# Sockeye Salmon (*Oncorhynchus nerka*) from the Skeena and Nass Basins, British Columbia: Population Structure and Spawner-Recruit Data

Gottfried P. Pestal, Charmaine Carr-Harris, Steven Cox-Rogers, Karl English, Richard Alexander, and the Skeena Nass Sockeye Technical Working Group

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# SOCKEYE SALMON (*ONCORHYNCHUS NERKA*) FROM THE SKEENA AND NASS BASINS, BRITISH COLUMBIA: POPULATION STRUCTURE AND SPAWNER-RECRUIT DATA

by

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## CONTENTS

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## SHORT FORMS AND TECHNICAL TERMS

ADF&G: Alaska Department of Fish and Game
CU: Conservation Unit
DFO: Fisheries and Oceans Canada
GSI: Genetic stock identification
LHAZ: Life History and Adaptive Zone
NBRR and NBSRR: Northern Boundary Run Reconstruction and Northern Boundary Sockeye Run Reconstruction model
NCCSDB: North and Central Coast Salmon Data Base
nuSEDS: Fisheries and Oceans Canada New Salmon Escapement Database
PR: Photosynthetic Rate
SR: Spawner-Recruit
SSIRR: Skeena Sockeye In-River Run Reconstruction model

**ABSTRACT**

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Sockeye salmon (*Oncorhynchus nerka*) spawn throughout the Skeena and Nass basins in British Columbia, and are harvested in numerous Canadian and Alaskan commercial, indigenous and recreational fisheries. Aggregate sockeye returns to each basin consist of genetically distinct smaller populations. This report describes the population structure of Skeena and Nass sockeye, summarizes stock assessment programs and run reconstruction analyses, documents the available spawner-recruit data, and discusses the implications for escapement goal analyses. 31 stocks (24 Skeena, 7 Nass) were identified and organized into 3 groups based on available data: Group 1 includes 14 stocks with mostly complete high-quality time series and accounts for approximately 98% of the abundance of returning sockeye. Group 2 includes 9 smaller stocks with incomplete time series of medium quality and accounts for about 2% of the total abundance of returning sockeye. Group 3 includes 8 data deficient stocks.

## RÉSUMÉ

Pestal, G.P., Carr-Harris, C., Cox-Rogers, S., English, K., Alexander, R., and the Skeena Nass Sockeye Technical Working Group. 2025. Sockeye Salmon (Oncorhynchus nerka) from the Skeena and Nass Basins, British Columbia: Population Structure and Spawner-Recruit Data. Can. Tech. Rep. Fish. Aquat. Sci. 3661: x + 182 p. https://doi.org/10.60825/zye0-7q50

Le saumon rouge (*Oncorhynchus nerka*) se reproduit dans les bassins de la Skeena et de la Nass en Colombie-Britannique et fait l'objet de nombreuses pêches commerciales, autochtones et récréatives au Canada et en Alaska. Les remontées globales de saumons rouges dans chaque bassin sont constituées de petites populations génétiquement distinctes. Le présent rapport décrit la structure de la population de saumon rouge de la Skeena et de la Nass, résume les programmes d'évaluation des stocks et les analyses de reconstitution des remontées, documente les données disponibles de geniteurs-recrues et examine les implications pour les analyses des objectifs d'échappée. 31 stocks (24 pour la Skeena, 7 pour la Nass) ont été identifiés et organisés en 3 groupes sur la base des données disponibles : Le groupe 1 comprend 14 stocks dont les séries chronologiques de haute qualité sont pour la plupart complètes et représente environ 98 % de l'abondance des saumons rouges en montaison. Le groupe 2 comprend 9 stocks plus petits avec des séries temporelles incomplètes de qualité moyenne et représente environ 2 % de l'abondance totale du saumon rouge en montaison. Le groupe 3 comprend 8 stocks pour lesquels les données sont insuffisantes.

# 1 Introduction

## 1.1 Escapement Goal Review

### 1.1.1 Background

Under the renewed Pacific Salmon Treaty (PST) provisions, Canada has agreed to complete a comprehensive escapement goal analysis prior to the 2023 fishing season for sockeye salmon (*Oncorhynchus nerka*) returning to the Skeena and Nass rivers (Pacific Salmon Commission 2020). A combined escapement goal for Skeena and Nass sockeye is used to set Annual Allowable Harvests (AAH) for U.S. and Canadian fisheries targeting both stock aggregates. In addition to renewed PST provisions, biologically-based escapement goals for Skeena and Nass River sockeye are used for Canadian fishery management including the implementation of the Nisga'a Treaty (British Columbia, Canada, and Nisga'a Lisims Government 2000) and other fisheries in the Skeena and Nass rivers.

The current aggregate escapement goals are based on the aggregate spawner abundance needed to produce maximum sustainable yield ($S_{msy}$), which has been estimated at 900,000 for Skeena sockeye and 200,000 for Nass sockeye (Shepard and Withler 1958; Ricker and Smith 1975; Bocking et al. 2002).

Aggregate sockeye returns to the Skeena and Nass basins consist of numerous genetically distinct smaller populations, many of which are data-limited. In addition, enhanced sockeye from artificial spawning channels in two tributaries to Babine Lake account for a large proportion of aggregate Skeena sockeye production.

Canada is seeking to maintain the future productivity of Skeena and Nass sockeye returns by maintaining the genetically unique wild sockeye populations that contribute to overall returns consistent with Canada's *Wild Salmon Policy* (DFO 2005).

### 1.1.2 Project Mandate

The Northern Panel of the Pacific Salmon Commission (PSC) has requested scientific advice to inform the development of biologically-based aggregate escapement goals for Skeena and Nass sockeye. Canadian members of the Northern Boundary Technical Committee (NBTC) have been tasked with leading the technical work related to this outcome, and a technical working group (TWG) was formed to provide advice to this process. The TWG includes participants from Fisheries and Oceans Canada, First Nations from BC's North Coast Area, Pacific Salmon Foundation, and consulting organizations (Table A.1). TWG participants have specific expertise in Skeena and Nass sockeye salmon biology, databases, and/or spawner-recruit modeling.

The bilaterally-agreed objectives for the escapement goal review are:

1. Summarize and evaluate relevant biological information to inform the development of aggregate escapement goals for Skeena and Nass sockeye including an assessment

of key uncertainties and gaps in the data for sockeye populations in these basins.

2. Evaluate alternative aggregate escapement goals for Nass and Skeena River sockeye, including an evaluation of stock status, production, and implications of key uncertainties.

The technical work is being carried out in discrete stages that address the objectives described above, including (1) conducting a technical review of available information, methods and metrics that can be used to address the biological status of Nass and Skeena sockeye populations (data review) and (2) conducting a quantitative assessment of alternative stock- and aggregate-level escapement goals for these populations.

The two main deliverables are:

- *Data Report* (this technical report): Comprehensive review of available data, covering population structure, data sources, quality criteria, and sensitivity testing.
- *Analysis Report* (Research Document): Describes spawner-recruit model fitting and how the resulting parameter estimates can be used to consider alternative aggregate management targets. The analyses were reviewed in a Regional Peer Review process coordinated through the Canadian Science Advisory Secretariat (CSAS) in 2022, as documented in a *Science Advisory Report* (DFO 2023), proceedings (DFO 2022), and a CSAS Research Document (Pestal and Carr-Harris 2025).

In addition to the CSAS process, two independent reviewers on behalf of Canada (Dr. Randall Peterman) and the U.S. (Dr. Milo Adkison) provided feedback and guidance for the data review and analyses.

## 1.2 Purpose of this *Data Report*

The main purpose for this initial part of the escapement goal review was to develop an agreed-upon data set as a solid, common foundation for the subsequent analyses which looked at alternative spawner-recruit model forms, alternative approaches for setting benchmarks and management targets, and alternative management objectives.

The TWG identified five key questions that shape the model-building step of the escapement goal review, given the project mandate established by the Northern Panel of the Pacific Salmon Commission:

- What information is available?
- Which sources of uncertainty have the greatest impact on estimates of biological benchmarks for Skeena and Nass sockeye?
- What are the implications of observed differences in productivity (i.e., changes over time, differences between stocks)?
- What are the implications of Pinkut and Fulton spawning channels for spawner-recruit modelling and management strategies for enhanced and wild Skeena stocks?

- How can aggregate-level objectives and stock-level considerations be explored in the analysis?

This data report is intended to answer the five key questions and serve three roles within the broader review of escapement goals for Skeena/Nass sockeye to: (1) document where the available data comes from and how it is treated, (2) document agreed-upon rules for quality control, and (3) discuss implications for subsequent analyses.

Our review of data quality identifies long-term changes (e.g., abundance, stock composition, age composition, productivity) and rapid changes (e.g., changes in fishery regulation) and provides a qualitative commentary on potential implications for subsequent analyses. We also developed quantitative criteria for flagging unusual brood years and potential data errors (e.g., more than *x* recruits per spawner).

*Note that this pdf file includes clickable cross-references for sections, figures, and tables. In many pdf viewers you can return to where you left off by pressing "Alt + Left Arrow"*

# 2 Population Structure

## 2.1 Concepts

The concept of a salmon *stock* or *population* seems clear at first glance, but the exact operational interpretations depend on the decision setting (e.g., international harvest management vs. Canadian domestic conservation measures) and continue to evolve as additional information is incorporated (e.g. Indigenous knowledge systems), new methods are developed (e.g. hydroacoustics, radio tags, changes in genetic methods), additional baseline samples are collected, and new policies are developed and implemented, such as the *Wild Salmon Policy* (WSP, DFO 2005). There are long-running debates regarding the overall biological structure of Pacific salmon (e.g., Simon and Larkin 1970; Walters and Korman 1999; DFO 2005; Holtby and Ciruna 2007), as well as the specific application of these definitions to Skeena and Nass sockeye (Hall et al. In Press; Beacham and Wood 1999; Gottesfeld et al. 2002; Beacham et al. 2004, 2014a, 2014b; Price et al. 2014).

One approach for organizing our description of salmon population structure is to group the alternative concepts and definitions into four types: Indigenous knowledge, geographic scales, biological scales, and assessment/management scales.

### 2.1.1 Indigenous Knowledge

Long before the modern technical perspective on Pacific Salmon biodiversity started to take shape in the 1960s (e.g., Simon and Larkin 1970), First Nations along the coast and throughout the salmon-bearing watersheds in the BC interior developed their individual knowledge systems that distinguished between different groups of salmon based on their appearance, life history, and behaviour (e.g. Indigenous Foundations 2020; Atlas et al. 2021a). For example, the WSÁNEC (Saanich) First Nation considered individual salmon runs as lineages in a larger kinship of relatives that included other salmon, other animals, and people (Indigenous Foundations 2020).

First Nations developed detailed knowledge systems to understand their environment, including views on the population structure of salmon based on observed differences in appearance and behaviour, with distinct run of salmon identified based on timing, appearance, spawning location, and traditional use (e.g. drying vs. smoking).

Frameworks and case studies exist for aboriginal participation in stock assessment and harvest management (Pinkerton and Weinstein 1995; Murray et al. 2011; Pinkerton et al. 2018, 2019), but we are not aware of any publicly available documentation that summarizes traditional aboriginal knowledge about the population structure of Skeena and Nass sockeye.

Indigenous salmon groupings are not explicitly incoporated in the current stock assessment framework or genetic baselines for Skeena and Nass sockeye salmon. First Nations participants provided feedback on the population structure of Skeena and Nass sockeye during the *Independent Science Review Panel* (ISRP) process which evaluated Canadian domestic harvest measures and was completed in 2008 (Walters et al. 2008).

### 2.1.2 Geographic Scales

Salmon are highly adapted to the landscape features of their spawning and rearing habitats, and how the waterways are connected in basins, watersheds and individual tributaries (Table 1).

This adaptation of salmon allows us to use landscape features as a proxy for biological differences. For example, Babine sockeye spawn and rear less than 50 km from Early Stuart sockeye in northern BC, but they live in different river basins and enter the ocean almost 800km apart (near Prince Rupert vs. Vancouver). Some regional climate drivers are similar for the two systems (e.g. winter snow pack, timing of spring freshet), but many other characteristics are very different (e.g. temperature and prey availability during ocean entry). Likewise, there are some shared characteristics and clear differences between the Skeena and Nass basins, and the watersheds within those basins.

Table 1. *Geographic Scales of Salmon Population Structure.* Other geographic scales are commonly used for salmon and salmon fisheries. The table includes only those concepts that are used in this report.

| Concept | Description |
|---|---|
| Tributary | Individual river contributing to the main river in a watershed (e.g. Bear and Asitka in the Sustut watershed) |
| Watershed | Area that drains 1 or more tributaries of a large river (e.g. Sustut watershed, Bell-Irving watershed, Bulkley watershed) |
| Basin | Entire area drained by a large river and its tributaries (e.g. Nass basin, Skeena basin) |

### 2.1.3 Biological Scales

The *Wild Salmon Policy* (Figure 2 in DFO 2005) defines four levels of genetic diversity for Pacific salmon (demes, populations, conservation units, and species). The delineation of conservation units (Holtby and Ciruna 2007) takes into account biological and ecological consideration (e.g., genetics, life history, freshwater adaptive zone). Table 2 defines these concepts.

Table 2. *Biological Scales of Salmon Population Structure.*. Other biological scales are commonly used for salmon and salmon fisheries. The table includes only those concepts that are used in this report.

| Concept | Description |
|---|---|
| Freshwater Adaptive Zone (FAZ) | Holtby and Ciruna (2007) identified distinct freshwater and marine adaptive zones for salmon, based on shared environmental and biological forces that influence salmon throughout their life history, and used them to delineate conservation units. For example, three adaptive zones were identified for the Skeena: Lower, Middle, Upper. |
| Life History Type | Characteristics of a salmon population that affect survival and reproduction (e.g., juvenile rearing behaviour). This is a broad concept, but we use it here to refer specifically to variations in juvenile rearing behaviour (lake, river, or ocean type sockeye) |
| Conservation Unit (CU) | DFO (2005) defined conservation units as the fundamental unit of biodiversity for Pacific Salmon, specifically "a group of wild salmon sufficiently isolated from other groups that, if lost, are very unlikely to recolonize naturally within an acceptable timeframe (e.g., a human lifetime or a specified number of salmon generations)". Conservation Units are delineated by their ecology, life-history, and genetics. Sockeye CUs are generally based on rearing lakes (e.g., all sockeye rearing in Lakelse Lake). |
| Population (deme) | Group of interbreeding organisms that is relatively isolated (i.e. demographically uncoupled) from other such groups and is likely adapted to the local habitat. For example, sockeye that spawn in WIlliams Creek and are part of the Lakelse conservation unit. A single population may include more than one deme. |
| Spawning Site (Deme) | Group of salmon at a persistent spawning site or within a stream comprised of individuals that are likely to breed with each other (i.e., well mixed). For example, Sockeye Creek is one spawning sites within the Williams Creek population. |

*Adaptive Zones*

The Skeena basin includes 3 freshwater adaptive zones (FAZ): Lower, Middle, and Upper. The Nass basin has 2 FAZ: Lower and Upper. Table 52 of Holtby and Ciruna (2007) summarizes the key characteristics of all BC FAZ.

Previous work on Skeena and Nass may use the same names to capture different groupings. For example, Gottesfeld et al. (2002) used “Lower” and “Middle” to describe mainstem spawning areas downstream and upstream of Terrace), but the FAZ boundary is further upstream and includes the Zymoetz watershed upstream of Terrace within the Lower Skeena. In this report, stock groups are based on FAZ, which are more clearly defined by biological considerations.

*Life history types*

Beacham and Withler (2017) describe three alternative life history strategies observed in the juveniles of sea-going (anadromous) sockeye salmon:

- *lake-type sockeye* spawn in lakes or lake tributaries, and rear in the lake for at least 1 year after hatching.
- *sea-type sockeye* spawn in tributaries or mainstem side channels, and the juveniles rear for several months in estuarine waters after hatching.
- *river-type sockeye* spawn in tributaries or mainstem side channels, and the juveniles rear in the river environment for at least 1 year before migrating to the ocean.

Lake-type sockeye account for most of the large stocks on the Pacific Coast, but the river- and sea-type sockeye, which are less specialized for specific sites, and are more versatile in their use of variable or changing habitats, may represent more adaptive potential (Sec. 9.2 in Holtby and Ciruna 2007). Evolutionary linkages between lake-type, sea- and river-type sockeye populations continue to be explored (Wood et al. 1987; Wood 1995; Beacham et al. 2004; Wood et al. 2008; e.g., Beacham and Withler 2017).

Most sockeye spawning in the Skeena and Nass follow the lake-type life history, but there are river-type populations that spawn throughout both basins. There are also at least two sea-type populations that spawn in the lower Nass River in Gingit and Gityzon creeks. While these river-type and sea-type populations are persistent, they usually account for a small part of the total abundance in each stock aggregate and most are inconsistently surveyed. However, the Lower Nass sea-type population, for which the most abundant spawning population (Gingit Creek) has been surveyed regularly since 2000 (Beveridge et al. 2017), has increased substantially in recent years, and contributed about 31% of the Nass sockeye return in 2019 (Nisga’a Fisheries and Wildlife Department 2020).

For Skeena river-type sockeye, there is not enough information about spawning abundance or distribution of these populations to estimate total watershed abundance for these stocks which are thus considered data deficient. While there are small persistent river-type spawning populations that are enumerated annually in the Kispiox watershed and Bulkley River, it is not known whether these populations account for most or just a small portion of river-type spawners in the Skeena watershed. Anecdotal information from historic and recent surveys suggest that persistent or ephemeral populations are also present in Upper Skeena tributaries in some years. The population structure of river-type spawners in the Skeena watershed is unclear, with few spawning sites represented in the genetic baseline. There is poor genetic differentiation between Skeena and Nass river-type populations and is not known whether Skeena river-types should be assigned to one or multiple populations, or a single population for Skeena and Upper Nass river-types. A detailed examination and review of the spawning sites and population structure for Skeena river-type sockeye is needed, but outside the scope of the current project.

*Conservation Units*

Under the *Wild Salmon Policy*, Canadian anadromous salmon have been grouped into distinct *conservation units* (CU), which are defined as “a group of wild salmon sufficiently isolated from other groups that, if extirpated, is very unlikely to recolonize naturally within an acceptable timeframe” (DFO 2005).

A coastwide list of CUs covering all five species of anadromous salmon was first developed by Holtby and Ciruna (2007). CU lists for Fraser sockeye, Interior Fraser coho, and Southern BC Chinook were reviewed and updated as part of integrated status assessments (Grant et al. 2011b, 2020; Grant and Pestal 2012; DFO 2015, 2016). A formal process for identifying and reviewing potential revisions to the CU list was then established to ensure regional consistency (Wade et al. 2019).

Sockeye CUs separate lake-type and river-type sockeye. For lake-type sockeye, each rearing lake is generally considered a unique CU (Holtby and Ciruna 2007), except for large lakes or lake complexes (e.g., Stuart-Takla-Trembleur system on the Fraser) where sockeye may be split further based on run-timing (e.g., early vs. late) or spawning location (e.g., lake outlet spawners vs. river spawners).

Using this default assumption, each sockeye rearing lake in the Skeena and Nass basins is currently considered a distinct CU, except for the Babine-Nilkitkwa and Tahlo-Morrison groups of lakes, where current CU delineations are based on timing and spawning location, with details described in Section 2.3.3.

### 2.1.4 Assessment/Management Scales

Canadian stock assessment and harvest management has been structured into five conceptual levels (Table 3): survey sites, stocks, stock aggregates, management units, stock management units.

Stock assessment of Skeena and Nass sockeye focuses on (1) total return estimates for stock aggregates (2) spawner estimates for survey sites on indicator stocks, (3) total harvest estimates for major fisheries, (4) stock identification to apportion total returns and total harvests into stock-specific estimates.

Harvest management of Skeena and Nass sockeye is coordinated internationally at the level of stock aggregates or groups of aggregates. For instance, the US harvest share of sockeye harvested in the District 104 purse seine fisheries is calculated based on the combined annual allowable harvest of Skeena and Nass sockeye. Other management and stock assessment focuses on each stock aggregate (e.g., Canadian marine fisheries targeting Skeena sockeye) or groups of stocks (e.g., in-river fisheries targeting Babine sockeye).

Stock assessment and Canadian harvest management of Skeena and Nass sockeye have identified individual stocks since early 1900s, long before CUs were defined under the WSP. This stock delineation was originally based on major lakes, and has been adapted over time to incorporate run timing derived from tagging studies, and more recently using genetic sampling.

Table 3. *Management and stock assessment scales of salmon population structure*. Definitions in this table are those used by DFO for domestic processes.

| Concept | Description |
|---|---|
| Survey Site | Locations at which spawner surveys are conducted (e.g. Twain Creek, Babine River Section 5). Survey sites may match up with a biologically defined population, cover several populations, or just capture one spawning site (deme) within a larger population. |
| Stock | Group of spawning populations assessed and managed together (e.g., Meziadin stock within the Nass stock aggregate, Babine Late Wild stock within the SkeenaWild stock aggregate) |
| Stock Aggregate | Group of stocks managed or assessed together. For sockeye, these are typically major basins (Nass sockeye) or timing groups within a basin (e.g. Early Summer Fraser sockeye). Three stock aggregates are used in this project (Nass = all Nass stocks, Skeena = all Skeena stocks, SkeenaWild = Skeena stocks except enhanced Pinkut and Fulton). Note that bilateral processes under the Pacific Salmon Treaty refer to the Skeena and Nass aggregates as stocks. |
| Management Unit | Group of stock aggregates used in regional or international management and assessment (e.g. Skeena-Nass sockeye, WCVI Chinook) |
| Stock Management Unit (SMU) | Groups of stocks specifically designated for status assessment under the modernized Fisheries Act (Holt et al. 2023). Skeena and Nass sockeye are currently each identified as a SMU. |

The escapement goal review focuses on stocks and stock aggregates. Aggregate reference points are being developed for two stock aggregates (SkeenaWild, Nass) and the overall management unit, while considering the productivity and capacity of component stocks. Different scales may be appropriate for other types of analysis (e.g. First Nations traditional use studies, WSP status assessment, catch monitoring review).

### 2.2 Overview of the Skeena and Nass Sockeye Management Units

For this report, Skeena and Nass sockeye have been organized into 31 stocks, which fall into seven distinct groups based on life history type and freshwater adaptive zone (Figure 1). Stocks are also grouped into Stock Management Units (SMU) under the modernized Fisheries Act (2019). The SMUs currently align with the Skeena and Nass stock aggregates.

Skeena lake-type sockeye are grouped into 6 stocks that spawn in the lower Skeena FAZ, 9 stocks in the middle Skeena, and 8 stocks in the Upper Skeena (Figure 1). There are 5 lake-type sockeye stocks in the upper Nass FAZ. River-type and sea-type sockeye from the 2 basins are grouped into 3 stocks: Skeena River Type, Upper Nass River Type, and Lower Nass Sea/River Type.

Quantitative analyses for the escapement goal review (Pestal and Carr-Harris 2025) included all stocks with sufficient data, which captured most of the sockeye spawning abundance in the two basin, as summarized in Section E.

For Nass and Skeena sockeye, most of the stocks identified for our analyses align with a single CU. For some of the smaller stocks, we have combined 2-3 CUs, either because they rear in cojoined lakes and the population structure is unclear, or they are assessed together, and the data cannot be separated. Sockeye in the Babine-Nilkitkwa and Tahlo-Morrison groups of lakes, accounting for the majority of Skeena and Nass sockeye, are split into 5 distinct stocks based on enhancement status and run timing. Details are documented in the summaries below, which include commentary on potential revisions to the CU delineations. Note, however, that revisions have yet to undergo the formal review process described by Wade et al. (2019) before the official CU list (e.g., in DFO's regional escapement database) can be modified.

There are numerous small, coastal sockeye populations in Portland Inlet (Pacific Fishery Management Area) and Chatham Sound (Pacific Fishery Management Area 4) which do not spawn in the Skeena or Nass basins and are therefore not included in our work here, but may be intercepted in marine mixed-stock fisheries targeting Skeena and Nass sockeye. These include lake-type sockeye in Prudhomme and Shawatlan lakes near Prince Rupert with populations that range from a few hundred to a few thousand spawners and two coastal system in Portland Canal (Clements, Leverson) where abundance is unknown, but assumed to be small.

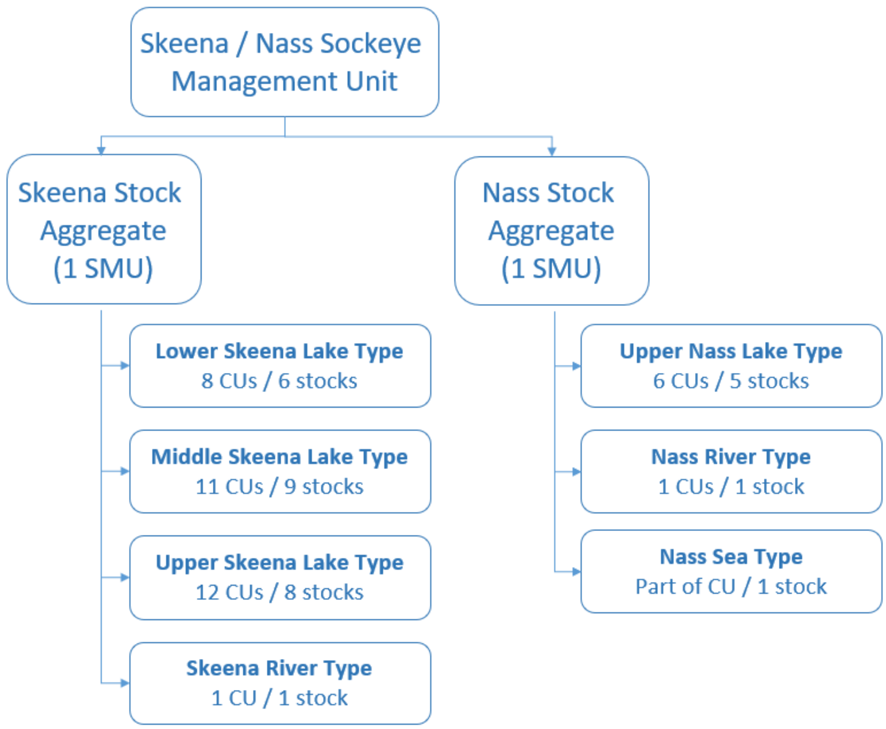


Figure 1. *Overview of the Skeena/Nass Sockeye Management Unit*. The overall management unit combines Skeena and Nass stock aggregates. Each stock aggregate is currently a stock management unit (SMU) under the modernized *Fisheries Act* (2019). Each SMU contains several groups delineated based on life history and freshwater adaptive zone (e.g., Lower Skeena Lake Type), and each of these groups is further split into stocks for harvest management and conservation units (CU) for status assessments under the *Wild Salmon Policy* (2005). Stocks and CUs mostly match up for Skeena and Nass sockeye, but there are some differences, summarized below.

## 2.3 Skeena Sockeye Stocks, Conservation Units, and Survey Sites

### 2.3.1 Skeena Sockeye - Key Points

Skeena sockeye salmon include 24 stocks, which we have organized into 3 lake-type groups (lower, middle, upper Skeena) and one stock of river-type sockeye that spawn throughout the basin (Table 4). Exploitation rate indicators are available for most of the stocks.

Skeena lake-type sockeye have common characteristics, with some exceptions:

- Fry from most populations spend one year rearing in freshwater prior to their seaward migration. Morice and Alastair sockeye exhibit higher proportions of sockeye which can spend 2+ years following emergence rearing in their natal lake.
- Most spawn in lake tributaries or lakeshore spawning areas. Fry from tributary spawners typically migrate downstream into their rearing lake, except for a few systems such as Babine River sockeye which spawn just downstream of Babine Lake and produce fry that migrate upstream into the lake.
- Most Skeena, including Babine, sockeye exhibit the $4_2$ or $5_2$ age class, denoting fish that spend one winter in freshwater following emergence and two or three winters at sea prior to the return migration. Some populations, such as Morice sockeye, exhibit a higher proportion of age $5_3$ or $6_3$.
- Most of the annual return of Skeena sockeye now originates from enhancement facilities at Pinkut Creek and Fulton River, which are tributaries to Babine Lake. These are large-scale spawning channels and actively-managed natural river sections with flow controls.

Table 4. *Overview of Skeena Sockeye Stocks*. *LHAZ* is a stock grouping based on life history (i.e. lake-type vs. sea- and river-type) and freshwater adaptive zone (i.e. landscape characteristics and species assemblages). *PerEffSpn* is the % of the cumulative spawner abundance since 2000 (i.e. sum of the annual estimates by stock / sum across all stocks for Skeena and Nass sockeye, combined). Effective spawners exclude the non-spawning surplus on Pinkut and Fulton (i.e., fish that escape to Pinkut and Fulton rivers, but have nowhere to spawn due to channel access control). For wild Skeena stocks, all spawners are assumed to be effective spawers. *ERInd* lists the exploitation rate indicator matched to the stock. Some ER indicators include "+" in the name to indicate that they cover the named stock "and others". The 24 Skeena stocks fall into 4 distinct groups based on life history type and freshwater adaptive zone (*LHAZ*) and 15 watersheds. Exploitation rate indicators (*ERInd*) are available for most of the stocks. Stocks match up with one or more conservation units (*numCU*). Note that Babine is currently assessed and analyzed as five distinct stocks, but the corresponding CU match is pending review (marked with *).

| LHAZ | Watershed | Stock | PercEffSpn | ERInd | NumCU |
|---|---|---|---|---|---|
| Lower Skeena Lake Type | Ecstall | Johnston | 0.13 | Johnston | 1 |
| | | Ecstall | 0 | | 1 |
| | Gitnadoix | Alastair | 2.5 | Alastair | 1 |
| | Lakelse | Lakelse | 1.3 | Lakelse | 1 |
| | Kitsumkalum | Kitsumkalum | 2.5 | Kalum | 1 |
| | Zymoetz | Mcdonell | 0.48 | Zymoetz | 3 |
| Middle Skeena Lake Type | Kitwanga | Kitwanga | 0.33 | Kitwanga | 1 |
| | Bulkley | Upper Bulkley Lakes | 0 | | 2 |
| | | Morice | 1.72 | Morice+ | 2 |
| | Kispiox | Swan/Stephens | 1.28 | Swan+ | 3 |
| | Babine | Babine Early Wild | 4.46 | Babine-WE | 1* |
| | | Babine Late Wild | 14.7 | Babine-WL | 1* |
| | | Babine Mid Wild | 2.95 | Babine-WM | 2* |
| | | Pinkut | 10.72 | Babine-P | 1* |
| | | Fulton | 37.08 | Babine-F | 1* |
| Upper Skeena Lake Type | Sicintine | Sicintine | 0 | | 1 |
| | Slamgeesh | Slamgeesh | 0.04 | Slamgeesh | 2 |
| | Motase | Motase | 0.04 | | 1 |
| | Sustut | Bear | 0.89 | Bear+ | 2 |
| | | Asitka | 0.1 | Bear+ | 1 |
| | | Sustut | 0.15 | Sustut+ | 3 |
| | Kluatantan | Kluantantan | 0 | | 1 |
| | Kluayaz | Kluayaz | 0 | | 1 |
| Skeena River Type | All | Skeena River Type | 0 | Swan+ | 2 |

### 2.3.2 Lower Skeena Lake Type

Lower Skeena lake-type sockeye include fish that spawn in 5 watersheds, which are grouped into 6 stocks and 8 conservation units (Figure 2).

The Ecstall watershed is closest to the river mouth and includes 2 stocks (Johnston and Ecstall), which match up with 2 conservation units. Genetic baseline samples are available for 1 site (Johnston Lake), which accounts for most of the sockeye spawners in the watershed. Spawner estimates are available for 3 sites.

The Gitnadoix (Alastair Lake), Lakelse, and Kitsumkalum watersheds each contain one stock that corresponds to a single CU. For each stock, 1 or more sites have been sampled for the genetic baseline and several spawner sites are surveyed.

The Zymoetz watershed at the upper end of the lower Skeena FAZ includes 3 CUs (Mcdonell, Dennis, Aldrich) which we have grouped into one stock. Genetic baseline samples are currently available for 2 sites in the McDonell CU, but not for the other 2 CUs. The 3 CUs are combined into a single stock, because current spawner surveys focus on Mcdonell, which is the major sockeye producer in the lake complex. Spawner estimates and run reconstructions are also developed for Mcdonell. Aldrich and Dennis are considered data deficient CUs.

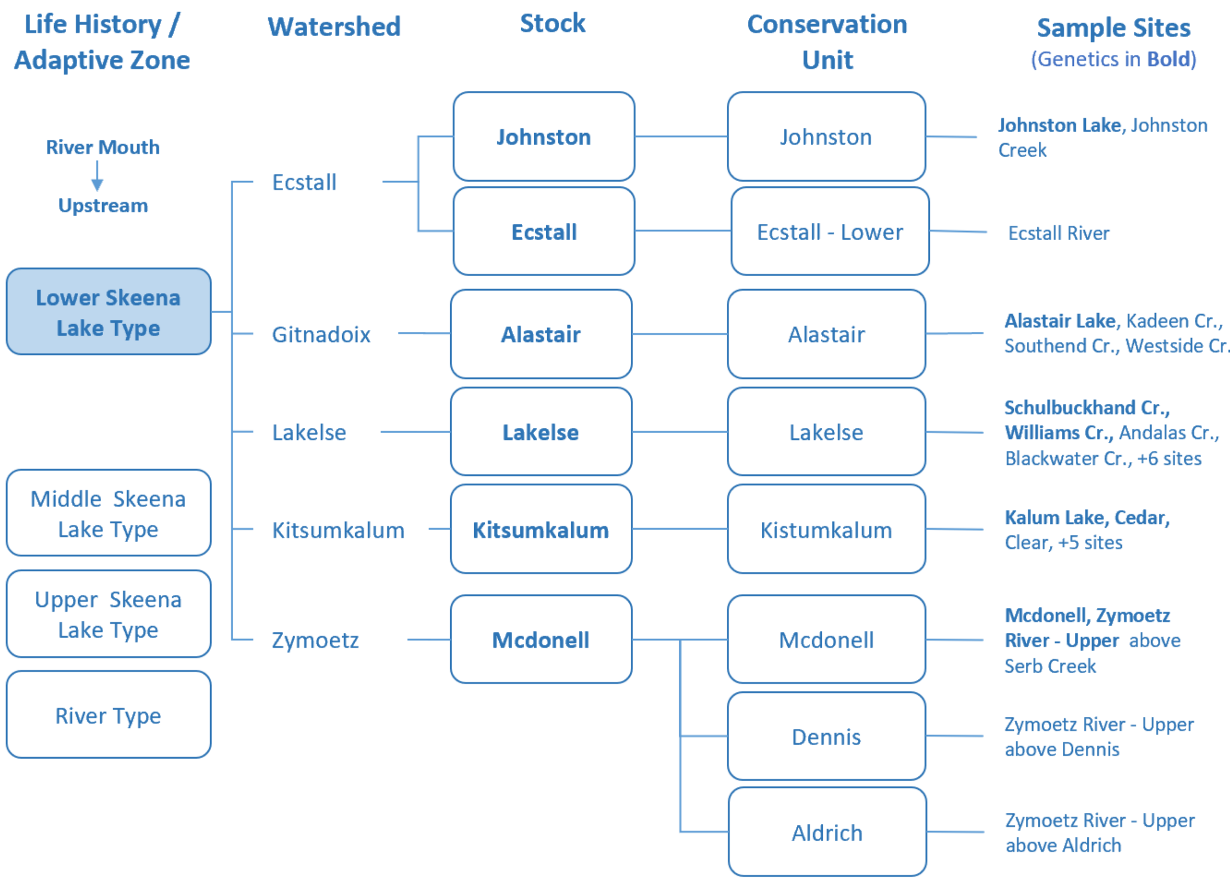


Figure 2. *Lower Skeena Sockeye Stocks, Conservation Units, and Sampling Sites*. Sample sites with genetic samples are highlighted in bold font.

### 2.3.3 Middle Skeena Lake Type

Middle Skeena lake-type sockeye include fish spawning in 4 watersheds, which are grouped into 9 stocks and 11 conservation units (Figure 3).

At the downstream end of the Middle Skeena FAZ is the Kitwanga watershed, which contains 1 stock and a matching CU (Kitwancool, a.k.a Kitwanga or Gitanyow Lake). Genetic samples are available for this stock.

The Bulkley watershed contains 2 stocks, each with 2 rearing lakes, for a total of 4 CUs:

- *Morice stock*: Sockeye rearing in Morice and Atna lakes are combined into a single stock, but there is insufficient information at this time to determine whether these are two distinct CUs or a single spawning population. Pending further research, we retained the 2 CUs identified by Holtby and Ciruna (2007). Genetic samples for Morice sockeye are available from 2 sites (Nanika and Atna Lake).
- *Upper Bulkley stock*: There are confirmed records of sockeye in Bulkley and Maxan lakes, but spawning sockeye have not been observed in over 20 years and hydroacoustic surveys observed no fry rearing in the lakes. There are no genetic samples for sockeye from Bulkley or Maxan lakes. Pending confirmation of extirpation, we've retained the 2 CUs identified by Holtby and Ciruna (2007) and treat them as data deficient, and potentially extirpated, for CU-level status assessments.

The Kispiox watershed contains 1 stock, but covers 3 conjoined rearing lakes which Holtby and Ciruna (2007) considered three separate conservation units (Swan, Stephens, Club). Genetic samples from 2 sites are available (Falls Creek, Club Creek). Spawner counts are based on combination of aerial and foot surveys on streams. Survey sites could be assigned to either Swan or Stephens/Club, but Club vs. Stephens spawners cannot be separated (Club Lake is immediately upstream of Stephens Lake). Current run reconstruction and SR model fits are performed for the combined data set, labelled the Swan/Stephens stock. Stephens accounts for roughly 3/4 of the available estimates on average, but it is unclear what proportion of Swan spawners is not counted by the current survey coverage.

The Babine watershed at the upper end of the middle Skeena FAZ accounts for most of the sockeye production on the Skeena. Babine sockeye have a complex population structure that includes a large enhanced component that returns to Pinkut Creek and Fulton River. The wild component of Babine sockeye is further separated by run timing, resulting in a total of 5 stocks that are assessed separately: Pinkut-Enhanced, Fulton-Enhanced, Early-Wild, Mid-Wild, and Late-Wild. Genetic samples are available for 1 or more sites for each stock. While there is not enough genetic resolution to distinguish between the different Babine genetic sites/stocks using the current Canadian microsatellite baseline, on-going work on a SNP baseline may make finer stock resolution possible. The 5 stocks have distinct spawner-recruit dynamics (i.e. Pinkut and Fulton are enhanced with spawning channels) and are subject to different fishing patterns given their implied run timing through major fishing areas (Early, Mid, Late).

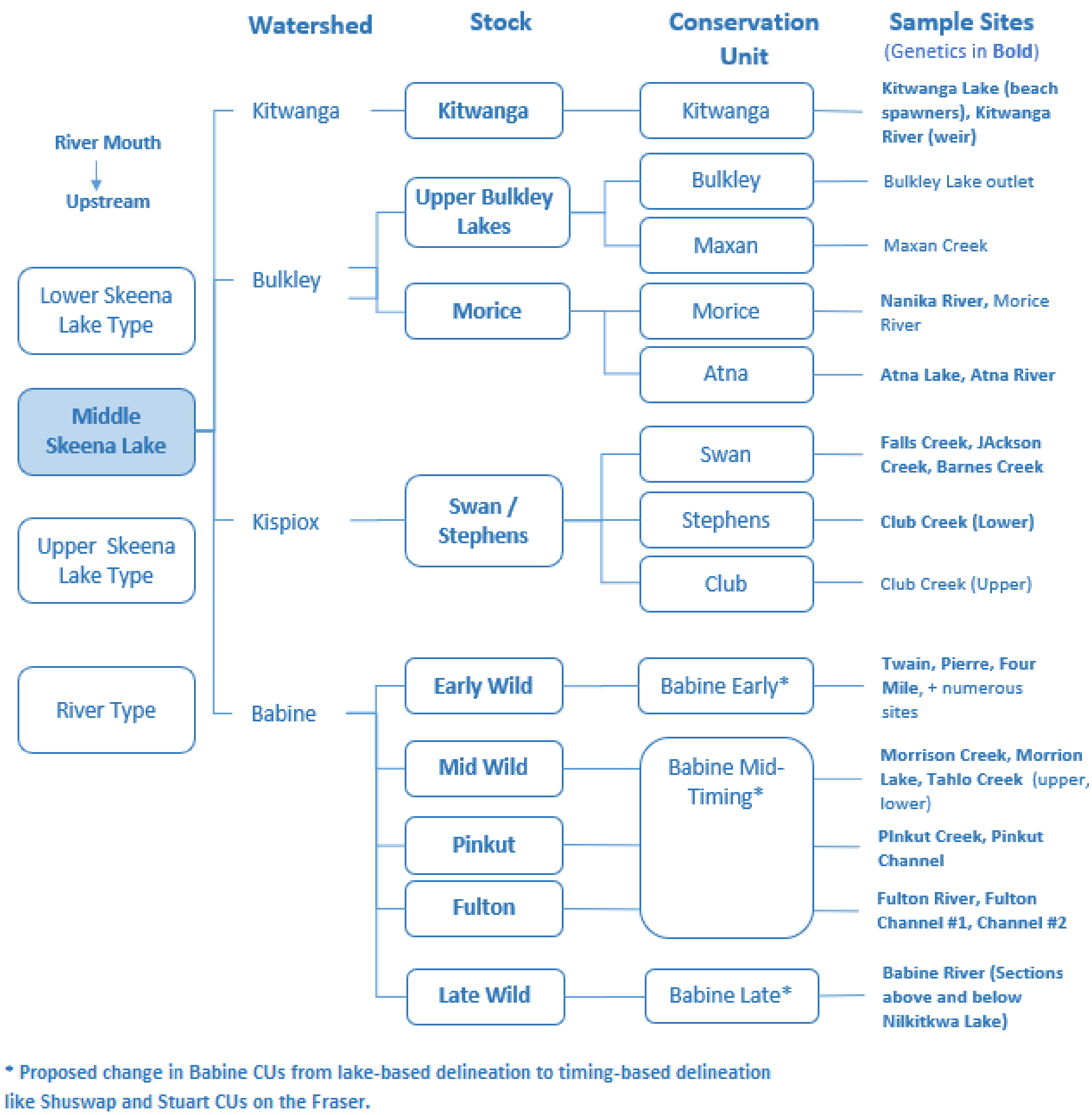


Figure 3. *Middle Skeena Sockeye Stocks, Conservation Units, and Sampling Sites*. Sample sites with genetic samples are highlighted in bold font.

Holtby and Ciruna (2007) discussed the population structure of the Babine sockeye complex in detail (Section 9.8 of Holtby and Ciruna 2007) and identified 3 distinct conservation units based on rearing lakes (Babine, Nilkitkwa , and Tahlo/Morrison). The regional escapement database (DFO 2021) has an updated CU delineation, identifying 2 current CUs (Babine, Tahlo/Morrison) and one *'verification required'* potential CU (Onerka). We propose a revised delineation of 3 CUs based on run timing and life history variations:

- *Babine Early (1 Stock, 1 CU)*: spawn in tributaries of the main basin of Babine Lake other than Pinkut or Fulton and rear in Babine Lake
- *Babine Mid (3 Stocks, 1 CU)*: Wild stock with intermediate timing that spawns in Morrison Creek, Morrison Lake, and Tahlo Creek, and juveniles migrate downstream to rear in Tahlo and Morrison lakes, as well as Morrison Arm of Babine Lake. Pinkut and Fulton are also consider mid-timed and are genetically very similar, but most of the recruitment originates in actively managed spawning channels, so they are treated as distinct stocks in the current run reconstructions. Pinkut and Fulton sockeye are excluded from the *wild* time series used for status assessment under the WSP.
- *Babine Late (1 Stock, 1 CU)*: Lake outlet spawners which spawn in Babine River between Babine and Nilkitkwa Lake and downstream of Nilkitkwa Lake and rear in Nilkitkwa Lake and North Arm of Babine Lake, and exhibit upstream fry migration characteristic of lake outlet spawners.

### 2.3.4 Upper Skeena Lake Type

Upper Skeena lake-type sockeye include fish spawning in 5 watersheds, which are grouped into 8 stocks and 12 conservation units (Figure 4).

On the downstream end of the Upper Skeena FAZ is the Sicintine watershed, which contains 1 stock and a matching CU (Sicintine). No genetic samples are currently available.

The Slamgeesh watershed contains 1 stock and 2 rearing lakes, which are currently treated as 2 distinct CUs, but may actually be sockeye complex spanning both lakes (Slamgeesh, Damshilgwit). Genetic samples are available from both lakes.

The Motase watershed contains 1 stock and 1 matched CU. Genetic samples are available.

Sockeye spawning in the Sustut watershed have a more complex population structure, with 6 rearing lakes currently classified as 6 conservation units, which are grouped into 3 stocks (details below).

Furthest upstream is the Kluantantan watershed, which includes the Kluayaz as a major tributary. Kluantantan and Kluayaz each contain 1 stock and 1 matching CU. Genetic samples are not available from either stock.

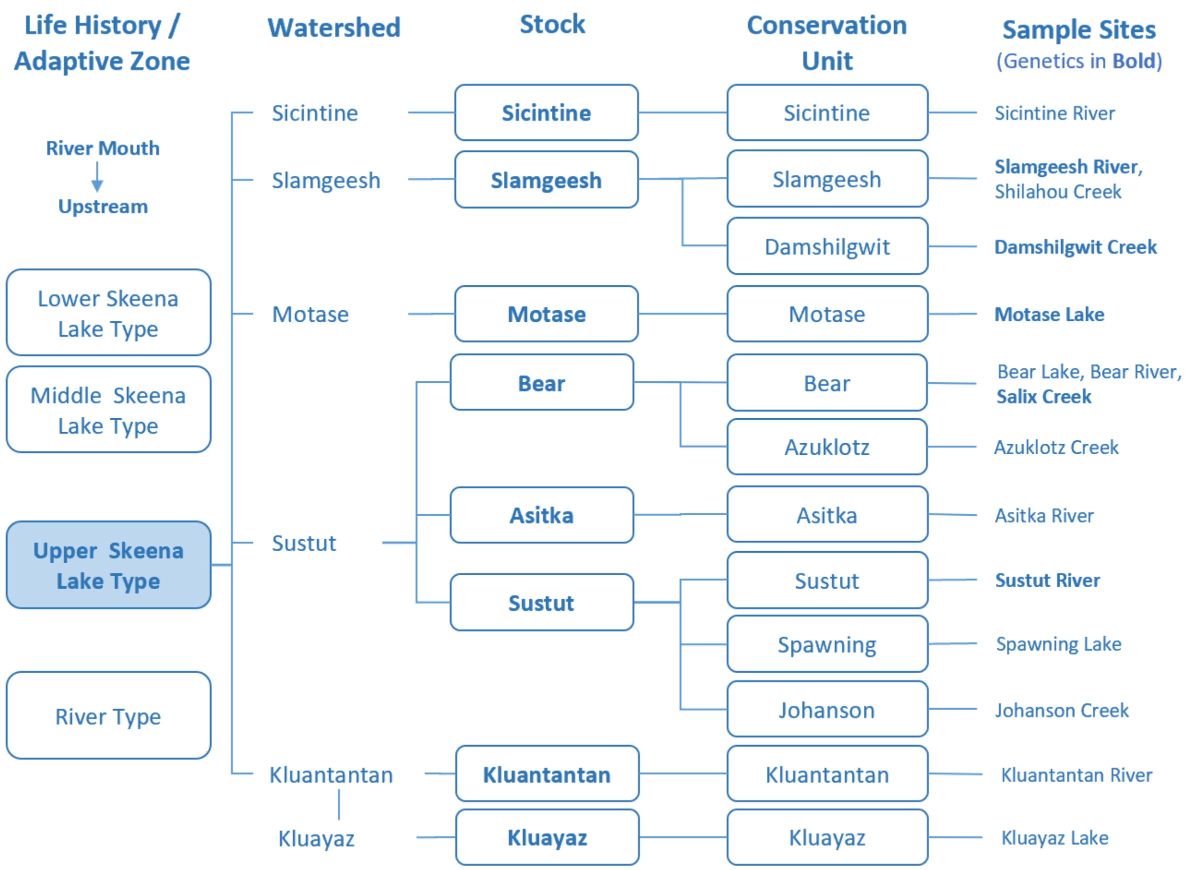


Figure 4. *Upper Skeena Sockeye Stocks, Conservation Units, and Sampling Sites.* Sample sites with genetic samples are highlighted in bold font.

Population structure and survey data for sockeye in the Sustut watershed are currently under review. Spawner-recruit analyses for the escapement goal review used three stocks: Bear, Asitka, and Sustut (Pestal and Carr-Harris 2025).

The Bear stock matches up with two CUs and includes fish rearing in the cojoined Bear and Azuklotz lakes, which are only 100m apart. Genetic samples for Bear sockeye are available from Salix Creek, lakeshore spawners from Bear Lake, and Azuklotz Creek. Azuklotz is the much smaller lake, but is better enumerated and is the largest known spawning population in the system. Salix Creek, the main indicator stream for the Bear Lake CU, drains into Bear Lake. Preliminary results from a new assessment program (video weir installed in 2021 on Bear River downstream of Bear Lake) suggest that the combined visual spawner escapements based on aerial surveys may underestimate the actual spawning population by a much larger factor than what has been accounted for with the expansion factors that are currently used in the run reconstruction. Work is also on-going to identify the degree of genetic overlap between the two lakes and to investigate the potential for timing-based CUs within each lake. We use the current stock-level estimates for the escapement goal review.

The Asitka stock matches up with a single CU and includes fish rearing in Asitka lake.

The Sustut stock includes 3 CUs, one for each rearing lake (Sustut, Spawning, Johanson). Genetic samples for the Sustut stock are only available from Sustut Lake. Note that Sustut and Johanson are not conjoined lakes, but are considered a single stock in our anlyses, because the current data set relies on estimates from a counting fence downstream of the Johanson Creek confluence. From hydroacoustic surveys conducted on both Sustut and Johanson Lakes in 2009, 2012, 2014 and 2017, Sustut accounted for approximately 18% of the combined juvenile abundance of both lakes. For NCCDSB run reconstructions, the weir count was apportioned to Sustut and Johanson Lake using either the average proportion of fry from hydroacoustic data, or the actual data for years when surveys were conducted.

### 2.3.5 Skeena River Type

River type sockeye in the Skeena watershed are grouped into a single stock , given that river-type sockeye typically have more straying than lake-type sockeye, and will tend to opportunistically select spawning sites based on local conditions (i.e., less site fidelity than lake type sockeye).

Holtby and Ciruna (2007) originally combined all river-type sockeye spawning in the lower Skeena and Middle Skeena FAZ, which exhibit "*no differences in timing or genetics*" (Table 49 of Holtby and Ciruna 2007) into the *Skeena River Type* CU, covering 4 known persistent spawning sites: Kispiox, Nangeese, Bulkley, and Lakelse. Genetic samples are available for the first 3 of these. Another 17 sampling sites have spawner estimates for at least some years.

Holtby and Ciruna (2007) assigned river-type sockeye spawning in the upper Skeena into a separate CU called *Skeena River Type - High Interior*. However, there is only one survey site for river-type sockeye in the Upper Skeena FAZ: Jackson Creek, a tributary to Swan Lake which may have been misassigned as river-type sockeye.

This stock is currently considered data deficient, because there is not enough information about spawning abundance or distribution of Skeena river type sockeye to estimate total watershed abundance for these populations. While there are small persistent river-type spawning populations that are enumerated annually in the Kispiox watershed and Bulkley River, it is not known whether these populations account for most or only a portion of river-type spawners in the Skeena watershed. Anecdotal information from historic and recent surveys suggest that persistent or ephemeral populations are also present in Upper Skeena tributaries. The population structure of river-type spawners in the Skeena watershed is unclear, with few samples in the genetic baseline and poor differentiation between some Skeena and Nass river-type populations. It is not known whether Skeena river-types represent one or multiple populations, or a single population for Skeena and Upper Nass river-types.

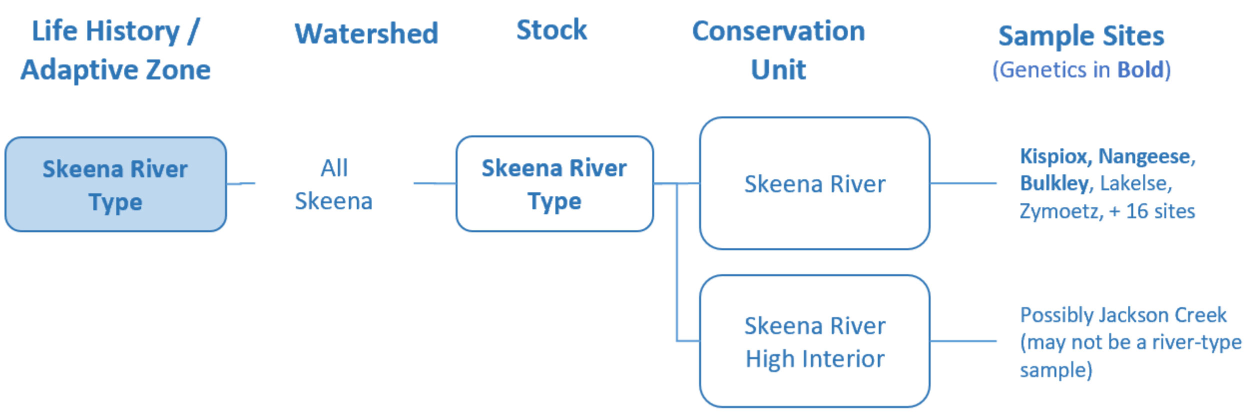


Figure 5. *River-Type Skeena Sockeye Stocks, Conservation Units, and Sampling Sites*. Sample sites with genetic samples are highlighted in bold font.

## 2.4 Nass Sockeye Stocks, Conservation Units, and Survey Sites

### 2.4.1 Nass Sockeye - Key Points

Nass sockeye salmon include 1 group of lake-type stocks (Upper Nass FAZ), 1 river-type stock that spawns in Bear Creek in the upper Nass, and 1 sea and river-type stock that spawns in lower Nass tributaries and includes at least 2 sea-type and 3 river-type populations (Table 5, Figure 6).

There is more variation in rearing times, fry migration and age composition in Nass sockeye compared to Skeena sockeye and these factors are related to each other. For example:

- Meziadin spawners account for most of the abundance of Nass sockeye spawners (mean = 65% and range = 36-88% for 1985 to 2019).
- a high proportion of early-timed sea types (mean = 6% and range = 1% – 31% from 1994 to 2019), in addition to a higher proportion of sub-3's (smolts that have remained three years in freshwater) in Meziadin and other upper Nass systems (mean = 54% and range = 19–76% from 1994 to 2019).
- Fred Wright and Damdochax produce mainly 1 year smolts, Bowser 2 year smolts, Meziadin a mix of the two age classes. Gingit and Gitzyon in the Lower Nass Sea/River Type stock have age-0, or sea-type, smolts, meaning they migrate to sea in the year of emergence.

