast return to GW fishwheels based on mean-run timing with lower and upper ranges based on mean ± 2 S.D of run-timing from the historical period.

4.4.1 "Run-to-date" Method 1: historical catchability

Method 1 provides daily run size estimates to GW using historical estimates of daily catchability for the GW fishwheels 1 and 2 based on the ratio of the daily catch at the fishwheels to the estimated daily number of fish arriving at the GW fishwheels from 1994 to 2018. For Sockeye Salmon, the daily catchability is assumed to be equal across dates within 6 periods during which the fishwheels operate (June, 1-15 July, 16-31 July, 16-31 July and 1-3 August, 4-7 August, 8-15 August; 16-31 August, and September). For example, the same catchability is used for all days in June (except near the end of the month, see below). For the other species, the daily catchability is assumed to be constant for all days over the entire time the fishwheels are operating.

If a fishwheel does not operate for a full 24 hours and passage is expected (i.e., water level is not rising to stop passage [> 2,000 m^3/s]), the catch for the hours when the fishwheel was operating is expanded to account for the time when the fishwheel is not operating. The expansion can be based on catch per hour at a specific fishwheel or comparison between FW1 and FW2 catchability differences.

Let

- $GW_{i,p,y}$ be the observed catch[14] at GW (both fishwheels) for day *i* in period *p* in historical year *y.*
- $N_{p,y}$ be the estimated number of fish passing the fishwheels at GW in historical year *y*

For sockeye, the estimated daily catchability in period *p* for historical year *y* (*)* is defined as:

$$q_{p,y}^{sockeye} = \frac{\sum_i GW_{i,p,y}}{N_{p,y}}$$ (summation is over the days in the period)

The estimated total number of fish passing GW by period for Sockeye Salmon ($N_{p,y}$) is obtained from a time-stratified (by statistical week) estimator from the post-season analysis each historical year (recall that different coloured tags are applied to Sockeye every one or two weeks) that gives the run size for the statistical week at GH. The Nisg̱a'a catch between GW and GH is then added back to give the run size for the statistical week at GW.

For the other species, the estimated daily catchability does not vary by period and so the daily catchability (for Coho Salmon) is defined for historical year *y* as:

$$q_y^{coho} = \frac{\sum_i GW_{i,y}}{N_y}$$ (summation is over all days when the fishwheel operates)

where N_y is the post-season estimate of the total run passing GW in historical year *y*. A similar computation is done for Chinook Salmon and steelhead.

The expansion factor for period *p* in historical year *y* is computed as:

$$E_{p,y}^{sockeye} = \frac{1}{q_{p,y}^{sockeye}}$$

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$$E_y^{coho} = \frac{1}{q_y^{coho}}$$

with similar computations for Chinook Salmon and steelhead.

The mean, minimum, and maximum daily expansion factor is found over the historical years for each period for Sockeye Salmon as:

$$\bar{E}_p^{sockeye} = \frac{\sum_y E_{p,y}^{sockeye}}{\#\ historical\ years}$$

$$E_{p,min}^{sockeye} = \min\left(E_{p,y}^{sockeye}\right)$$

$$E_{p,max}^{sockeye} = \max\left(E_{p,y}^{sockeye}\right)$$

Note that the minimum and maximum values for Sockeye Salmon could be from different years for each period.

The mean, minimum, and maximum daily expansion factor is found over the historical years the other species is found similarly.

$$\bar{E}^{coho} = \frac{\sum_y E_y^{coho}}{\#\ historical\ years}$$

$$E_{min}^{coho} = \min\left(E_y^{coho}\right)$$

$$E_{max}^{coho} = \max\left(E_y^{coho}\right)$$

with similar computations for Chinook Salmon and steelhead.

To compute the in-season estimate, these expansion factors are assembled into an array for each day the GW fishwheels are operating with a separate array using the mean, minimum or maximum expansion factor. For example, Table 47 presents part of the arrays for the 2019 season.

The first period for Sockeye Salmon consists of all days in June while the second period consists of 1-15 July. Rather than having a sharp break in the expansion factor at 30 June, the expansion factors for 28, 29, and 30 June are averages of the expansion factors for June and 1-15 July periods. A similar interpolation takes place at the boundaries of the other periods for Sockeye Salmon. For the other species, the expansion factor is the same for all days the wheel is operating because of insufficient data to estimate historical weekly catchability estimates as too few tags are recovered by week.

Finally, the observed catch at the GW fishwheel in 2019 for each day is multiplied by the expansion factor for that day to estimate the number of fish that arrived at the fishwheel on that date (some of which are caught by the fishwheel). For example, in 2019, two Sockeye Salmon were captured at the GW fishwheels on 3 June. If the average expansion factor for that date is used (22.2), an estimated 2 x 22.2 = 44.4 fish arrived at the GW fishwheel on 3 June.

The cumulative sum of these values provides the time series of the in-season cumulative estimates. Note that because the expansion factor for the other species is the same for all days, the in-season cumulative estimate can also be computed by multiplying the cumulative catch at the GW fishwheels by the (common for all days) expansion factor.

For all species, the in-season estimates based on the mean, minimum, or maximum expansion factor from the historical data provides a "range" of in-season estimates, but the actual interpretation is unclear (i.e., they cannot be considered to be confidence intervals of a certain size). This is especially so for Sockeye Salmon where the minimum or maximum expansion factor for the different periods could be from different years. However, these estimates are only used earlier in the season until sufficient tag recaptures are captured at the GH fishwheels to estimate run sizes based on mark-rate data as described for Method 3 (see page 64). The selection of the appropriate estimate to use for early estimates is based on water levels (mean, low, high, and variable) experienced during operation. The mean, maximum, and minimum expansion factors are used if the fishwheels operated at water levels near the historical mean, low, or high levels, respectively. If the water levels are greatly varied through the operation of the fishwheels, then daily water level expansion factors are used as part of Method 2.

4.4.2 "Run-to-date" Method 2: daily water level

For Method 2, the daily water level is used to determine the daily expansion factor to multiply the daily catch at the GW fishwheels. At high water conditions, the fishwheels are assumed to encounter a higher proportion of the fish that pass the GW fishwheels as fish are pushed more along the sides of the canyon where the wheels are located, resulting in a lower expansion factor (1/catchability)). The opposite occurs under low water levels as more fish can pass in the center of the channel away from the streambanks. Method 2 applies mean, low, and high-water levels expansion factors that correspond to the historical fishwheel expansion factors associated with those water conditions.

The water levels are determined for each day that the fishwheels are in operation. Then depending on the water level, the appropriate daily expansion factor is chosen. In some cases, the water level is very low and the expansion factor from 1998 is used. This was the lowest water level experienced since 1994 and the poorest operation of FW2 that was experienced from the program. For some periods, water levels were so low that fishwheels did not spin during operations. For sockeye, this year is excluded from the historical in-season catchability.

For example, the right side of Table 47 contains the water levels for these dates. The daily water level is used to select the expansion factor from the average, minimum or maximum expansion factors found in Method 1. The Method 2 expansion factor varies from day to day.

Finally, in Method 2, the observed catch at the GW fishwheel is multiplied by the expansion factor for that day to estimate the number of fish that arrived at the fishwheels on that date (some of which are caught by the fishwheel). For our 2019 example, two Sockeye Salmon were captured at the GW fishwheels on 3 June which was an average water level. The average expansion factor for that date is used (22.2), an estimated 2 x 22.2 = 44.4 fish arrived at the GW fishwheel on 3 June using Method 2.

The cumulative sum of these values provides the time series of the in-season cumulative estimates. The shortcut for Coho and Chinook salmon and summer-run steelhead used in Method 1 of using the cumulative catch directly cannot be used in Method 2.

For all species, no estimate of uncertainty is presented for the in-season estimate from this method, but ranges are reviewed with DFO each week. In addition, the point estimates for run size are also used to project run size forecasts to GW using mean run timing and standard deviation ranges (± 2 S.D.; Figure 9; Figure 10; Figure 11; Figure 12).

Preliminary research (e.g., Alexander and Bocking 2003) has shown that there is not a direct correlation between water levels and catchability at the fishwheels which is confounded by other factors (e.g., differences by species passing, and abundance densities being caught over time). However, using a variable expansion factor provides more realistic estimates of abundance passage when water levels have greatly fluctuated earlier in the season.

If the water levels have varied substantially during June, the daily water level catchability estimate is used to estimate the run passing the GW fishwheels until enough tagged fish from GW (usually > 12) are recovered at the GH fishwheels for estimating mark-rates from the GH fishwheels in Method 3.

4.4.3 "Run-to-date" Method 3: mark rates

Method 3 is an estimator that is based on capture-recapture methodology using fish captured at GW on day *i* as the "marked set of fish" expanded by the (smoothed) marked fraction at GH on day *i+x* to account for travel time between the two sets of fishwheels. The value of *x* used is 5 days for Sockeye and 6 days for Coho salmon but can vary if water levels are substantially lower or higher as fish will travel faster or slower, respectively. The water levels can be measured during the season, but fixed values for the travel times have been used for most years.

Let

- GW_i represent the number of fish captured at GW on day *i* (both tagged and untagged)[15].
- *tt* represent the travel time for tagged fish to travel between GW and GH.

- MF_i represents the marked fraction at GH on day *i.*

Then the number of fish that arrive at the GW fishwheels on day *i* is found as

$$N_i = GW_i / MF_{i+tt}$$

For example, if the "marked fraction" at GH on day *i* was 0.10, then this indicates that the number of fish captured at GW *tt* days earlier must be multiplied by 10. This number is occasionally adjusted to account for days when the fishwheels are running less than 24 hours during passable conditions.

The "marked fraction" at GH on day *i+tt* *(MF_{i+tt})* is not the actual proportion of tagged fish. The marked fraction is calculated using the number of recaptures on day *i+tt* at GH and this value needs to be adjusted (expanded) to account for several factors that can influence the number of tags available for recapture, including: 1) not all fish captured at GW *tt* days earlier were tagged; 2) initial tagging mortality; 3) individual sale fishery recaptures between GW and GH; and 4) differential travel time, where tagged fish travel slower than untagged fish due to drop back delay while recovering from tagging. To prevent large jumps in MF_{i+tt} between successive days, the adjusted recaps are smoothed over a seven-day window.

The marked fraction is calculated as:

$$MF_{i+tt} = (AdjustedRecaps_{i+tt-6:i+tt}/0.88)/(GH_{i+tt-6:i+tt} + IS_{i+tt-6:i+tt})$$

where,

- 0.88 is the factor that accounts for initial tagging mortality/fallback. It is implicitly assumed that tag-loss cannot occur in the small distance between GW and GH and so tag loss is not accounted for.
- $(GH_{i+tt-6:i+tt} + IS_{i+tt-6:i+tt})$ is the total number of fish captured at GH in a seven-day (smoothing) window ending on day *i+tt* from both the fishwheels and the IS fishery.
- $AdjustedRecaps_{i+tt-6:i+tt}$ is the number of fish from those captured at GW on day *i* over a 7-day window ending on day *i+tt*.

AdjustedRecaps accounts for: 1) the different travel times of untagged and tagged fish, and 2) the fact that not all fish captured at the GW on day *i* are tagged, and is computed as:

$$AdjustedRecaps_{i+tt} = TaggedRecaps_i \times GW_{i-1:i+4}/TaggedatGH_{i-3:i+2}$$

The differential index in the last term accounts a 2-day time period for untagged fish to migrate between GW and GH and a 5-day time period for tagged fish to migrate between GW and GH plus a 4-day window to smooth the estimate. Extra time is used for tagged fish to account for "sulking" after tagging before fish resume their migration.

For our 2019 example, Table 49 includes part of the raw data for Sockeye Salmon and we wish to find the estimate of the number of fish arriving at GW for 9 July (*i*). The value of *tt* for Sockeye Salmon is 5 days.

On 14 July (*i*+*tt*), 25 tagged fish from GW were recaptured at GH ($Recaps_{i+tt}$). There were 678 fish tagged at GW in the 5-day window ending 4 days earlier (on 10 July; $TaggedGW_{i-3:i+2}$) and 1,167 fish captured at GW (tagged and untagged fish) in the 4-day window ending 2 days earlier (on 12 July; $GW_{i-1:i+4}$). Therefore, $\text{AdjustedRecaps}_{i+tt}$ is

25 x 1,167 / 678 = 43.0 recaptured fish.

The "marked fraction" is then found as the 7-day window of the adjusted recaptures 285.1 / 0.88 (to account for initial mortality) / 3,376 (7-day window total catch at GH [fishwheels and IS]) = 0.096. So just under 10% of the fish captured at GH on 14 July were "marked" (i.e., from fish that were captured at GW earlier).

Finally, the 392 fish captured at GW on 2019-07-09 is expanded by the marked fraction 5 days later on 2019-07-14 to estimate the number of fish that arrived on 2019-07-09 at GW, or 392 / 0.096 = 4,084 fish.

The in-season estimate is found as the cumulative total of the estimated number of fish arriving at GW. Sample calculations for in-season estimates for Sockeye salmon using Method 3 are provided in Table 49.

The same procedure is currently being used for Chinook Salmon and summer-run steelhead for in-season run size estimates, but Chinook Salmon uses GH mark rates derived from Sockeye Salmon whereas steelhead uses a combination from Sockeye and Coho salmon if enough Coho Salmon tag recoveries are captured at the GH fishwheels. Generally, Sockeye mark rates tend to be the best to use for in-season estimates of GW fishwheel abundance passing for all species with more tags released at GW fishwheels and recovered at GH fishwheels during the season (i.e., higher sample size of tags recovered and fish examined). Additional mark rate data at GH are collected when IS fisheries (or harvesting at GH fishwheels) occur using tags returned and total catch estimated to be harvested in the upper stratum (above Beaver Creek catch location to Kinskuch Bridge) from the fisheries. The sub-sample of catch from the upper stratum is assumed to have good mixing of tagged and untagged fish relative to catch locations nearer the GW fishwheels (i.e., below Beaver [aka Chemaniuk] Creek).

No estimate of uncertainty is provided for in-season estimates generated using Method 3, but ranges of estimates are reviewed with DFO each week. In addition, the point estimates for run size are also used to project run size forecasts to GW using mean run timing and standard deviation ranges (±2 S.D.; Figure 9; Figure 10; Figure 11; Figure 12).

4.4.4 Combining "run-to-date" estimation methods

The different "run-to-date" estimates are combined using estimates from Method 1 and 2 early in the season and then switching to Method 3 once enough tags (at GW) and recaptures (n > 25) (at GH fishwheels) have been recovered.

For example, for the "run-to-date" estimates for Sockeye Salmon in 2019, Method 2 was used from the start of the season to 25 June and Method 3 used starting 26 June to the end of operations.

4.4.5 "Total-run" forecast to Gitwinksihlkw

The "run-to-date" point estimate is then expanded to estimate the (future) total-run using historical data on run-timing. At the end of each year, the run-to-date forecast formed using a combination of methods above, is divided by the final in-season estimate.

For example, consider Table 49 for Sockeye Salmon in 2019. The estimated "run-to-date" from 2019-06-03 is 65 fish. Historically (1994-2018), the proportion of the total-run that has passed GW by this date has a mean of 0.067% and a standard deviation of 0.14%. The estimated forecast of the total run is then 65/0.067% = 96,115 fish. Using a ±2 SD range, gives a range of forecasts from 18,892 to 192,231 fish.

The final in-season estimate for 2019 for Sockeye Salmon was 286,548. After the 2019 season ended, another year of "historical" data are added where the proportion of the total-run that passes on 2019-06-03 is 65/286,548 = 0.00227%. So, the total-run expansion values are based only on in-season estimates and never calibrated against the post-season estimates from the larger-recapture study.

Similar tables of run-timing have been developed for the other species and are used in a similar fashion.

The lower range would estimate if the run was early and the upper range if the run was late and typically if the mean was above the run size target, this would guide whether commercial fisheries would be wise to continue to fish.

Figures 9 to 12 show that the "total-run" forecast can be quite variable, especially early in the season. Some smoothing of the expansion factors may be helpful in alleviating this problem.

4.4.6 Estimates for each species in 2019

4.4.6.1 Chinook Salmon

Daily catchability estimates were used to generate a range of estimates for Chinook Salmon passing the GW fishwheels based on historical operations from 1994 to 2018.

Historical derived expansion factors for Chinook Salmon caught at the GW fishwheels were multiplied by total fishwheel catch each day for mean (14.75 or 6.78%), low (32.18 or 3.11% from 2014), and high (7.66 or 13.06% from 2001) catchability run size estimates to generate the historical index estimates (Method 1).

The daily water level estimate was based on the daily water level compared to historical estimates (mean, low or high) and use of one of the historical expansion factors (Method 2).

The Sockeye Salmon mark-rate data were also used to generate in-season Chinook Salmon run size estimates to GW fishwheels with the most tag recoveries to counts at the GH fishwheels to estimate weekly passage rates at GW. In 2019, the low water level estimates were used to generate Chinook Salmon run size estimates from 2 June (first Chinook Salmon caught) to 30 June until 14 Sockeye Salmon tags were recovered from the GH fishwheels to begin generating the GH mark rate estimates starting on 1 July. The Sockeye Salmon mark-rate determination at GH fishwheels in 2019 is described below.

The 2019 summary of in-season estimates for Chinook Salmon passing GW fishwheels ranged between 5,974 (13.06%) and 25,103 (3.11%) for the high and low catchability expansion factors, and the mean was 11,506 (6.78%) using the historical factors described above and a GW catch of 780 Chinook Salmon. The daily water level catchability estimate was 26,490 (2.94%). The GH mark rate estimate was 21,181 (3.68%) Chinook Salmon using in-season Sockeye Salmon mark rates. The post-season run size estimate to GW fishwheels was 13,342 (5.85%; 7,839 less or 59.0% lower than the in-season mark rate estimate) Chinook Salmon using the stratified population estimate generated for 2019 (Table 50).

The comparison between in-season and post-season estimates (Table 50 and Figure 13) for Chinook Salmon requires further review to ensure proper accounting is occurring with marking at both GW and GH fishwheels for any tags that would be part of the escapement between GW and GH. Genetic stock identification data (Table 13) indicates that about 15% of fish at GW would spawn between GW and GH and not be available for recapture at GH. This affects both tagged and untagged fish so the Method 3 estimate (based on capture-recapture of tagged fish at GW at GH) would be unaffected.

There does not appear to be general under or overestimation of the in-season total run size compared to the post-season estimates (Table 50 and Figure 13) with a mean absolute error of about 25%, and it is not clear why the in-season estimate performed poorly from 2005 to 2013.

4.4.6.2 Coho Salmon

Daily catchability estimates were used to generate a range of estimates for Coho Salmon passing the GW fishwheels based on historical operations from 1994 to 2018.

Historical derived expansion factors for Coho Salmon were multiplied by total GW fishwheel catch each day for mean (21.21 or 4.71%), low (38.60 or 2.59% from 2011), and high (12.82 or 7.80% from 2012) catchability run size estimates to generate the historical index estimates (Method 1).

The daily water level estimate was based on the daily water level compared to historical estimates (mean, low or high) and use of one of the historical expansion factors (Method 2).

The Sockeye Salmon mark rate data were also used to generate in-season run size estimates. In 2019, the Sockeye Salmon mark rates were used to generate Coho Salmon in-season run size estimates from 16 June (first Coho Salmon caught) to 3 August until enough Coho Salmon tags were recovered from the GH fishwheels to begin generating the GH mark rate estimates from Coho Salmon tag releases starting on 4 August.

The first estimate using GH Coho Salmon mark rates (1,354) in 2019 was generated by multiplying the total catch at the GW fishwheels on 4 August (45) by the GH mark rate on 10 August (30.1 or 3.32%) that was offset by 6 days to account for travel time of GW marked fish to the GH fishwheels. The GH mark rate was the sum of the total GH catch (1,232) divided by the sum of the adjusted GW tag recaps (38) over an 8-day period (3 to 10 August). The GW tag recap was adjusted for the initial handling losses (6% or

38/0.94 = 40) at the GW fishwheels for reducing the expansion factor with fewer tags being available for recapture at GH fishwheels. The adjusted recaps (171) over the 8-day period were the number of daily recaptures at the GH fishwheels multiplied by the sum of GW catch divided by the number of tags released at GW over a 5-d period. The GW catch and tag release sums were offset by 5 days and 7 days, respectively, to account for differences in travel time of untagged and tagged fish based on historical observations.

Other adjustments can occur when one or both of the GW fishwheels were unable to operate due to high water or other factors and when IS fisheries occurred that harvested Coho Salmon and generated additional mark rate data in the upper stratum. In 2019, no GW catches required expanding for Coho Salmon and no IS fisheries harvested Coho Salmon.

The 2019 summary of in-season estimates for Coho Salmon ranged between 55,914 (7.8%) and 168,407 (2.59%) for the high and low catchability expansion factors, and the mean was 92,543 (4.71%) using the historical factors described above and a GW catch of 4,363 Coho Salmon. The daily water level catchability estimate was 102,448 (4.26%). The Grease Harbour mark rate estimate was 132,547 (4.40%) using Sockeye Salmon mark rates and 77,383 (5.64%) using Coho Salmon mark rates based on 11,941 Coho Salmon examined for marks from the GH fishwheels and 580 tags recovered and adjusted to 626 from the tag recap adjustment process. The post-season run size estimate to GW fishwheels was 82,319 (5.30%; 4,936 more or 6.0% higher than the in-season GH mark rate estimate using Coho Salmon mark rates) Coho Salmon using the pooled population estimate generated for 2019 (Table 51).

Figure 10 shows that the “total-run” forecast can be quite variable, especially early in the season. Some smoothing of the expansion factors may be helpful in alleviating this problem.

The comparison between in-season and post-season estimates (Table 51 and Figure 14) does not show a consistent general under or overestimation of the in-season total run size compared to the post-season estimates with an average absolute error of about 20%.

4.4.6.3 Sockeye Salmon

Period specific catchability estimates were used to generate a range of estimates based on historical operations from 1994 to 2018.

Table 52 shows 9 period-specific expansion factor ranges that were multiplied by total fishwheel catch each day for mean, low, and high catchability run size estimates from 1 June to 13 September 2019 for Methods 1 and 2. The daily water level estimate was based on the daily water level compared to historical estimates (mean, low or high) and use of one of the historical expansion factors. The daily water level catchability estimate was used for Sockeye Salmon from 2 June to 25 June until 14 tags were recovered from the GH fishwheels to begin generating the GH mark rate estimates starting on 26 June.

The first estimate using Method 3 (6,562), was generated by multiplying the total catch at the GW fishwheels on 26 June (216) by the GH mark rate on 1 July (30.4 or 3.3%)

that was offset by 5 days to account for travel time of GW marked fish to the GH fishwheels. The GH mark rate was the sum of the total GH catch (457) divided by the sum of the adjusted GW tag recaps (13) over a 4-d period (28 June to 1 July). The GW tag recap was adjusted for the initial handling losses (12% or 13/0.88 = 15) at the GW fishwheels for reducing the expansion factor with fewer tags being available for recapture at GH fishwheels. The adjusted recaptures (13) over the 4-d period were the number of daily recaps at the GH fishwheels multiplied by the sum of GW catch divided by the number of tags released at GW over a 5-d period. The GW catch and tag release sums were offset by 2 days and 5 days, respectively, to account for differences in travel time of untagged and tagged fish based on historical observations.

Other adjustments occur when one or both of the GW fishwheels are unable to operate due to high water or other factors and when IS fisheries occur that generate additional mark rate data in the Upper stratum. If applicable, these adjustments are also done for Chinook and Coho salmon and summer-run steelhead. In 2019, GW catches of Sockeye Salmon (240) were expanded on 13 July (+8 fish = 248) to account for reduced operation of FW2 based on estimated Sockeye Salmon caught per hour during operation. No other catch adjustments were needed at the GW fishwheels in 2019 as they operated for 24 hours/day during operation. Four IS fisheries for Sockeye Salmon occurred in 2019 on 4 July (1,027 caught, 15 tags returned), 5 July (1,127 caught, 7 tags returned), 11 July (1,317 caught, 52 tags returned), and 12 July (821 caught, 45 tags returned) and harvested 4,292 Sockeye Salmon with 119 tag recoveries above Beaver Creek. These data were incorporated into GH mark rates. These numbers are lower than those used for tag compliance estimates because the location used for these estimates are assumed to have adequate mixing of tagged fish than using locations too close to the GW fishwheels. This was based on observations of very high mark rates nearer the fishwheels and the tag recoveries above site 5 from the upper stratum catch zone.

The 2019 summary of in-season estimates for Sockeye Salmon ranged between 125,446 (10.0%) and 533,313 (2.4%) for the high and low catchability expansion factors, and the mean was 279,000 (4.5%) using the factors shown in Table 53 and a GW catch of 12,596 Sockeye Salmon. The daily water level catchability estimate was 431,527 (2.9%) and the GH mark rate estimate was 286,548 (4.4%) based on 28,395 Sockeye Salmon examined for marks from the GH fishwheels (24,103) and IS fisheries (4,292) and 916 tags recovered and adjusted to 1,842 from the tag recap adjustment process. The post-season run size estimate to GW fishwheels was 268,000 (4.7%; 18,548 less or 6.9% lower than the in-season GH mark rate estimate) Sockeye Salmon using the stratified population estimate generated for 2019 (Table 53).

Figure 15 shows that the “total-run” forecast to GW can be quite variable, especially early in the season. Some smoothing of the expansion factors may be helpful in alleviating this problem.

The comparison between in-season and post-season estimates (Table 53 and Figure 15) does not show a consistent general under or overestimation of the in-season total run size compared to the post-season estimates with an average absolute error of about 9%, which is considerably better than for Chinook or Coho Salmon.

4.4.6.4 Summer-run steelhead

Daily catchability estimates were used to generate a range of estimates for summer-run steelhead passing the GW fishwheels after 1 July based on historical operations from 1994 to 2018. Historical derived expansion factors for summer-run steelhead caught at the GW fishwheels were multiplied by total fishwheel catch each day for mean (38.01 or 2.63%), low (83.68 or 1.20% from 1997), and high (18.02 or 5.55% from 2004) catchability run size estimates to generate the historical index estimates (Method 1).

The daily water level estimate was based on the daily water level compared to historical estimates (mean, low or high) and use of one of the historical expansion factors (Method 2).

The Coho Salmon mark rate data were used to generate run size estimates to GW fishwheels for steelhead in 2019. The Coho Salmon mark rate determination at GH fishwheels in 2019 has been described above. An additional adjustment was made to the steelhead estimates to account for difference (84.23%) in Coho Salmon catchability method to steelhead estimate from BC Fisheries funded capture-recapture years.

The 2019 summary of in-season estimates for summer-run steelhead passing GW fishwheels ranged between 6,505 (5.55%) and 30,200 (1.20%) for the high and low catchability expansion factors, and the mean was 13,717 (2.63%) using the historical factors described above and a GW catch of 391 summer-run steelhead. The daily water level catchability estimate was 17,502 (1.74%). The GH method was 5,423 (5.61%) summer-run steelhead using in-season Coho Salmon mark rates. The post-season estimate was 8,588 (4.55%; 3,165 more or 37.0% higher than the in-season estimate) using the Coho Salmon mark rate method to estimate the summer-run steelhead return in 2019.

The comparison between in-season and post-season estimates for summer-run steelhead requires further review to ensure proper accounting is occurring with marking at both GW and GH fishwheels for any tags that would be part of the escapement between GW and GH.

4.4.7 Comments on the in-season methods

The current methods are implemented in (complex) Excel worksheets. These are difficult to reverse engineer and difficult to modify if assumptions are changed over time. There may be a benefit to converting these to a set of *R* scripts which explicitly list all the steps.

Estimates of uncertainty for the “run-to-date” are only produced for Method 1 and the interpretation of the range in estimates from using the minimum, average, and maximum expansion factors is difficult to interpret (they are not confidence intervals nor are they prediction intervals). It is not clear how to provide estimates of uncertainty for Method 2 and Method 3.

The “run-to-date” point estimates are used to forecast the total returns based on the mean run timing data and ±2 SD in the run-timing data to provide a measure of uncertainty. These ranges are likely to be too narrow given that the uncertainty in the “run-to-date” has not been incorporated.

The run timing forecasts have helped determine whether current abundances are above or below run size targets (e.g., Figure 9; Figure 10; Figure 11; Figure 12).

A comparison of the in-season total run and post-season estimates shows that there can be large differences. Ideally, the in-season estimates of total-run should “converge” to the post-season estimates by the end of the season. Unfortunately, it is not possible to compare the daily values to actual run-to-date for calibration purposes. Perhaps a more robust approach would be to derive in-season estimates at only a few points in time, e.g., at around the 25%, 50%, and 75% of the season. By looking at larger aggregates, a modified capture-recapture estimate based on recaptures at Meziadin Fishway further upriver may be possible but because the median travel time from GW to MF is 18 days, estimates would be too late to be useful for in-season fishery management, as peak passage of sockeye at Meziadin Fishway is typically 3-4th week of July and commercial fisheries start in second or third week of June and typically end by 10 July.

