Taku River Sockeye Salmon Stock Assessment Review and Updated 1984-2018 Abundance Estimates

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February 2020

Pacific Salmon Commission Technical Report No. 43

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For

Pacific Salmon Commission
Joint Transboundary Technical Committee

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Correct citation for this publication:

Pestal, G., C. J. Schwarz and R. A. Clark. 2020. Taku River Sockeye Salmon Stock Assessment Review and Updated 1984-2018 Abundance Estimates. Pacific Salmon Comm. Tech. Rep. No. 43: 118 p.

Taku River Sockeye Salmon Stock Assessment Review and Updated 1984-2018 Abundance Estimates

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February 11, 2020

Fisheries and Oceans Canada, the Alaska Department of Fish and Game, and the Taku River Tlingit First Nation conducted a review of the Taku River Sockeye Salmon stock assessment program as directed by the Transboundary Panel of the Pacific Salmon Commission. The review was conducted over two years by a working group with representatives from each agency and capture-recapture specialists from both Canada and the U.S., supported by funding from the Northern Endowment Fund of the PSC. The review focused on compiling, cross-verifying, and analyzing capture-recapture program data from 1984 to 2018. Tagged fish dropping out of the study and capture gear selectivity were identified as sources of bias in estimating inriver abundance, and adjustments were made to each historical annual estimate to account for these. Taku River Sockeye Salmon stock assessment operational plans were improved to minimize and account for these biases. Alternative means of estimating abundance were explored, but we recommend that capture-recapture continue as the primary assessment method. However, a ratio-based estimator using genetic stock identification was identified as having potential for post-season abundance estimates.

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Acronyms

Acronym	*Explanation*
ADF&G	Alaska Department of Fish & Game
ASL	Age/sex/length sampling
DFO	Fisheries and Oceans Canada
PSC	Pacific Salmon Commission
PST	Pacific Salmon Treaty
TRTFN	Taku River Tlingit First Nation

Definitions

Term	**Definition**
run	Abundance of adult Sockeye Salmon returning in a calendar year
return	Abundance of adult Sockeye Salmon produced in a brood year (called *recruits* in most DFO documents) that return over multiple calendar years
catch	All adult Sockeye Salmon caught, whether retained or released
harvest	Only those caught fish that are retained
terminal run	Abundance of Sockeye Salmon entering the Taku River and those harvested in U.S. District 111
inriver abundance	Abundance of Sockeye Salmon passing Canyon Island assessment site into Canada
dropout	Any fish tagged at Canyon Island that did not cross the U.S./Canada border
stock	Group of Sockeye Salmon populations managed or assessed together (e.g. Tatsamenie Lake Sockeye Salmon)
statistical week (SW)	Numbered weeks of the year, starting on Sundays. The first week of the year may be a partial week until SW2 starts on the first Sunday. ADF&G has an on-line calendar of statistical weeks at https://mtalab.adfg.alaska.gov/OTO/reports/sbp_calendar.aspx?value=statweek
age class	This report uses the *European* age designation system for salmon, which gives the age as 2 numbers capturing the number of winters spent in the freshwater and marine environment, respectively. For example, a fish aged 1.4 spent 1 winter in freshwater, 4 winters in the ocean, and returns for spawning in the 6th year after its parents spawned.

1 Introduction

1.1 Stock Assessment Overview

The Taku River is a transboundary river system originating in the Stikine Plateau of northwestern British Columbia and terminating in Taku Inlet in Southeast Alaska (Figure 1). The Taku River produces one of the largest runs of Sockeye Salmon (*Oncorhynchus nerka*) in Southeast Alaska and northern British Columbia, which is jointly managed by the Alaska Department of Fish and Game (ADF&G) and the Department of Fisheries and Oceans Canada (DFO). The Pacific Salmon Commission (PSC) commits Canada and the U.S. to conservation and allocation obligations for salmon originating in the waters of the Canadian portion of the Taku River. The PSC via the Pacific Salmon Treaty (PST) of 1985, and subsequent revisions, has established conservation and harvest sharing obligations for Taku River Sockeye Salmon.

The core of the current Taku River stock assessment program is a capture–recapture study that has been conducted annually since 1984 (Clark et al. 1986; McGregor and Clark 1987, 1988, 1989; McGregor et al. 1991; Boyce and Andel 2012, 2014). The study operates as a joint U.S./Canada program involving ADF&G, DFO, and the Taku River Tlingit First Nation (TRTFN) to provide weekly estimates of the Taku River salmon abundance at the Canada/U.S. border. Migrating adult salmon are captured with fish wheels located downstream from the international border. The two primary fish wheels are positioned in the vicinity of Canyon Island on opposite riverbanks, approximately 200 m apart, and have been operated in identical locations since 1984. The Taku River is fully channelized through a relatively narrow, steep-walled canyon at this location, which is ideal for fish wheel operation. Tag recovery and secondary mark data are obtained from Canadian commercial and assessment fisheries. These are gillnet fisheries, involving both set nets and drift nets, which occur in Canadian portions of the Taku River within 20 km of the international border and almost all of the harvest occurs within 5 km of the border.