Overall, on average for 1994 to 2019, 54% (range: 19-76%) of the Nass sockeye return resided in the Nass for three years before smolting.

Table 5. *Overview of Nass Sockeye Stocks*. *LHAZ* is a stock grouping based on life history (i.e. lake-type vs. sea- and river-type) and freshwater adaptive zone (i.e. landscape characteristics and species assemblages). *PerEffSpn* is the % of the cumulative spawner abundance since 2000 (i.e. sum of the annual estimates by stock / sum across all stocks for Skeena and Nass sockeye, combined). On the Nass, all spawners are assumed to be effective spawers. *ERInd* lists the exploitation rate indicator matched to the stock. Some ER indicators include "+" in the name to indicate that they cover the named stock "and others". The 7 Nass stocks fall into 3 distinct groups based on life history type and freshwater adaptive zone (*LHAZ*) and 6 watersheds. Exploitation rate indicators (*ERInd*) are available for most of the stocks. Stocks match up with one or more conservation units (*numCU*).

| LHAZ | Watershed | Stock | PercEffSpn | ERInd | NumCU |
|---|---|---|---|---|---|
| Nass Sea/River Type | Lower Nass Tribs | Lower Nass Sea & River Type | 1.85 | Gingit+ | 1 |
| Upper Nass Lake Type | Meziadin | Meziadin | 14.57 | Meziadin | 1 |
| | Bell-Irving | Bowser | 0 | | 1 |
| | | Oweegee | 0 | | 1 |
| | Kwinageese | Kwinageese | 0.36 | Kwinagees | 2 |
| | Damdochax | Damdochax | 0.2 | Damdochax | 1 |
| Nass River Type | Upper Nass Tribs | Upper Nass River Type | 0.05 | BrownBear | 1 |

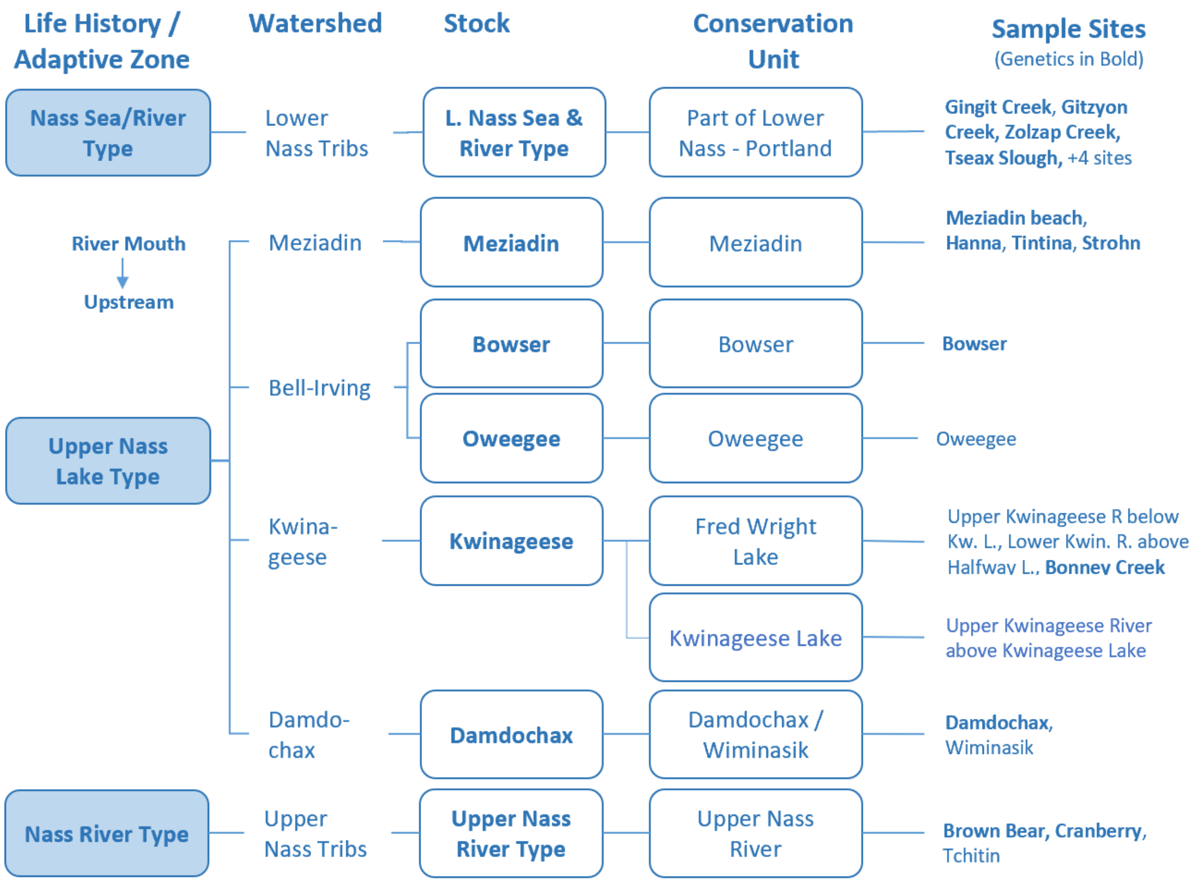


Figure 6. *Nass Sockeye Stocks, Conservation Units, and Sampling Sites*. Sample sites with genetic samples are highlighted in bold font.

### 2.4.2 Nass Sea Type and River Type

Sea-type sockeye spawn in lower Nass tributaries. The more typical river-type sockeye, which rear in freshwater for at least a year prior to the seaward migration, spawn in the lower and upper Nass tributaries. These populations are grouped into 2 stocks.

Lower Nass sea- and river-type sockeye are grouped into into a single stock, and are part of a larger conservation unit that also includes other river- and sea-type sockeye spawning in coastal rivers throughout Portland Inlet. Genetic samples are available from 4 sites in the lower Nass (Gingit, Gitzyon, Zolzap, Tseax).

Upper Nass river-type sockeye are grouped into 1 stock and corresponding CU. They are likely distributed throughout the upper basin in low numbers, but only 2 sites are consistently surveyed. Genetic samples are available for Brown Bear Creek and Cranberry River. Note that Brown Bear genetic samples are indistinguishable from the Skeena-Babine complex, which potentially affects mixed-stock fishery assessments that rely on genetic stock identification (e.g. run reconstructions). Further work to determine the origin of Brown Bear Creek sockeye spawners is on-going.

### 2.4.3 Upper Nass Lake Type

Upper Nass lake-type sockeye include fish spawning in 4 watersheds, which are grouped into 5 stocks and 6 conservation units (Figure 6).

The Meziadin watershed is closest to the river mouth (~206km), but upstream from the Nass test fishery fish wheels (~150 km) and the lower Nass tributaries where sea-type and river-type sockeye spawn. It includes 1 stock and 1 corresponding conservation unit. Genetic baseline samples are available for 4 spawning sites from the Meziadin stock (lakeshore spawners and Hanna, Tintina, and Strohn Creeks).

The Bell-Irving watershed includes 2 stocks and 2 corresponding CUs, each with 1 rearing lake: Bowser and Oweegee. Genetic samples are available from Bowser, which is a much larger lake and has a much larger sockeye abundance, but not from Oweegee. Oweegee is generally data poor, but not combined with Bowser due to assumed differences in life history (2 yr smolts vs. 1 yr smolts). Bowser sockeye mostly spend 2 years in rearing in freshwater and can be distinguished based on scale patterns from other Upper Nass stocks. Additional genetic sampling and stock assessment of Oweegee could help clarify the population structure of sockeye in the Bell-Irving watershed. Bowser Lake was likely a major contributor to the Nass aggregate sockeye return historically. Visual escapement estimates, which are confounded by high glacial turbidity, have not been regularly conducted for Bowser Lake sockeye, which are primarily a lakeshore spawning population. Previous abundance estimates for Bowser sockeye have been derived using different methods including stock identification using scale pattern analyses, and more recently, GSI applied to Nass aggregate escapements. The different methods have produced divergent estimates for some years, and further assessment is required to reconcile these estimates before spawner recruit time series can be developed. Bowser sockeye are therefore not part of the current run reconstructions and were not modelled as part of the escapement goal review (Pestal and Carr-Harris 2025).

The Kwinageese watershed contains 1 stock (Kwinageese) and 2 conservation units with separate rearing lakes (Fred Wright Lake, Kwinageese Lake). Genetic samples are available from Bonney Creek spawners, which rear in Fred Wright Lake. These 2 CUs are combined into a single stock for the escapement goal review, because current stock assessment generates a single combined estimate that cannot be separated into the component CUs. In addition, they likely have very similar run timing and age structure.

The furthest upstream Nass sockeye watershed is Damdochax, which includes two rearing lakes (Damdochax, Wiminasik), currently grouped into one stock and one CU, with genetic samples available from one spawning location. Although Wiminasik are currently being assessed separately from Damdochax, Holtby and Ciruna (2007) did not delineate Wiminasik as a distinct CU, but this might simply be due to a lack of spawner records in the regional database at the time. Unless there is additional information, we recommend maintaining a single CU for sockeye spawning in the Damdochax watershed, but changing the name to Damdochax/Wiminasik to reflect both rearing lakes.

# 3 Data Sources

New data for Skeena and Nass sockeye are being produced continually. This report uses the most current available datasets as of April 2021, covering brood years up to 2019. Source data and data treatment steps were reviewed as part of this project, as summarized below. Details of the data review are documented in the appendices.

## 3.1 Stock Assessment

Comprehensive annual stock assessment and catch monitoring programs are in place for Skeena and Nass sockeye. Methods and assumptions are documented in a series of technical reports (e.g., English et al. 2004, 2006, 2012, 2013; English et al. 2019). Here we provide a brief overview of the different programs. Key components are described in detail in the appendices of this report.

Catch monitoring covers marine fisheries, approach areas, and in-river fisheries, estimating numbers caught, and in some cases also sampling for age and stock composition using scale patterns or genetic variation. Program implementation differs between fisheries (Appendix B.2)

Major programs on the Nass include fishwheels on the lower Nass, the Meziadin fishway above the mainstem confluence, and the Kwinageese fence (Figure 7).

Major programs on the Skeena include a test fishery on the lower Skeena at Tyee, Moricetown fishway, and counting fences at Babine, Kitwanga, and Sustut (Figure 8).

Aerial surveys and stream walks cover a combination of indicator streams and supplementary sites in both basins (Appendix B.1). Nass indicator stocks include Meziadin, Damdochax, and Lower Nass Sea & River Type. Skeena indicator surveys cover 13 stocks in 10 watersheds.

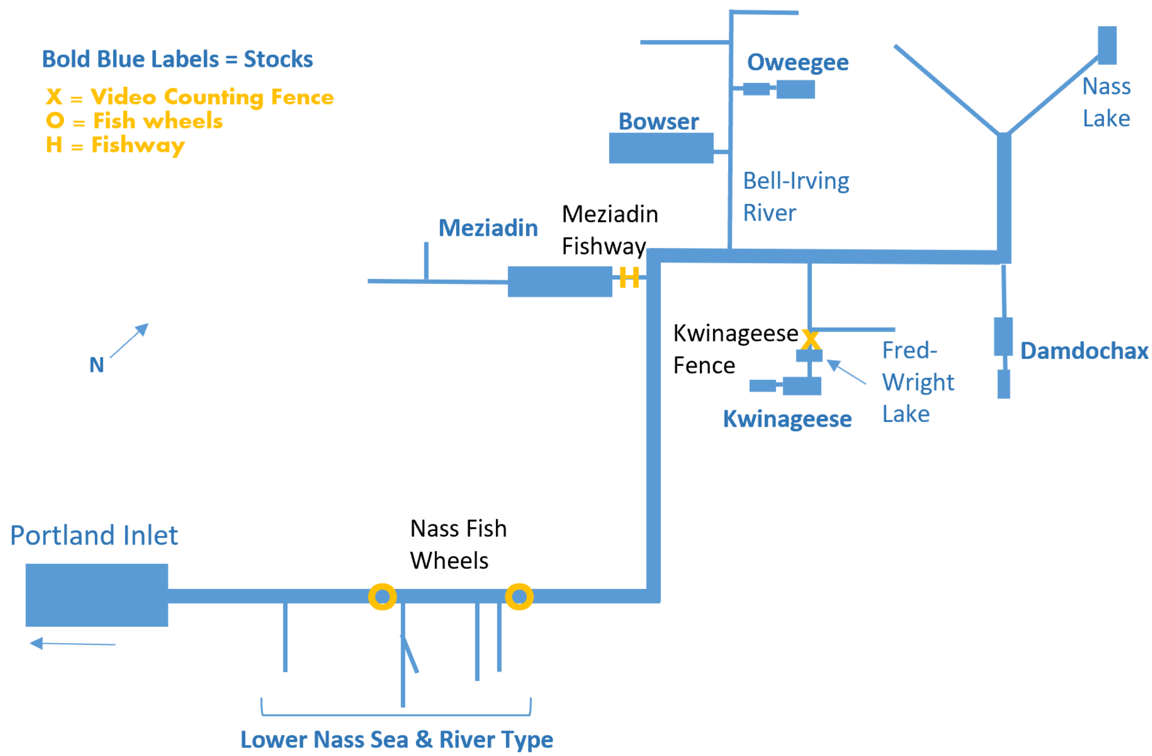


Figure 7. *Schematic overview of Nass sockeye stocks*. The diagram focuses on highlighting the spatial relationship between the stocks, watersheds and major components of the assessment program, so distances and angles are not to scale. *Plot design adapted from a collaboration with Pete Nicklin (T^silhqot'in Fisheries)*.

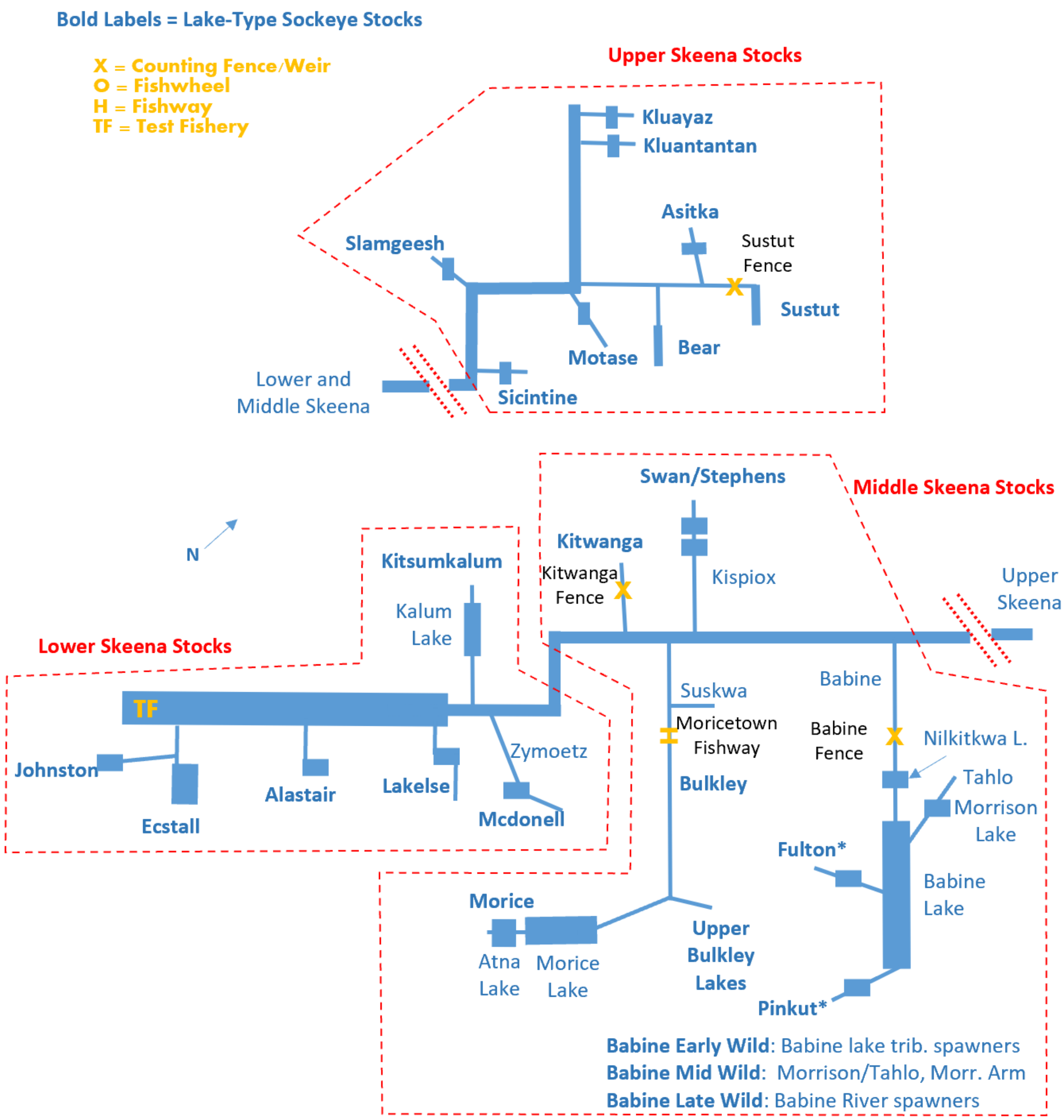


Figure 8. *Schematic overview of lake-type Skeena sockeye stocks*. The diagram focuses on highlighting the spatial relationship between the stocks, watersheds and major compoents of the assessment program, so distances and angles are not to scale. Enhanced Pinkut and Fulton are marked with an asterisk (*). *Plot design adapted from a collaboration with Pete Nicklin (T^silhqot'in Fisheries).*

### 3.2 Lake Productivity and Juvenile Surveys

Rearing lakes for Skeena and Nass sockeye are assessed regularly or periodically. Surveys include:

- *Lake productivity* (Appendix B.4.1): Estimates of lake-rearing capacity are available for most Skeena and Nass sockeye rearing lakes. The data were contributed by the DFO Lakes Research Program at the Cultus Lake laboratory (Jeremy Hume, pers. comm.), and included all surveys completed between 1978 and 2008. The data set includes estimates of raw photosynthetic rate and resulting estimates of capacity for juvenile sockeye, as well as a corresponding estimate of spawner abundance that maximizes smolt biomass.
- *Juvenile surveys* (Appendix B.4.2): Rotating juvenile surveys with hydroacoustic transects and biological sampling, with all the major lakes surveyed several times over the years. Data from juvenile surveys of sockeye rearing lakes was compiled from reports provided by Skeena Fisheries Commission, which has conducted annual rotational hydroacoustic surveys of Skeena and Nass sockeye rearing lakes since 2006, the DFO-Cultus Lake group, who conducted surveys throughout the North Coast until 2008, and other sources. Estimates of fry abundance, density and size data were extracted and summarized for a total of 119 surveys on 21 Skeena and Nass sockeye rearing lakes.

### 3.3 Run Reconstruction

Well-documented methods are used to develop consistent estimates of spawner abundance, run size, exploitation rates, and recruitment for the two stock aggregates and for most of the component stocks, as summarized in Figure 9 and described in detail in Appendix C.

Aggregate total returns for Nass and Skeena sockeye are estimated using the Northern Boundary Sockeye Run Reconstruction (NBSRR) which models marine catches from commercial Canadian and U.S. fisheries to the terminal run entering each river (Appendix C.4).

Estimates of spawner abundance, catch, and run size for component Skeena and Nass stocks are estimated in the North Coast & Central Coast Salmon Database (NCCSDB), which combines outputs from the NBSRR and in-river reconstructions to estimate total exploitation rates and total returns for Skeena and Nass sockeye stocks. Appendices C.2 to C.5 describe the data and analyses that populate the NCCSDB, including spawner escapement estimation and run reconstruction procedures. English et al. (2019) describe the most recent review of the NCCSDB.

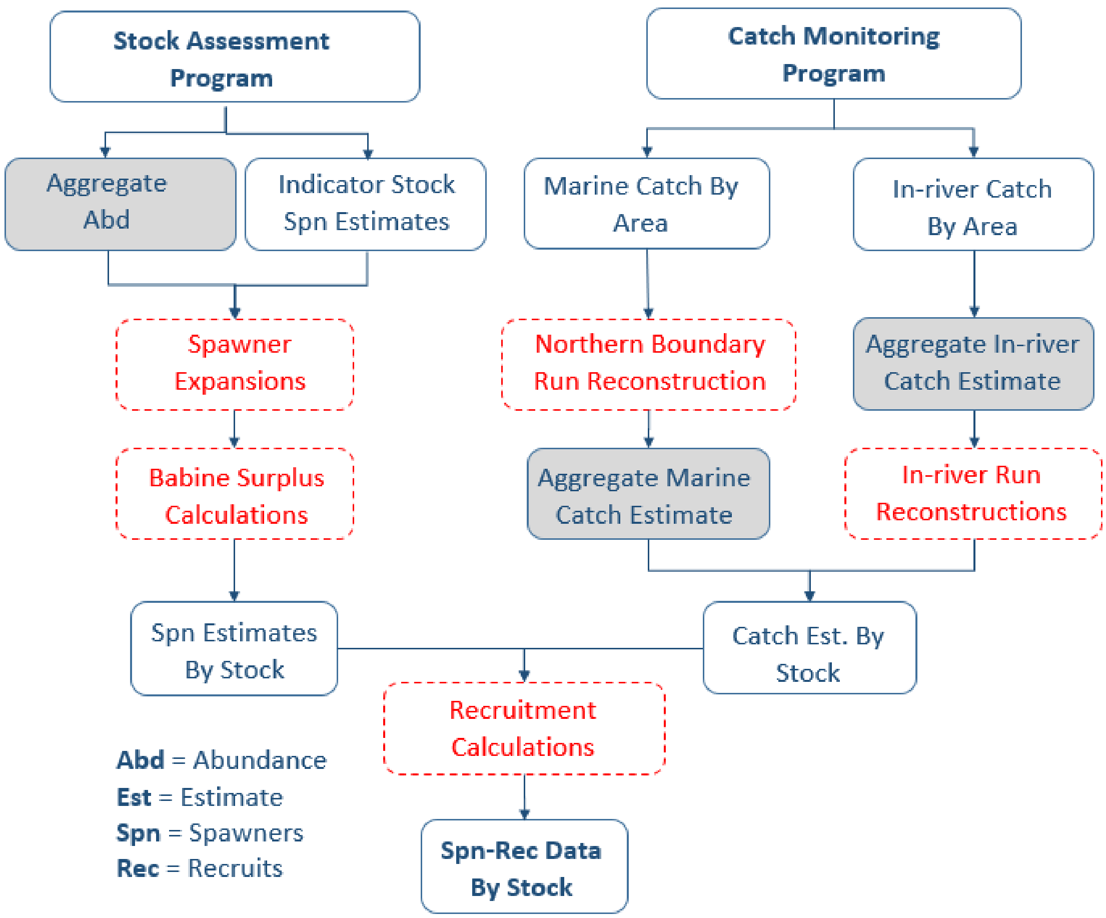


Figure 9. *Overview of Assessment Programs and Run Reconstruction Inputs*. Boxes with grey shading indicate aggregate-level estimates that are "split up" to generate the stock-level estimates. Red boxes with dashed outlines show the key analytical steps needed to combine the available data into consistent estimates of stock-level spawner abundance and resulting recruitment.

The key analytical steps are:

- Expand spawner estimates to estimate the total number of spawners based on the number observed in the surveys of indicator systems (Appendix C.2). Indicator systems for North Coast Sockeye were selected following discussions with North Coast Area DFO stock assessment biologists based on the length of the time series of available data, survey frequency, and relative contribution to the stock represented by each indicator system (English et al. 2006). The expansions account for fish that were not counted (depends on survey method and annual implementation), as well as fish from systems that were not surveyed.
- For Babine stocks, additional spawner calculations are performed to account for (1) the difference between aggregate counts at the Babine fence and spawning ground estimates, and (2) effective capacity of the channels and natural spawning habitats (Appendix C.3). Effective spawner abundance for the channel systems is the number of spawners let into the channel plus the estimated capacity of natural spawning grounds above and below the spawning channels. Any additional adults that do not spawn in the channels, Pinkut River, Fulton Creek, or other wild Babine tributaries are considered a biological surplus, and are excluded from the estimates of spawner abundance, but are included in estimates of run size.
- Run reconstructions for the 2 stock aggregates, which account for Canadian and U.S marine catches in approach waters (NBRR model; Appendix C.4). NBRR estimates are bilaterally developed each year as part of the PSC-Northern Boundary Technical Committee process, and the data we used here is the latest available.
- Run reconstructions for the component stocks in each basin, which account for in-river catches and stock-specific run timing (Appendix C.5)
- Apply age composition estimates and calculate brood-year recruitment for each stock aggregate and modeled component stock (Appendix C.6)

### 3.4 Run Reconstruction Updates

As part of this project, the NCCSDB was updated from the version described in English et al. (2019) to incorporate additional years of data up through 2019, as well as reviews of (1) spawner estimates for indicator systems; (2) age composition data for the aggregates and individual stocks; (3) timing assumptions for Skeena and Nass substocks, using updated genetic data collected from 2000-2020 at the Tyee Test Fishery and Nass fish wheel programs; (4) marine and in-river harvests for Skeena First Nations.

Note that several other reviews of different components of relevant Skeena and Nass sockeye data were occurring concurrently with this project, including:

- A review of the Northern Boundary Run Reconstruction (NBRR) model (Appendix C.4)
- A comprehensive review of aggregate Nass salmon abundance estimation programs

- Harvest pattern analysis of District 104 (Southeast Alaska) pink salmon fisheries that intercept Skeena and Nass sockeye (completed June 2021, available at: https://www.psc.org/publications/technical-reports/technical-report-series/).

Results from these other projects will be considered in the next update of the stock-level data for Skeena and Nass sockeye.

#### 3.4.1 Review of spawner estimates for indicator systems

Indicator systems with major assessment programs are listed in Tables B.1 and B.3. Indicator systems covered by visual surveys are listed in Tables B.2 and B.4.

Raw spawner estimates from the indicator systems are expanded to account for observer efficiency, the proportion of indicator streams within a stock, and the proportion of indicator streams surveyed each year (Appendix C.2). The NCCSDB assigns quality ratings for spawner estimates based on 3 components: survey quality for the index streams (e.g., visual vs. fence), survey execution (e.g., adjustments for changes in fence duration or aerial survey extent), and the proportion of the stock covered by the survey. While the expansion and quality rating procedures have been reviewed on several occasions (e.g., English 2016; English et al. 2019), the underlying escapement estimates had not been reviewed prior to this project.

DFO completed an extensive review of spawner estimates for Skeena and Nass indicator streams (Appendix C.1). All available stream escapement information from local and regional data holdings were compiled and reviewed to assess whether any additional data were available for indicator streams and years previously identified as missing in earlier versions of the NCCSDB. For years that individual stream count data were available (1998 onwards for most Skeena indicator systems, 1997 onwards for some Nass indicators), escapement estimates were recalculated and compared with the NUSEDS data to identify any discrepancies.

We reviewed escapement estimates for 23 indicator streams from 1998-2019, and identified 137 escapement estimates that were not previously included in NUSEDS or the NCCSDB. In addition, we recommended changes to 84 estimates which differed substantially from the published NUSEDS estimate. Altogether, we made recommendations for 177 new or revised escapement estimates for Skeena sockeye indicator streams and 68 for Nass indicator streams.

#### 3.4.2 Review of age composition data for the aggregates and individual stocks

DFO staff updated all available age information for Skeena and Nass component and aggregate stocks (Appendix C.6.1). Age data for individual fish were downloaded from DFO regional databases. Annual age composition is available from biosampling programs for both aggregate stocks, and for Meziadin sockeye, but not for most other Skeena and Nass stocks. Digital data are available from 1989 onward. For earlier years, age readings were tallied from scanned scale age cards to estimate the proportions of each age class for a given year. With these efforts, we compiled age data for Meziadin for all years and several other small systems for some years that were not included in previous versions of published spawner-recruit data (Korman and English 2013; Pacific Salmon Foundation 2021).

### 3.4.3 Review of timing assumptions

The timing offset assumptions used in NCCSDB run reconstructions, which originate from historic tagging studies in the 1960s and 1970s and genetic data to 2010, were updated to incorporate genetic data collected up to 2019. Genetic sampling has been conducted annually at the Tyee Test Fishery (Skeena sockeye) and in many years at the Nisga'a Fish Wheels program (Nass sockeye) since 2000. For both systems, all years of available genetic data were re-run against a consistent baseline, and timing offsets for each component stock were recalculated for the full times series of available data and a number of variations (ie. all years, most recent 5 and 10 years periods) to update run timing assumptions for all stocks and to determine whether there have been any apparent shifts in timing for any of the stocks examined. The results of these analyses were incorporated into the April 2021 version of NCCSDB run reconstructions for each stock.

Appendix C.5 summarizes the Skeena timing updates. Alexander et al. (2021) describe the Nass timing updates in detail.

### 3.4.4 Review of marine and in-river harvests for Skeena First Nations

Skeena sockeye are harvested by at least 12 First Nations groups which differ by area, timing, and gear type, and have different management and catch reporting requirements (Appendix B.2.2). For most First Nations fisheries on the Skeena and Nass sockeye, some harvest estimates are available since the early 1990s. First Nations harvests, which are aggregated by fishing area, are incorporated into in-river models that estimate the total exploitation rate for each stock.

For this review, TWG members worked with Skeena First Nations to review and update previously reported catch data for the different modelled fishing areas. Generally, catch estimates for middle Skeena fishing areas, including Babine and Bulkley sockeye, were found to be consistent with previously reported estimates. The biggest identified gaps were in coastal and marine areas, where work with local First Nations fisheries groups to review historic catch estimates is ongoing. Pending completion of updated estimates for coastal and marine areas, the run reconstruction estimates used for the escapement goal review relied on existing estimates.

### 3.4.5 Stock-level data adjustments

For most stocks, we used the NCCSDB data series directly, but for a few stocks we adjusted the data. Specifically:

- *Combined data for multiple CUs*: We combined Bear and Azuklotz time series into a single Bear stock, and combined Sustut and Johanson time series into a single Sustut stock. Given the assumptions required to split the combined survey data into individual CU estimates, we consider the combined series more reliable for spawner-recruit modelling (See Section 2.3.4 for details). The merged time series is simply the sum of available estimates for the components, because the original survey estimate was split for the NCCSDB.

- *Excluded estimates for the Tahlo-Morrison CU*: These estimates were found to be also part of the NCCSDB estimate for the Babine Mid-Wild CU, so we used the combined version for the Babine Mid-Wild stock in this report to avoid double-counting.
- *Skeena River Type*: The NCCSDB includes some estimates of spawner abundance and run size for Skeena River Type sockeye, which represent a very small proportion of Skeena sockeye compared with lake-type stocks. However, we excluded these records from the analyses in this report, because it is not known what proportion of river type sockeye are represented in surveys. Skeena River Type are still included in the summary tables throughout the document, but are designated as a data-deficient stock.
- *Fred Wright vs. Kwinageese*: The NCCSDB labels sockeye spawning in the Kwinageese watershed as "Fred Wright", because that is the rearing lake for Bonney Creek spawners where biological samples have been collected. However, current stock assessment generates a combined estimate for both CUs, and we've labelled the combined stock "Kwinageese". No change was made to the actual time series.

### 3.5 Data quality check

The TWG reviewed a checklist of available information, which was developed to cover the spawner-recruit data and broader considerations that affect their interpretation. For each element, we worked towards consensus notes summarizing the available information and its relevance to the escapement goal review.

For some elements, the consensus statement was simply based on general considerations and summarized in a short note for each stock aggregate (e.g., changing ocean conditions and other large-scale patterns). For others, more formal criteria were applied to the available data (e.g., minimum number of brood years required to fit a spawner-recruit model, threshold for flagging implausible estimates of recruits/spawner). The results were summarized in short notes by stock and for the stock aggregates (Appendix D.2).

For high-priority components of the spawner-recruit data derivation and model fitting, sensitivity tests were conducted to check for the potential magnitude of effects on standard biological benchmarks, again by stock and for the stock aggregates. We considered the following components a high priority for sensitivity testing: data variations (retrospective, etc.), uncertainty in the data (bootstrap), uncertainty in the model fit (basic Bayesian), and age composition assumptions (average vs. annual).

Appendix D describes the methods for each element of the data quality check. Appendix E shows the detailed results, including the summary notes by stock.

To support this project we developed the *RapidRicker* R package (Appendix D.4), which runs spawner-recruit data quality checks and tests the sensitivity of standard biological benchmarks to different assumptions using simple Ricker fits.

The development of this package was motivated by the challenge of developing consistent methodology for assessing data quality and modeling the large number of stocks covered by the Skeena and Nass sockeye escapement goal review. Routine aspects of data review, such as checking for potential outliers or concerns regarding contrast, presented a non-trivial challenge in an analysis covering dozens of stocks within 2 aggregates, with data continuously being updated as the data reviews progressed. With the large number of stocks, we also faced the challenge of being consistent across stocks with data treatment choices (e.g., criteria for identifying outliers).

Most of the quantitative data checks and sensitivity tests described in Appendix D were implemented within the *RapidRicker* package. Appendix D.4 provides a worked example.

# 4 Available Data

## 4.1 Context for Interpreting the Spawner-Recruit Data

Skeena and Nass sockeye live in a dynamic environment. The populations exhibit long-term changes and high variability between years, face extreme events, and are subject to changing management and assessment approaches. The observed time series of spawner abundance and recruitment are a result of interactions between all of these mechanisms, and need to be interpreted in that context (e.g., when choosing a model structure for spawner-recruit analysis). Key topics are covered in more detail in the *Analysis Report* (Pestal and Carr-Harris 2025), but the intent here is to compile a broad overview to orient readers and establish an overall context.

### 4.1.1 Large-Scale Environmental Changes and Local Habitat Events

Large-scale environmental changes that affect Pacific Salmon have been extensively documented, including increased frequency and intensity of droughts and marine heat waves. Grant et al. (2019) summarize the available information on environmental patterns and discuss how they are linked to the status of Canadian Pacific Salmon populations. Note that these processes interact across geographic and temporal scales. For example, long-term and large-scale changes in regional temperatures and precipitation can influence survival rates and productivity of salmon population for long periods of time, but also increase the likelihood of local catastrophic events, such as landslides (e.g. Cloutier et al. 2017), with the potential for extirpating whole stock groups (e.g. the Big Bar and Hells Gate slides on the Fraser).

Environmental changes and notable habitat events relevant to the interpretation of sockeye data from the Skeena and Nass basins include:

- *Babine River slide (Skeena)*: Large scale rock slide affecting Babine system spawning returns from 1951 to 1953 (Godfrey et al. 1954).
- *Kwinageese Blockage (Nass)*: A landslide in 2010 resulted in a near complete blockage affecting adult spawners for that brood year. The blockage was cleared in 2011, however fisheries management measures to rebuild the Kwinageese stock continued through 2023.
- *Marine Heatwave (Skeena and Nass)*: Affected north Pacific from 2014-2018 (i.e., 2012-2016 brood years for most Skeena and Nass sockeye).
- *Severe drought in 2018 (Skeena and Nass)*: Resulted in fish passage obstructions related to low water and dewatered stream sections for the spawners in the 2018 brood year.

### 4.1.2 Biological Changes

Sockeye populations change over time (e.g., changing productivity). While it may not be possible to clearly link a particular observed change to a specific cause, we can still attempt to distinguish underlying long-term changes from the high amount of annual variation that is typical for Pacific Salmon. Several broad, regional changes have been documented in recent years, including changes in migration timing, decreases in size-at-age, increases in proportion of younger fish, changes in sex ratio, increases in up-stream migration mortality, and increasing frequency and intensity of pre-spawn mortality events. All these changes interact to affect abundances, fecundity, survival rate, and therefore overall productivity.

Observed changes in the biological characteristics of Skeena and Nass sockeye populations include:

- *Decreasing size and condition of spawners (Skeena and Nass)*: General decrease observed in size-at-age and condition since the 1980s, but variable by stock, age class, and year)
- *Brood year failures (Skeena and Nass)*: Increased frequency of brood year failures (significantly lower returns than predicted for one or more major age classes in the return) since 2010.
- *Later timing of Skeena aggregate return*: Later aggregate timing observed in 2014-2019 (except 2018), when compared to the long term average.
- *Spawning channel disease outbreak (Babine, Skeena)*: Disease outbreak (*Ichtheyophthirius multifilis*) in 1994 and 1995 resulted in high pre-spawn mortality and low escapements that affected returns in 1998 and 1999.

### 4.1.3 Enhancement Activities

In this report, we use a broad definition of enhancement to include any human activity intended to increase production of salmon, ranging from active hatchery supplementation to passage improvement (e.g. fishway, beaver dam removals) and riparian habitat improvements (e.g. placement of large woody debris).

There has been no large-scale hatchery supplementation of sockeye in the Skeena and Nass basins in recent years, but there have been hatchery-reared fry releases as part of recovery initiatives for stocks of concern. Specifically:

- *Lakelse Lake (Lower Skeena)*: Fry outplant program from 2006 to 2013
- *Kitwanga Lake (Skeena)*: Fry outplant program from 2007 to 2008

Numerous initiatives for passage improvements have been undertaken throughout both Nass and Skeena basins, and many programs have been in place for decades. Activities range from regular removal of beaver dams and other beaver management actions to larger scale infrastructure projects, such as culvert removal, culvert upgrade, or fishway installations. Specifically:

- *Meziadin (Nass)*: Fishway built in 1965

- *Lakelse (Lower Skeena)*: Since the early 2000s, a range of measures including beaver management, fishway installations and improvements (Schulbuckhand, Scully South), and spawning bed improvements with gravel placement (Schulbuckhand, Scully North).
- *Babine (Middle Skeena)*: Wild sockeye tributary beaver management and debris jam management since early 2000s.
- *Gingit (Nass early sea type)*: Consistent beaver dam removals since 2004.
- *Bear (Nass)*: Culvert replacement in Clements Creek with bridge, as well as beaver management and sockeye passage improvement since early 2000s.
- *Kitwanga Lake Recovery Program (Middle Skeena)*: Research program and implementation of measures to improve stock health and productivity, documented in the Kitwanga Sockeye Recovery Plan (Cleveland et al. 2011).
- *Cross Creek (Babine tributary, Skeena)*: Culvert replacement and beaver dam management in 2021.

The most significant enhancement activity is the Babine Lake Development project (BLDP) in the Skeena Basin, which consists of a series of spawning channels and flow control structures that maintain consistent water flow to the channels and natural sections of spawning habitat in Pinkut Creek and Fulton River. The BLDP spawning channels, adult control weirs, and flow control structures were built in stages starting with construction of Fulton Channel 1 in 1965, and the Fulton weir and Pinkut flow-control structures in 1966. Pinkut Channel and weir, and the Fulton flow-control structures were installed in 1968, followed by Fulton Channel #2, which was completed in two phases, in 1969 and 1971. The BLDP spawning channels increased available spawning habitat by 116,000 $m^2$ to accommodate approximately 190,000 additional spawners, and flow control provides stable spawning and incubation habitat in Pinkut Creek and Fulton River (West and Mason 1987).

Outside of the Babine watershed, there is one smaller artificial spawning channel adjacent to Kitsumkalum Lake that was built in the 1980s and is not currently maintained.

## 4.2 Aggregate Data

Long time series of total run size, spawner abundance, and annual age composition are available for both stock aggregates, starting in 1967 for the Skeena and in 1982 for the Nass (Figure 10). For the Nass aggregate, spawner abundance has been relatively constant since the late 1990s, yet recruits have been steadily decreasing. That means productivity (recruits/spawner) has been decreasing. Similarly, the Skeena sockeye aggregate has produced fewer recruits per spawner compared to the pre-mid-1990s period. Section 4.6 summarizes the observed productivity patterns, and Section 5.3 discusses the implications for the escapement goal review.

Although longer time series of catch and escapement information, starting in the 1950s, have been collected for both systems, the data collection and run reconstruction methods are not consistent and may not be equivalent to the more recent time series.

The quality of the aggregate estimates is considered generally good, and the TWG assigned low coefficients of variation (CV) to spawner and catch estimates. These CV values were used in an exploratory bootstrap test to evaluate the sensitivity of biological benchmark estimates and set the stage for future analyses using state-space models that combine run reconstruction and spawner-recruit estimation. Assigned CV values are listed in Table D.8.

Aggregate abundance estimates for Nass sockeye are based on an estimation program with tags applied at fish wheels in the Lower Nass since 1994. A comprehensive review of mark and recapture estimation procedures for sockeye and other species of salmon assessed in the fish wheel program is currently underway. A full count of Meziadin sockeye, which has historically accounted for the highest proportion of Nass sockeye abundance (~65% of Nass sockeye), has taken place since at the Meziadin Fishway was completed in 1966. The Meziadin fishway count and spawner enumeration counts conducted on most major small tributaries throughout the Nass do not contribute to current aggregate estimation procedures for Nass sockeye, because aggregate-level Nass estimates are based on the Lower Nass mark and recapture estimation program (Tables B.1 and B.2).

Aggregate abundance estimates for Skeena sockeye combine stock composition estimates from a test fishery in the lower river with a complete fence count of Babine sockeye, which historically account for most of the aggregate Skeena abundance (~90% in recent years), supplemented by various tributary surveys for most of the major and some of the minor Skeena stocks (Tables B.3 and B.4).

Total sockeye catch estimates for each aggregate (total Skeena, total Nass) are considered to be of good quality for Southeast Alaska fisheries and Canadian marine commercial fisheries based on daily catch log data and stock composition based on genetic stock identification (GSI) since 2002 and scale pattern analysis (SPA) prior to 2002 (Appendix B.2). The quality of other catch estimates varies across approach-area fisheries and in-river fisheries, but the overall total catch is well estimated. The total recreational catch of Skeena and Nass sockeye is more uncertain than the marine commercial and First Nations catches, but actual amounts are assumed to be much smaller than for the other harvester groups. Therefore, at the aggregate level, uncertainty in recreational catch is considered negligible.

Stock identification methods have changed over time, shifting from scale patterns to genetics (Appendix B.3). Consensus among the Northern Boundary Technical Committee (pers. comm.) is that estimated percent contributions from the different stock aggregates (Skeena and Nass) are generally consistent across methods and comparable over time. However, potential concerns have been raised for river-type sockeye, which may be mis-assigned between the Skeena and Nass aggregates.

Contrast (i.e., the range covered by estimates) in spawner estimates is low for both aggregates, and this potential issue is particularly pronounced when focusing on recent years (Table E.1). For the Skeena, this is due to the upper limit on effective spawners, which is determined by loading objectives for enhanced Babine sockeye populations (Section 5.4). For the Nass, this is probably due to the management to a fixed escapement goal and reliable in-season estimates of escapement.

Annual estimates of age composition are available for both aggregates, covering all years starting 1970 for the Skeena and 1982 for Nass. These estimates are based on extensive scale sampling in assessment programs (Appendix C.6.1).

Lake-rearing capacity estimates are available from lake-productivity surveys that have been completed for the major Skeena and Nass sockeye rearing lakes. Juvenile sockeye surveys have also been completed for most major lakes, but these are rotating surveys designed to provide snapshots of fry abundance over time rather than annual programs that generate time series that could feed into spawner-recruit modelling (Appendix B.4).

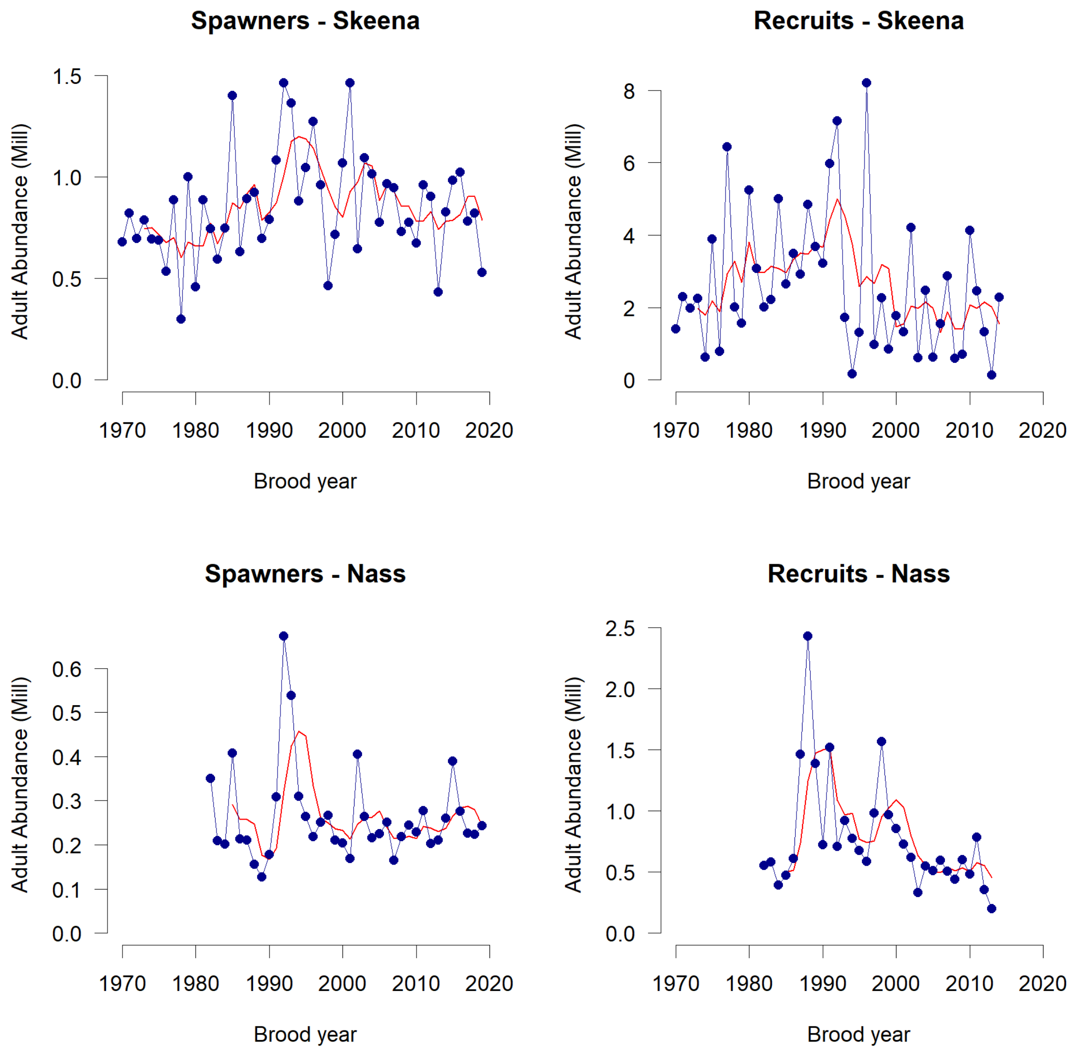


Figure 10. *Spawner-Recruit Data Availability - By Aggregate*. Plots show time series of spawner abundance (effective spawners, which exclude enhanced surplus for Skeena) and corresponding recruits for main age classes (i.e., age classes that contributed more than 2% in at least one year). Red trend lines are the four year running average.

### 4.3 Stock-Level Data

#### 4.3.1 Data filtering and infilling

For our analyses of individual Skeena and Nass stocks, we used the NCCSDB reconstructions of spawner escapement and total returns, which go back to 1960 for Skeena and 1982 for Nass sockeye stocks (English et al. 2019) and represent the longest time series of consistent estimates for Skeena and Nass stocks.

However there are significant gaps in the time series for some of the stocks due to incomplete escapement records (Figure 11). Most of the stock-level time series also have several brood years with unusual spawner or recruit estimates, or implausible productivity (R/S) estimates (Figure 12) that were flagged based on the criteria described in Section D.1 and listed in Table D.2. We filtered out extreme values and infilled any single-year gaps (Figure 13). Sensitivity tests summarized in the SR modelling report (Pestal and Carr-Harris 2025) explore how excluding or including flagged brood years affects estimates of standard biological benchmarks, such as $S_{MSY}$.

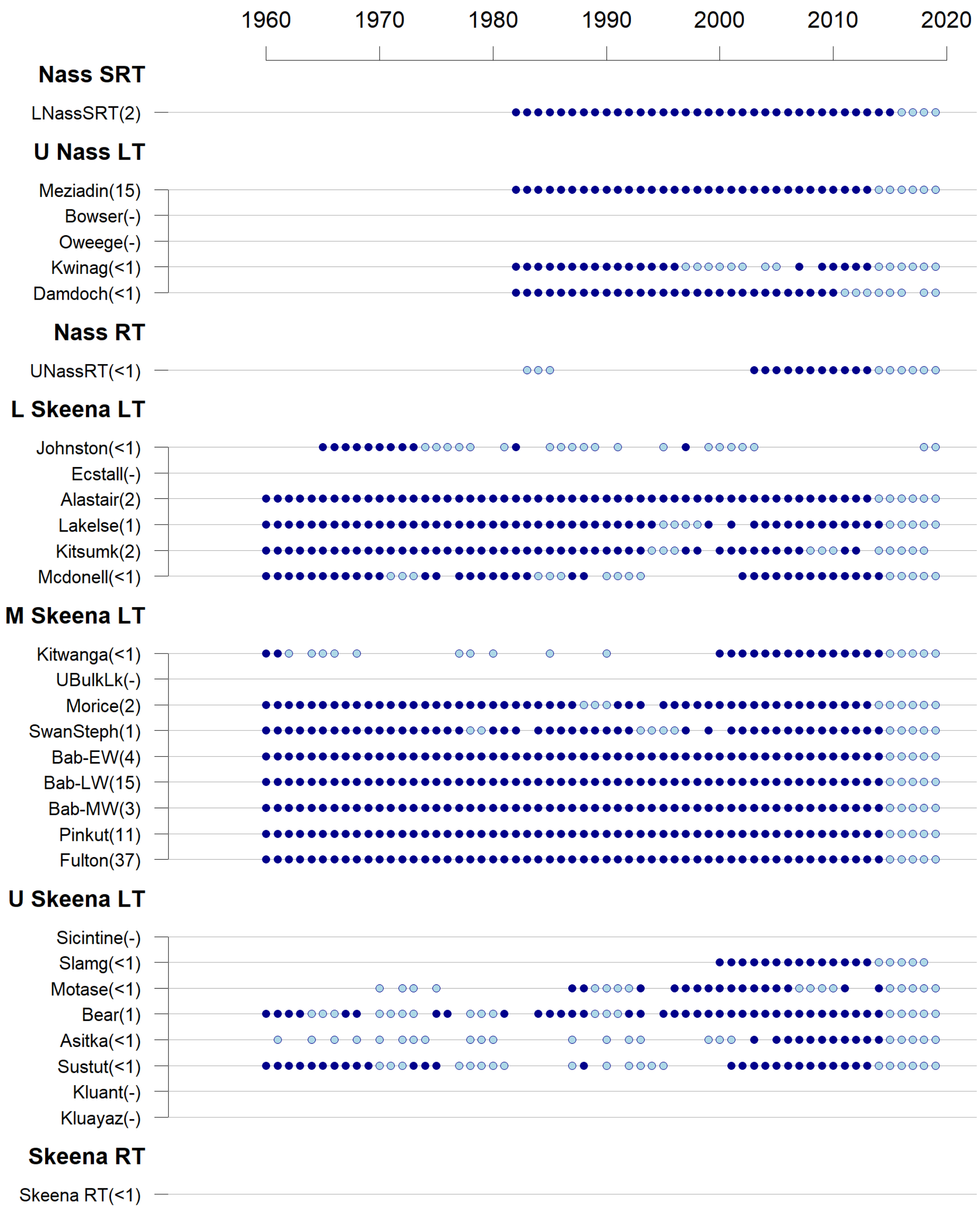


Figure 11. *Spawner-Recruit Data Availability - By Stock*. Plot shows the timeline of available data by brood year, with stocks grouped based on life history and adaptive zone. Dark blue points are brood years with both spawner and recruit estimates. Light blue points are brood years with only spawner estimates. Numbers in brackets are the share of cumulative spawner abundance since 2000 across both stock aggregates. SRT = Sea and River-Type, LT = Lake-Type, RT= River-Type, U = Upper, M = Middle, L = Lower.

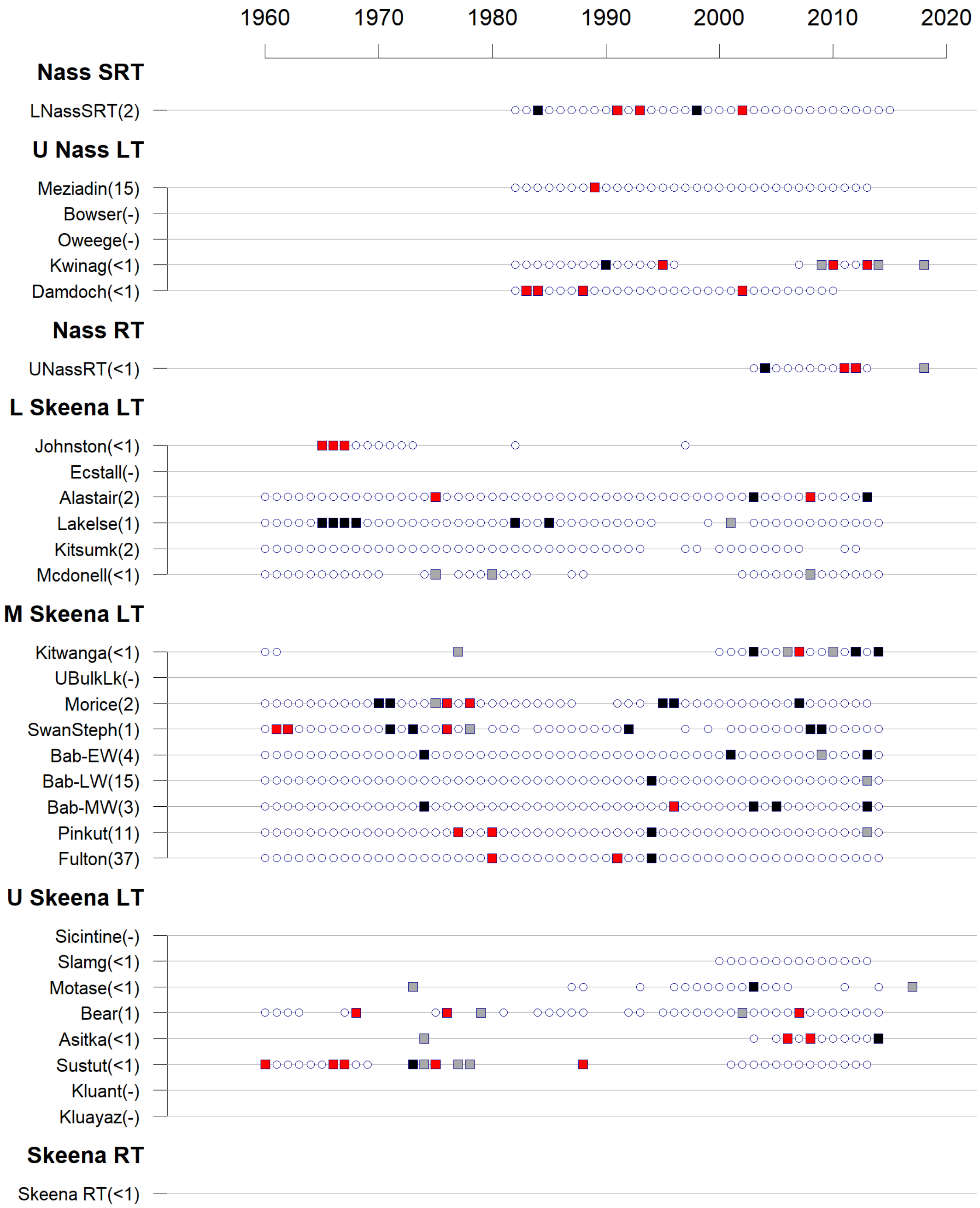


Figure 12. *Spawner-Recruit Observations Flagged in the Data Check - By Stock*. Plot layout matches Figure 11, but only brood years with both spawner and recruit estimates are shown. Estimates are colour-coded based on key metrics listed in Table D.2. White circles indicate data points that were not flagged for any of the key metrics. Grey squares flag observations where either spawner or recruitment estimates were unusual compared to the rest of the time series. Black squares are brood years with very low productivity estimates, indicating either a recruitment failure or a potential data error. Red squares indicate productivity estimates > 15 R/S, indicating a potential data error. SRT = Sea and River-Type, LT = Lake-Type, RT= River-Type, U = Upper, M = Middle, L = Lower.