Simplification of method 3

Method 3 attempts to expand the catch at GW in day *i* by the marked fraction at GH some days later. The current method makes many adjustments to account for the fact that not all fish captured at GW are tagged and the differential travel times of tagged and untagged fish. Because a large fraction of fish captured at GW are actually tagged, the methods may be simplified by expanding the number of tagged fish released at GW by the actual marked fraction using (smoothed) number of tagged fish to total catch.

$$N_i = GW_i^{tagged}/AMF_{i+tt}$$

For example, if the “actual marked fraction” at GH on day *i* was 0.10, then this indicates that the number of fish captured at GW *tt* days earlier must be multiplied by 10.

The “actual marked fraction” at GH on day *i+tt* (AMF_{i+tt}) is now the (smoothed) actual proportion of tagged fish. The actual marked fraction is calculated using (1) the actual number of recaptures on day *i+tt* at GH plus the individual sale fishery recaptures between GW and GH; (2) adjusting for tag loss; and (3) using differential travel times for tagged and untagged fish. To prevent large jumps in MF_{i+tt} between successive days, the adjusted recaps are smoothed over a seven-day window.

The actual marked fraction would be calculated as:

$$AMF_{i+tt} = (Recaps_{i+tt+2-6:i+tt+2}/0.88)/(GH_{i+tt-6:i+tt} + IS_{i+tt-6:i+tt})$$

where

- 0.88 is the factor that accounts for initial tagging mortality
- $(GH_{i+tt-6:i+tt} + IS_{i+tt-6:i+tt})$ is the total number of fish captured at GH in a seven-day (smoothing) window ending on day *i+tt* from both the fishwheels and the IS fishery.

- $Recaps_{i+tt+2-6:i+tt+2}$ is the number of fish recaptured with tags from those tagged at GW on day *i* over a 7-day window ending on day *i+tt+2*. The extra 2 days are to account for the longer travel time of tagged vs untagged fish between GW and GH.

The procedure to generate the in-season forecast of the total run are quite complicated and much of the data are used multiple-times in each of the steps. A more direct approach may be easier to implement and understand where a regression of the total run (based on post-season estimates) is regressed against the cumulative catch by day x at the GW fishwheels based on the historical results that could also incorporate covariates such as water level. With this more direct approach, it would be relatively simple to add prediction intervals using standard regression methods.

5. Summary and Recommendations

The current capture-recapture methodology is a result of over 25 years of methodical implementation, testing alternative ways of tagging fish and recovering fish, and adapting the methods to correct deficiencies in the program. Consequently, the current methods are, for the most part, defensible and produce estimates with good properties.

The primary concerns with the current estimation methodology are listed below, and Detailed recommendations for improvements or modifications to existing methodology, or additional studies to address these concerns, are provided in subsequent sections.

Low estimates of uncertainty:
The current estimates of uncertainty are understated because the current model does not account for the uncertainty in the number of tags removed after application due to initial mortality, tag loss, and removal in Nisga'a harvests. A Bayesian version of the estimation model will produce more realistic estimates of uncertainty, and the companion document on Bayesian methods shows how much the current estimates of uncertainty need to be increased.
Chinook salmon and summer-run steelhead spawning between GW and GH: The methodology for Chinook Salmon and summer-run steelhead should be adjusted to account for spawning between GW and GH because tagging takes place at both locations. The current methods produce detectable biases in the estimates of run size at GH and GW.

Index method for summer-run steelhead estimates using coho mark rates: The methodology for the index method for summer-run steelhead estimates needs to be modified to use a better calibration estimator and to compute the uncertainty correctly.

Size-based stratification: The need for size- or sex-based stratification should be based on the size of potential bias to the estimates rather than yes/no decisions from statistical tests which are highly dependent on sample sizes. Alternatively, as shown in the companion document on Bayesian methods, a Bayesian stratification "automatically" chooses the right degree of stratification needed based on sample sizes and the size of the estimated difference in the marked fraction.

Data management for in-season estimation: The current in-season methods are implemented in (complex) Excel worksheets. These are difficult to reverse engineer and difficult to modify if assumptions are changed over time. Measures of uncertainty are not provided (nor is it clear how these would be computed). There may be a benefit to converting these to a set of R scripts which explicitly list all the steps to ensure better maintenance of the code and enable measures of uncertainty to be derived once the model is better understood.

Enroute losses: The current methodology does not account for enroute losses between the capture sites at the fish wheels and terminal recovery sites. Although the mark and recapture-based abundance estimates reviewed here produce estimates of the terminal run of the different species as they enter the river, this can differ substantially from the number of fish that reach the spawning grounds. While the terminal run is used in Treaty accounting to implement provisions in both the Nisga'a and the international Pacific Salmon Treaty, the current MSY-based escapement goal assumes that a high proportion of the terminal run actually spawn and contribute to future generations. For sockeye, the terminal run size estimate can be considerably higher than the sum of spawning ground estimates, for most years since 1992, even after fisheries are accounted for.

Differential enroute mortality of tagged fish: The current methodology assumes no elevated enroute mortality rate of tagged fish due to tagging and handling related physiological stress or injury, potentially leading to overestimation of terminal run size if elevated enroute mortality of tagged fish does indeed occur upstream of the fishwheels. Further work is recommended to better understand the potential for differential mortality for tagged and untagged fish and how this might interact with changing environmental conditions and higher stream temperatures in the Nass basin. A 2018 sockeye radiotelemetry study, which occurred in a year of near-drought conditions, reported that one third of tagged fish that were genotyped as Meziadin-origin did not make it to their destination (Alexander et al. 2022). The evidence presented for higher catches of tagged fish in Nisga'a fisheries immediately below the fish wheels (Section 4.1.3) suggests some potential for delayed mortality related to tagging stress. While a growing body of literature has documented the effects of capture and tagging mortality and their interactions with thermal stress in other systems such as the Fraser (i.e. Gale et al. 2011, Gale et al. 2014), similar studies have not been conducted in the Nass.

5.1 Implementation of Bayesian methods

Bayesian methods should be used to account for all sources of uncertainty, including the number of tags removed from the Nisga'a harvest; uncertainty about the initial mortality, and other factors. A Bayesian model will be able to: incorporate tag loss information from secondary locations (such as Kwinageese Weir); easily address stratification for small sample sizes; incorporate new recovery sites with adequate inspections of fish and mark recoveries ($R > 7$) and incorporate reverse capture-recapture methods when the issues associated with genetic methodology are resolved.

5.2 Spawning between GW and GH

The current methodology for Chinook Salmon and summer-run steelhead does not adjust for tag removals from those applied at GW for fish that spawn between GW and GH, primarily in Ksi Sii Aks (Tseax River) or Ksi Sgasginist (Seaskinnish Creek).

GSI showed that about 10-15% of the Chinook Salmon captured at GW belonged to these two stock groups. This fraction is large enough for Chinook Salmon that detectable bias can be introduced into the estimates of run size at GH and GW. The current methodology for Chinook Salmon should be modified to adjust the number of tags applied at GW using information from the stock proportions determined from the GSI applied on the tagged fish.

Habitat-capacity modelling (Bocking et al. 2005) and limited historical GSI results (Nelson et al. 2001; Alexander et al. 2015) show that around 3% of the summer-run steelhead captured at GW belonged to Ksi Sii Aks (Tseax River) or Ksi Sgasginist (Seaskinnish Creek) stock groups. This fraction is sufficiently small that any bias introduced into estimates of run size at GH or GW may be smaller relative to the uncertainty in the estimates. However, for standardizing methods and recent annual changes in fish productivity in these systems, modifying the methodology to account for summer-run steelhead spawning between GW and GH is recommended.

5.3 Adjustments to index methods used for estimating summer-run steelhead

The index-methods used for summer-run steelhead estimates when capture-recapture sample sizes are small require some revisions as noted in section *4.2.2 Index methods for summer-run steelhead*. Specific recommendations include:

- Use the ROGM calibration factor
- Use the corrected formula for computing the standard errors. This will need to be applied to all past years.
- Investigate the use of multiple stocks (e.g., Sockeye and Coho salmon) in the calibration process using multivariate calibration.
- Bayesian methods can be used where a multi-variate normal distribution on the log(abundances) may allow imputation for cases where the capture-recapture estimator cannot be formed for steelhead. This would produce another index-type method.

5.4 Addressing size- or sex-based stratification

The current methodology performs several tests of hypotheses of equal recovery probabilities or equal marked fractions as a proxy for the need for stratification by sex or by size. A “yes/no” decision for stratification is made on the basis of these statistical tests.

Failure to detect a differential marked fraction or differential recovery probabilities does not imply stratification is not needed. Conversely, detection of differential marked fractions or differential recovery probabilities may indicate a need for stratification, but the effect of stratification may be moot because the bias induced by stratification may be small relative to the uncertainty of the estimates. A small spreadsheet-based computation can indicate the approximate size of the bias introduced by failing to stratify as a better guide for the need for stratification, regardless of the outcomes of the statistical tests.

Based on the datasets analyzed in Part II, there does not appear to be a need for stratified estimates for any species.

Alternatively, the Bayesian stratified model is self-calibrating in the sense that when data are sparse, the observed marked fractions are shrunk towards each other. In extremely sparse data, this will automatically approach a completely pooled-Petersen estimator and applying ad hoc methods to deal with this case is not necessary. It would be sensible, if practical, to always fit the stratified model and let the Bayesian model automatically deal with the choice of a stratified vs. unstratified model.

5.5 Time-stratified estimates

These methods are not feasible for most species because individual tags are not read further up the system with the exception of Sockeye Salmon where tag colour varies weekly or bi-weekly. It may also be possible for Coho Salmon because there are many individual tag recoveries at Meziadin Fishway.

Current analysis methods should also switch from SPAS to BTSPAS. The “fall-back” version of BTSPAS can be used to account for initial tagging mortality/fall back, removal of tags in the Nisg̱a’a Domestic Fishery, spawning between GW and GH, and tag-loss by specifying suitable values for the “fall-back” probability if these values do not vary much over strata. Hand computations would be needed to adjust the run size just upriver of GH to estimate the run size at GW. The advantage of using BTSPAS is that the estimated uncertainty in the adjustments can be incorporated into the overall uncertainty.

Additional development of BTSPAS would be needed if the tag availability proportions varied by release strata.

5.6 In-season estimation

The current procedures for generating the in-season forecast of the total run are quite complicated and much of the data are used multiple-times in each of the steps. One recommendation for a more direct approach that may be easier to implement and understand where a regression of the total run (based on post-season estimates) is regressed against the cumulative catch by day x at the GW fishwheels based on the historical results, where covariates such as water levels could be incorporated. This is much more direct, and it is simpler to add prediction intervals using standard regression methods.

5.7 Removals from in-river fisheries

Removals of tags in the Nisg̱a’a harvest are currently based on information collected from individual sale fisheries (ISF). In some years, no ISF are conducted/monitored, and so no information is available. We recommend addressing this in a Bayesian formulation by the prior on the marked fraction in the ISF and can be set to any appropriate value along with a measure of uncertainty.

Non-selective removal of tags in the upper Nass fisheries does not need to be accounted for in the estimation procedures because the capture-recapture methodology automatically accounts for such non-selective harvests (this has no impact on the marked fraction in the second sample).

5.8 Addressing lower Nass stocks

For some species, stocks that originate from the lower Nass below the GW fishwheels may be captured at the GW fishwheels. For example, Coho Salmon from the Ksi Ts'oohl Ts'ap (Zolzap Creek) and Chinook Salmon from Ksi Hlginx̲ (Ishkeenickh River) have been documented at the fishwheels where they may drop back and spawn below the GW fishwheels. The Bayesian model described in the second report assumes that this movement is accounted for in the estimated initial mortality/fall back/drop out estimated from the radio-telemetry studies. Unless such movement is large, it is unlikely to have a high impact on the final estimates given the current level of uncertainty. Again we recommend addressing this uncertainty with a Bayesian approach as the Bayesian model could be modified to account for this, and this again shows the need for future radio-telemetry studies to approximate what happens to fish tagged at the GW fishwheels.

5.9 Minimum sample sizes and tagged fish in recovery samples

The current practice is to avoid computing estimates when the number of tagged fish recovered is small. The theory for capture-recapture methods does not depend on the number of tagged fish recovered or sample sizes in the recovery samples. However, as noted in Seber (1982), there is likely to be significant overestimation of abundance when the number of tagged fish recovered is less than 6. Additionally, the uncertainty in the estimates with very small sample sizes and/or small numbers of tagged fish recovered is likely to be so large that estimates are not useful in practice.

This current practice should be continued as a reasonable course of action.

5.10 Tag loss

Primary tag loss is an issue for Coho and Sockeye salmon and is estimated by reinspection of untagged fish at MF for anchor and spaghetti tags, respectively. Typically, about 1,000-2,000 fish with no observed tag are inspected for evidence of tag loss. On an individual year basis, this provides an estimate of tag loss with quite poor precision, but the Bayesian model uses a hierarchical model to share information across years so the small sample sizes in individual years do provide reasonable information on the tag-loss probability for a specific year. In Part 2 of this report, it is shown that the number of tags removed due to tag loss has an uncertainty of about 50%. While this seems large, the uncertainty in the estimated run size due to uncertainty about tag-loss is overwhelmed by the uncertainty induced in the run size by the small number of radio-telemetry studies. At this moment, additional sampling to estimate primary tag-loss is not warranted.

Notice that if multiple recovery locations are used, it is assumed that the primary tag loss measured at MF is applicable to the other recovery locations. This may not be justified if the additional recovery locations are very far upstream, but at the same time, these additional recovery stations typically have very few recoveries so any tag loss adjustment would be small. Additional study would be required at the KW recovery location where fish would need to be physically handled to detect primary tag loss.

5.11 Pooling data from multiple recovery locations

The Bayesian model assumes that the marked fraction as fish move upriver is the same at all recovery locations. For example, recoveries of Chinook Salmon at Meziadin Fishway, Kwinageese Weir, Damdochax Creek, and Cranberry River are pooled in the model.

In some cases, the marked fractions may differ among locations or problems may exist with part of a location's recovery data. For example, in 1997, one of the Chinook Salmon observers was found to not have recorded recaptures properly. In the latter case, these data should be excluded from the data for that location.

In some cases, (e.g., refer to the comments about the marked fraction at MF and KW for Sockeye Salmon below) the marked fraction is different among recovery locations. Assuming that this is not an artefact of data collection procedures, a differential marked fraction may be an indication of differential marking at the fishwheels among stocks that pass different upstream locations, or differential tag-loss, harvest, or in-river mortality between tagged or untagged fish among the stocks as they move upriver. Generally speaking, recovery locations where the majority of the migration is inspected and tag recoveries are greater than 6 (e.g., MF and KW) can be effectively modeled using the Bayesian model.

Fish are also recaptured at the GH fishwheels and the number of tagged fish in the sample is also recorded. Currently, this information is not used except for in-season estimation. In theory, if the GH fishwheels are non-selective for tagged/untagged fish, they also could be used in the Bayesian models. However, it is not clear if drop out/fall back/initial mortality or tag loss have fully occurred between GW and GH and so the modelled number of tagged fish available for recapture at GH may not be correct. "Trap happy" behavior has been also suggested (Link and Nass 1999; Alexander et al. 2015) as a potential bias issue (i.e., tagging bank orientated fish that are captured in higher proportion using same capture gear). These issues would require further examination before including recaptures at GH in post-season run size estimates.

Alternative potential mark recovery locations further upstream for the different species are discussed below.

5.11.1 Chinook Salmon

It may be possible to also include information from aerial surveys if methodology could be developed to estimate the number of tagged fish, because operculum tags are not visible from the air. On the ground" examination of the stream to determine visibility/loss of tags would be necessary for adjusting the estimates.

Currently, the abundance estimation program only uses verified captures where both the tag and batch marking can be determined (so tag loss is not an issue) and excludes all additional surveys where only observed tags are reported. For example, the tag loss information collected at Damdochax Creek may be useful for further adjusting observed tags in other surveys for tag loss but note that batch marks are generally not visible at Damdochax, only the hole and tag mark on the operculum..

5.11.2 Coho Salmon

It is possible to include recaptures at the Kwinageese Weir for the Bayesian model, but some care is needed to determine whether the primary tag loss estimate from Meziadin Fishway is appropriate for all stocks. On average from 2009-2023, 1,122 Coho Salmon have been video counted at the Kwinageese Weir from mid-July to mid-October with 23 anchor tag recoveries (range: 0-79).

If fish at KW are to be used in the Bayesian model, we recommend only using the fish with observed tags. The tag loss correction is then applied to all tags released after mortality is estimated the results of subsampling at MF.

5.11.3 Sockeye Salmon

Additional fish are inspected and tags are recovered at KW from annual monitoring since 2009. However, the marked fraction appears to be appreciably different than MF. For example, in 2019, 2,021 tags were recovered from 88,128 inspected at MF (2.3% mark rate), but only 68 tags were recovered in 6,161 inspected at KW (1.1% mark rate). Similarly, in 2020, the mark-rate at MF was 3.2% and 1.8% at KW. The likely explanation of lower mark rates for the Kwinageese Sockeye stock vs. Meziadin Sockeye stocks is lower capture proportions at the GW fishwheels when fishwheels are operating at lower water levels. The Kwinageese Sockeye run timing passing the GW fishwheels is much later than the major Meziadin Sockeye sub stocks (e.g., Hanna and Tintina) that pass at higher water levels and higher capture/tagging rates (Alexander et al. 2023). The reasons for this are unknown. We recommend that collaborative work be undertaken for further investigation into the causes for discrepancies between mark rates generated from all programs and to develop criteria and protocols for inclusion of recovery data from other programs.

Like Coho Salmon, if sockeye at KW are to be used in the Bayesian model, we recommend only using the fish with observed tags. The tag loss correction is then applied to all tags released after mortality is estimated the results of subsampling at MF.

On average from 2009-2023, 73 (range: 0-244) spaghetti tag recoveries were video counted at KW from Sockeye Salmon counts averaging 5,364 (range: 48-19,797).While the KW capture-recapture data are numerically sufficient to include in future Bayesian modelling, tag loss data are not available.

5.11.4 Summer-run steelhead

Summer-run steelhead are also tagged at both fishwheel locations (similar to Chinook Salmon). However, habitat-capacity modelling and historical GSI data (Table 19) shows that only about 3% of fish are predicted to spawn between the GW and GH. Consequently, the additional complexity in adjusting the tags applied at GW for tagged fish that belong to the Ksi Sii Aks (Tseax River) and Ksi Sg̲asginist (Seaskinnish Creek) stocks may be moot, but annual productivity changes to these systems in recent years may make the Bayesian modelling helpful for future assessments.

Currently, a minimum of 12 tagged summer-run steelhead needs to be recaptured before the capture-recapture estimates are used; for small sample sizes, the index method is used. This seems like a reasonable course of action (see previous comments).

5.12 Improved data management

Many hundreds of spreadsheets in many workbooks were examined during this review. These often represent consecutive years of the same analysis/reporting in a somewhat standardized formatting. However, given that data may appear in several worksheets and given the (understandable) difficulty in maintaining consistency and in updating the individual spreadsheets, there were often (mostly minor) inconsistencies in the worksheets (e.g., wrong date, same data differs slightly among sheets). It is often not clear which spreadsheet is the final version. Consequently, it is recommended that some reorganizing of the way in which these data are stored and presented be undertaken to rationalize where data are stored (e.g., a central database contains the original data), and to rationalize reporting from the data base (e.g., a script is used to extract and report from the centralized database).

Similarly, complex calculations in a spreadsheet (e.g., in-season estimation) are difficult to understand and it is easy to introduce errors into the worksheets when updating the data. It may be beneficial to convert complicated spreadsheets to *R* code to make it easier to maintain and review.

There may also be some benefit in standardizing the annual reports (e.g., using RMarkdown or similar software) to ensure that reports are consistent across years, computed properly, and always use the final data values.

5.13 Recommendations for Additional Studies

5.13.1 Radio-telemetry studies

The fall back/drop out/initial mortality estimated from radio-telemetry studies includes all three sources of tag removals and cannot distinguish between these sources unless additional telemetry stations are included in the design downriver of the radio-tagging site.

Radio-tagged fish lost to harvest should be “ignored” and not included in the fall back/drop out/initial mortality probability because harvest is either accounted for in the number of tags removed by the Nisg̲a’a harvest, in the number of tags removed in fishwheel harvests, or does not matter if harvest upstream is non-selective between tagged and untagged fish and the capture-recapture estimate automatically account for such harvest.

Future studies should be carefully designed so that they provide information about the fate of fish tagged at the fishwheels. For example, if the radio-tagging study selected fish far downstream of the GW fishwheels, then some of these radio-tagged fish may belong to stocks that don’t migrate to the upper Nass (and should be excluded from the analysis). A genetic sample from each sampled fish may be helpful to know the stock the sampled fish represents. If the radio-tagging study was conducted at the GW fishwheels, then sampled fish that do not belong to the upper Nass stocks are likely also sampled at the fishwheel and so the estimated fall back/drop out/initial mortality estimate should include those fish that do not migrate to the upper Nass.

Fall back/drop out/initial mortality may vary across years. Currently, estimates of these quantities are based on a small number of studies. The companion document on the Bayesian methods and second part of this report shows that most of the uncertainty in the number of tagged fish removed between GW and GH is due to uncertainty in the initial mortality/ fall back probability. Additional radio-telemetry studies are needed to estimate fall back/drop out/initial tagging mortality in multiple years so that the variability in this value can be determined. Presumably, a simpler survey setup than employed in previous radio telemetry studies (i.e., Robichaud and English 2006) would be suitable as it is not necessary to monitor tags all the way to the spawning grounds.

Unfortunately, the radio-tagging studies place additional stress on the fish and so the observed mortality/fall back/drop out may differ from that of fish captured and tagged at the fishwheels. Consequently, the initial mortality/fall back/drop out from the radio-tagged fish may overestimate the impact of tagging at fishwheels and so estimates of abundance may have a negative bias because the model then has a negative bias in the number of marked fish available upriver. There is no obvious way to rectify this problem so careful handling of radio-tagged fish will be essential. The Bayesian model could be adjusted to also include a prior belief on the amount of bias based on expert opinion, but this is unlikely to be data based.

At the moment, a simple hierarchical model is used to model fall back/drop out/initial mortality across years which assumes there is no additional information for a specific year. However, other observable factors, such as river condition or general observations about fish health in a year, may provide information that the probability for a particular year should be higher or lower than the hierarchical mean. The current Bayesian model cannot easily incorporate such information but could be modified to include covariate information or prior belief on adjustments to the yearly value. Covariate information will likely require 10-15 years of radio-telemetry data to estimate initial mortality along with the covariate information (e.g., measures of fish health).

5.13.2 PIT tagging

Adding PIT tags and readers in the system, e.g., at Meziadin Fishway (for Coho and Sockeye Salmon) and Kwinageese Weir (for Chinook, Coho, and Sockeye Salmon) may reduce costs because less personnel time will be needed to review video images, reduce tag loss, and improve observer efficiencies for detecting tags and reading individual recoveries more easily than the current system.

5.13.3 Incorporating genetic sampling in reverse capture-recapture estimation

The reverse-capture-recapture methods could provide large sample sizes and highly precise estimates to augment the current methodology if good estimates of escapement for stocks are available and the genetic analysis taken from the fishwheels is accurate.

A sub-sample of fish captured by the fishwheels is selected and scales and/or adipose tissue are collected. In many cases, these scale samples are subject to a genetic analysis and the stock composition of fish captured by the fishwheels can be determined (see 2.6 Genetic information).

If escapement information is available for a stock, this genetic information can be used to estimate total population abundance using a “reverse capture-recapture” method. For example, if a stock represents 10% of the escapement and 2,000 fish spawned, then the estimated initial run size is 2,000/0.10 = 20,000 fish.

This methodology is explained in more detail in Hamazaki and DeCovich (2014). The key assumptions for the genetic reverse-capture-recapture method (in addition to the usual for a Petersen estimator) are discussed in Beveridge et al. 2019 (p.31). They include:

1. Complete enumeration of stock on the spawning ground or at a weir. A complete enumeration of the stock is needed to ensure that the “tagging” event is complete. This assumption could be violated by the stock spawning elsewhere (e.g., mainstem), or not all spawning areas surveyed. Or multiple stocks with different genetic baselines could spawn in the same spawning grounds.
2. The genetic baseline is complete and accurate. The baseline needs to be complete in order to confidently assign individuals to the “marked” (genetically distinct) population. If incomplete, individuals from genetically similar populations may be assigned to the “marked” population (see below) because it is the “closest” populations for assignment. This assumption can be relaxed if “not in baseline” is an acceptable assignment for samples from stocks not in the baseline. The genetic baseline must also be accurate, e.g., fish that form the baseline really belong to the stock of interest and are not a mixture of multiple stocks.
3. Marked population is genetically distinct. The identified “marked” population needs to be genetically distinct from all other populations in the Nass so that individuals from genetically similar populations are not assigned to the “marked” population introducing bias in the estimated proportion of the “marked” population during the “second” sampling occasion at the fishwheels.
4. Marked population size. While the size of the “marked population” theoretically has no bearing on the estimator, a small stock may have too few “recaptures” in the biological samples and so the estimator may have very poor precision.
5. Equal enroute mortality among different components of the run. Enroute morality in the reverse capture-recapture method acts like “immigration” in the forward capture-recapture methods and so leads to valid estimates at the fishwheels. Homogeneous enroute mortality may be violated when there are differential stock-specific harvest rates among stocks. This assumption can be assessed in the harvest through tissue collection of harvested individuals. The assumption may also be violated if stocks have different distances between the fishwheel and their spawning sites and so the enroute mortality may also differ. One way to test this assumption is via the goodness of fit testing of equal recovery probabilities discussed earlier.
6. Random sampling at the fishwheels. Random sampling at the fishwheels would occur if the fishwheels are sampling approximately proportional to the run and a constant fraction of the tagged fish have biological samples taken, e.g., every n^{th}

tagged fish is sampled. Currently, tissue samples are only collected at the first marking location (Gitwinksihlkw fishwheels). This will satisfy the assumption of random sampling at the fishwheels.

5.13.3.1 Reverse capture-recapture estimation for Chinook salmon using GSI

More explicitly, consider the escapement estimate for Chinook Salmon at Damdochax Creek. The AUC estimate is 338 fish (Table D-3 of the 2018 Chinook Salmon report [Beveridge et al. 2019]). These are treated as number of Marks. A total of 313 fish were genetically typed (Beveridge et al. 2019) of which 11.6% or 0.116 x 313 = 36 are from Damdochax Creek. This gives a Petersen estimate of total escapement of 338 x 313 / 36 = 2,938 fish. However, this estimate is much smaller than the estimated total escapement of around 17,000. A similar discrepancy occurs using escapement from the Kwinageese or Cranberry/Kiteen river systems and for the other species.

There are many issues that need careful attention for this method to work. For example, the Damdochax Chinook Salmon AUC estimates are based on only four surveys done over the year and may miss early or late fish, or fish that spawn in unsurveyed areas of the system, or smaller fish, and be impacted by uncertainty in survey life or observer efficiency. It likely should be used as an index to abundance only. Counts at Kwinageese Weir were impacted by a blockage upstream of the confluence with the Nass for a few years after 2011 (reference to reports).

The mismatch in the reverse-capture-recapture estimates and the forward-capture-recapture estimates for Chinook Salmon may be due to genetic uncertainty. We have assumed that genetic assignments are performing as expected, both with respect to procedures and methods, and with genetic baseline performance. However, the poor match between recovery locations and genetic stock identities in 2011 (Alexander et al. 2012), 2012 (Alexander et al. 2013), 2013 (Alexander et al. 2014), and 2014 (Alexander et al. 2015) suggests that genetic stock ID data for populations of Nass River Chinook Salmon should be treated cautiously. One potential problem with the baseline genetic samples for Nass Chinook Salmon populations is that some samples may have been obtained from migrating fish and not from the actual spawning population (e.g., samples collected at Meziadin Fishway or tributary angling samples collected in the lower reaches of tributaries early in the season). Sampling of this type risks including fish from other populations that have nosed into a system in the genetic baseline sample for that system. Nass Chinook Salmon genetic baseline data should be further evaluated to identify samples of this type and where possible baselines should be replaced with samples from fish captured during or after spawning.