In addition to the capture–recapture study, counting weirs are operated by DFO at Little Trapper and Tatsamenie lakes and by TRTFN at Kuthai and King Salmon lakes (Figure 2). The counting weirs provide information on the distribution and abundance of discrete spawning stocks in the watershed. Radiotelemetry studies were conducted on the Taku River in 1984, 1986, 2015, 2017, and 2018, which provided additional information on the distribution of spawning sockeye salmon and also provided critical information on the proportions of tagged fish from the capture–recapture study that moved upstream and crossed the border. If tagged fish fail to cross the border (called *dropouts*) and are not available to be recaptured, they will cause the inriver abundance estimates to be biased high (McPherson et al. 1999).

The Taku River is a large and complex system, with multiple tributaries and lake systems, as well as inriver Aboriginal, personal use, and commercial sockeye salmon fisheries, which create special challenges for capture–recapture studies in the drainage. During recent negotiation of the PST, the need to review the Taku River stock assessment program and the current escapement goal for sockeye salmon was recognized and added into treaty language. A working group with representatives from each agency and capture–recapture specialists from both Canada and the U.S. was assembled to complete these reviews and this report documents work that was completed to review all aspects of the stock assessment program. Much of the information in this report was critical to the reevaluation of the Taku River sockeye salmon escapement goal, which is covered in a separate report (Miller and Pestal, in press).

1.2 Watershed Overview

The Taku River is a glacially turbid transboundary river system originating in the Stikine Plateau of northwestern British Columbia (Figure 2). The merging of two principal tributaries, the Inklin and Nakina rivers, approximately 50 km upstream from the border, forms the mainstem of the Taku River. The river flows southwest from this point through the Coast Mountain Range eventually draining into Taku Inlet in Southeast Alaska, about 30 km east of Juneau (Subdistrict 111-32). A majority of the

17,000 km^2 Taku River watershed lies within Canada, and nearly the entire watershed is accessible to salmon. The river produces one of the largest runs of Sockeye Salmon in northern British Columbia and Southeast Alaska and Sockeye Salmon spawn throughout the drainage in both river and lake habitats.

Discharge and peak flow data for the Taku River are available from the U.S. Geological Survey water gauging station located on the lower Taku River near Canyon Island (Station ID 15041200) for 1988 to 2018. Water data are available through the USGS National Water Information System Web Interface (https://nwis.waterdata.usgs.gov/nwis). Temperature and gauge data are available from the Canyon Island fish wheels covering most of the sockeye run in most years.

Water discharge in the winter (November–March) ranges from approximately 49 to 196 m^3/s. Discharge increases in April and May and reaches a maximum average flow of 890-1,000 m^3/s during June. Flow usually remains high in July but drops to approximately 500 m^3/s in late August. Sudden increases in discharge in the lower river result from a Jökulhlaup; release of the glacially impounded waters along the Tulsequah Glacier (Kerr 1948; Marcus 1960). These floods usually occur once or twice a year between June and September. During the floods, water levels fluctuate dramatically, water temperatures drop, and the river carries a tremendous load of debris. Between 1987 and 2003, a majority of the annual peak floods from the Jökulhlaup occurred in August (53%) and since 2004 to 2018 only 2 annual peak floods from the Jökulhlaup occurred in August with majority of the peaks occurring in July (53%). During water years 1987 to 2018 the instantaneous peak flow due to a Jökulhlaup event was as high as 3,200 m^3/s (July 22, 2007).

Resident fish that spawn in the Taku River include all 5 species of Pacific salmon: Chinook (*O. tshawytscha*), coho (*O. kisutch*), sockeye, pink (*O. gorbuscha*) and chum salmon (*O. keta*).

1.3 Stock Overview

The Canadian-origin Taku River Sockeye Salmon stock aggregate is currently described as five Sockeye Salmon stocks (Figure 2). There are four lake-type stocks within the Taku River drainage which spawn in lakes or adjacent streams and primarily smolt after spending at least one year of rearing in those lakes. Moving upstream from the mouth of Taku River, these stocks are King Salmon Lake, Kuthai Lake, Little Trapper Lake, and Tatsamenie Lake. Established stock assessment programs exist for these four lake-type stocks. The remaining Sockeye Salmon in the drainage are grouped together as one Mainstem stock for assessment purposes, because they are all considered to be river-type Sockeye Salmon. River-type Sockeye Salmon spawn mostly in rivers and streams, with varied rearing strategies from smolting in their first year to spending one year in freshwater before smolting. There are no stock assessment programs in place for Taku river-type Sockeye Salmon.