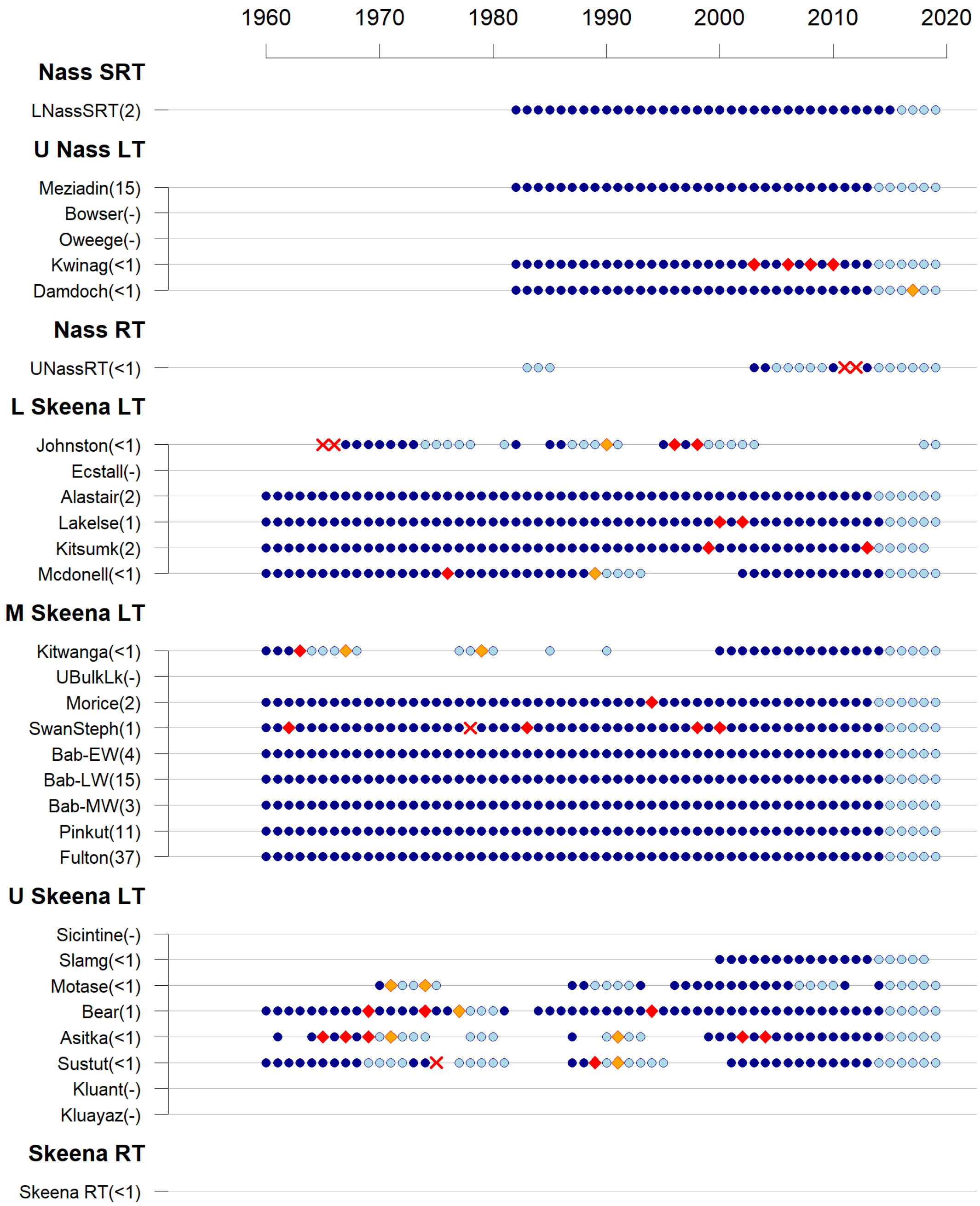


Figure 13. *Filtered and infilled data used for stock-level spawner-recruit model fitting*. Timeline of available data by brood year, with stocks grouped based on life history and adaptive zone. Dark blue circles are brood years with both spawner and recruit estimates. Light blue points are brood years with only spawner estimates. Light red diamonds mark brood years where a 1yr gap in spawner estimates was infilled. Dark red diamonds mark infilled brood years where a corresponding recruit estimate could be calculated. Red “x” mark filtered observations (R/S > 45) that could not be infilled. Numbers in brackets are the share of cumulative spawner abundance since 2000 across both stock aggregates. SRT = Sea and River-Type, LT = Lake-Type, RT= River-Type, U = Upper, M = Middle, L = Lower.

### 4.3.2 Stocks grouped based on data availability

Nass and Skeena sockeye have been organized into 31 stocks, including 7 Nass and 24 Skeena stocks, as described in Section 2.2. Available spawner and recruit data varies between stocks, as summarized in Tables 6 and 7.

The 31 stocks fall into three groups of spawner-recruit data availability (Table 8): (1) larger stocks with a lot of data, (2) smaller stocks with some data, and (3) data deficient (for spawner recruitment analysis) stocks. Model scoping considerations for fitting spawner-recruit models and estimating biological benchmarks differ between the three groups.

Most of the lakes have been surveyed to estimate rearing capacity based on photosynthetic rate (PR), as well as fall fry abundance, density and biomass of juvenile sockeye. PR-based capacity estimates are available for sockeye rearing lakes associated with all 14 stocks identified in Group 1, most stocks in Group 2, and many of the stock-recruit data-deficient stocks in Group 3. Hydroacoustic estimates of fall fry abundance, biomass and density have been conducted for all of the sockeye stocks in Group 1, 7 of 11 stocks in Group 2 , and 2 of 8 stocks in Group 3, and are available for multiple years for most of these stocks (Appendix B.4).

### 4.3.3 Group 1: Larger stocks with lots of data

Group 1 includes stocks with more than 30 brood years of spawner and recruit data that have contributed at least 0.5 % of the cumulative spawner abundance since 2000.

14 of the 31 Nass and Skeena sockeye stocks meet these criteria. This group of stocks accounts for more than 95% of the cumulative surveyed abundance of effective spawners since 2000, and long time series of spawner-recruit estimates are available for all 14 stocks in this group (Table 8). Using a 5-point scale from Very Poor to Very Good (Section D.2, Table D.4), data quality ranges from good to very good for the 6 largest stocks, which account for more the 85% of the cumulative surveyed effective spawners. Data quality for the 6 smaller stocks in this group is mostly moderate, except for Kitsumkalum (poor) and Morice (good). These quality ratings incorporate quality of spawner data, quality of catch estimates (incl. stock identification in mixed-stock fisheries) and quality of age composition estimates used to determine recruits by brood year. The quality considerations are reflected in their assigned coefficients of variation (Tables D.6 and D.7).

All 14 stocks in this group have high contrast (10+) in spawner abundances, where contrast is calculated as the ration of largest to smallest spawner abundance in the SR data set (Section D.1) when all available years of data are used. However, when earlier years of data are trimmed for various reasons (e.g., exclude pre-channel years, exclude years before a change in assessment methodology), contrast for the two largest stocks is very low. For Fulton, contrast in spawner abundances since 1993 is less than the threshold of 4 recommended by Clark et al. (2014a) to flag a potential concern for SR model fitting.

Observed contrast in the spawner time series can also be used to trim the data set. For example, the 57 available spawner estimates for Swan/Stephens range from 2 spawners to 82,000 spawners (contrast ~3,700), but most of that variation happens early in the time series, so excluding data before 1995 leaves out almost 2/3 of the data, but retains a more plausible data set with a contrast of 11.

#### 4.3.4 Group 2 - Smaller stocks with some data

9 small stocks account for about 2% of the cumulative surveyed abundance of effective spawners since 2000 but represent about 1/3 of the genetic diversity (9/32 stocks, 14/43 conservation units) for Skeena and Nass sockeye.

10 or more brood years of spawner-recruit data are available for most stocks in this group (8/9) when using all available estimates, but only 4 of the 9 stocks have 10+ observations in the trimmed data set that excludes earlier estimates using different methods or from different productivity regimes (Table 8).

Data quality ranges from very good to very poor, with differences determined by the local setting rather than the relative abundance of the stock. For example, Kitwanga, Kwinageese, and Slamgeesh have relatively small spawner abundances compared to most other Skeena and Nass sockeye stocks, but spawner estimates since 2000 are very high quality due to intensive assessment projects led by local First Nations (i.e., fences installed in most years).

Catch estimates are more uncertain, due to challenges with stock composition estimates for small stocks. Reconstructed harvests for small stocks assume similar exploitation rates for stocks with similar run timing. There is additional uncertainty around recruitment estimates, which rely on average age composition estimates from larger stocks. Stock-specific age composition estimates are available for 6 of the 9 stocks, and the remaining 4 rely on Babine age composition estimates (Mcdonell, Johnston, Asitka, Motase). Average age composition, rather than annual estimates, are used to derive recruitment by brood year for all 9 of these smaller stocks. These quality considerations are reflected in the respective coefficients of variation for the recruitment estimates (Tables D.6 and D.7).

All 9 stocks in this group have high contrast (10+) in spawner abundances when using all available years of data, as well as the trimmed data set excluding earlier years for various reasons.

#### 4.3.5 Group 3 - Data Deficient Stocks

8 of 31 stocks have no available spawner-recruit data (Table 8). Spawner estimates may be available for some sites within those stocks in some years, but spawner expansions and run reconstruction calculations are not currently being done for these stocks, most of which (with the exception of Bowser sockeye), are assumed to be very small.

Some estimates of spawner abundance and run size are available for Skeena River Type sockeye, but it is not known what proportion of river type sockeye are represented in the surveys, so they were excluded from the analysis.

New information for the following stocks has recently become available. It could not be incorporated into the current version of the analyses, but we consider these a high priority for updating in subsequent phases of the escapement goal review:

- *Bowser*: Bowser Lake was likely a major contributor to the Nass aggregate sockeye return in some years. Visual escapement estimates, which are confounded by high glacial turbidity, have not been regularly conducted for Bowser Lake sockeye, which are primarily a lakeshore spawning population. Previous abundance estimates for Bowser sockeye have been derived using different methods including stock identification using scale pattern analyses, and more recently, GSI applied to Nass aggregate escapements. The different methods have produced divergent estimates for some years, and further assessment is required to incorporate information from new sources, update GSI data, and reconcile these estimates before spawner recruit time series can be developed.
- *Bear/Azuklotz*: Preliminary results from a new assessment program (video weir installed in 2021 on Bear River downstream of Bear Lake) suggest that the combined visual spawner escapements based on aerial surveys may underestimate the actual spawning population. Furthermore, genetic analyses are on-going to determine whether Bear and Azuklotz sockeye represent a single or multiple populations that rear in these cojoined lakes. For our analyses, we used the existing time series of reconstructed abundances that do not account for new information from the camera weir program, with the understanding that these data may change in the future.

Table 6. *Stock Overview - Nass*. Table summarizes Nass sockeye stocks by life history type and adaptive zone (*LHAZ*: LT = lake-type, RT = river-type, SRT = sea and river type). See Ch. 2 for more information about stock and conservation unit delineations used here. *ERInd* shows the run-timing group assigned to each stock for stock-level run-reconstructions (Section C.6.1). Some ER indicators include "+" in the name to indicate that they cover the named stock "and others". *PSpn* is the percent of cumulative spawner abundance since 2000, calculated across both aggregates to allow grouping of stocks by abundance and data availability (Table 8, Section 4.3). *S* is the number of years for which spawner estimates are available (effective spawners for the Babine stocks, total spawners for the remaining stocks). *SR* is the number of years for which both spawner and recruitment estimates are available. Recruitment estimates are based on the major age classes (i.e., ages that have contributed more than 2% of the run at least once).

| LHAZ | Watershed | Stock | ERInd | CU | pSpn | S | SR |
|---|---|---|---|---|---|---|---|
| Nass SRT | Lower Nass Tribs | Lower Nass Sea & River Type | Gingit+ | 1 | 2 | 38 | 34 |
| U Nass LT | Meziadin | Meziadin | Meziadin | 1 | 15 | 38 | 32 |
| | Bell-Irving | Bowser | | 1 | | 0 | 0 |
| | Bell-Irving | Oweegee | | 1 | | 0 | 0 |
| | Kwinageese | Kwinageese | Kwinagees | 2 | <1 | 35 | 21 |
| | Damdochax | Damdochax | Damdochax | 1 | <1 | 37 | 29 |
| Nass RT | Upper Nass Tribs | Upper Nass River Type | BrownBear | 1 | <1 | 20 | 11 |

Table 7. *Stock Overview - Skeena*. Table summarizes Skeena sockeye stocks by life history type and adaptive zone. Table layout and column definitions as per Table 6.

| LHAZ | Watershed | Stock | ERInd | CU | pSpn | S | SR |
|---|---|---|---|---|---|---|---|
| L Skeena LT | Ecstall | Johnston | Johnston | 1 | <1 | 31 | 11 |
| | Ecstall | Ecstall | | 1 | | 0 | 0 |
| | Gitnadoix | Alastair | Alastair | 1 | 2 | 60 | 54 |
| | Lakelse | Lakelse | Lakelse | 1 | 1 | 58 | 49 |
| | Kitsumkalum | Kitsumkalum | Kalum | 1 | 2 | 57 | 46 |
| | Zymoetz | Mcdonell | Zymoetz | 3 | <1 | 50 | 35 |
| M Skeena LT | Kitwanga | Kitwanga | Kitwanga | 1 | <1 | 32 | 17 |
| | Bulkley | Upper Bulkley Lakes | | 2 | | 0 | 0 |
| | Bulkley | Morice | Morice+ | 2 | 2 | 59 | 50 |
| | Kispiox | Swan/Stephens | Swan+ | 3 | 1 | 57 | 46 |
| | Babine | Babine Early Wild | Babine-WE | 1 | 4 | 60 | 55 |
| | Babine | Babine Late Wild | Babine-WL | 1 | 15 | 60 | 55 |
| | Babine | Babine Mid Wild | Babine-WM | 1 | 3 | 60 | 55 |
| | Babine | Pinkut | Babine-P | 1 | 11 | 60 | 55 |
| | Babine | Fulton | Babine-F | 1 | 37 | 60 | 55 |
| U Skeena LT | Sicintine | Sicintine | | 1 | | 0 | 0 |
| | Slamgeesh | Slamgeesh | Slamgeesh | 2 | <1 | 19 | 14 |
| | Motase | Motase | | 1 | <1 | 33 | 16 |
| | Sustut | Bear | Bear+ | 2 | 1 | 54 | 36 |
| | Sustut | Asitka | Bear+ | 1 | <1 | 34 | 11 |
| | Sustut | Sustut | Sustut+ | 3 | <1 | 47 | 27 |
| | Kluatantan | Kluantantan | | 1 | | 0 | 0 |
| | Kluayaz | Kluayaz | | 1 | | 0 | 0 |
| Skeena RT | All | Skeena River Type | Swan+ | 2 | <1 | 0 | 0 |

Table 8. *Available Spawner-Recruit Data for Nass and Skeena Sockeye Stocks*. Stocks are sorted based on size and grouped based on data availability. *LHAZ* is a combination of life history and adaptive zone. *pSpn* is the % of cumulative surveyed effective spawners since 2000. *NumSR* is the number of brood years with spawner recruit estimates and *Contr* is the contrast in spawner estimates. Values in brackets are for data sets after *TrimYr*. *Spn*, *Ct*, and *Rec* are quality ratings summarizing the information in Tables E.9 to E.14. Group 1 includes stocks with more than 30 brood years of spawner and recruit data and *pSpn* larger than about 0.5. *DD* = Data Deficient.

| LHAZ | Stock | pSpn | TrimYr | NumSR | Contr | Spn | Rec |
|---|---|---|---|---|---|---|---|
| **Group 1: Larger stocks, many brood years with spawner and recruit estimates** | | | | | | | |
| M Skeena LT | Fulton | 37.08 | 1993 | 55(22) | 13.1(3.7) | V. Good | Good |
| M Skeena LT | Bab-LW | 14.7 | 1993 | 55(22) | 15.8(15.6) | Good | Good |
| U Nass LT | Meziadin | 14.57 | 1990 | 32(24) | 11.8(6.7) | V. Good | Good |
| M Skeena LT | Pinkut | 10.72 | 1993 | 55(22) | 14.1(8.3) | V. Good | Good |
| M Skeena LT | Bab-EW | 4.46 | 1993 | 55(22) | 33.4(33.4) | Good | Good |
| M Skeena LT | Bab-MW | 2.95 | 1993 | 55(22) | 30.6(30.6) | Good | Good |
| L Skeena LT | Alastair | 2.5 | 1990 | 54(24) | 80.4(80.4) | Mod | Mod |
| L Skeena LT | Kitsumk | 2.5 | 1990 | 46(16) | 82.7(8.5) | Poor | Poor |
| Nass SRT | LNassSRT | 1.85 | 2000 | 34(16) | 82.9(74.7) | Mod | Mod |
| M Skeena LT | Morice | 1.72 | 1998 | 50(16) | 205(13.1) | Good | Mod |
| L Skeena LT | Lakelse | 1.3 | 1990 | 49(19) | 34.7(11.8) | Mod | Mod |
| M Skeena LT | SwanSteph | 1.28 | 1995 | 46(16) | 36924.5(11) | Mod | Mod |
| U Skeena LT | Bear | 0.89 | 1990 | 36(22) | 97.6(61.7) | Poor | Poor |
| L Skeena LT | Mcdonell | 0.48 | 1990 | 35(13) | 75(45.9) | Mod | Mod |
| **Group 2: Small Stocks, some brood years with spawner and recruit estimates** | | | | | | | |
| U Nass LT | Kwinag | 0.36 | 1990 | 21(13) | 520.8(412.4) | Good to V. Gd | Mod |
| M Skeena LT | Kitwanga | 0.33 | 2000 | 17(15) | 416.1(166.4) | V. Good | Good |
| U Nass LT | Damdoch | 0.2 | 1990 | 29(21) | 32.4(17.7) | Good | Mod |
| U Skeena LT | Sustut | 0.15 | 1990 | 27(13) | 2600(30.6) | V. Good | Mod |
| L Skeena LT | Johnston | 0.13 | 1980 | 11(2) | 3750(48.7) | Poor | Poor |
| U Skeena LT | Asitka | 0.1 | 2000 | 11(11) | 2415.9(54.9) | Mod | Mod |
| Nass RT | UNassRT | 0.05 | 1990 | 11(11) | 1301(1301) | Good | Poor |
| U Skeena LT | Slamg | 0.04 | 2000 | 14(14) | 13.8(13.8) | Good | Mod |
| U Skeena LT | Motase | 0.04 | 1990 | 16(14) | 1050(360.4) | | |
| **Group 3: No brood years with spawner and recruit estimates** | | | | | | | |
| U Nass LT | Bowser | 0 | 1990 | 0(NA) | 0(NA) | DD | DD |
| U Nass LT | Oweege | 0 | 1990 | 0(NA) | 0(NA) | DD | DD |
| L Skeena LT | Ecstall | 0 | 1990 | 0(NA) | 0(NA) | DD | DD |
| M Skeena LT | UBulkLk | 0 | 1990 | 0(NA) | 0(NA) | DD | DD |
| U Skeena LT | Sicintine | 0 | 1990 | 0(NA) | 0(NA) | DD | DD |
| U Skeena LT | Kluant | 0 | 1990 | 0(NA) | 0(NA) | DD | DD |

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| LHAZ | Stock | pSpn | TrimYr | NumSR | Contr | Spn | Rec |
|---|---|---|---|---|---|---|---|
| U Skeena LT | Kluayaz | 0 | 1990 | 0(NA) | 0(NA) | DD | DD |
| Skeena RT | Skeena RT | 0 | 2000 | 0(0) | 0(NA) | DD | DD |

### 4.4 Lake Productivity and Genetic Data

Most Skeena and Nass sockeye rearing lakes have been surveyed to estimate juvenile biomass, juvenile density, and fall fry abundance (Tables 9 to 12). Hydroacoustic estimates of fall fry abundance, biomass and density have been conducted for all of the sockeye stocks in Group 1, 7 of 11 stocks in Group 2, and 2 of 8 stocks in Group 3. Fall fry abundance estimates are available for multiple years for most systems.

Estimates of rearing capacity based on photosynthetic rate (PR) are available for sockeye rearing lakes associated with all 12 stocks identified in Group 1, most stocks in Group 2, and many of the data-deficient stocks in Group 3 (Table B.9).

Although regular rotational hydroacoustic surveys for the major Nass and Skeena sockeye rearing lakes have occurred since the early 2000s, most of the PR-based lake rearing capacity estimates reported here are based on surveys that took place between 10 and 20 years ago. Given rapid environmental changes that have occurred during the recent time period, and ongoing efforts to update these data, caution should be considered when using these estimates for developing biological benchmarks directly or in a spawner recruitment modeling framework.

Table 9. *Synthesis of Lake Information - Nass*. Commentary on lake characteristics based on ranking of juvenile size and density (Figure B.1). Fry size was categorized into *large* (top third), *mid* (middle third), or *small* (lower third). Juvenile density was similarly categorized into *high*, *mid*, or *low*.

| LHAZ | Watershed | StkNmS | Lake |
|---|---|---|---|
| Nass SRT | Lower Nass Tribs | LNassSRT | Not applicable (river-type) |
| U Nass LT | Meziadin | Meziad | 1 rearing lake. Multiple juvenile surveys. Mid-size fry. High density. PR-based estimate available. |
| U Nass LT | Bell-Irving | Bowser | 1 rearing lake. No juvenile surveys. PR-based estimate available |
| U Nass LT | Bell-Irving | Oweeg | 1 rearing lake. No juvenile surveys. No PR-based estimate. |
| U Nass LT | Kwinageese | Kwina | 2 rearing lakes. Multiple juvenile surveys for larger lake (Fred Wright). Small fry, high density. PR-based estimates available for both lakes. |
| U Nass LT | Damdochax | Damdoch | 2 rearing lakes (Damdochax, Wiminasik). Multiple juvenile surveys on both lakes. PR-based estimate available for Damdochax. |
| Nass RT | Upper Nass Tribs | UNassRT | Not applicable (river-type) |

Table 10. *Synthesis of Lake Information - Skeena*. Table description and categories used for lake characteristics (e.g., small fry, low density) as per Table 9.

| LHAZ | Watershed | StkNmS | Lake |
|---|---|---|---|
| L Skeena LT | Ecstall | Johnst | 1 rearing lake. Multiple juvenile surveys. Smallest fry among the surveyed lakes, but highest density (about triple the density of the other lakes with high juveniledensity). PR-based estimate available |
| L Skeena LT | Ecstall | Ecst | 1 rearing lake. Multiple juvenile surveys. Mid-size fry. Very low density. PR-based estimate available |
| L Skeena LT | Gitnadoix | Alast | 1 rearing lake. Multiple juvenile surveys. Mid-size fry. Medium density. PR-based estimate available. |
| L Skeena LT | Lakelse | Lakels | 1 rearing lake. Many juvenile surveys. Largest fry among surveyed lakes in Skeena. Medium density. PR-based estimate available. |
| L Skeena LT | Kitsumkalum | Kitsumk | 1 rearing lake. Multiple juvenile surveys. Juvenile size and density on the lower end. PR-based estimate available. |
| L Skeena LT | Zymoetz | Mcdon | 3 rearing lakes (Mcdonell, Dennis, Aldrich; roughly equal contribution). Many juvenile surveys on Mcdonell. Mid-size juvenilemedium density. No surveys on the other 2. PR-based estimates available for all 3 lakes. |
| M Skeena LT | Kitwanga | Kitwang | 1 rearing lake. Multiple juvenile surveys. Large size, low density. PR-based estimate available. |
| M Skeena LT | Bulkley | UBulkLk | 2 rearing lakes (Bulkley, Maxan). No juvenile surveys. No PR-based estimates. |
| M Skeena LT | Bulkley | Moric | 2 rearing lakes. Morice is much larger than Atna (> 80/20 split by area). Multiple juvenile surveys on Morice. Multiple juvenile surveys: mid-size, low density. PR-based estimate available for Morice. |
| M Skeena LT | Kispiox | SwanSteph | 3 rearing lakes (ca. 60% Swan, 30% Stephens, 10% Club, most sockeye rear in Stephens Lake). Multiple juvenile surveys on Swan and Stephens. Swan: small juvenile low density. Stephens: large juvenile medium density. PR-based estimate available for Swan and Stephens lakes. |
| M Skeena LT | Babine | Bab-EW | Part of 1 rearing lake. Juvenile surveys and PR capacity estimate available for all Babine lake (not separated by stock). |
| M Skeena LT | Babine | Bab-LW | Part of 1 rearing lake. Juvenile surveys and PR capacity estimate available for all Babine lake (not separated by stock). |
| M Skeena LT | Babine | Bab-MW | Part of 1 rearing lake. Juvenile surveys and PR capacity estimate available for all Babine lake (not separated by stock). |
| M Skeena LT | Babine | Pinkut | Part of 1 rearing lake. Juvenile surveys and PR capacity estimate available for all Babine lake (not separated by stock). |
| M Skeena LT | Babine | Fulton | Part of 1 rearing lake. Juvenile surveys and PR capacity estimate available for all Babine lake (not separated by stock). |
| U Skeena LT | Sicintine | Sicint | 1 rearing lake. No juvenile surveys. No PR-based estimate available. |

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| LHAZ | Watershed | StkNmS | Lake |
|---|---|---|---|
| U Skeena LT | Slamgeesh | Slamg | 2 rearing lakes (Slamgeesh, Damshilgwit). Muliple years of smolt estimates available from 2000-2018. PR-based estimate available. |
| U Skeena LT | Motase | Motas | 1 rearing lake. Multiple juvenile surveys. Small juvenile lowest density among surveyed lakes. PR-based estimate available. |
| U Skeena LT | Sustut | Bear | 2 rearing lakes. Bear is much larger than Azuklotz (ca. 80/20 split). Both have large juveniles at low density. PR-based estimates available for both lakes. |
| U Skeena LT | Sustut | Asitk | 1 rearing lake. No juvenile surveys or PR-based estimate. |
| U Skeena LT | Sustut | Sustut | 3 rearing lakes (Sustut, Spawning, Johanson; Sustut is largest contribution (>75%). Multiple juvenile surveys on Sustut and Johanson. Sustut: small juveniles at high density. Johanson: small juvenileat medium density. PR-based estimates available for Sustut and Johanson lakes. |
| U Skeena LT | Kluatantan | Kluant | 1 rearing lake. No juvenile surveys. No PR-based estimate. |
| U Skeena LT | Kluayaz | Kluaya | 1 rearing lake. No juvenile surveys. PR-based estimate available. |
| Skeena RT | All | Skeena RT | Not applicable (river-type) |

Table 11. *Summary of Available Lake and Genetics Data - Nass*. Stocks are grouped by life history type and adaptive zone (*LHAZ*), then sorted based on the share of cumulative spawner abundance since 2000 across both stock aggregates (*pSpn*). *Lk* is the number of rearing lakes that have had at least 1 juvenile survey. *Dens*, *Wt*, and *Fall* show the number of juvenile density estimates, juvenile weight estimates, and fall fry surveys, respectively. *Last* is the year of the most recent juvenile survey. *Samples* is the number of genetic samples in the Canadian microsatellite baseline. *Sites* is the number of baseline sample sites. *Yrs* shows the number of years sampled for the baseline, followed by the first and last sample year in brackets.

| | | | **Lake Surveys** | | | | | **GSI** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| LHAZ | Stock | pSpn | Lk | Dens | Wt | Fall | Last | Samples | Sites | Yrs |
| Nass SRT | LNassSRT | 2 | | 0 | 0 | 0 | 0 | 532 | 3 | 7 (1987-2014) |
| U Nass LT | Meziadin | 15 | 1 | 9 | 8 | 1 | 2017 | 784 | 4 | 5 (2001-2018) |
| | Kwinag | <1 | 1 | 9 | 1 | 9 | 2012 | 738 | 2 | 7 (1987-2001) |
| | Damdoch | <1 | 2 | 9 | 9 | 9 | 2017 | 557 | 1 | 6 (1987-2001) |
| | Bowser | | 0 | 0 | 0 | 0 | 0 | 827 | 1 | 7 (1986-2001) |
| | Oweege | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Nass RT | UNassRT | <1 | | 0 | 0 | 0 | 0 | 237 | 1 | 7 (1997-2013) |

Table 12. *Summary of Available Lake and Genetics Data - Skeena*. Table columns defined as per Table 11.

| | | | **Lake Surveys** | | | | | **GSI** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| LHAZ | Stock | pSpn | Lk | Dens | Wt | Fall | Last | Samples | Sites | Yrs |
| L Skeena LT | Alastair | 2 | 1 | 5 | 5 | 4 | 2019 | 354 | 1 | 5 (1987-2006) |
| | Kitsumk | 2 | 1 | 6 | 6 | 6 | 2018 | 266 | 3 | 3 (1994-2012) |
| | Lakelse | 1 | 1 | 13 | 11 | 13 | 2018 | 536 | 2 | 5 (1987-2006) |
| | Mcdonell | <1 | 1 | 17 | 16 | 16 | 2019 | 347 | 2 | 5 (1987-2006) |
| | Johnston | <1 | 1 | 4 | 4 | 4 | 2019 | 121 | 1 | 1 (2010) |
| | Ecstall | | 1 | 3 | 3 | 3 | 2019 | 0 | 0 | |
| M Skeena LT | Fulton | 37 | 0 | 0 | 0 | 0 | 0 | 536 | 1 | 4 (1985-1994) |
| | Bab-LW | 15 | 0 | 0 | 0 | 0 | 0 | 340 | 2 | 4 (1959-1994) |
| | Pinkut | 11 | 0 | 0 | 0 | 0 | 0 | 492 | 1 | 4 (1985-1994) |
| | Bab-EW | 4 | 0 | 0 | 0 | 0 | 0 | 1119 | 5 | 7 (1987-2014) |
| | Bab-MW | 3 | 1 | 4 | 4 | 4 | 2016 | 789 | 3 | 6 (1987-2014) |
| | Morice | 2 | 1 | 4 | 4 | 2 | 2019 | 258 | 2 | 6 (1988-2016) |
| | SwanSteph | 1 | 2 | 11 | 10 | 11 | 2019 | 490 | 2 | 5 (1988-2006) |
| | Kitwanga | <1 | 0 | 0 | 0 | 0 | 0 | 554 | 1 | 3 (1998-2009) |
| | UBulkLk | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| U Skeena LT | Bear | 1 | 2 | 10 | 10 | 10 | 2018 | 116 | 1 | 2 (1987-1988) |
| | Sustut | <1 | 2 | 10 | 10 | 10 | 2018 | 341 | 1 | 4 (1993-2006) |
| | Asitka | <1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | Slamg | <1 | 0 | 0 | 0 | 0 | 0 | 672 | 1 | 3 (2004-2008) |
| | Motase | <1 | 1 | 3 | 1 | 2 | 2013 | 75 | 1 | 1 (1987) |
| | Sicintine | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | Kluant | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | Kluayaz | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Skeena RT | Skeena RT | <1 | 0 | 0 | 0 | 0 | 0 | 554 | 5 | 12 (2002-2015) |

### 4.5 Recruitment Productivity

Productivity, in terms of recruits per spawner, referred to simply as productivity in this report, of both Skeena and Nass stock aggregates has varied substantially over the available time series (Figure 14), both in terms of raw recruits per spawner and Ricker model residuals that account for density effects (i.e., Rec/Spn will be lower at large spawner abundances, even if the underlying productivity of the stock is the same). Note that values listed in the text below are R/S for easier interpretation, but Figure 14 plots the natural log of R/S to better highlight the pattern over time. Figure 14 includes a secondary axis with the corresponding R/S values.

Aggregate Skeena productivity increased throughout the 1970s and 1980s, then declined to barely above replacement in the mid-1990s (Figure 14). While average productivity of the Skeena aggregate has gradually increased since then, it is still much lower than it was before the mid-1990s (i.e., 1.5 to 2 recruits/spawner compared to 3 to 5 recruits/spawner). The pattern for the Ricker residuals is the same.

Aggregate Nass productivity has followed a roughly decadal pattern of large fluctuations in productivity (Figure 14), with recruits/spawner 2-3 times higher during peak productivity than during the low productivity periods. This pattern is also evident in the Ricker residuals, but less pronounced, because abundance builds up during the high productivity period, resulting in a decrease in productivity of subsequent brood years.

Long-term average productivity differs substantially across stocks, is highly variable from one year to the next, and which stocks are the most productive changes over time (Figures 15 to 17).

Observed patterns in productivity for the 14 largest Skeena and Nass sockeye stocks are both highly variable across years and between stocks (Figures 18 and 19).

We explored pairwise correlations in log(R/S) using the approach described by Dorner et al. (2018). Note that this is intended to be an illustration of the patterns across stocks, and how they change across different time periods. This exploration used simple correlations between the values in each pair of time series. We did not fully investigate the time series patterns (e.g., detrending, cross-correlations).

Productivity generally follows a similar pattern (i.e., positive correlation) for the 14 largest stocks with long time series of spawner-recruit data, except for Lower Nass sea and river-type sockeye, which are negatively correlated (Figure 20). Note that correlations can vary by time period (Figures 21 and 22, Table 13).

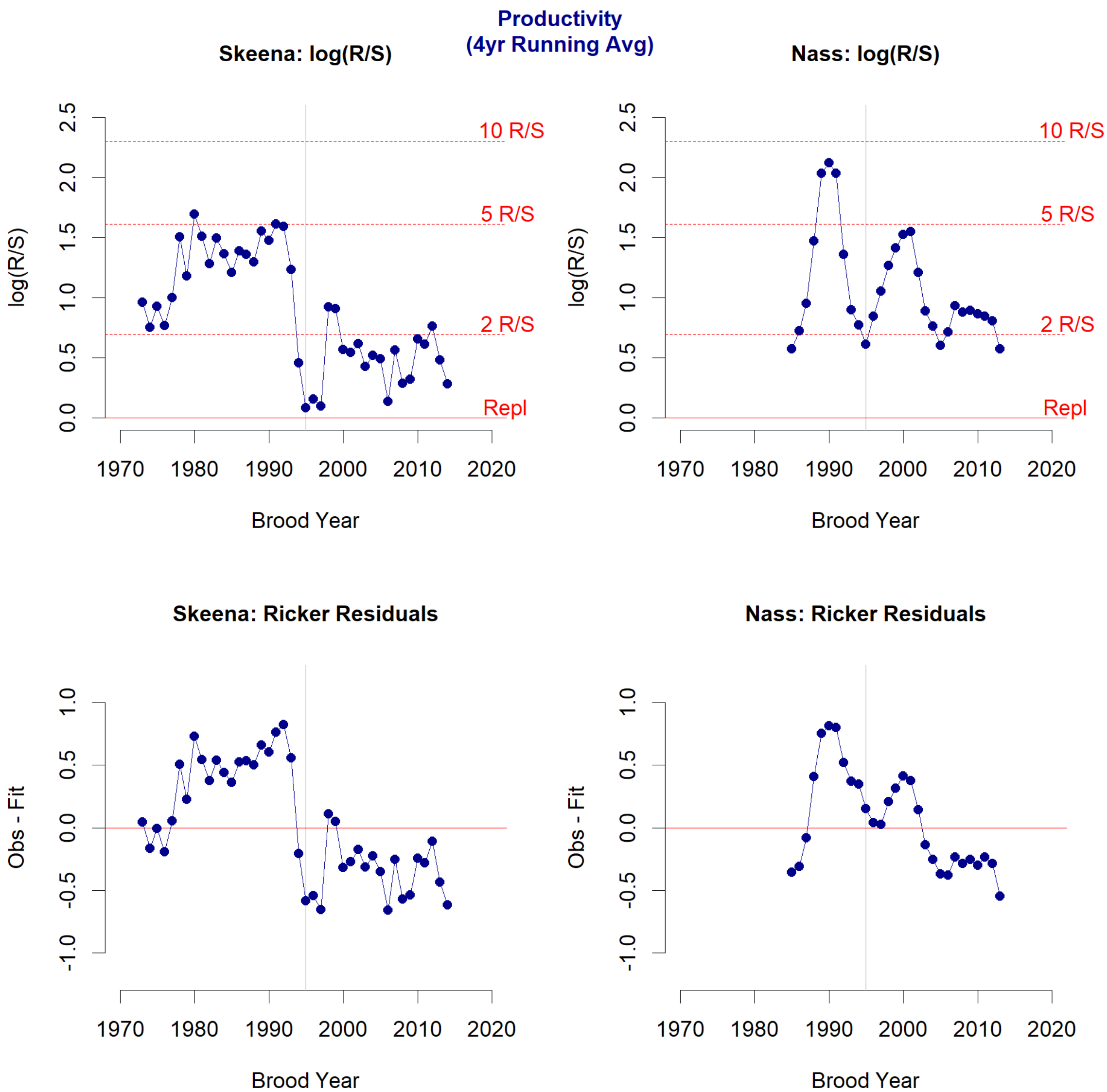


Figure 14. *Changes over time in recruitment productivity of Skeena and Nass Aggregates.* Top panels show productivity in terms of recruits/spawner (R/S), log-transformed to adjust for the commonly observed skewed distribution and smoothed as a 4-yr running average to highlight the underlying pattern. For the Skeena, spawners exclude the channel surplus. Red horizontal lines mark the corresponding raw numbers that can be more directly interpreted: At 1 R/S (*Repl*), the stock replaces itself *in the absence of any harvest*. At 2 R/S, the stock could sustain 50% exploitation rate while maintaining the same spawner abundance (under theoretical stable long-term conditions, i.e., *equilibrium*). The bottom panels show productivity patterns as deviations from the expected log(R/S) based on a simple deterministic Ricker fit, smoothed as 4-yr running average to highlight the underlying pattern. The Ricker residuals, in units of ln(R/S), account for within-stock density effects, so that the pattern is a better reflection of fundamental, underlying productivity changes as spawner abundance naturally varies from year to year. With these residuals, the pattern can be directly interpreted, but the specific values are not as biologically meaningful. For Skeena and Nass sockeye aggregates, the two alternative productivity patterns are generally similar, but the density effect is more pronounced for Nass in the late 1990s: R/S was very low, but density-adjusted Ricker residuals are ~0, indicating that recruitment was close to model expectations (i.e., long-term average conditions).

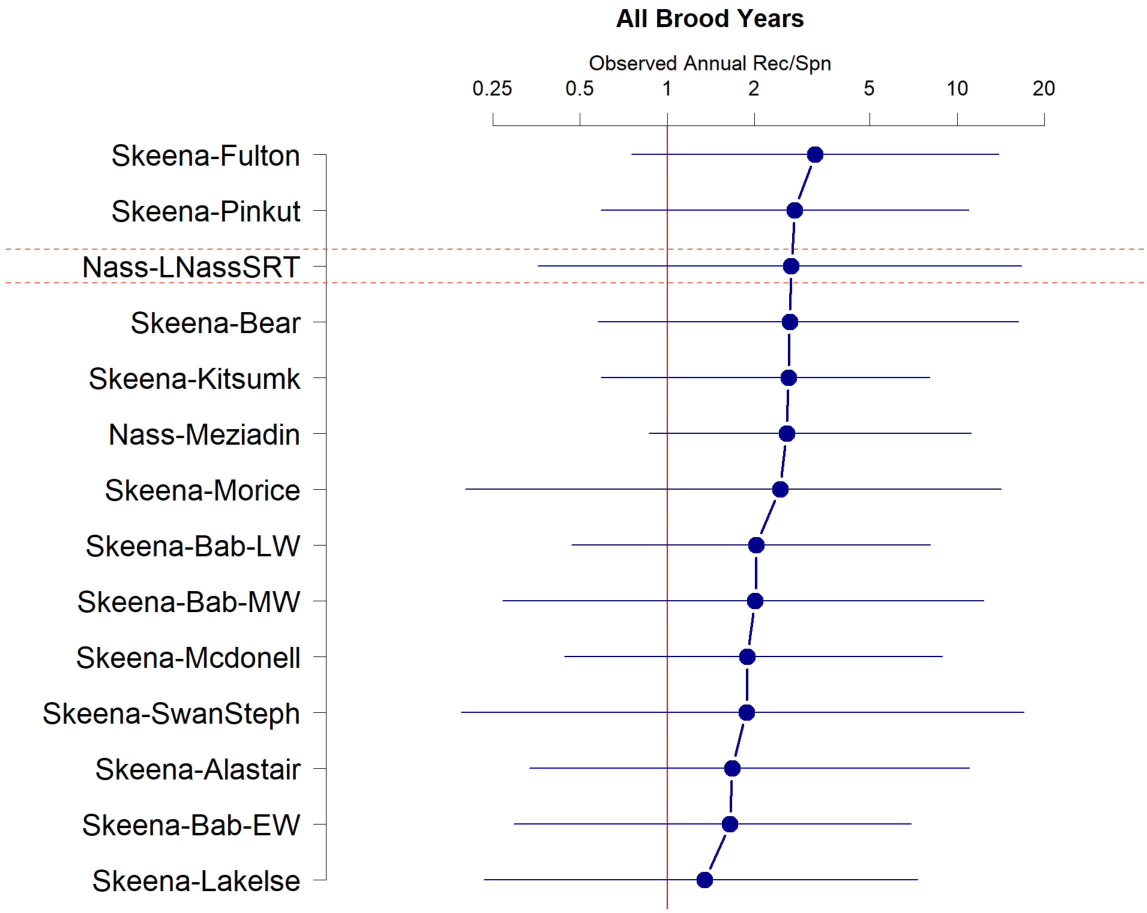


Figure 15. *Group 1 of Skeena and Nass Stocks (14 largest) Ranked by Mean Productivity (R/S) - All Brood Years*. Plot shows geometric mean recruits per spawner (points) and 90% of the observed distribution (i.e., 5th to 95th percentile). Vertical red line at 1 R/S marks replacement. Values below replacement indicate that there were fewer recruits from that brood year than spawners. This can be due to poor conditions (e.g., poor survival during early ocean entry) or high density (i.e., spawner abundance exceeded the capacity of either the spawning grounds or the rearing lake). Long-term average productivity differs substantially across stocks (points range from a lower end of about 1.3 R/S to and upper end of about 3.3 R/S). Productivity is also highly variable from one year to the next (long whiskers). The channel-enhanced Babine stocks (Fulton, Pinkut) are the most productive stocks in the 2 basins on average, over the long-term. However, Lower Nass sea and river-type (highlighted with dashed lines), Bear, Kitsumkalum, and Meziadin have similar average productivity as Pinkut.

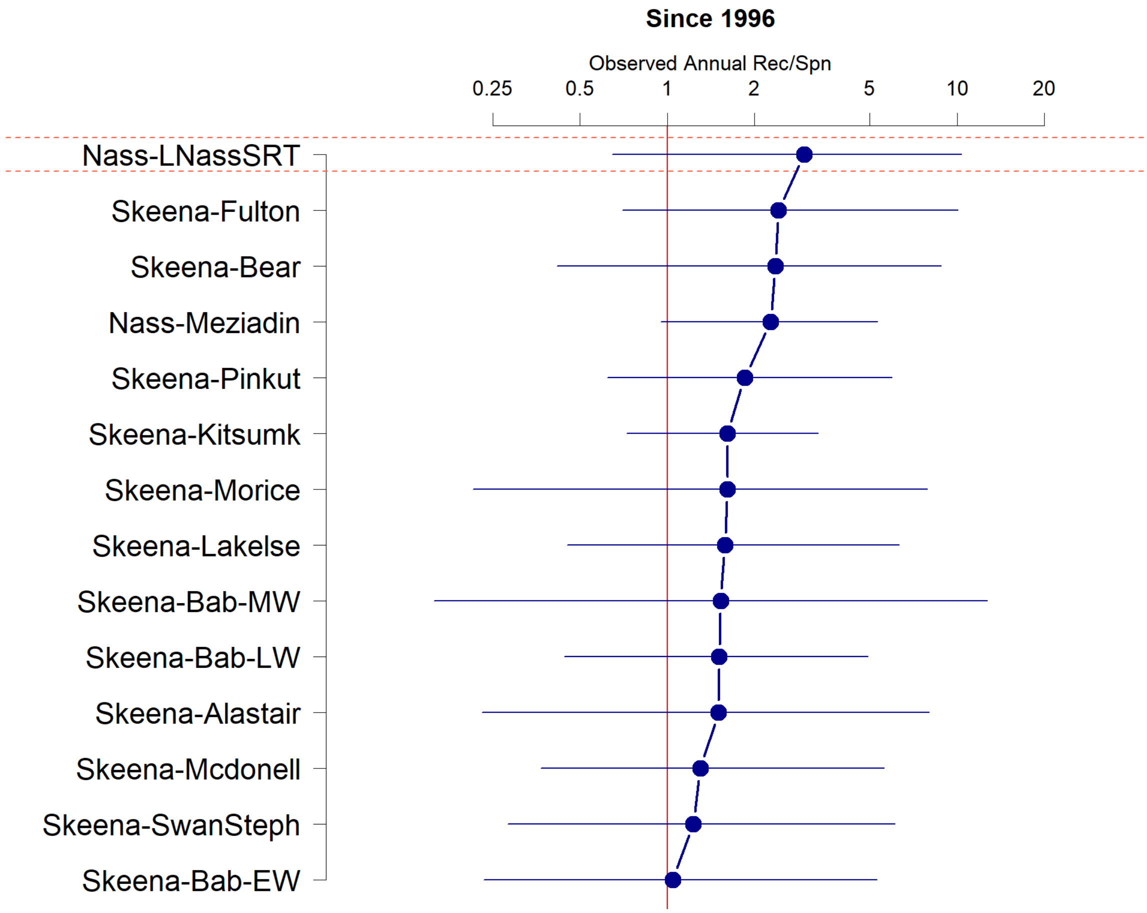


Figure 16. *Group 1 of Skeena and Nass Stocks (14 largest) Ranked by Mean Productivity (R/S) - Since 1996*. Layout as per Figure 15. Key changes compared to the previous figure covering all brood years: (1) the difference between the most productive stocks and other stocks is larger, and (2) the Lower Nass sea and river-type sockeye (highlighted with dashed lines) have been the most productive stock in recent decades, with higher productivity than the channel-enhanced Babine stocks or Meziadin, the largest Nass stock (per spawner, not in terms of total production).

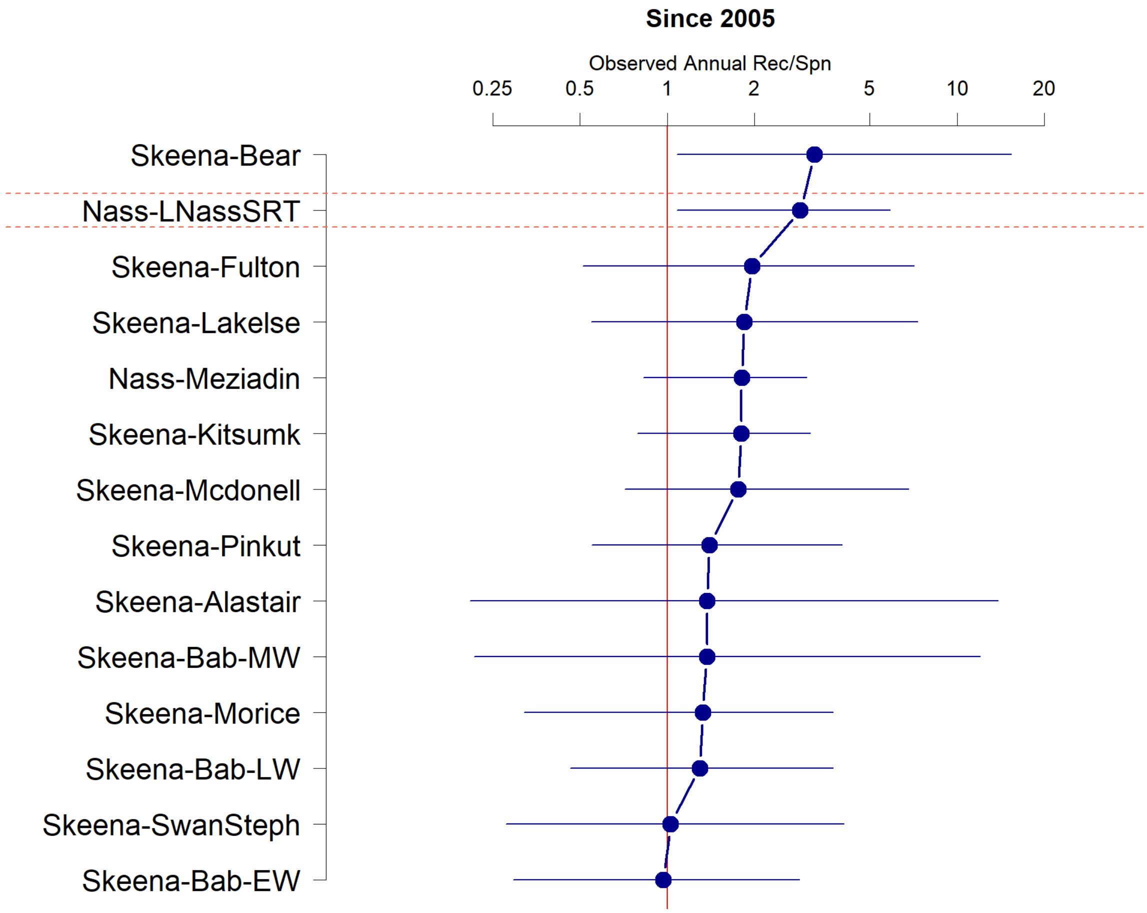


Figure 17. *Group 1 of Skeena and Nass Stocks (14 largest) Ranked by Mean Productivity (R/S) - Since 2005*. Layout as per Figure 15. Lower Nass sea and river-type sockeye are highlighted with dashed lines.

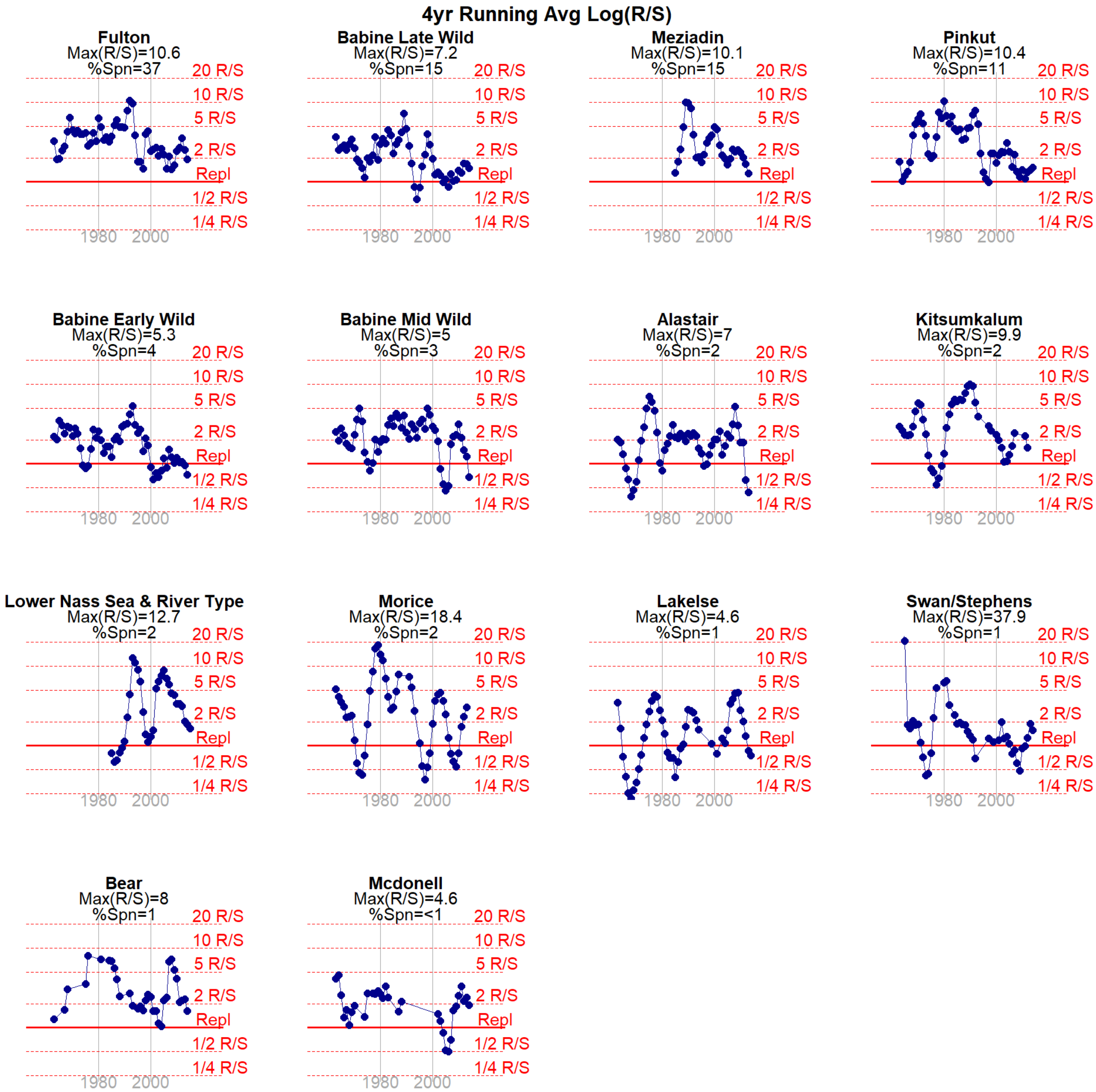


Figure 18. *Productivity Pattern for 14 largest Skeena and Nass Stocks - Log(R/S)*. Layout as per the top panels in Figure 14. Patterns differ between stocks, but most stocks had 1 or more periods where productivity was below replacement (i.e., less than 1 R/S), particularly within the last 20 years for Skeena stocks.