Another possible explanation for the poor match between recovery locations and genetic stock identities is that Upper Nass River Chinook Salmon constitute a single meta-population. For populations upstream of and including the Cranberry River; pairwise F_{ST} values are generally less than 0.01, suggesting that these populations are poorly differentiated from each other (Figure 6). It is possible that this is a consequence of the volcanic eruption which impacted the lower Nass River approximately 250 years ago (Williams-Jones et al. 2020). If this eruption extirpated most or all Chinook Salmon stocks upstream, current Upper Nass Chinook Salmon populations may have recently diverged from a small colonizing population.

If these problems could be resolved, the reverse capture-recapture estimates are easily incorporated into the Bayesian model.

5.13.3.2 Using GSI data to assess enroute losses for Sockeye Salmon

Reverse capture-recapture methodology may also be used to inform abundance estimates for Nass sockeye. The biggest proportion of Nass sockeye return to Meziadin Lake, and the various Meziadin stocks in the genetic baseline have generally good genetic differentiation and thus less uncertainty than for Chinook salmon.

Genetic stock identification may also be used to explore enroute losses and the potential for differential mortality between tagged and untagged fish. On average, Meziadin sockeye comprise 75% (range: 51-96%) of the aggregate sockeye return for years where GSI data are available (Table 18) The difference between the aggregate estimate for Nass sockeye and the Meziadin Fishway count ranges from 1 – 50% (average 22%) (Alexander et al. 2022).

As noted in the previous section, a key assumption of reverse capture-recapture abundance estimates using GSI is that mortality between tagged and untagged fractions is equal. There is potential for future studies to combine genetic and tagging data to investigate the difference between genetic capture recapture and standard escapement estimates across years with different conditions to infer the potential of differential mortality beyond what is captured in estimates of fallback, dropout and initial mortality of tagged fish.

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TABLES

Table 1. Summary of Chinook Salmon abundance estimates from 1994 to 2019. No adjustment for tag loss is made because only fish that are fully inspected for the presence of tags and adipose marks are used for Chinook Salmon recaptures.

Year	Marks released (M)	Marks removed: Nisga'a fisheries below GH n	%	Initial mortality, fall-back, drop out n	%	Loss of primary mark n	%	Net marks released (M adj)	Examined for marks (C)	Marks recovered (R)	GH estimate Population (N)	SE (N)	Nisga'a harvests above GW	Sport harvests between GW and GH	GW estimate Population (N)	SE (N)
1994	1,917	360	19	96	5	0	0	1,461	634	39	23,208	3,509	2,098	240	25,546	3,509
1995	719	110	15	36	5	0	0	573	379	21	9,914	2,006	1,812	166	11,892	2,006
1996	570	86	15	29	5	0	0	456	619	12	21,794	5,763	1,834	264	23,893	5,763
1997	2,541	246	10	127	5	0	0	2,168	1,486	165	19,429	1,378	1,877	253	21,559	1,378
1998	1,606	242	15	80	5	0	0	1,284	1,573	85	23,517	2,451	1,595	200	25,312	2,451
1999	2,502	308	12	125	5	0	0	2,069	356	62	11,729	1,330	1,608	132	13,469	1,330
2000	1,907	522	27	95	5	0	0	1,290	443	30	18,489	3,152	2,498	400	21,616	3,152
2001	3,600	824	23	180	5	0	0	2,596	1,614	144	28,924	2,284	5,457	321	34,703	2,284
2002	1,246	377	30	62	5	0	0	807	2,341	135	13,913	1,154	1,875	296	16,081	1,154
2003	1,536	375	24	77	5	0	0	1,085	834	33	26,670	4,415	2,403	400	29,462	4,415
2004	979	304	31	49	5	0	0	626	853	33	15,748	2,608	1,926	320	17,984	2,608
2005	957	261	27	48	5	0	0	648	1,550	69	14,379	1,668	2,262	260	16,765	1,668
2006	1,499	342	23	75	5	0	0	1,082	1,472	64	24,541	2,953	3,525	444	28,618	2,953
2007	1,782	637	36	89	5	0	0	1,056	942	43	22,652	3,297	4,020	423	27,173	3,297
2008	801	66	8	40	5	0	0	695	728	24	20,294	3,911	1,085	340	21,687	3,911
2009	1,213	213	18	61	5	0	0	939	1,692	57	27,437	3,510	2,785	470	30,853	3,510
2010	363	94	26	18	5	0	0	251	1,191	15	18,773	4,522	1,703	270	20,706	4,522
2011	1,432	216	15	72	5	0	0	1,144	1,157	123	10,692	904	1,232	121	12,018	904
2012	3,081	378	12	154	5	0	0	2,549	1,095	299	9,315	458	1,460	329	11,309	458
2013	1,654	340	21	83	5	0	0	1,231	1,100	155	8,694	643	1,711	231	10,841	643
2014	1,480	321	22	74	5	0	0	1,080	706	56	13,407	1,688	1,941	499	18,847	1,688
2015	2,814	842	30	141	5	0	0	1,830	1,242	125	18,778	1,580	3,175	309	22,262	1,580
2016	1,217	226	19	61	5	0	0	930	900	85	9,379	956	1,519	111	11,009	956
2017	637	97	15	32	5	0	0	508	287	30	4,568	763	1,047	63	5,677	763
2018	793	142	18	40	5	0	0	610	560	22	14,510	2,900	1,779	150	16,289	2,900
2019	1,500	224	15	75	5	0	0	1,201	793	85	10,796	1,093	2,223	192	13,211	1,093

Table 2. Summary of Coho Salmon abundance estimates from 1994 to 2019.

		Marks removed									GH estimate				GW estimate	
Year	Marks released (M)	Nisg̱a'a fisheries below GH n	%	Initial mortality, fall-back, drop out n	%	Loss of primary mark n	%	Net marks released (M adj)	Examined for marks (C)	Marks recovered (R)	Population (N)	SE (N)	Nisg̱a'a harvests above GW	Sport harvests between GW and GH	Population (N)	SE (N)
1994	4,811	337	7	481	10	144	3	3,849	3,570	95	143,204	14,343	553	135	143,891	14,343
1995	842	74	9	84	10	25	3	658	1,792	52	22,308	2,991	439	21	22,768	2,991
1996	669	47	7	67	10	20	3	535	1,951	23	43,610	8,668	803	41	44,454	8,668
1997	1,020	71	7	102	10	31	3	816	637	41	12,410	1,829	75	12	12,497	1,829
1998	2,716	190	7	272	10	81	3	2,173	1,991	114	37,653	3,394	57	36	37,746	3,394
1999	4,055	284	7	406	10	122	3	3,244	2,974	168	57,123	4,255	70	54	57,247	4,255
2000	2,078	68	0	208	10	62	3	1,802	1,423	35	71,326	11,577	757	91	72,174	11,577
2001	3,317	637	16	332	10	100	3	2,348	5,942	173	80,227	5,975	9,206	103	89,536	5,975
2002	3,806	251	4	381	10	114	3	3,174	5,082	99	161,390	15,900	6,336	102	167,828	15,900
2003	2,349	522	19	235	10	70	3	1,592	3,907	91	67,674	6,934	9,857	43	77,574	6,934
2004	3,088	1,070	32	309	10	93	3	1,710	4,172	154	46,053	3,618	13,998	54	60,105	3,618
2005	4,371	752	14	437	10	131	3	3,182	7,189	259	88,008	5,348	11,760	138	99,906	5,348
2006	3,148	596	16	315	10	94	3	2,237	5,466	251	48,551	2,981	6,156	22	54,729	2,981
2007	1,905	377	17	191	10	57	3	1,337	2,500	67	49,224	5,845	6,609	110	55,944	5,845
2008	4,138	48	1	414	10	124	3	3,552	3,861	162	84,183	6,433	609	24	84,815	6,433
2009	5,059	741	15	253	5	658	13	3,392	5,423	96	189,733	18,994	11,446	503	201,682	18,994
2010	3,302	469	14	165	5	363	11	2,315	4,063	111	84,042	7,796	8,028	104	92,174	7,796
2011	1,786	17	2	107	6	71	4	1,565	2,562	54	72,975	9,646	1,040	101	74,116	9,646
2012	4,450	455	9	267	6	712	16	3,068	5,135	251	62,548	3,835	6,778	57	69,383	3,835
2013	3,422	586	17	205	6	137	4	2,487	6,697	141	117,356	9,709	12,479	73	129,908	9,709
2014	5,084	395	7	305	6	356	7	4,068	8,452	291	117,791	6,762	5,317	115	123,223	6,762
2015	1,721	123	7	103	6	138	8	1,361	3,014	97	41,901	4,142	2,172	189	44,262	4,142
2016	3,726	302	39	224	6	522	14	2,713	7,684	155	133,698	10,561	3,466	111	137	10,561
2017	4,457	204	6	267	6	401	9	3,544	10,205	336	107,359	5,742	5,466	869	113,694	5,742
2018	1,318	13	0	79	6	119	9	1,116	2,392	45	58,107	8,394	716	156	58,979	8,394
2019	3,442	4	0	207	6	207	6	3,026	6,024	223	81,417	5,326	716	156	82,319	5,326

Table 3. Summary of Sockeye Salmon estimates from 1994 to 2019.

Year	Marks released (M)	Marks removed: Nisga'a fisheries below GH n	%	Initial mortality, fall-back, drop out n	%	Loss of primary mark n	%	Net marks released (M adj)	Examined for marks (C)	Marks recovered (R)	GH estimate: Population (N)	SE (N)	Nisga'a harvests above GW	Sport harvests between GW and GH	GW estimate: Population (N)	SE (N)
1994	10,916	546	5	1,092	10	546	5	8,733	158,627	4,794	288,937	4,109	10,167	0	299,104	4,109
1995	9,031	433	5	903	10	542	6	7,062	205,853	5,139	282,868	3,896	13,779	0	296,647	3,896
1996	4,843	242	5	484	10	242	5	3,874	181,840	3,033	232,245	4,180	9,126	0	241,371	4,180
1997	6,513	326	5	651	10	326	5	5,210	158,656	3,098	266,782	4,745	11,167	0	277,950	4,745
1998	4,030	202	5	403	10	202	5	3,224	163,998	1,875	281,927	6,470	9,189	0	291,116	6,470
1999	10,755	538	5	1,076	10	538	5	8,604	180,350	6,483	239,345	2,918	9,304	0	248,649	2,918
2000	6,833	1,666	24	683	10	0	0	4,484	137,042	2,964	207,283	3,765	36,293	0	243,576	3,765
2001	6,841	1,799	26	684	10	0	0	4,358	116,192	2,982	169,796	3,068	34,736	0	204,532	3,068
2002	10,292	1,785	17	1,029	10	0	0	7,478	332,442	6,027	412,455	5,264	57,627	0	470,082	5,264
2003	10,190	2,860	28	1,019	10	0	0	6,311	196,852	4,650	267,159	3,870	61,756	0	328,915	3,870
2004	12,463	4,368	35	1,246	10	0	0	6,848	140,923	4,417	218,478	3,235	65,233	0	283,711	3,235
2005	9,308	2,100	23	931	10	0	0	6,277	142,833	3,820	234,671	3,745	51,244	0	285,915	3,745
2006	11,626	2,250	19	1,163	10	0	0	8,213	146,954	4,694	257,101	3,691	39,236	0	296,337	3,691
2007	9,007	1,607	18	901	10	0	0	6,499	104,308	4,082	166,065	2,547	29,166	0	195,231	2,547
2008	9,297	516	6	930	10	186	2	7,625	150,396	5,016	228,616	3,173	7,711	0	236,327	3,173
2009	10,393	1,756	17	1,039	10	208	2	7,345	168,392	4,887	253,071	3,566	28,163	0	281,234	3,566
2010	6,140	1,378	22	614	10	123	2	3,999	159,120	2,670	238,164	4,569	23,314	119	261,597	4,569
2011	9,286	843	9	929	10	186	2	7,289	167,524	4,213	289,798	4,407	18,827	0	308,625	4,407
2012	13,106	1,651	13	1,311	10	917	7	9,166	144,923	6,112	217,326	2,720	22,074	0	239,400	2,720
2013	7,102	1,101	16	710	10	426	6	4,832	170,376	3,726	220,936	3,579	27,577	0	248,513	3,579
2014	7,950	1,200	15	795	10	477	6	5,507	144,920	2,875	277,546	5,123	23,514	12	301,072	5,123
2015	13,702	2,249	16	1,370	10	1,507	11	8,518	185,917	3,859	410,319	6,535	59,147	0	469,466	6,535
2016	7,516	927	12	752	10	526	7	5,337	109,868	2,015	290,912	6,418	13,223	0	304,135	6,418
2017	6,946	841	12	695	10	417	6	4,977	119,088	2,482	238,753	4,740	21,832	0	260,585	4,740
2018	6,009	898	15	721	12	361	6	4,192	96,827	1,676	242,098	5,859	15,347	0	257,445	5,859
2019	8,240	835	10	989	12	330	4	6,070	88,128	2,021	264,604	5,815	15,347	0	279,445	5,815

Table 4. Summary of steelhead estimates from 1997 to 2019.No adjustment for tag loss is made because steelhead only receive adipose fin marks. No steelhead were marked from 1994 to 1996.

		Marks removed									GH estimate				GW estimate	
		Nisga'a fisheries below GH		Initial mortality, fall-back, drop out		Loss of primary mark										
Year	Marks released (M)	n	%	n	%	n	%	Net marks released (M adj)	Examined for marks (C)	Marks recovered (R)	Population (N)	SE (N)	Nisga'a harvests above GW	Sport harvests between GW and GH	Population (N)	SE (N)
1997	394	3	0.7	24	6	0	0	368	293	12	8,344	2,180	53	0	8,397	2,180
1998	635	3	0.5	38	6	0	0	594	438	25	10,045	1,875	40	0	10,085	1,875
1999	571	3	0.5	34	6	0	0	534	542	29	9,683	1,690	26	0	9,709	1,690
2000	1,383	13	1.0	83	6	0	0	1,287	437	41	13,431	1,948	74	0	13,505	1,948
2001	1,346	32	2.4	81	6	0	0	1,233	513	55	11,325	1,416	25	0	11,350	1,416
2002	1,052	30	2.9	53	5	0	0	969	308	10	27,258	7,727	26	0	27,284	7,727
2003	549	16	2.9	27	5	0	0	506	30	1	7,856	4,387	13	0	7,869	4,387
2004	596	41	6.9	36	6	0	0	519	318	40	4,045	583	48	0	4,093	583
2005	693	24	3.4	42	6	0	0	628	389	34	7,008	1,114	82	0	7,090	1,114
2006	447	13	2.9	22	5	0	0	412	168	7	8,722	2,838	84	0	8,806	2,838
2007	749	15	2.1	45	6	0	0	689	210	24	5,823	1,072	41	0	5,864	1,072
2008	800	23	2.9	40	5	0	0	737	29	2	7,381	3,501	72	0	7,453	3,501
2009	1,608	46	2.9	80	5	0	0	1,482	51	6	11,014	3,622	137	0	11,151	3,622
2010	1,114	13	1.1	67	6	0	0	1,034	648	34	19,191	3,111	216	0	19,407	3,111
2011	879	25	2.9	44	5	0	0	810	62	1	25,545	14,512	86	0	25,631	14,512
2012	1,397	40	2.9	70	5	0	0	1,287	330	33	12,538	2,008	293	0	12,831	2,008
2013	554	16	2.9	28	5	0	0	511	224	7	14,385	4,709	225	0	14,610	4,709
2014	1,324	38	2.9	66	5	0	0	1,220	487	30	19,220	3,288	149	0	19,369	3,288
2015	547	16	2.9	27	5	0	0	504	166	7	10,541	3,428	166	0	10,707	3,428
2016	889	25	2.9	44	5	0	0	819	358	3	73,594	32,728	157	0	73,751	32,728
2017	778	22	2.9	39	5	0	0	717	222	17	8,894	1,956	68	0	8,962	1,956
2018	943	27	2.9	47	5	0	0	869	30	0	26,969	18,760	207	0	27,176	18,760
2019	558	16	2.9	28	5	0	0	514	202	7	13,067	4,269	18	0	13,085	4,269

Table 5. Summary of current tagging operations and adjustments to the number of fish tagged.

Event	Component	Species			
		Chinook	Coho	Sockeye	Summer-run steelhead
Tagging	Size (mm)				All sizes but majority of fish are >450mm
	Medium	500-754	400-580	450-580	
	Large	755+	581+	581+	
	Run timing	1 June ->	1 July ->	1 June ->	1 July ->
	Tag at GW	Yes	Yes	Yes	Yes
	Type of tag	Left operculum aluminum tag	Anchor tag	Spaghetti tag with colour varying by week	None
	Batch mark (GW)	Adipose punch	Adipose punch	Adipose punch	Adipose punch
	Genetic samples[a]	Yes	No	Yes	No
	Spawning between GW and GH[b]	Mean 14%	Yes, but information is not needed.	Yes, but information is not needed	Mean 2-3% based on studies
	Tag at GH	Yes	No	No	Yes
	Type of tag	Left Operculum aluminum tag			None
	Batch mark (GH)	Adipose V-clip			Adipose V-clip
	Genetic samples	Yes (scales)	No	No	No
Adjustments (for 2019)	Initial mortality, fall-back, dropout	5.0%	6.0%	12.0%	6.0%
	Tag loss	0.0%[c]	6.3%	4.8%	0.0% (fin clips)
	Sport harvest	0.0%	0.0%	0.0%	0.0%
	Nisg̲a'a domestic harvest	15.0%	0.1%	10.1%	2.9%
	Nisg̲a'a GH fishwheel harvest	0.0%	0.0%	0.0%	0.0%
Recapture	**Meziadin Fishway** 2019: Jul 1 to Oct 10	Full inspection of fish to check for tag status and batch mark and to stratify by size.	Stratification by size possible. Subsample to check for tag loss.	Stratification by size possible. Subsample to check for tag loss.	Stratification by size possible.
	Kwinageese Weir[d] 2019: Jul 12 to Oct 8	Full inspection of fish to check for tag status and batch mark	Stratification by size possible. Subsample to check for tag loss.	Stratification by size possible. Subsample to check for tag loss.	Sub-sample of fish to check for tag loss.
	Damdochax Creek 2019: Sep 5, 12, 14	Full inspection of fish to check for tag status and batch mark	Not used	Not used	Not used
	Cranberry River	Full inspection of fish to check for tag status and batch mark	Not used	Not used	Not used

[a] Scale samples for aging are collected from Chinook, Sockeye, Coho, and steelhead. For Chinook and Sockeye, a subsample are analysed for genetic stock identifcation. For coho and steelhead, the scales are archived at PBS for future genetic analyses if required.

[b] Spawning between GW and GH occurs primarily in Ksi Sii Aks (Tseax River) and Ksi Sg̲asginist (Seaskinnish Creek).

[c] No adjustment for tag loss is made because only fish that are fully inspected for the presence of tags and adipose punch/clips are used for Chinook Salmon recaptures. So a fish with a missing tag, but an adipose punch/clip is considered as a recovery of a tagged fish.

[d] Some steelhead and Coho Salmon would continue to enter the system after these dates but start dates are early enough to capture all returning fish. Coho Salmon and steelhead would also have some spawning below the weir site.

Table 6. Summary of the number of salmon and summer-run steelhead tagged at the Gitwinksihlkw fishwheels.

Year	Period of operation	Chinook Salmon	Coho Salmon	Sockeye Salmon	Summer-run steelhead
1994	7 Jun to 10 Sep	1,824	4,811	10,916	
1995	8 Jun to 4 Sep	719	842	9,031	
1996	29 May to 22 Sep	570	669	4,843	
1997	21 May to 2 Sep	1,882	1,020	6,513	248
1998	12 June to 20 Sep	942	2,716	4,030	169
1999	7 June to 30 Sep	1,205	4,055	10,755	306
2000	11 June to 18 Sep	1,516	2,078	6,833	407
2001	7 June to 14 Sep	2,058	3,317	6,841	382
2002	20 June to 9 Sep	1,048	3,806	10,292	286
2003	14 June to 5 Sep	1,214	2,349	10,190	238
2004	11 June to 10 Sep	979	3,088	12,463	223
2005	6 June to 16 Sep	957	4,371	9,308	169
2006	8 June to 3 Sep	1,499	3,148	11,626	141
2007	14 June to 20 Sep	1,782	1,905	9,007	172
2008	5 June to 6 Sep	801	4,138	9,297	275
2009	1 June to 12 Sep	1,213	5,059	10,393	442
2010	7 June to 17 Sep	363	3,302	6,140	250
2011	12 June to 6 Sep	589	1,786	9,286	323
2012	9 June to 13 Sep	1,164	4,450	13,106	502
2013	9 June to 11 Sep	568	3,422	7,102	130
2014	8 June to 6 Sep	404	5,084	7,950	576
2015	9 June to 6 Sep	1,279	1,721	13,702	336
2016	7 June to 9 Sep	423	1,726	7,516	412
2017	6 June to 8 Sep	214	4,457	6,946	285
2018	5 June to 7 Sep	319	1,318	6,009	469
2019	3 June to 9 Sep	727	3,442	8,240	276
2020	31 May to 12 Sep	788	2,670	9,812	276

Table 7. Summary of the number of salmon and summer-run steelhead counted at the Grease Harbour fishwheels.

Year	Period of operation	Adult salmon and steelhead counted				Tags counted				Mark rates			
		Chinook	Coho	Sockeye	Steelhead	Chinook	Coho	Sockeye	Steelhead	Chinook	Coho	Sockeye	Steelhead
1994	Data not available	-	-	-	-	-	-	-	-	-	-	-	-
1995	Data not available	-	-	-	-	-	-	-	-	-	-	-	-
1996	Data not available	-	-	-	-	-	-	-	-	-	-	-	-
1997	21 May to 2 Sep	1,449	552	14,367	146	142	50	312	6	10%	9%	2%	4%
1998	12 Jun to 20 Sep	1,850	2,064	11,808	517	64	153	194	13	3%	7%	2%	3%
1999	7 Jun to 30 Sep	2,119	2,710	21,226	309	347	412	770	24	16%	15%	4%	8%
2000	11 Jun to 18 Sep	2,994	5,677	20,462	1,038	385	546	604	226	13%	10%	3%	22%
2001	7 Jun to 14 Sep	7,575	17,183	18,886	1,020	767	1,199	665	212	10%	7%	4%	21%
2002	20 Jun to 9 Sep	5,021	9,489	33,366	804	257	439	779	102	5%	5%	2%	13%
2003	14 Jun to 5 Sep	3,903	7,015	29,696	334	291	313	1,037	44	7%	4%	3%	13%
2004	11 Jun to 10 Sep	2,211	8,062	25,789	415	202	516	1,353	70	9%	6%	5%	17%
2005	6 Jun to 16 Sep	2,950	9,324	25,588	545	179	638	819	76	6%	7%	3%	14%
2006	8 Jun to 3 Sep	7,268	5,873	34,324	319	491	588	1,686	51	7%	10%	5%	16%
2007	14 Jun to 20 Sep	7,236	9,380	26,000	586	543	601	1,249	123	8%	6%	5%	21%
2008	5 Jun to 6 Sep	3,610	10,480	23,028	694	219	990	1,190	136	6%	9%	5%	20%
2009	1 Jun to 12 Sep	5,803	13,922	28,040	1,226	359	807	1,341	340	6%	6%	5%	28%
2010	7 Jun to 17 Sep	728	9,037	17,694	927	30	501	471	114	4%	6%	3%	12%
2011	12 Jun to 6 Sep	1,146	3,574	23,538	645	155	175	835	136	14%	5%	4%	21%
2012	9 Jun to 13 Sep	2,691	10,194	40,181	983	1,019	755	2,261	240	38%	7%	6%	24%
2013	9 Jun to 11 Sep	1,369	10,184	26,337	476	248	389	693	67	18%	4%	3%	14%
2014	8 Jun to 6 Sep	1,447	11,059	27,763	1,040	200	580	948	187	14%	5%	3%	18%
2015	9 Jun to 6 Sep	2,285	4,876	48,611	505	398	214	1,312	100	17%	4%	3%	20%
2016	7 Jun to 9 Sep	1,063	11,600	28,315	728	157	366	676	110	15%	3%	2%	15%
2017	6 Jun to 8 Sep	541	18,054	35,323	805	71	680	838	140	13%	4%	2%	17%
2018	5 Jun to 7 Sep	572	4,146	18,205	693	52	148	602	113	9%	4%	3%	16%
2019	3 Jun to 9 Sep	1,038	11,941	24,103	445	187	580	797	51	18%	5%	3%	11%

Table 8. Summary of the number of salmon and summer-run steelhead inspected at the Meziadin Fishway from 1994 to 2019.

		Adult salmon and steelhead counted				Tags counted				Mark rates			
Year	Period of operation	Chinook	Coho	Sockeye	Steelhead	Chinook	Coho	Sockeye	Steelhead	Chinook	Coho	Sockeye	Steelhead
1994	Data not available	-	-	-	-	-	-	-	-	-	-	-	-
1995	Data not available	-	-	-	-	-	-	-	-	-	-	-	-
1996	Data not available	-	-	-	-	-	-	-	-	-	-	-	-
1997	5 Jul to 29 Sep	296	637	158,656	6	36	41	3,098	0	12.2%	6.4%	2.0%	0.0%
1998	29 Jun to 22 Oct	499	1,991	163,998	46	24	114	1,875	4	4.8%	5.7%	1.1%	8.7%
1999	4 Jul to 15 Oct	174	2,974	180,350	46	27	168	6,483	2	15.5%	5.6%	3.6%	4.3%
2000	29 Jun to 13 Oct	416	1,423	137,042	46	30	35	2,964	2	7.2%	2.5%	2.2%	4.3%
2001	4 Jul to 15 Oct	613	5,942	116,192	72	66	173	2,982	9	10.8%	2.9%	2.6%	12.5%
2002	1 Jul to 15 Oct	464	5,082	332,442	41	21	99	6,027	2	4.5%	1.9%	1.8%	4.9%
2003	2 Jul to 10 Oct	479	3,907	196,852	30	18	91	4,650	1	3.8%	2.3%	2.4%	3.3%
2004	3 Jul to 3 Oct	490	4,172	140,923	58	20	154	4,417	12	4.1%	3.7%	3.1%	20.7%
2005	1 Jul to 15 Oct	638	7,189	142,751	85	33	259	3,819	9	5.2%	3.6%	2.7%	10.6%
2006	1 Jul to 12 Oct	721	5,466	146,954	39	35	251	4,694	1	4.9%	4.6%	3.2%	2.6%
2007	1 Jul to 11 Oct	754	2,504	104,308	27	34	67	4,082	2	4.5%	2.7%	3.9%	7.4%
2008	1 Jul to 9 Oct	518	3,861	150,396	29	17	167	5,016	2	3.3%	4.3%	3.3%	6.9%
2009	1 Jul to 6 Oct	336	5,423	168,392	18	15	96	4,887	2	4.5%	1.8%	2.9%	11.1%
2010	1 Jul to 23 Oct	315	4,138	159,120	81	3	129	2,670	7	1.0%	3.1%	1.7%	8.6%
2011	1 Jul to 6 Oct	330	2,336	167,524	12	28	44	4,213	1	8.5%	1.9%	2.5%	8.3%
2012	1 Jul to 4 Oct	255	4,980	144,923	34	42	246	6,112	5	16.5%	4.9%	4.2%	14.7%
2013	1 July to 4 Oct	126	5,934	170,376	23	19	128	3,726	0	15.1%	2.2%	2.2%	0.0%
2014	1 Jul to 7 Oct	51	7,223	144,920	28	5	268	2,875	1	9.8%	3.7%	2.0%	3.6%
2015	1 Jul to 8 Oct	95	2,713	185,917	3	14	89	3,859	0	14.7%	3.3%	2.1%	0.0%
2016	30 Jun to 5 Oct	36	5,051	109,868	9	2	130	2,015	0	5.6%	2.6%	1.8%	0.0%
2017	1 Jul to 5 Oct	38	7,556	119,088	5	2	279	2,482	0	5.3%	3.7%	2.1%	0.0%
2018	30 Jun to 5 Oct	36	2,145	96,827	9	1	39	1,676	0	2.8%	1.8%	1.7%	0.0%
2019	30 Jun to 10 Oct	111	4,334	88,128	6	5	148	2,021	0	4.5%	3.4%	2.3%	0.0%

Table 9. Summary of the numbers of fish passing the Kwinageese Weir from 2002 to 2019.