These distinct stocks have been identified over the years through observations of life history patterns, scale pattern analysis (Heinl et al. 2014) and through genetic stock identification (TTC 2019a). In spite of variations in life history and nuances between and within Sockeye Salmon stocks in the Taku River, we are currently confident in the ability of genetic tools to distinguish lake-type from river-type fish, as well as the ability to distinguish lake-type stocks from each other (Gilk-Baumer and Candy, pers comm). The Transboundary Technical Committee has a well-established Taku River Sockeye Salmon genetic baseline from which these stock assignments are made. This baseline includes 17 unique reporting groups to date, and improvements and additions are ongoing and bilateral.

For the U.S. District 111 commercial fishery and Canadian fisheries harvest assessment purposes, King Salmon Lake, Kuthai Lake, Little Trapper Lake, and Tatsatua stocks are combined into one reporting group referred to as Taku Lakes, while Tatsamenie Lake is reported individually, and river-type stocks are reported as Mainstem. Very recent Canadian genetic baseline work has confirmed that the small Tatsatua stock actually has a river-type life history, so it is included in the Mainstem river-type stock for genetic stock identification analyses in this report.

Sockeye Salmon populations are grouped into conservation units for Canadian domestic status assessments under the *Wild Salmon Policy*, but all Taku River CUs are currently aggregated into a single Taku River Sockeye Salmon stock aggregate for management purposes (e.g., inseason run-size, spawning escapement objectives). The analyses in this report are mostly done at this aggregate stock level, but the data overview and discussion include some commentary on the component stocks.

1.4 Review Process

1.4.1 Working Group

Under direction from the Transboundary Panel, DFO, ADF&G, and TRTFN reviewed the Taku River Sockeye Salmon stock assessment program to address an obligation identified in the Pacific Salmon Treaty (PST), which states: "The Taku River sockeye salmon assessment program will be reviewed by two experts (one selected by each Party) in mark-recovery estimation techniques. The Parties shall instruct these experts to make a joint recommendation to the Parties concerning improvements to the existing program including how to address inherent mark-recovery assumptions with an aim to minimize potential bias prior to the 2020 fishing season." (PST Chapter 1 Annex IV (3)(b)(i)(C)).

The process took two years and was supported by funding from the Northern Endowment Fund of the PSC.

A working group with representatives from each agency and capture-recapture specialists from both Canada and the U.S. was assembled. The two experts, required under the treaty, were identified as Robert Clark (ADF&G - retired) and Dr. Carl Schwarz (SFU – retired), and both are named co-authors of this report.

The full working group consisted of:

- Julie Bednarski - ADF&G – Fisheries Biologist - Co-chair
- Aaron Foos – DFO – Sr. Aquatic Science Biologist - Co-chair
- Robert Clark – retired ADF&G – Consulting Fisheries Scientist
- Dr. Carl Schwarz – retired SFU – Consulting Biometrician
- Ian Boyce – DFO – Sr. Aquatic Science Biologist
- Dr. Sara Miller – ADF&G – Biometrician
- Dr. Paul Vecsei – DFO – Sr. Aquatic Science Biologist
- Dr. Rich Brenner – ADF&G – Salmon Stock Assessment Biologist
- Richard Erhardt – Taku River Tlingit First Nation – Consulting Biologist
- Gottfried Pestal – DFO – Consulting Biometrician
- Andrew Piston – ADF&G – Fisheries Biologist
- Phil Richards – ADF&G – Fisheries Biologist

The Taku Sockeye Working Group closely coordinated all steps of the analysis through frequent conference calls, regular in-person meetings, and several sharing platforms (Sharepoint, GitHub). The data, analyses, and recommendations presented in this report reflect the consensus of the *Taku Sockeye Working Group*.

Building on the results of this review of the capture-recapture data, the Taku Sockeye Working Group also developed a Bayesian state-space model to estimate updated biological benchmarks (e.g., S_{msy}, S_{gen}) and develop recommendations for a biologically-based spawning goal (Miller and Pestal, in press).

1.4.2 Products & Linkages

The Taku Sockeye Working Group completed a comprehensive review of the stock assessment program for Taku River Sockeye Salmon, which is documented in a two main reports and various supplementary materials:

- *Literature review*: extensive literature review of primary literature and agency publications focused on capture-recapture studies, dropout estimates, and other Sockeye Salmon assessment techniques (Vecsei, in prep; included in supplementary materials: Pestal et al., in prep).
- *Data review*: review of assessment data, review of capture-recapture estimation approaches, updated abundance estimates (This report)

- *Supplementary materials*: additional diagnostic plots and data files for the analyses in this report (Pestal et al., in prep).
- *Biological benchmarks and escapement goal recommendations*: Bayesian state-space model using the updated abundance estimates to develop Biological escapement goals (Miller and Pestal, in press; DFO, in press)

In addition, many of the decisions and recommendations from the WG process are reflected in the revised operational plans for the annual implementation of the assessment program (Bednarski et al. 2019).

1.5 This Report

1.5.1 Outline

Chapter 2 outlines the assessment program and summarizes available data, including fish wheel counts, tag releases and recoveries, harvests, age and size composition, weir counts, genetic sampling, and radio telemetry studies.