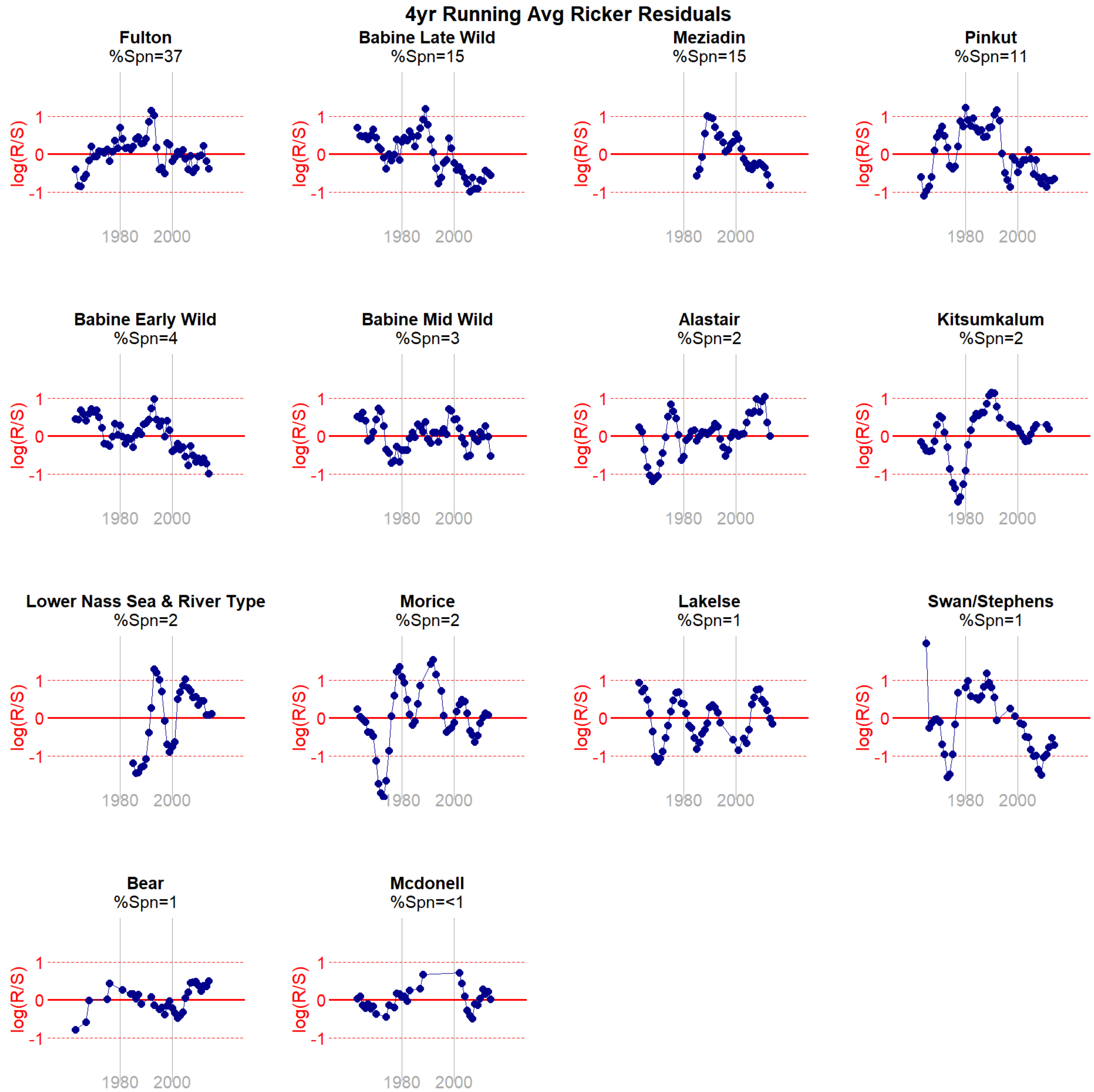


Figure 19. *Productivity Pattern for 14 largest Skeena and Nass Stocks - Ricker Residuals*. Layout as per the bottom panels in Figure 14. Patterns differ between stocks.

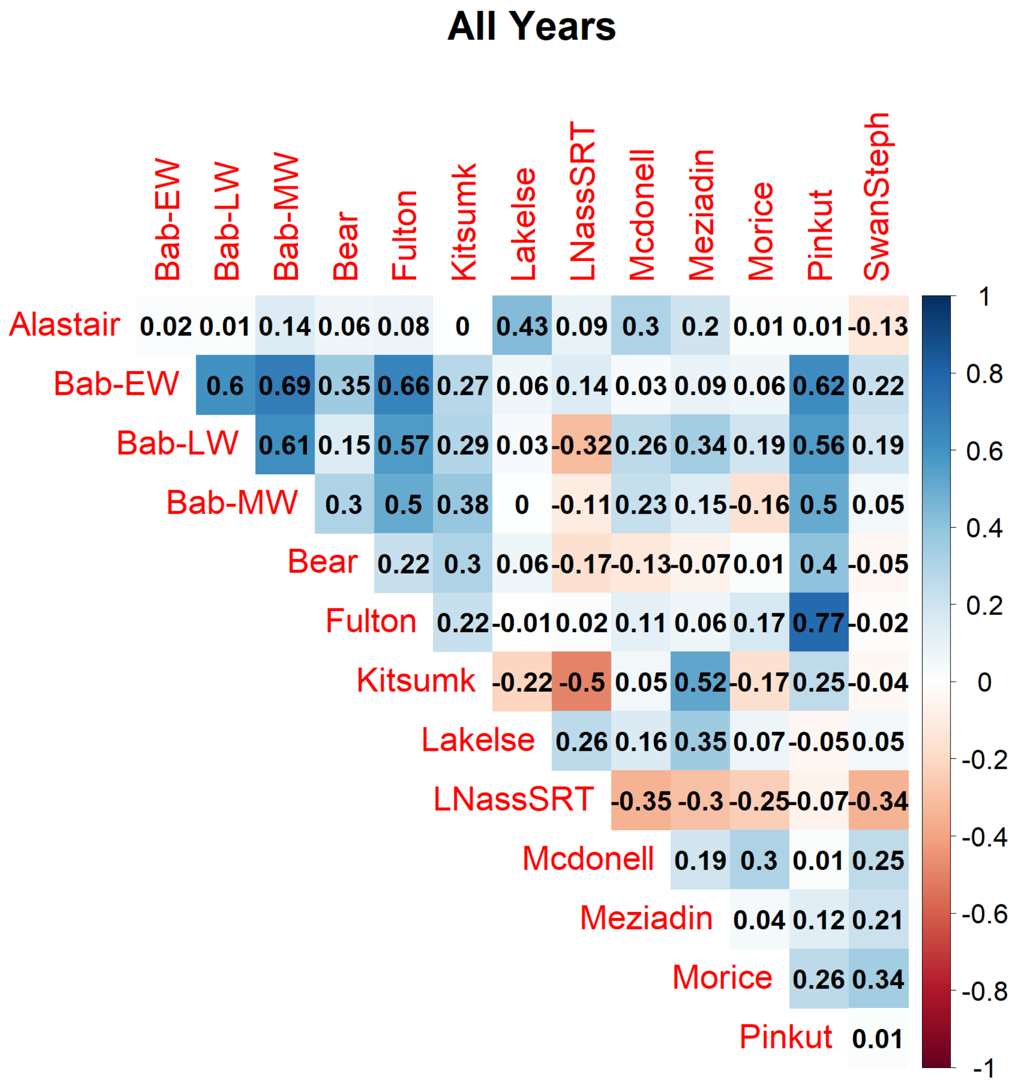


Figure 20. *Correlation in Productivity (Log R/S) for 12 largest Skeena and Nass Stocks - All Years*. Each cell in the grid shows the pairwise correlation between the stock in the horizontal label and the stock in the vertical label. Correlations can range from +1 (perfect positive relationship; brood years with high productivity for Stock 1 also have high productivity for Stock 2) to -1 (perfect negative relationship; brood years with high productivity for stock 1 have low productivity for stock 2, and the other way around). Stocks are sorted alphabetically. Correlations are calculated for all brood years that have an estimate for both stocks, so that the number of observations differs between cells. Table 13 below lists the correlations and number of observations. Productivity of lake-type stocks generally has a positive correlation (shades of blue in the figure), and is particularly correlated among the 2 channel-enhanced (Pinkut, Fulton) and 3 wild (Early, Mid, Late) wild stocks of the Babine system. Lower Nass Sea and River type sockeye (*LNassSRT*) are the only stock among the 12 largest that does not rear in a lake, and their productivity has a strong negative correlation with most of the lake-type stocks. Brood years where LNassSRT were highly productive have been generally poor for the lake-type stocks, and the other way around. Note, however, that the time series for LNassSRT is short, and the observed correlation reflects that LNassSRT had high productivity in the early 2000s while most of the other stocks had low productivity. Figures 21 and 22 show the correlation for 2 different time periods, to isolate the effect of these recent brood years.

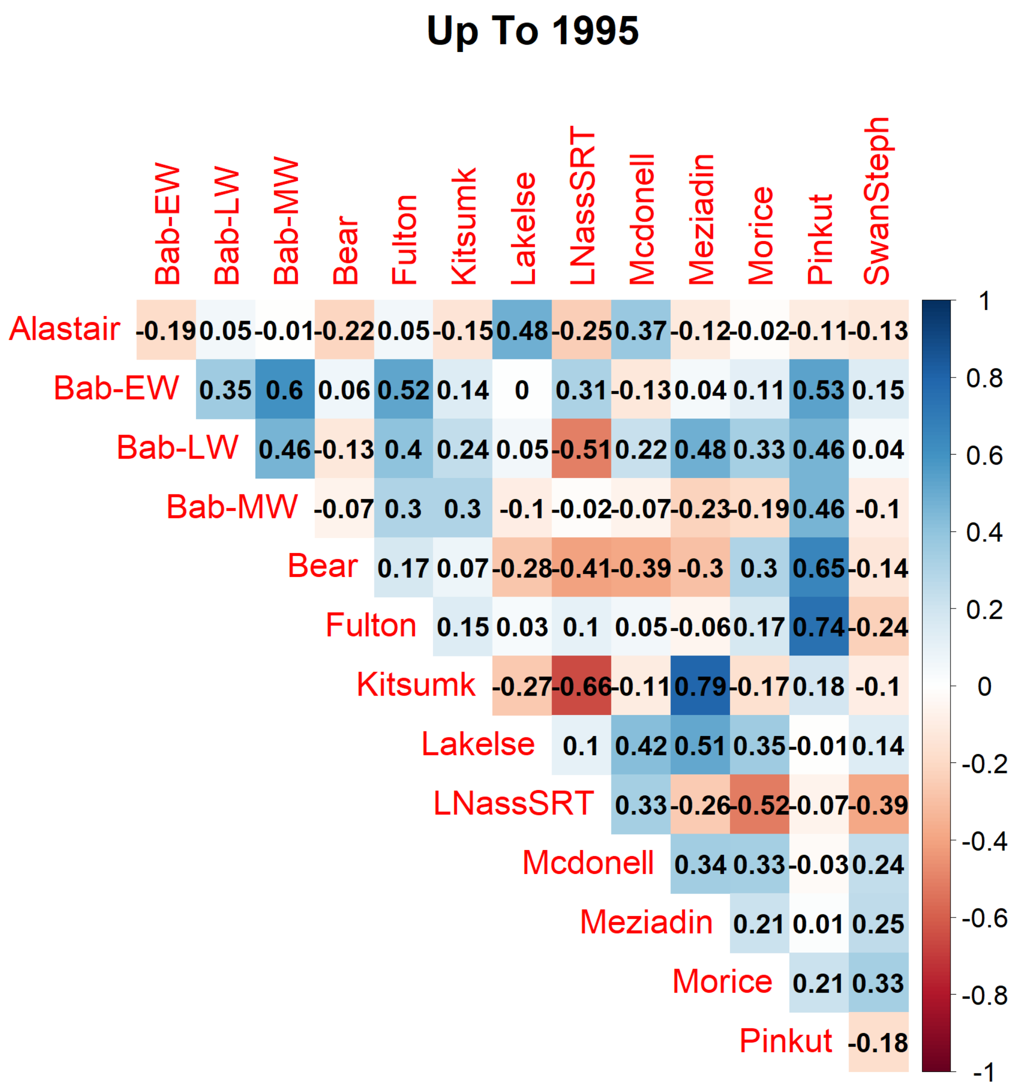


Figure 21. *Correlation in Productivity (Log R/S) for 12 largest Skeena and Nass Stocks - Up To 1995*. Layout as per Figure 20. Patterns are generally the same as for the correlations based on all available brood years, but the correlations tend to be weaker (i.e., same direction, but smaller value and lighter shading). Stocks in the Babine system have generally strong positive correlation among each other, most lake-type stocks have weak to moderate correlations. Lower Nass Sea and River type sockeye are negatively correlated with many of the lake-type stocks, even when the high productivity period for LNassSRT in the early 2000s is excluded.

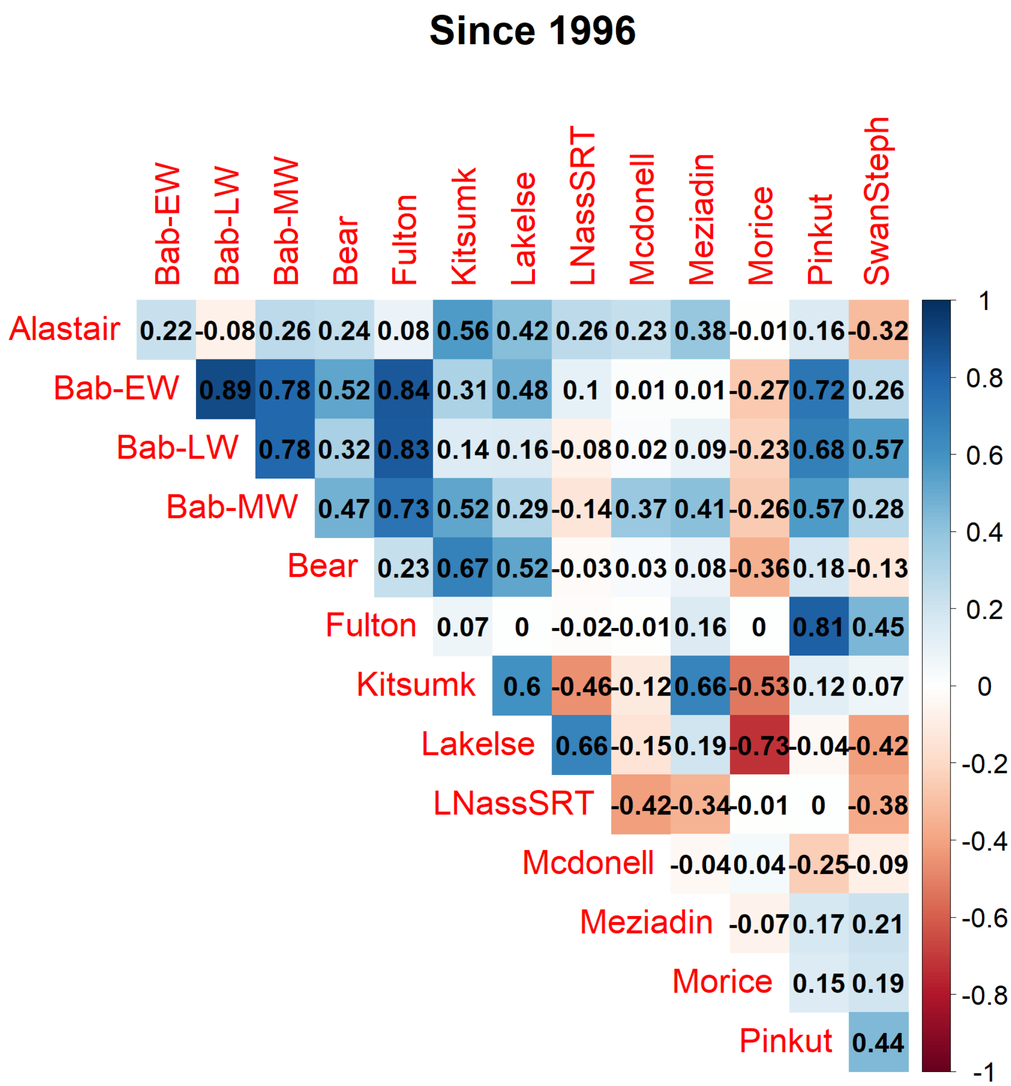


Figure 22. *Correlation in Productivity (Log R/S) for 12 largest Skeena and Nass Stocks - Since 1996*. Layout as per Figure 20. Patterns are generally the same as for the correlations based on all available brood years, but the correlations tend to be stronger (i.e., same direction, but higher value and darker shading). Stocks in the Babine system have strong positive correlation among each other, most lake-type stocks have moderate to strong correlations. Lower Nass Sea and River type sockeye are negatively correlated with several of the lake-type stocks, but the difference between productivity of lake-type stocks and the Lower Nass sea and river-type sockeye is more pronounced when comparing all available brood years (Figure 20).

Table 13. *Correlation in Productivity (Log R/S) for 14 largest Skeena and Nass Stocks (Group 1)*. Table lists the values from Figures 20 to 22. Correlations more positive than 0.4 are shaded blue. Correlations more negative than -0.4 are shaded orange. Note that the number of brood years used for the correlation calculation varies widely, from less than 10 to more than 50. When fewer brood years are available for a comparison, then the chance of a random (i.e., spurious) correlation increases.

| Stock 1 | Stock 2 | All Corr | All Obs | <1996 Corr | <1996 Obs | 1996+ Corr | 1996+ Obs |
|---|---|---|---|---|---|---|---|
| Alastair | Bab-EW | 0.02 | 54 | -0.19 | 36 | 0.22 | 18 |
| Alastair | Bab-LW | 0.01 | 54 | 0.05 | 36 | -0.08 | 18 |
| Alastair | Bab-MW | 0.14 | 54 | -0.01 | 36 | 0.26 | 18 |
| Alastair | Bear | 0.06 | 35 | -0.22 | 17 | 0.24 | 18 |
| Alastair | Fulton | 0.08 | 54 | 0.05 | 36 | 0.08 | 18 |
| Alastair | Kitsumk | 0 | 46 | -0.15 | 34 | 0.56 | 12 |
| Alastair | LNassSRT | 0.09 | 32 | -0.25 | 14 | 0.26 | 18 |
| Alastair | Lakelse | 0.43 | 48 | 0.48 | 35 | 0.42 | 13 |
| Alastair | Mcdonell | 0.3 | 34 | 0.37 | 22 | 0.23 | 12 |
| Alastair | Meziadin | 0.2 | 32 | -0.12 | 14 | 0.38 | 18 |
| Alastair | Morice | 0.01 | 50 | -0.02 | 32 | -0.01 | 18 |
| Alastair | Pinkut | 0.01 | 54 | -0.11 | 36 | 0.16 | 18 |
| Alastair | SwanSteph | -0.13 | 45 | -0.13 | 30 | -0.32 | 15 |
| Bab-EW | Bab-LW | 0.6 | 55 | 0.35 | 36 | 0.89 | 19 |
| Bab-EW | Bab-MW | 0.69 | 55 | 0.6 | 36 | 0.78 | 19 |
| Bab-EW | Bear | 0.35 | 36 | 0.06 | 17 | 0.52 | 19 |
| Bab-EW | Fulton | 0.66 | 55 | 0.52 | 36 | 0.84 | 19 |
| Bab-EW | Kitsumk | 0.27 | 46 | 0.14 | 34 | 0.31 | 12 |
| Bab-EW | LNassSRT | 0.14 | 33 | 0.31 | 14 | 0.1 | 19 |
| Bab-EW | Lakelse | 0.06 | 49 | 0 | 35 | 0.48 | 14 |
| Bab-EW | Mcdonell | 0.03 | 35 | -0.13 | 22 | 0.01 | 13 |
| Bab-EW | Meziadin | 0.09 | 32 | 0.04 | 14 | 0.01 | 18 |
| Bab-EW | Morice | 0.06 | 50 | 0.11 | 32 | -0.27 | 18 |
| Bab-EW | Pinkut | 0.62 | 55 | 0.53 | 36 | 0.72 | 19 |
| Bab-EW | SwanSteph | 0.22 | 46 | 0.15 | 30 | 0.26 | 16 |
| Bab-LW | Bab-MW | 0.61 | 55 | 0.46 | 36 | 0.78 | 19 |
| Bab-LW | Bear | 0.15 | 36 | -0.13 | 17 | 0.32 | 19 |
| Bab-LW | Fulton | 0.57 | 55 | 0.4 | 36 | 0.83 | 19 |
| Bab-LW | Kitsumk | 0.29 | 46 | 0.24 | 34 | 0.14 | 12 |
| Bab-LW | LNassSRT | -0.32 | 33 | -0.51 | 14 | -0.08 | 19 |
| Bab-LW | Lakelse | 0.03 | 49 | 0.05 | 35 | 0.16 | 14 |
| Bab-LW | Mcdonell | 0.26 | 35 | 0.22 | 22 | 0.02 | 13 |

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| Stock 1 | Stock 2 | All Corr | All Obs | <1996 Corr | <1996 Obs | 1996+ Corr | 1996+ Obs |
|---|---|---|---|---|---|---|---|
| Bab-LW | Meziadin | 0.34 | 32 | 0.48 | 14 | 0.09 | 18 |
| Bab-LW | Morice | 0.19 | 50 | 0.33 | 32 | -0.23 | 18 |
| Bab-LW | Pinkut | 0.56 | 55 | 0.46 | 36 | 0.68 | 19 |
| Bab-LW | SwanSteph | 0.19 | 46 | 0.04 | 30 | 0.57 | 16 |
| Bab-MW | Bear | 0.3 | 36 | -0.07 | 17 | 0.47 | 19 |
| Bab-MW | Fulton | 0.5 | 55 | 0.3 | 36 | 0.73 | 19 |
| Bab-MW | Kitsumk | 0.38 | 46 | 0.3 | 34 | 0.52 | 12 |
| Bab-MW | LNassSRT | -0.11 | 33 | -0.02 | 14 | -0.14 | 19 |
| Bab-MW | Lakelse | 0 | 49 | -0.1 | 35 | 0.29 | 14 |
| Bab-MW | Mcdonell | 0.23 | 35 | -0.07 | 22 | 0.37 | 13 |
| Bab-MW | Meziadin | 0.15 | 32 | -0.23 | 14 | 0.41 | 18 |
| Bab-MW | Morice | -0.16 | 50 | -0.19 | 32 | -0.26 | 18 |
| Bab-MW | Pinkut | 0.5 | 55 | 0.46 | 36 | 0.57 | 19 |
| Bab-MW | SwanSteph | 0.05 | 46 | -0.1 | 30 | 0.28 | 16 |
| Bear | Fulton | 0.22 | 36 | 0.17 | 17 | 0.23 | 19 |
| Bear | Kitsumk | 0.3 | 28 | 0.07 | 16 | 0.67 | 12 |
| Bear | LNassSRT | -0.17 | 27 | -0.41 | 8 | -0.03 | 19 |
| Bear | Lakelse | 0.06 | 30 | -0.28 | 16 | 0.52 | 14 |
| Bear | Mcdonell | -0.13 | 23 | -0.39 | 10 | 0.03 | 13 |
| Bear | Meziadin | -0.07 | 26 | -0.3 | 8 | 0.08 | 18 |
| Bear | Morice | 0.01 | 34 | 0.3 | 16 | -0.36 | 18 |
| Bear | Pinkut | 0.4 | 36 | 0.65 | 17 | 0.18 | 19 |
| Bear | SwanSteph | -0.05 | 31 | -0.14 | 15 | -0.13 | 16 |
| Fulton | Kitsumk | 0.22 | 46 | 0.15 | 34 | 0.07 | 12 |
| Fulton | LNassSRT | 0.02 | 33 | 0.1 | 14 | -0.02 | 19 |
| Fulton | Lakelse | -0.01 | 49 | 0.03 | 35 | 0 | 14 |
| Fulton | Mcdonell | 0.11 | 35 | 0.05 | 22 | -0.01 | 13 |
| Fulton | Meziadin | 0.06 | 32 | -0.06 | 14 | 0.16 | 18 |
| Fulton | Morice | 0.17 | 50 | 0.17 | 32 | 0 | 18 |
| Fulton | Pinkut | 0.77 | 55 | 0.74 | 36 | 0.81 | 19 |
| Fulton | SwanSteph | -0.02 | 46 | -0.24 | 30 | 0.45 | 16 |
| Kitsumk | LNassSRT | -0.5 | 24 | -0.66 | 12 | -0.46 | 12 |
| Kitsumk | Lakelse | -0.22 | 42 | -0.27 | 34 | 0.6 | 8 |
| Kitsumk | Mcdonell | 0.05 | 30 | -0.11 | 22 | -0.12 | 8 |
| Kitsumk | Meziadin | 0.52 | 24 | 0.79 | 12 | 0.66 | 12 |
| Kitsumk | Morice | -0.17 | 43 | -0.17 | 31 | -0.53 | 12 |

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| Stock 1 | Stock 2 | All Corr | All Obs | <1996 Corr | <1996 Obs | 1996+ Corr | 1996+ Obs |
|---|---|---|---|---|---|---|---|
| Kitsumk | Pinkut | 0.25 | 46 | 0.18 | 34 | 0.12 | 12 |
| Kitsumk | SwanSteph | -0.04 | 40 | -0.1 | 30 | 0.07 | 10 |
| LNassSRT | Lakelse | 0.26 | 27 | 0.1 | 13 | 0.66 | 14 |
| LNassSRT | Mcdonell | -0.35 | 17 | 0.33 | 4 | -0.42 | 13 |
| LNassSRT | Meziadin | -0.3 | 32 | -0.26 | 14 | -0.34 | 18 |
| LNassSRT | Morice | -0.25 | 28 | -0.52 | 10 | -0.01 | 18 |
| LNassSRT | Pinkut | -0.07 | 33 | -0.07 | 14 | 0 | 19 |
| LNassSRT | SwanSteph | -0.34 | 26 | -0.39 | 10 | -0.38 | 16 |
| Lakelse | Mcdonell | 0.16 | 34 | 0.42 | 22 | -0.15 | 12 |
| Lakelse | Meziadin | 0.35 | 26 | 0.51 | 13 | 0.19 | 13 |
| Lakelse | Morice | 0.07 | 44 | 0.35 | 31 | -0.73 | 13 |
| Lakelse | Pinkut | -0.05 | 49 | -0.01 | 35 | -0.04 | 14 |
| Lakelse | SwanSteph | 0.05 | 44 | 0.14 | 30 | -0.42 | 14 |
| Mcdonell | Meziadin | 0.19 | 16 | 0.34 | 4 | -0.04 | 12 |
| Mcdonell | Morice | 0.3 | 33 | 0.33 | 21 | 0.04 | 12 |
| Mcdonell | Pinkut | 0.01 | 35 | -0.03 | 22 | -0.25 | 13 |
| Mcdonell | SwanSteph | 0.25 | 32 | 0.24 | 19 | -0.09 | 13 |
| Meziadin | Morice | 0.04 | 28 | 0.21 | 10 | -0.07 | 18 |
| Meziadin | Pinkut | 0.12 | 32 | 0.01 | 14 | 0.17 | 18 |
| Meziadin | SwanSteph | 0.21 | 25 | 0.25 | 10 | 0.21 | 15 |
| Morice | Pinkut | 0.26 | 50 | 0.21 | 32 | 0.15 | 18 |
| Morice | SwanSteph | 0.34 | 42 | 0.33 | 27 | 0.19 | 15 |
| Pinkut | SwanSteph | 0.01 | 46 | -0.18 | 30 | 0.44 | 16 |

## 4.6 Run Timing of Skeena sockeye

Aggregate run-timing of Skeena sockeye has become more variable since 2000. Since 2015 run timing has been up to one week later than average, with the latest timing ever observed occurring in 5 of the 6 most recent years. The date at which 50% of the run has passed Tyee Test Fishery has ranged from July 17 in 2013 to August 2 in 2019 (Figure 23; Panel A). The spread of the run, illustrated by the temporal window during which the middle half of the run passes the Tyee test fishery, has generally narrowed in many recent years (i.e., run passes faster, less separation between stocks), but is also highly variable (Figure 23; Panel B). Aggregate Skeena migration timing seems to be independent of run size (Figure 23; Panel C), but larger runs tend to return over a longer time period, as expected.

For most genetic stock groupings of Skeena sockeye, the average timing curve was unimodal and roughly normally distributed, with the exception of Alastair Lake timing, which is bimodal in many years (Figure 24). Alexander et al. (2021) found similar patterns for Nass sockeye stocks (their Figure 11). Five stock groupings return consistently earlier than the Babine stocks , which account for most of the aggregate run and determine the aggregate run timing curve (Figure 24). The early stock groupings are Lakelse, Alastair, Kispiox River lake types (Swan/Stephens), Morice, and Zymoetz River lake types (Mcdonell).

In-river run reconstructions use stock-specific offsets from the aggregate run timing to allocate harvests across stocks. Estimated offsets differ by time period (Figure 25). Alexander et al. (2021) found similar patterns for Nass sockeye stocks (Figure 16 in Alexander et al. 2021).

The run-timing evaluation of components of the Skeena aggregate combined all Babine sockeye into a single grouping, but there was also considerable timing variation among the different components of Babine sockeye (Figure 26). Although poor genetic differentiation among Babine sockeye stocks using current genetic methods (microsatellite baseline) precludes genetic assignment to the different Babine stocks for individual fish, we compared weekly proportions of individual Babine stocks across the different time periods examined. These data support previously observed timing patterns for the different Babine wild and enhanced stock groups, which suggest that there are three distinct run-timing groups of wild and enhanced Babine sockeye. These groups include three groups of wild sockeye: a mid-timed group, consisting of spawners in Morrison Creek and the Morrison-Tahlo lake complex upstream of Morrison Arm, a late-timed group, which consists mainly of sockeye that spawn in the upper and lower sections of Babine River between Babine and Nilkitkwa Lake, and just downstream of Nilkitkwa Lake, and an early-timed group, which includes sockeye that spawn in most of the tributaries that drain into the main basin of Babine Lake. Enhanced sockeye returning to Pinkut and Fulton share timing with the mid-timed wild stocks, with Pinkut sockeye returning on average a few days after Fulton (Tagaki and Smith 1973).

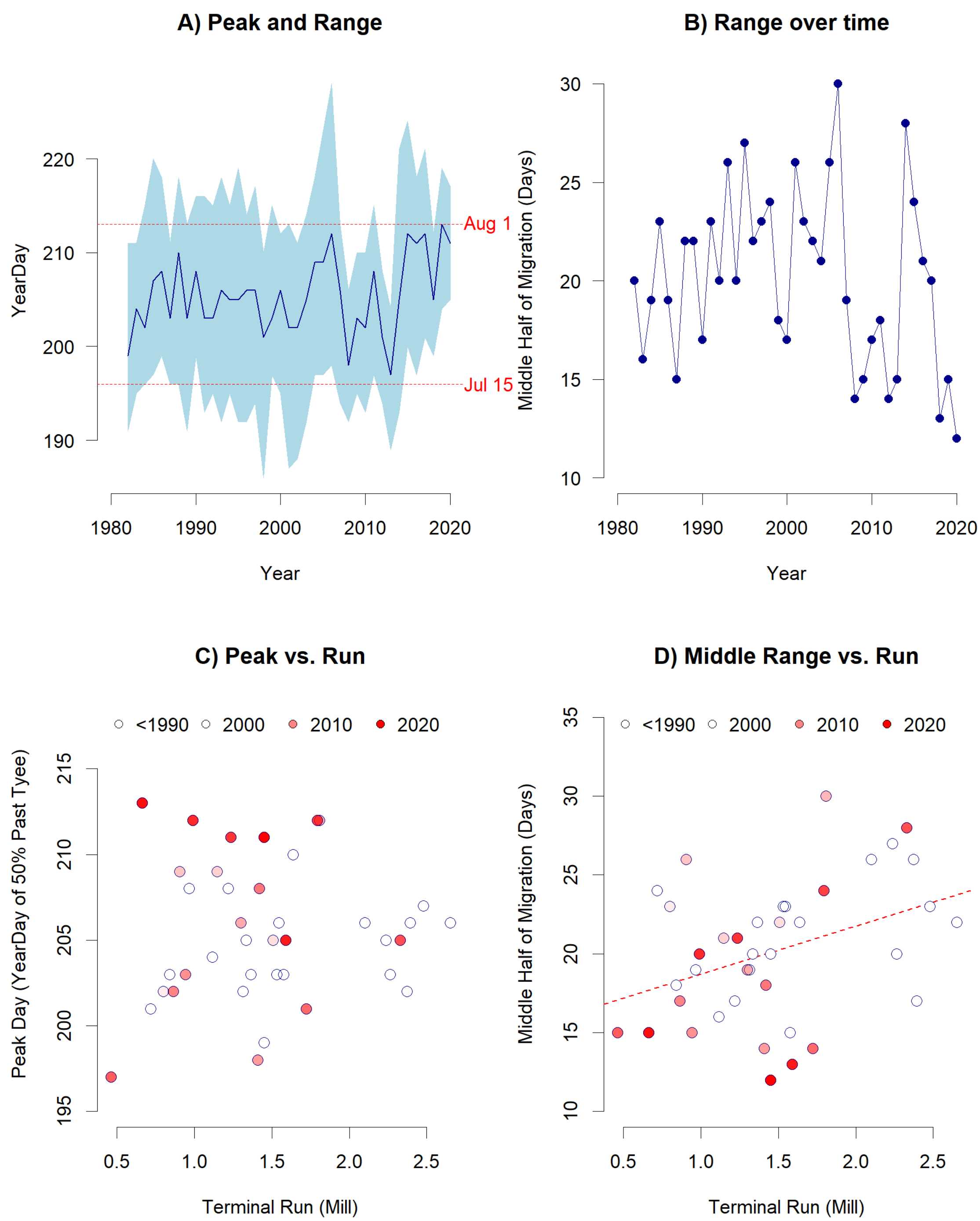


Figure 23. *Skeena aggregate run timing at Tyee test fishery*. (A) Timing of aggregate Skeena Sockeye escapement passing Tyee Test Fishery, 1982-2020, showing date of 50% passage (line) and time window covering middle half of the run (shaded area; from 25% to 75% cumulative passage). YearDay reference lines are for years that are not leap years. (B) Spread of the run, shown as the number of days for middle half of the run to pass through Tyee. (C) Peak timing compared to terminal run size. More recent years are shaded darker. (D) Spread of the run compared to terminal run size. More recent years are shaded darker. Simple linear trend line shown for visual reference.

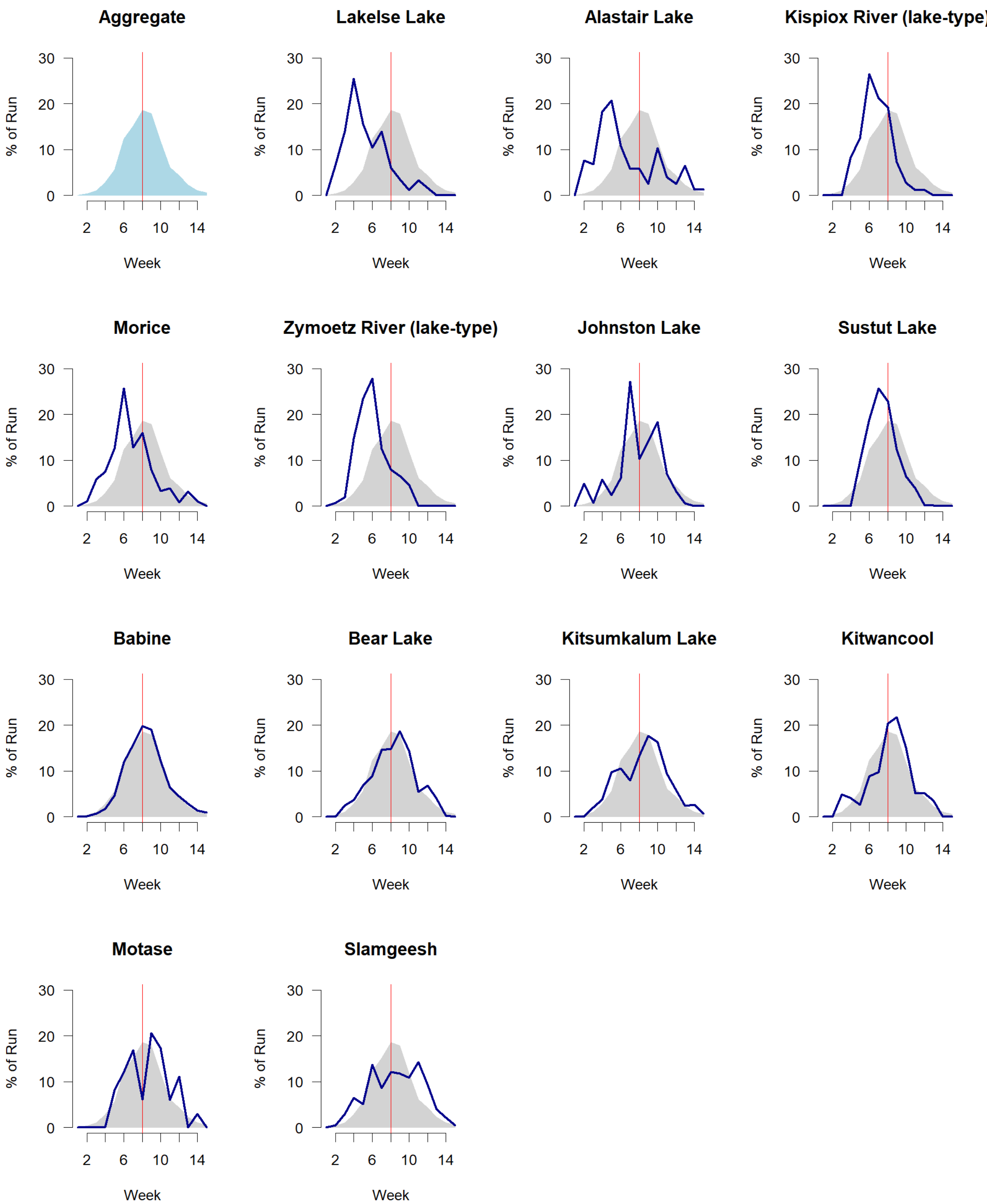


Figure 24. *Aggregate and stock-level run-timing at Tyee test fishery*. Mean timing for Skeena sockeye genetic stock ID groups for 2000-2019, showing average % of run past Tyee for each week from second week of June (Week 2) to end of September (Week 15). Red vertical line marks the date of largest proportion for the aggregate.

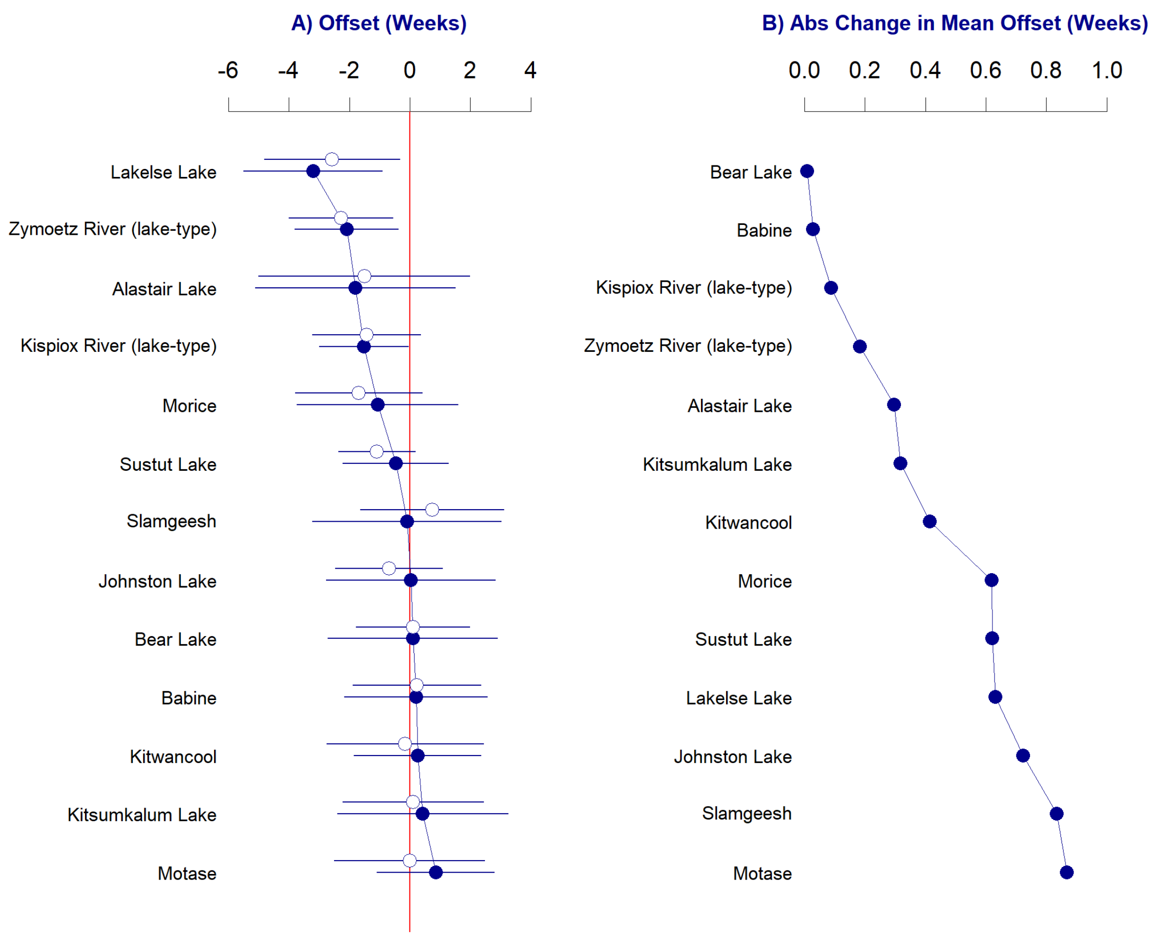


Figure 25. *Timing offsets for Skeena in-river run reconstructions*. (A) Timing offset for genetic stock ID groups relative to aggregate Skeena run timing past Tyee test fishery for 2000-2009 (solid points) and 2010-2019 (open circles). Horizontal lines indicate ± 1 SD. Stock ID groups ranked from earliest to latest migration. (B) Absolute change in offset from the earlier period (2000-2009) to the later period (2010-2019). Stock ID groups ranked by magnitude of change.

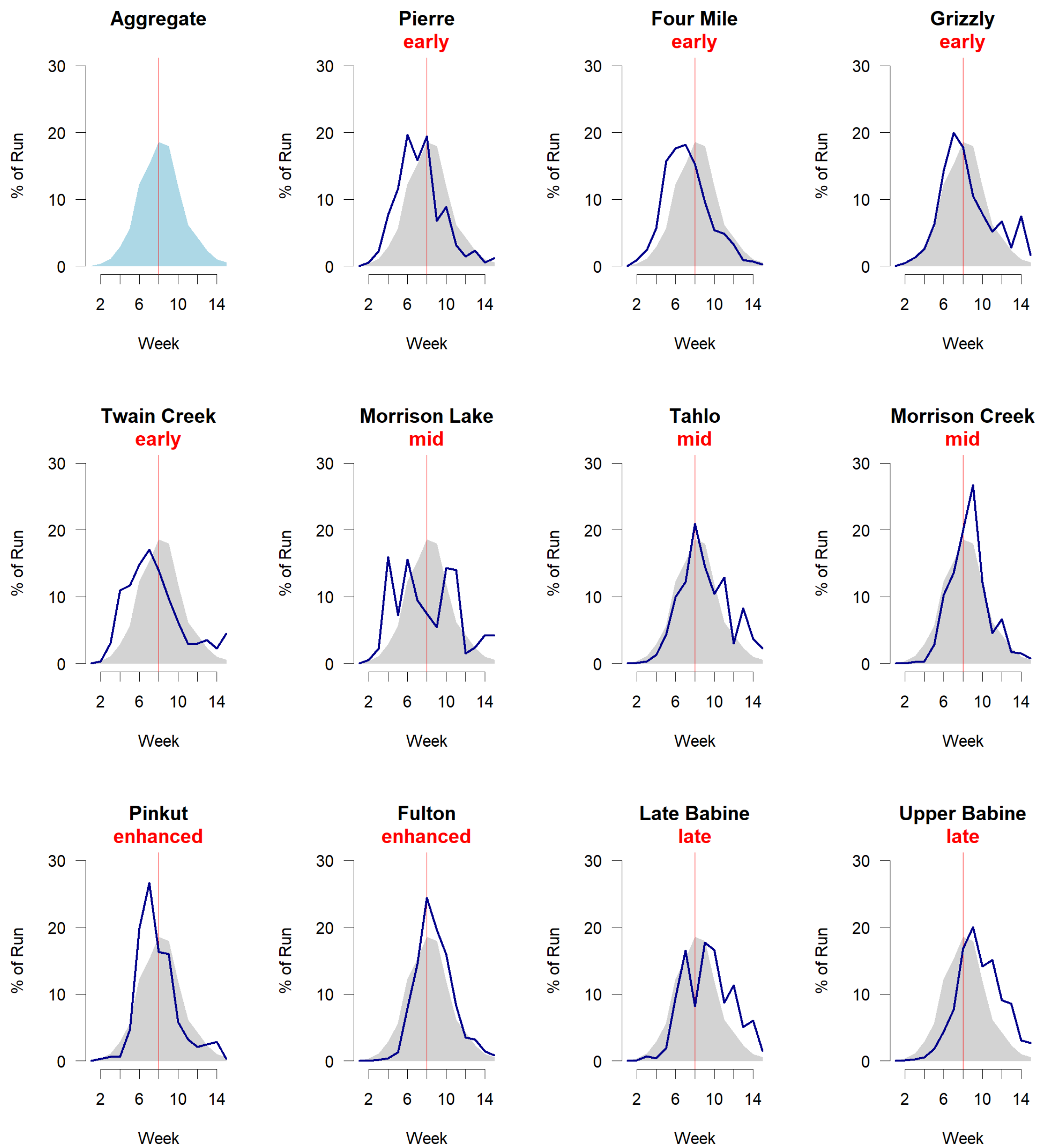


Figure 26. *Aggregate and Babine component run-timing at Tyee test fishery*. Mean timing for Babine sockeye genetic stock ID groups for 2000-2019, showing average % of run past Tyee for each week from second week of June (Week 2) to end of September (Week 15). Red vertical line marks the date of largest proportion for the aggregate.

### 4.7 Non-spawning Surplus of Channel Stocks (Pinkut, Fulton)

Most Skeena sockeye production currently comes from the Fulton and Pinkut stocks which have been enhanced since the implementation of the Babine Lake Development Project (BLDP), a series of spawning channels and flow control structures that were built in stages starting in 1965 and became fully operational by the mid-1970s. BLDP facilities include one small and one large spawning channel on Fulton River, and one spawning channel on Pinkut Creek.

Total escapement for the BLDP-enhanced stocks usually exceeds the combined capacity of the spawning channels and available spawning habitat downstream of the channel. These surplus fish are not considered to be effective spawners. Estimates of effective spawner abundance account for this surplus abundance (Appendix C.3), a portion of which is harvested in ESSR (Excess-Salmon-to-Spawning-Requirements) fisheries in Babine Lake in some years. ESSR opportunities and harvest levels are determined by the amount of available surplus and other factors including the economic viability of the fishery. Since 2001, between 0 and nearly 500,000 sockeye have been harvested annually in Babine Lake ESSR fisheries.

The average enhanced surplus (after ESSR fisheries) has been smaller in recent years than in the 1980s and 1990s, but the surplus relative to total Skeena run size and total Skeena catch has increased steadily since implementation of the BLDP (Figure 27). In 2018 and 2019, the enhanced surplus was as large as or substantially larger than the total catch of Skeena sockeye.

The relative abundance of surplus production for Pinkut and Fulton stocks is estimated by apportioning the estimated total combined surplus based on effective loading estimates for the two channel stocks and estimates of the number of fish that returned to each channel based on visual estimates of fish “locked out” below the enhanced systems (See Appendix B.1 for an overview of the spawner surveys and Appendix C.3 for a summary of the surplus calculations).

Surplus abundance is not synchronous for the two enhanced stocks (Figure 28). Both stocks had larger surpluses in the 1980s and 1990s, and much smaller average surpluses in recent years, after a sharp decline in 1998 related to a disease outbreak in both Pinkut and Fulton spawning channels in 1994 and 1995, which affected returns in subsequent years. While Fulton has had very large surpluses in some recent years, Pinkut channel surpluses do not appear to have changed substantially in the last 20 years (i.e., annual values fluctuate, but the magnitude of surpluses in years with large run size has remained around 80,000 to 100,000 fish).

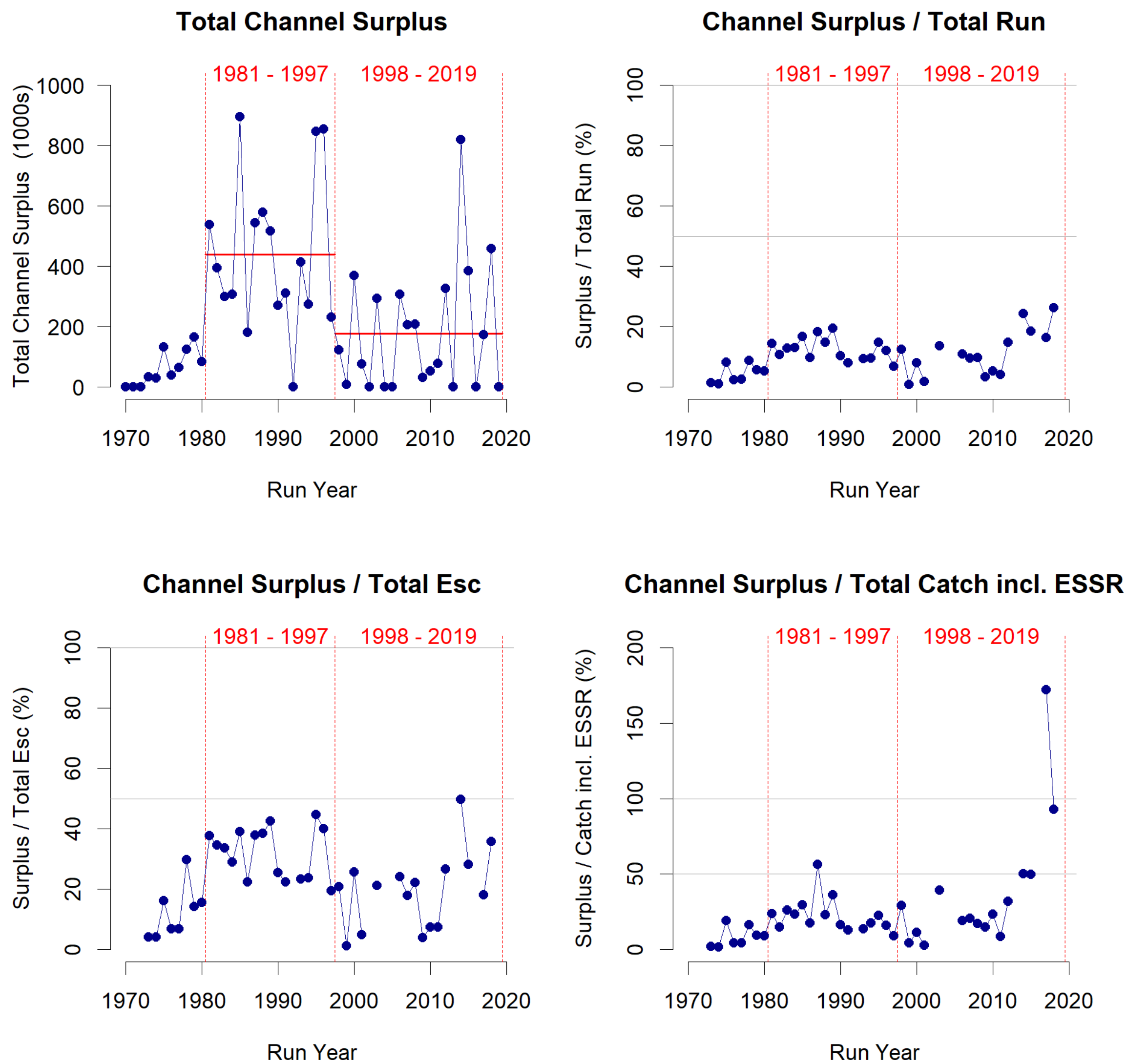


Figure 27. *Channel Surplus Pattern - Total Skeena*. Top left panel shows the time series of estimated surplus spawners from both channel-enhanced stocks, excluding ESSR harvests. Surplus calculations are described in Appendix C.3. The remaining panels show the relative magnitude of the surplus relative to total run size, total escapement (i.e., effective spawner abundance), and total catch including ESSR harvest. The total surplus is highly variable from one year to the next, but the average surplus has dropped substantially from over 400,000 fish in the 1980s and 1990s to under 200,000 in the 2000s and 2010s. However, surplus relative to run size has increased in recent years as run sizes and exploitation rates have declined. In 2 recent years, the surplus matched or exceed the total catch.

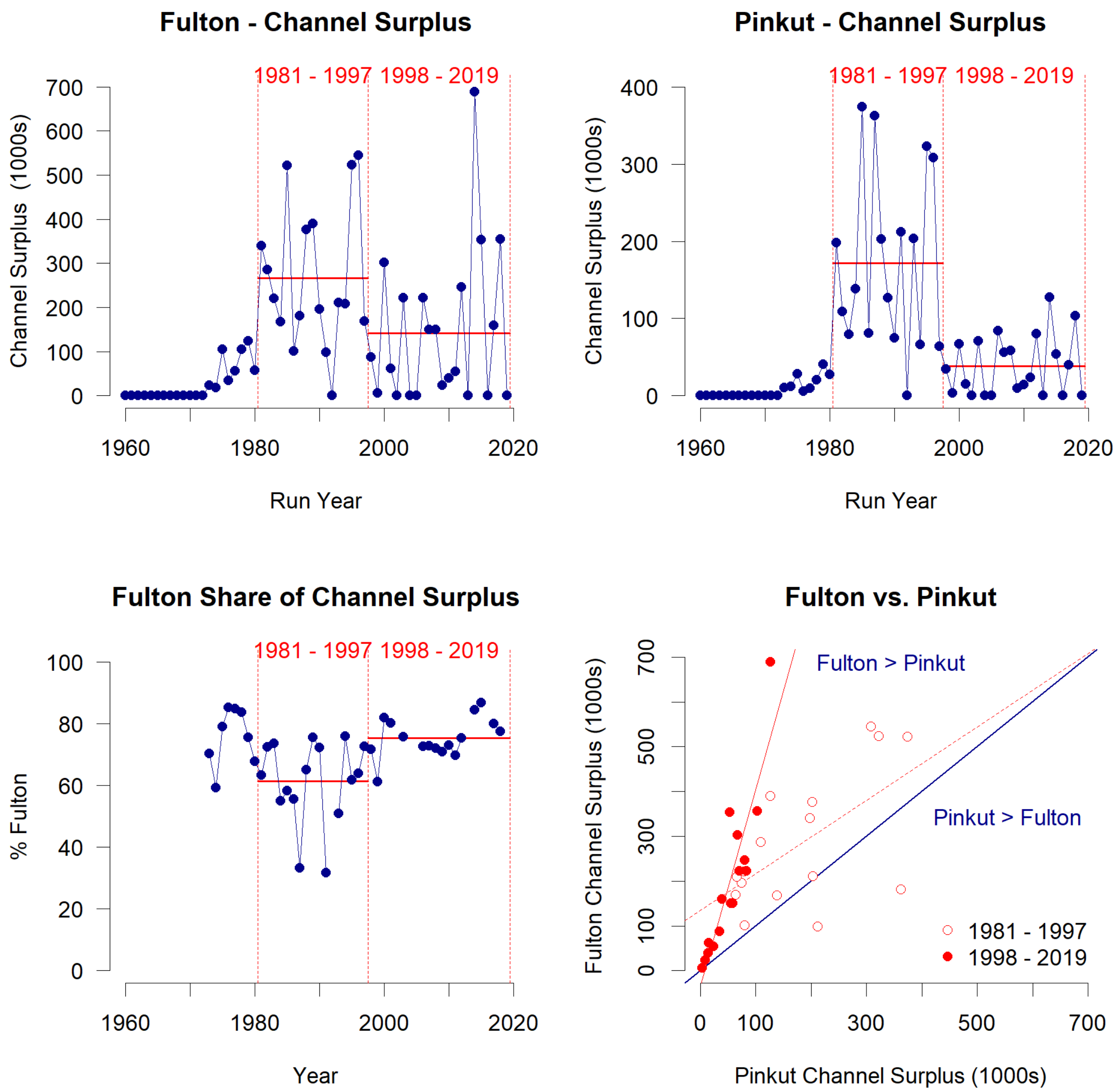


Figure 28. *Channel Surplus Pattern - Pinkut and Fulton.* Top panel show the time series of estimated surplus spawners for the channel-enhanced stocks. Surpluses for both stocks declined in the late 1990s, but the decrease is more pronounced for Pinkut. As a result, the Fulton share of the channel surplus has increased from an average of about 60% in the 1980s and 1990s to an average of about 75% in the 2000s and 2010s (bottom left panel). The relationship between annual stock-specific surpluses has also shifted (bottom right panel).