		Adult salmon and steelhead counted				Tags counted				Mark rates			
Year	Period of operation	Chinook	Coho	Sockeye	Steelhead	Chinook	Coho	Sockeye	Steelhead	Chinook	Coho	Sockeye	Steelhead
2002	17 Jul to 17 Oct	1,893	1,283	5,891	267	114	8	86	8	6.0%	0.6%	1.5%	3.0%
2005	12 Aug to 22 Oct	538	2,663	3,186	304	19	59	37	25	3.5%	2.2%	1.2%	8.2%
2006	25 Aug to 5 Oct	410	1,582	2,700	129	27	51	123	6	6.6%	3.2%	4.6%	4.7%
2009	12 Jul to 15 Oct	895	60	107	33	28	0	0	4	3.1%	0.0%	0.0%	12.1%
2010	9 Jul to 19 Oct	131	191	48	110	2	8	0	7	1.5%	4.2%	0.0%	6.4%
2011	10 Jul to 5 Oct	740	226	10,273	50	87	10	240	0	11.8%	4.4%	2.3%	0.0%
2012	19 Jul to 11 Oct	715	155	3,688	296	224	9	143	28	31.3%	5.8%	3.9%	9.5%
2013	13 Jul to 11 Oct	813	763	397	208	109	13	4	7	13.4%	1.7%	1.0%	3.4%
2014	10 Jul to 14 Oct	560	1,229	438	459	41	25	3	29	7.3%	2.0%	0.7%	6.3%
2015	3 Jul to 9 Oct	1,093	301	7,044	163	108	8	60	7	9.9%	2.7%	0.9%	4.3%
2016	11 Jul to 13 Oct	853	2,633	19,797	380	83	25	244	4	9.7%	0.9%	1.2%	1.1%
2017	9 Jul to 14 Oct	241	2,649	7,240	217	27	58	71	17	11.2%	2.2%	1.0%	7.8%
2018	6 Jul to 15 Oct	456	247	290	21	18	6	2	0	3.9%	2.4%	0.7%	0.0%
2019	6 Jul to 8 Oct	518	1,690	6,007	196	64	75	66	7	12.4%	4.4%	1.1%	3.6%

Table 10. Summary of the number of Chinook Salmon examined and recaptured at Damdochax Creek, 1995 to 2019.

	Survey dates		Chinook Salmon		Marked
Year	August	September	Examined	Recaptured	fraction
1995	24	1, 9, 19	205	7	3.4%
1996	-	5, 15	271	5	1.8%
1997	27	5, 11, 16	480	48	10.0%
1998	-	7, 16, 23	844	49	5.8%
1999	-	7, 14, 21	24	4	16.7%
2000	-	3, 12	27	0	0.0%
2001	-	9, 13, 18	566	50	8.8%
2002	Not surveyed		-	-	-
2003	-	5, 13, 17	355	15	4.2%
2004	-	2, 8, 13, 16	95	4	4.2%
2005	-	8, 12, 15	386	15	3.9%
2006	-	9, 12, 15	578	18	3.1%
2007	-	7, 12, 19	188	9	4.8%
2008	-	8, 12, 13, 14	213	7	3.3%
2009	-	4, 13, 14, 15, 16	461	14	3.0%
2010	30	7, 13, 14, 15, 16	536	10	1.9%
2011	30	6, 16	87	8	9.2%
2012	-	4, 10, 15	125	33	26.4%
2013	29	5, 10, 14	161	27	16.8%
2014	28	4, 10, 14, 15	95	10	10.5%
2015	29	3, 8, 15	54	3	5.6%
2016	31	4, 10, 14	11	0	0.0%
2017	-	5, 10, 21	5	0	0.0%
2018	26	5, 10, 16	6	0	0.0%
2019	-	5, 10, 14	150	16	10.7%

Table 11. Detailed example of 2019 tagging and recovery data.

Section	River km[a]	Location	Species: Chinook	Coho	Sockeye	Steelhead
Marine	N/A	↓→ Nisga'a harvest				
		Gingolx gillnet	676	445	7,860	31
		Seine	N/A	N/A	N/A	N/A
		↓→ Escapement				
		Salmon Cove Creek		1,220		
		Dogfish Creek		92		
Freshwater		↓→ Nisga'a harvest				
		Laxgalts'ap gillnet	1,731	668	6,731	21
	N/A	Gitwinksihlkw (GW) gillnet	1,824	291	8,768	25
		Gitlaxt'aamiks gillnet	2,214	855	10,614	18
		Total (includes Gingolx)	6,446	2,279	33,973	95
Lower	24	↓→ Diskangieq Creek		2,096		
	37	↓→ Anudol Creek		Trace		
	46	↓→ Ansedagan Creek		112		
	55	↓→ Ksi Ts'oohl Ts'ap (Zolzap Creek)		879		
	60	↓ **Estimated run size to GW**	**13,512**	**82,319**	**268,000**	**13,067**
		↓→↑ GW fishwheels: Tagged	727	3,442	8,240	276
		↓→ Nisga'a harvest	2,223	855	14,841	16
		↓→ Sport harvest	192	46	0	0
	67	↓→ Ksi Sii Aks[b] (Tseax River)	GSI = 7.3% or 53 tags	No info	Gingit Creek 14,812 (AUC) Gitzyon Creek 420 (Peak)	GSI ≈ 1% or 3 tags
	74	↓→ Ksi Sgasginist[b] (Seaskinnish Creek)	GSI = 12.1% or 88 tags	No info	No info	GSI ≈ 1% or 3 tags
	78	↓ **Estimated run size to GH**	**11,097**	**81,417**	**253,159**	**13,067**
		↓→↑ GH fishwheels: Tagged	773	N/A	N/A	282
		Total tagged (GW + GH)	1,500	3,442	8,240	558
		Tags removed by[c]:				
		Nisga'a harvest	-224	-4	-835	-16
		Handling/fall back	-75	-207	-989	-28
		Tag loss	0	-205	-346	-2
		↓→ **Net tags above GH (M)[d]**	**1,201**	**3,026**	**6,070**	**514**

Table continues on next page

Table 11 continued.

Section	River km[a]	Location	Chinook	Coho	Sockeye	Steelhead
			Species			
Middle		↓→ Tchitin River	Trace	No info	Trace	No info
	107	Nass (Alice Arm) Bridge – UFN harvest	??	??	??	??
	114	↓→ Cranberry River	17 (C) 2 (R)	No info	Trace	No info
	146	↓→ Brown Bear Creek				
	205	↓ Meziadin Fishway	110 (C) 5 (R)	4,334 (C) 148 (R)	88,128 (C) 2,021 (R)	6 (C) 0 (C)
	205	↓ Meziadin River				
		UFN harvest	??	49	8,745	0
		Sport harvest		156	0	0
Upper	various	↓→ Other spawning areas	No info	No info	No info	No info
	232	↓→ Bell-Irving River	No info	No info	No info	No info
	247	↓→ Kwinageese Weir	516 (C) 62 (R)	1685 (C) 64 (R)	Not used	196 (C) 7 (C)
	315	↓→ Damdochax Creek	150 (C) 16 (R)	No info	4,675 (AUC)	No info
	various	↓→ Other spawning areas	No info	No info	No info	No info
		Pooled Petersen				
		Net tags above GH (M)	1,201	3,026	6,070	514
		Examined (C)	793	6,019	88,128	202
		Tags recaptured (R)	85	212	212	7
Estimated run size at GH			**11,097**[e]	**85,551**	**253,159**	**13,067**
		Nisga'a Harvest between GW and GH	2,223	853	14,841	18
		Sport Harvest between GW and GH	192	46	0	0
		Escapement between GW and GH	32,521	Not needed	Not needed	3
N̂ at GW			**16,764**	**86,452**	**268,000**	**13,085**

[a] Measured from the Area 3-12 boundary.

[b] GSI indicates that about 2-3% of steelhead at GW belong to the Ksi Sii Aks and Ksi Sg̱asginist stocks, but no adjustment is currently made in the number of tags available upriver of GH or in adding back escapement between GW and GH.

[c] Steelhead were batch marked with a fin clip in 2019 so no tag loss expected.

[d] The estimated number of tags available at GH after adjustments for losses between GW and GH currently does not remove tags from Chinook Salmon that spawn in Ksi Sii Aks (Tseax River) or Ksi Sg̱asginist (Seaskinnish Creek)

[e] Footnote to Table 9 of the 2019 Chinook report (Beveridge et al. 2020) indicates that any escapement between GW and GH will be included in the estimated run-size at GH. As noted in this report, this is incorrect.

Table 12. Illustration of the number of tags removed by the Nisga'a gillnet harvest for Chinook, Sockeye and Coho salmon in 2019. Steelhead are not monitored.

			Domestic fishery			Individual sale fishery			Estimated	Estimated	
Species	River stratum	Total catch[a]	Tags returned	Estimated catch	% tags	Tags returned[b]	Observed catch	% tags	tags returned	tags removed[c,d]	% tags returned
Chinook	Upper	2,223	52	1,733	3.0%	40	490	8.2%	92	181	
	Middle	1,817	33	1,561	2.1%	6	256	2.3%	39	43	
	Lower	1,709	1	1,653	0.1%	0	56	0.0%	1	1	
	Total	5,749	86	4,947	1.7%	46	802	5.7%	132	225	59%
Coho	Upper	855	1	855	0.1%	0	0	0.0%	1	1	
	Middle	291	2	290	0.7%	0	1	0.0%	2	2	
	Lower	688	0	685	0.0%	0	3	0.0%	0	0	
	Total	1,834	3	1,830	0.2%	0	4	0.0%	3	4	86%
Sockeye	Upper	14,841	127	10,096	1.3%	191	4,745	4.0%	318	597	
	Middle	12,314	138	8,850	1.6%	52	3,464	1.5%	190	190	
	Lower	7,264	0	6,805	0.0%	3	459	0.7%	3	47	
	Total	34,419	265	25,751	1.0%	246	8,668	2.8%	511	835	61%

[a] Catch and tag removals are for periods commencing 31 May with the start of fishwheel operation. Note that the total catch used to expand the tag-fraction in the ISF may differ from the total catch reported in harvest monitoring due to timing issue. For example, harvest monitoring may measure harvest starting in May, but fishwheels may not start operating until June and so only the harvest from June onwards (when the fishwheels are operating and tagging fish) is used. In most cases, the difference in estimates of catch is small except for Sockeye Salmon in 2000-2006.

[b] Tags returned for all individual sale fisheries.

[c] Estimated tags removed for Sockeye and Chinook Salmon = Total catch (all fisheries) x % tags returned in the sale fishery.

[d] Estimated tags removed for Coho Salmon (shaded) = Total catch (all fisheries) x mean % tags returned (85.6%) from 2000 to 2017.

Table 13. Annual Chinook Salmon stock composition from radio-telemetry studies and genetic analyses, 1992 to 2019.

		Stock contribution (%)[a]								
Year	Method[b]	Damdochax	Kwinageese	Bell-Irving[c]	Meziadin	Cranberry	Kiteen	Ksi Sg̲asginist (Seaskinnish Creek)	Ksi Sii Aks (Tseax River)	Lower Nass/ Coastal[d]
1992	RT	22	13	26	9	14	3	3	5	4
1993	RT	23	8	19	6	17	3	8	14	1
2007	$GSI_{\mu S}$	5	17	13	8	12	25	10	8	3
2010	$GSI_{\mu S}$	20	21	10	6	14	19	1	5	3
2011	$GSI_{\mu S}$	15	13	11	13	23	21	1	2	3
2012	$GSI_{\mu S}$	22	14	10	9	14	21	1	4	4
2013	$GSI_{\mu S}$	14	19	11	6	4	29	10	3	3
2014	$GSI_{\mu S}$	8	12	10	9	22	19	8	8	3
2017	$GSI_{\mu S}$	12	9	14	5	15	15	9	13	8
2018	$GSI_{\mu S}$	11	14	11	3	25	17	5	9	4
2019	GSI_{SNP}	15	11	12	6	11	24	12	7	2
Mean		15	14	13	7	16	18	6	7	3

[a] Within the Nass River, the Chinook SNP panel currently in use by DFO has the highest resolution at the conservation unit level. The resolution of individual assignments to sub-stocks has lower resolution and greater uncertainty, but provides useful trend data on the distribution of stocks within the Nass watershed. In the upper Nass CU, the Ksi Sii Aks stock has high resolution.

[b] RT = radio telemetry studies; $GSI_{\mu S}$ = genetic stock identification from microsatellites; GSI_{SNP} = genetic stock identification from single nucleotide polymorphisms (SNP).

[c] Bell-Irving stocks include Oweegee, Teigen, and Snowbank. For the SNP baselines, Teigen and Snowbank have been grouped as Snowbank.

[d] Lower Nass/Coastal stocks can included Ksi Hlginx̲ (Ishkeenickh River) and Ksi Ging̲olx (Kincolith River).

Table 14. Summary of estimated tag compliance probabilities for the Nisga'a Domestic Fishery. Shaded cells indicate years and/or species where compliance monitoring was not conducted. Average values were used in those years.

	Species			
Year	**Chinook**	**Coho**	**Sockeye**	**Steelhead**
2000	60%	95%	79%	not available
2001	51%	89%	74%	not available
2002	37%	94%	95%	not available
2003	64%	99%	90%	not available
2004	57%	91%	85%	not available
2005	66%	87%	92%	not available
2006	76%	83%	93%	not available
2007	23%	71%	78%	not available
2008	23%	71%	78%	not available
2009	63%	62%	79%	not available
2010	50%	80%	67%	not available
2011	63%	94%	100%	not available
2012	84%	90%	89%	not available
2013	65%	86%	78%	not available
2014	61%	70%	88%	not available
2015	58%	87%	92%	not available
2016	62%	89%	61%	not available
2017	59%	88%	70%	not available
2018	64%	86%	63%	not available
2019	59%	86%	61%	not available

Table 15. Summary of tag-types used in the Nass River system from 1992 to 2020.

	Tag type[a] by species			
Year	**Chinook**	**Coho**	**Sockeye**	**Steelhead**
1992	O+R	S	S	S
1993	S+R	S	S	S+R
1994	O	S	S	S
1995	O	S	S+R	None
1996	O	S	S	None
1997	O	S	S	A
1998	O	S	S	A
1999	O	S	S	A
2000	O	S	S	A
2001	O	S	S	A
2002	O	S	S	FM
2003	O	S	S	FM
2004	O	S	S	A
2005	O	S+R	S	A+R
2006	O	S	S	FM
2007	O	S	S	A
2008	O	S+O	S	FM
2009	O	O	S	FM
2010	O	O	S	A
2011	O	A	S	FM
2012	O	A	S	FM
2013	O	A	S	FM
2014	O	A	S	FM
2015	O	A	S	FM
2016	O	A	S	FM
2017	O	A	S	FM
2018	O	A	S+R	FM
2019	O	A	S	FM
2020	O	A	S	FM

[a] A = anchor; O = operculum; R = radio; S = spaghetti;
FM = adipose fin mark

Table 16. Summary of Nisga'a harvest between Gitwinksihlkw (GW) and Grease Harbour (GH). Gillnet harvest values in the upper river stratum exclude fishwheel harvests.

	Nisga'a harvest between GW and GH[a]											
	Chinook Salmon			Coho Salmon			Sockeye Salmon			Steelhead		
	Fishwheel harvest			Fishwheel harvest			Fishwheel harvest			Fishwheel harvest		
Year	GW	GH	Gillnet	GW	GH	Gillnet	GW	GH	Gillnet	GW	GH	Gillnet
1994	0	0	2,098	0	0	553	0	0	10,167	0	0	150
1995	0	0	1,812	0	0	439	0	0	13,779	0	0	100
1996	0	0	1,834	0	0	803	0	0	9,126	0	0	150
1997	0	0	1,877	0	0	75	0	0	11,167	0	0	38
1998	0	0	1,595	0	0	57	0	0	9,189	0	0	83
1999	0	0	1,608	0	0	70	0	0	9,304	0	0	60
2000	0	0	2,583	0	517	240	1,876	13,872	22,421	0	0	114
2001	48	1,852	3,605	569	5,176	4,030	4,263	8,004	26,732	0	0	199
2002	0	0	1,875	344	4,031	2,305	5,005	15,891	41,736	0	0	265
2003	0	0	2,403	0	3,355	6,522	2,954	25,258	36,498	0	0	244
2004	0	0	1,926	0	6,876	7,122	2,627	22,370	42,854	0	0	263
2005	0	0	1,943	0	8,533	2,654	1,963	15,028	35,673	0	0	36
2006	0	1,031	2,153	0	5,080	762	1,334	16,183	22,949	0	0	48
2007	0	2,004	2,016	0	5,694	915	0	12,074	17,092	0	0	41
2008	0	0	1,085	0	0	609	0	0	7,711	0	0	72
2009	0	1,031	1,754	0	10,340	1,106	0	8,262	19,901	0	0	137
2010	0	155	1,548	0	6,927	1,101	0	6,023	17,291	0	0	216
2011	0	0	1,232	0	518	522	0	1,793	17,034	0	0	86
2012	0	0	1,431	0	677	6,762	0	39	21,675	0	0	293
2013	0	0	1,711	0	5,629	6,520	0	5,097	22,376	0	0	219
2014	0	0	1,921	0	4,158	1,159	0	4,916	18,447	0	0	149
2015	0	0	3,175	0	138	2,035	0	7,508	51,639	0	0	166
2016	0	0	1,519	0	496	3,466	0	0	13,233	0	0	157
2017	0	0	1,047	0	940	4,526	0	0	21,832	0	0	68
2018	0	0	1,779	0	0	716	0	0	15,347	0	0	137
2019	0	0	2,223	0	0	855	0	0	14,841	0	0	18

[a] Upper catch monitoring stratum

Table 17. Non-Nisga'a sport harvest between Gitwinksihlkw and Grease Harbour, 1994 to 2019.

	Non-Nisga'a sport catch			
Year	**Chinook**	**Coho**	**Sockeye**	**Steelhead**
1994	240	135	0	0
1995	166	21	0	0
1996	264	41	0	0
1997	253	12	0	0
1998	200	36	0	0
1999	132	54	0	0
2000	400	91	0	0
2001	321	103	0	0
2002	296	102	0	0
2003	400	43	0	0
2004	320	54	0	0
2005	260	138	0	0
2006	444	22	0	0
2007	423	110	0	0
2008	340	24	0	0
2009	470	503	0	0
2010	270	104	119	0
2011	121	101	0	0
2012	329	57	0	0
2013	231	73	0	0
2014	499	115	12	0
2015	309	189	0	0
2016	111	111	0	0
2017	63	869	0	0
2018	150	156	0	0
2019	192	156	0	0

Table 18. Stock composition estimates from genetic analysis of Sockeye Salmon in selected years. Provided by JTC.

Stock	2000	2001	2002	2005	2009	2010	2011	2013	2014	2015	2018	2019	Mean
Bonney	0%	0%	1%	2%	2%	2%	2%	1%	0%	4%	0%	2%	1%
Bowser	2%	3%	1%	2%	2%	3%	3%	3%	4%	3%	3%	2%	3%
Damdochax	2%	6%	0%	1%	2%	2%	4%	4%	5%	3%	4%	6%	3%
Gingit_RT	3%	7%	0%	3%	12%	9%	10%	7%	6%	10%	24%	32%	10%
Hanna_Cr	28%	22%	17%	33%	22%	21%	18%	19%	30%	21%	7%	16%	21%
Kwinageese	0%	3%	2%	2%	0%	3%	3%	0%	0%	3%	1%	1%	2%
Meziadin_beach	32%	23%	34%	22%	20%	14%	26%	21%	18%	13%	19%	9%	21%
Tintina_Cr	13%	25%	33%	21%	23%	25%	12%	33%	15%	17%	19%	14%	21%
Strohn_Cr	2%	4%	12%	7%	14%	10%	18%	11%	16%	21%	18%	12%	12%
Brown_Bear_RT	17%	8%	0%	8%	3%	10%	4%	2%	6%	5%	6%	7%	6%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 19. Stock composition estimates from genetic analysis of steelhead in selected years. Notice that the Ksi Sgasginist (Seaskinnish) stock was not included in the genetic baseline, so this stock is missing from the GSI analyses.

	Stock composition method										
		Radio-telemetry		Genetic analysis							
System	**Habitat[a]**	**1993[b]**	**2005**	**1998[c]**	**1999[d]**	**2000[d]**	**2005[e]**	**2007[e]**	**2009[e]**	**2010[e]**	**Mean[j]**
Damdochax	12%	31%	14%	17%	14%	5%	24%	32%	19%	12%	18%
Kwinageese	2%	3%	13%	16%	20%	33%	31%	10%	14%	10%	19%
Bell-Irving	61%	6%	17%	39%	31%	32%	20%	26%	30%	23%	28%
Meziadin	1%	8%	16%	1%	2%	3%	3%	9%	12%	29%	9%
Cranberry-Kiteen	19%	17%	20%	27%	33%	27%	21%	19%	25%	24%	25%
Below Cranberry Main.	0%	11%	9%								
Kinskuch	0%	0%	1%								
Tchitin	2%	0%	1%								
Below Grease Harbour	0%	11%	4%								
Ksi Sgasginist (Seaskinnish)	1%	3%	1%								
Ksi Sii Aks (Tseax)	1%	11%	1%				0%	3%	0%	2%	1%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

[a] Habitat capacity estimates from Bocking et al. 2005.

[b] Alexander and Koski 1995.

[c] Genetic results from Beacham et al. 2000.

[d] Genetic results from Nelson et al. 2001.

[e] Unpublished genetic results from DFO PBS (John Candy) in 2014.

[j] Mean genetic stock composition estimates from 1998-2000, 2005, 2007, 2009 and 2010 studies.

Table 20. Summary of the number of fish sampled for biological data at the fishwheels in 2019.

		Sampled at fishwheels (2019)					Proportion of tagged fish				
Species	Tagged	Size class	Size	Sex	Age	Genetics	Size class	Size	Sex	Age	Genetics
Chinook Salmon	1,500	1,500	1,491	1,488	664	468	100%	99%	99%	44%	31%
Coho Salmon	3,442	2,442	2,441	3,434	495	-	71%	71%	100%	14%	-
Sockeye Salmon	8,240	1,345	906	1,337	1,189	498	16%	11%	16%	14%	6%
Steelhead	558	556	556	553	276	-	100%	100%	99%	49%	-

Table 21. Summary of the number of fish sampled for biological data at the Meziadin Fishway in 2019.

			Sampled at Meziadin Fishway (2019)					Proportion of counted fish				
Species	Count type	Count	Size class	Size	Sex	Age	Genetics	Size class	Size	Sex	Age	Genetics
Chinook Salmon	All	110	5	5	5	5	-	5%	5%	5%	5%	-
	Recap	5	5	5	5	5	-	100%	100%	100%	100%	-
Coho Salmon	All	4,334	467	467	466	467	-	11%	11%	11%	11%	-
	Recap	148	130	130	130	18	-	88%	88%	88%	12%	-
Sockeye Salmon	All	88,128	1,125	1,125	1,122	1,125	-	1%	1%	1%	1%	-
	Recap	2,021	1,880	1,874	1,869	122	-	93%	93%	92%	6%	-
Steelhead	All	6					-	0%	0%	0%	0%	-
	Recap	0	-	-	-	-	-	-	-	-	-	-

Table 22. Summary of radio-tagging experiments to estimate initial tagging mortality.

Species	Year	Tag type	Radio tags			Capture/handing/tagging mortalities				Mortalities	
			Applied	Failed	Net available	Regurgitation	Death in a short time	Death downstream	Other Mortality	Total	% of available
Chinook Salmon	1992	Operculum	360	10	350	11	1	5	5	22	6.3%
	1993	Spaghetti	350	9	341	6	1		3	10	2.9%
Coho Salmon	2005	Spaghetti	249		249	2	7	18		27	10.8%
Sockeye Salmon	1995	Spaghetti	118	3	115	11				11	9.6%
	2018	Spaghetti	781	13	768	94				97	12.6%
Steelhead	1993	Spaghetti	66	9	57	3				3	5.3%
	2005	Anchor	106		106	6				6	5.7%

Table 23. Summary of fates of radio-tagged Chinook Salmon from the 1992 radio-telemetry study (Koski et al 1996a).

Table 9. Destination or fate of chinook salmon that were radio-tagged on the Nass River, 1992.

System Tributary of system	Number of fish tracked		Percent of fish tracked to their destination	
Damdochax Creek	56		19.2	
Cranberry River	59		20.3	
Kiteen River		9		3.1
Kwinageese River	32		11.0	
Meziadin River	26		8.9	
Bell-Irving River (All)	72		24.7	
Taft Creek		6		2.1
Snowbank-Teigen Creeks		40		13.7
Oweegee Creek		12		4.1
Upper Nass Mainstem	6		2.1	
Lower Nass Mainstem	6		2.1	
Lower Nass Tributaries	34		11.7	
Tchitin River		6		2.1
Seaskinnish River		15		5.2
Tseax River and Slough		9		3.1
Total tracked to destination	291		100	
Alive but no destination (wandered)	2			
Moving toward destination	3			
Native fishery	30	(32) *		
Recaptures before destination		16		
Suspected recaptures not reported **		7		
Suspected tags lost at capture ***		7		
Sport fishery	2	(10) *		
Recaptures before destination		1		
Suspected recaptures not reported **		1		
Tagging losses	27			
Died shortly after tagging		1		
Regurgitations at tagging site		11		
Dead tags - fish never tracked		10		
Tag died en route to destination		5		
Non-tagging mortality	5			
Total number radio tagged	360			

* Numbers in parentheses include tags that were (or suspected to be) recaptured in a spawning tributary and are included among those tracked to their final destination.
** Tags disappeared at a fishery location.
*** Tags became stationary at a fishery location.

Table 24. Summary of fates of radio-tagged Chinook Salmon from the 1993 radio-telemetry study (Koski et al. 1996b).

Table 10. Destination or fate of chinook salmon that were radio tagged on the Nass River, 1993.

System Tributary of system	Number of fish tracked		Percent of fish tracked to their destination	
Damdochax Creek	38		16.1	
Cranberry River	52		22.0	
Kiteen River		6		2.5
Kwinageese River	28		11.9	
Meziadin River	22		9.3	
Bell-Irving River (All)	40		16.9	
Taft Creek		5		2.1
Snowbank-Teigen Creeks		18		7.6
Oweegee Creek		8		3.4
Upper Nass Mainstem	5		2.1	
Lower Nass Mainstem	3		1.3	
Lower Nass Tributaries	48		20.3	
Seaskinnish River		9		3.8
Tseax River and Slough		19		8.1
Anudol Creek		5		2.1
Total tracked to destination	**236**		**100**	
Strays - fish never tracked	9			
Non-tagging mortality	3			
Alive but no destination	0			
Native fisheries	90	(91) [c]		
Recaptures before destination		40		
Suspected recaptures not reported [a]		47		
Suspected tags lost at capture [b]		3		
Sport fishery	5	(17) [c]		
Recaptures before destination		4		
Regurgitation at fishing site [b]		1		
Tagging losses	7			
Died shortly after tagging		1		
Regurgitations at tagging site		6		
Tag died en route to destination		0		
Total number radio tagged	**350**			

[a] Tags disappeared at a fishery location.
[b] Tags became stationary at a fishery location.
[c] The number in parentheses includes tags that were (or suspected to be) recaptured in a spawning tributary and are included among those tracked to their final destination. One fish was recaptured twice and three fish caught by sport fishermen were released unharmed.

Table 25. Last known location or fates of radio-tagged Coho Salmon from a 2005 telemetry study (Alexander and Bussanich 2006).