Chapter 3 summarizes the stock structure of Taku River Sockeye Salmon. The stock aggregate includes lake and river-type stocks that spawn throughout the drainage. The assessment program includes fish wheels at Canyon Island, harvest monitoring in U.S. and Canadian fisheries, and spawning ground surveys with weirs at four key lakes.

Chapter 4 focuses on the review of the capture-recapture estimates of inriver abundance, including assumption checking, different estimation approaches to address potential sources of bias, and updated estimates for 1984-2018.

Chapter 5 explores alternative assessment methods (e.g., headwater-based capture-recapture estimates, ratio-based estimators using GSI).

Chapter 6 briefly summarizes the implementation of updated methods for inseason estimates of inriver abundance.

Chapter 7 summarizes the conclusions from Chapters 4 to 6.

2 Data Sources

This section summarizes the components of the assessment program, briefly describes each of the data sources, and how we cross-verified the raw records to build an updated data set for this analysis.

2.1 Stock Assessment Program

Sockeye Salmon abundance in the Taku River has been primarily estimated from U.S./Canada capture–recapture studies conducted annually by ADF&G, DFO, and TRTFN since 1984 (TTC 2019a). The primary objective of the capture–recapture study is to estimate the inriver abundance of Sockeye Salmon above the U.S./Canada border (Figure 2). Each year, inriver run estimates are generated weekly over the run to inform salmon harvest management, and a final inriver run estimate is generated post-season. These data, along with harvest data, are used to reconstruct and estimate the annual terminal run of Taku River Sockeye Salmon (TTC 2019a).

The capture-recapture study follows a 2-event design (Figure 2). For Event I, tagging of fish, Sockeye Salmon are caught with fish wheels at Canyon Island in Alaska near the U.S./Canada border. They are biologically sampled for age, sex, and length (ASL), tagged with spaghetti tags, and marked with secondary marks (e.g. fin clips). Event II, recovery of spaghetti tags from harvested fish, happens upriver in the Canadian commercial fishery and test/assessment (scientific) fishery. Fishers remove and return all tags from harvested fish, and a portion of the harvest is sampled, which includes inspecting for tag scars and secondary marks, as well as taking ASL samples. Tagged-to-untagged ratios of Sockeye Salmon caught in Canadian inriver gillnet fisheries are then used to develop estimates of the inriver abundance of Sockeye Salmon.

Escapements of lake-type stocks of Taku River Sockeye Salmon are also enumerated in Taku River headwaters using escapement weirs at the four main Sockeye Salmon lakes in the drainage: King Salmon, Kuthai, Little Trapper, and Tatsamenie.

Detailed summaries of the annual assessment results have been documented in periodic reports, initially in the ADF&G Regional Report Series, and starting in 1998 in the Pacific Salmon Commission Technical Report series. The most recent published report is for the 2013 season (Boyce and Andel 2014).

2.2 Quality Control

U.S. fish wheel data (tags, ASL) are maintained in the ADF&G Zander Database (Zander 2019). Stock composition from the fish wheel data is stored in spreadsheets and summarized in the TTC reports (TTC 2019a). Since 2012 the stock identification data has been stored in ADF&G's Gene Conservation Laboratory database. Canadian weir counts, harvest records, ASL samples, and tag data are maintained and housed in Excel format by DFO. All fishery otolith data are maintained by the ADF&G Mark Lab. Tag records for this project were compiled from these sources.

Raw input data was verified and basic error checks performed (e.g. ensuring that tag numbers of recaptures exist in the tag release records, ensuring that recapture dates are later than tag application dates, etc.). The remaining valid records were then merged across sources based on a *Year_Tag* identifier. The merging step also cross-checked records between files, and flagged discrepancies. Record cleaning used a series of custom functions to calculate dates from stat week data and fix date formats. Section 11.4 documents the steps and code.

Data by individual tag ID was compiled for 1998 to 2018. However, for 1984-1997 (excluding 1986), the summary matrices by statistical week were extracted from hard-copies of annual reports, scanned, and cross-verified. ASL data was matched to the tags for 2003-2018.

For the years where tag application data was match with recovery data (1998-2018), the annual number of valid tag records ranged from about 3,000 to about 7,000, for a total data set of over 90,000 records (Table 1; Figure 10) . The proportion of valid tag records ranged from 92% to 99%

and has been above 98% for 2016-2018 (valid = complete tag id, plausible dates). Fish wheel samples have been consistently tagged at a very high proportion (95% or more tagged in years with data), but the number of tags released and recovered varied by year. The proportion of tags recovered in the Canadian Commercial fishery has been quite stable over time, ranging from 12% to 23%.

2.3 Assessment Details

2.3.1 Canyon Island Fish Wheel Sampling and Tag Application

From 1984 to 2018 two fish wheels were generally operated from late May to mid-September. Fish wheels are positioned downstream of the Canada/U.S. border in the vicinity of Canyon Island on opposite riverbanks, approximately 200 m apart (Figure 2). The Taku River channel at this location is ideal for fish wheel operation since the river is fully channelized through a relatively narrow canyon that has very steep walls. Migrating salmon are captured in the rotating fish wheel baskets as they swim under the structure and held in perforated aluminum live boxes until sampled. In 2016 and 2017 a third fish wheel was operated downriver from Canyon Island across from Yehring River.