## 4.8 Summary of Sensitivity Tests

### 4.8.1 Outline of Completed Tests

As part of the data quality check (Section 3.5), sensitivity tests were conducted to check for the potential magnitude of effects on standard biological benchmarks, by stock and for the stock aggregates.

Senstivity testing focused on relative changes compared to a base case, rather than the actual benchmark estimates. The base case for all stocks was to apply simple Ricker fits (i.e., least-squares linear regression of $log(R/S) \sim S$) to all available years of data, with recruits calculated using the best available estimates of age composition (i.e., annual estimates where available, filled in with averages where needed).

Alternative estimates used either:

- *Data variation*: apply same estimation method, but to alternative subsets of the data (e.g., jackknife, retrospective).
- *Bootstrap estimate*: for each observation, take many samples with some assumed random error, and estimate the benchmarks for each sample.
- *Bayesian estimate*: use the original data, but calculate Bayesian estimates with generic uninformative priors for all stocks.
- *Alternative age composition*: For stocks with annual estimates of age composition, generate an alternative SR data set using long-term average age composition, and re-estimate the benchmarks.

Appendix D.3 describes the sensitivity tests in more detail (e.g., boostrap settings). Sensitivity tests were implemented within the *RapidRicker* package. Appendix D.4 provides a worked example.

### 4.8.2 Sensitivity to Alternative Data Treatments

For most stocks, estimates of standard biological benchmarks were highly sensitive to variations in the spawner-recruit data (e.g., a few additional years of data, removing potential outliers), as well the chosen estimation methods. We tested 6 data variations and 3 alternative estimation methods. Note, however, that all these tests started with the same set of updated run reconstruction estimates. Assumptions about age composition, run timing, and spawner expansions can affect the run reconstruction results, which in turn can affect the estimates of biological benchmarks.

$S_{MSY}$ estimates for most Skeena and Nass sockeye stocks with spawner and recruit data (i.e., Groups 1 and 2 from Table 8) were quite sensitive to data variations and estimates have moderate to large uncertainty (Tables 14 and 15). $S_{MSY}$ estimates for the 4 largest stocks are highly sensitive to data variations, with retrospective (*R*), reverse retrospective (*RR*), and trimming (*T*) having a large effect on $S_{MSY}$ estimates for Fulton, Meziadin, Babine-Late-Wild, and Pinkut. Meziadin $S_{MSY}$ estimates are also strongly affected by just dropping the two largest spawner abundances (*D2*). $S_{MSY}$ estimates for the 6 smallest stocks in Group 1 (Lower Nass Sea and River Type to Mcdonell), which still have long time series of data, are highly sensitive to one or more of the tested data variations (columns *J* to *T* of tables 14 and 15). $S_{MSY}$ estimates for Lower Nass Sea and River Type differed by more than ±30% for 4 of the 5 data variations. For Morice, Lakelse, and Swan/Stephens the effects were moderate to large for all 5 of the tested data variations. Estimates for Bear and Mcdonell had moderate to large differences in $S_{MSY}$ for some data variations, but small differences for others.

### 4.8.3 Sensitivity to Alternative Estimation Methods

Bootstrap intervals and Bayesian estimates of $S_{MSY}$ show moderate uncertainty (columns *BtA* to *BayTF*) for many of the stocks in Group 1, but there is a notable difference between the larger and the smaller stocks. Stocks in Table 14 are sorted from larger to smaller abundance, based on *pSpn*, which is the % of cumulative surveyed effective spawners since 2000. The larger stocks tend to have narrower bootstrap intervals than the smaller stocks (columns *BtA* to *BtTF*), which reflects the assumptions of better data quality (i.e., better stock identification, more age composition data and better catch estimates). The smaller stocks tend to have narrower posterior distributions for the Bayesian estimates.

Three stocks in Group 1 have large uncertainty in $S_{MSY}$ estimates. Bayesian estimates for Pinkut, when the data set is trimmed to only include brood years after 1993 (columns *BayT* and *BayTF*). Bootstrap and Bayesian estimates using all data for Lower Nass Sea and River-type sockeye (LNassSRT) and for Swan/Stephens sockeye (SwanSteph). Bootstrap intervals and Bayesian posteriors tighten for both these stocks if earlier brood years are excluded. $S_{MSY}$ estimates for small stocks with some spawner and recruit data (Group 2; Table 15) show moderate to large sensitivity for most of the tests that could be done. Four of the 9 stocks do not have enough years of data to explore data variations.

Table 14. *Overview of $S_{MSY}$ Sensitivity Tests for Nass and Skeena Sockeye Stocks - Group 1*. Stocks are sorted by size spawner abundance (*pSpn*, the % of cumulative surveyed effective spawners since 2000). *SR* is the total number of brood years with spawner recruit estimates. The remaining columns summarize the results from sensitivity tests, which included data variations (*J* = jackknife, *D2* = drop 2 largest Spn, *R* = retrospective, *RR* = reverse retrospective, *T* = use data starting in *TrimYr*, *TF* = additional effect of filtering any R/S > 15 out of the trimmed data set), bootstrap estimates (*Bt*) and Bayesian estimates (*Bay*). Deterministic estimates were calculated as a base case using all data (*A*), and sensitivity tests with trimmed data after a stock-specific cut-off year (*T*), or trimmed data with any R/S > 15 filtered out (*TF*). Figure 11 shows the brood years with spawner and recruit data for each stock. For each test, this table summarizes the range of effects on $S_{MSY}$ relative to the base case, which is the deterministic point estimate using all available data, into 4 categories: **N**one (0-2% difference), **S**mall (2-15% difference), **M**oderate (15-30% difference), or **L**arge (>30% difference). For data variations and bootstrap tests (*J* to *BtTF*), this comparison uses the full range of deterministic point estimates (e.g., if the largest difference between a retrospective estimate and the base case is ± 20%, then the table shows *M*). For Bayesian tests, the same scale was applied to the interquartile range of the posterior distribution (e.g., if either the 25th of 75th percentile of the posterior differs by more than ± 30% from the base case, then the table shows *L*).

| | | | | **Data Variations** | | | | | | **Bootstrap** | | | **Bayesian** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stock | SR | TrimYr | pSpn | J | D2 | R | RR | T | TF | BtA | BtT | BtTF | BayA | BayT | BayTF |
| **Group 1: Larger stocks, many brood years with spawner and recruit estimates** | | | | | | | | | | | | | | | |
| Fulton | 55 | 1993 | 37 | M | S | L | L | S | N | S | L | L | L | L | L |
| Bab-LW | 55 | 1993 | 15 | M | M | L | L | L | N | S | S | L | L | L | L |
| Meziadin | 32 | 1990 | 15 | M | L | S | L | M | N | S | S | L | L | L | L |
| Pinkut | 55 | 1993 | 11 | M | S | L | L | M | N | M | L | L | L | M | M |
| Bab-EW | 55 | 1993 | 4 | S | S | S | L | M | N | S | S | M | L | L | L |
| Bab-MW | 55 | 1993 | 3 | S | S | L | S | S | N | S | S | S | M | L | L |
| Alastair | 54 | 1990 | 2 | M | M | L | M | S | S | S | S | L | S | M | M |
| Kitsumk | 46 | 1990 | 2 | S | S | L | M | S | N | M | M | M | L | S | S |
| LNassSRT | 34 | 2000 | 2 | L | L | L | L | M | M | M | M | L | L | L | L |
| Morice | 50 | 1998 | 2 | S | S | L | S | S | N | S | S | M | M | S | S |
| Lakelse | 49 | 1990 | 1 | M | M | M | M | M | N | S | S | M | S | L | L |
| SwanSteph | 46 | 1995 | 1 | M | S | L | L | L | N | L | S | L | L | L | L |
| Bear | 36 | 1990 | 1 | S | S | L | S | S | S | M | M | L | S | M | S |
| Mcdonell | 35 | 1990 | <1 | S | S | M | L | S | N | S | M | M | S | S | S |

Table 15. *Overview of $S_{MSY}$ Sensitivity Tests for Nass and Skeena Sockeye Stocks - Groups 2 and 3*. Table layout as per Table 14.

| | | | | **Data Variations** | | | | | | **Bootstrap** | | | **Bayesian** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stock | SR | TrimYr | pSpn | J | D2 | R | RR | T | TF | BtA | BtT | BtTF | BayA | BayT | BayTF |
| **Group 2: Small Stocks, some brood years with spawner and recruit estimates** | | | | | | | | | | | | | | | |
| Kwinag | 21 | 1990 | <1 | M | S | L | L | L | M | S | S | L | L | L | L |
| Kitwanga | 17 | 2000 | <1 | L | L | L | S | N | N | S | S | S | L | L | L |
| Damdoch | 29 | 1990 | <1 | M | L | S | L | L | S | S | S | L | L | L | L |
| Sustut | 27 | 1990 | <1 | M | S | L | L | L | N | S | S | L | M | S | S |
| Johnston | 11 | 1980 | <1 | M | - | N | M | - | - | M | - | - | L | - | - |
| Asitka | 11 | 2000 | <1 | L | - | L | S | N | - | M | M | M | L | L | - |
| UNassRT | 11 | 1990 | <1 | M | - | N | N | N | - | S | S | - | L | L | - |
| Slamg | 14 | 2000 | <1 | S | S | S | M | N | N | S | S | S | L | L | L |
| Motase | 16 | 1990 | <1 | S | M | S | S | S | N | S | S | M | M | L | L |
| **Group 3: No brood years with spawner and recruit estimates** | | | | | | | | | | | | | | | |
| Bowser | 0 | 1990 | | | | | | | | | | | | | |
| Oweege | 0 | 1990 | | | | | | | | | | | | | |
| Ecstall | 0 | 1990 | | | | | | | | | | | | | |
| UBulkLk | 0 | 1990 | | | | | | | | | | | | | |
| Sicintine | 0 | 1990 | | | | | | | | | | | | | |
| Kluant | 0 | 1990 | | | | | | | | | | | | | |
| Kluayaz | 0 | 1990 | | | | | | | | | | | | | |
| Skeena RT | 0 | 2000 | <1 | - | - | - | - | | | | | | | | |

### 4.8.4 Sensitivity to Alternative Age Composition Estimates

The percent difference between $S_{MSY}$ estimates based on annual vs. average age composition varied widely between stocks (Table 16). Note that the comparison was only tested for the base case of all the variations explored (i.e., all brood years, simple deterministic Ricker fit). The effect of age composition assumptions could be much more pronounced when using subsets of the data, given the sensitivity of estimates observed in the other tests.

Table 16. *Effect of using average vs. annual age composition on estimates of $S_{MSY}$*. For stocks with sufficient data to apply year-specific age composition in the calculation of brood-year recruits (Table C.6), the effect of using average age composition instead can be tested. The percent difference (*pDiff*) between $S_{MSY}$ estimates based on annual vs. average age composition varied widely between stocks. Negative *pDiff* values indicate that $S_{MSY}$ based on average age composition was larger.

| Stock | pDiff |
|---|---:|
| Kwinageese | -7 |
| Meziadin | -8 |
| Lower Nass Sea & River Type | 15 |
| Babine Early Wild | -7 |
| Babine Late Wild | 13 |
| Babine Mid Wild | -12 |
| Fulton | -2 |
| Pinkut | -3 |

## 4.9 Comparison of $S_{MAX}$ Estimates Based on Spawner-Recruit Data vs. Photosynthetic Rate (PR) of Nursery Lakes

Bayesian Ricker fits for Pacific salmon SR data can be highly sensitive to prior assumptions about the capacity of the stock. The capacity prior is typically specified either for the density-dependent parameter $\beta$ or its inverse $S_{MAX} = 1/\beta$, where $S_{MAX}$ is defined as the spawner abundance that maximizes the number of adult recruits.

For cases where the available data results in poor model fits, other sources of information can be used to define *informative* priors for $S_{MAX}$ and reduce the uncertainty in the parameter estimates for the Ricker model. Estimates of lake-rearing capacity, using photosynthetic rate (PR) as an indicator for primary production, have been used to define priors for $S_{MAX}$ (e.g., Korman and English 2013).

We completed a preliminary comparison to illustrate practical challenges that need to be resolved on a stock-by-stock basis before available estimates of lake rearing capacity can be used as informative priors for Skeena and Nass sockeye spawner-recruit model fits.

For this comparison, we used the PR-based estimates listed in Table B.9 and the SR-based estimates for the Bayesian Ricker fit using trimmed and filtered stock-level data. To match these stock-level estimates to lake-based estimates of rearing capacity, two types of adjustment were required:

- For some lakes the stock-level SR-based estimate had to be apportioned to component lakes (Table 17)
- For Babine, stock-level estimates for Babine-EW, Babine-MW, Babine-LW, Pinkut, and Fulton were combined.

For many of the lakes with both estimates, the PR-based estimate is 2-4 times larger than the SR-based estimate (Table 18, Figure 29). These large observed differences need to be carefully considered in subsequent analyses due to potentially large effects on Ricker parameters, biological benchmarks, status assessments, and simulation model outcomes.

Table 17. *Proportion (Prop) of stock-level SR-based $S_{MAX}$ apportioned to lake components*. Only lakes with corresponding PR-based estimates are listed in the table, so proportions don't add up to 1 for all stocks. For example, the stock-level estimate for Morice includes both Morice and Atna lakes, but we assumed that Morice Lake accounts for 80% of the stock's spawning abundance (Prop = 0.8), and there is no PR-based estimate for Atna Lake. In Table 18 and Figure 29 we therefore compare the lake-based estimate for Morice to 80% of the SR-based stock-level estimate.

| Basin | Watershed | Stock | Prop | Lake |
|---|---|---|---|---|
| Nass | Damdochax | Damdochax | 0.5 | Damdochax |
| Nass | Kwinageese | Kwinageese | 0.5 | Fred Wright |
| Nass | Kwinageese | Kwinageese | 0.5 | Kwinageese |
| Skeena | Bulkley | Morice | 0.8 | Morice |
| Skeena | Kispiox | Swan/Stephens | 0.1 | Club |
| Skeena | Kispiox | Swan/Stephens | 0.3 | Stephens |
| Skeena | Kispiox | Swan/Stephens | 0.6 | Swan |
| Skeena | Slamgeesh | Slamgeesh | 0.5 | Slamgeesh |
| Skeena | Sustut | Bear | 0.2 | Azuklotz |
| Skeena | Sustut | Bear | 0.8 | Bear |
| Skeena | Sustut | Sustut | 0.3 | Johanson |
| Skeena | Sustut | Sustut | 0.3 | Sustut |
| Skeena | Zymoetz | Mcdonell | 0.3 | Aldrich |
| Skeena | Zymoetz | Mcdonell | 0.3 | Dennis |
| Skeena | Zymoetz | Mcdonell | 0.4 | Mcdonell |

Table 18. *Comparison table of $S_{MAX}$ estimated based on lake photosynthetic rate (PR.Est) or based on a stock-level spawner-recruit fit (SR.Est)*. $S_{MAX}$ estimates are shown in 1,000s of spawners. SR-based estimates are the median of the posterior distribution. For stocks combining multiple rearing lakes, the SR-based estimates were apportioned as per Table 17. For Babine Lake, stock-level estimates for Babine-EW, Babine-MW, Babine-LW, Pinkut, and Fulton were combined. Lakes are sorted based on the ratio between the two estimates (*EstRatio*). An *EstRatio* of 4 means that the PR-based estimate is 4 times larger than the SR-based estimate. Figure 29 shows the same values in a log-log plot.

| Basin | Watershed | Lake | PR.Est | SR.Est | EstRatio |
|---|---|---|---|---|---|
| Skeena | Bulkley | Morice | 191.4 | 10.5 | 18.18 |
| Skeena | Sustut | Bear | 40.5 | 6.4 | 6.38 |
| Skeena | Sustut | Sustut | 2.8 | 0.5 | 5.55 |
| Skeena | Sustut | Johanson | 2.7 | 0.5 | 5.45 |
| Skeena | Zymoetz | Mcdonell | 4.1 | 1 | 3.94 |
| Skeena | Sustut | Azuklotz | 5.9 | 1.6 | 3.73 |
| Nass | Kwinageese | Fred Wright | 20.2 | 6.1 | 3.3 |
| Nass | Kwinageese | Kwinageese | 19.1 | 6.1 | 3.12 |
| Skeena | Lakelse | Lakelse | 35.9 | 15.1 | 2.38 |
| Skeena | Kispiox | Swan | 21.4 | 11.9 | 1.8 |
| Skeena | Kitwanga | Kitwanga | 37 | 21.1 | 1.75 |
| Nass | Damdochax | Damdochax | 4.9 | 3.3 | 1.48 |
| Skeena | Slamgeesh | Slamgeesh | 0.4 | 0.3 | 1.48 |
| Skeena | Zymoetz | Aldrich | 1.1 | 0.8 | 1.44 |
| Skeena | Zymoetz | Dennis | 1.1 | 0.8 | 1.41 |
| Skeena | Kispiox | Stephens | 7.1 | 6 | 1.19 |
| Skeena | Kitsumkalum | Kitsumkalum | 20.5 | 18.5 | 1.11 |
| Skeena | Babine | Morrison | 44.6 | 55.2 | 0.81 |
| Skeena | Babine | Babine | 1808.2 | 2557.8 | 0.71 |
| Skeena | Gitnadoix | Alastair | 23.4 | 33.9 | 0.69 |
| Nass | Meziadin | Meziadin | 175 | 495.1 | 0.35 |
| Skeena | Kispiox | Club | 0.6 | 2 | 0.3 |

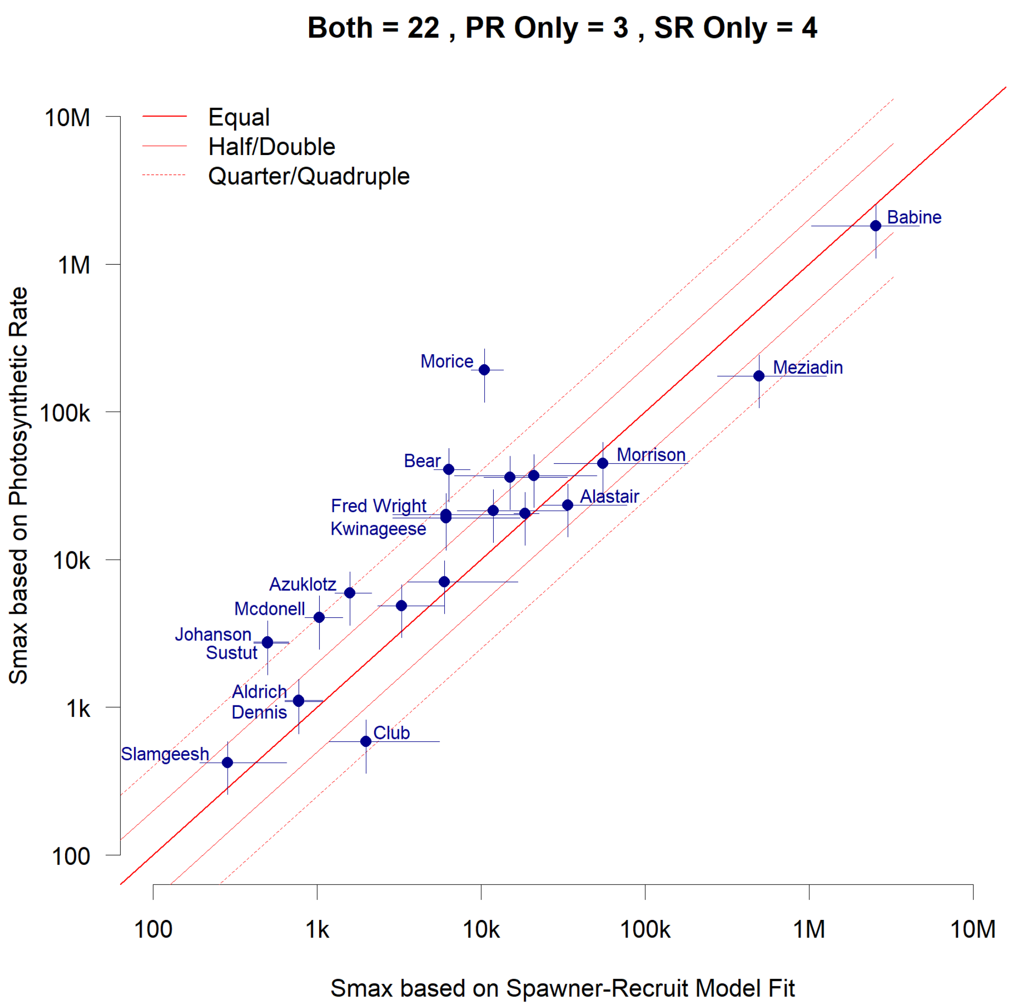


Figure 29. *Comparison plot of $S_{max}$ estimates based on spawner-recruit (SR) data vs. photosynthetic rate (PR) of nursery lakes*. Both axes are on a log-scale, but reference lines indicate the actual magnitude of the ratio, $S_{max}$ (PR model)/$S_{max}$ (SR model). Table 18 lists the corresponding values.

# 5 Discussion

The TWG identified five key questions that inform model building and subsequent stages of the escapement goal review, given the project mandate established by the Northern Panel of the Pacific Salmon Commission (Section 1.1). These questions, which have shaped the data review reported here, are:

- What information is available?
- Which sources of uncertainty have the greatest impact on estimates of biological benchmarks for Skeena and Nass sockeye?
- What are the implications of Pinkut and Fulton spawning channels for spawner-recruit modelling and management strategies?
- What are the implications of observed differences in productivity (i.e., changes over time, differences between stocks)?
- How can aggregate-level objectives and stock-level considerations be explored in the analysis?

The main focus of the data review was to develop agreed-upon spawner-recruit datasets for Skeena and Nass sockeye at the stock and aggregate levels, identify key sources of uncertainty and assumptions, and their implications for subsequent analyses. In this section we discuss the results of the data review and sensitivity tests, and their implications for addressing these questions in the next stages of the Skeena and Nass sockeye escapement goal review, leading up to the analysis plan. Throughout, we briefly refer to previous work on developing escapement goals for Skeena and Nass sockeye. Section 1.3 of Pestal and Carr-Harris (2025), and specifically their Table 2, provide a more detailed summary and discussion of relevant previous work.

## 5.1 What information is available?

Long time series of data are available for aggregate Nass and Skeena aggregate stocks, and for many of the component stocks, but there are significant gaps in the time series for the component stocks due to incomplete escapement records. Here we have used the NCCSDB reconstructions of spawner escapement and total returns to describe population dynamics of Skeena and Nass stocks. The NCCSDB estimates, which go back to 1960 (English et al. 2019), represent the longest time series of consistent estimates available for individual Skeena and Nass sockeye stocks.

For some stocks, there are earlier records of escapement or harvest data that have not been included in these analyses. The choice to use NCCSDB reconstructions rather than other information sources reflects a tradeoff between completeness and consistency. While older catch and escapement datasets may provide valuable information about historic conditions for some populations, they have not been consistently recorded or stored in an accessible format that is directly comparable to contemporary data. For example, salmon escapement to many systems was historically (before the 1960s) recorded as relative abundances using qualitative designations (i.e., “Light”, “Medium”, “Heavy”), that were assigned ranges of values, from which a midpoint was selected as a placeholder for escapement datasets that were created later, including NUSEDS. While these estimates provide an important perspective of historic abundance for these systems, they would be difficult to incorporate into spawner recruitment modeling.

#### 5.1.1 Aggregate Data

Overall, the aggregate spawner-recruit data sets for Skeena and Nass sockeye are similar in length and quality to other major northern and transboundary systems, and are sufficient for applying the standard spawner-recruit model fitting procedures that have been used for these systems. Challenges include low contrast (which is a common problem), observed changes in productivity over time, and productivity differences between the component stocks within each aggregate. These challenges are discussed below. Spawning capacity for the enhanced Babine stocks, which account for the largest proportion of both the Skeena and the combined Skeena/Nass abundance has remained relatively stable since the implementation of the Babine Lake Development Project and spawning channels starting in the 1970s.

#### 5.1.2 Stock-Level Data

Nass and Skeena sockeye have been organized into 31 stocks, including 7 Nass and 24 Skeena stocks, as summarized in Tables 6 and 7. Stocks are mostly aligned with the conservation units (CU) defined under the *Wild Salmon Policy*, with a few exceptions where 2-3 small CUs are combined (e.g., cojoined lakes) and the Babine complex, which is split into 5 stocks based on timing and channel enhancement (Tables 6 and 7).

The 31 stocks fall into three groups of spawner-recruit data availability (Table 8): (1) larger stocks with a lot of data, (2) smaller stocks with some data and (3) stock-recruit data deficient stocks, most of which are assumed to be small. Model scoping considerations for fitting spawner-recruit models and estimating biological benchmarks differ between the three groups.

*Group 1: Larger stocks, many brood years with spawner and recruit estimates*

The spawner-recruit data sets for the 14 stocks in this group are similar in length and quality to other large northern and transboundary sockeye stocks, and are therefore assumed to be sufficient for applying the standard spawner-recruit model fitting used there, either individually or in a hierarchical model. Challenges include low contrast for the largest stocks, and high variability in observed patterns of productivity.

*Group 2: Small Stocks, some brood years with spawner and recruit estimates*

9 small stocks account for about 2% of the cumulative surveyed abundance of effective spawners since 2000, but represent about 1/3rd of the genetic diversity (9/31 stocks, 15/43 conservation units) for Skeena and Nass sockeye. Overall, the spawner-recruit data sets for the 9 stocks in

this group sockeye have a similar range of length and quality as small stocks in other northern and transboundary systems. For some of these stocks, it may be possible to fit individual spawner-recruit models by incorporating additional information, such as informative priors on productivity and capacity. It also may be possible to include most of these stocks in a hierarchical model, where productivity is assumed to be similar for stocks that share an adaptive zone and have the same life history.

*Group 3: No brood years with spawner and recruit estimates*

8 of 31 stocks have no available spawner recruit data (Table 8). Spawner estimates may be available for some sites within those stocks in some years, but spawner expansions and run reconstruction calculations are not currently being done for these stocks, most of which (with the exception of Bowser sockeye) are assumed to be very small. Without spawner-recruit data, it is not possible to fit standard spawner-recruit models for the stocks in this group, but other information such as lake rearing capacity could be used to estimate biological benchmarks. Estimates could be based on the capacity of the rearing lakes, using photosynthetic rates, or combining information from lake capacity and juvenile surveys.

Given their relative size, and the inherent uncertainty in biological benchmark estimates for the larger stocks, it is unlikely that including these Group 3 stocks would result in any substantial changes in an aggregate escapement goal.

## 5.2 Which sources of uncertainty have the greatest impact on estimates of biological benchmarks for Skeena and Nass sockeye?

Stock-level estimates of biological benchmarks based on spawner-recruit modelling are required for the Skeena and Nass sockeye escapement goal review (Section 1.1). Science advice developed through the peer-review process should include technical recommendations regarding which estimates are the most appropriate for aggregate- and stock-level benchmarks given the available data and current conditions.

Our data review and sensitivity tests found that estimates of standard biological benchmarks for both aggregates and many component stocks are sensitive to variations in the data (e.g., dropping 1 or 2 extreme values, excluding earlier or more recent time periods - Tables 14 to 15). In addition, exploratory bootstrap and Bayesian estimates revealed large uncertainty in SR model fits. The issue is more pronounced for the Skeena aggregate and its largest stocks, due to the lower contrast in spawner estimates associated with managing the major component stocks for optimal loading of the spawning channels. Section 5.4 discusses the implications of spawning channel operations for benchmark estimation and broader management considerations.

The age composition test (Table 16) compared estimates of spawners and recruits generated using average vs. annual age compositions and found some substantial differences for some stocks where annual age composition data were available.

The choice of alternative SR model forms, which have been explored as part of the benchmark estimation phase of this project (Pestal and Carr-Harris 2025), introduce additional uncertainty.

Our subsequent work to develop estimates of biological benchmarks using alternative model spawner recruit model forms and data decisions (i.e. different capacity priors, data subsets, infilling decisions) found that SR-based estimates of biological benchmarks for some stocks were also highly sensitive to the choice of priors, specifically whether to include a PR-based habitat capacity estimates as weak or informative priors on $S_{MAX}$. While PR-based $S_{MAX}$ estimates can be used to inform biological benchmarks, either by bounding the capacity parameter for Bayesian SR fits, or on their own to develop SR model parameters for data-poor stocks, the quality of the available data and their suitability for being used for these applications must be carefully considered.

The PR-based habitat capacity estimates reported here come from surveys that were conducted over a decade ago, and there is little to no information available about whether or how freshwater rearing conditions for sockeye have changed in recent years.

Methods for using proportions of capacity-based $S_{MAX}$ values on their own to develop biological benchmarks have not been extensively tested or published. Where PR estimates cannot be directly substituted for SR parameters for the purpose of recommending benchmarks for data-limited systems, they can supplement the SR information. On-going work suggest that including even weak $S_{MAX}$ priors based on the the PR_$S_{MAX}$ reduces uncertainty in the other estimated parameters, and might help with some of the wide ranges that the Bayesian and bootstrap tests produced for many of the Skeena and Nass CUs (Atlas et al. 2021b).

We compared SR and PR-based $S_{MAX}$ estimates using all available data. PR-based estimates are from Table B.9, and SR-based $S_{MAX}$ estimates are from the simple Bayesian Ricker fit using trimmed and filtered data, summed for stocks that share a lake (e.g., the 5 Babine stocks). PR-based estimates are only available for about half of the Skeena and Nass sockeye stocks considered here, the remaining had only SR-based estimates. For the stocks with both types of estimates, the PR-based $S_{MAX}$ estimate was usually larger, and in many cases about double the SR-based $S_{MAX}$ value. For some stocks, PR-based $S_{MAX}$ was 4x larger than SR-based $S_{MAX}$ (Figure 29).

Shortreed et al. (2001) identified limiting factors, including spawning ground capacity and limnetic competitors within the different North Coast rearing lakes, which are summarized in their Table 7. While this information provides some insight as to which Skeena and Nass sockeye rearing lakes are not suitable for using habitat capacity for setting biological benchmarks, this study is now is now 20 years old and should be updated.

## 5.3 What are the implications of observed differences in productivity (i.e., changes over time, differences between stocks)?

Productivity for Skeena and Nass sockeye has fluctuated with increasing variability and a downward trend observed in recent years since the late 1990s. These observations are part of a coastwide phenomenon (Peterman and Dorner 2012). While the annual recruitment and subsequent run sizes from different spawner abundances vary over time due to many inter-related factors, the definitions for standard biological benchmarks assume stable, long-term average conditions (i.e equilibrium) over time. The near-term performance of alternative escapement goals will be strongly affected by current abundance levels, current productivity, and expected productivity in the near future. An important aspect of the current escapement goal review is exploring how updated aggregate escapement goals based on observed changes in productivity for Skeena and Nass aggregate and component stocks compare to the current aggregate escapement goals.

The implications of productivity differences between stocks in an aggregate are discussed in Section 5.5, but even at the aggregate level the observed patterns raise fundamental questions that are relevant to science advice and management decisions, especially if bilaterally accepted aggregate escapement goals are not achieved on a regular basis. For example, observed changes in productivity can affect both the spawner-recruit model fitting and interpretation of the resulting parameter estimates. Given the observed productivity patterns at both the aggregate and stock level, the spawner-recruit analyses should include model forms that explicitly account for time-varying productivity (e.g., Peterman et al. 2000, 2003; Holt and Michielsens 2020). Choosing dynamic rather than equilibrium, or static biological reference points can result in variations in stock status (Berger 2019) and different methods for incorporating time-varying productivity may produce different biological reference points (O'Leary et al. 2020). Given uncertainty about changing environmental conditions, dynamic reference points may not improve management procedures (Punt et al. 2014).

Incorporating time-varying productivity into escapement goals would allow technical staff and managers to formally quantify the magnitude of productivity changes but poses significant challenges for subsequent decision-making processes, especially in cases when returns fall short of accepted aggregate escapement goals due to periods of low productivity. A fixed escapement goal, which is the simplest management option, does not account for long or short-term shifts in productivity. An escapement goal that changes with productivity may improve performance for fisheries and/or conservation objectives, but would be more challenging to implement.

Forward simulations can be used to evaluate the expected performance of these options relative to the expected performance of a fixed escapement goal (Section 5.5.4).

## 5.4 What are the implications of BLDP-enhanced Skeena sockeye stocks for spawner-recruit modelling and management strategies?

The BLDP improvements and associated surplus escapement (Section 4.7) have implications for the spawner-recruit data and how the stock dynamics can be modelled. In terms of fitting models, there are several key issues:

- The spawning channels increased the productivity of of Pinkut and Fulton sockeye, which are the largest Babine sockeye stocks, so pre-channel data are not directly comparable, and need to be either excluded from the model fit or incorporated through a time-varying productivity model.
- When pre-BLDP are excluded, then the remaining brood years have low contrast in spawner abundances, because the channels are managed to capacity and account for most of the effective spawners for each enhanced stock. Low contrast results in more uncertain model fits.

- The BLDP surplus must be estimated and excluded from the observed escapement to determine effective spawner abundance. The approach for estimating surplus by stock has been applied consistently since the 1990s, and is summarized in Appendix C.3.
- The BLDP increased the total aggregate abundance of Skeena sockeye, resulting in increased harvest pressure for wild Skeena stocks from fisheries targeting enhanced Babine sockeye, especially for stocks with run-timing that overlaps with the enhanced stocks. The effect of large returns of the enhanced Pinkut and Fulton stocks on the productivity of wild Babine stocks should also be examined, as there are many factors that could affect sympatric wild and enhanced populations within Babine, such as competition during lake rearing or a breakdown of population structure.

Options for accounting for changes in relationships between spawners and recruits for component and aggregate stocks related to BLDP implementation could include incorporating a random-year effect in spawner-recruit models, or using a change-point analysis to identify regimes as identified in Punt et al. (2014, see also Punt et al. 2014b).

Alternative approaches for finding a balance between channel surplus and mixed-stock fisheries will have broad biological and economic implications for the management of Skeena sockeye. Reduced harvests in mixed stock fisheries will reduce impacts to wild Skeena stocks but result in increased size and frequency of surpluses. Conversely, larger harvest rates on the channel stocks in mixed-stock fisheries will reduce surpluses, but increase the probability of declines for less productive wild stocks. These effects can be quantified with standard salmon spawner-recruit models and forward simulations, to explore interactions between aggregate escapement goals, aggregate harvest rates, channel surplus, and trajectories of individual non-channel stocks.

## 5.5 How can aggregate-level objectives and stock-level considerations be explored in the analysis?

### 5.5.1 Concepts

The project mandate established by the Northern Panel of the Pacific Salmon Commission (Section 1.1) requires the “development and evaluation of candidate benchmarks at the stock level and aggregate level.” Aggregate benchmarks are needed to address international management provisions under the renewed Pacific Salmon Treaty (Pacific Salmon Commission 2020), while stock-level benchmarks are needed to address conservation objectives under Canada’s Wild Salmon Policy (DFO 2005). Within these overarching requirements, there are many options for technical work to develop biological benchmarks at the stock and aggregate level to inform decision making. Previous work on Skeena and Nass sockeye has explored many different approaches (Table 2 of Pestal and Carr-Harris 2025).

Considerations for developing the scope of our analysis approach have been structured into distinct steps:

- Spawner-Recruit parameter estimation

- Benchmark calculation
- Simulation evaluation

All three steps can be done at the aggregate level, the stock level, or a combination of both. For stock-level analyses, there are further considerations regarding which stocks to include in the analyses (i.e., only the 14 larger stocks with long time series, all stocks that have any data, or all 31 stocks)

### 5.5.2 Spawner-Recruit Parameter Estimation

Long time series of spawner abundance and associated recruitment are available for both aggregates, and for the 14 largest stocks (12 Skeena, 2 Nass). Another 9 smaller stocks (6 Skeena, 3 Nass) have some spawner-recruit data, and the 9 remaining stocks (6 Skeena, 2 Nass) are data deficient for stock recruitment analyses. Table 8 summarizes the available data.

Spawner-recruit models can be fitted to the aggregate data, to individual stocks, or to stocks within an aggregate together in a hierarchical framework. Hierarchical models use assumed similarities between stocks to improve the model fit and to develop estimates for data-poor stocks.

Regardless of the model scope and framework (aggregate, individual, or hierarchical), there are many implementation choices that can potentially affect the resulting parameter estimates and subsequent benchmark estimation. These include data treatment decisions (Section 5.2), different approaches for modelling SR relationships (i.e. alternative model forms, including time-varying model forms, or capacity priors), and different computational approaches (i.e. deterministic vs. Bayesian fits to data, state space models or hierarchal approaches).

Previous work on Skeena and Nass sockeye, which has differed widely in scope and approach, has explored many of these model variations. Bocking et al. (2002) used a deterministic Ricker model for a single stock (Meziadin, the largest Nass stock). Walters et al. (2008) and Hawkshaw (2018) developed state-space Ricker models for 9 Skeena CUs. Cox-Rogers et al. (2010) developed Ricker parameters derived from lake-capacity estimates. CU-level biological benchmarks were developed for Skeena (Korman and English 2013) and Skeena and Nass (Pacific Salmon Foundation 2021) CUs using hierarchical Bayesian Ricker fits for the larger stocks in each basin using PR-based lake rearing capacity as priors for $S_{MAX}$ for all CUs except for Babine-Nilkitkwa.

Recent work on northern transboundary stocks has used single-stock state-space models with assumed stable productivity, auto-regression correction, and built-in run reconstruction (e.g., Miller and Pestal 2020).

Parameter estimation for the Skeena and Nass sockeye escapement goal review (Section 1.1) could build on any of these previous analyses to produce an expanded version of the model structure used at the time to encompass stocks and time periods of interest.

### 5.5.3 Benchmark Calculation

Three types of approaches for estimating benchmarks are available:

- *Spawner-Recruit-based Benchmarks*: Biological benchmarks can be calculated from spawner-recruit parameters estimated with any of the alternative approaches discussed in the previous section. There are standard definitions and calculation is straight-forward once challenges with data treatment and parameter estimation have been resolved. SR-based benchmarks can be calculated for aggregate or stock-level SR parameters.
- *Percentile Benchmarks*: Approximate benchmarks based on observed spawner abundances (e.g., 25th and 50th percentile of observed distribution) have been widely used for stocks without recruitment estimates (e.g., Volk et al. 2009; English et al. 2014), but simulation studies have shown that stock-specific context, such as exploitation rate, needs to be carefully considered when applying percentile-based benchmarks (e.g., Clark et al. 2014b; Holt et al. 2018). Percentile benchmarks can be calculated for aggregate or stock-level spawner data.
- *Habitat-based Benchmarks*: Habitat information can be used to estimate capacity directly (e.g., extent of available spawning habitat or lake rearing capacity). Habitat-based benchmarks can only be calculated for individual stocks (if based on spawning habitat) or for a group of stocks sharing a nursery lake (if based on photosynthetic rate).

Previous work on Skeena and Nass sockeye has covered all 3 of these alternative types of approaches. Earlier work was mainly focused on SR benchmarks (Bocking et al. 2002; Walters et al. 2008; Korman and English 2013; Hawkshaw 2018). Pacific Salmon Foundation (2021) includes percentile benchmarks. Cox-Rogers et al. (2010) used nursery lake capacity estimates based on photosynthetic rate in a spawner-recruit framework. For wild Skeena and Nass sockeye stocks, our focus has been to develop SR-based biological benchmarks (Pestal and Carr-Harris 2025), but percentile and habitat-based benchmarks could be explored in future work

Once aggregate-level and stock-specific benchmarks, such as $S_{gen}$ or $S_{MSY}$ have been calculated, there are several approaches for incorporating them into aggregate management reference points. Some of these approaches have been explored for Skeena and Nass sockeye in previous work (Table 2 in Pestal and Carr-Harris 2025) and a detailed comparison of alternative approaches was developed as part of the CSAS peer-review process (Tables 12 to 15 and Appendix B of Pestal and Carr-Harris 2025). The current escapement goals for Skeena and Nass sockeye are based on aggregate-level $S_{MSY}$ estimates produced in 1958 (for the Skeena, prior to the implementation of Babine spawning channels) and 1990s (Nass). In 2016, the Skeena First Nations Technical Committee recommended increasing the limit reference point for aggregate Skeena sockeye from 400,000 to 600,000 for aggregate Skeena, based on the sum of lower benchmarks for the different stocks, and the observed stock composition of the aggregate (DFO 2019). Cox-Rogers et al. (2010) used a forward simulation to estimate the probability of component CUs attaining different target reference points at different fishing scenarios.

### 5.5.4 Simulation evaluation

The benchmark calculations outlined in the previous section are based on the implicit assumption that the future will be like the long-term average conditions from the past, with random variation, of course, but no directional change. As a result, benchmarks like $S_{gen}$ or $S_{MSY}$ reflect past conditions, but would not necessarily be appropriate for current or future conditions. Forward simulation can be used to explore how different management actions perform over a range of alternative assumptions about future conditions, with risk quantified using the resulting escapement trajectories as part of a formal decision analysis (e.g., Hilborn and Peterman 1996; deYoung et al. 1999; Punt et al. 2016).

The appropriate scope and form for a simulation model depends on the question being asked, but defining a specific, relevant question is not a trivial task, and typically requires a comprehensive process. Another substantial challenge is choosing alternative scenarios for future changes.

The key benefit of building forward simulation models is that they allow us to compare the expected performance of alternative strategies and identify strategies that are more robust to uncertainty (e.g., Punt et al. 2016), which has been characterised as searching for a *"safe-fail"* strategy that avoids catastrophic outcomes even when things go wrong, rather than identifying a strategy that is optimal under very specific assumptions and conditions (Ann-Marie Huang, DFO, and Mike Staley, Fraser River Aboriginal Fisheries Secretariat; pers. comm).

Forward simulations have been explored in previous work on Skeena and Nass sockeye. Cox-Rogers et al. (2010) tested the effect of average harvest rates from the 1990s over 15 years and 100 years . Hawkshaw (2018) used optimization techniques to compare alternative harvest strategy types. The harvest rates in Cox-Rogers et al. (2010) were applied equally to all stocks. Hawkshaw (2018) explored alternative harvest control rules and fishing plans for multi-species mixed-stock fishery (i.e. 5 Pacific salmon species and steelhead, each modeled as a single stock).

Several recent assessments of BC salmon stocks with conservation concerns have focused on short forward simulations: Huang et al. (2021) used 12 year forward simulations of 9 endangered of threatened stocks of Fraser River sockeye to estimate the probability of meeting recovery targets under a range of fixed exploitation rates, given a range of alternative productivity assumptions, centered on recent productivity, which was estimated with time-varying spawner-recruit models. Corresponding work for all Fraser River sockeye stocks is testing alternative harvest control rule variations over 12 years and 48 years to support management planning (Ann-Marie Huang, DFO; pers. comm.), using the same spawner-recruit parameter sets and productivity assumptions as Huang et al. (2021).

### 5.6 Analysis Plan

Based on available data, observed patterns, initial sensitivity tests of biological benchmarks, and considering the five questions discussed in previous sections, the TWG and external reviewers identified three priorities for estimating biological benchmarks for Skeena and Nass sockeye:

1. *Productivity patterns*: Productivity for Skeena and Nass sockeye has declined considerably in recent years with increasing variability in total returns and productivity for both aggregates, and the component stocks. An effective escapement goal needs to consider that these changes are likely to persist in the future. Both reviewers identified time-varying productivity as one of the most important factors to consider in the analytical plan.

2. *Enhanced stocks vs. wild stocks*: The largest component of aggregate Skeena sockeye (and Skeena and Nass sockeye combined) originates from the two stocks that are enhanced with spawning channels and flow control structures. Consequently, Skeena sockeye returns are managed for optimal loading of the spawning channels. As a result, there is low contrast in spawner abundances for Skeena sockeye, which poses a challenge to spawner recruitment models which assume density dependence. An escapement goal for Skeena sockeye needs to consider channel loading limitations for these enhanced stocks.

3. *Aggregate benchmarks vs. stock-level benchmarks*: Skeena and Nass sockeye are both comprised of many small stocks with unique characteristics and population dynamics. A key objective for the review of Skeena and Nass sockeye escapement goals is to recommend a combined aggregate escapement goal for Skeena and Nass sockeye which considers stock-level genetic diversity in addition to variable productivity and channel capacity noted above.

These priorities were addressed in subsequent benchmark analyses and engagement processes. Initial results are reported in the *Analysis Report* (Pestal and Carr-Harris 2025), which explored observed changes in productivity over time for the different wild Skeena and Nass sockeye stocks using alternative approaches depending on the length and quality of available datasets.

Further analyses were applied to four alternative productivity scenarios, generated based on stock-specific productivity changes observed in the SR model fitting step: long-term average productivity, current productivity, and high/low productivity bookends.

The *Analysis Report* focuses on SR analyses, resulting estimates of biological benchmarks, and alternative aggregation approaches for the 20 wild stocks for which sufficient spawner-recruit data are included in the current version of the data (16 Skeena Stocks, 4 Nass stocks).

For the two enhanced Babine sockeye stocks (Pinkut and Fulton), the *Analysis Report* includes an overview of available information (e.g. fry and smolt abundances, smolt sizes) and a summary of observed changes over time.

Finally, the *Analysis Report* explores several alternative approaches for developing aggregate-level management targets based on stock-level considerations described above, and illustrates alternative results generated using different productivity scenarios.

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# APPENDIX A Technical Working Group Members

Table A.1. *Members of the Technical Working Group (TWG)*. The TWG consists of members from Fisheries and Oceans Canada, First Nations from BC's North Coast Area, Pacific Salmon Foundation, and consulting organizations. Members of the TWG have specific expertise in Skeena and Nass sockeye salmon biology, databases, and/or spawner-recruit modeling.

| Type | Name | Affiliation |
|---|---|---|
| TWG | Addison, Angela | North Coast Skeena First Nations Stewardship Society |
| TWG | Alexander, Richard | LGL Ltd. |
| TWG | Carr-Harris, Charmaine | Fisheries and Oceans Canada |
| TWG | Challenger, Wendell | LGL Ltd. |
| TWG | Cleveland, Mark | Gitanyow Fisheries Authority |
| TWG | Cox-Rogers, Steve | Fisheries and Oceans Canada |
| TWG | Davies, Sandra | Fisheries and Oceans Canada |
| TWG | English, Karl | LGL Ltd. |
| TWG | Gordon, Jenn | Fisheries and Oceans Canada |
| TWG | Grout, Jeff | Fisheries and Oceans Canada |
| TWG | Hertz, Eric | Pacific Salnon Foundation |
| TWG | Holt, Carrie | Fisheries and Oceans Canada |
| TWG | Holt, Kendra | Fisheries and Oceans Canada |
| TWG | Huang, Ann-Marie | Fisheries and Oceans Canada |
| TWG | McAllister, Murdoch | University of British Columbia / United Fishermen and Allied Workers Union |
| TWG | Nyce, Harry | Nisga'a Lisims Government |
| TWG | Pestal, Gottfried | SOLV Consulting Ltd. |
| TWG | Rosenberger, Andrew | Coastland Research / Skeena Fisheries Commission |
| Reviewer | Adkison, Milo | University of Alaska Fairbanks / Alaska Dept. of Fish and Game |
| Reviewer | Peterman, Randall | Emeritus, Simon Fraser University |

# APPENDIX B Assessment Programs

## B.1 Stock Assessment

While escapement surveys cannot count every single adult sockeye salmon returning to the Skeena and Nass basins, full census programs for the major populations for each river account for a large proportion of the total escapement for the two stock aggregates. The Babine counting weir (minus harvests above the weir) accounts for an average of 83% Skeena sockeye spawners (1985-2019), and the Meziadin fishway accountd for an average of 65% (1992-2019) of Nass sockeye spawners.

Survey effort for the remaining stocks is conducted by DFO, First Nations, and other groups and covers a combination of mainstem sampling and spawning ground surveys. Spawning ground surveys focus on tributaries and lake areas with known persistent sockeye presence. Systems with consistent survey coverage have been identified as *indicator systems*, which form the basis for spawner estimates at the level of conservation units, stocks, and stock aggregates.

The *Core Stock Assessment Plan* for North and Central Coast salmon (including Nass and Skeena sockeye salmon) was developed to provide a general plan for assessing these populations (English et al. 2006). For each sockeye CU, the original assessment plan identified at least one indicator system to be assessed annually for spawner abundance in addition to regular rotational assessments of lake rearing capacity and fry abundance in sockeye rearing lakes. Annual implementation has been shaped by this general plan but adapted to meet other priorities and reflect practical constraints, which differ by species and area.

The rest of this section provides a brief overview of the Skeena and Nass sockeye assessment plan and the major program components (fishwheels, test fishery, fences, fishways). It is beyond the scope of this review to compile and summarize the details for all the spawning ground surveys (e.g., which systems were surveyed which year, whether surveys consisted of one or more streamwalks). While this information is available in stream inspection logs (SIL), it has not been comprehensively integrated into a database. However, annual survey coverage has been reviewed extensively through interviews with field staff (e.g., English et al. 2012) and is reflected in the expansion factors used to scale up raw spawner survey results from indicator systems to estimates of total spawner abundance (Appendix C.2). Our review of data quality includes flagging years with high expansion factors (Section D.1).

Tables B.1 and B.3 summarize the major assessment program components. Tables B.2 and B.4 list visual surveys for indicator systems that have been surveyed consistently for at least 20 years.