Stratum	No. tracked	% of total	Tagging losses[a]		Unknown fates[b]		Fishery removals[c]		Total
Stream/Fate Category	to destination	tracked	Reg.	Mort.	Stationary	Missing	First Nation	Sport	tagged
Upper Nass									
Damdochax River	2	1.3%							
Un-named Upper Creek#1 - between Taylor and Vile	1	0.7%							
Kwinageese River	7	4.7%							
Bell-Irving River - total system	20	13.3%							
Mainstem - Nass/Bell to Oweegee Creek	5	3.3%							
Mainstem - Above Oweegee Creek	4	2.7%							
Teigen/Snowbank creeks	4	2.7%							
Oweegee Creek	3	2.0%							
Bowser River	4	2.7%							
Un-named Upper Creek#2 - between Meziadin and Bell	5	3.3%							
Un-named Upper Creek#3 - between Meziadin and Bell	1	0.7%							
Upper Nass Total	**36**	**24.0%**	**0**	**0**	**0**	**0**	**0**	**0**	
Middle Nass									
Meziadin River	13	8.7%	*1**						
Un-named Middle Creek#1 - between White and Paw	1	0.7%							
Paw Creek	1	0.7%							
Brown Bear Creek (Axnegrelga)	2	1.3%							
Un-named Middle Creek#2 - between Cran. and Brown Bear	2	1.3%							
Un-named Middle Creek#3 - between Cran. and Brown Bear	2	1.3%							
Cranberry and Kiteen rivers[d]	29	19.3%						*1**	
Kinskuch River	1	0.7%							
Un-named Middle Creek#4 - between Tchitin and Kinskuch	1	0.7%							
Tchitin River	5	3.3%							
Un-named Middle Creek#5 - between Kshadin and Tchitin	3	2.0%							
Kshadin Creek	1	0.7%							
Un-named Middle Creek#6 - between Kwinatahl and Kshadin	4	2.7%							
Kwinatahl River	3	2.0%							
Kwinamuck Creek	1	0.7%							
Un-named Middle Creek#7 - between GH and Kwinamuck	1	0.7%							
Mainstem - Grease Harbour to Cranberry					6	11			
Khimatlque Creek	3	2.0%							
Seaskinnish Creek	7	4.7%							
Tseax River & Gingit Creek	9	6.0%							
Chemainuk Creek	14	9.3%							
Un-named Middle Creek#8 - between Shumal and Chem.	2	1.3%							
Gish Creek	1	0.7%							
Un-named Middle Creek#9 - between FW1 and Gish	1	0.7%							
Fishery Removals before destination							21	1	
Mainstem - Gitwinksihlkw to Grease Harbour					12	7			
Middle Nass Total	**107**	**71.3%**	**0**	**0**	**18**	**18**	**21**	**1**	
Lower Nass and Tag Losses									
Ksedin Creek (Kwiniak)	1	0.7%							
Un-named Lower Creek #1 - between Greenville and GW	3	2.0%							
Anliyen Creek (Greenville)	1	0.7%							
Mainstem - Greenville Br. to Gitwinksihlkw				16		1			
Ginlulak Creek	1	0.7%							
Ishkeenickh River	1	0.7%							
Fishery removals before destination							9		
Mainstem - below Greenville Bridge				2		4			
Tagging losses (reg. & suspected handling/capture mortality)			2	7					
Lower Nass and Tag Loss Total	**7**	**4.7%**	**2**	**25**	**0**	**5**	**9**	**0**	
Grand Total	**150**	**100.0%**	**2**	**25**	**18**	**23**	**30**	**1**	**249**

[a] Not included in the tagging losses is one radio-tagged coho sampled at the Meziadin Fishway that was missing its radio tag but was tracked to a spawning destination (asterix). The radio tag was last tracked just below the Kinskuch River and is suspected to have regurgitated its tag after suspected capture in First Nation fisheries at Kinskuch River.

[b] Radio tagged coho that were detected stationary (and not near the tagging site) were classified as unknown fate, either regurgitating their radio tag or died of unknown cause. Radio tagged coho that were last detected in a mainstem strata but not tracked to a destination were also classified as unknown fate.

[c] Of the 31 fishery removals before reaching their destination, 28 were returned and 3 were not returned but tracked to towns. Not included in the removals is one radio tag that was removed from the Cranberry River and based on tracking information is suspected to have been recaptured in the recreational fishery but not reported.

[d] Of the 29 radio tagged coho tracked to the Cranberry and Kiteen systems, 26 radio tags were tracked within the Cranberry River and 2 radio tags were tracked within the Kiteen River.

Table 26. Summary of fates of radio-tagged Sockeye Salmon from a 1995 telemetry study (Link and Gurak 1997).

Stratum / Reach/tributary	Sockeye		%	
	No. tracked		Dest.	All
Upper Nass				
Bell-Irving R.		0	0%	0%
Mainstem: above Bell-Irving		1	1%	1%
Mainstem: above Meziadin		0	0%	0%
Upper Nass total	**1**		**1%**	**1%**
Middle Nass				
Meziadin R.		57 [a]	69%	50%
Cranberry R.		0	0%	0%
Mainstem: Cranberry - Meziadin		2	2%	2%
Middle Nass total	**59**		**71%**	**51%**
Lower Nass				
Gingit Cr. (near New Aiyansh)		6	7%	5%
Mainstem: Old Aiyansh and above		16	19%	14%
Mainstem: Tagsite - Old Aiyansh		1	1%	1%
Lower Nass total	**23**		**28%**	**20%**
Total tracked to a destination	**83**		**100%**	**72%**
Recaptures in the Nisga'a fishery	15			**13%**
Tags returned		13		
Tags captured but not returned		2		
Other Losses	17			**15%**
Tagging related [b]		11		10%
Possibly fishing related [c]		2		2%
Left the system [d]		4		3.5%
Fish never tracked [e]	3			2.5%
Total number radio-tagged	**118**			**115**

Table 27. Summary of fates of radio-tagged Sockeye Salmon from a 2018 telemetry study (Alexander et al. 2022).

Stratum		Radio tagged Sockeye			% Active
	Reach/tributary	No. tracked		Tracked (%)	Tags[a]
Upper Nass					
	Damdochax		8	2%	1%
	Mainstem: above Kwin		2	0%	0%
	Kwinageese		0	0%	0%
	Bell-Irving		9	2%	1%
	Mainstem: above Meziadin		4	1%	1%
Upper Nass total		**23**		**5%**	**3%**
Middle Nass					
	Meziadin River		164	34%	21%
	Cranberry River		1	0%	0%
	Mainstem: above Brown Bear		28	6%	4%
	Mainstem: Cranberry - Brown Bear		24	5%	3%
	Mainstem: Alice Arm Br. - Cranberry		40	8%	5%
	Mainstem: GH to Alice Arm Br		72	15%	9%
Middle Nass total		**329**		**69%**	**43%**
Lower Nass					
	Ksi Sgasginist (Seaskinnish R.)		4	1%	1%
	Gingit		71	15%	9%
	Ksi Sii Aks (Tseax R.) & Gitzyon Cr.		23	5%	3%
	Ksi Ts'oohl Ts'ap (Zolzap Creek)		4	1%	1%
	Mainstem: above FWs		25	5%	3%
Lower Nass total		**127**		**27%**	**17%**
Total tracked to a destination		**479**		**100%**	**62%**
Recaptures in the Nisga'a fishery		109			**14%**
	Tags returned		102		13%
	Tags captured but not returned		7		1%
Other Losses		180			**23%**
	Tagging related[b]		97		13%
	Possibly fishing related[c]		55		7%
	Left the system[d]		28		4%
Fish never tracked[e]		13			2%
Total number radio-tagged		**781**			

[a] Active tags was 768 of 781 radio tags applied; 13 radio tags were never tracked once and assume to have failed working.

[b] Determined by downstream migration or stationary detection below the tagging site within 14 d of tagging.

[c] These fish were detected stationary near FN fishery areas.

[d] Radio tagged Sockeye that were tracked moving and last detected on lower Nass River telemetry station. Of the 28 radio tags, 47% were river type Sockeye using Nass only genetic baselines and 15% Skeena stocks using coastwide genetic baselines.

[e] A total of 13 radio tags were never tracked after release and considered a malfuntion. Several of the radio tags had been reused with potential antenna quality impacted.

Table 28. Summary of fates of radio-tagged steelhead from a 1995 Skeena telemetry study (Table 9 from Alexander et al. 1996). This study was conducted at much higher water temperatures so some caution may be needed in using the results.

Stratum / **Reach/tributary**	**Number of fish tracked**		**Percent of fish tracked to Skeena**	
Upper Skeena				
Mainstem: above Sustut	1		1	
Mainstem: Babine-Sustut	6		6	
Mainstem: Hazelton-Babine[a]	1		1	
Sustut	3		3	
Babine	12		12	
Kispiox	6		6	
Upper Skeena total	**29**		**28.7**	
Middle Skeena				
Mainstem: Terrace-Hazelton[b]	20		20	
Bulkley System[c]	15		15	
Bulkley		14		14
Morice/Gosnell		1		1
Zymoetz	0		0	
Middle Skeena total	**35**		**34.7**	
Lower Skeena				
Mainstem: Exchamsiks-Terrace[d]	15			15
Mainstem: below Exchamsiks[e]	22			22
Lower Skeena total	**37**		**36.6**	
Total tracked to a destination	**101**		**100**	
Fish never tracked	**0**			
Total number radio-tagged	**101**			
Radio tags attributed to in-river fisheries[f]				
Native fisheries	3			
Sport fishery	0			
Regurgitations/mortalities	8			
At sport fishing site		1		
At native fishing site		7		
Tags disappeared	3			
Near sport fishery location		0		
Near food fishery location		3		
Left Skeena (alive)	2			
After susp. recap. at sport fishery location		1		
After susp. recap. at native fishery location		1		
Total in-river fisheries	**16**			
Tagging losses				
Regurgitation at tagging site		1		
Possible mortality[g]		16		
Left Skeena (alive)		9		
Total tagging losses	**26**			

[a] Includes one tag regurgitated along the mainstem at a native fishery location at the mouth of Kispiox River.

[b] Includes one tag recovered at Price Cr., one tag recovered at Kitseguecla and 10 suspected recoveries in the Middle Skeena.

[c] Includes one tag recovered at Moricetown (Idiot Rock).

[d] Includes one tag regurgitated at a sport fishery location.

[e] Includes three radio-tagged steelhead that were suspected to have regurgitated their tag, died or left the Skeena as a result of capture by sport (one) or native (two) fisheries.

[f] The in-river fisheries classification includes regurgitated and harvested radio-tagged steelhead that are included among those tracked to a destination.

[g] Radio-tagged steelhead last detected near Tyee may or may not be dead.

Table 29. Summary of fates of radio-tagged steelhead from a 1993 telemetry study on the Nass River (Table 7 from Alexander and Koski 1995).

Stratum Reach/tributary	Number of fish tracked		Percent of fish tracked to their destination	
Upper Nass				
Mainstem: above Damdochax	3		8	
Mainstem: below Damdochax	6		16	
Damdochax	2		5	
Kwinageese	1		3	
Bell-Irving River (All)	2		5	
Snowbank-Teigen Creeks		1		3
Oweegee Creek		1		3
Upper Nass total	**14**		**37.8**	
Middle Nass				
Mainstem: Meziadin-Arbour br.	1			3
Mainstem: Cranberry-Grease Harbour	4			11
Meziadin River	2			5
Cranberry River	6			16
Middle Nass total	**13**		**35.1**	
Lower Nass				
Mainstem: Grease Harbour-Beaver	2			5
Mainstem: Tseax-Ksedin	2			5
Seaskinnish River	1			3
Tseax River and Slough	4			11
Zolzap Slough	1			3
Lower Nass total	**10**		**27.0**	
Total tracked to destination	**37**		**100.0**	
Recaptures before destination	8			
Returned tags		2		
Suspected to be removed[a]		3		
Non-tagging[b]		3		
Mortality	3			
Tag-related		3		
Left system	9			
Never tracked	9			
Total number radio tagged	66			

[a] Tags disappeared at a fishery location.

[b] Tags became stationary at a fishery location.

Table 30. Last known locations or fates of radio-tagged steelhead on the Nass River from a 2005 telemetry study (Alexander et al. 2005) PSR 2006; 2014 steelhead draft report Alexander et al 2014.

Stratum Stream/Stock Category	No. tags assigned to stock	% of total stock det.	Tagging losses[a] Reg./mort.	Enroute tag losses[b] Stationary	Enroute tag losses[b] Missing	Fishery removals[c] First Nation	Fishery removals[c] Sport	Total tagged	Kelted[d]	% Kelt
Upper Nass										
Mainstem above Damdochax	3	4.3%							2	67%
Damdochax River	1	1.4%							1	100%
Mainstem below Damdochax	6	8.7%								
Kwinageese River	7	10.1%							4	57%
Mainstem below Kwinageese	2	2.9%								
Bell-Irving River	12	17.4%							4	33%
Upper Nass Total	**31**	**44.9%**		**0**	**0**	**0**	**0**		**11**	**35%**
Middle Nass										
Meziadin River	3	4.3%							1	33.3%
Mainstem - Cranberry to Meziadin	8	11.6%							1	12.5%
Cranberry and Kiteen rivers	14	20.3%				1*	1*		1	8.3%
Mainstem - Grease Harbour to Cranberry	6	8.7%		7	4					
Kwinamuck Creek	1	1.4%								
Kinskuch River	1	1.4%							1	100.0%
Seaskinnish Creek	1	1.4%								
Tseax River & Gingit Creek	1	1.4%								
Mainstem - Tagging site to Grease Harbour	3	4.3%			4	3				
Middle Nass Total	**38**	**55.1%**		**7**	**8**	**3**	**0**		**4**	**11.1%**
Lower Nass and Tag Losses										
Mainstem - Greenville Br. to Gitwinksihlkw				2	2	2				
Mainstem - Below Greenville Bridge				1	6					
Tagging losses (regurgitations & suspected mortality)			6							
Lower Nass and Tag Loss Total	**0**	**0.0%**	**6**	**3**	**8**	**2**	**0**		**0**	**0**
Grand Total	**69**	**100.0%**	**6**	**10**	**16**	**5**	**0**	**106**	**15**	**22.4%**

[a] Radio-tagged fish that were stationary near or below the tagging site at Gitwinksihlkw with no evidence of movement within 14 d were classified as losses associated with capture, tagging and handling procedures that include initial tag regurgitations.

[b] Radio-tagged fish that were either stationary or went missing after being at large for more than 14 d were classified as enroute losses and could not be classified to stock. Stationary losses were radio-tagged fish that remained in a stationary location based on detections from tracking surveys conducted over the entire study and were thought to have died or regurgitated their tag. Missing losses were radio-tagged fish that were tracked a few times after tagging but were no longer tracked on subsequent surveys during the study and were either removed or not tracked for whatever reason.

[c] A total of 5 radio-tagged steelhead were recovered from Nisga'a fishers during migration and could not be classified to stock. Two radio-tagged steelhead (asterix) that were recovered in First Nation and recreational fisheries on the Cranberry River are not included in the total fishery removals as fish were released without tags but are included in the stock assignment total.

[d] Radio-tagged steelhead that were tracked after spawning from May to June 2006.

Table 31. Summary of fall back/drop-out/initial mortality probabilities used for salmon and steelhead estimates in the Nass system from 1994-2019.

Year	Chinook Salmon	Coho Salmon[a]	Sockeye Salmon	Steelhead[b]
1994	5.0%	10.0%	10.0%	10.0%
1995	5.0%	10.0%	10.0%	NA
1996	5.0%	10.0%	10.0%	NA
1997	5.0%	10.0%	10.0%	6.0%
1998	5.0%	10.0%	10.0%	6.0%
1999	5.0%	10.0%	10.0%	6.0%
2000	5.0%	10.0%	10.0%	6.0%
2001	5.0%	10.0%	10.0%	6.0%
2002	5.0%	10.0%	10.0%	5.0%
2003	5.0%	10.0%	10.0%	5.0%
2004	5.0%	10.0%	10.0%	6.0%
2005	5.0%	10.0%	10.0%	6.0%
2006	5.0%	10.0%	10.0%	5.0%
2007	5.0%	10.0%	10.0%	6.0%
2008	5.0%	10.0%	10.0%	5.0%
2009	5.0%	5.0%	10.0%	5.0%
2010	5.0%	5.0%	10.0%	6.0%
2011	5.0%	6.0%	10.0%	5.0%
2012	5.0%	6.0%	10.0%	6.0%
2013	5.0%	6.0%	10.0%	5.0%
2014	5.0%	6.0%	10.0%	6.0%
2015	5.0%	6.0%	10.0%	5.0%
2016	5.0%	6.0%	10.0%	5.0%
2017	5.0%	6.0%	10.0%	6.0%
2018	5.0%	6.0%	12.0%	5.0%
2019	5.0%	6.0%	12.0%	5.0%

[a] Coho fall back/drop-out/initial mortality probabilities were set to: 10% (spaghetti tag); 5% operculum tag; and 6% anchor tag

[b] Steelhead fall back/drop-out/initial mortality probabilities were set to: 6% (anchor tag); 5% (adipose fin batch mark); and 10% (spaghetti tag).

Table 32. Estimates of operculum tag loss proportions for Chinook Salmon. All fish are fully inspected so no additional sampling is needed to estimate tag loss.

	Tag loss sample			Meziadin Fishway					Kwinageese Weir					Seaskinnish Weir				
Year	No tag	Lost tag	Total	No tag	Lost tag	Tags observed	Total marked	Estimated tag loss (%)	No tag	Lost tag	Tags observed	Total marked	Estimated tag loss (%)	No tag	Lost tag	Tags observed	Total marked	Estimated tag loss (%)
2000				387	1	29	30	3.3										
2001				548	1	65	66	1.5										
2002				445	2	19	21	9.5										
2003				462	1	17	18	5.6										
2004				470	0	20	20	0.0										
2005				606	1	32	33	3.0										
2006				684	0	37	37	0.0										
2007				720	0	34	34	0.0						557	0	14	14	0
2008				502	1	16	17	5.9						467	0	20	20	0
2009				322	1	14	15	6.7	875	8	20	28	28.6					
2010				312	0	3	3	0.0	130	1	1	2	50					
2011				302	0	28	28	0.0	674	21	66	87	24.1					
2012				219	6	36	42	14.3	511	20	204	224	8.9					
2013				109	2	17	19	10.5	723	19	90	109	17.4					
2014				46	0	5	5	0.0	527	8	33	41	19.5					
2015				83	2	12	14	14.3	1,014	29	79	108	26.9					
2016				34	0	2	2	0.0	798	28	55	83	33.7					
2017				36	0	2	2	0.0	218	4	23	27	14.8					
2018				35	0	1	1	0.0	445	7	11	18	38.9					
2019				106	0	5	5	0.0	464	10	54	64	15.6					
2020				139	1	16	17	5.9	465	22	119	141	15.6					

Table 33. Estimates of anchor tag loss for Coho Salmon since 2011.

	Tag loss sample			Meziadin Fishway[a]					Kwinageese Weir				
Year	**No tag**	**Lost tag**	**Total**	**No tag**	**Lost tag**	**Tags observed**	**Total marked**	**Estimated tag loss (%)**	**No tag**	**Lost tag**	**Tags observed**	**Total marked**	**Estimated tag loss (%)**
2011	1,106	1	1,107	2,292	2	44	46	4.3	216	2	10	12	16.7
2012	519	5	524	4,733	46	246	292	15.8	150	5	5	10	50.0
2013	964	1	965	5,806	6	128	134	4.5	750	0	13	13	0.0
2014	722	2	724	6,955	19	268	287	6.6	1,207	4	22	26	15.4
2015	326	1	327	2,624	8	89	97	8.2	295	2	6	8	25.0
2016	695	3	698	4,921	21	130	151	13.9	2,608	6	25	31	19.4
2017	737	0	737	7,277	Unavailable	279	Unavailable	8.9	2,591	2	58	60	3.3
2018	233	0	233	2,106	Unavailable	39	Unavailable	8.9	241	2	6	8	25.0
2019	419	1	420	4,186	10	148	158	6.3	1,626	1	64	65	1.5
2020	255	0	255	1,934	Unavailable	91	Unavailable	8.5	701	3	26	29	10.3

[a] In cases where a tag loss estimate cannot be estimated, the mean tag loss proportion from previous years is currently used in the estimation procedure.

Table 34. Estimates of anchor tag loss for Sockeye Salmon since 2011.

	Tag loss sample			Meziadin Fishway					Kwinageese Weir				
Year	No tag	Lost tag	Total	No tag	Lost tag	Tags observed	Total marked	Estimated tag loss (%)	No tag	Lost tag	Tags observed	Total marked	Estimated tag loss (%)
2011									10,033	8	240	248	3.2
2012	1,506	6	1,512	138,811	553	6,112	6,665	8.3	3,547	4	141	145	2.8
2013	1,736	3	1,739	166,650	288	3,726	4,014	7.2	393	1	4	5	20.0
2014	1,480	2	1,482	142,045	192	2,875	3,067	6.3	435	0	3	3	0.0
2015	1,948	6	1,954	182,058	561	3,859	4,420	12.7	6,984	3	60	63	4.8
2016	1,337	2	1,339	107,853	161	2,015	2,176	7.4	19,553	7	244	251	2.8
2017	1,259	2	1,261	116,606	185	2,482	2,667	6.9	7,169	3	71	74	4.1
2018	1,459	1	1,460	95,151	65	1,676	1,741	3.7	288	0	2	2	0.0
2019	1,706	2	1,708	86,107	101	2,021	2,122	4.8	5,938	1	69	70	1.4
2020	1,926	5	1,931	122,240	317	4,007	4,324	7.3	3,192	6	57	63	9.5

Table 35. Estimates of anchor tag loss for steelhead, 1997 to 2007. Currently, steelhead are batch marked using adipose fin clips so tag loss is not relevant to recent studies.

	Tag loss sample			Meziadin Fishway				
Year	No tag	Lost tag	Total	No tag	Lost tag	Tags observed	Total marked	Estimated tag loss (%)
1997	281	0	281	281	0	12	12	0.0
1998	413	0	413	413	0	25	25	0.0
1999	513	0	513	513	0	29	29	0.0
2000	396	0	396	396	0	41	41	0.0
2001	457	1	458	458	1	54	55	1.8
2004	274	4	278	278	4	36	40	10.0
2005	355	0	355	355	0	34	34	0.0
2007	186	0	186	186	0	24	24	0.0

Table 36. Example of a chi-square test to examine differences total recoveries by size category. Taken from Appendix E in the 2019 Chinook Salmon report (Beveridge et al. 2020). Note that the number of fish marked has not been adjusted for initial tagging mortality, tag loss (not an issue here because all Chinook Salmon are fully inspected), or removals in the Nisga'a Domestic Harvest.

Size class	Recaptured	Not recaptured	Marked	Recapture rate
Medium	23	663	686	3.4%
Large	62	752	813	7.6%
All fish	85	1,415	1,499	5.7%

Chi-square = 12.66, df = 1, P < 0.001.

Table 37. Example of a chi-square test to examine differences in the marked fraction (i.e., mark rate) for Chinook Salmon by size class. Taken from Appendix E in the 2019 Chinook Salmon report (Beveridge et al. 2020). Note that the number of fish marked has not been adjusted for initial tagging mortality, tag loss (not an issue here because all Chinook Salmon are fully inspected), or removals in the Nisga'a Domestic Harvest.

Size class	Recaptured	Not marked	Inspected for marks	Mark rate
Medium	23	124	147	15.6%
Large	62	461	523	11.9%
All fish	85	585	670	12.7%

Chi-square = 0.51, df = 1, P = 0.475.

Table 38. Example of a chi-square test to examine differences recapture rates, by size class, for Chinook Salmon captured in the Nisga'a gillnet fisheries, 2019, using expanded tag recaptures.

	Removed				
Size class	n	%	Not removed	Marked	Recapture rate
Medium	125	56%	561	686	18.2%
Large	99	44%	715	814	12.2%
All Fish	224		1,276	1,500	14.9%

Chi-square = 10.8, df = 1, P = 0.001.

Table 39. Example of a chi-square test to examine differences recapture rates, by size class, for Chinook Salmon captured in the Nisga'a gillnet fisheries, 2019, using actual tag recaptures.

	Removed[a]				
Size class	n	%	Not removed	Marked	Recapture rate
Medium	74	56%	612	686	10.8%
Large	58	44%	756	814	7.1%
All Fish	132		1,368	1,500	8.8%

Chi-square = 6.2, df = 1, P = 0.013.

[a] Recaptured fish include only tag removals for which fishwheel measurements were available and does not include estimated non-reported removals.

Table 40. Comparison of reported size-stratified and pooled Petersen estimates for Chinook, Coho, and Sockeye salmon, and steelhead.

		Pooled Petersen		Size-stratified Petersen		Difference	
Species	**Year**	**N**	**SE (N)**	**N**	**SE (N)**	**Strat-Pooled**	**% of stratified**
Chinook	2009	27,437	3,510	26,865	5,106	-572	-2%
	2010	18,773	4,522	22,470	7,066	3,697	16%
	2011	10,692	904	10,124	910	-568	-6%
	2012	9,315	458	8,996	440	-319	-4%
	2013	8,694	643	8,298	659	-396	-5%
	2014	13,407	1,688	11,914	1,467	-1,493	-13%
	2015	18,062	1,580	18,778	1,709	716	4%
	2016	9,753	956	9,379	960	-374	-4%
	2017	4,728	763	4,567	914	-161	-4%
	2018	14,510	2,900	14,603	2,913	93	1%
	2019	11,097	1,093	10,796	1,122	-301	-3%
	Mean	*13,315*	*1,729*	*13,345*	*2,115*	*29*	*-2%*
Coho	2018	58,107	8,394	64,731	11,179	6,624	10%
	2019	81,417	5,326	87,501	7,025	6,084	7%
	Mean	*69,762*	*6,860*	*76,116*	*9,102*	*6,354*	*9%*
Sockeye	2015	410,319	6,535	411,689	7,221	1,370	0%
	2017	238,753	4,740	256,484	5,870	17,731	7%
	2018	242,098	5,859	232,877	5,657	-9,220	-4%
	2019	264,604	5,815	253,159	5,657	-11,445	-5%
	Mean	*288,943*	*5,737*	*288,552*	*6,101*	*-391*	*0%*
Steelhead	2000	13,431	2,015	14,042	2,247	611	4%
	2001	11,326	1,472	12,507	1,751	1,181	9%
	2004	4,045	647	3,953	593	-92	-2%
	2005	7,008	1,191	6,881	1,170	-127	-2%
	2007	5,823	1,165	5,593	1,119	-230	-4%
	2010	19,191	3,262	18,656	3,172	-535	-3%
	2012	12,538	2,131	12,357	2,101	-181	-1%
	2014	19,220	3,460	18,539	3,337	-681	-4%
	Mean	*11,573*	*1,918*	*11,566*	*1,936*	*-7*	*0%*

Table 41. Adjusted releases of tagged Sockeye Salmon in 2019 stratified by week showing the adjustment to the number of tags released at Gitwinksihlkw (GW) for domestic harvest, initial mortality, and tag loss. (Source Alexander, R. pers. comm).

			Observed tags in Nisga'a harvest				Adjusted tags removed in Nisga'a harvest			Removals of fish with tags					
Week ending	Stat week	Tagged at GW	Lower stratum	Middle stratum	Upper stratum	Total	Lower stratum (adj. = 0.063)	Middle stratum (adj. = 1.000)	Upper stratum (adj. = 0.532)	Nisga'a harvest	Initial mortality (12%)	Tag loss (4.19%)	Fishwheels	Sport fishery	Adjusted tags released
01-Jun-19	22	0				0	0	0	0	0	0	0	0	0	0
08-Jun-19	23	16				0	0	0	0	0	2	1	0	0	13
15-Jun-19	24	107	0	6	5	11	0	6	9	15	13	4	0	0	74
22-Jun-19	25	602	2	26	42	70	32	26	79	137	72	25	0	0	368
29-Jun-19	26	759	1	66	95	162	16	66	179	260	91	32	0	0	376
06-Jul-19	27	930	0	22	54	76	0	22	102	124	112	39	0	0	656
13-Jul-19	28	879	0	8	22	30	0	8	41	49	105	37	0	0	687
20-Jul-19	29	584	0	40	48	88	0	40	90	130	70	24	0	0	359
27-Jul-19	30	509	0	9	34	43	0	9	64	73	61	21	0	0	354
03-Aug-19	31	551	0	11	18	29	0	11	34	45	66	23	0	0	417
10-Aug-19	32	527	0	2	0	2	0	2	0	2	63	22	0	0	440
17-Aug-19	33	745				0	0	0	0	0	89	31	0	0	624
24-Aug-19	34	178				0	0	0	0	0	21	7	0	0	149
31-Aug-19	35	1,321				0	0	0	0	0	159	55	0	0	1,107
07-Sep-19	36	394				0	0	0	0	0	47	17	0	0	330
14-Sep-19	37	138				0	0	0	0	0	17	6	0	0	116
21-Sep-19	38					0	0	0	0	0	0	0	0	0	0
28-Sep-19	39					0	0	0	0	0	0	0	0	0	0
05-Oct-19	40					0	0	0	0	0	0	0	0	0	0
12-Oct-19	41					0	0	0	0	0	0	0	0	0	0
Totals		8,240	3	190	318	511	48	190	598	835	989	345	0	0	6,071

For example, consider the 107 fish actually tagged at GW in statistical week 24. The observed number of fish in the Nisga'a harvest with tags in the three catch monitoring river strata were 0, 6, and 5. From the compliance study, the reporting rates in the three strata were 0.063, 1.00, and 0.532 respectively which gives a estimated 0/0.063 = 0, 6/1.00 = 6, and 5/0.532 = 9 tagged fish removed in the Nisga'a harvest. A total of 0+6+9=15 were estimated to be removed in the Nisga'a harvest. An additional 12% of fish tagged at GW are estimated to be removed through initial mortality or fall back (13 tags); an additional 4.19% of tagged fish are thought to loose their tag (4 fish). These sources lead to the adjusted number of tags released at GW that are available just upriver of GH of 74 fish. This adjusted value is then used in the time-stratified estimation procedures (SPAS, SPAS R, or BTSPAS) summarized in subsequent Figures and Tables.