From 1984 to 2017 fish wheels were operated 24 hours per day and generally sampled twice a day around 8:00 and 16:00, which included a holding time over 12 hrs. Several other studies have documented adverse effects on fish captured and handled in fish wheels with extended holding times (Bromaghin and Underwood 2003; Cleary 2003; Underwood et al. 2004; Bromaghin et al. 2007; Liller et al. 2011). In order to reduce stress associated with fish wheel capture and tagging from 2018 onward, fish wheel methods were changed to general hours of operation from 4:00 to 12:00 and from 16:00 to 22:00, with hourly fish wheel sampling. Fish wheels were not operated outside of these hours.

Annual sampling consists of counting all healthy Sockeye Salmon captured in fish wheels and recording sex, mideye-to-fork (MEF) length, and collecting scale samples. Fish with deep wounds, damaged gills, or in a lethargic or otherwise unhealthy condition are counted then released without being tagged. Fish <350 mm MEF (defined as jacks) are measured but are not tagged. All healthy adult Sockeye Salmon ≥350 mm MEF are tagged as part of the annual capture–recapture study (Figure 10).

The fish are tagged with spaghetti tags (Floy Tag and Manufacturing Inc., Seattle, WA) made of hollow fluorescent orange PVC tubing (approximately 2.0 mm in diameter and 30 cm in length) that are consecutively numbered and labeled with project description information. Spaghetti tags are inserted with a 15 cm applicator needle through the dorsal musculature immediately below the dorsal fin. The ends of the spaghetti tag are then knotted together with a single overhand hitch (Figure 9).

Other information recorded daily at the fish wheels includes water temperature, fish wheel rotation speed, and fish wheel start and stop times. River water level is measured daily at gauging staff on river right.

For 1985 to 2018, paper records of ASL data were scanned and archived in Zander (Zander 2019). From 2003 to 2018, individual spaghetti tag data are matched to the ASL data in Zander. The fish wheel catch used in this capture-recapture analysis is from Zander and not from inseason spreadsheets, except fish wheel 3 data from years 2016 and 2017. The catch data used to calculate fish wheel CPUE data is from Zander and the fish wheel effort is from an excel spreadsheet maintained by ADF&G in Douglas.

2.3.2 Monitoring Canadian Harvests and Tag Recovery

In Canada, a commercial set and drift gill net fishery extends from the international border upstream for approximately 18 km (Figure 2), with test/assessment and Aboriginal fisheries also harvesting Taku River Sockeye Salmon. The majority of harvest occurs within 5 km of the border.

Canadian commercial fishing periods have averaged three days per week during the directed Sockeye Salmon fishery, with openings ranging from zero to seven days per week, and are chosen weekly inseason by fishery managers based on available stock assessment data. The Canadian commercial and test/assessment fisheries are sampled weekly. On average DFO samples about 2,200 Sockeye Salmon per season from the Canadian commercial fishery for ASL, otoliths (non-matched), and genetic tissue (matched since 2018).

The spaghetti tag recovery data used in developing abundance estimates comes from almost exclusively from the commercial fishery. Prior to 2016 a monetary reward (initially $2, increasing to $5 in 2000) was provided to fishers for each spaghetti tag return. In 2016 this was discontinued during a review of commercial licence conditions – since it was already identified as a condition of licence, a cash reward was deemed to be no longer appropriate. Conditions stipulate that tags must be provided to DFO on a daily basis. Field staff gather these from fishers on a daily basis and record individual tag numbers. Secondary mark sampling provides insight on tag return compliance. While sampling for ASL data, escapement project (weir) staff inspect Sockeye Salmon for tags and secondary marks, and record individual tag numbers.

During the fishing season, tag IDs are matched with release data on a weekly or more frequent basis. Nonsensical results, such as no application record, tag recovery preceding application, or excessive travel time, are investigated and corrected inseason. In addition, further quality control is done post-season by cross-checking digital recovery records against paper records. For this project, the existing multi-year tag recovery data set was revised and expanded to cover tag data back to 1992, including a review of paper records and other data sources (e.g. technical reports).

The Canadian commercial fishery harvests an average of 24,700 wild and enhanced Taku River Sockeye Salmon each year (1984 - 2017). Harvest records, ASL sample, and tag data are maintained and housed in Excel and internal database formats by DFO.

The Canadian Aboriginal food, social, and ceremonial (FSC) fishery harvests are monitored and reported to DFO by the TRTFN and have averaged less than 200 Taku River Sockeye Salmon per year.

Tags are also recovered from headwater areas, primarily through weir projects. On these projects all fish are inspected for tags and a subset of the tags are retrieved in order to record IDs.