Table B.1. *Overview of Major Assessment Projects - Nass*. Project location is described as distance upstream (km) from mouth of the river (*UM*) and distance upstream (km) from confluence with the mainstem (*UC*), where available. Major projects are implemented by the Nisga'a Fisheries and Wildlife Department (NFWD), the Gitanyow Fisheries Authority (GFA), and DFO. Stiff et al. (2015) describe the Meziadin fishway in detail. Beveridge et al. (2020) describe the Kwinageese fence.

| Project | Location | Covered | Active | Description | SurveyBy |
|---|---|---|---|---|---|
| Test Fishery (Gillnet) | Monkley Dump | All Nass | 1963 to 1993 | Gillnet test fishery operated at Monkley Dump on the Nass River, 16 km upstream of Area 3-12 from 1963 to 1993. Salmon sampled for age, size, sex, and in a few years, stock composition from DNA analyses. | DFO |
| Test Fishery (Fishwheels) | Gitwinksihlkw (58 km UM) | All Nass | 1994 to Current | 2 fishwheels from 1 June to mid-Sep. Salmon are sampled for age, size, sex, and in recent years, stock composition from DNA analyses. | NFWD |
| Fishwheels | Grease Harbour | Upper Nass | 1994 to Current | 2-4 fishwheels. Sockeye in-season mark rates are collected annually, and some selective harvesting has occurred since implementation of Nisga'a Treaty in 2000. | NFWD |
| Fishway | Meziadin R. (206km UM) | Meziadin | 1966 to Current | 220 m vertical slot design with 33 ascending pools and concrete weir to direct fish to ladder, was built in 1966 by DFO to enable salmon passage over Victoria Falls on Meziadin River. Salmon are counted and sampled annually for size, age, sex, and tag status. | DFO, NFWD, and GFA |
| Fence | Kwinageese R. (265 km UM, 18km UC) | Kwinageese | 2002, 2005, 2006, 2009 to Current | The project started in 2002 and is operated by NFWD annually from mid July to mid October since 2009 . The weir design forces salmon to pass through a viewing box that contains lights and two color-recording cameras that record fish passage 24 hours per day. No fish are handled. Video records are reviewed for species identification, size, and tag status | NFWD |

Table B.2. *Overview of Visual Surveys - Nass*. Visual surveys are conducted by the Nisga'a Fisheries and Wildlife Department (NFWD), Gitanyow Fisheries Authority (GFA), Gitskan Watershed Authorities (GWA), and DFO.

| WS | Stock | Indicator Surveys | Supplementary Surveys | SurveyBy |
|---|---|---|---|---|
| Lower Nass Tributaries | Lower Nass Sea/River Type | Gingit Creek (Foot) | Gitzyon Creek (Foot), Zolzap (Fence/Foot), Tseax (Foot), Seaskinnish (Foot) | NFWD |
| Upper Nass Tributaries | Upper Nass River Type | Brown Bear (Foot) | Cranberry (Foot/Aerial) | GFA/NFWD |
| Meziadin | Meziadin | 3 Foot: Hanna, Tintina, Strohn | None | GFA |
| Damdochax | Damdochax | Aerial, Foot: covering 2 areas (Damdochax, Wiminasik) | | NFWD/GWA |

Table B.3. *Overview of Major Assessment Projects - Skeena*. Project location is described as distance upstream (km) from mouth of the river (*UM*) and distance upstream (km) from confluence with the mainstem (*UC*), where available. Major programs are implemented by Lake Babine First Nation Fisheries (LBNF), the Gitanyow Fisheries Authority (GFA), Gitksan Watershed Authority (GWA), Kitselas Nation, Kitsumkalum Nation, Office of the Wet'suwet'en (OW), BC Ministry of Environment (BC MOE), and DFO. Details of the Tyee test fishery and daily data summaries are available at (https://www.pac.dfo-mpo.gc.ca/fm-gp/northcoast-cotenord/nass-eng.html). A description of the Kitwanga fence and annual and weekly reports are available at http://www.gitanyowfisheries.com/projects/kitwanga-river-salmon-enumeration-facility-1. Cox-Rogers and Spilsted (2012) describe the Babine fence details and daily data are available at https://www.pac.dfo-mpo.gc.ca/fm-gp/northcoast-cotenord/babine-eng.html. Whitmore (2019) describes the Slamgeesh fence.

| Project | Location | Covered | Active | Description | SurveyBy |
|---|---|---|---|---|---|
| Test fishery | Tidal portion of Skeena at Tyee | All Skeena | 1955 to Current | Lower Skeena test fishery using a multipanel variable mesh gillnet (200 fathoms length, 20-foot depth, made of 10 equal length panels of mesh size ranging from 3.5 – 8 inches). Test fishing occurs during daylight hours at high and low slack tide, for a total of between two and four sets per day. The Tyee sockeye index, calculated as the average catch per unit effort for each day fished, is the primary tool for in-season estimation for Skeena sockeye. Biological sampling including length, age, and genetic material are collected. | DFO |
| Fence | Kitwanga R. (4km UC) | Kitwanga | 2003 to Current | Permanent fence structure with removable panels. Annual operation includes sampling for length, age, DNA, and sex. | GFA |
| Mark-Recapture | Wit'set canyon (Bulkley River) | Bulkley, Morice | 2002 to Current | A mark-recapture assessment program, sockeye are captured and tagged below Wit'set Canyon by beach seine and recaptured above the canyon by dipnet. Mark rates are determined during snorkel surveys at Nanika River which represents the largest spawning aggregation of Bukley/Morice Sockeye. | OW |

*Continued on next page ...*

... *Continued from previous page*

| Project | Location | Covered | Active | Description | SurveyBy |
|---|---|---|---|---|---|
| Fence | Babine, 1km below Nilkitkwa Lake, 360 km UM) | 4 Babine | 1946 to Current | Permanent fence structure with removable panels. Annual installation of 66 aluminum panels (4 by 7-foot) and 7 holding traps (6 by 8.5 feet) along the 330-foot frame that spans the entire width of the Babine River. The fence is opened to allow fish through from 0600h to 2200h daily and counting between these times is performed in a series of two hour shifts by 2-4 observers. 25 sockeye sampled daily for sex, nose fork and hypural lengths and general age, size and sex make-up of that year's migration, therefore enabling potential egg deposition to be estimated | DFO/LBNF |
| Fence | Sustut | Sustut, Johanson | 2001 to Current | Steelhead enumeration fence that also counts sockeye. | BC MOE |
| Fence | Damshilgwit Creek, just below Slamgeesh lake. | Slamgeesh | 2000 to Current | Temporary aluminum modular fence. Bar spacing of 25 mm ensures that adults and jacks are redirected into live-box. Sampling includes sex, fork length, pre/post spawn morphology, five scales, and tissue. | GWA |

Table B.4. *Overview of Visual Surveys - Skeena*. Visual surveys are conducted by Lake Babine First Nation Fisheries (LBNF), the Gitanyow Fisheries Authority (GFA), Kitselas, Kitsumkalum, Office of the Wet'suwet'en (OW), and DFO.

| WS | Stock | Indicator Surveys | Supplementary Surveys | SurveyBy |
|---|---|---|---|---|
| Ecstall | Johnston | Johnston Lake (Aerial) | None | DFO |
| Gitnadoix | Alastair | 2 Aerial: Alastair Lake, Southend Creek | None | DFO |
| Lakelse | Lakelse | Schulbuckhand Creek (Camera), Sockeye Creek (Foot), Williams Creek (Foot) | None | Kitselas, DFO |
| Kitsumkalum | Kitsumkalum | Clear Creek (Foot), Kalum Lake (Foot) | None | Kitsumkalum |
| Zymoetz | Mcdonell | Upper Zymoetz River (Foot and/or Aerial) | | DFO or GWA |
| Bulkley | Morice | Nanika River (Snorkel) | None | OW |
| Kispiox | Swan / Stephens | Foot: Barnes Creek, Club Creek - Upper and Lower, Falls Creek | Foot: Jackson Creek, Stephens Creek | GFA |
| Babine | Wild-Early | Up to 17 streams surveyed visually, estimates combined. | | LBNF |
| Babine | Wild-Mid | Regular Foot surveys on Morrison Creek, Tahlo Creek - Upper and Lower; Morrison Lake. | None | LBNF |
| Babine | Wild-Late | Babine River - Sections 1-4 (Aerial) | None | DFO |
| Motase | Motase | Motase Lake (Aerial) | None | DFO |
| Sustut | Bear | Azuklotz Creek (Aerial), Bear Lake (Aerial), Salix Creek (Foot) | None | DFO |
| Sustut | Asitka | Asitka River (Aerial) | None | DFO |

### B.2 Catch Monitoring Program

#### B.2.1 Northern Boundary Fisheries

Alaskan Marine commercial salmon fisheries are monitored with a combination of hails, sales slips, and on-board observers. Canadian Marine Commercial salmon fisheries were monitored with a combination of annual hails and sales slips (until 2012). Since 2012, estimates are based on hails only but adjusted based on a historical linear-regression relationship between hails and sales slips for years when gillnet catches were greater than 100,000 (Northern Boundary Technical Committee 2020). Weekly catch and effort are estimated annually for up to 14 Alaskan and 14 Canadian fisheries, of which only 9 Canadian fisheries have been active in recent years.

Note that any potential interceptions of sub-adult sockeye during their marine residency are considered part of marine mortality (together with predation), and are not explicitly incorporated in the spawner-to-recruit data. This is consistent with other sockeye data sets (e.g., Huang et al. 2021), but differs from Chinook data sets that estimate adult equivalents for sub-adult catches (e.g., Chinook Technical Committee 2020).

The general consensus among the *Northern Boundary Technical Committee* (pers. comm.) is that the total numbers of retained sockeye in the marine fisheries are well estimated with the current monitoring program (i.e., unreported catch is likely small) with accurate stock composition data at the aggregate level from well-developed genetic sampling programs in Alaska and BC fisheries since 2002. Another common source of uncertainty in estimates of total catch is fishing-related mortality in Canadian Fisheries. Canadian PFM Area 3 seine fisheries targeting Pink salmon have mandatory sockeye releases with an estimated release mortality of 15% (Alexander 2018), which has been incorporated into the Northern Boundary run reconstruction during sockeye closure periods since 2016 (Section C.4).

Another, possibly larger, source of uncertainty is the allocation of catch to different stocks based on scale patterns or genetics (Section B.3) or run timing in run reconstruction modeling (Section C.4).

#### B.2.2 First Nations Coastal and In-River

First Nations fisheries for Skeena and Nass sockeye are very diverse. First Nations throughout the Skeena and Nass harvest sockeye salmon in constitutionally protected *Food, Social, and Ceremonial* (FSC) and conduct economic fisheries in some years in formal agreements with DFO. The Nisga'a Treaty has been implemented on the Nass River since 2000 and provides annual agreed sockeye (and other salmon) allocations to the Nisga'a Nation based on estimated total returns to Canada (https://www.nisgaanation.ca/stock-assessments). Fisheries for FSC or economic allocations on both the Skeena and the Nass deploy many different gear types, including marine gillnet and seine fisheries, in-river drift and set nets, dipnets, and weirs. First Nation fisheries can be community-based, and fish may be caught by community organizations or individual harvesters. Catch estimates are developed through a combination of harvester reporting, guardian observation, and effort surveys, which vary across Nations.

First Nations economic fisheries include Nisga'a Treaty Individual-sale (IS) fisheries on the Nass River, Skeena and Nass Economic Opportunity (EO) harvests and, Nass/Skeena demonstration (Demo) fisheries, which are managed by license shares and monitored like commercial fisheries, and Skeena *Excess-Salmon-to-Spawning-Requirements* (ESSR) fisheries, in which a part of the biological surplus at the Pinkut and Fulton spawning channels (Section C.3) is harvested. First Nations economic landings are reported with high accuracy.

The relative magnitude of these fishery types changes with abundance and agreements between DFO and First Nations that have come into effect (e.g., Nisga'a Treaty in 2000). FSC and Treaty specific fisheries have the highest allocation priority in Canadian domestic catch sharing. They typically have similar effort across a wide range of abundances, and an upper limit on catches shaped by gear types, access points, participation, and allocation limit. Harvest agreements (including a separate allocation of Nass sockeye by the Nisga'a Nation), EO, and ESSR fisheries, on the other hand, are managed based on annual estimates of allowable catch, and therefore vary more from one year to the next. In a large run year, EO and ESSR catches may be several times larger than the FSC catch (e.g., 2000, 2001, 2006, 2008, 2011, 2014, 2015, and 2018) in Skeena fisheries, while in a low run year most or all the First Nations catch is in FSC fisheries.

Most Skeena sockeye harvested in First Nations fisheries are caught in marine approach areas near the mouth of the river and at traditional fishing sites throughout the middle Skeena between the Tyee Test Fishery and the mouth of the Babine River, and at the Babine counting facility (the site of an Indigenous weir that was the most important sockeye harvesting location for Lake Babine Nation) and in Babine Lake.

Most of the Nass sockeye FSC catches occur in the Nisga'a Nation's fisheries from the mouth of the Nass River to below Kinskuch River with catches averaging approximately 81,000 sockeye (range: 39,000–154,000). Mathews and Morven. (2012) describe the Nisga'a catch monitoring program. Annual catches above the Kinskuch River occur in Upper First Nation fisheries (Gitanyow and Gitksan), have averaged approximately 13,000 (range: 8,200–21,000) since 2009. Smaller marine catches by First Nations in outside areas of Area 3 include both Skeena and Nass sockeye in varying proportions throughout the fishing season and across years.

First Nations fisheries intercept different stock mixtures depending on their location and timing, and run reconstruction analyses are used to allocate the estimated weekly catches to individual stocks based on residence time in the different fishing areas. Skeena sockeye run reconstructions combine in-river harvest data from 12 fishing areas (Table 1 in English et al. 2017) with stock-specific timing to allocate catch to stocks.

A detailed in-river run reconstruction model has not been developed for Nass sockeye. Instead, we have estimated in-river harvest rate for the aggregate Nass stock (i.e., total in-river harvest divided by the run size entering the Nass River) and applied this in-river harvest rate equally across all Nass sockeye sub-stocks. This approach was used on the Nass because the majority of in-river harvest occurs in the lower Nass where all stocks are vulnerable.

Raw catch estimates for Skeena First Nation fisheries are adjusted based on local knowledge and historic patterns, as described in English et al. (2017). Catch data and adjustments are reviewed periodically, as estimation procedures change over time, and catch estimates need to be updated to incorporate new information. For this review, TWG members worked with Skeena First Nations to review and update previously reported catch data for the different modelled fishing areas. Generally, catch estimates for middle Skeena fishinga areas, including Babine and Bulkley sockeye, were found to be consistent with previously reported estimates. The biggest identified gaps were in coastal and marine areas, where work with local First Nations fisheries groups to review historic catch estimates is ongoing.

Based on these reviews, the quality of estimates for First Nations harvests varies by fishery. The TWG considered the total number of sockeye caught in Skeena River First Nations fisheries to be reasonably well estimated, but that the step of assigning catch to individual stocks introduces some uncertainty. The key assumptions are migration timing and residence time in different fishing areas (i.e., up-river migration speed, and holding due to water levels).

### B.2.3 Recreational Marine and In-River

Recreational fisheries intercepting Skeena and Nass sockeye are concentrated in a few locations. On the Skeena, the most important recreational harvest sites for sockeye are near Terrace, Hazelton, and on Babine Lake. For the Nass, sockeye are mainly harvested in recreational fisheries in Meziadin Lake and in some Nass tributaries.

Recreational catch monitoring in Northern BC salmon fisheries uses a combination of surveys (e.g., DFO 2019). Catch reporting is a condition of all licences, and additional information is collected from a random subset of licences using the monthly *Internet Recreational Effort and Catch* (iREC) survey. Annual creel surveys of marine recreational fisheries are conducted by the *North Coast Skeena First Nations Stewardship Society*, but sockeye catches in these fisheries are typically very small (<100 fish/year). In some years, Skeena First Nations conduct in-river creel surveys in their respective territories. For example, Doire and Gottesfeld (2011) estimated that about 20,000 sockeye were removed by recreational fisheries at all fishing areas in the Skeena compared with a total return of about 1.5 Million sockeye for that year (ca. 1.5% harvest rate). Very small numbers of sockeye salmon are captured in lower sections of the Skeena River, where an annual creel survey conducted by Kitsumkalum Nation estimated 224 sockeye harvested in 2019 (Robichaud et al. 2020).

While the estimates of total recreational sockeye harvested in both the Skeena and Nass basins are far more uncertain than the marine and First Nations catches, the actual amounts are much smaller than for the other harvester groups. Therefore, at the aggregate level, uncertainty in recreational catch is considered negligible.

## B.3 Stock Identification

### B.3.1 Brief history of Skeena and Nass Sockeye Stock Identification Approaches

Abundance estimates from Skeena and Nass test fisheries, fish wheels, and some counting fences (e.g., Babine, Meziadin) reflect aggregate run sizes from multiple stocks. Similarly, most of the catch estimates come from mixed-stock fisheries. In both cases, we need to separate the estimates into smaller stock groups to estimate total returns for individual stocks.

Methods for estimating stock composition of Pacific salmon date back a century, starting with scale patterns and then switching over to genetics. Both approaches rely on comparing the observed patterns in samples to the patterns in known baseline samples. With scale patterns, stock identification is based on the number and size of growth rings, or circuli. With genetics, samples are matched to baseline stocks based on a combination of markers. Stock ID based on scales or genetics can be more straightforward for some samples, and uncertain for others, due to the natural variation between individuals and challenges with reading the sample (e.g., partly re-absorbed or damaged scales, incomplete DNA sequencing).

Major et al. (1970) describe how stock-specific growth patterns, which can be identified in processed scales under a microscope, started to be systematically documented and analyzed in the 1920s. Scale-based stock identification became part of the international management of Fraser River sockeye under the *International Pacific Salmon Fisheries Commission* in the 1940s. Methods in scale-pattern-based stock identification have continued to evolve (e.g., scale processing, statistical approach) and became widely used throughout Canadian and US salmon fisheries in the 1980s.

Scale-based stock ID, or SPA (scale pattern analysis), of marine catches in Northern Boundary Alaskan fisheries started in 1982 (English et al. 2004) to distinguish 6 large stock aggregates (Southeast Alaska, Nass, Skeena, Stikine, Tahltan, and South Coast) analogous to the sockeye salmon stocks that are modelled in the Northern Boundary Run Reconstruction Model (Appendix C.4). SPA used a single baseline established at the beginning of the program to separate the different stocks in Alaskan fisheries.

In the 1990s, emerging technology for using genetic techniques for salmon stock identification started to become feasible for large-scale implementation (e.g., Beacham et al. 1998, 2001). This approach uses automated DNA sequencers, which are more specialized equipment than the microscopes used for reading scales, but the end-result is conceptually the same: a pattern is extracted from a sample that can be matched with some probability to a baseline sample.

### B.3.2 Implementation of Genetic Stock Identification for Northern Boundary Area Fisheries

Starting in 2013, samples from marine fisheries in Alaskan waters were analyzed by two different agencies using different genetic baselines. The *Alaska Department of Fish and Game* (ADF&G) collects and analyzes samples from fisheries in districts that are not regulated by provisions in the Pacific Salmon Treaty (Districts 101-108), and the *National Oceanic and Atmospheric Agency* (NOAA) collects and analyzes samples from Treaty-regulated seine and gillnet fisheries in Districts 101 and 104. Starting in 2004, the Canadian Department of Fisheries (DFO) collected and analyzed samples collected in fisheries south of the Alaska-BC border, in Canadian PFM Areas 3-5. ADF&G switched from SPA to GSI-based stock ID in 2013.

The focus of stock ID for international management is to distinguish the major stock aggregates (Skeena, Nass, SE Alaska (McDonald and other), and Stikine) through the modelling process rather than stock-specific assignments used for Canadian domestic run reconstructions.

### B.3.3 Canadian Genetic Baseline

In addition to analyzing mixed-stock fishery samples to determine the aggregate stock of origin, genetic assignments to the level of individual stocks are used domestically for estimating stock composition within aggregates (i.e., for estimating the proportion of non-Babine escapement at the Tyee Test fishery), and for determining run-timing for individual stocks entering the Skeena and Nass Rivers.

The current standard used by DFO for sockeye stock ID (Withler et al. 2000; Beacham et al. 2001) looks for variations (called *alleles*) in several unique DNA sequences (called *microsatellite loci*). Specific variations in these sequences are more common in some stocks than others, and samples are assigned to stocks based on the number of matched patterns. The current DFO baseline for sockeye uses 14 loci (e.g., Beacham et al. 2010). An updated Canadian genetic baseline using single nucleotide polymorphism (SNP) is currently under development for sockeye.

Microsatellite baseline samples for Skeena and Nass sockeye started to be systematically collected in the 1990s and in the early 2000s genetics-based stock ID started to be used at the Tyee test fishery in the lower Skeena and at the fish wheels on the lower Nass (English et al. 2012).

Since 2004, in-season monitoring and post-season run reconstruction have used genetic stock ID based on microsatellite loci (English et al. 2012) for estimating modelled stock catches in marine fisheries. The current approach uses the frequency of variations at 14 microsatellite loci to match genetic samples to one of 36 baseline groups on the Skeena and 11 baseline groups on the Nass. Beacham et al. (2014a) and Beacham and Wood (1999) describe the details, but note that baseline coverage has expanded since then.

The current Canadian microsatellite baseline includes 3,675 samples from 12 sites on the Nass and 7,885 samples from 34 sites on the Skeena (Table B.5). Large baseline samples (n >300) covering multiple years have been collected for most of the larger stocks with long time series of spawner-recruit data (Group 1) and most of the smaller stocks with limited spawner-recruit data (Group 2). Baseline sampling is now focused on expanding coverage for some data-poor stocks (Group 3), and for increasing sample sizes for river-type populations with poor genetic resolution.

Sample size varies for sites within a stock, and some sites do not currently meet the minimum sample size for inclusion in analyses that estimate population structure (Tables B.6 and B.7).

### B.3.4 Quality of Stock Composition Estimates

Estimates of stock composition are available for the majority of Alaskan fisheries in most years since 1982 (SPA to 2012, GSI to present) and for Canadian fisheries since 2004. Catch estimates with no stock composition estimates are modelled using the Northern Boundary Run Reconstruction (NBRR) equal vulnerability method and predicted migration route (Section C.4). Although the Canadian and U.S. genetic baselines differ by number and composition of baseline samples, they are generally considered equivalent with respect to distinguishing between the aggregate stocks, but this assumption is currently being assessed by the NBTC as part of an ongoing review of the NBRR model.

While different methods and baselines are used for different fisheries, the general consensus among the *Northern Boundary Technical Committee* (pers. comm.) is that estimated percent contributions from different stock aggregates are generally consistent across methods and comparable over time. However, potential concerns have been identified for river-type sockeye, where baseline samples for river-type sockeye may be mis-assigned between the Skeena and Nass, which can affects allocations of catches to the two basins, but does not affect the estimate of Canadian-origin sockeye in the Alaskan catch for Pacific Salmon Treaty allocations.

Although the Canadian and US genetic baselines were initially developed with close collaboration between agencies to share baseline samples between the different countries, the genetic baselines have diverged somewhat in the past decade. A recent review of the stocks used for the different baselines found that while the Canadian, ADF&G, and NOAA all included a total of 239 stocks in 2019, only 53% of the stocks (n = 127), matched between the Canadian and U.S. baselines, and there were significant differences in the number of stocks within each aggregate group and between years since 2012. For example, Alaska baseline stocks ranged between 84 and 173 stocks and matched 26%-33% between 2012 and 2016 (Alexander and English 2022). It is not known how these differences affect estimates of stock composition and catch assignments to Skeena and Nass sockeye in Alaska fisheries, but it is generally thought that it is more likely to have a greater effect at the level of individual stocks, which are not reported by the respective agencies for Northern Boundary fisheries, rather than by aggregate groups. Efforts are currently underway to share updated information between agencies to better align the Canadian and U.S. baselines.

Table B.5. *Genetic Baseline Samples By Stock*. For each stock, table lists the life history and adaptive zone (*LHAZ*), watershed, percent of total combined spawner abundance (*PercSpn*), and number of baseline samples (*n*). Stocks with fewer than 300 baseline samples are marked in orange.

| LHAZ | Watershed | Stock | PercSpn | n | Years |
|---|---|---|---|---|---|
| **Group 1: Larger Stocks, Lots of SR Data** | | | | | |
| M Skeena LT | Babine | Fulton | 37 | 536 | 4 (1985-1994) |
| M Skeena LT | Babine | Bab-LW | 15 | 340 | 4 (1959-1994) |
| U Nass LT | Meziadin | Meziadin | 15 | 784 | 5 (2001-2018) |
| M Skeena LT | Babine | Pinkut | 11 | 492 | 4 (1985-1994) |
| M Skeena LT | Babine | Bab-EW | 4 | 1119 | 7 (1987-2014) |
| M Skeena LT | Babine | Bab-MW | 3 | 789 | 6 (1987-2014) |
| L Skeena LT | Gitnadoix | Alastair | 2 | 354 | 5 (1987-2006) |
| L Skeena LT | Kitsumkalum | Kitsumk | 2 | 266 | 3 (1994-2012) |
| Nass SRT | Lower Nass Tribs | LNassSRT | 2 | 532 | 7 (1987-2014) |
| M Skeena LT | Bulkley | Morice | 2 | 258 | 6 (1988-2016) |
| L Skeena LT | Lakelse | Lakelse | 1 | 536 | 5 (1987-2006) |
| M Skeena LT | Kispiox | SwanSteph | 1 | 490 | 5 (1988-2006) |
| **Group 2: Small Stocks, Limited SR Data** | | | | | |
| U Skeena LT | Sustut | Bear | 1 | 116 | 2 (1987-1988) |
| L Skeena LT | Zymoetz | Mcdonell | <1 | 347 | 5 (1987-2006) |
| U Nass LT | Kwinageese | Kwinag | <1 | 738 | 7 (1987-2001) |
| M Skeena LT | Kitwanga | Kitwanga | <1 | 554 | 3 (1998-2009) |
| U Nass LT | Damdochax | Damdoch | <1 | 557 | 6 (1987-2001) |
| U Skeena LT | Sustut | Sustut | <1 | 341 | 4 (1993-2006) |
| L Skeena LT | Ecstall | Johnston | <1 | 121 | 1 (2010) |
| U Skeena LT | Sustut | Asitka | <1 | 0 | |
| Nass RT | Upper Nass Tribs | UNassRT | <1 | 237 | 7 (1997-2013) |
| U Skeena LT | Slamgeesh | Slamg | <1 | 672 | 3 (2004-2008) |
| U Skeena LT | Motase | Motase | <1 | 75 | 1 (1987) |
| **Group 3: No SR Data** | | | | | |
| U Nass LT | Bell-Irving | Bowser | | 827 | 7 (1986-2001) |
| U Nass LT | Bell-Irving | Oweege | | 0 | |
| L Skeena LT | Ecstall | Ecstall | | 0 | |
| M Skeena LT | Bulkley | UBulkLk | | 0 | |
| U Skeena LT | Sicintine | Sicintine | | 0 | |
| U Skeena LT | Kluatantan | Kluant | | 0 | |
| U Skeena LT | Kluayaz | Kluayaz | | 0 | |
| Skeena RT | All | Skeena RT | <1 | 554 | 12 (2002-2015) |

Table B.6. *Overview of DNA Baseline Samples For Nass Sockeye.*. U = Upper, M = Middle, L = Lower, SRT = Sea and River Type, RT = River Type, LT = Lake Type.

| LHAZShort | Watershed | Stock | SampleSite | Samples | Years |
|---|---|---|---|---|---|
| Nass SRT | Lower Nass Tribs | Lower Nass Sea & River Type | Gingit_RT | 442 | 4 (1987-2011) |
| Nass SRT | Lower Nass Tribs | Lower Nass Sea & River Type | Gitzyon_RTCr | 30 | 2 (2013-2014) |
| Nass SRT | Lower Nass Tribs | Lower Nass Sea & River Type | Zolzap_juv_RT | 60 | 2 (1996-1997) |
| U Nass LT | Meziadin | Meziadin | Hanna_Cr | 253 | 3 (2001-2006) |
| U Nass LT | Meziadin | Meziadin | Meziadin_beach | 188 | 1 (2001) |
| U Nass LT | Meziadin | Meziadin | Strohn_Cr | 140 | 2 (2017-2018) |
| U Nass LT | Meziadin | Meziadin | Tintina_Cr | 203 | 3 (2001-2006) |
| U Nass LT | Bell-Irving | Bowser | Bowser | 827 | 7 (1986-2001) |
| U Nass LT | Kwinageese | Kwinageese | Bonney | 544 | 6 (1987-2001) |
| U Nass LT | Kwinageese | Kwinageese | Kwinageese | 194 | 3 (1987-2001) |
| U Nass LT | Damdochax | Damdochax | Damdochax | 557 | 6 (1987-2001) |
| Nass RT | Upper Nass Tribs | Upper Nass River Type | Brown_Bear_RT | 237 | 7 (1997-2013) |

Table B.7. *Overview of DNA Baseline Samples For Skeena Sockeye.* U = Upper, M = Middle, L = Lower, SRT = Sea and River Type, RT = River Type, LT = Lake Type.

| LHAZShort | Watershed | Stock | SampleSite | Samples | Years |
|---|---|---|---|---|---|
| L Skeena LT | Gitnadoix | Alastair | Alastair | 354 | 5 (1987-2006) |
| L Skeena LT | Lakelse | Lakelse | Schulbuckhand | 102 | 2 (1988-2005) |
| L Skeena LT | Lakelse | Lakelse | Williams | 434 | 5 (1987-2006) |
| L Skeena LT | Kitsumkalum | Kitsumkalum | Kalam/Cedar_Cha | 100 | 1 (2012) |
| L Skeena LT | Kitsumkalum | Kitsumkalum | Kalum | 77 | 1 (1994) |
| L Skeena LT | Kitsumkalum | Kitsumkalum | Kalum_lake | 89 | 1 (2006) |
| L Skeena LT | Zymoetz | Mcdonell | McDonnell | 283 | 4 (1987-2002) |
| L Skeena LT | Zymoetz | Mcdonell | Zymoetz | 64 | 1 (2006) |
| M Skeena LT | Kitwanga | Kitwanga | Kitwanga | 554 | 3 (1998-2009) |
| M Skeena LT | Bulkley | Morice | Atna_Lake | 101 | 2 (2015-2016) |
| M Skeena LT | Bulkley | Morice | Nanika | 157 | 4 (1988-2012) |
| M Skeena LT | Kispiox | Swan/Stephens | Stephens_Lk | 202 | 2 (2001-2004) |
| M Skeena LT | Kispiox | Swan/Stephens | Swan_Lk | 288 | 3 (1988-2006) |
| M Skeena LT | Babine | Babine Early Wild | Four_Mile | 227 | 3 (1987-2006) |
| M Skeena LT | Babine | Babine Early Wild | Grizzly | 78 | 1 (1987) |
| M Skeena LT | Babine | Babine Early Wild | Pierre | 318 | 4 (1987-2013) |
| M Skeena LT | Babine | Babine Early Wild | Twain_Cr | 205 | 3 (1987-2014) |
| M Skeena LT | Babine | Babine Early Wild | U_Babine | 291 | 3 (1987-2006) |
| M Skeena LT | Babine | Babine Late Wild | Babine_Fence | 190 | 2 (1959-1960) |
| M Skeena LT | Babine | Babine Late Wild | L_Babine | 150 | 2 (1987-1994) |
| M Skeena LT | Babine | Babine Mid Wild | Morrison_Cr | 306 | 4 (1988-2014) |
| M Skeena LT | Babine | Babine Mid Wild | Morrison_L | 88 | 1 (2012) |
| M Skeena LT | Babine | Babine Mid Wild | Tahlo | 395 | 5 (1987-2013) |
| M Skeena LT | Babine | Pinkut | Pinkut | 492 | 4 (1985-1994) |
| M Skeena LT | Babine | Fulton | Fulton_L | 536 | 4 (1985-1994) |
| U Skeena LT | Slamgeesh | Slamgeesh | Slamgeesh | 672 | 3 (2004-2008) |
| U Skeena LT | Sustut | Bear | SalixBear | 116 | 2 (1987-1988) |
| U Skeena LT | Sustut | Sustut | Sustut | 341 | 4 (1993-2006) |
| Skeena RT | All | Skeena River Type | Bulkley_R_upper | 46 | 5 (2004-2015) |
| Skeena RT | All | Skeena River Type | Cranberry_RT | 16 | 1 (2008) |
| Skeena RT | All | Skeena River Type | HallidaySlou_RT | 68 | 4 (2005-2009) |
| Skeena RT | All | Skeena River Type | Kispiox_RT | 261 | 3 (2002-2009) |
| Skeena RT | All | Skeena River Type | NangeeseKisp_RT | 163 | 8 (2002-2011) |
| L Skeena LT | Ecstall | Johnston | Johnston_Lake | 121 | 1 (2010) |

## B.4 Lake Surveys

### B.4.1 Lake Trophic Assessments

Estimates of lake-rearing capacity are available for most Skeena and Nass sockeye rearing lakes. Lake rearing capacity can be used to estimate biological benchmarks for lake-type sockeye populations, either in a Bayesian framework that incorporates prior information for habitat capacity (Bodtker et al. 2007), or directly as alternatives to abundance-based benchmarks, especially for data-limited populations. Habitat-capacity estimation models such as the Euphotic Volume (EV) model (e.g., Koenings and Burkett 1979) and the Photosynthetic Rate (PR) capacity model (e.g., Shortreed et al. 2000) can be used to predict the smolt biomass ($R_{MAX}$) and spawner escapement ($S_{MAX}$) that maximize recruitment for sockeye salmon based on the estimated total carbon production of a lake for sockeye populations where productivity is limited by lake rearing capacity.

The PR capacity model is considered to be more reliable for BC sockeye rearing lakes than the EV model (Shortreed et al. 2000). The PR model was derived from the EV model, but estimates lake rearing capacity directly from measurements of photosynthetic rate. The EV model estimates rearing capacity indirectly from euphotic zone depth.

The PR capacity estimates reported here were collected from surveys conducted on sockeye nursery lakes in the Skeena and Nass watersheds. Data were collected in 1978 (Stockner and Shortreed 1979), 1994-1995 (Shortreed et al. 1998), and throughout the 2000s (Cox-Rogers and Hume, pers. comm.). PR-based estimates of Rmax and Smax were provided by the DFO-Freshwater Lakes Research group (Cultus Lake Laboratory, Dan Selbie, pers. comm.). Detailed descriptions of data collection and analysis methods are provided in Shortreed et al. (1998) and summarized below.

PR-capacity estimates are based on full-season surveys that incorporate the results of monthly sampling events throughout the growing season. In the absence of a full-season survey, a "synoptic" survey, or single late-season sampling event may be used for estimating PR. A full-season PR capacity estimate can be derived from a synoptic survey using established relationships between the two, using a correlation between full-season and late-summer values from a range of BC sockeye rearing lakes (Cox-Rogers et al. 2010). However, a single sampling event does not capture seasonal variability. Estimates of optimal smolt and spawner production based total PR use linear relationships based coastwide surveys. Table B.8 summarizes the calculations.

Further adjustments, which are made for some Skeena and Nass lakes to account for lakes with a high proportion of limnetic competitors, lakes which produce smaller smolts than the 4.5 g biostandard used in the standard PR model, and lakes with a high proportion of age-2 smolts, are described in Cox-Rogers et al. (2010).

Habitat- and abundance-based benchmarks can be compared using established relationships. For nine data-rich sockeye salmon conservation units in the Fraser, $S_{MSY}$ estimated using a Ricker-based spawner recruitment model was approximately equal to 70% of habitat-based $S_{MAX}$ estimated using the PR capacity model and $S_{GEN}$ was roughly equal to 25% of habitat-based $S_{MAX}$ (Grant et al. 2011b). Therefore, an escapement goal of 80% of $S_{MSY}$, which has been recommended as an upper benchmark of spawner abundance (Holt et al. 2009), would be equivalent to 56% of habitat capacity-based $S_{MAX}$ (Grant et al. 2011a). Alternatively, Holt et al. (2009) recommend using 20% and 40% of habitat-capacity $S_{MAX}$ as upper and lower benchmarks under conditions of moderate productivity assuming Ricker-type recruitment dynamics.

Table B.8. *Phototsynthetic Rate Model Equations*. Extracted from Shortreed et al. (2000) and using their notation.

| Quantity | Variable | Calculation |
|---|---|---|
| Seasonal Average PR (from seasonal data) | $PR_{mean}$ | Integrate daily PR observations; divide by length of growing season |
| Seasonal Average PR (from 1 synoptic survey) | $PR_{mean}$ | $PR_{mean} = PR * 0.748$ (r2 = 0.60, n=113) |
| Total Seasonal PR (standardized to May 1 - Oct31) | $PR_{total}$ | $PR_{total} = PR_{mean} * lake\ area * length\ of\ growing\ season$ |
| Maximum smolt biomass a lake can produce (kg) | $R_{max}$ | $R_{max} = 45.5 * PR_{total}$ |
| Optimum escapement (the number of spawners needed to maximize smolt production) | $S_{max}$ | $S_{max} = 187 * PR_{total}$ |
| Maximum smolts (number of 4.5 g smolts) a lake can produce | N | $N = 10120 * PR_{total}$ |

Table B.9. *Summary of Available Lake Capacity Estimates*. Lakes are sorted by size (*Area* in $km^2$). Estimates of the spawner abundance that maximizes recruitment ($S_{max}$) can be derived from observed photosynthetic rate (PR) in the lake, which reflects primary production at the base of the lake's food chain (Appendix B.4.1). Table lists the year of the last limnological survey (*Last*) used to derive the PR-based $S_{max}$ (*Mean*). 95% confidence intervals (*Lower*, *Upper*) are based on assumed 20% coefficient of variation and a normal distribution (Cox-Rogers and Hume, pers. comm.). Optimal juvenile density (*Rmax*) is in kg of smolts per hectare. Estimates are from two sources: 1 = Cox-Rogers and Hume (pers. comm.) which include lake-specific adjustments for non-sockeye competitors (e.g., stickleback) and juvenile competition , 2 = Atlas et al. (2020) which do not include adjustments. However, adjustments would likely be small for the Nass nursery lakes where we use estimates from Atlas et al. (2020). Note that the Babine estimates combine Babine and Nilkitkwa lakes.

| | | | | | **S_MAX** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Basin | Lake | Stks | Area | Source | Last | Lower | Mean | Upper | Rmax |
| Skeena | Babine | 5 | 461.00 | 1 | 1995 | 1,099,413 | 1,808,245 | 2,517,077 | 10 |
| Skeena | Morice | 1 | 96.10 | 1 | 2002 | 116,348 | 191,362 | 266,376 | 6 |
| Nass | Bowser | 1 | 34.09 | 2 | 2008 | 3,411 | 5,610 | 7,809 | |
| Nass | Meziadin | 1 | 33.21 | 2 | 2008 | 106,419 | 175,032 | 243,645 | |
| Skeena | Bear | 1 | 18.80 | 1 | 2003 | 24,643 | 40,532 | 56,421 | 5.3 |
| Skeena | Kitsumkalum | 1 | 18.50 | 1 | 1996 | 12,483 | 20,531 | 28,579 | 2.7 |
| Skeena | Swan | 1 | 17.50 | 1 | 2002 | 13,031 | 21,432 | 29,833 | 2.95 |
| Skeena | Lakelse | 1 | 13.64 | 1 | 2003 | 21,837 | 35,916 | 49,995 | 6 |
| Skeena | Morrison | 1 | 13.20 | 1 | 1996 | 27,109 | 44,587 | 62,065 | 8.2 |
| Skeena | Kitwanga | 1 | 7.74 | 1 | 2003 | 22,486 | 36,984 | 51,482 | 17 |
| Skeena | Alastair | 1 | 6.90 | 1 | 1996 | 14,250 | 23,437 | 32,624 | 8.2719 |
| Skeena | Atna | 1 | 5.10 | | | | | | |
| Nass | Fred Wright | 1 | 3.97 | 2 | 1978 | 12,279 | 20,195 | 28,111 | |
| Skeena | Motase | 1 | 3.97 | 1 | 2003 | 1,073 | 1,764 | 2,455 | 1.1 |
| Nass | Kwinageese | 1 | 2.66 | 2 | 2008 | 11,597 | 19,074 | 26,551 | |
| Skeena | Sustut | 1 | 2.50 | 1 | 2004 | 1,687 | 2,775 | 3,863 | 2.7 |
| Skeena | Mcdonell | 1 | 2.32 | 1 | 2001 | 2,476 | 4,072 | 5,668 | 4.3 |
| Skeena | Azuklotz | 1 | 2.20 | 1 | 2003 | 3,607 | 5,933 | 8,259 | 6.6 |
| Skeena | Stephens | 1 | 1.97 | 1 | 2002 | 4,298 | 7,069 | 9,840 | 8.7 |
| Skeena | Johnston | 1 | 1.87 | 1 | 2005 | 2,508 | 4,125 | 5,742 | 5.4 |
| Nass | Damdochax | 1 | 1.48 | 2 | 2008 | 2,956 | 4,862 | 6,768 | |
| Skeena | Kluayaz | 1 | 1.45 | | | | | | |
| Skeena | Johanson | 1 | 1.40 | 1 | 2004 | 1,656 | 2,723 | 3,790 | 5 |
| Skeena | Ecstall | 1 | 1.02 | | | | | | |
| Skeena | Sicintine | 1 | 0.68 | | | | | | |
| Skeena | Aldrich | 1 | 0.64 | 1 | 2001 | 679 | 1,116 | 1,553 | 4.2 |
| Skeena | Maxan | 1 | 0.60 | | | | | | |
| Skeena | Dennis | 1 | 0.50 | 1 | 2001 | 663 | 1,091 | 1,519 | 5.3 |
| Skeena | Slamgeesh | 1 | 0.45 | 1 | 2001 | 257 | 423 | 589 | 2.3 |
| Skeena | Asitka | 1 | 0.40 | | | | | | |
| Skeena | Club | 1 | 0.39 | 1 | 2002 | 358 | 589 | 820 | 3.6 |
| Skeena | Damshilgwit | 1 | 0.32 | 1 | | | | | |
| Skeena | Spawning | 1 | 0.20 | | | | | | |

### B.4.2 Juvenile Surveys of Rearing Lakes

Rotating lake surveys have been completed annually since the mid-1990s (e.g., Doire and Carr-Harris 2017). Lake surveys included hydroacoustic transects with a zodiac-mounted echosounder and biological sampling using trawl and gill nets. Table 7 of Doire and Carr-Harris (2017) lists the annual survey results and corresponding source reports.

Sockeye rearing lakes have been covered comprehensively in the rotating surveys, with all the major lakes surveyed multiple times (Tables B.10 and B.11).

Weight and density of age-0 sockeye differ between lakes, both in terms of median and observed range (Figure B.1). Lakes with higher densities tend to have smaller sockeye juveniles (e.g., Johnston, Meziadin, Sustut), while the lakes with the largest sockeye juveniles tend to have lower densities (e.g., Lakelse, Azuklotz, Kitwancool). Some lakes with multiple surveys show large variations in weight of sockeye juveniles (e.g., Lakelse, Azuklotz, Morice), while in others density varies considerably across years (e.g., Johnston, Fred Wright).

Estimates of fall fry abundance can serve as a status indicator for systems where spawner estimates are highly uncertain, and provide a cross-check on the spawner estimates (Figure B.2). Overall, there is a strong correlation between brood year spawners and fall fry abundance the following year. However, the observed pattern differs between lakes, with some lakes showing correlation in the small data set (e.g., Fred Wright, Morrison), while for other lakes there seems to be little relationship between the two sets of estimates (Lakelse, Mcdonell).

Comparisons between lakes and across years are affected by the interaction between size and density, which in turn is linked to variable spawner abundances (Figure B.4). In addition, annual estimates of fry biomass are affected by sampling date, due to the rapid growth of juvenile sockeye (Figure B.3).

Table B.10. *Overview of Nass Sockeye Rearing Lakes*. Lakes are grouped by watershed, and then ranked by *pSpn*, the % of the cumulative spawner abundance since 2000 (i.e., sum of the annual estimates for stocks rearing in each lake / sum across all stocks). *Clarity* is a qualitative assessment of lake clarity. *Productivity* is a qualitative classification of primary production in the lake into *oligotrophic* (low nutrients, low plant growth) or *eutrophic* (high nutrients, high plant growth). *YrsDens* and *YrsWt* show the number of years for which density and weight estimates for juvenile sockeye are available, respectively. *YrsFallFry* is the number of years with estimates of fall fry abundance. *LastSurv* is the most recent year in which any type of lake survey was completed.

| Watershed | Lake | pSpn | Clarity | Productivity | YrsDens | YrsWt | YrsFallFry | LastSurv |
|---|---|---|---|---|---|---|---|---|
| Meziadin | Meziadin | 14.57 | Clear | | 9 | 8 | 1 | 2017 |
| Bell-Irving | Bowser | 0 | | | | | | |
| | Oweegee | 0 | | | | | | |
| Kwinageese | Fred Wright | 0.18 | Clear | | 9 | 1 | 9 | 2012 |
| | Kwinageese | 0.18 | | | | | | |
| Damdochax | Damdochax | 0.1 | Clear | | 5 | 5 | 5 | 2017 |
| | Wiiminosik | 0.1 | Clear | | 4 | 4 | 4 | 2017 |

Table B.11. *Overview of Skeena Sockeye Rearing Lakes*. Column explanations as per Table B.10.

| Watershed | Lake | PercEffSpn | Clarity | Productivity | YrsDens | YrsWt | YrsFallFry | LastSurv |
|---|---|---|---|---|---|---|---|---|
| Ecstall | Johnston | 0.13 | Clear | | 4 | 4 | 4 | 2019 |
| | Ecstall | 0 | Stained | | 3 | 3 | 3 | 2019 |
| Gitnadoix | Alastair | 2.5 | Clear | Eutrophic | 5 | 5 | 4 | 2019 |
| Lakelse | Lakelse | 1.3 | Clear | Oligotrophic | 13 | 11 | 13 | 2018 |
| Kitsumkalum | Kitsumkalum | 2.5 | Turbid | Oligotrophic | 6 | 6 | 6 | 2018 |
| Zymoetz | Mcdonell | 0.19 | Clear | | 17 | 16 | 16 | 2019 |
| | Dennis | 0.14 | | | | | | |
| | Aldrich | 0.14 | | | | | | |
| Kitwanga | Kitwanga | 0.33 | Clear | Eutrophic | | | | |
| Bulkley | Bulkley | 0 | | Eutrophic | | | | |
| | Maxan | 0 | | | | | | |
| | Morice | 1.38 | Stained | Oligotrophic | 4 | 4 | 2 | 2019 |
| | Atna | 0.34 | | | | | | |
| Kispiox | Swan | 0.77 | Clear | Oligotrophic | 4 | 4 | 4 | 2017 |
| | Stephens | 0.38 | Clear | Oligotrophic | 7 | 6 | 7 | 2019 |
| | Club | 0.13 | | | | | | |
| Babine | Tahlo | 1.62 | | | | | | |
| | Morrison | 2.95 | Clear | Oligotrophic | 4 | 4 | 4 | 2016 |
| | Babine | 69.91 | | | | | | |
| | Nilkitkwa | 1.62 | Clear | Oligotrophic | 4 | 4 | 2 | 2016 |
| Sicintine | Sicintine | 0 | | | | | | |
| Slamgeesh | Slamgeesh | 0.02 | | | | | | |
| | Damshilgwit | 0.02 | | | | | | |
| Motase | Motase | 0 | Turbid | | 3 | 1 | 2 | 2013 |
| Sustut | Bear | 0.71 | Clear | Eutrophic | 6 | 6 | 6 | 2018 |
| | Azuklotz | 0.18 | Clear | Eutrophic | 4 | 4 | 4 | 2015 |
| | Asitka | 0.1 | | | | | | |
| | Sustut | 0.04 | Clear | Oligotrophic | 5 | 5 | 5 | 2018 |
| | Spawning | 0.04 | | | | | | |
| | Johanson | 0.04 | Clear | Oligotrophic | 5 | 5 | 5 | 2018 |
| Kluantantan | Kluantantan | 0 | | | | | | |
| Kluayaz | Kluayaz | 0 | | | | | | |

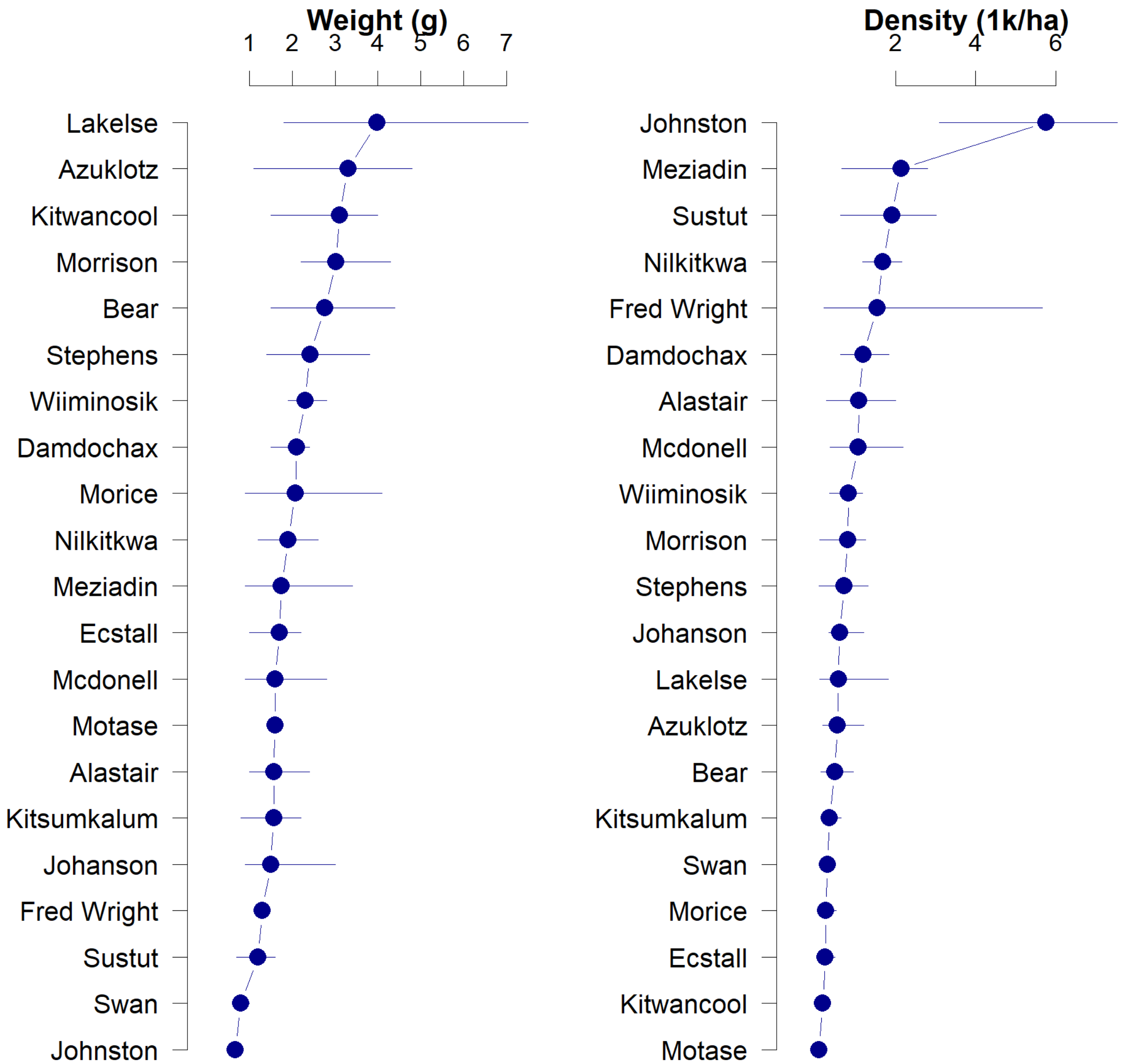


Figure B.1. *Surveyed Lakes Ranked By Weight and Density of Juveniles*. Points show the median, and whiskers show the min-max range.

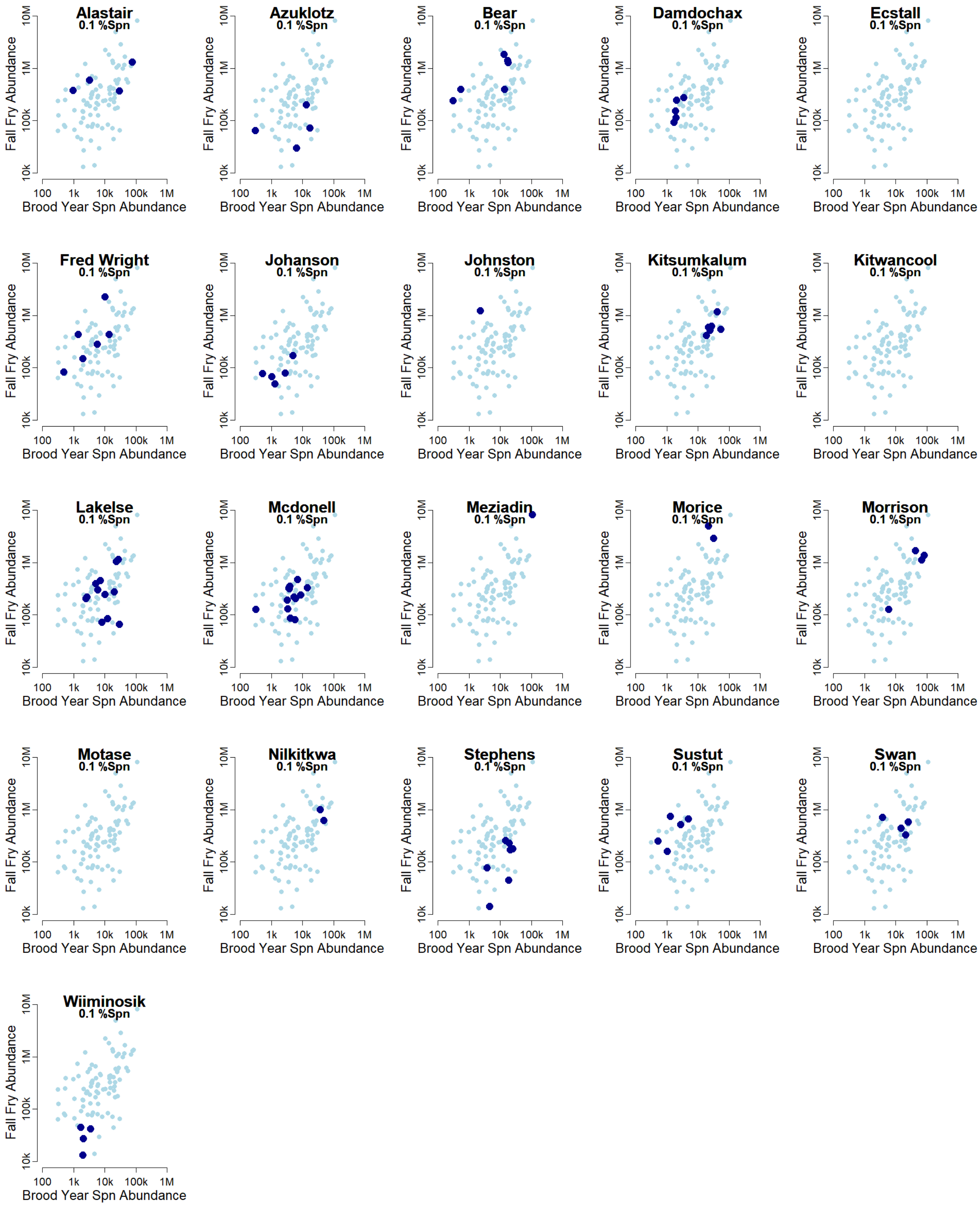


Figure B.2. *Fall Fry Abundance vs. Brood Year Spawner Abundance*. Fall fry estimates are from the lake surveys. Brood year spawner estimates are the sum of spawner estimates (Section C) for all stocks rearing in the lake. Light points show all available data (all lakes, all years). Dark points show data for the lake identified in the title for each panel.

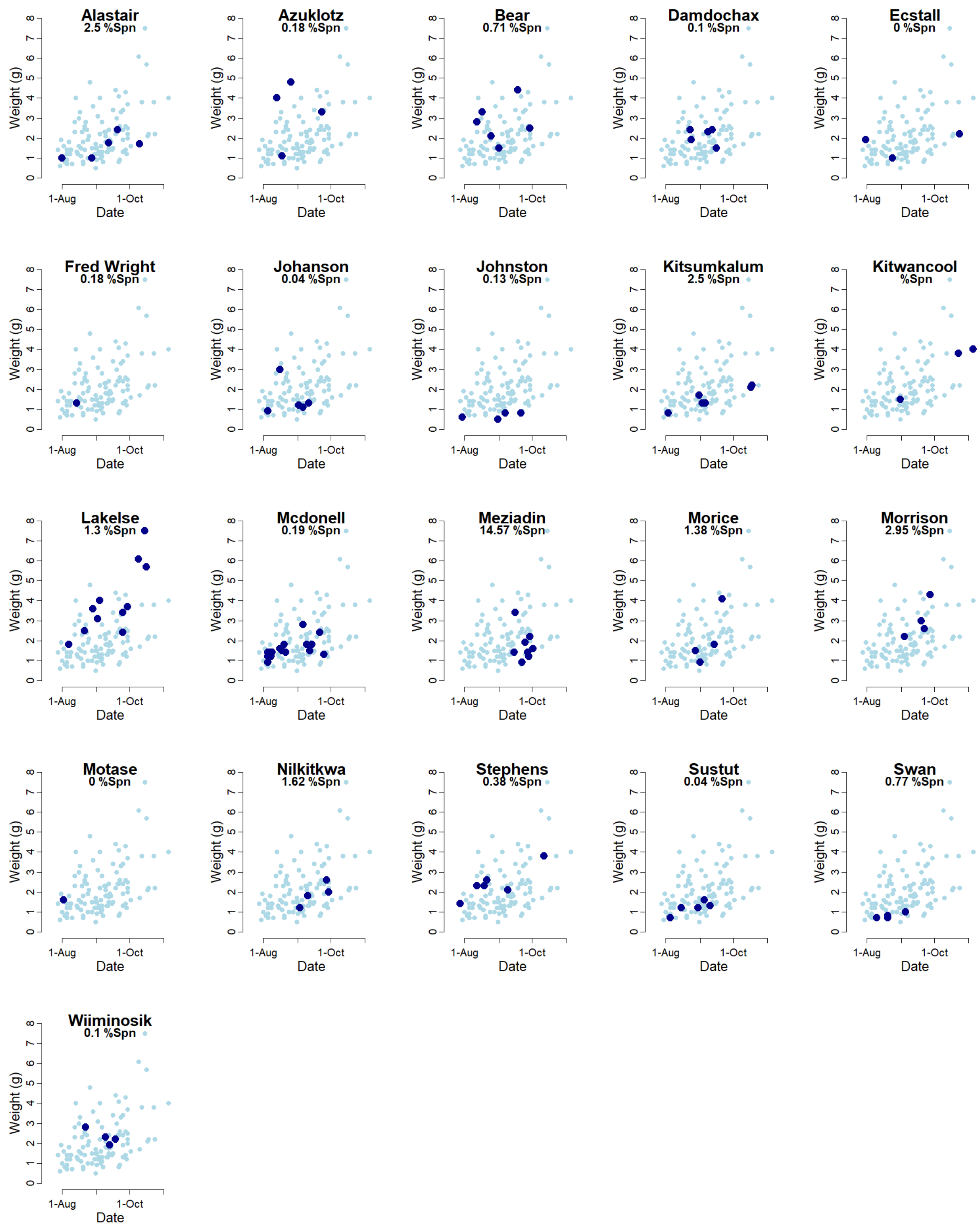


Figure B.3. *Juvenile Weight by Sampling Date.* Light points show all available data (all lakes, all years). Dark points show data for the lake identified in the title for each panel.