Table 42. Adjusted releases and recoveries of Sockeye Salmon in 2019 stratified by statistical week (Alexander, R. pers. comm.). The adjusted number of tags fish available just upriver of Grease Harbour (GH) was computed in Table 41. The final row is total recoveries (tagged and untagged).

Stat	**Adjusted**	**Recoveries of tagged fish by statistical week**															
week	**releases**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	
23	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
24	74	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
25	368	0	4	5	5	0	0	0	0	0	0	0	0	0	0	0	
26	376	0	0	7	36	2	0	0	0	0	0	0	0	0	0	0	
27	656	0	0	0	131	31	7	2	0	0	0	0	0	0	0	0	
28	687	0	0	0	80	97	28	8	4	6	0	0	0	0	0	0	
29	359	0	0	0	6	45	26	62	14	7	6	0	1	0	0	0	
30	354	0	0	0	0	0	3	55	24	16	24	3	2	0	0	0	
31	417	0	0	0	0	0	1	20	14	40	73	11	6	0	0	0	
32	440	0	0	0	0	0	0	0	2	14	94	48	13	0	1	0	
33	624	0	0	0	0	0	0	0	0	1	97	132	34	5	4	2	
34	149	0	0	0	0	0	0	0	0	0	8	25	10	2	1	0	
35	1107	0	0	0	0	0	0	0	0	0	30	273	180	20	7	3	
36	330	0	0	0	0	0	0	0	0	0	0	8	53	9	14	6	
37	116	0	0	0	0	0	0	0	0	0	0	0	0	3	8	1	
Total	*6,070*	*1*	*4*	*12*	*258*	*175*	*65*	*147*	*58*	*84*	*332*	*500*	*299*	*39*	*35*	*12*	
		Total fish inspected (tagged and untagged) by statistical week															Total
		33	230	978	11,248	6,546	2,741	10,743	3,751	8,450	25,120	11,695	4,884	880	634	195	88,128

Table 43. Output from the SPAS program for the 2019 capture-recapture program for Sockeye Salmon (Alexander, R. pers. comm.).

>>>NASS RIVER SOCKEYE MEZ 2019 - Chi-square Test Statistics

Complete Mixing : 460.06 (11 df)
Significance... 0.00
Equal Proportions: 795.38 (6 df)
Significance... 0.00
> End of Pooling Tests

>> ML Darroch Estimate

Failed to form an estimate

>> Least squares Estimate

Estimate (std. err) : 258104.60 (-1.00)
G-square : 2226.76 (5 df)
Significance... 0.00
Chi-square : 2457.24 (5 df)
Significance... 0.00

> Table of Stratum Estimates & Predicted counts N(recap), m(cap,rec), u(rec)

	WK 27-30	WK 31-32	WK 33	WK 34-35	WK 36	WK 37	WK 38-41	Unseen
WK 23-25	75.92	0.00	0.00	0.00	0.00	0.00	0.00	66.51
WK 26	47.00	2.02	0.00	0.00	0.00	0.00	0.00	191.42
WK 27	55.40	36.14	1.41	0.00	0.00	0.00	0.00	599.67
WK 28	90.17	126.35	8.52	10.00	0.00	0.00	0.00	419.67
WK 29	6.52	71.52	64.72	21.00	6.34	0.00	1.07	213.56
WK 30	0.00	2.97	52.03	40.01	22.32	3.06	1.83	198.78
WK 31	0.00	1.00	20.33	54.00	74.54	10.93	6.16	269.03
WK 32	0.00	0.00	0.00	16.00	91.91	48.32	13.62	281.71
WK 33	0.00	0.00	0.00	1.00	96.10	132.37	44.48	329.31
WK 34	0.00	0.00	0.00	0.00	11.90	21.37	20.84	48.35
WK 35	0.00	0.00	0.00	0.00	28.89	276.00	200.40	606.12
WK 36-37	0.00	0.00	0.00	0.00	0.00	7.95	96.61	331.16
Stratum Si	67867.18	12780.79	34892.29	12114.22	98079.09	1571.59	30305.72	
P(Recaptur	0.1840	0.7266	0.3079	1.0072	0.2561	7.4415	0.2175	

> End of Table

>>Schaefer Estimate

Estimate : 264834.58

> Table of Stratum Estimates: N(cap), N(cap,rec), N(rec)

Stratum	Si	P(Capture)	27-30	31-32	33	34-35	36	37	38-41			
WK 23-25	20,664	0.022	20663.62	0	0	0	0	0	0		20,664	19,753
WK 26	16,964	0.0222	16316.94	646.65	0	0	0	0	0		16,964	16,216
WK 27	29,025	0.0226	22823.07	5640.99	560.72	0	0	0	0		29,025	27,745
WK 28	30,542	0.0225	11192.75	14901.37	1801.15	2647.03	0	0	0		30,542	29,196
WK 29	21,124	0.017	585.77	5906.1	9740.43	3878.86	975.91	0	36.81		21,124	20,193
WK 30	26,460	0.0134	0	323.58	11203.93	9580.02	5061.65	195.59	95.47		26,460	25,294
WK 31	30,387	0.0137	0	97.79	3693.94	11726.08	13959.07	650.24	259.67		30,387	29,047
WK 32	25,196	0.0175	0	0	0	3516.83	18194.23	2872.07	613.3		25,196	24,086
WK 33	25,603	0.0244	0	0	0	194.97	16653.49	7005.77	1748.59		25,603	24,474
WK 34	4,576	0.0326	0	0	0	0	1960.65	1894.08	721.1		4,576	4,374
WK 35	26,438	0.0419	0	0	0	0	4898.16	13779.17	7760.18		26,438	25,272
WK 36-37	7,857	0.0568	0	0	0	0	0	818.19	7038.58		7,857	7,510
Stratum Si	264,835		71582.14	27516.48	27000.17	31543.8	61703.16	27215.13	18273.7		264,835	253,159
P(Recaptur			0.1745	0.3375	0.3979	0.3868	0.4071	0.4297	0.3608			

> End of Table

Stratified	
253,159	0.955915
241,848	
264,471	

>>Pooled Petersen Estimate

Estimate (std. err) : 264603.93 (4749.02)

95 % normal C I :(255295.86, 273912.00)
95 % transform C I :(255509.92, 274134.59)

Table 44. Sample output from SPAS (R version) for 2019 time-stratified Sockeye Salmon run size.

SPAS.
Rows (1,2,3), (4,5), (6,7), (8,9), (10,11), (12,13), (14,15) pooled
Columns (1,2,3) pooled.

Population estimate is 288,528 (SE14,445)

```
## Estimates
##              pool1   pool4  pool5  pool6   pool7  pool8  pool9  pool10  pool11
## pool1           10     5.0    0.0    0.0     0.0    0.0    0.0     0.0     0.0
## pool4            7   166.3   33.5    7.2     2.0    0.0    0.0     0.0     0.0
## pool6            0    85.7  143.7   55.1    68.9   16.0   13.3     6.2     0.0
## pool8            0     0.0    0.0    4.3    71.3   26.7   60.8   109.2    11.8
## pool10           0     0.0    0.0    0.0     0.0    1.6   15.6   202.7   164.3
## pool12           0     0.0    0.0    0.0     0.0    0.0    0.0    38.0   298.0
## pool14           0     0.0    0.0    0.0     0.0    0.0    0.0     0.0     7.8
## est unmarked  1224 10991.0 6369.0 2674.0 10601.0 3707.0 8360.0 24764.0 11213.0
##              pool12 pool13 pool15 psi cap.prob exp factor Pop Est
## pool1           0.0    0.0    0.0 440    0.011       89.7   41254
## pool4           0.0    0.0    0.0 816    0.021       46.1   48632
## pool6           1.0    0.0    0.0 656    0.029       33.6   36144
## pool8           7.9    0.0    0.0 479    0.009      115.0   89444
## pool10         46.8   10.2    5.7 617    0.017       59.2   64044
## pool12        190.0   22.0   11.0 697    1.000        0.0    1256
## pool14         52.9   14.0   27.3 344    0.058       16.4    7755
## est unmarked 4585.0  834.0  785.0  NA       NA         NA  288528
##
## SE of above estimates
##              pool1 pool4 pool5 pool6 pool7 pool8 pool9 pool10 pool11 pool12
## pool1          3.2   2.2   0.0   0.0   0.0   0.0   0.0    0.0    0.0    0.0
## pool4          2.7  12.9   5.7   2.6   1.4   0.0   0.0    0.0    0.0    0.0
## pool6          0.0   9.2  11.0   6.0   8.0   3.7   3.7    2.5    0.0    1.0
## pool8          0.0   0.0   0.0   1.7   5.6   2.3   4.7    8.6    3.0    2.4
## pool10         0.0   0.0   0.0   0.0   0.0   1.2   4.0   13.3   11.7    5.2
## pool12         0.0   0.0   0.0   0.0   0.0   0.0   0.0    6.2   17.3   13.8
## pool14         0.0   0.0   0.0   0.0   0.0   0.0   0.0    0.0    2.8    7.1
## est unmarked    NA    NA    NA    NA    NA    NA    NA     NA     NA     NA
##              pool13 pool15  psi cap.prob exp factor Pop Est
## pool1           0.0    0.0 21.0    0.004       31.9   14499
## pool4           0.0    0.0 28.6    0.002        5.3    5488
## pool6           0.0    0.0 25.6    0.003        3.6    3737
## pool8           0.0    0.0 21.9    0.001        9.2    7056
## pool10          1.8    2.0 24.8    0.001        4.9    5242
## pool12          4.7    3.3 26.4    0.000        0.0       0
## pool14          4.0    5.2 18.5    0.018        5.6    2480
## est unmarked     NA     NA   NA       NA         NA   14445
##
```

Table 45. Sample output from BTSPAS for 2019 time-stratified Sockeye Salmon escapement. Population estimate is 280,072 (SD 12,705).

```
sockeye.2019.btspas.fit1$summary[ grepl("Ntot", rownames(sockeye.2019.btspas.fit1$summary)),]
```

```
##         mean           sd         2.5%          25%          50%          75%        97.5%         Rhat 
n.eff 
## 2.800720e+05 1.270527e+04 2.586671e+05 2.711377e+05 2.787960e+05 2.875790e+05 3.082854e+05 1.000957e+00 6.0000
00e+03
```

Table 46. Sample output from BTSPAS for 2019 time-stratified Sockeye Salmon run size. The tagged availability proportion was specified with three different levels of uncertainty.

		Run size	
x	**n**	**Estimate**	**SD**
15	20	283,000	37,000
30	40	273,000	36,000
150	200	289,000	20,000
300	400	289,000	17,000
3,000	4,000	290,000	16,000
30,000	40,000	290,000	15,000

Table 47. Expansion factors used in the 2019 in-season estimation using Method 1 and water levels and expansion factors for Method 2.

	Sockeye Salmon			Coho Salmon			Daily water level expansion factor (EF)		
Select dates	Average	Min	Max	Average	Min	Max	Water level[a]	Sockeye EF	Coho EF
31-May-19	22.2	11.4	32.3	21.21	12.82	38.60	A	22.2	21.21
01-Jun-19	22.2	11.4	32.3	21.21	12.82	38.60	A	22.2	21.21
02-Jun-19	22.2	11.4	32.3	21.21	12.82	38.60	A	22.2	21.21
26-Jun-19	22.2	11.4	32.3	21.21	12.82	38.60	L98	33.5[b]	38.60[b]
27-Jun-19	22.2	11.4	32.3	21.21	12.82	38.60	L98	33.5[b]	38.60[b]
28-Jun-19	19.1	9.4	31.4	21.21	12.82	38.60	L	31.4	38.60
29-Jun-19	19.1	9.4	31.4	21.21	12.82	38.60	L	31.4	38.60
30-Jun-19	19.1	9.4	31.4	21.21	12.82	38.60	A	19.1	21.21
01-Jul-19	16.0	7.5	30.4	21.21	12.82	38.60	L	30.4	38.60
02-Jul-19	16.0	7.5	30.4	21.21	12.82	38.60	A	16.0	21.21
13-Jul-19	16.0	7.5	30.4	21.21	12.82	38.60	L	30.4	38.60
14-Jul-19	16.0	7.5	30.4	21.21	12.82	38.60	L	30.4	38.60
15-Jul-19	20.5	8.1	41.2	21.21	12.82	38.60	L	41.2	38.60
16-Jul-19	25.1	8.8	52.1	21.21	12.82	38.60	L	52.1	38.60
17-Jul-19	25.1	8.8	52.1	21.21	12.82	38.60	L	52.1	38.60
21-Sep-19	24.3	12.4	48.5	21.21	12.82	38.60	A	24.3	21.21
22-Sep-19	24.3	12.4	48.5	21.21	12.82	38.60	A	24.3	21.21

[a] A = Average water level; H = High water level; L = Low water level; L98 = Extra low water level (expansion factor from 1998 used)

[b] When the water levels are very low, the Sockeye Salmon expansion factor is taken from 1998 for that period. For the other species, the expansion factor from Low water levels is used.

Table 48. Example computations for the in-season estimates for Sockeye Salmon using Method 3. Blank entries cannot be computed because they require data outside the window shown. The estimate of in-season number of fish passing Gitwinksihlkw (GW) on 2019-07-19 is wanted and uses data up to 5 days later to account for travel time.

	GW		GH			GW rolling average			GH rolling average			
Date	Catch	Tagged	Catch	IS fishery	Tag recaptures	5-day catch	5-day tagged	Adjusted recaps at GH	7-day adjusted recaps	7-day GH catch + IS fishery[a]	Marked fraction	Sockeye arriving at GW
29-Jun-19	110	78	67		0							
30-Jun-19	136	86	142		3							
01-Jul-19	192	119	130		4					-		
02-Jul-19	258	186	94		1					-		
03-Jul-19	326	184	14		0	1,022	653			-		
04-Jul-19	212	109	13	1,027	16	1,124	684					
05-Jul-19	157	121	24	1,127	7	1,145	719			2,638		
06-Jul-19	209	125	131		9	1,162	725			2,702		
07-Jul-19	240	136	279		6	1,144	675	10.5		2,839		
08-Jul-19	260	104	205		12	1,078	595	20.4		2,914		
09-Jul-19	392	214	204		7	1,258	700	11.1		3,024		4,084
10-Jul-19	177	99	69	1,317	53	1,278	**678**	78.8		4,396		
11-Jul-19	120	99	160	821	51	1,189	652	95		4,337		
12-Jul-19	218	124	212		10	**1,167**	640	21.5		3,398		
13-Jul-19	2,481	103	149		9	3,388	639	15.3	252.7	3,416		
14-Jul-19	202	96	239		25	3,198	521	43	285.2	3,376	0.096	

[a] Some arbitrary pooling was done for expansion factors to account for more recaps and capture. These are the bolded estimates that deviate for summing over a 4-day period of catch and adjusted recaptures. Typically, these estimates are found based on smoothing the expansion factors to avoid big changes in the in-season estimates.

Table 49. Portion of the total-run timing proportions for Sockeye Salmon used to expand the 2019 “run-to-date” estimates to obtain the 2019 “total-run expected” estimate.

	Run-to-date	Run timing for select years (1994-2019)							Total-run estimate		
Date	estimate (2019)	1994	1995	1996	1997	2018	Mean	SD	Mean	- 2 * SD	+ 2 * SD
29-May-19							0.00%				
03-Jun-19	65			0.10%	0.00%	0.00%	0.07%	0.14%	96,115	18,892	192,231
04-Jun-19	129			0.10%	0.00%	0.00%	0.10%	0.19%	121,506	26,603	243,012
05-Jun-19	196			0.10%	0.00%	0.00%	0.20%	0.30%	130,250	26,377	260,500
06-Jun-19	263			0.10%	0.00%	0.00%	0.20%	0.36%	134,930	28,962	269,860
07-Jun-19	364			0.10%	0.00%	0.00%	0.20%	0.41%	148,803	34,212	297,605
08-Jun-19	532	0.00%		0.10%	0.00%	0.10%	0.30%	0.50%	178,248	41,070	356,497
09-Jun-19	901	0.00%	0.00%	0.10%	0.10%	0.10%	0.40%	0.65%	232,622	53,309	465,245
10-Jun-19	1,236	0.00%	0.00%	0.10%	0.10%	0.10%	0.50%	0.82%	246,612	57,930	493,225
11-Jun-19	1,527	0.10%	0.00%	0.30%	0.20%	0.10%	0.60%	0.98%	255,102	59,783	510,205
12-Jun-19	2,174	0.10%	0.00%	1.20%	0.30%	0.10%	0.80%	1.19%	284,293	68,939	568,587
13-Jun-19	2,462	0.10%	0.00%	2.00%	0.40%	0.10%	1.00%	1.57%	245,027	59,502	490,055
14-Jun-19	2,795	0.10%	0.10%	3.10%	0.50%	0.20%	1.20%	1.85%	228,505	56,668	457,010
15-Jun-19	3,798	0.20%	0.70%	4.30%	0.70%	0.30%	1.50%	2.09%	248,429	66,465	496,857
16-Jun-19	5,802	0.30%	1.10%	4.90%	0.80%	0.60%	2.00%	2.49%	289,554	83,033	579,108
17-Jun-19	8,454	0.60%	1.70%	5.40%	0.90%	0.90%	2.60%	2.88%	328,191	101,392	656,382
18-Jun-19	9,675	0.80%	2.40%	6.20%	1.00%	1.30%	3.40%	3.54%	280,559	91,892	561,118
19-Jun-19	14,428	1.10%	3.50%	7.50%	1.30%	1.60%	4.30%	4.08%	333,861	115,637	667,723
20-Jun-19	19,764	1.40%	5.30%	9.30%	1.50%	1.70%	5.20%	4.56%	378,400	137,802	756,801

Table 50. In-season and post-season estimates of aggregate escapement to date for Nass River adult Chinook Salmon to the Gitwinksihlkw fishwheels, 1999 to 2019. Post-season estimates could be a mixture of stratified and unstratified estimates. In-season estimates are a combination of Methods 1-2 in June and then Method 3 starting in late-June onward. For example, in 2019, Method 2 was used until 25 June, and Method 3 started on 26 June.

	Estimate		Difference	
Year	**In-season**	**Actual**	**Actual - Estimate**	**%**
1999	11,670	13,427	1,757	13%
2000	28,113	21,606	-6,507	-30%
2001	41,232	34,703	-6,529	-19%
2002	17,464	16,081	-1,383	-9%
2003	19,971	29,462	9,491	32%
2004	17,887	17,984	97	1%
2005	13,256	16,736	3,480	21%
2006	21,261	28,609	7,348	26%
2007	20,316	27,128	6,812	25%
2008	14,178	21,681	7,503	35%
2009	23,964	30,253	6,289	21%
2010	8,521	20,598	12,077	59%
2011	13,723	11,509	-2,214	-19%
2012	16,640	10,785	-5,855	-54%
2013	10,849	10,240	-609	-6%
2014	13,132	14,290	1,158	8%
2015	26,279	22,540	-3,739	-17%
2016	15,407	11,009	-4,398	-40%
2017	5,762	5,695	-67	-1%
2018	9,719	16,293	6,574	40%
2019	21,181	13,342	-7,839	-59%

Mean absolute percent error 25% (range 1% to 41%).

Table 51. In-season and post-season estimates of aggregate escapement to date for Nass adult Coho Salmon to the Gitwinksihlkw test fishery fishwheels, 1994 to 2019. Post-season estimates could be a mixture of stratified and unstratified estimates. In-season estimates are a combination of Methods 1-2 in June and then Method 3 starting in late-June onward. For example, in 2019, Sockeye Salmon Method 2 was used until 25 June, Sockeye Salmon Method 3 from 26 June to 3 August, and finally Coho Salmon Method 3 from Aug 4 to the end of operations. The Sockeye Salmon Method 3 implies that the adjusted mark rate from Sockeye Salmon were used to expand the Coho Salmon catches.

	Estimate		Difference	
Year	In-season	Actual	Actual - Estimate	%
1994	115,416	144,053	28,637	20%
1995	13,842	22,731	8,889	39%
1996	26,100	43,872	17,772	41%
1997	8,146	12,537	4,391	35%
1998	36,274	37,146	872	2%
1999	25,262	52,149	26,887	52%
2000	22,449	71,036	48,587	68%
2001	89,262	89,261	-1	0%
2002	124,176	167,829	43,653	26%
2003	77,583	77,574	-9	0%
2004	82,633	60,106	-22,527	-37%
2005	96,298	97,651	1,353	1%
2006	55,292	54,730	-562	-1%
2007	47,067	54,210	7,143	13%
2008	89,176	84,817	-4,359	-5%
2009	166,277	201,683	35,406	18%
2010	97,456	88,273	-9,183	-10%
2011	53,765	64,819	11,054	17%
2012	101,348	68,846	-32,502	-47%
2013	145,230	129,882	-15,348	-12%
2014	132,958	123,221	-9,737	-8%
2015	45,126	44,353	-773	-2%
2016	142,002	137,214	-4,788	-3%
2017	134,892	116,419	-18,473	-16%
2018	34,914	58,516	23,602	40%
2019	77,183	82,319	5,136	6%

Mean absolute percent error 20% (range 0% to 32%).

Table 52. Expansion factors used to multiply the total catch of Sockeye Salmon at the Gitwinksihlkw fishwheels in 2019 based on historical catchability estimates from 1994 to 2018. The values (%) on the right most columns are computed as 1/value of the corresponding value on the left side of the table.

	Sockeye catchability expansion factors							
Period	**Average**	**Low**	**Low (98)**	**High**	**%Avg**	**%Low**	**%High**	**%1998**
1-27 Jun	22.2	32.3	33.5	11.4	4.5%	3.1%	8.8%	3.0%
28-30 Jun	19.1	31.4	33.5	9.4	5.2%	3.2%	10.6%	3.0%
1-14 Jul	16.0	30.4	33.4	7.5	6.2%	3.3%	13.4%	3.0%
15 Jul	20.5	41.2	64.5	8.1	4.9%	2.4%	12.3%	1.6%
16-31 Jul; 1-3 Aug	25.1	52.1	95.6	8.8	4.0%	1.9%	11.4%	1.0%
4-7 Aug	27.1	58.2	88.3	9.6	3.7%	1.7%	10.4%	1.1%
8-14 Aug	29.1	64.3	81.0	10.4	3.4%	1.6%	9.7%	1.2%
15 Aug	26.7	56.4	62.1	11.4	3.7%	1.8%	8.8%	1.6%
16-31 Aug; Sep	24.3	48.5	43.3	12.4	4.1%	2.1%	8.1%	2.3%

Table 53. In-season and post-season estimates of aggregate escapement to date for Nass River adult Sockeye Salmon to the Gitwinksihlkw fishwheels, 1994 to 2019. Post-season estimates could be a mixture of stratified and unstratified estimates. In-season estimates are a combination of Methods 1-2 in June and then Method 3 starting in late-June onward. For example, in 2019, Method 2 was used until 25 June, and Method 3 from 26 June to the end of operations.

	Estimate		Difference	
Year	**In-season**	**Actual**	**Actual - Estimate**	**%**
1994	296,305	348,116	51,811	15%
1995	259,744	310,872	51,128	16%
1996	257,412	233,713	-23,699	-10%
1997	261,769	266,806	5,037	2%
1998	204,922	281,599	76,677	27%
1999	263,141	238,631	-24,510	-10%
2000	245,989	243,151	-2,838	-1%
2001	208,349	204,515	-3,834	-2%
2002	378,171	470,083	91,912	20%
2003	285,480	328,916	43,436	13%
2004	297,460	283,712	-13,748	-5%
2005	282,530	282,573	43	0%
2006	276,612	296,338	19,726	7%
2007	199,095	194,434	-4,661	-2%
2008	191,861	235,222	43,361	18%
2009	259,981	281,234	21,253	8%
2010	207,732	261,397	53,665	21%
2011	338,137	303,097	-35,040	-12%
2012	240,112	239,400	-712	0%
2013	254,036	248,513	-5,523	-2%
2014	271,134	301,072	29,938	10%
2015	481,341	469,466	-11,875	-3%
2016	283,355	304,135	20,780	7%
2017	259,277	260,585	1,308	1%
2018	220,291	254,178	33,887	13%
2019	286,548	268,000	-18,548	-7%

Mean absolute percent error 9% (range 0% to 27%).

FIGURES

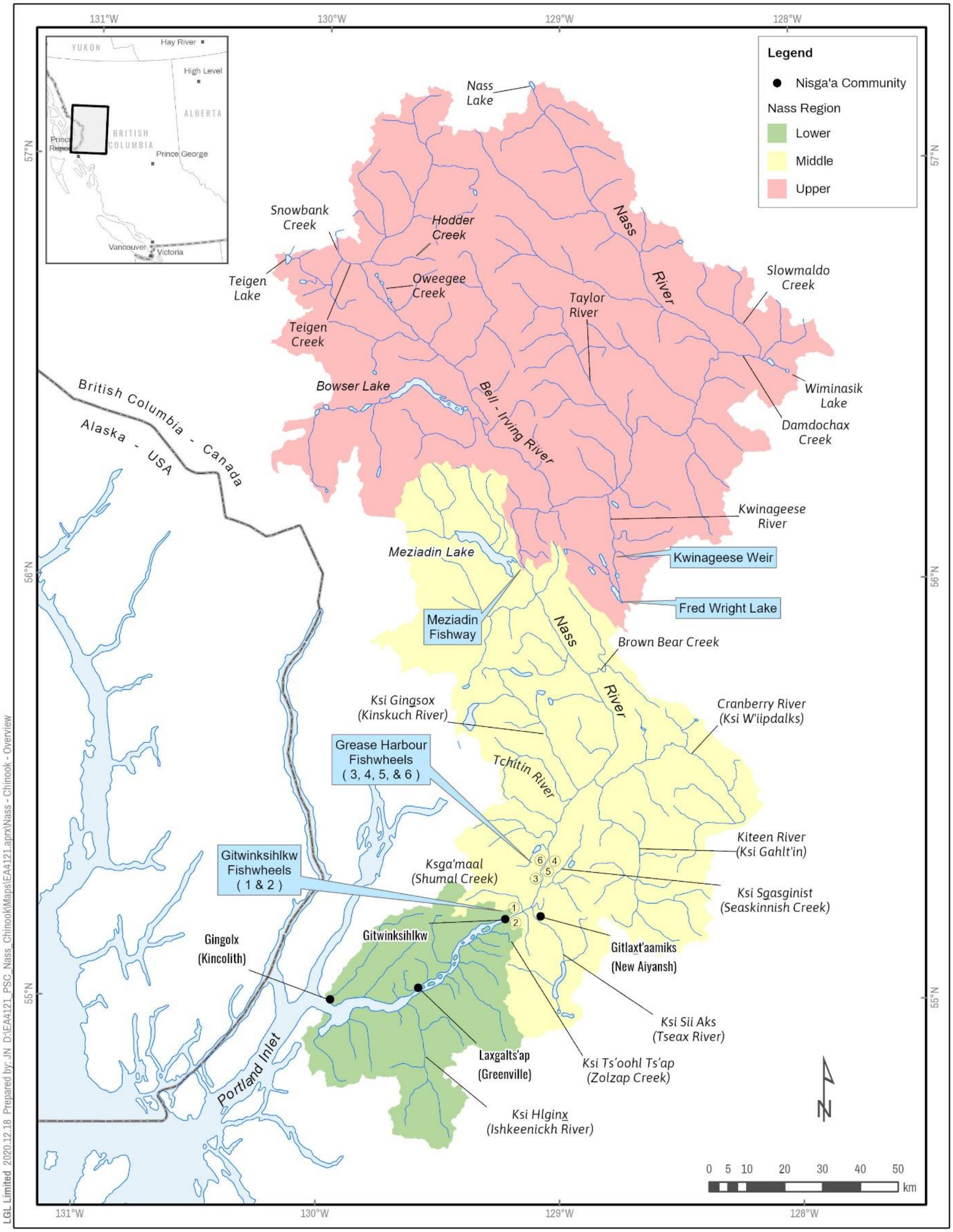

Figure 1. Overview map of the Nass River watershed.