2.3.3 Monitoring U.S. Harvests

In the terminal Alaskan District 111, Taku River Sockeye Salmon are harvested in the mixed-stock U.S. commercial drift gillnet and inriver personal use fisheries. There is also incidental harvest in the hatchery purse seine fishery at Amalga harbor in District 111. The traditional U.S. commercial drift gillnet fishery is sampled weekly for matched ASL, otolith samples and genetic tissue data. On average 4,400 ASL samples have been taken each year in the District 111 gillnet fishery (1982–2018). On average 80,900 fish harvested annually are wild and enhanced fish of Taku River origin (73% of the harvest). The mixed stock analysis is based on scale pattern analysis (1983–2011; Heinl et. al 2014) and an age-enhanced genetic mixed-stock analysis (MAGMA) model, which is an extension of the Pella-Masuda GSI model (Pella and Masuda 200; 2012–2017).

The U.S. fishery and related data was not reviewed or analyzed during this stock assessment review. A thorough review of the data was conducted prior to the Speel Lake escapement goal analysis in 2014 (Heinl et al. 2014).

2.3.4 Escapement Monitoring

Taku River Sockeye Salmon escapements are monitored through various weir and headwater projects. Four lake-type runs are enumerated annually, ASL samples are collected, spaghetti tags are enumerated and/or recovered, and tag loss is monitored. There have not been any escapement monitoring projects for populations in the Mainstem (river-type) Sockeye Salmon stock.

King Salmon Lake

King Salmon Lake Sockeye Salmon have been continuously monitored through an escapement weir since 2003. The weir is operated by the TRTFN through funding provided by DFO, and is located at the outlet of King Salmon Creek. The weir was operated as a traditional counting weir through 2016, and was modified to a passive video monitoring weir in 2017.

Kuthai Lake

Kuthai Lake Sockeye Salmon were first monitored with an escapement weir in 1980 and 1981, but have been continuously monitored through an escapement weir since 1992. The weir is operated by the TRTFN through funding provided by DFO, and is located at the outlet of Silver Salmon River. The weir was operated as a traditional counting weir through 2016, and was modified to a passive video monitoring weir in 2017.

Little Trapper Lake

Little Trapper Lake Sockeye Salmon have been continuously monitored through an escapement weir since 1983. The weir is operated by Metla Environmental Inc. under contract to DFO, and is located at the outlet of Kowatua Creek. The weir is operated as a traditional counting weir.

Tatsamenie Lake

Tatsamenie Lake Sockeye Salmon have been continuously monitored through an escapement weir since 1995. The weir is operated by Metla Environmental Inc. under contract to DFO, and is located at the outlet of Tastatua Creek. The weir is operated as a traditional counting weir.

River-Type Stock

Enumeration of the Taku river-type Sockeye Salmon stock is currently completed by simply removing the known lake-type escapements from the total drainage escapement estimate. There has been sporadic ASL sampling of river-type fish over various years and locations as part of sample collection for stock identification.

Available Data

Escapement data include daily weir passage counts, tag recoveries, and Sockeye Salmon ASL sample data by location. On average about 800 samples have been taken annually from Tatsamenie and Little Trapper lakes, while about 400 – 450 samples are taken annually from King Salmon and Kuthai lakes.

2.3.5 Genetic Stock Identification

Sockeye Salmon genetic baseline data have been collected by all management agencies in the Taku River. The baseline has been developed bilaterally and agreed to through the Transboundary Technical Committee (Olive et al. 2018, TTC 2019b). Each year since 2012, genetics data collected from the U.S. District 111 commercial fishery has been analyzed by ADF&G’s Gene Conservation Laboratory for stock composition data required to meet PST harvest allocation criteria. Each year since 2008, genetics data collected from the Canadian commercial fishery have been analyzed by DFO’s Molecular Genetics Laboratory for stock composition data required to meet PST harvest allocation criteria. Analyzed samples average 1,200 per season in Canada. Consistent annual sampling for genetics began at the fish wheels in 2019. This is to inform any potential bias in inriver stock composition that may be occurring in the fishery sampling.

2.3.6 Radio Telemetry Studies

Radio telemetry studies on Taku River Sockeye Salmon have been conducted in 1984, 1986, 2015, 2017, and 2018. These and other studies have provided valuable information on tagged fish that drop out of the capture–recapture study because not all fish tagged in the capture event are available for recapture (Table 2). Fish dropout is defined as any fish tagged at the Canyon Island fish wheels that did not cross the border; this includes mortality of marked fish due to predation, fish spawning below the border, or mortality due to capture, handling, and tagging at the Canyon Island fish wheels. If dropouts are not accounted for, abundance estimates will be biased high (McPherson et al. 1999). Fish that are spaghetti tagged in capture–recapture studies are assumed to experience similar “dropouts” to radio tagged fish.