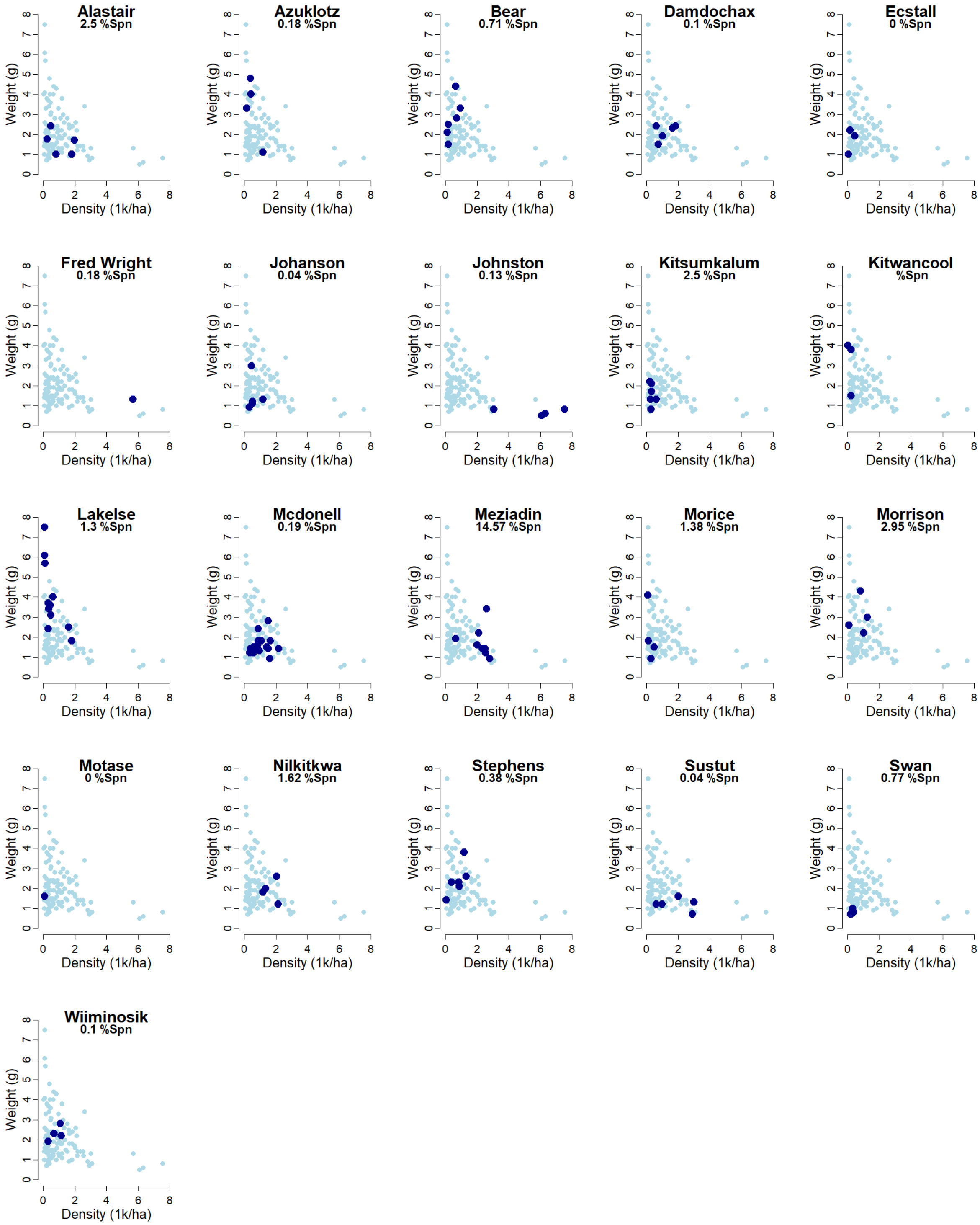


Figure B.4. *Juvenile Size vs. Density*. Light points show all available data (all lakes, all years). Dark points show data for the lake identified in the title for each panel.

# APPENDIX C Abundance Estimation

## C.1 Spawner Data Review

Escapement estimates and raw stream count data for all North Coast streams are stored in local and regional databases. Annual escapement reports (also known as BC16 records) for all North Coast streams (PFM Areas 1-6) are processed and stored locally. They are available from all years to present as scanned paper records prior to 2003, and have been entered in a database for years since 1998.

Stream inspection logs (SIL) that document raw count data for all North Coast streams are available in a local database for all years since 1998 for Skeena systems, and 1993 for some Nass systems. Although some paper records are available for years prior to 1998, these records are incomplete due to inconsistent storage and archiving procedures over time.

Annual escapement estimates for all North Coast indicator streams are stored in a regional database, the *New Salmon Escapement Database System* (NUSEDS) which is publicly accessible at https://open.canada.ca/data/en/dataset/c48669a3-045b-400d-b730-48aafe8c5ee6. Some Stream Inspection Log (SIL) data (raw count data) for stream surveys are also stored in NUSEDS.

The information contained in local databases is generally more detailed than the regional data base system and contain more information about estimation methods used and conditions encountered by surveyors. The information contained in the regional database has not been reviewed by DFO area biologists for completion or accuracy since 2009 (Spilsted and Spencer 2009). Since 1998, stream escapement and SIL data have been uploaded directly to the regional database by DFO North Coast Area staff.

Quality of the raw data, estimates for indicator systems, and expanded estimates of spawner abundance vary between stocks and over time. Spilsted and Spencer (2009) discuss the data limitations (their Section 3 and Figure 24), and identify the following potential concerns:

- incomplete or erroneous transcription of raw data from the *Stream Inspection Log* (SIL) or *Annual Stream Report* (a.k.a BC16) into the database (*"recovered paper documents entered into the database may represent only a partial dataset of what was originally generated by field staff"*).
- documented and undocumented expansions (*"expansions may occur in total estimates for individual stream inspections and for estimates of total annual spawners"*)
- variable survey methods (*"fence count, fixed and rotary wing over-flight, mark-recapture, swim, boat floats and stream walks"*)
- variable estimation methods (*"total count, partial count, peak live plus dead, area-under-the curve"*)
- interpretation of "0" or blank records (*"A zero may mean that a species was surveyed and none were seen, or during a stream visit the species was simply not surveyed for, or no inspection was ever done, or possibly some other reason. Blanks may mean that a species*

*was never surveyed or that the data never made it to the database or that the species is not known to spawn in the particular stream. Where supporting information has been lost or where time has not permitted proper analysis, some questionable zeroes and blanks may still remain in the database.”*)

The escapement estimates for indicator streams that have been used for NCCSDB run reconstructions were downloaded from NUSEDS. While the expansion procedures have been reviewed on several occasions (e.g., English et al. 2019), the underlying escapement estimates were not previously reviewed.

DFO staff reviewed escapement estimates for Skeena and Nass sockeye indicator streams, and searched regional and North Coast data holdings, described above, for additional information for missing stream-years, and estimates that were flagged as questionable.

For indicator streams and years after 1998 for which stream count data were available (in either the local or regional SIL databases, escapement estimates for indicator streams were reviewed and revised according to the following procedures:

- Download and extract raw survey count data from SILs from regional and area databases for the years 1998-2019 for each indicator stream.
- Recalculate AUC estimates for stream-years where more than two counts were available. For these estimates, observer efficiency and stream residence time were chosen based on information provided by observers in the SIL comments, if available.
- Calculate peak * 2 estimate ((maximum count/observer efficiency)* 2) for each stream-year
- Identify any alternative escapement estimates that were conducted for indicator streams during this time period (ie. mark-recapture estimates)
- Select the best estimate for each stream-year based on available data (generally, AUC for years where count data from 3+ surveys were available, peak * 2 for years when data for 1-2 surveys were available).
- If an alternative estimate was available for a given year from a weir count or mark recapture program (assume lower uncertainty for mark-recapture compared with estimates based on AUC or peak counts), it was recommended as the best estimate for that stream-year.
- If the best estimate (above) differed substantially from the published NUSEDS estimates (we applied a threshold of 35% difference), a recommendation was made to revise the indicator stream escapement estimate for the NCCSDB.

Additional estimation review procedures were applied to systems where there was additional available information that had not previously been included in the NUSEDS regional database, including:

*Morice Lake sockeye*

The Office of the Wet’suwet’en operates a mark and recapture program in the lower Bulkley River near the community of Wit’set, which has generated abundance estimates for all species of salmon entering the Bulkley River since 2002. Morice River is the largest tributary of the Bulkley River and sockeye from Morice Lake account for most Bulkey River sockeye. Other known Bulkley sockeye populations include upper Bukley River, and Maxan and Bulkley lakes. Few to no sockeye have been observed in any of these systems since 1998, and we used the Wit’set mark and recapture estimate as a proxy for Morice sockeye abundance for years since 2002.

AUC estimates are available for most years (2003 – 2019) for Nanika River, the primary indicator which accounts for most sockeye spawners for Morice lake sockeye. For years where AUC estimates were not available (2002 and 2005) escapement estimates were calculated using a linear regression between mark-recapture estimates from the Lower Bulkley and Nanika River spawning ground estimates.

*Sustut/Johanson sockeye*

The BC Ministry of Environment operates a counting weir on the Sustut River which produces accurate counts of sockeye, steelhead, and Chinook salmon. Although these counts have not been included in the NUSEDS regional database, the sockeye estimates are considered to be high quality. Because the Sustut weir is located downstream of the confluence with Johanson Creek, the weir count represents adult spawner for both the Sustut Lake and Johanson Lake CU’s. Fall fry hydroacoustic surveys which were conducted at both Sustut and Johanson Lakes in 2010, 2013, 2015, and 2018 suggest that most of these fish return to Sustut Lake. To apportion the weir count by CU, we combined the observed fry population for Sustut and Johanson Lake for each year that hydroacoustic data were available, and estimated the relative proportion for each lake by brood year, which was multiplied by the weir count for each year to estimate the number of fish that returned to each lake. For years where hydroacoustic data were not available, we multiplied the weir count by the average proportion of Sustut and Johanson sockeye fry in hydroacoustic surveys across years (82% Sustut, 18% Johanson).

## C.2 Spawner Estimate Expansions (Most Stocks, except Babine)

For non-Babine systems, raw spawner escapement estimates for indicator streams are expanded to account for sockeye not counted in surveys of indicator streams. English et al. (2012) describe the expansion calculations in detail in their Appendix A.

Briefly, the observed spawner records for indicator streams are expanded in 3 steps. Expansion factor 1 (EF1) infills spawner abundances to account for indicator streams that were not surveyed in a given year, and Expansion Factor 2 (EF2) expands spawner abundances to account for escapement from non-indicator streams. Expansion Factor 3 (EF3) expands the estimate to account for observer efficiency.

EF 1 and 2 use decadal averages from time periods when spawner escapement data for all indicator and non-indicator streams for a given CU were available, and assume that the relative contributions of indicators and non-indicator streams to each CU are constant.

EF 3 is intended to account for fish that are missed by the surveys, while EF 1 and 2 account for systems without records (not done in a year, do not meet quality criteria, not a surveyed system). Observer efficiency varies by survey method and species (e.g., counting Chinook redds during an overflight is more accurate than estimating sockeye spawner numbers), but can also be affected by local annual conditions (e.g., water conditions, weather). Assumed observer efficiency corrections for Skeena and Nass sockeye salmon are based on expert judgement. English et al. (2004) used an adjustment of 2.59 for non-Babine Skeena sockeye (i.e., the actual abundance for an indicator stream is about 2 1/2 times larger than the counted number of fish).

In addition to these expansion factors, the NCCSDB also assigns quality ratings to the expanded annual abundance estimates for each CU. These quality ratings have three components, which are summed to produce an overall quality rating for each estimate. Each of the quality rating components are assigned on a scale of 5, which are derived from the expansion factors described above, and include:

- Q1, which describes the quality of each survey on a scale of 1-5, ranging from poor (surveys of low reliability due to counting deficiencies or few surveys) to excellent (i.e., a full, unbreached fence count);
- Q2, which describes the degree to which surveys of indicator streams were conducted, estimated as $5/EF1$; and
- Q3, which describes the portion of indicator streams represented by all indicator streams in a CU, or $5/EF2$ (English et al. 2012).

The quality ratings therefore have a maximum value of 15.

### C.3 Babine Spawner Estimates

Babine Sockeye are enumerated at the Babine weir at the outlet of Nilkitkwa Lake, which provides a full census count of all wild and enhanced sockeye entering the Babine Lake complex. Enhanced Babine Sockeye are enumerated by weir counts as they enter the BLDP facilities, and by visual surveys in wild spawning tributaries and in spawning areas downstream of the Pinkut and Fulton weirs.

The Babine weir program is assumed to provide a complete count for most years, but adjusted in some years for estimated passage during times when the fence was not operational. A variable proportion of the fish that are counted through the Babine weir do not spawn in the spawning channels or wild tributaries. Although it was previously assumed that Babine sockeye spawners in excess of the capacity of known spawning areas in wild and enhanced systems spawned in lakeshore spawning habitats, dive surveys in the 1990s confirmed that these additional fish do not spawn successfully. Adjustments are made to estimate the magnitude of the enhanced surplus and assign catches that occur within the Babine system to the different stocks. Wood et al. (1998) and Cox-Rogers and Spilsted (2012) describe the rationale and procedures and equations that are used for these adjustments. Appendix Table 2 in Cox-Rogers and Spilsted (2012) lists the equations. Briefly, the adjustments are implemented as follows (Figure C.1):

- The total run size into the Babine system, which is available from the fence counts, is usually larger than the sum of the capacity of the spawning channels and visual counts for wild tributaries. The unaccounted difference between the fence count and escapements to wild and enhanced systems is adjusted to account for the known bias in underestimation for visual escapement surveys of the wild systems.
- Effective spawner abundance for the channel systems is the number of spawners let into the channel plus the estimated capacity of natural spawning grounds below the channel. Any additional large sockeye that do not spawn in the wild parts of Pinkut and Fulton, or in the wild systems (adjusted estimates) are considered a biological surplus, and are excluded from the estimates of spawner abundance (but are included in estimates of run size).

Wood (1995) developed a simple reconstruction to estimate the surplus production after correcting visual escapement estimates for early, mid and late wild timing groups for underestimation bias, which were updated in Wood (1998) and Cox-Rogers and Spilsted (2012) and maintained in a DFO database.

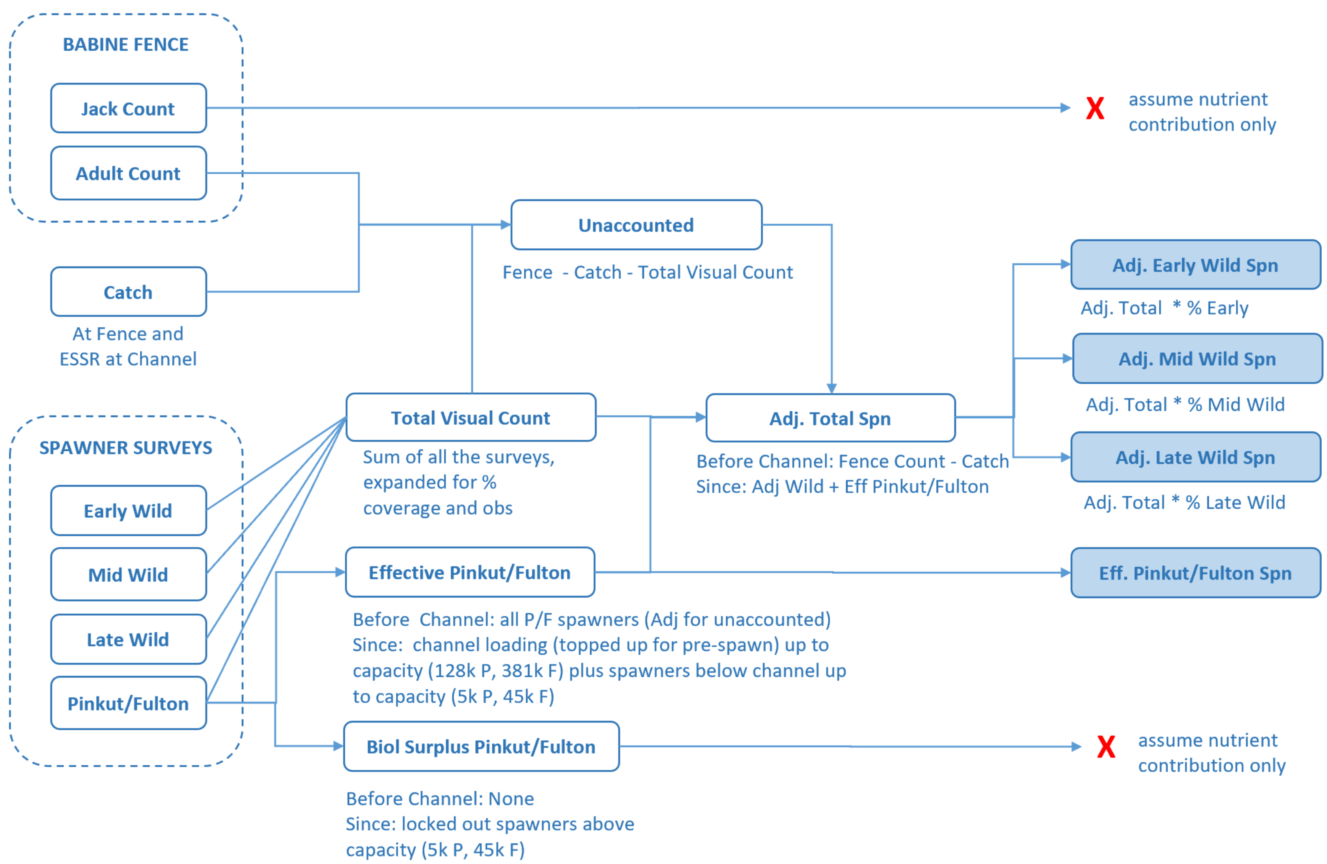


Figure C.1. Overview of Terminal Babine Run Size and Spawner Calculations. Figure illustrates the general flow of information from survey data (left side) through estimates of intermediate variables to final spawner estimates (blue boxes on the right.

## C.4 Northern Boundary Sockeye Run Reconstruction

The Northern Boundary Sockeye Run Reconstruction (NBSRR) model builds aggregate run estimates for Skeena and Nass sockeye. Gazey and English (2000) and English et al. (2004) describe *Northern Boundary Run Reconstruction* (NBRR) calculations in detail. Alexander (2018) provide an update on methods. This section summarizes the key components of the model.

The NBSRR works backwards, beginning with the best estimate of the number of fish entering each river system and adds daily catch from all fisheries along a migration path, and produces catch, exploitation rate, and run size estimates for 5 modelled stocks, including Skeena, Nass, and Stikine stocks originating from Canada, and Hugh Smith and MacDonald which are Southeast Alaska origin sockeye stocks. Catches of non-modelled stocks like Fraser, Central Coast, Washington and non SE Alaska sockeye stocks were estimated from Alaska DNA programs and removed from modelled catches. Since 1982, Fraser catch removals averaged 108,000 sockeye (range: <100-539,000) and other non-modelled stock catch removals averaged 19,000 (range: 6,000-39,000) since 2013 that included any non-modelled stock catches in Canadian fisheries.

In-river abundance estimates for sockeye entering the Nass are based on the size of the terminal run passing the lower Nass fish wheels, which are estimated using a mark-recapture program, plus catches of Nass sockeye below the fishwheels to estimate the terminal run. A 3 day lag at the fishwheels is used to estimate the terminal run entry timing to the mouth of the Nass River. For the Skeena, terminal run size abundance is estimated as the number of fish enumerated at the Babine weir, which is expanded to account for in-river fisheries and the proportion of non-Babine sockeye determined by GSI sampling at the Tyee Test Fishery. Daily escapement estimates for both fisheries are estimated using the daily proportion of fish of fish passing the Nass fish wheels or Tyee Test Fishery from in-season models English et al. (2004).

The NBSRR incorporates catch data from 14 US and 14 Canadian fisheries (only 9 of the 14 Canadian fisheries have been active in recent years; Section B.2). Fisheries are modelled as a network of 22 fishing areas that fish can pass through (Table C.1, Figure C.2) to approximate the migration routes of sockeye returning to the Nass and Skeena basins.

Observed catches in each fishing area are assigned to stock aggregates based on stock composition data from scale or genetic sampling programs (Section B.3), or the modelled migration paths themselves, by assuming equal vulnerability (EV), where stock composition for all fisheries is determined by the abundance of each fishery (Figure C.2).

The possible modelled migration routes for sockeye passing through the network of fisheries are based on the results of tagging studies conducted in 1982 and 1983 (English et al. 1984) that defined an initial 5 migration routes when the model was developed (Gazey and English 2000) based on the results of tagging studies to establish residence times in each fishery and the relative proportion anticipated to pass each fishery. Another 3 migration routes were developed in later years based on matching EV and DNA results for Nass and Skeena sockeye in key Alaska fisheries. Alternative migration patterns were modelled as proportions at each split in the pathway moving backwards along the migration route through the fisheries. The most likely migration route for a given year is chosen using least squares regression.

Catch estimates, and therefore run size for modeled stocks are sensitive to the chosen migration path when stock composition estimates are not available. For example, the proportion of Skeena sockeye migration through the Cordova Bay fishery could be as high as 25% of the run, or as low as 2%, depending on the modelled path. However, the proportion of Skeena sockeye entering PFM Area 4W from a northern route (through PFM Area 3) is modelled as 85% across all alternative migration paths. The specific routing is less important if DNA coverage is available for the majority of catches in each fishery.

The approach for assigning catch to modeled stocks for fisheries without direct stock ID sampling has evolved over time (Table 8 and Appendix C in English et al. 2004; Alexander 2018), from 2 to 8 options for different migration routes.

The NBRR model results are undergoing review to determine the utility of moving towards a simpler model based on more thorough genetic sampling of Alaska and BC fisheries.

Table C.1. *Modelled Marine Fishing Areas For Nass and Skeena Sockeye*. Specific boundaries for some Canadian fisheries were modified over time (Table 1 in English et al. 2004). Alaskan fishery definitions have not changed (Table 2 in English et al. 2004).

| Country | Area | Fishery | Descriptions |
|---|---|---|---|
| US | D105 | D105 | District 105 |
| US | D106 | Sumner | Sumner Strait |
| US | D106 | UClar | Upper Clarence Strait |
| US | D102 | MClar | Middle Clarence Strait |
| US | D101/102 | LClar | Lower Clarence Strait |
| US | D101 | Revilla | Revilla |
| US | D101 | Tree | Tree Point (Cape Fox) |
| US | D104 | Noyes | Noyes Island |
| US | D104 | Dall | Dall Island |
| US | D103 | Cordova | Cordova Bay |
| CA | A1 | Langara | Net: (Langara Isl., Virago Sd., Naden Hrb.) |
| CA | A1 | South Troll | Troll South (Dixon Entrance) |
| CA | 3A | Dundas West | |
| CA | 3B | Entrance | |
| CA | 3C | Outside Portland | |
| CA | 3D | Inside Portland | |
| CA | 3E | Nass Terminal | Pearse Isl., Kincolith, Obs. Inl., Dogfish B. |
| CA | 4W | Outside Area 4 | |
| CA | 4X | Lower Chatham Sound | |
| CA | 4Y | Smith | |
| CA | 4Z | River / Gap / Slough | |
| CA | 5 | Area 5 Net | |

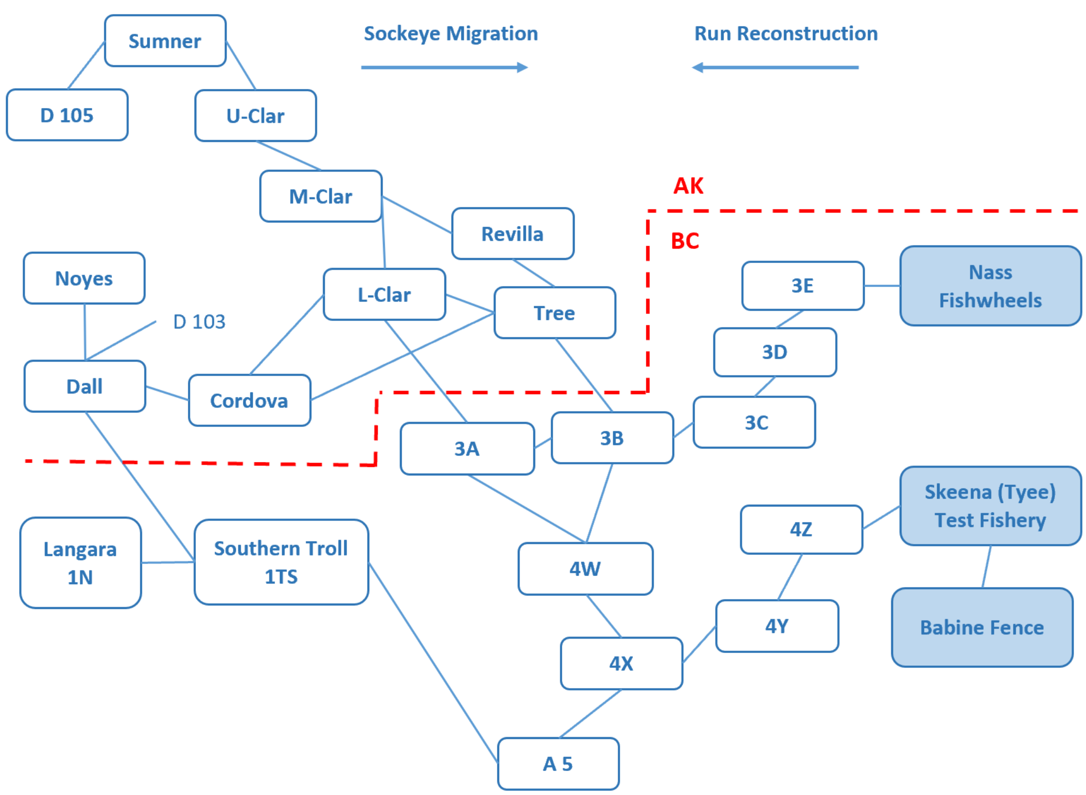


Figure C.2. *Modelled Migration Paths for Nass and Skeena Sockeye*. Figure adapted from Alexander (2018). Fishery definitions in Table C.1. Network of fishing areas approximates the migration paths.

## C.5 In-river Run Reconstruction

### C.5.1 General Approach

In-river harvests are an important component of the total Canadian harvest for Skeena and Nass sockeye. Estimates of in-river harvest, exploitation rates, and total run size for the different stocks are calculated using different approaches for Skeena sockeye and Nass sockeye. For Skeena River fisheries, an in-river reconstruction model combines information from in-river harvests (timing and abundance), escapement (Appendix B.1) and run timing to apportion catches to stocks based on run timing and fishery location (English et al. 2017).

A detailed in-river run reconstruction model has not been developed for Nass sockeye. Instead, we have estimated annual in-river harvest rates for the aggregate Nass stock (i.e., total in-river harvest divided by the run size entering the Nass River) and applied these annual in-river harvest rates equally across all Nass sockeye sub-stocks. This approach was used on the Nass because the majority of in-river harvest occurs in the lower Nass where all stocks are vulnerable. In-river harvest rates are combined with marine exploitation rates from the NBSRR to estimate the total exploitation rate for the different substocks.

Stock-specific estimates of run size and exploitation rate for Skeena sockeye are developed using the *Skeena Sockeye In-river Run Reconstruction* (SSIRR) model (English et al. 2013, 2017), using the same approach as the peer-reviewed run reconstruction model for Fraser River Chinook (English et al. 2018). The SSIRR models in-river harvests for 12 Aboriginal in-river fishing areas throughout the Skeena watershed in daily time steps derived from daily aggregate run size estimates for Skeena sockeye from the Tyee Test fishery in the Lower Skeena (Section B.1). The SSIRR model builds run size estimates forward along the upriver migration through the fisheries.

Reconstructions are done at the stock level (Table C.2). In some cases stocks are modelled as a group, because genetic stock ID currently cannot separate out the component stocks to estimate individual run timing curves. The model therefore assumes equal run timing for the components. At present, the SSIRR models 20 Skeena sockeye stocks, the annual in-river harvest rates for the aggregrate Nass sockeye stock are applied to each of the 10 Nass sub-stocks that were modelled in 2021. The same number of stocks were used from (English et al. (2019); with some changes to stock groupings (e.g., Brown Bear/Cranberry, Gingit/Zolzap, and the addition of Strohn Creek). Run timing and stock composition parameters and escapement estimates were also updated for generating the NBRR for the years 1982 to 2019.

### C.5.2 Skeena Sockeye In-river Run Reconstruction and Nass Sub-stock Timing

Fisheries are modelled as a network of 12 major Aboriginal fishing areas (Table C.3, Figure C.3), that range geographically from coastal/estuarine approach areas to terminal fisheries in tributary streams and lakes. Observed catches in each fishing area are assigned to stocks or stock groups based on modelled run timing and residence time (Figures C.3). Run timing assumptions for different stocks are based on observed stock composition in the Tyee Test Fishery. Catch assignments are based on estimated timing and assumed residence time, because in-river fisheries are not sampled directly for stock composition data. Note that recreational in-river harvests of sockeye, which are assumed to be small, are not accounted for in Skeena or Nass in-river models.

Key assumptions in the Skeena Sockeye In-river Run Reconstruction model, identified by English et al. (2017), include:

- The modelled stocks adequately represent run timing and total escapement
- Daily sockeye CPUE in the Tyee Test Fishery is a reliable abundance index
- Stock specific run timing curves (normal distribution) can be used to derive daily stock composition at Tyee
- Fishing areas and catch data adequately represent timing and location of the major harvests
- Stocks are equally vulnerable to harvesting when present in a fishery (ie harvests are proportional to relative abundance).

The major sources of uncertainty for estimates of stock-specific run size and exploitation rates estimated using in-river run reconstruction techniques include assumptions around run timing, residence time, and uncertain catch and escapement data for some stocks.

The timing of different stocks through the different marine fishing areas for both Skeena and Nass sockeye and in-river fishing areas for Skeena sockeye are modelled using the timing offset relative to aggregate run timing for each stock. Timing offset assumptions for the different stocks are based on historic tagging studies, and more recently GSI from samples collected at the Tyee Test Fishery and Nass fish wheels. Previous assessments of run timing for the different Skeena and Nass substocks were conducted using genetic data collected from 2000 to 2010 (Cox-Rogers et al 2012, English et al. 2015 and 2019) and 2011 (Beacham et al. 2014).

As part of this review, we updated run timing assumptions for Skeena sockeye using genetic data collected up to 2019 and Nass timing data were concurrently updated (Alexander et al. 2021). Weighted weekly genetic proportions were calculated for each stock and year, and averaged across years to estimate the mean weekly proportion and for each stock for different time periods. The peak week of migration past Tyee or the Nass fish wheels for each stock was estimated as the categorically weighted mean for all weeks. The duration of the run for each stock was set using 2 times the standard deviation. For both Skeena and Nass, including data to 2019 had little effect on previous run-timing assumptions for most stocks, however there was evidence of a shift in timing in very recent years (2015-2019) with both aggregate and sub-stocks for both the Skeena and Nass arriving up to one week earlier during this time period relative to the 2000-2014 time period.

Several changes were made to Nass stock groupings from previous runs of the NBSRR, including:

- A new stock, Strohn Creek, was added to the Meziadin stock complex, which had previously included Hanna/Tintina and Meziadin Beach groups. The overall exploitation rate for Meziadin sockeye was calculated as a weighted average of the three groups.

- River-type sockeye from Cranberry River were combined with Brown Bear in the Upper Nass RT stock
- Zolzap was combined with Gingit and Gitzyon Creek in the Lower Nass SRT stock

Very small stocks are represented by very few genetically determined samples from Tyee and the Nass fish wheels, which results in high uncertainty around mean timing for these stocks. Uncertainty in run timing may also arise from year-to-year differences in timing relative to timing offset assumptions, which are estimated across decadal or longer time periods. Each sub-stock is modeled as an assumed average peak day with a constant standard deviations (SD) across years. Shifts in timing for each substock is assumed to be synchronous with shifts in timing for the aggregate stock.

Different stocks can be more sensitive to escapement data depending on the location of fisheries. For instance, Babine sockeye represent the vast majority of the sockeye escapement at Tyee and thus the in-river harvest rates for mainstem fisheries that intercept Babine sockeye are less sensitive to the escapement values used for the smaller sockeye stocks. Harvest rate estimates for stocks where a large portion of the in-river catch is taken in tributaries where smaller stocks aren't mixed with Babine sockeye (such as Morice and Sustut) are more sensitive to escapement values used for these stocks English et al. (2017). Depending on run timing and residence time, smaller stocks might have higher/lower harvest rate than the Babine component.

Residence time, or the number of days that fish are present and vulnerable to each fishery were derived from historical tagging studies, the differences between peak abundances estimated at the Tyee Test Fishery (Skeena) and the Babine fence (Skeena), and information on the size (river kms) and location of each fishery (English et al. 1985, Steve Cox-Rogers, pers. comm.). The fishery residence times in the current version of the SSIRR model are the same as those in the 2017 version (English et al. 2017).

Table C.2. *Modelled Stocks For Skeena Sockeye In-river Run Reconstruction*. Adapted from Table 1 of English et al. (2017). LHAZ = Life History and Adaptive Zone, NumRR = number of years with a run reconstruction estimate, LastRR = most recent year with a run reconstruction estimate.

| LHAZ | Watershed | Stock | NumRR | LastRR |
|---|---|---|---|---|
| Lower Skeena Lake Type | Ecstall | Johnston | 31 | 2019 |
| Lower Skeena Lake Type | Gitnadoix | Alastair | 60 | 2019 |
| Lower Skeena Lake Type | Lakelse | Lakelse | 58 | 2019 |
| Lower Skeena Lake Type | Kitsumkalum | Kitsumkalum | 57 | 2018 |
| Lower Skeena Lake Type | Zymoetz | Mcdonell | 50 | 2019 |
| Middle Skeena Lake Type | Kitwanga | Kitwanga | 32 | 2019 |
| Middle Skeena Lake Type | Bulkley | Morice | 59 | 2019 |
| Middle Skeena Lake Type | Kispiox | Swan/Stephens | 57 | 2019 |
| Middle Skeena Lake Type | Babine | Babine Early Wild | 60 | 2019 |
| Middle Skeena Lake Type | Babine | Babine Late Wild | 60 | 2019 |
| Middle Skeena Lake Type | Babine | Babine Mid Wild | 60 | 2019 |
| Middle Skeena Lake Type | Babine | Pinkut | 60 | 2019 |
| Middle Skeena Lake Type | Babine | Fulton | 60 | 2019 |
| Upper Skeena Lake Type | Slamgeesh | Slamgeesh | 19 | 2018 |
| Upper Skeena Lake Type | Motase | Motase | 33 | 2019 |
| Upper Skeena Lake Type | Sustut | Bear | 54 | 2019 |
| Upper Skeena Lake Type | Sustut | Asitka | 34 | 2019 |
| Upper Skeena Lake Type | Sustut | Sustut | 47 | 2019 |

Table C.3. *Modelled In-river Fishing Areas For Skeena Sockeye*. Adapted from Tables 1 and 6 of English et al. (2017). FSC fisheries are aboriginal fisheries for Food, Social, and Ceremonial purposes. ESSR and Demonstration fisheries are commercial fisheries by First Nations. The magnitude of ESSR and Demo fisheries differs between areas, varies with abundance, and has changed substantially over time. Not all of the listed fisheries are currently active, and for those cases the last year of the fishery is listed.

| Area | FSC | ESSR and Demo |
|---|---|---|
| Coastal to Kasiks | LaxKwalaams, Metlakatla, Prince Rupert (excl. Kitkatla, Hartley Bay) | NCSFNSS, LaxKwalaams, Metlakatla (Recent) |
| Kasiks to Terrace | Kitsumkalum | Tsimshian First Nations (2011) |
| Terrace to Fiddler | Kitselas | Tsimshian First Nations (2000) |
| Fiddler to Hazelton | 95% of Skeena (e.g. Hazelton) plus Gitanyow | Gitksan & Wet'suwet'en Watershed Authority (Active) |
| Hazelton to L. Babine | 5% of Skeena (e.g. Hazelton) | Gitksan & Wet'suwet'en Watershed Authority (2012) |
| Babine below Fence | Gitksan Watershed Authority | Gitksan & Wet'suwet'en Watershed Authority (2008) |
| Babine Fence | | Lake Babine Nation (Active) |
| Babine Lake | Lake Babine Nation | Lake Babine Nation (Active) |
| Pinkut Terminal | Lake Babine Nation, Yekooche Nation | Lake Babine Nation (2014) |
| Fulton Terminal | Lake Babine Nation | Lake Babine Nation (Active) |
| BulkleyMorice | Wet'suwet'en Nation | Gitksan & Wet'suwet'en Watershed Authority (1997) |
| Sustut | Takla | None |

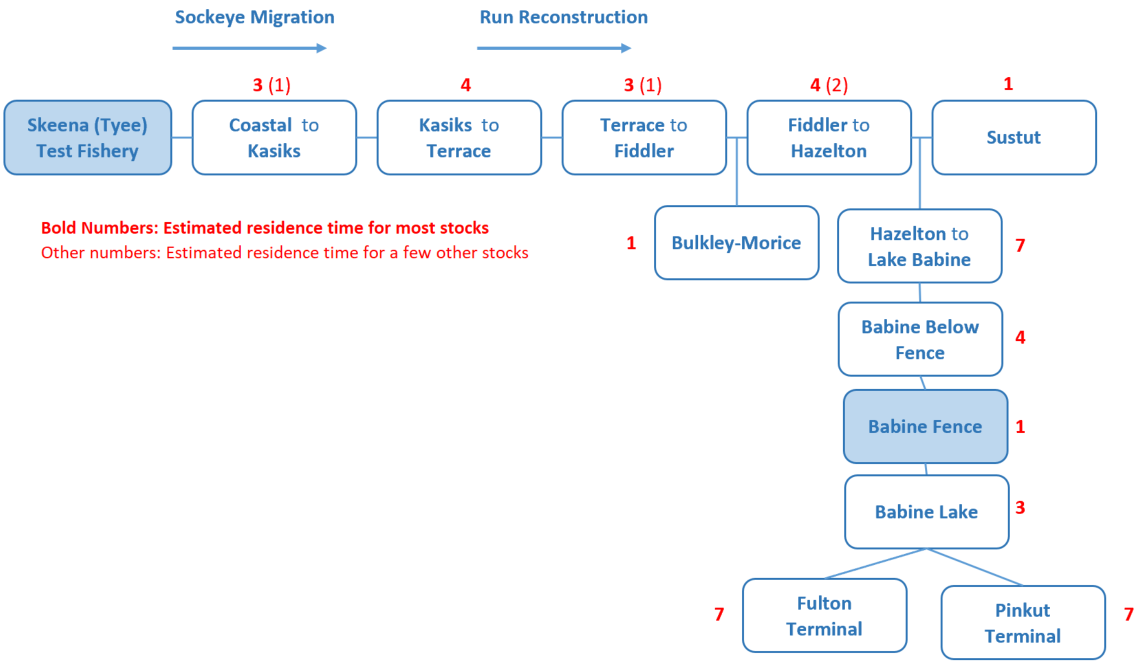


Figure C.3. *Modelled In-river Migration for Skeena Sockeye*. Fisheries are defined in Table C.3. Numbers in red show estimated residence time of migrating sockeye in each modelled fishery (bold = most stocks, brackets = a few other stocks).

## C.6 Brood-year Recruitment Estimates

The three building blocks of spawner recruitment data are:

1. estimates of spawner abundance (i.e., the number of *parents*) for each brood year,
2. estimates of run size (i.e., the number returning, all ages) for each return year, which are the sum of estimated spawner abundance, estimated catches, and estimated other mortalities (e.g., handling mortality, upstream migration mortality), and
3. estimates of age composition in a return year, which assign components of the annual run to different brood years (i.e., to calculate the number of *adult offspring* from the parents in a brood year)

All three components were updated in April 2021 based on the results of ongoing or completed reviews of spawner estimates for indicator systems (Appendix C.1), First Nations catch estimates (Appendix B.2.2), the Northern Boundary Run Reconstruction (NBSRR) model (Appendix C.4), and in-river run reconstructions (Appendix C.5).

This section summarizes our review of the age composition estimates and alternative calculations of brood-year recruitment.

### C.6.1 Stock-Specific Age Composition Data Review

Annual age composition data are not available for most component Skeena and Nass sockeye stocks, with the exception of Meziadin sockeye, which are sampled annually at the Meziadin fishway from 1 July until early October. Age data for some Skeena and Nass sockeye stocks, collected from various scale and otolith sampling projects, are available for some years. Note that ages assigned based on scales alone may underestimate the actual age due to scale resorption in freshwater. Most historic records include paired scale/otolith samples. Most of these samples with some exceptions (below) were aged at the DFO scale ageing lab at Pacific Biological Station, and the data are stored in stored in a regional database (PADS) in digitized records of individual age readings (1989-2019) or as scanned scale/otolith age cards (prior to 1989).

All available age records for Skeena and Nass sockeye stocks were downloaded from PADS. For years prior to 1989, the number of fish from each age class were tallied from scanned age cards for each stock/year for which data were available. Age proportions for each stream/year were calculated as the number of each age class divided by the total number of samples for that year, excluding partial ages or unreadable samples.

Age proportions for Slamgeesh and Kitwanga sockeye which were not aged by Fisheries and Oceans Canada for all years that sampling was conducted, were provided by Gitksan Watershed Authorities (GWA) and Gitanyow Fisheries Authority (GFA), respectively.

Estimates of age composition by return year for Babine stocks were derived from the annual Skeena aggregate age composition for years since 1970, as described in the next section.

A potential source of age composition data for the Lower Nass SRT stock group for the sea type component are the results from annual age data collected at the Nass fish wheels. The proportion of sockeye that are aged as having spent 1 year in freshwater may provide an estimate of the age composition in addition to the abundance of Gingit and other early-timed, sea type sockeye returning to the Lower Nass.

### C.6.2 Aggregate Age Composition Data Review

Annual estimates of age composition for aggregate Skeena and Nass sockeye stocks come from aggregate test fishery programs including Tyee Test Fishery (Skeena, 1955 – present), the Nisga’a Fish Wheels (1992-present) and the Monkley Dump Test Fishery (Nass, prior to 1992), and from Canada and U.S. marine commercial fisheries (Skeena and Nass, until the late 1990s). Scale samples from commercial and test fisheries have been aged by Alaska Department of Fish and Game since 2000, and by Fisheries and Oceans Canada (for Canadian fisheries) in years prior.

An important source of uncertainty for brood-year recruitment estimation at both the aggregate and stock level is the proportion of subadult male, or “jack” sockeye which are smaller and not consistently sampled in the different aggregate assessment programs. Jack sockeye are not effectively captured in gillnet test fisheries, including the Tyee Test fishery and the historic Monkley Dump test fishery for Nass sockeye, and have different rates of capture, tagging-related mortality and recapture compared with larger fish in the Nass fish wheel programs. Consequently, for both Skeena and Nass sockeye, jack and “large” sockeye (which are defined as sockeye > 45 cm NFL) are assessed separately.

For the Skeena, jacks are effectively enumerated at the Babine weir (where small sockeye have not been observed to breach the weir). Because few jack sockeye have been observed in visual escapement monitoring programs for other Skeena systems, it is assumed that the Babine system accounts for most jack sockeye returning to the Skeena.

Age samples are collected from sockeye >45 cm NFL at the Tyee Test Fishery to determine the proportion of the major age classes ($4_2$, $5_2$, and “Other”, which includes all other age classes including $5_3$ and $6_2$). These age proportions are applied to the total escapement of large fish to apportion the return of large fish into the major age classes. The return of Age – 3 sockeye from terminal fence counts are added to the total return, and the annual return for each age class (Ages 3 to 5 and “Other”) is recalculated using the relative proportion of all age classes in the total return, including jacks.

For the Nass, it is not known what proportion of jack sockeye returning to the Meziadin fishway or Kwinageese weirs are counted because small (jack sockeye) have been observed on occasion passing through the bars of both installations.

Annual estimates for jack sockeye are developed for the Nass aggregate by expanding the total catch of jacks at the fishwheels using the annual adult mark rate that is adjusted to account for the assumption of a higher mark rate for the smaller fish. An average 1200 small sockeye are caught each year at the Nass fishwheels since 2000, or 8% of the total Nass fishwheel catch. Since 2002, jack returns to the Meziadin fishway account for an average of 45% of the estimate of return of jacks to the Nass fishwheels.

### C.6.3 Available Age Composition Data

We compiled a total of 176,022 age records for individual Skeena and Nass sockeye stocks from across the alternative sources described above. Age data from the regional PADS database were combined with older data, which were extracted from scans, which substantially expanded the available data for age composition estimates (Table C.5).

Age composition estimates differed substantially across years (Figure C.4). While this is primarily due to natural variation, sampling error may also contribute to some of this variation.

Given the available data, recruitment calculations for most stocks are currently based on an average age composition (Table C.6). Stock-specific age composition estimates were used for most Nass stocks, but for the majority of Skeena stocks, including the 5 Babine stocks, we relied on average aggregate Skeena age composition. Annual estimates of age composition were used for Lower Nass Sea/River types.

### C.6.4 Alternative Brood Year Recruitment Calculations

Recruitment estimates for aggregate and individual stocks were back-calculated using run size and age composition. Three variations were explored:

1) use all age classes, and if any return year estimate is missing, then the recruitment estimate for that brood year is NA
2) use all age classes, and use the sum of available estimates as the recruitment estimate for that brood year (i.e., NA ages are ignored)
3) use only age classes that contributed at least 2% of the run at least once. If any of the corresponding return year estimates is missing, then the recruitment estimate for that brood year is NA.

Numerical values for all 3 types are very close when there are no missing data, but the 3rd option results in fewer data gaps while still maintaining consistency across years when there are data gaps. Version 3 is used for the analyses in this report.

Table C.4. *Summary of Available Age Data*. Table lists the number of years with age samples (*n*) and the range of years covered (*FirstYr*,*LastYr*). *Total*, *Min*, *Med*, and *Max* are the total, smallest annual , median annual, and largest annual sample size, including only records with complete age determination (i.e., records like *52*, denoting a 5-yr old fish with 2 years of freshwater rearing, are included. Records like *2M*, indicating unknown marine residence, are excluded). Babine, Skeena and Nass aggregate age compositions are derived from various source data, so sample sizes are not listed here. Kitwanga age composition estimates were contributed by the Gitanyow Fisheries Authority, and sample sizes are not available at this time.

| | **Years** | | | **Samples** | | | |
|---|---|---|---|---|---|---|---|
| Stock | n | First | Last | Total | Min | Med | Max |
| Alastair | 6 | 1970 | 1998 | 769 | 15 | 98.5 | 246 |
| Babine | 20 | 1989 | 2019 | 11183 | 187 | 500 | 1083 |
| BabineAgg | 50 | 1970 | 2019 | | | | |
| Bear | 1 | 1996 | 1996 | 46 | 46 | 46 | 46 |
| Bowser | 35 | 1964 | 2001 | 7233 | 53 | 169 | 752 |
| Damdochax | 36 | 1965 | 2001 | 4767 | 29 | 100 | 487 |
| Kitwanga | 18 | 2002 | 2019 | | | | |
| Kwinageese | 33 | 1965 | 2012 | 4470 | 3 | 101 | 433 |
| Lakelse | 4 | 2010 | 2013 | 849 | 199 | 208 | 234 |
| Meziadin | 57 | 1959 | 2020 | 66476 | 269 | 1082 | 3159 |
| Morice | 22 | 1944 | 2019 | 11684 | 65 | 306.5 | 2400 |
| NassAgg | 38 | 1982 | 2019 | | | | |
| SkeenaAgg | 50 | 1970 | 2019 | | | | |
| Slamgeesh | 9 | 2001 | 2019 | 1186 | 12 | 140 | 229 |
| Stephens | 1 | 1996 | 1996 | 100 | 100 | 100 | 100 |
| Sustut | 3 | 1997 | 2012 | 193 | 21 | 50 | 122 |
| Tyee Test Fishery | 30 | 1989 | 2018 | 66776 | 527 | 2250 | 4227 |
| Upper Nass River | 6 | 2010 | 2017 | 290 | 29 | 44 | 66 |

Table C.5. *Summary of age samples extracted from scanned scale/otolith age cards.* Table lists the number of samples (*Samples*), number of years in which samples were taken (*NumYears*), and the range of years sampled (*FirstYear*, *LastYear*).

| Stock | Samples | NumYears | FirstYear | LastYear |
|---|---|---|---|---|
| Alastair | 614 | 4 | 1970 | 1988 |
| Bowser | 5021 | 25 | 1964 | 1990 |
| Damdochax | 3299 | 24 | 1965 | 1989 |
| Kwinageese | 2593 | 20 | 1965 | 1989 |
| Meziadin | 21064 | 25 | 1959 | 1988 |
| Morice | 3331 | 11 | 1962 | 1988 |

Table C.6. *Stock-specific age composition estimates used in the recruitment calculations*. Tables 6 and 7 show the full stock names and list the number of brood years with spawner-recruit data, based on the matched age compositions from this table.

| LHAZ | Watershed | Stock | Type | AgeComp |
|---|---|---|---|---|
| Nass SRT | Lower Nass Tribs | LNassSRT | Annual | LowerNassSRT |
| U Nass LT | Bell-Irving | Bowser | Avg | Bowser |
| | | Oweege | Avg | Meziadin |
| | Damdochax | Damdoch | Avg | Damdochax |
| | Kwinageese | Kwinag | Annual | Kwinageese |
| | Meziadin | Meziadin | Annual | Meziadin |
| Nass RT | Upper Nass Tribs | UNassRT | Avg | UpperNassRT |
| L Skeena LT | Ecstall | Ecstall | Avg | Skeena |
| | | Johnston | Avg | Skeena |
| | Gitnadoix | Alastair | Avg | Alastair |
| | Kitsumkalum | Kitsumk | Avg | Skeena |
| | Lakelse | Lakelse | Avg | Lakelse |
| | Zymoetz | Mcdonell | Avg | Skeena |
| M Skeena LT | Babine | Bab-EW | Annual | Skeena |
| | | Bab-LW | Annual | Skeena |
| | | Bab-MW | Annual | Skeena |
| | | Fulton | Annual | Skeena |
| | | Pinkut | Annual | Skeena |
| | Bulkley | Morice | Avg | Morice |
| | | UBulkLk | Avg | Skeena |
| | Kispiox | SwanSteph | Avg | Stephens |
| | Kitwanga | Kitwanga | Avg | Kitwanga |
| U Skeena LT | Kluatantan | Kluant | Avg | Skeena |
| | Kluayaz | Kluayaz | Avg | Skeena |
| | Motase | Motase | Avg | Skeena |
| | Sicintine | Sicintine | Avg | Skeena |
| | Slamgeesh | Slamg | Avg | Slamgeesh |
| | Sustut | Asitka | Avg | Skeena |
| | | Bear | Avg | Bear |
| | | Sustut | Avg | Sustut |
| Skeena RT | All | Skeena RT | Avg | Skeena |

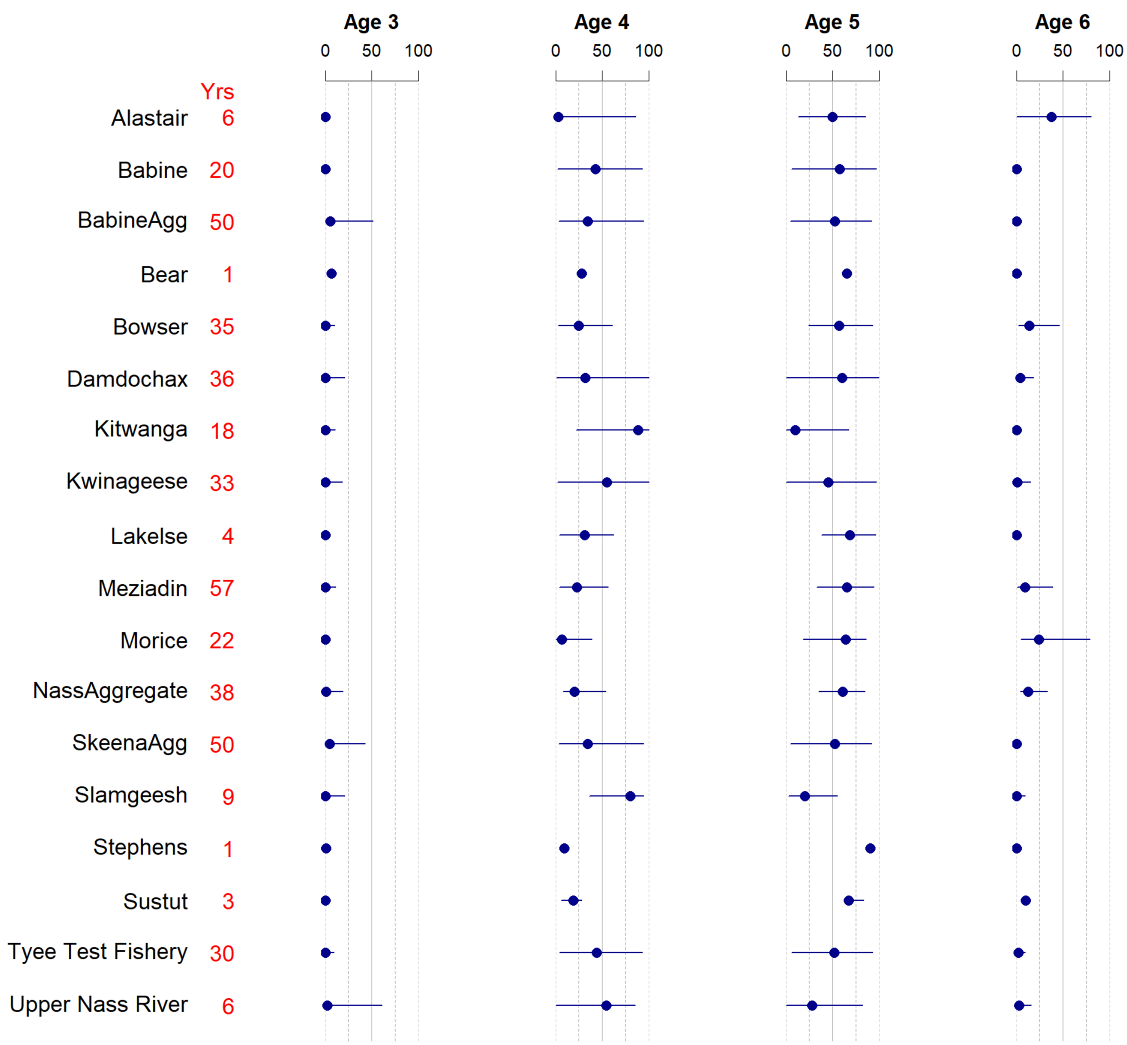


Figure C.4. *Summary of age composition estimates*. For each age class and stock, the figure shows the median (point) and range (whiskers) of the percent contribution across *Yrs* of data.