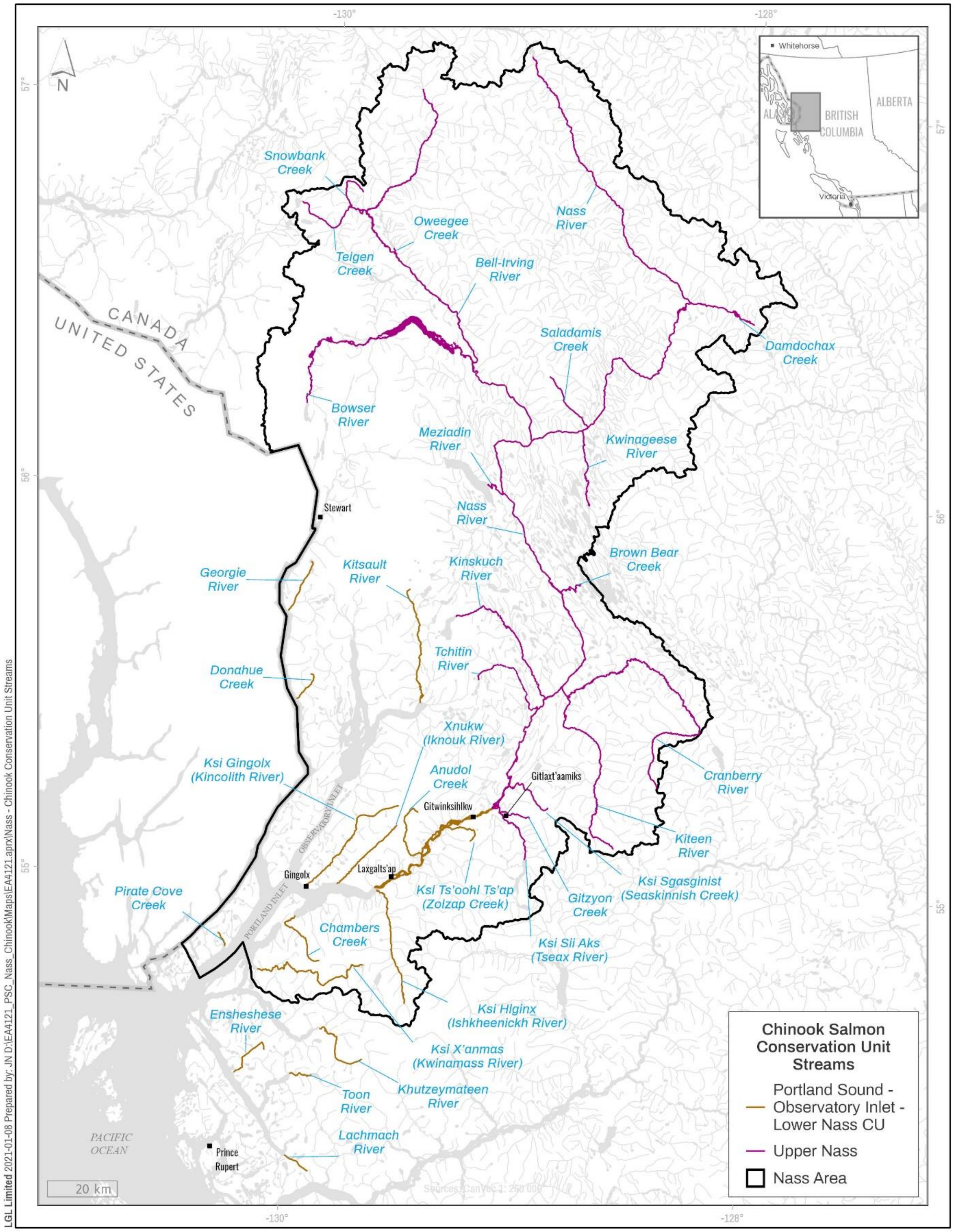

Figure 2. Map of Chinook Salmon spawning streams in the Upper Nass and Portland Sound-Observatory Inlet-Lower Nass conservation units.

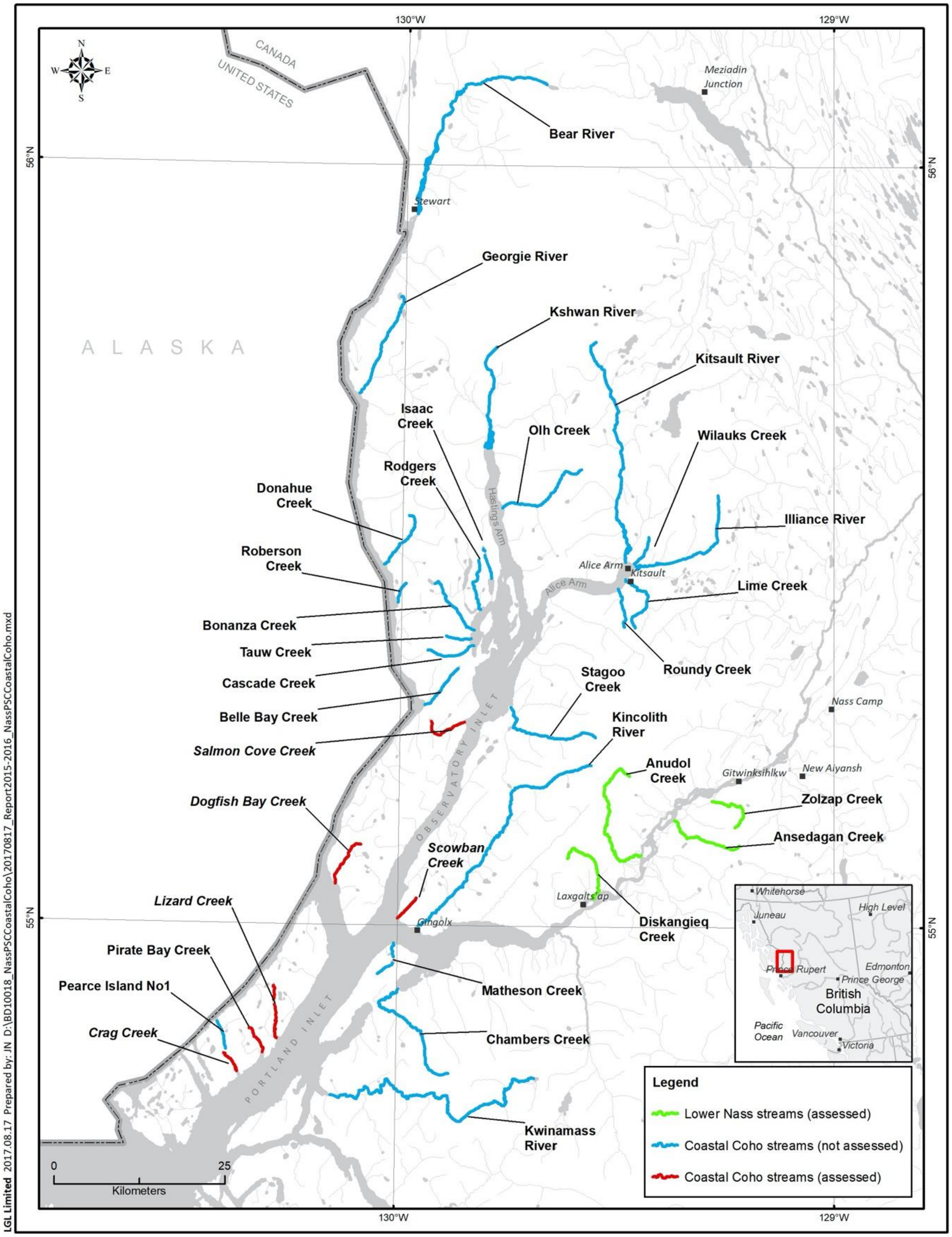

Figure 3. Map of Coho Salmon spawning streams in the lower Nass Area. Note that this map does not show all coho spawning tributaries above Gitwinksihlkw.

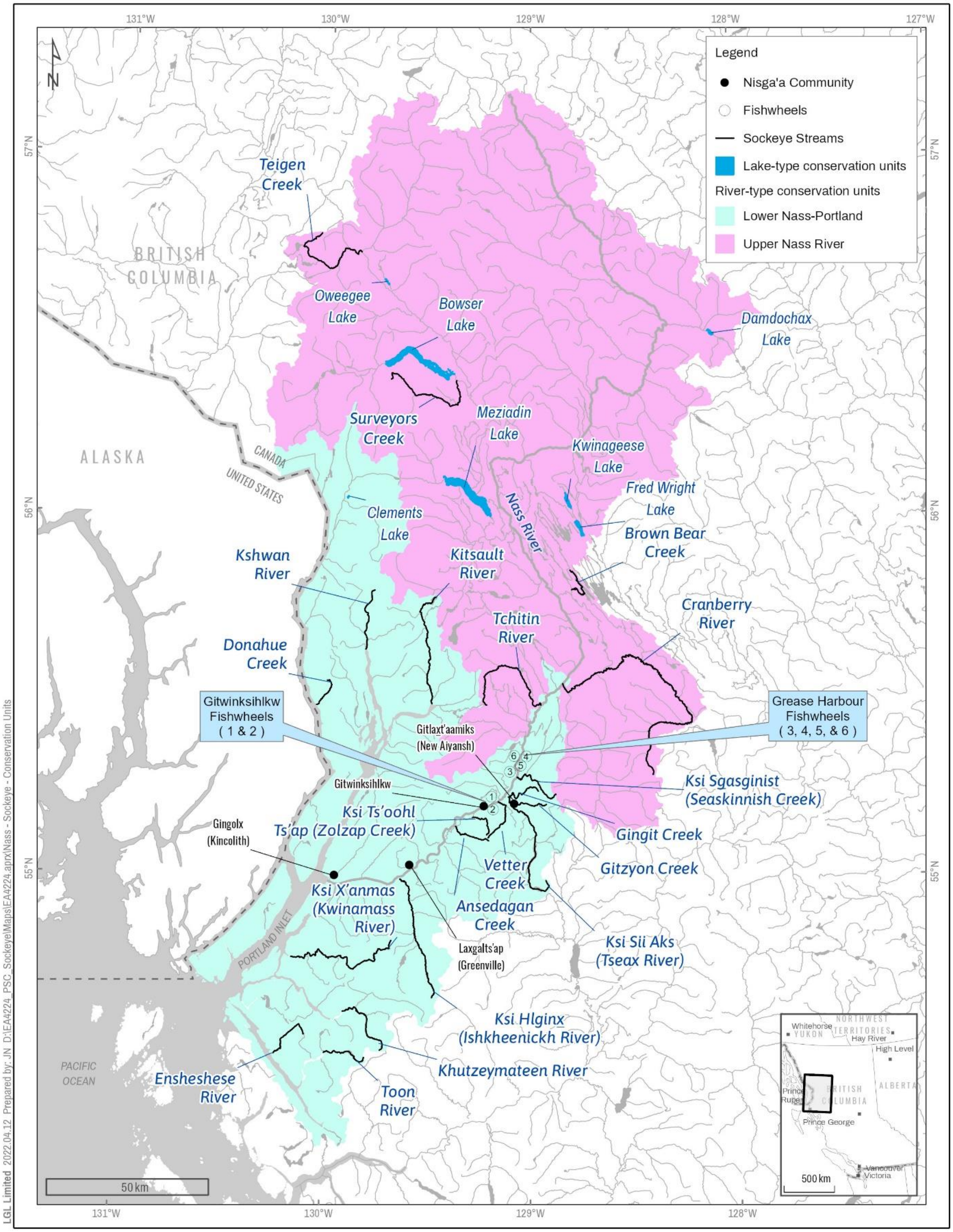

Figure 4. Map of Sockeye Salmon conservation units and river-type Sockeye Salmon spawning streams.

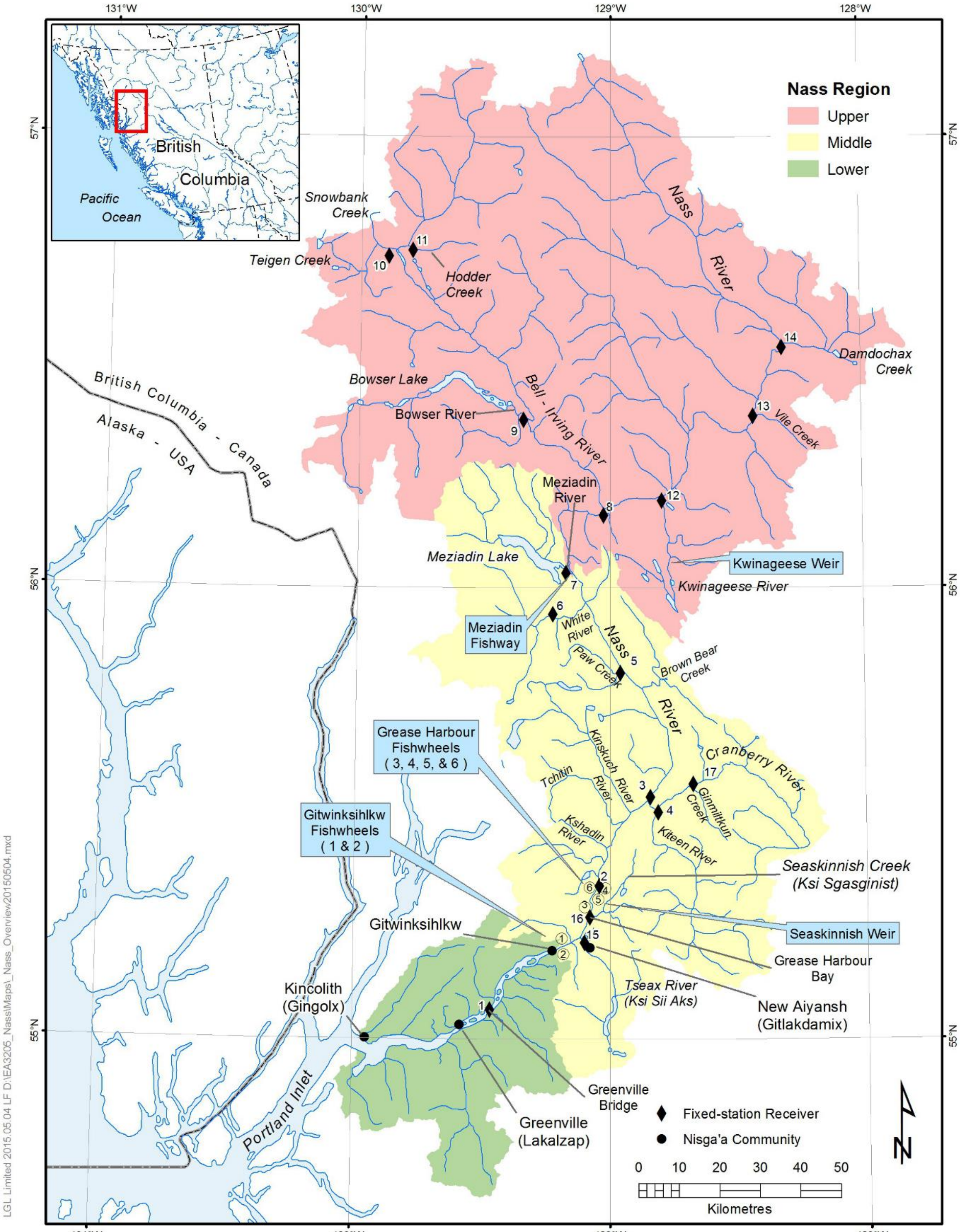

Figure 5. Map of 2005 radio-telemetry monitoring stations. Summer-run steelhead probably spawn in every tributary above Ksi Sii Aks (Tseax River).

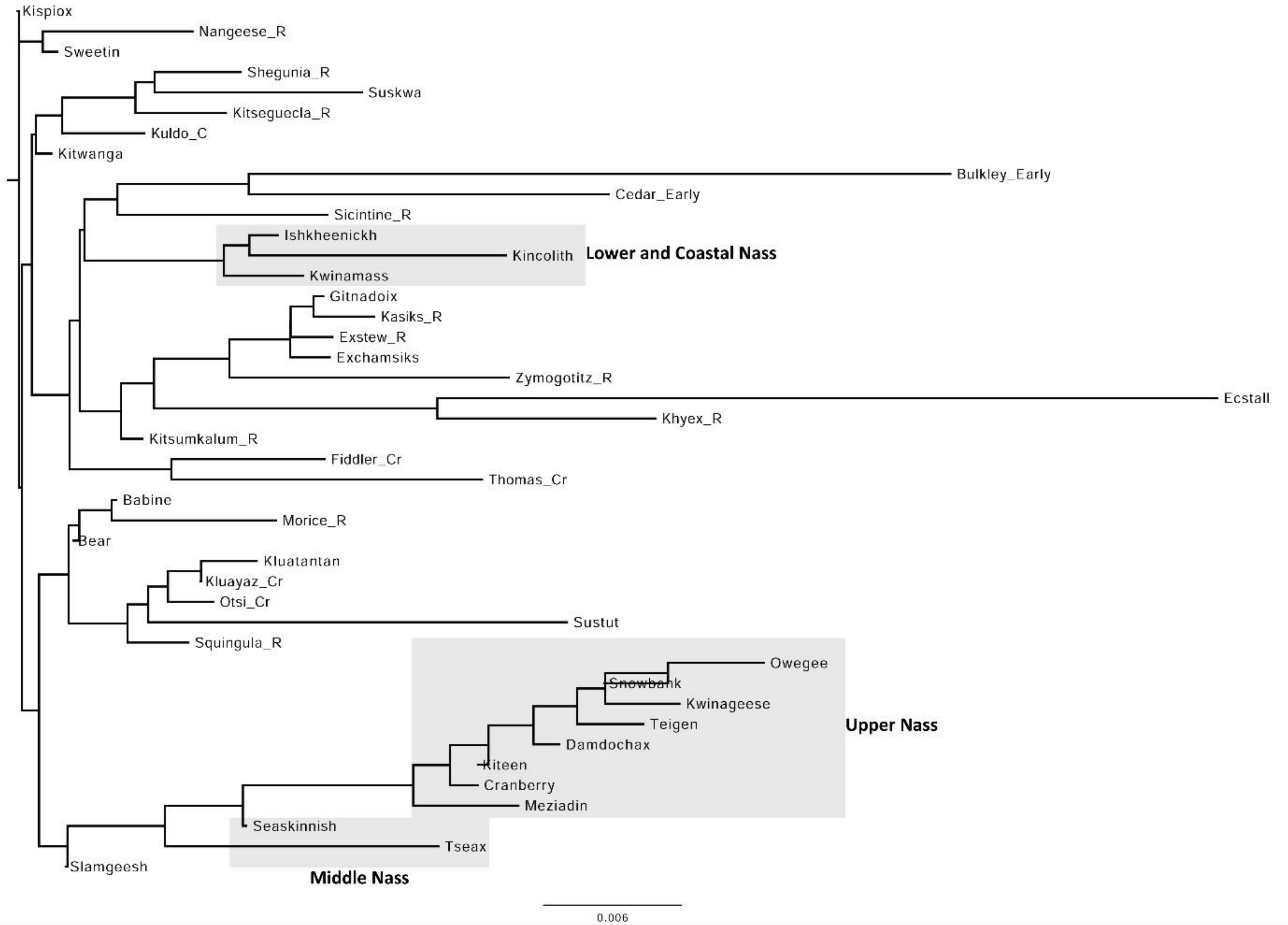

Figure 6. Dendrogram showing the relationship between the different Nass Chinook Salmon stocks. The upper Nass stocks are genetically similar. Coastal Nass and Skeena stocks are shown for reference.

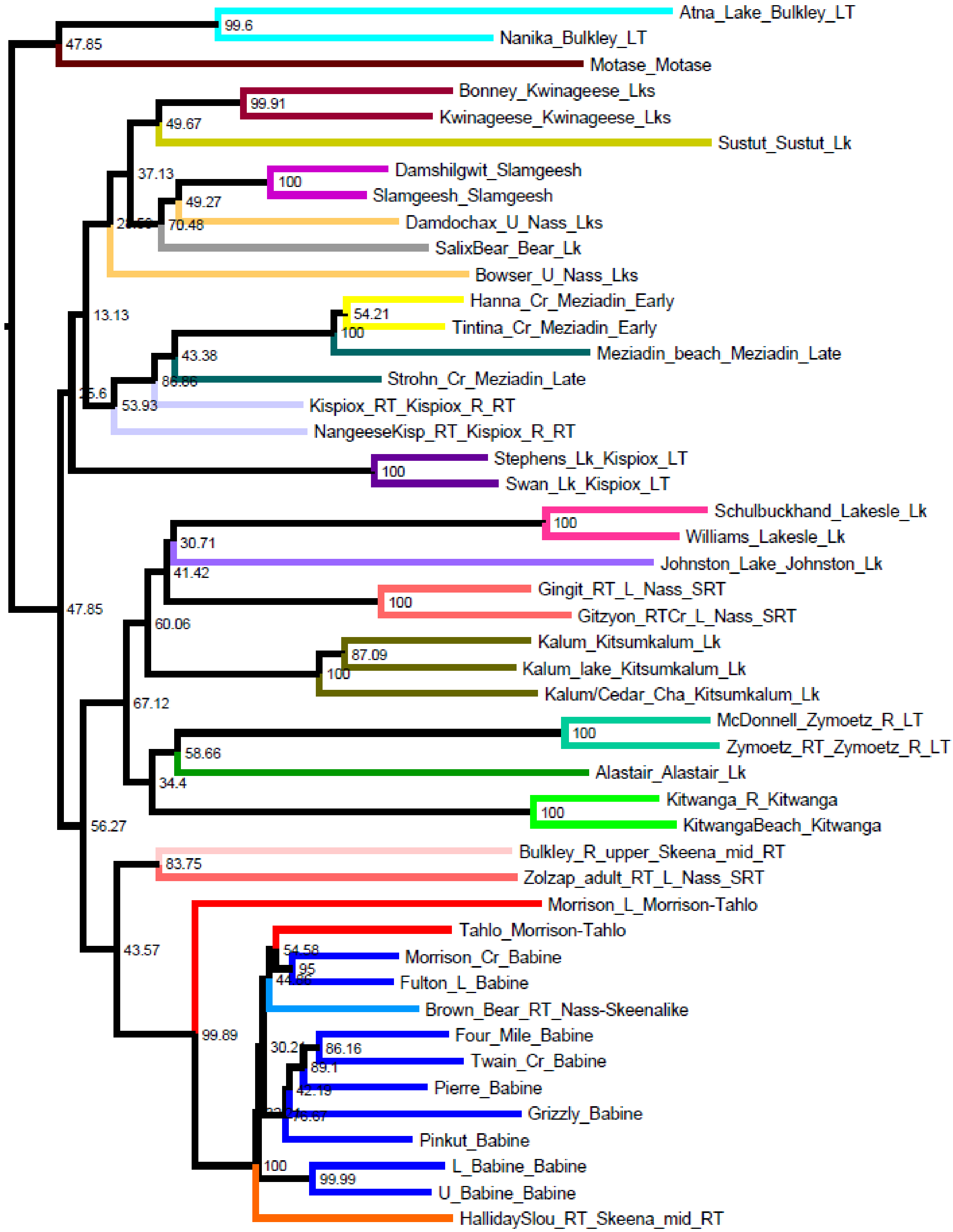

Figure 7. Genetic distance of Sockeye Salmon stocks in Nass River. Source: DFO Molecular Genetics Laboratory, Nanaimo, BC.

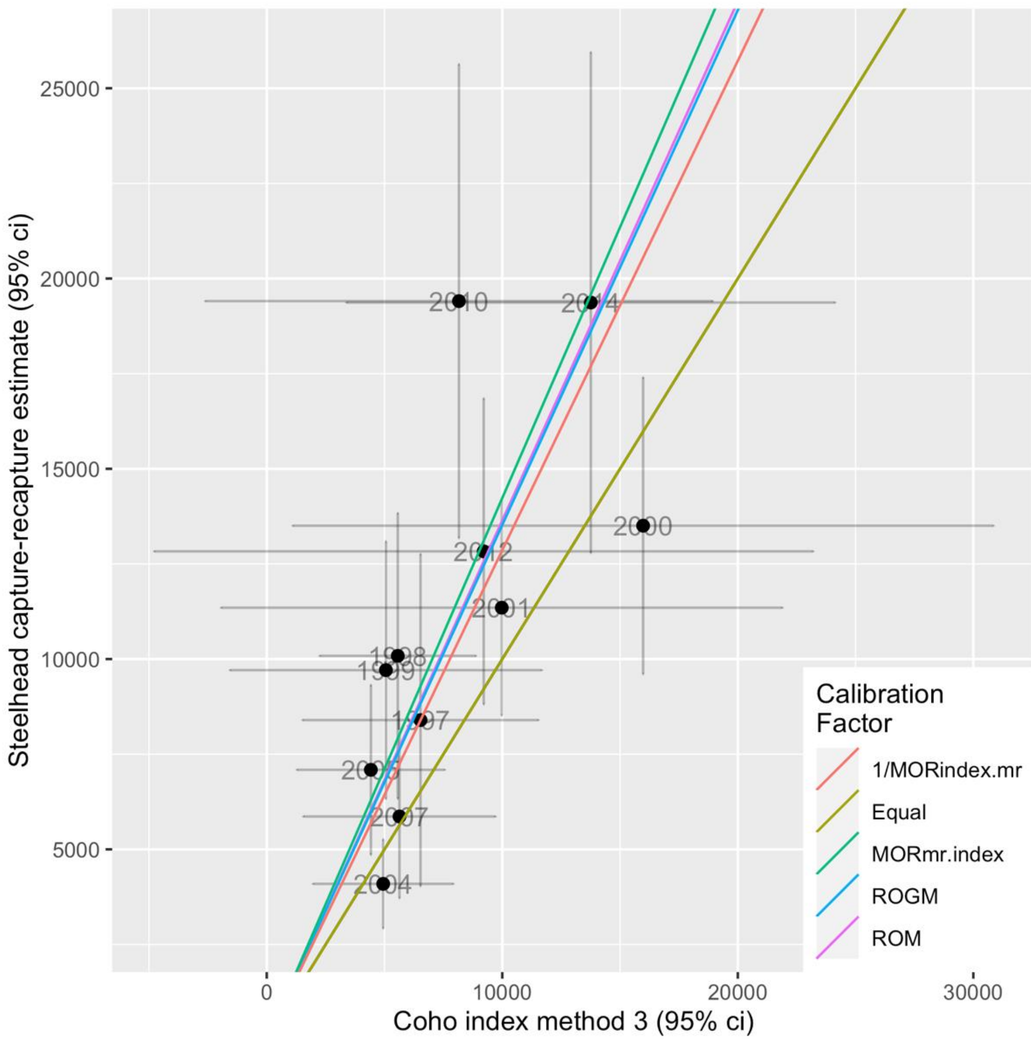

Figure 8. Comparison of the steelhead capture-recapture estimates and the steelhead index based on Coho Salmon recaptures at the fishwheel. Lines represent equality between the index and the capture-recapture estimates and correction factor computed in various way.

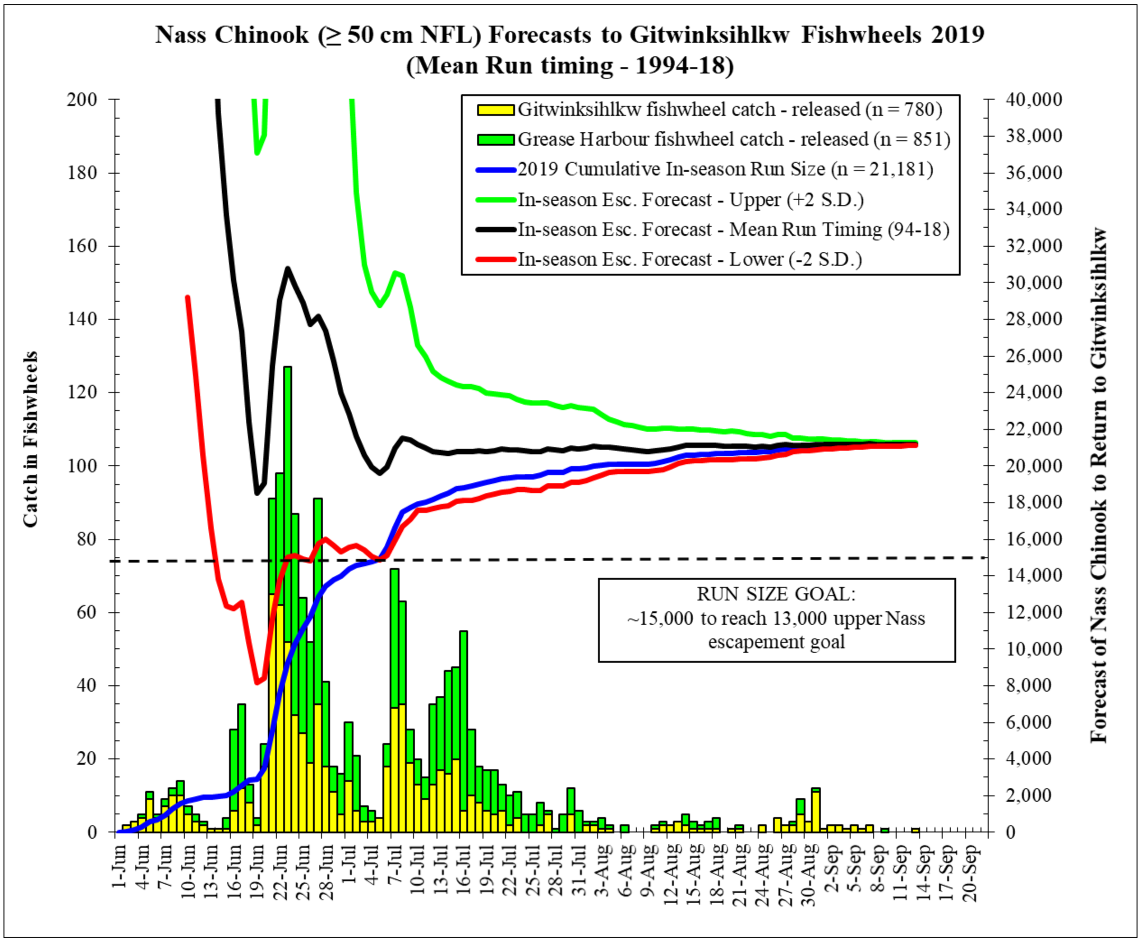

Figure 9. Run-size forecasts for Chinook Salmon to the Gitwinksihlkw fishwheels in 2019 based on mean run timing and standard deviation ranges (± 2 S.D.).