In 1984, 93 Sockeye Salmon were captured using 2 fish wheels and tagged with radio transmitters and 74 of those fish crossed the border (20.4% dropout rate; Eiler et al. 1992; Table 2). In 1986, the study site included tagging downriver near the estuary (Eiler et al. 1988), so the results are not directly relevant to this review of our program. In 2015, 17 of the 99 radiotagged fish did not cross the border and were considered dropouts (17%); note that tagging focused on Kuthai fish early in the run. In 2017, 277 Sockeye Salmon were captured, radiotagged, and assigned a fate using three fish wheels in the lower Taku River. Of the 277 fish radiotagged in 2017, 32.1% (89/277 fish) did not cross the border and were considered dropouts. Of the remaining radiotagged fish that crossed the border, 28% were harvested in inriver fisheries (53/188 fish) and 69% (130/188 fish) likely spawned in the Canadian portion of the Taku River.

In 2018, 458 Sockeye Salmon were captured, radiotagged, and assigned a fate. Of the 458 fish radiotagged, 14.6% (67/458 fish) did not cross the border and were considered dropouts. Of the remaining radiotagged fish that crossed the border, 17% were harvested in inriver Canadian fisheries (80/458 fish) and 68% (311/458 fish) likely spawned in the Canadian portion of the Taku River. An additional 118 radio tags were deployed in a related side project. Once per week during the season, a fish wheel was operated overnight, and fish were held for 16 hours. The purpose of this side project was to simulate the historic fish wheel operations, which was necessary in order to provide comparable radiotelemetry dropout results to previous years with longer holding times. The dropout rate for the side project in 2018 was 20.3% (24/118 fish), and this estimate is used as part of the average historical dropout estimate. For a description of the side versus regular project see Appendix C in Andel et al. (2018).

3 Taku River Sockeye Salmon Stocks

3.1 Overview

Using newly revised non-expanded abundance estimates for Taku River Sockeye Salmon, all stocks combine to a recent ten-year (2009-2018) average escapement estimate of about 67,200 fish. In order of abundance the four monitored lake-type stock escapements are Tatsamenie Lake, with a ten-year average of about 10,000 fish, followed by Little Trapper Lake with about 7,000 fish, King Salmon Lake with about 2,500 fish, and Kuthai Lake with about 750 fish. There are no other lakes in the drainage that support known lake-type Sockeye Salmon stocks. By subtraction, all remaining escapements are therefore considered to be river-type or Mainstem fish, with a ten-year average of about 47,200 fish.

Based on tag recoveries in the headwaters, the general run timing sequence of these stocks past the Canyon Island fish wheels is Kuthai Lake (median return in SW 26), King Salmon Lake (SW28), Mainstem (SW28), Little Trapper Lake (SW29), and then Tatsamenie Lake (SW32) (Figure 5).

The lake-type stocks are mostly comprised of ages 1.2 or 1.3 (4 and 5 year old fish that spend one year rearing in freshwater) with varying relative contribution, and <1% age 0.x ("zero-check" fish that do not rear in freshwater), while the river-type stock is comprised of about 45% zero-check fish (ages 0.2 and 0.3, 3 and 4 year old fish that do not rear in freshwater) with most of the remainder "one-check" fish (ages 1.2 and 1.3, 4 and 5 year old fish that spend one year rearing in freshwater) (Figure 7).

3.2 Lake-Type Stocks

3.2.1 King Salmon Lake

The recent ten-year average abundance of natural Sockeye Salmon spawners in King Salmon Lake is 2,680 fish (Figure 4), which constitutes approximately 4.0% of the average Taku River drainage Sockeye Salmon escapement.

King Salmon Lake fish tend to be smaller (median size = 490 mm) than all the other stocks (medians of 535 mm to 560 mm) (Figure 6).

The ten-year average age composition of King Salmon Lake Sockeye Salmon is unique from other Taku River lake-type Sockeye Salmon stocks, as this stock is dominated by 4 year old fish (68% - all 1.2 age class) followed by 5 year old fish (25% - mostly 1.3 age class) (Figure 7).

There have been limited enhancement activities conducted at King Salmon Lake, with egg takes in 2012 and 2014 and subsequent fry outplants (TTC 2019a). Survival of enhanced fish appears to be very high (TRTF 2018) and the lake is a candidate for further enhancement activities.

3.2.2 Kuthai Lake

The recent ten-year average abundance of natural Sockeye Salmon spawners in Kuthai Lake is 760 fish (Figure 4), which constitutes about 1.1% of the average Taku River drainage Sockeye Salmon escapement. Escapements over the recent ten-year period have been much lower in comparison to the long term average Kuthai Lake escapements of nearly 3,000 fish.

Ongoing investigations since 2015 have been assessing a series of challenges to Sockeye Salmon passage in the canyon at the lower reaches of the Silver Salmon River, which appear to be preventing the passage of significant portions of recent runs (TRTF 2018). Recent years of low water have likely exacerbated these challenges, and physical works began in 2018 to address these challenges and make improvements for salmon passage.

Kuthai Lake fish tend to be similar length (median size = 560 mm) to all the other stocks except King Salmon (Figure 6), but anecdotally these fish are skinnier and more “snake-like” in appearance.