# APPENDIX D Data Quality Check - Methods

## D.1 Data Flags

Data quality metrics were calculated for each stock looking at the entire time series and at individual observations (Table D.2). Potential data concerns are flagged if metric values fall below, above, or outside the range of user-specified trigger values, depending on the metric. Trigger values were selected based on published guidance where available or based on TWG consensus. Metric calculations were implemented with the *RapidRicker* package (Pestal et al. 2020) as illustrated in Appendix D.4.

### D.1.1 Metrics evaluating the entire time series

To fit meaningful spawner-recruit (SR) models, the SR data should have good contrast (i.e., cover a wide range of spawner abundances) and should use reliable estimates. In addition, the data should capture the full range of observed values for both spawners and recruits (e.g., a recent estimate of spawner abundances may fall far outside the previously observed range of values, but corresponding recruitment estimates are not yet available).

The following metrics were used to generate a snapshot of these considerations for the 31 stocks of Skeena and Nass sockeye:

- *Contrast*: low contrast in spawner data is flagged if $Max(Spn)/Min(Spn) < 4$, using the threshold from Clark et al. (2014a).
- *Number of observations*: insufficient data for fitting SR models is flagged if the number of brood years with estimates of both spawners and recruits is less than 10. This trigger value was selected based on general experience with other sockeye stocks. This is intended as a way to identify stocks with “little” data using a consistent definition, and does not preclude subsequent analyses which may attempt to estimate biological benchmarks for stocks with little data (e.g., using priors based on nearby stocks, or formally combining stocks in a hierarchical model).
- *Large/small estimates not available for model fitting*: Estimates of spawners or recruits are available in addition to the brood years which have estimates of both spawners and recruits (e.g., last few brood years for which return estimates are not yet available). If any of these additional estimates fall far outside the range observed in the SR data set, they may indicate a state of the system that is not captured in the SR model fit (e.g., if spawners in the most recent brood years are much lower or much higher than any of the spawner abundances in the data set used for model fitting). The performance measure flags a potential issue if the largest observed value is more than double the largest value for the brood years which have estimates of both spawners and recruits. Similarly, small estimates of spawners or recruits outside of the SR data set are flagged if the smallest observed value is less than half the largest value for the brood years with estimates of both spawners and recruits. The double/half trigger values were selected to identify extreme values.

- *Large/small estimates not in model fit*: Estimates of spawners or recruits are available in addition to the brood years which have estimates of both spawners and recruits (e.g., last few brood years for which return estimates are not yet available). If any of these additional estimates fall far outside the range observed in the SR data set, they may indicate a state of the system that is not captured in the SR model fit (e.g., if spawners in the most recent brood years are much lower or much higher than any of the spawner abundances in the data set used for model fitting). The performance measure flags a potential issue if the largest observed value is more than double the largest value for the brood years which have estimates of both spawners and recruits. Small estimates of spawners or recruits outside of the SR data set are flagged if the smallest observed value is less than half the largest value for the brood years with estimates of both spawners and recruits. The double/half trigger values were selected to identify extreme values.
- *Large expansion factor*: the expansion from index spawners to total spawner estimate is flagged if the average expansion for the whole time series is larger than 3 (i.e., observations are multiplied by more than 3).

### D.1.2 Metrics evaluating individual observations

Individual observations that are very different from the rest of the data may be potential data errors or capture important information about dynamics of the stock. Either way, they need to be identified for closer review.

The following metrics were used to generate a snapshot of unusual observations for the 31 Skeena and Nass sockeye stocks:

- Unusual abundance estimates are flagged if they are an order of magnitude different from the median abundance (i.e., less than 10%, or more than 10 times bigger).
- Unusual spawner expansions are flagged if they are more than 5 times bigger, or less than 1/5th, of the median expansion.

For all these metrics, the trigger values were selected to identify potential issues for a closer review, and they are not intended as hard-and-fast rules for automated data filtering.

Table D.1. *Information Checklist*. The TWG developed a checklist of available information that covers the spawner-recruit data and broader considerations that relate to their interpretation. For each criterion, this table summarizes the type of information considered and whether data are available. Summary notes were prepared for all criteria. Critera look at either individual records (e.g., potential outlier in R/S), or and average for the time series (e.g., average spawner expansion factor), or the pattern over time (e.g., changes in R/S). For some criteria, identified in the *Flag* column, quantitative metrics and associated trigger values were developed to flag potential data concerns (Table D.2). We were unable to develop robust quantitative metrics for the remaining criteria (e.g., age compositions for Skeena and Nass sockeye are highly variable between years, so there was no clear-cut way of delineating an “unusual” record). Various sensitivity tests were used to check how the potential data issues affect estimates of standard biological benchmarks (e.g., $S_{MSY}$). Specific data checks for exploitation rate were not included, because these are derived from the spawner and catch estimates, which are evaluated here.

| Criterion | Consider | Notes | Data | Flag |
|---|---|---|---|---|
| Spawner estimate quality | Survey type and exp. factor | Yes | Yes | Yes |
| Catch Estimate Quality | stock size, catch area | Yes | Yes | Yes |
| Age composition estimate quality | | Yes | Yes | No |
| Lake information | | Yes | Most lakes | No |
| Outlier/Error Check | S, R, R/S, age comp | Yes | Yes | Yes |
| Data Gaps | Min obs, consecutive years | Yes | Yes | Yes |
| Pattern in Abd | S, R | Yes | Yes | Yes |
| Pattern in Age Comp | age comp | Yes | Large stocks | No |
| Pattern in stock comp | | Yes | Yes | No |
| Pattern in run timing | | Yes | Yes | No |
| Other patterns | | Yes | Some | No |
| Stock differences | S, R, R/S, age comp, juv | Yes | Yes | No |

Table D.2. *Summary of Data Flags*. Data quality metrics were calculated for each stock looking at the entire time series and at individual observations. Potential data concerns are flagged if metric values fall below, above, or outside the range of user-specified trigger values. For example, low contrast in spawner data (*Contr*) is flagged if $Max(Spn)/Min(Spn) < 4$ or $> 100$, using the lower threshold from Clark et al. (2014a) and an arbitrary upper threshold to flag time series with changes larger than two orders of magnitude. Individual spawner or recruit observations (*OddSpn*, *OddRec*) are flagged if they are an order of magnitude different from the median (i.e., less than 10%, or more than 10 times bigger). Individual spawner expansions are flagged if they are more than 5 times bigger, or less than 1/5th, of the median (*OddExp*). Metric calculations were implemented with the *RapidRicker* package (Pestal et al. 2020, as illustrated in Appendix D.4). Section D.1 summarizes the rationale for each metric and trigger value.

| Label | Criterion | Scope | Metric | Trigger |
|---|---|---|---|---|
| Contr | Low contrast in Spn Data | Series | Contrast in Spn | <4 or >100 |
| NumObs | Insufficient SR data | Series | Num brood years with data | <10 |
| LgSpn | Missing large Spn | Series | Large obs Spn not in SR data | >2 |
| LgRec | Missing large Rec | Series | Large obs Rec not in SR data | >2 |
| SmSpn | Missing small Spn | Series | Small obs Spn not in SR data | <0.5 |
| SmRec | Missing small Rec | Series | Small obs Rec not in SR data | <0.5 |
| LgExp | Large Spn Exp | Series | total expansion | >3 |
| OddSpn | Unusual Spn obs | Obs | Obs vs. Med | <0.1 or >10 |
| OddRec | Unusual Rec obs | Obs | Obs vs. Med | <0.1 or >10 |
| OddProd | Unusual productivity | Obs | Recruits/Spawner | <0.3 or >15 |
| OddExp | Unusual Spn Exp obs | Obs | Obs vs Med | <0.2 or >5 |

Table D.3. *Categories of Spawner Expansion*. The magnitude of factor applied to expand estimates from indicator systems to estimates of total spawner abundance was categorized into 5 levels, from *Low* at less than 1.5 to *Extreme* at more than 10.

| LowerThreshold | Label |
|---|---|
| 0 | None |
| 1 | Low |
| 1.5 | Moderate |
| 3 | High |
| 5 | Very High |
| 10 | Extreme |

Table D.4. *5-Point Scale for Data Quality Ratings*. This scale summarizes the general intent for the rating. Specific considerations differ for the type of variable being rated. For example, spawner estimates were rated as *very good* if indicator systems were surveyed with a high-quality program (e.g., fence, mark-recapture) and expansion factors were small. Appendix E.2 lists the components considered in the ratings for each stock.

| Rating | Intent |
|---|---|
| Very Poor | Very high uncertainty, concerns about significant potential bias or errors. |
| Poor | High uncertainty, concerns about potential bias. |
| Moderate | Some uncertainty and some potential bias. |
| Good | Low uncertainty,bias assumed to be low based on methods. |
| Very Good | Low uncertainty, no indication of bias. |

Table D.5. *Categories of Spawner Expansion Factors and Assigned CV*. A bootstrap test can be used to quickly explore the potential effects of uncertainty in estimates on SR model fits and benchmark estimates. This was intended as a quick, preliminary check on how uncertainty in the various inputs carries through the steps of the analysis. Based on the results, we can identify key considerations for the subsequent model development, such as sources of uncertainty that should be captured in a state-space model. A base level of uncertainty, expressed as a coefficient of variation (*CV*) was assigned to spawner estimates based on the factor applied to expand estimates from indicator systems to estimates of total spawner abundance. For example, an expansion factor between 1.5 and 3 was categorized as *moderate*, and assigned a CV of 0.1 (i.e., the standard deviation for the estimate is 10% of the mean). Bootstrapped values for the spawner estimate were then calculated by sampling from a normal distribution. Note that these assigned *CV* values are determined based on the expansion factor for each observation, and are therefore the same across stocks. Tables D.6 and D.7 list stock-specific CV values.

| LowerThreshold | Label | BaseCV |
|---|---|---|
| 0 | None | 0.03 |
| 1 | Low | 0.06 |
| 1.5 | Moderate | 0.1 |
| 3 | High | 0.3 |
| 5 | Very High | 0.5 |
| 10 | Extreme | 0.8 |

### D.2 Data Notes

Qualitative commentary was compiled to describe spawner data, catch data, age composition data, recruitment estimates, and lake survey data.

Quality of spawner estimates by stock:

- *Indicator quality*: commentary on quality of spawner surveys (i.e., sum of estimates from indicator streams), based on survey types and coverage. Weirs and fishways were generally categorized as highly accurate, but if they capture multiple stocks then quality of stock composition estimates and relative abundance of the component stocks was also considered.
- *Expansions*: categorizes the total expansion factor applied to the estimate from indicator streams into 4 categories (Table D.3). Expansion factors were taken from the previously published run reconstruction estimates (e.g., English et al. 2019).
- *Total spawner estimate quality*: Commentary on overall quality of the spawner estimate, considering the quality of the index estimate and the expansion factor.
- *Overall rating for spawner estimate*: The quality of spawner estimates was assessed on a 5-point scale from Very Good to Very Poor, based on the commentary for *TotalSpn*.

Quality of catch estimates by stock:

- *Marine*: commentary on whether the marine migration of the stock is likely similar to the aggregate migration route used in the NBRR model (Appendix C.4), considering life history (e.g., sea type vs. lake type) and stock size (i.e., model captures major stocks better: Meziadin on Nass and Babine stocks on the Skeena); this in turn affects whether the proportion of aggregate marine catch in the major fisheries for this stock is likely similar to the stock composition in lower river assessment project (i.e., Nass fishwheels, Tyee test fishery), considering migration behaviour and stock size.
- *In-river*: commentary covering 2 considerations: (1) the quality of run timing and migration speed estimates: (2) quality of catch estimates in different modelled river sections.
- *Total catch estimate quality*: commentary on overall quality of the total catch estimates, considering the quality of the above components
- *Overall Rating for catch estimate*: The quality of catch estimates was assessed on a 5-point scale from Very Good to Very Poor, based on the commentary for *TotalCt*.

Quality of recruitment estimates by stock:

- *Run Rating*: Describes the quality of run size estimates on a 5-point scale from Very Good to Very Poor, based on the commentary ratings for expanded spawner estimates and total catch estimates, and the relative magnitude of catch and spawner abundance (e.g., very poor catch estimate has little effect on quality of run size estimate if catches are very small).
- *Age Data Match*: categorizes the age composition estimates as either stock-specific (*Stock*) or based on a proxy from a different stock (*Proxy*)
- *Age Data Type*: categorizes the age composition estimates as either *Annual* (estimates available for most years, remainder filled in with average), or *Average* (a few years of data, using average for all years).
- *Age Data Amount*: short note on number of available estimates (e.g., “many years”, “few years”).
- *Total Recruitment estimate quality*: commentary on overall quality of the recruitment estimates, considering the quality of the estimates for total run size and age composition.
- *Overall rating for recruitment estimate*: The quality of recruitment estimates was assessed on a 5-point scale from Very Good to Very Poor, based on the commentary for *TotalRec*.

Quality of lake surveys (summarized across lakes by stock):

- *Coverage*: commentary on the number of juvenile surveys and whether they cover the main rearing lakes for the stock
- *Juvenile Size*: categorized juvenile size based on the ranking plot (Figure B.1) into *large* (top third), *mid* (middle third), or *small* (lower third).

- *Juvenile Density*: categorized juvenile density based on the ranking plot (Figure B.1) into *high* (top third), *mid* (middle third), or *low* (lower third).
- *Capacity*: commentary on the number and stock-specific relevance of lake capacity estimates based on photosynthetic rate (Appendix B.4.1).

### D.3 Sensitvity Analyses

The data checks described in the previous sections were designed to identify potential data issues. Sensitivity tests can be used to check whether these potential data issues have an effect on estimates of standard biological benchmarks (e.g., $S_{MSY}$, $S_{MAX}$), in order to assist model scoping for the escapement goal review. These sensitivity analyses are intended to identify which priority areas of uncertainty will need to be considered in the next phase of the project (Section 1.2), rather than choosing the "best" version of the data or the "best" estimation procedure at this point. Accordingly, senstivity testing focused on relative changes compared to a base case, rather than the actual benchmark estimates.

The base case for all stocks was to apply simple deterministic Ricker fits (i.e., least-squares linear regression of $log(R/S) \sim S$) to all available years of data, with recruits calculated using the best available estimates of age composition (i.e., annual estimates where available, filled in with averages where needed).

We performed three sets of sensitivity tests: data variations, uncertainty in the data (bootstrap), and uncertainty in the model fit (Bayesian estimates). Sensitivity tests were implemented with the *RapidRicker* package (Pestal et al. 2020), as illustrated in Appendix D.4, which cycles through a comprehensive set of data variations and calculates standard biological benchmarks. Model fits and benchmark calculations were done for both a deterministic Ricker model fit (simple linear regression) and a Bayesian version.

#### D.3.1 Data Variation Tests

Four data variations were tested for all 31 stocks and both aggregates:

- *Jackknife*: drop individual observations from the SR data set (one at a time)
- *Drop 2*: exclude the 2 brood years with the largest spawner abundances
- *Retrospective*: start with the 10 earliest brood years, and then add later years to the data set (i.e., start in the past, and then grow the data set)
- *Reverse retrospective*: start with all available brood years, and then drop earlier years until 10 observations are left (i.e., remove earlier data one by one, starting with the earliest brood year).

The first two data variations check how much leverage individual data points have on the regression fit and resulting benchmark estimates. The retrospective and reverse retrospective tests are a quick check for changes over time that may influence the time period used for model fitting in the next phase of the project.

For those stocks with annual age data (Table C.6), another data variation was tested: recalculate the recruit estimates using the average age composition instead of the annually observed age composition, and check how much the benchmark estimates change. This procedure can provide insights about potential problems with benchmark estimates for the majority of stocks where only average age composition is available. Note, however, that long time series of annual age data are only available for comparison with average age composition for the largest Skeena and Nass stocks. The age composition sensitivity test was completed for 3 Nass stocks (Kwinageese, Meziadin, Lower Nass Sea & River Type) and the 5 Babine stocks on the Skeena (Babine Early Wild, Babine Mid Wild, Babine Late Wild, Pinkut, Fulton).

### D.3.2 Bootstrap Test

Estimates of uncertainty are not currently available for the Skeena and Nass spawner-recruit data. However, we know that this can affect model fits substantially. For a simple exploration of the magnitude of potential effects, we assigned coefficients of variation (CV) for each annual estimate based on general data quality considerations, considerations, as described previously in Tables D.5 to D.7. This is commonly done to generate inputs for Bayesian state-space models (e.g., Miller and Pestal 2020). We used the same concept, but simplified it for a rapid preliminary test by generating a bootstrap sample and calculating deterministic Ricker fits for each sample, instead of building separate state-space models for 31 stocks and 2 stock aggregates (or 2 hierarchical models) as part of the data review. The intent of the bootstrap test is to explore whether a state-space approach is appropriate for the estimation of biological benchmarks, and to explore the input assumptions that would be used in that case (i.e the assigned CV values).

Bootstrapped spawner estimates were generated as using the following procedure:

- assign a *base* CV based on expansion factor (Table D.5)
- assign an *additional* CV based on survey type (Tables D.6 to D.8)
- generate a random sample with mean = Obs and standard error = Obs * CV)

Catch estimates were bootstrapped using CVs based on stock size (Tables D.6 and D.7), given that stock identification and resulting catch allocation in mixed-stock fisheries more accurately reflects the major stocks (Appendix B.2).

For each bootstrapped sample of spawners and run size, recruitment by brood year was calculated using the best available age composition estimates (i.e., annual estimates where available, average age composition for missing years, age composition from proxy stocks where necessary; Section 3).

Bootstrap estimates of biological benchmarks were calculated for 3 versions of the data:

- *All (A)*: all brood years

- *Trimmed (T)*: trimmed data after stock-specific start year (Tables D.6 and D.7)
- *Trimmed and Filtered (TF)*: trimmed data with any R/S > 15 filtered out (based on the *OddProd* criterion from Table D.2)

Table D.6. *Bootstrap Inputs - Nass*. Coefficients of Variation (CV) were assigned to spawner and catch estimates based on data quality consideration. For spawner estimates, a base level CV was assigned based on the expansion factor (Table D.5), and combined with an additional CV based on the type of survey coverage (*SpnAddCV*). Major stocks with high-quality estimates were assigned small values for *SpnAddCV* (0 for the Meziadin fishway counts, 5% for the Babine fence counts due to the uncertainty introduced when splitting the count across 5 stocks). All other stocks rely on estimates derived from lower quality surveys for all or part of the time series, and tend to cover only part of the stocks (Tables E.9 and E.12). The additional CV was set at 10%, to yield a reasonable total CV in combination with the expansion factor consideration (Table D.5). The CV for catch (*CtCV*) was assigned using values similar to Miller and Pestal (2020), with lower values for larger stocks that tend to be better reflected in mixed-catch stock identification (Section B.3). *TrimYr* is a stock-specific cut-off used for sensitivity analysis to test the effect of excluding earlier observations (e.g., due to poor data quality or changes in the system, like adding a spawning channel).

| LHAZ | WS | Stock | TrimYr | SpnAddCV | CtCV |
|---|---|---|---|---|---|
| Nass SRT | Lower Nass Tribs | LNassSRT | 2000 | 0.1 | 0.3 |
| U Nass LT | Meziadin | Meziadin | 1990 | 0 | 0.2 |
| | Bell-Irving | Bowser | 1990 | 0.1 | 0.3 |
| | Bell-Irving | Oweege | 1990 | 0.1 | 0.3 |
| | Kwinageese | Kwinag | 1990 | 0.1 | 0.3 |
| | Damdochax | Damdoch | 1990 | 0.1 | 0.3 |
| Nass RT | Upper Nass Tribs | UNassRT | 1990 | 0.1 | 0.3 |

Table D.7. *Bootstrap Inputs - Skeena*. Table columns defined as per Table D.6.

| LHAZ | WS | Stock | TrimYr | SpnAddCV | CtCV |
|---|---|---|---|---|---|
| L Skeena LT | Ecstall | Johnston | 1980 | 0.1 | 0.3 |
| | Ecstall | Ecstall | 1990 | 0.1 | 0.3 |
| | Gitnadoix | Alastair | 1990 | 0.1 | 0.3 |
| | Lakelse | Lakelse | 1990 | 0.1 | 0.3 |
| | Kitsumkalum | Kitsumk | 1990 | 0.1 | 0.3 |
| | Zymoetz | Mcdonell | 1990 | 0.1 | 0.3 |
| M Skeena LT | Kitwanga | Kitwanga | 2000 | 0.075 | 0.3 |
| | Bulkley | UBulkLk | 1990 | 0.1 | 0.3 |
| | Bulkley | Morice | 1998 | 0.1 | 0.3 |
| | Kispiox | SwanSteph | 1995 | 0.1 | 0.2 |
| | Babine | Bab-EW | 1993 | 0.05 | 0.2 |
| | Babine | Bab-LW | 1993 | 0.05 | 0.2 |
| | Babine | Bab-MW | 1993 | 0.05 | 0.2 |
| | Babine | Pinkut | 1993 | 0.05 | 0.2 |
| | Babine | Fulton | 1993 | 0.05 | 0.2 |
| U Skeena LT | Sicintine | Sicintine | 1990 | 0.1 | 0.3 |
| | Slamgeesh | Slamg | 2000 | 0.075 | 0.3 |
| | Motase | Motase | 1990 | 0.1 | 0.3 |
| | Sustut | Bear | 1990 | 0.1 | 0.3 |
| | Sustut | Asitka | 2000 | 0.1 | 0.3 |
| | Sustut | Sustut | 1990 | 0.1 | 0.3 |
| | Kluatantan | Kluant | 1990 | 0.1 | 0.3 |
| | Kluayaz | Kluayaz | 1990 | 0.1 | 0.3 |
| Skeena RT | All | Skeena RT | 2000 | 0.1 | 0.3 |

Table D.8. *Bootstrap Inputs - Aggregates*. Table columns defined as per Table D.6.

| Aggregate | TrimYr | SpnAddCV | CtCV |
|---|---|---|---|
| Nass | 2000 | 0.2 | 0.1 |
| Skeena | 1993 | 0.05 | 0.2 |
| SkeenaWild | 1993 | 0.05 | 0.2 |

### D.3.3 Bayesian Test

The bootstrap test described in the previous section shuffles the data, then applies an estimation approach that treats the predictor variable (spawner abundance) as true values but allows for noise in the estimates of the response variable (recruits) and generate a single point estimate for each.

A contrasting exploration of the uncertainty is to use the original estimates, but use Bayesian estimation to generate a distribution of model fits and resulting benchmark estimates. We used the *calcMCMCRickerModelFit()* and *calcMCMCRickerBM()* functions from the *RapidRicker* package (Pestal et al. 2020), as illustrated in Appendix D.4.

As for the bootstrap test, Bayesian estimates of the biological benchmarks were calculated for 3 versions of the data (All, Trimmed, Trimmed and Filtered).

## D.4 Using the *RapidRicker* package for data quality checks

The motivation for building this package was the large number of stocks covered by the Skeena and Nass sockeye escapement goal review. Routine aspects of data review, such as checking for potential outliers or concerns regarding contrast, presented a non-trivial challenge in an analysis covering dozens of stocks within 2 aggregates, with data continuously being updated as the data reviews progressed. With the large number of stocks, we also faced the challenge of being consistent across stocks with data treatment choices (e.g., criteria for identifying outliers).

Most of the analyses in this report were implemented using the *RapidRicker* package. A basic worked example follows. Package functions are available at https://github.com/SOLV-Code/RapidRicker

### D.4.1 Worked Example

Setting Up

```
# Install
install.packages("devtools") # Install the devtools package
library(devtools) # Load the devtools package.
install_github("SOLV-Code/RapidRicker", dependencies = TRUE,
               build_vignettes = FALSE)

# Load
library(RapidRicker)
library(tidyverse)

# check the built in data set
?SR_Sample # opens help file
head(SR_Sample) # shows the first few rows
```

```
# check the function help files
?checkSRData
```

### D.4.2 Run the data check

```
# look at the default criteria for the data check
flags_default

# apply the data check to data for 1 stock
data.chk <- checkSRData(SR_Sample[SR_Sample$Stock == "Stock1",])
names(data.chk)
print(data.chk$Summary)
print(head(data.chk$Data))
```

### D.4.3 Run the deterministic sensitivity test of data variations

```
# run the wrapper function
rapid.ricker.out <- RapidRicker(sr_obj_m = SR_Sample, min.obs = 10,  trace=TRUE)

# check the components of the output
names(rapid.ricker.out)

# look at the data check outputs
names(rapid.ricker.out$DataCheck)
rapid.ricker.out$DataCheck$TabSeriesVal
rapid.ricker.out$DataCheck$TabSeriesFlags
rapid.ricker.out$DataCheck$TabObsFLags
head(rapid.ricker.out$DataCheck$Summary)
head(rapid.ricker.out$DataCheck$Data)

# look at the BM outputs
names(rapid.ricker.out$BM)
head(rapid.ricker.out$BM$Retro)

# look at the PercDiff outputs (sensitivity test vs. base case)
head(rapid.ricker.out$PercDiff$RetroPercDiffMin)
head(rapid.ricker.out$PercDiff$RetroPercDiffMax)
```

## APPENDIX E Data Quality Check - Results

### E.1 Quantitative data checks

Table E.1. *Summary of Available Spawner-Recruit Data and Data Check Results - Skeena and Nass Aggregates*. Columns show the results for all available data (*Nass*, *Skeena*) or data trimmed by excluding earlier brood years *NassTr2000*, *SkeenaTr1993*). Rows show either the value (*Val*) for a criterion (Section D.1), or whether it was flagged as a potential issue (*X*) using the thresholds listed in Table D.2. *NumObs* is the number of brood years with estimates of both spawners and recruits. *LgSpn* and *LgRec* compare largest available observation to the largest observation with both estimates (i.e. a value of 3 means that there is a spawner estimate 3 times larger than the largest estimate used in the spawner-recruit model fits, because no matching recruit estimate is available). *Contr* is the contrast in available spawner estimates, calculated as the ration of largest and smallest spawner esimates in the time series. *SmSpn* and *SmRec* similarly compare the smallest estimates (i.e. a value of 0.5 means that there is a spawner estimate half the smallest estimate used in the spawner-recruit model fit). The *LgExp* metric shows the median expansion factor used to adjust index escapement estimates to get a total spawner estimate. Observations were flagged if they are an order of magnitude smaller or larger than the median (*OddSpn*, *OddRec*) or fall outside a range considered reasonable for this group of stocks (e.g. more than 15 recruits/spawner).

| Variable | Nass | NassTr2000 | Skeena | SkeenaTr1993 |
|---|---|---|---|---|
| NumSpn | 38 | 20 | 50 | 27 |
| NumRec | 32 | 14 | 45 | 22 |
| NumSR | 32 | 14 | 45 | 22 |
| ContrVal | 5.28 | 2.46 | 4.90 | 3.38 |
| ContrX | - | X | - | X |
| NumObsVal | 32 | 14 | 45 | 22 |
| NumObsX | - | - | - | - |
| LgSpnVal | 1 | 1 | 1 | 1 |
| LgSpnX | - | - | - | - |
| LgRecVal | 1 | 1 | 1 | 1 |
| LgRecX | - | - | - | - |
| SmSpnVal | 1 | 1 | 1 | 1 |
| SmSpnX | - | - | - | - |
| SmRecVal | 1 | 1 | 1 | 1 |
| SmRecX | - | - | - | - |
| LgExpVal | 1 | 1 | 1 | 1 |
| LgExpX | - | - | - | - |
| OddSpn | 0 | 0 | 0 | 0 |
| OddRec | 0 | 0 | 2 | 1 |

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| Variable | Nass | NassTr2000 | Skeena | SkeenaTr1993 |
|---|---|---|---|---|
| OddProd | 1 | 0 | 1 | 1 |
| OddExp | 0 | 0 | 0 | 0 |

Table E.2. *Data Checklist - Summary Metrics - Nass Stocks*. Summary metrics calculated for each stock's spawner recruit time series, using the definitions in Table D.2. *NumObs* is the number of brood years with estimates of both spawners and recruits. *NumSpn* and *NumRec* are the number of brood years with each type of estimate. *Contr* is the contrast in available spawner estimates, calculated as the ration of largest and smallest spawner esimates in the time series. *LgSpn* and *LgRec* compare largest available observation to the largest observation with both estimates (i.e. a value of 3 means that there is a spawner estimate 3 times larger than the largest estimate used in the spawner-recruit model fits, because no matching recruit estimate is available). *SmSpn* and *SmRec* similarly compare the smallest estimates (i.e. a value of 0.5 means that there is a spawner estimate half the smallest estimate used in the spawner-recruit model fit). The *LgExp* metric shows the median expansion factor used to adjust index escapement estimates to get a total spawner estimate.

| LHAZ | Stock | Contr | NumObs | LgSpn | LgRec | SmSpn | SmRec | LgExp |
|---|---|---|---|---|---|---|---|---|
| Nass SRT | LNassSRT | 82.9 | 34 | 1.23 | 1 | 1 | 1 | 2.72 |
| U Nass LT | Meziadin | 11.8 | 32 | 1 | 1 | 1 | 1 | 1 |
| U Nass LT | Bowser | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| U Nass LT | Oweege | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| U Nass LT | Kwinag | 520.8 | 21 | 1 | 1 | 1 | 1 | 1 |
| U Nass LT | Damdoch | 32.4 | 29 | 1 | 1.17 | 1 | 1 | 1 |
| Nass RT | UNassRT | 1301 | 11 | 1.72 | 1 | 0.5 | 1 | 1 |

Table E.3. *Data Checklist - By Series - Nass Stocks*. This table shows which data quality considerations were flagged for each stock, by comparing the metric values in Table E.2 to the trigger values listed in Table D.2. *X* denotes metric values that fell outside the range defined for each metric. - denotes metric values that did not flag a potential data issue. Blank fields indicate that there was insufficient data for calculating the metric.

| LHAZ | Stock | Contr | NumObs | LgSpn | LgRec | SmSpn | SmRec | LgExp |
|---|---|---|---|---|---|---|---|---|
| Nass SRT | LNassSRT | - | - | - | - | - | - | - |
| U Nass LT | Meziadin | - | - | - | - | - | - | - |
| U Nass LT | Bowser | | | | | | | |
| U Nass LT | Oweege | | | | | | | |
| U Nass LT | Kwinag | X | - | - | - | - | - | - |
| U Nass LT | Damdoch | - | - | - | - | - | - | - |
| Nass RT | UNassRT | X | - | - | - | - | - | - |

Table E.4. *Data Checklist - By Observation - Nass Stocks*. This table shows how many spawner-recruit observations were flagged as unusual, using the criteria listed in Table D.2. Observations were flagged if they are an order of magnitude smaller or larger than the median (*OddSpn*, *OddRec*) or fall outside a range considered reasonable for this group of stocks (e.g. more than 15 recruits/spawner). Table E.8 illustrates the flagged observations.

| LHAZ | Stock | NumObs | OddSpn | OddRec | OddProd | OddExp |
|---|---|---|---|---|---|---|
| Nass SRT | LNassSRT | 34 | 0 | 1 | 5 | 0 |
| U Nass LT | Meziadin | 32 | 0 | 0 | 1 | 0 |
| U Nass LT | Bowser | 0 | 0 | 0 | 0 | 0 |
| U Nass LT | Oweege | 0 | 0 | 0 | 0 | 0 |
| U Nass LT | Kwinag | 21 | 5 | 0 | 4 | 0 |
| U Nass LT | Damdoch | 29 | 0 | 0 | 4 | 0 |
| Nass RT | UNassRT | 11 | 3 | 0 | 3 | 0 |

Table E.5. *Data Checklist - Summary Metrics - Skeena Stocks*. Table columns defined as per Table E.2.

| LHAZ | Stock | Contr | NumObs | LgSpn | LgRec | SmSpn | SmRec | LgExp |
|---|---|---|---|---|---|---|---|---|
| L Skeena LT | Johnston | 3750 | 11 | 1 | 1 | 1 | 1 | 2 |
| L Skeena LT | Ecstall | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| L Skeena LT | Alastair | 80.4 | 54 | 1 | 1 | 1 | 1 | 2.22 |
| L Skeena LT | Lakelse | 34.7 | 49 | 1 | 1 | 1 | 1 | 2.19 |
| L Skeena LT | Kitsumk | 82.7 | 46 | 1.11 | 1 | 1 | 1 | 3.82 |
| L Skeena LT | Mcdonell | 75 | 35 | 1.5 | 1 | 1 | 0.71 | 2 |
| M Skeena LT | Kitwanga | 416.1 | 17 | 1 | 1 | 0.23 | 0.3 | 1 |
| M Skeena LT | UBulkLk | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M Skeena LT | Morice | 205 | 50 | 1 | 1 | 1 | 1 | 1.16 |
| M Skeena LT | SwanSteph | 36924.5 | 46 | 1 | 1.11 | 1 | 0.09 | 3.55 |
| M Skeena LT | Bab-EW | 33.4 | 55 | 1 | 1 | 0.8 | 1 | 1 |
| M Skeena LT | Bab-LW | 15.8 | 55 | 1 | 1 | 1 | 1 | 1 |
| M Skeena LT | Bab-MW | 30.6 | 55 | 1 | 1 | 0.7 | 1 | 1 |
| M Skeena LT | Pinkut | 14.1 | 55 | 1 | 1 | 1 | 1 | 1 |
| M Skeena LT | Fulton | 13.1 | 55 | 1 | 1 | 1 | 1 | 1 |
| U Skeena LT | Sicintine | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| U Skeena LT | Slamg | 13.8 | 14 | 1.35 | 1 | 1 | 1 | 1 |
| U Skeena LT | Motase | 1050 | 16 | 2.91 | 1 | 0.06 | 1 | 2 |
| U Skeena LT | Bear | 97.6 | 36 | 1 | 1 | 1 | 1 | 2.34 |
| U Skeena LT | Asitka | 2415.9 | 11 | 1 | 1 | 0.02 | 0.95 | 2 |
| U Skeena LT | Sustut | 2600 | 27 | 1.04 | 1.03 | 0.17 | 1 | 1 |
| U Skeena LT | Kluant | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| U Skeena LT | Kluayaz | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Skeena RT | Skeena RT | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table E.6. *Data Checklist - By Series - Skeena Stocks*.Table columns defined as per Table E.3. Note that contrast is high for Pinkut and Fulton using the entire time series, which includes the years before and after the spawning channels were built.

| LHAZ | Stock | Contr | NumObs | LgSpn | LgRec | SmSpn | SmRec | LgExp |
|---|---|---|---|---|---|---|---|---|
| L Skeena LT | Johnston | X | - | - | - | - | - | - |
| L Skeena LT | Ecstall | | | | | | | |
| L Skeena LT | Alastair | - | - | - | - | - | - | - |
| L Skeena LT | Lakelse | - | - | - | - | - | - | - |
| L Skeena LT | Kitsumk | - | - | - | - | - | - | X |
| L Skeena LT | Mcdonell | - | - | - | - | - | - | - |
| M Skeena LT | Kitwanga | X | - | - | - | X | X | - |
| M Skeena LT | UBulkLk | | | | | | | |
| M Skeena LT | Morice | X | - | - | - | - | - | - |
| M Skeena LT | SwanSteph | X | - | - | - | - | X | X |
| M Skeena LT | Bab-EW | - | - | - | - | - | - | - |
| M Skeena LT | Bab-LW | - | - | - | - | - | - | - |
| M Skeena LT | Bab-MW | - | - | - | - | - | - | - |
| M Skeena LT | Pinkut | - | - | - | - | - | - | - |
| M Skeena LT | Fulton | - | - | - | - | - | - | - |
| U Skeena LT | Sicintine | | | | | | | |
| U Skeena LT | Slamg | - | - | - | - | - | - | - |
| U Skeena LT | Motase | X | - | X | - | X | - | - |
| U Skeena LT | Bear | - | - | - | - | - | - | - |
| U Skeena LT | Asitka | X | - | - | - | X | - | - |
| U Skeena LT | Sustut | X | - | - | - | X | - | - |
| U Skeena LT | Kluant | | | | | | | |
| U Skeena LT | Kluayaz | | | | | | | |
| Skeena RT | Skeena RT | - | X | - | - | - | - | - |

Table E.7. *Data Checklist - By Observation - Skeena Stocks*. Table layout as per Table E.4.

| LHAZ | Stock | NumObs | OddSpn | OddRec | OddProd | OddExp |
|---|---|---|---|---|---|---|
| L Skeena LT | Johnston | 11 | 2 | 0 | 3 | 0 |
| L Skeena LT | Ecstall | 0 | 0 | 0 | 0 | 0 |
| L Skeena LT | Alastair | 54 | 2 | 0 | 4 | 0 |
| L Skeena LT | Lakelse | 49 | 0 | 0 | 6 | 1 |
| L Skeena LT | Kitsumk | 46 | 0 | 0 | 0 | 0 |
| L Skeena LT | Mcdonell | 35 | 3 | 0 | 0 | 0 |
| M Skeena LT | Kitwanga | 17 | 3 | 2 | 4 | 0 |
| M Skeena LT | UBulkLk | 0 | 0 | 0 | 0 | 0 |
| M Skeena LT | Morice | 50 | 2 | 2 | 7 | 0 |
| M Skeena LT | SwanSteph | 46 | 4 | 1 | 8 | 0 |
| M Skeena LT | Bab-EW | 55 | 0 | 2 | 3 | 0 |
| M Skeena LT | Bab-LW | 55 | 0 | 2 | 1 | 0 |
| M Skeena LT | Bab-MW | 55 | 0 | 1 | 5 | 0 |
| M Skeena LT | Pinkut | 55 | 0 | 1 | 3 | 0 |
| M Skeena LT | Fulton | 55 | 0 | 1 | 3 | 0 |
| U Skeena LT | Sicintine | 0 | 0 | 0 | 0 | 0 |
| U Skeena LT | Slamg | 14 | 0 | 0 | 0 | 0 |
| U Skeena LT | Motase | 16 | 2 | 0 | 1 | 0 |
| U Skeena LT | Bear | 36 | 2 | 0 | 3 | 1 |
| U Skeena LT | Asitka | 11 | 1 | 0 | 3 | 0 |
| U Skeena LT | Sustut | 27 | 7 | 1 | 6 | 0 |
| U Skeena LT | Kluant | 0 | 0 | 0 | 0 | 0 |
| U Skeena LT | Kluayaz | 0 | 0 | 0 | 0 | 0 |
| Skeena RT | Skeena RT | 0 | 0 | 0 | 0 | 0 |

Table E.8. *Illustration of Flagged Records - At least 2 Key Metrics*. As an illustration of the kind of observations that were flagged in the data check (Tables E.4 and E.7), this table lists all the data points which were flagged for at least 2 of the 4 key metrics, using the criteria listed in Table D.2.

| Stock | Year | SpnIdx | SpnTot | Exp | Rec | RpS | OddSpn | OddRec | OddProd | OddExp |
|---|---|---|---|---|---|---|---|---|---|---|
| Alastair | 1975 | 600 | 1329 | 2.22 | 30861 | 23.21 | X | - | X | - |
| Alastair | 2008 | 444 | 983 | 2.22 | 25326 | 25.76 | X | - | X | - |
| Bab-EW | 2013 | 8760 | 8760 | 1 | 2109 | 0.24 | - | X | X | - |
| Bab-LW | 1994 | 132299 | 132299 | 1 | 35177 | 0.27 | - | X | X | - |
| Bab-MW | 2013 | 7960 | 7960 | 1 | 1323 | 0.17 | - | X | X | - |
| Bear | 1976 | 100 | 200 | 2 | 3263 | 16.31 | X | - | X | - |
| Fulton | 1994 | 428141 | 428141 | 1 | 58055 | 0.14 | - | X | X | - |
| Johnston | 1965 | 2 | 4 | 2 | 7079 | 1769.77 | X | - | X | - |
| Johnston | 1966 | 25 | 50 | 2 | 15234 | 304.68 | X | - | X | - |
| Kitwanga | 2014 | 13699 | 13699 | 1 | 1434 | 0.1 | X | - | X | - |
| Kwinag | 2010 | 48 | 48 | 1 | 9310 | 193.95 | X | - | X | - |
| Kwinag | 2013 | 397 | 397 | 1 | 6304 | 15.88 | X | - | X | - |
| LNassSRT | 1998 | 3868 | 10504 | 2.72 | 1525 | 0.15 | - | X | X | - |
| Morice | 1970 | 4700 | 10891 | 2.32 | 1541 | 0.14 | - | X | X | - |
| Morice | 1971 | 3300 | 7647 | 2.32 | 1438 | 0.19 | - | X | X | - |
| Morice | 1976 | 100 | 232 | 2.32 | 9505 | 41.02 | X | - | X | - |
| Sustut | 1960 | 100 | 100 | 1 | 2667 | 26.67 | X | - | X | - |
| Sustut | 1966 | 50 | 50 | 1 | 1874 | 37.48 | X | - | X | - |
| Sustut | 1967 | 100 | 100 | 1 | 2720 | 27.2 | X | - | X | - |
| Sustut | 1973 | 3300 | 3300 | 1 | 63 | 0.02 | - | X | X | - |
| Sustut | 1975 | 12 | 12 | 1 | 1061 | 88.44 | X | - | X | - |
| SwanSteph | 1961 | 750 | 1671 | 2.23 | 37330 | 22.33 | X | - | X | - |
| SwanSteph | 1962 | 1 | 2 | 2.23 | 66425 | 29807.35 | X | - | X | - |
| SwanSteph | 1976 | 425 | 1206 | 2.84 | 50614 | 41.96 | X | - | X | - |
| UNassRT | 2011 | 4 | 4 | 1 | 2206 | 551.61 | X | - | X | - |
| UNassRT | 2012 | 6 | 6 | 1 | 2758 | 459.61 | X | - | X | - |

## E.2 Data Quality Notes

Table E.9. *Quality of Spawner Data - Nass Stocks*. *PercSpn* is the share of cumulative spawner abundance since 2000 across *both* stock aggregates. Stocks are sorted from largest to smallest. *IdxSpn* is a qualitative commentary based on survey types and coverage, based on the *Q1* quality rankings in the NCCSDB (Section 3). *SpnExp* categorizes the total expansion factor. *TotalSpn* is a qualitative commentary on the overall quality of the spawner estimate, considering the quality of the index estimate and the expansion factor. *SpnRating* is the TWG consensus rating for the quality of spawner estimates on a 5-point scale from Very Good to Very Poor, based on the commentary for *TotalSpn*. Section D.2 describes the methods in more detail.

| Stock | PercSpn | IdxSpn | SpnExp | TotalSpn | SpnRating |
|---|---|---|---|---|---|
| Meziadin | 15 | Highly accurate fishway counts since 1966 | None | Very low uncertainty, No indication of bias | Very Good |
| Lower Nass Sea & River Type | 2 | Good quality index estimate. Multiple foot surveys and Zolzap fence some years. | Moderate | Moderate uncertainty due to expansion factor. | Moderate |
| Kwinageese | <1 | Highly accurate fence counts for 2002, 2005, 2006, 2009 to Current. Visual Surveys for other years. | None | Fence years: Very low uncertainty, No indication of bias. Other Years: Low uncertainty, likely biased low | Good to V. Gd |
| Damdochax | <1 | Good quality index estimate. Aerial surveys of 2 systems. | None | Low uncertainty because index streams cover the stock. | Good |
| Upper Nass River Type | <1 | Good quality index estimate. Foot/aerial surveys of 2 systems. | None most years. Low for a few early years. | Low uncertainty because index streams cover the stock. | Good |
| Bowser | | No estimates | | No estimates | Data Deficient |
| Oweegee | | No estimates | | No estimates | Data Deficient |

Table E.10. *Quality of Catch Data - Nass Stocks*. Qualitative commentary on the marine and in-river components of the total catch estimate, as well as the combined estimate. *CtRating* is the TWG consensus rating for the quality of catch estimates on a 5-point scale from Very Good to Very Poor, based on the commentary for *TotalCt*. Section D.2 describes the methods in more detail. *PercSpn* is the share of cumulative spawner abundance since 2000 across both stock aggregates. Stocks are sorted from largest to smallest.

| Stock | PercSpn | Marine | In-river | TotalCt | CtRating |
|---|---|---|---|---|---|
| Meziadin | 15 | Major stock | Major stock | Well estimated | Good |
| Lower Nass Sea & River Type | 2 | Migration may be different, introducing uncertainty | Well estimated, lower river stock. | | Good |
| Kwinageese | <1 | Likely similar to major stock | Well estimated | Mostly in-river and approach area, so well estimated | Moderate |
| Damdochax | <1 | Likely similar to major stock | Well estimated | Mostly in-river and approach area, so well estimated | Moderate |
| Upper Nass River Type | <1 | Migration may be different, introducing uncertainty | Highly uncertain | Half in-river and in approach areas. Poorly estimated. | Very Poor |
| Bowser | | | | | Data Deficient |
| Oweegee | | | | | Data Deficient |

Table E.11. *Quality of Recruitment Estimates - Nass Stocks*. Qualitative commentary on the run and age components of the recruitment estimate, as well as the combined estimate. *RecRating* is the TWG consensus rating for the quality of catch estimates on a 5-point scale from Very Good to Very Poor, based on the commentary for *TotalRec*. Section D.2 describes the methods in more detail. *PercSpn* is the share of cumulative spawner abundance since 2000 across both stock aggregates. Stocks are sorted from largest to smallest.

| Stock | PercSpn | RunRating | AgeMatch | AgeType | AgeData | RecRating |
|---|---|---|---|---|---|---|
| Meziadin | 15 | Good | Stock | Avg | Many years | Good |
| Lower Nass Sea & River Type | 2 | Moderate | Annual | Annual | Several years | Moderate |
| Kwinageese | <1 | Moderate | Stock | Avg | Many years | Moderate |
| Damdochax | <1 | Moderate | Stock | Avg | Many years | Moderate |
| Upper Nass River Type | <1 | Poor | Stock | Avg | Few years | Poor |
| Bowser | | Data Deficient | Stock | Avg | Many years | Data Deficient |
| Oweegee | | Data Deficient | Proxy | Avg | Many years | Data Deficient |

Table E.12. *Quality of Spawner Data - Skeena Stocks*. Table columns defined as per Table E.9.

| Stock | PercSpn | IdxSpn | SpnExp | TotalSpn | SpnRating |
|---|---|---|---|---|---|
| Fulton | 37 | Derived from high-quality fence count combine with second fence count. | None | Very low uncertainty, No indication of bias | Very Good |
| Babine Late Wild | 15 | Derived from high-quality fence count, proportioned based on AUC estimates. | None | Some uncertainty due to stock proportion estimates. | Good |
| Pinkut | 11 | Derived from high-quality fence count combine with second fence count. | None | Very low uncertainty, No indication of bias | Very Good |
| Babine Early Wild | 4 | Derived from high-quality fence count, proportioned based on AUC estimates. | None | Some uncertainty due to stock proportion estimates. | Good |
| Babine Mid Wild | 3 | Derived from high-quality fence count, proportioned based on AUC estimates. | None | Some uncertainty due to stock proportion estimates. | Good |
| Alastair | 2 | Fair quality index estimate. Only 1 missing year since 1960. 3 aerial surveys. | Moderate | Moderate uncertainty due to index quality and expansion factor. | Moderate |
| Kitsumkalum | 2 | Fair-Good quality index estimate. 2 missing years since 1960. 2 foot surveys. | High | High uncertainty due to high expansion. | Poor |
| Morice | 2 | Fair quality index estimates for most years since 1960. Mark-Recapture estimates from Lower Bulkley River supplemented by snorkel surveys and aerial counts on Nanika River in most years. | Low since 2000. Moderate before then. | Low uncertainty since 2000 | Good |
| Lakelse | 1 | Fair quality index estimate. A few missing years since 1960. 1 video weir and 2 foot surveys. | Moderate in most years, but extreme in 2 recent years. | Moderate uncertainty due to index quality and expansion factor. | Moderate |

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| Stock | PercSpn | IdxSpn | SpnExp | TotalSpn | SpnRating |
|---|---|---|---|---|---|
| Swan/Stephens | 1 | Fair quality index estimates for most years since 1960 on 2 sites. Foot and aerial surveys. | Variable. Moderate since 2001. High-very high most years before that. | Moderate uncertainty due to expansion factor. | Moderate |
| Bear | 1 | Poor-fair quality index estimate with many missing years, incl. since 2014. 2 aerial and 1 foot survey. | Moderate most years. High to Extreme in some years. | High uncertainty due to poor survey quality combined with expansion. | Poor |
| Mcdonell | <1 | Good quality index estimate for most years since 1960. Foot and/or aerial surveys. | Moderate | Moderate uncertainty due to expansion factor. | Moderate |
| Kitwanga | <1 | High quality index estimate since 2000. Some earlier estimates back to 1960. Weir counts since 2000. | None since 2000. Moderate before. | Low uncertainty since 2000 | Very Good |
| Sustut | <1 | High quality weir counts. | None | Very low uncertainty, No indication of bias | Very Good |
| Johnston | <1 | Poor quality index estimate. Missing years. 1 aerial survey. | Moderate | High uncertainty due to poor survey quality combined with expansion. | Poor |
| Asitka | <1 | Fair quality index estimate for most years since 2000, and many estimates before that. 1 aerial survey. | Moderate | Moderate uncertainty due to expansion factor. | Moderate |
| Slamgeesh | <1 | Good quality index estimates from counting weir on Damshilgwit Creek since 2000. | None | Low uncertainty | Good |
| Ecstall | | No Estimates | | No estimates | Data Deficient |
| Upper Bulkley Lakes | | No Estimates | | No estimates | Data Deficient |
| Sicintine | | No estimates | | No estimates | Data Deficient |

Continued on next page ...

| Stock | PercSpn | IdxSpn | SpnExp | TotalSpn | SpnRating |
|---|---|---|---|---|---|
| Kluantantan | | No estimates | | No estimates | Data Deficient |
| Kluayaz | | No estimates | | No estimates | Data Deficient |
| Skeena River Type | <1 | Good quality index estimate for most years since 2001, but proportion of the river type sockeye captured by surveys is unknown | None | Highly uncertain | DD |
| Motase | | Fair quality index estimates with a lot of missing years, including 2012-2016. 1 aerial survey. | Moderate | High uncertainty, lots of missing years | Very poor |

Table E.13. *Quality of Catch Data - Skeena Stocks*. Table columns defined as per Table E.10.

| Stock | PercSpn | Marine | In-river | TotalCt | CtRating |
|---|---|---|---|---|---|
| Fulton | 37 | Major stock | Major stock | Well estimated | Good |
| Babine Late Wild | 15 | Major stock | Major stock | Well estimated | Good |
| Pinkut | 11 | Major stock | Major stock | Well estimated | Good |
| Babine Early Wild | 4 | Major stock | Major stock | Well estimated | Good |
| Babine Mid Wild | 3 | Major stock | Major stock | Well estimated | Good |
| Alastair | 2 | Small stock | Moderate | Moderate | Moderate |
| Kitsumkalum | 2 | Small stock | Moderate | Moderate | Moderate |
| Morice | 2 | Assume similar to major stock | Uncertain | Well estimated | Moderate |
| Lakelse | 1 | Small stock | Moderate | Moderate | Moderate |
| Swan/Stephens | 1 | Small stock | Moderate | Moderate | Moderate |
| Bear | 1 | Small stock | Moderate | Moderate | Moderate |
| Mcdonell | <1 | Small stock | Moderate | Moderate | Moderate |
| Kitwanga | <1 | Small stock | Moderate | Moderate | Moderate |
| Sustut | <1 | Small stock | Moderate | Moderate | Moderate |
| Johnston | <1 | Small stock | Moderate | Moderate | Moderate |
| Asitka | <1 | Small stock | Moderate | Moderate | Moderate |
| Slamgeesh | <1 | Assume similar to major stock | Well estimated | Mostly in-river and approach area, so well estimated | Moderate |
| Ecstall | | | | | Data Deficient |
| Upper Bulkley Lakes | | | | | Data Deficient |
| Sicintine | | | | | Data Deficient |
| Kluantantan | | | | | Data Deficient |
| Kluayaz | | | | | Data Deficient |
| Skeena River Type | <1 | Migration may be different, introducing uncertainty | Highly uncertain | different life history, little data | Very Poor |
| Motase | | Small stock | Moderate | Moderate | Moderate |

Table E.14. *Quality of Recruitment Estimates - Skeena Stocks*. Table columns defined as per Table E.11.

| Stock | PercSpn | RunRating | AgeMatch | AgeType | AgeData | RecRating |
|---|---|---|---|---|---|---|
| Fulton | 37 | Good | Agg | Annual | Many years | Good |
| Babine Late Wild | 15 | Good | Agg | Annual | Many years | Good |
| Pinkut | 11 | Good | Agg | Annual | Many years | Good |
| Babine Early Wild | 4 | Good | Agg | Annual | Many years | Good |
| Babine Mid Wild | 3 | Good | Agg | Annual | Many years | Good |
| Alastair | 2 | Moderate | Stock | Avg | Few years | Moderate |
| Kitsumkalum | 2 | Poor | Proxy | Avg | Many years | Poor |
| Morice | 2 | Moderate | Stock | Avg | Many years | Moderate |
| Lakelse | 1 | Moderate | Stock | Avg | Few years | Moderate |
| Swan/Stephens | 1 | Moderate | Stock | Avg | 1 year | Moderate |
| Bear | 1 | Poor | Stock | Avg | 1 year | Poor |
| Mcdonell | <1 | Moderate | Proxy | Avg | Many years | Moderate |
| Kitwanga | <1 | Moderate | Stock | Avg | Many years | Good |
| Sustut | <1 | Moderate | Stock | Avg | Few years | Moderate |
| Johnston | <1 | Poor | Proxy | Avg | Many years | Poor |
| Asitka | <1 | Moderate | Proxy | Avg | Many years | Moderate |
| Slamgeesh | <1 | Moderate | Proxy | Avg | Many years | Moderate |
| Ecstall | | Data Deficient | Proxy | Avg | Many years | Data Deficient |
| Upper Bulkley Lakes | | Data Deficient | Proxy | Avg | Many years | Data Deficient |
| Sicintine | | Data Deficient | Proxy | Avg | Many years | Data Deficient |
| Kluantantan | | Data Deficient | Proxy | Avg | Many years | Data Deficient |
| Kluayaz | | Data Deficient | Proxy | Avg | Many years | Data Deficient |
| Skeena River Type | <1 | DD | Proxy | Avg | Many years | DD |
| Motase | | Moderate | Proxy | Avg | Many years | Very poor |