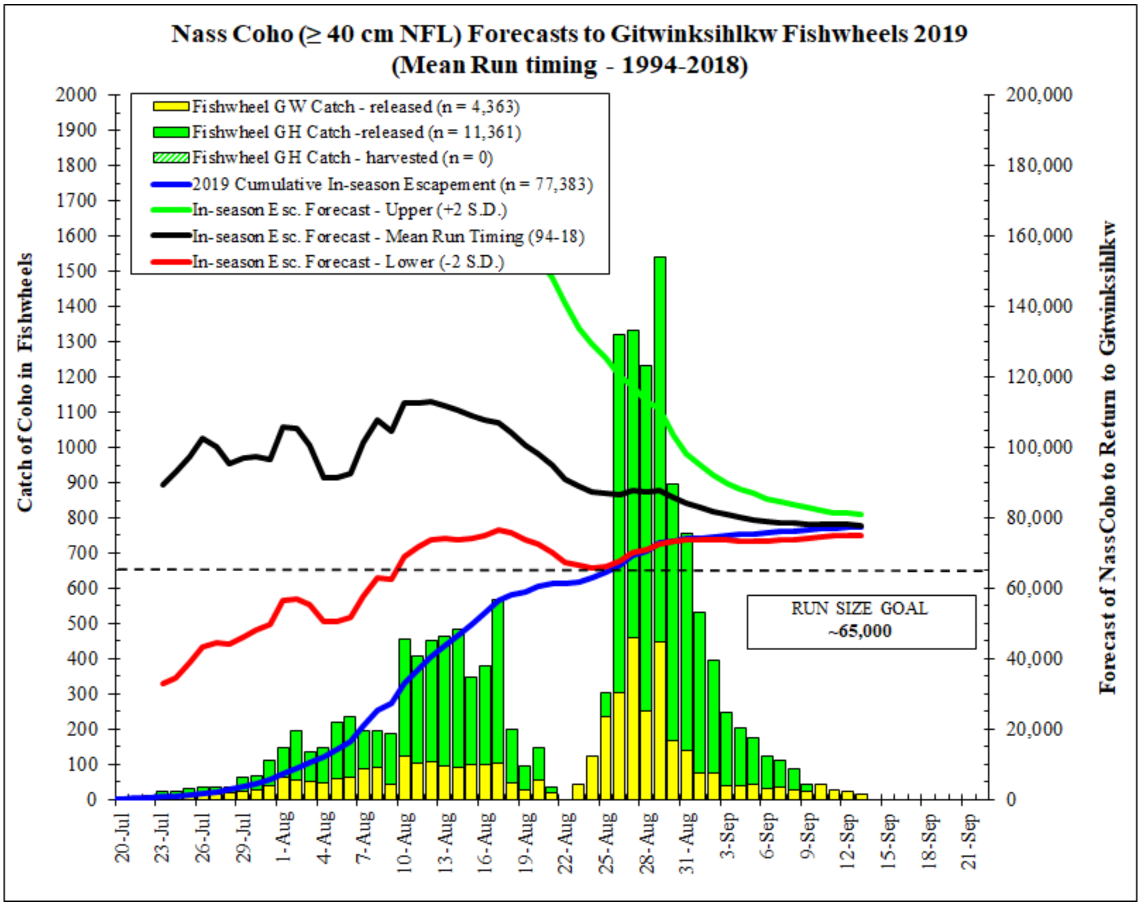

Figure 10. Run-size forecasts for Coho Salmon to the Gitwinksihlkw fishwheels in 2019 based on mean run timing and standard deviation ranges (± 2 S.D.).

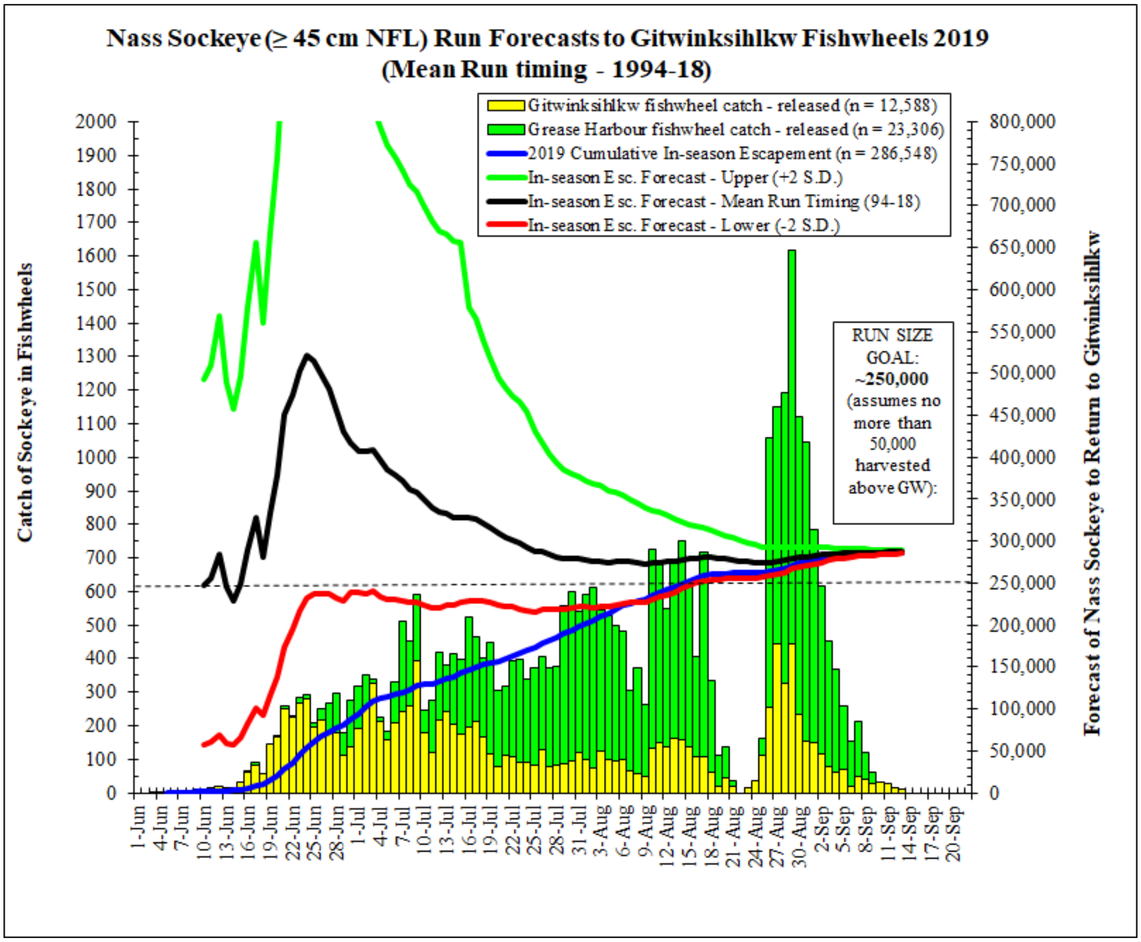

Figure 11. Run-size forecasts for Sockeye Salmon to the Gitwinksihlkw fishwheels in 2019 based on mean run timing and standard deviation ranges (± 2 S.D.).

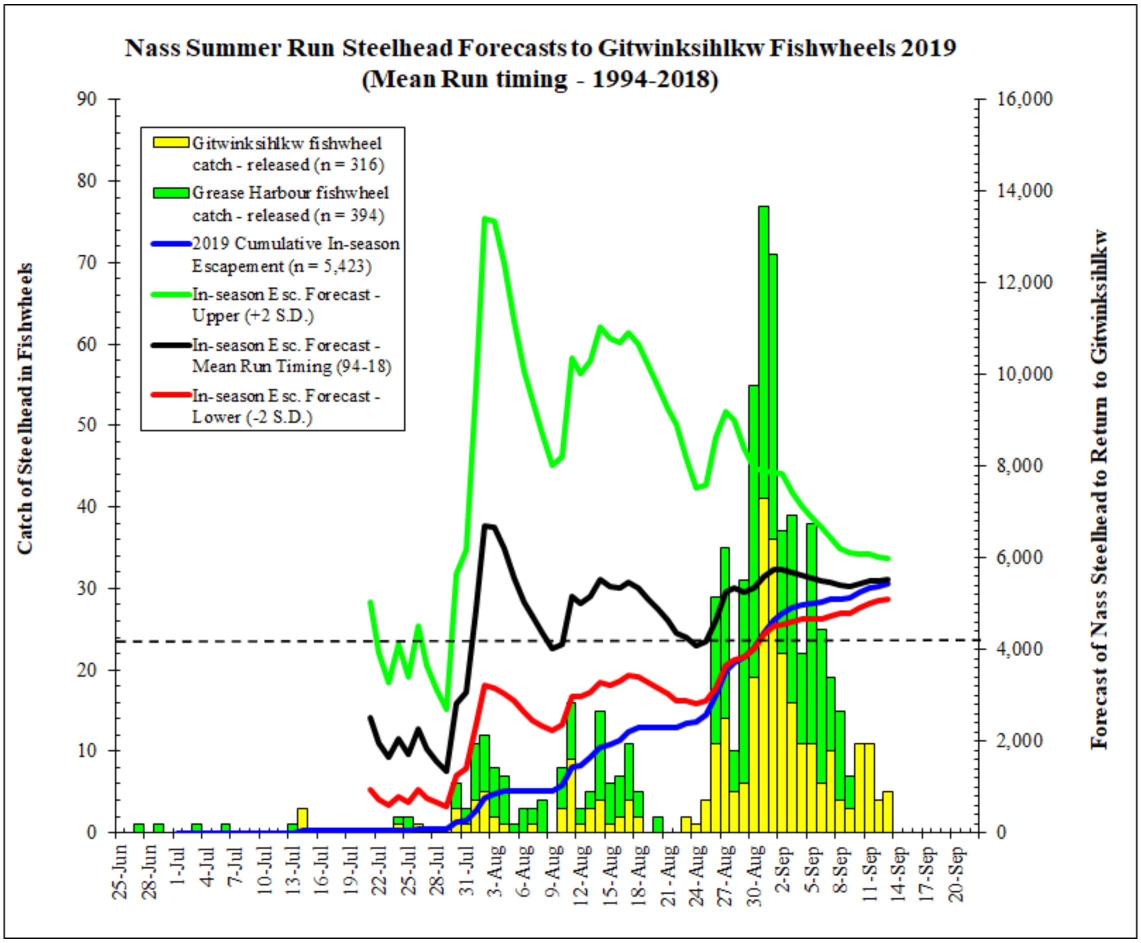

Figure 12. Run-size forecasts for summer-run steelhead to the Gitwinksihlkw fishwheels in 2019 based on mean run timing and standard deviation ranges (± 2 S.D.).

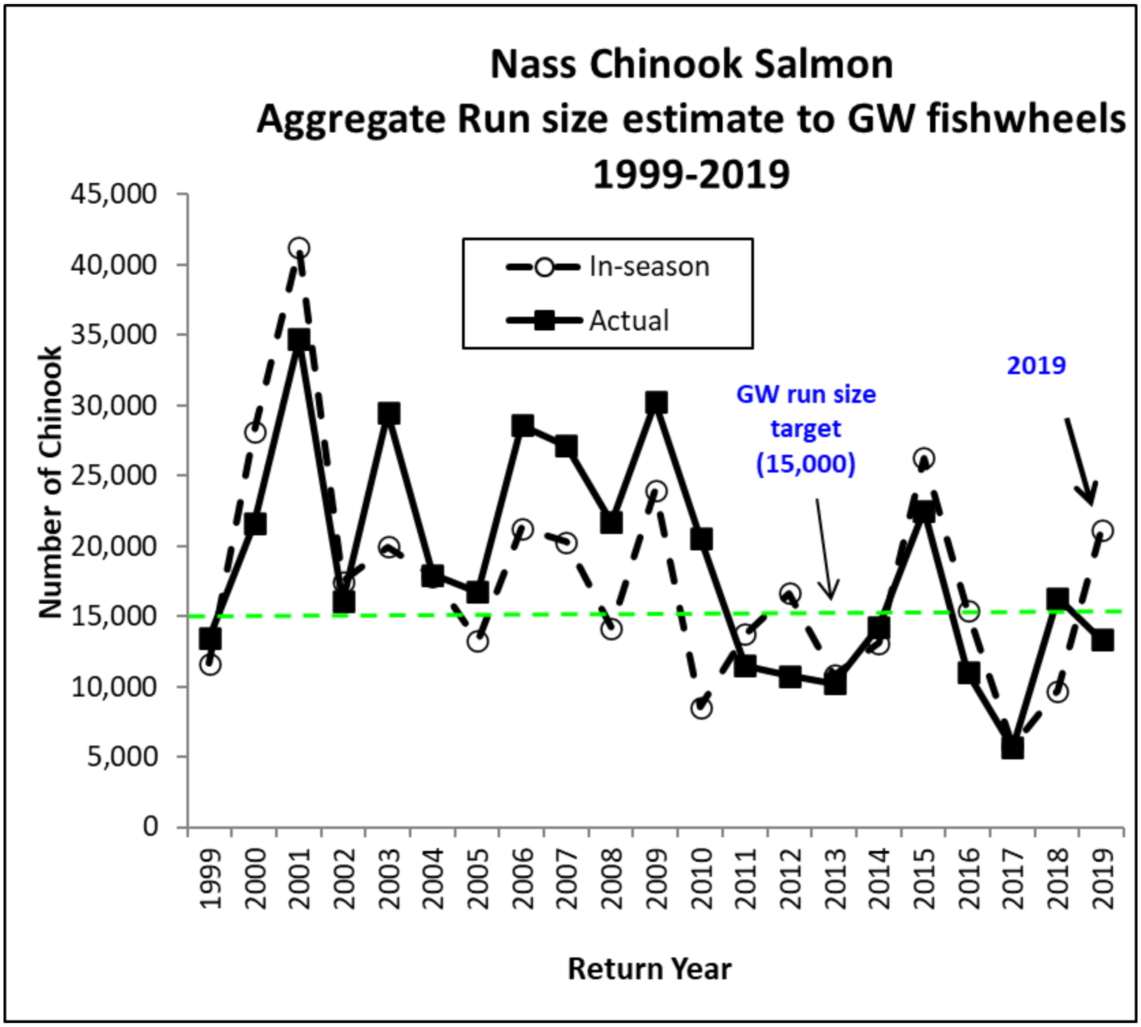

Figure 13. Comparison of in-season and post-season estimates of run-size at Gitwinksihlkw (GW) for Chinook Salmon.

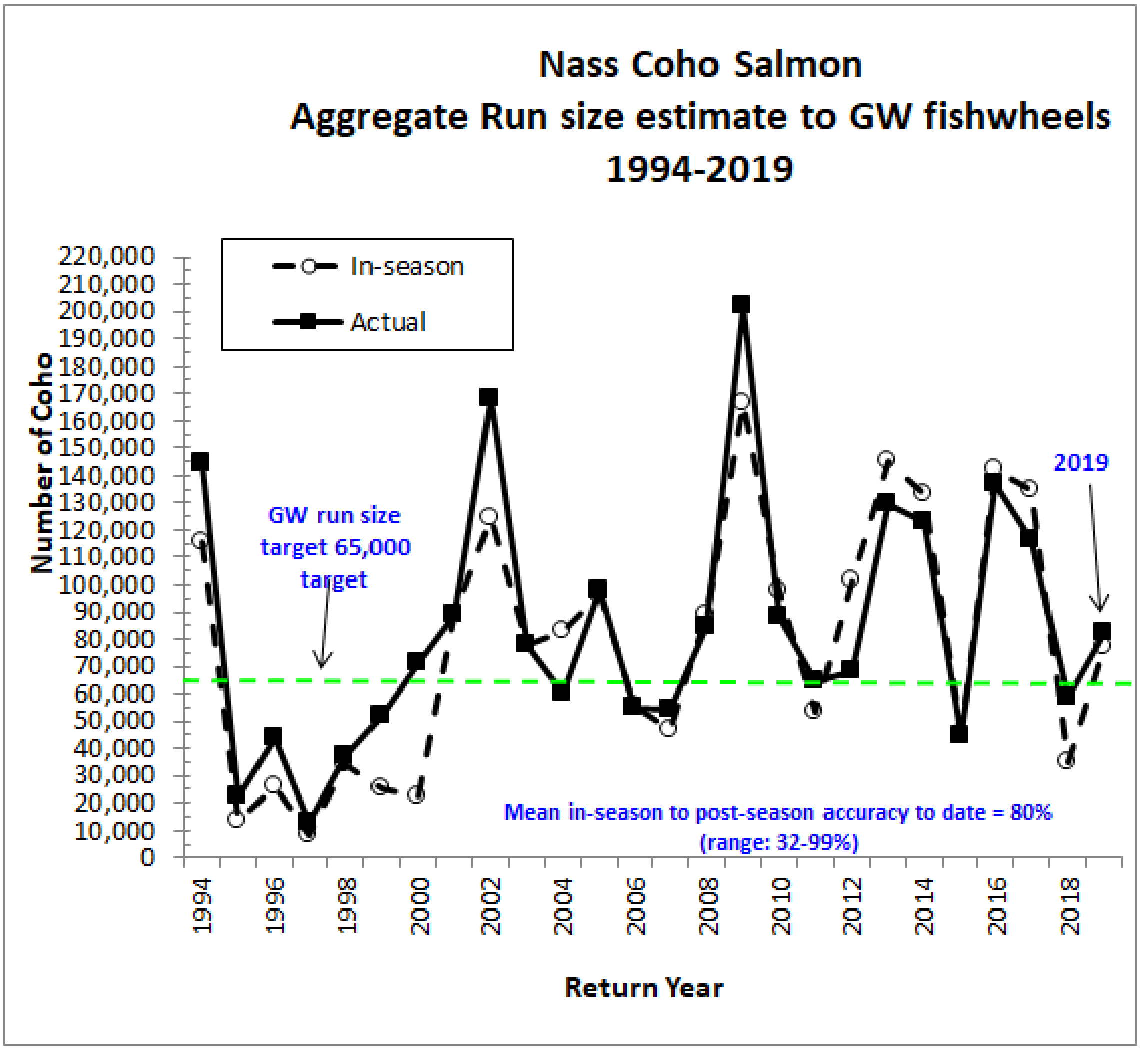

Figure 14. Comparison of in-season and post-season estimates of run-size for Coho Salmon at Gitwinksihlkw (GW) from 1994 to 2019.

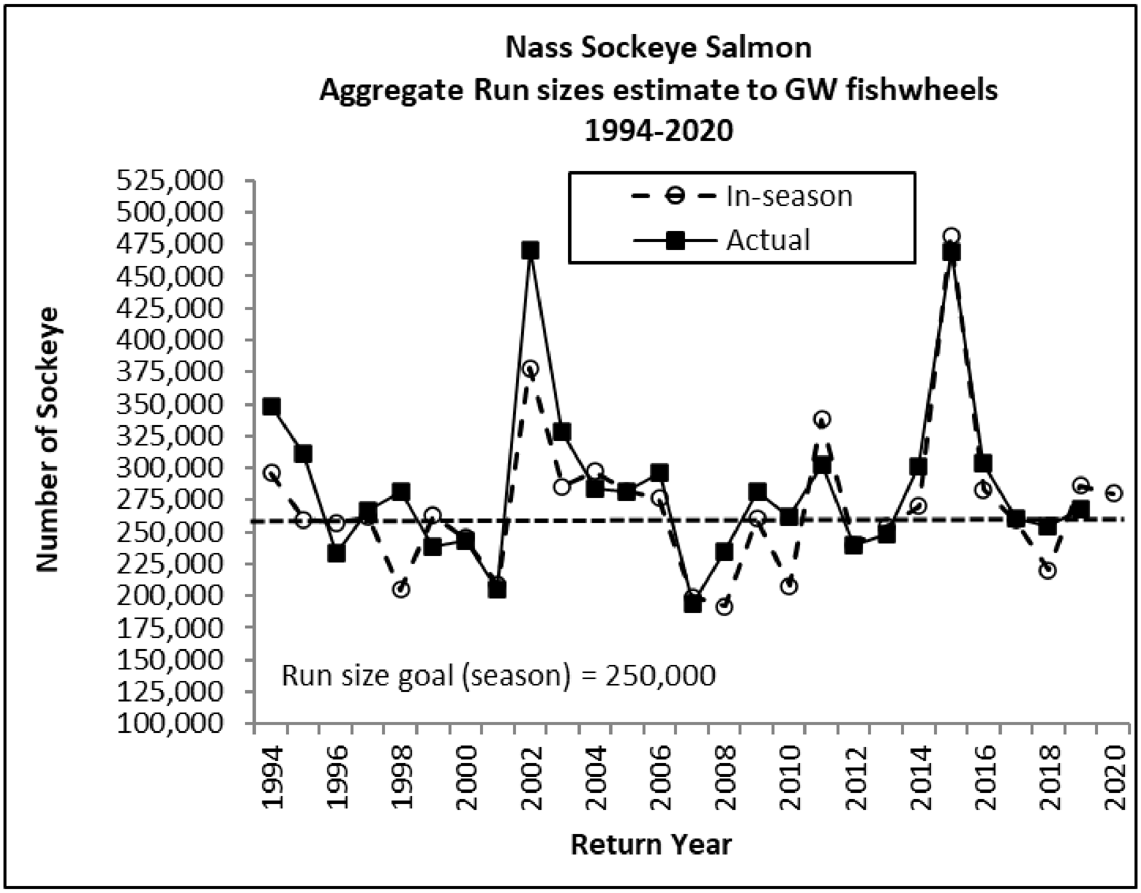

Figure 15. Comparison of in-season and post-season estimates of run-size for Sockeye Salmon at Gitwinksihlkw (GW) from 1994 to 2020.

APPENDICES

Appendix A. Comments about the stratified-Petersen estimator used for Chinook Salmon

The 2018 Chinook Salmon report (Beveridge et al. 2019) outlines on page 22 a method for dealing with small number of recaptures in one stratum (e.g., in medium stratum). This methodology is “equivalent” to a pooled-Petersen estimator using the large Chinook Salmon stratum to estimate the marked fraction (rather than a separate estimate of the marked fraction based on recaptured in the medium stratum). Notice that equation (9) in the report needs to be reformatted because the current equation (9) appears to be in error.

Let M_m, C_m, and R_m be the number marked (after adjustments), inspected, and tags recovered for the medium size class with similar notation for the large size class.

The pooled-Petersen estimator is (ignoring the Chapman modification of adding 1) and using the 2018 data from Table 10:

$$\widehat{N}_{PP} = \frac{(M_m + M_l)(C_m + C_l)}{(R_m + R_l)} = \frac{(310 + 300)(72 + 488)}{(2 + 20)} = 15{,}527.$$

The estimator for the large size class is:

$$\widehat{N}_{PP,L} = \frac{(M_L)(C_L)}{(R_L)} = \frac{(300)(488)}{(20)} = 7{,}320$$

The proposed estimator for the medium size class is:

$$\widehat{N}^*_{PP,m} = \frac{\widehat{N}_{PP,L}}{p_L} - \widehat{N}_{PP,L} = \frac{(M_m + M_L)(C_L)}{(R_L)} - \frac{(M_l)(C_l)}{(R_l)} = \frac{(M_m)(C_l)}{(R_l)} = \frac{(310)(488)}{(20)} = 7{,}564$$

where p_L is the proportion of (adjusted) tags that are large and $p_L = \frac{M_L}{M_m + M_L}$.

This is the Petersen estimator for medium-sized tagged fish that uses the mark ratio seen in the large fish rather than the mark ratio seen in the medium fish.

The combined stratified total is then:

$$\widehat{N}_{SP} = \widehat{N}^*_{PP,m} + \widehat{N}^*_{PP,L} = \frac{(M_m)(C_l)}{(R_l)} + \frac{(M_l)(C_l)}{(R_l)} = \frac{(M_m + M_l)(C_l)}{(R_l)} = \frac{(610)(488)}{(20)} = 14{,}884$$

This is equivalent to a pooled-Petersen estimator using the mark-ratio from the large fish only rather than the mark-ratio of all fish. If all fish are tagged in proportion to abundance at the tagging fishwheels, then the mark ratio in all sizes of fish should be the same. If you believe that fishwheels are selective and inspection is selective (and so need a stratified-Petersen), then this estimator ignores the mark ratio in the medium fish.

A hierarchical Bayesian model would be easy to develop where the mark rates in the different strata differ around a common mean and if there are enough data, it would automatically use separate mark fractions, but if the data are sparse, the estimator would automatically shrink the separate mark-fractions to the common mean. This Bayesian model would also then automatically incorporate all sources of uncertainty in the estimation process.

Appendix B. Introduction of bias to Chinook Salmon estimates by not censoring tagged fish spawning between Gitwinksihlkw and Grease Harbour

As described in the main report (see 4.1.4 Tags in escapement between GW and GH), bias in run size estimates to GH and GW can be introduced when tags lost to spawning between GH and GW are not accounted for. This is an issue for Chinook Salmon and summer-run steelhead which are tagged at both sets of fishwheels. Using example data, Table B-1 shows how bias can be introduced.

Table B-1. A comparison of Chinook Salmon run size estimates to Grease Harbour and Gitwinksihlkw using two methods, 2019.

Location	Parameter	Tagged	Untagged	Totals	Comments
Gitwinksihkw fishwheels	Arrive at GW	0	20,000	20,000	
	Tagged at GW	300	19,700	20,000	
Between GW & GH	Harvest proportion between GW and GH	5%	5%		
	Total harvest	15	985	**1,000**	
	Fish remaining after harvest	285	18,715	19,000	
	Escapement between GW & GH (from GSI)	**5%**	**5%**		
	Number escape to spawning	**14**	**936**	**950**	
Grease Harbour fishwheels	Fish arrive at GH	271	17,779	18,050	
	Tagged at GH	300	17,479		
	Total above GH	**571**	17,479	18,050	
Above GH	Harvest proportion above GH	0%	0%		
	Total harvest above GH	0	0	**0**	
	Net after harvest	571	17,479	18,050	
Meziadin fishway	Examined at Meziadin fishway	10%	10%		
	Numbers examined (and recaptured) at Meziadin	**57**	1,748	**1,805**	
Petersen estimate of run size	**1. CURRENT (2019) method**	Marked (M)	**585**		Notice how M differs from M in the recommended method
	NO adjusting tags at GH for escapement	Examined	**1,805**		
	between GW and GH	Recaptured	**57**		
		Nhat GH	**18,501**		Estimate at GH includes escapement btwn GW & GH
		% bias for GH	**2.50%**		Bias = (Nhat GH - Fish arrive at GH)/Fish arrive at GH
		GW-GH harvest	1,000		Add back harvest and escapement to get GW run size
		GW-GH escapement	950		
		Nhat GW	**20,451**		
		% bias for GW	**2.25%**		
	2. RECOMMENDED method	Marked (M)	**571**		Fewer marks available upstream of GH to account for spawning between GW & GH
	Adjusting tags at GH	Examined	**1,805**		
	for escapement between	Recaptured	**57**		
	GH and GW				
		Nhat GH	**18,050**		
		% bias for GH	**0.00%**		No bias
	Adjustments	GW-GH harvest	1,000		Add back harvest and escapement to get GW run size
		GW-GH escapement	950		
		Nhat GW	**20,000**		
		% bias for GW	**0.00%**		Unbiased for total run