The ten-year average age composition of Kuthai Lake Sockeye Salmon shows a dominance by 5 year old fish (66% - mostly 1.3 age class) followed by 4 year old fish (31% - all 1.2 age class) (Figure 7).

There have been no enhancement activities at Kuthai Lake.

3.2.3 Little Trapper Lake

Trapper Lake, just upstream of Little Trapper Lake, is larger, but a migration barrier in the connecting river precludes Sockeye Salmon from reaching the lake, although the presence of Kokanee Salmon (land-locked Sockeye Salmon) indicates that they once accessed the lake (PSC 1998).

The recent ten-year average abundance of natural Sockeye Salmon spawners in Little Trapper Lake is 6,970 fish (Figure 4), which constitutes 10.4% of the average Taku River drainage Sockeye Salmon escapement. Escapements over the recent ten-year period have been much lower in comparison to the long-term average return of nearly 11,000 fish.

Little Trapper Lake fish tend to be similar length (median size = 535 mm) to all the other stocks except King Salmon (Figure 6),), but show a bimodal length distribution more similar to the Mainstem fish.

The ten-year average age composition of Little Trapper Lake Sockeye Salmon shows a dominance by 5 year old fish (53% - mostly 1.3 with some 2.2 age classes) followed by 4 year old fish (39% - nearly all 1.2 age class) (Figure 7).

There have been intermittent enhancement activities at Little Trapper Lake, with egg takes conducted in 1991-1994, 2006-2008, and 2016-2017, with subsequent fry outplants (TTC 2019a). Further enhancement activities are planned for Little Trapper and Trapper lakes.

3.2.4 Tatsamenie Lake

The recent ten-year average abundance of natural Sockeye Salmon spawners in Tatsamenie Lake is 9,590 fish (Figure 4), which constitutes 14.3% of the average Taku River drainage Sockeye Salmon escapement. Escapements over the recent ten-year period have been extremely variable from a low of 939 fish in 2015 to a high of 31,434 fish in 2016.

Tatsamenie Lake fish tend to be similar length (median size = 555 mm) to all the other stocks except King Salmon (Figure 6),

The ten-year average age composition of Tatsamenie Lake Sockeye Salmon shows a dominance by 5 year old fish (52% - mostly 1.3 with some 2.2 age classes) followed by 4 year old fish (41% - nearly all 1.2 age class) (Figure 7).

There have been extensive enhancement activities at Tatsamenie Lake since 1995 (TTC 2019a). The lake has ongoing enhancement activities.

3.3 Mainstem (River-Type) Stock

Currently, all remaining Taku River Sockeye Salmon populations that are not one of the lake-type stock listed above are considered to be Mainstem (river-type) fish.

Mainstem populations are not enumerated directly but are estimated based on the difference between drainage-wide escapement estimates and the sum of known lake escapements. The ten-year average Sockeye Salmon escapement into the Taku River (2009-2018) is estimated at about 67,200 fish. The average lake-type stock escapements are about 20,000 fish and the Mainstem stock averages about 47,200 fish, approximately 70% of the average spawning escapement.

There are other indicators that provide additional insight into the Taku Mainstem stock. In 1984 and 1986, radiotelemetry was used to locate and characterize the distribution of spawning Sockeye Salmon in the Taku River (Eiler et al. 1992). Through this work, the Mainstem component was shown to contribute approximately 63% to the total inriver run. Radio telemetry work is currently ongoing on the Taku River and these forthcoming results will provide updated information.

Genetic stock composition data from five recent years of U.S. District 111 gillnet fishery harvest sampling (2014-2018) shows that the Taku Mainstem stock comprises about 56% of the harvest, compared to 44% for Taku lake-type stocks, indicating that river-type fish are slightly more abundant in the harvest than lake-type Sockeye Salmon. Genetic stock composition data from the Canadian commercial gillnet fishery harvest sampling over the same years (2014-2018) shows that the Taku Mainstem stock comprise about 52% of the harvest, compared to 48% for Taku lake-type stocks, indicating that river-type fish are also slightly more abundant in the harvest than lake-type fish (Figure 8). These data must be considered with the caveat of gear selectivity and the tendency of commercial gillnets to capture larger-sized fish in the run potentially under represent much of the smaller-sized age classes of fish, particularly age 0.2 fish (see size selectivity section for a discussion of the Canadian commercial fishery size bias).

Biological samples of river-type Sockeye Salmon escapement is available from spawning ground samples collected for scale pattern analyses from 2004-2012 as well as various baseline genetic sample collections. Data are available from Taku River mainstem, Nahlin River, Tulsequah River, Hackett River, Dudidontu River, and Nakina River.

Mainstem fish show a bimodal length distribution likely related to age class, but tend to be similar median length (median size = 550 mm) to all the other stocks except King Salmon (Figure 6).

Combining age composition data for all river-type populations, 45% of samples exhibit the classic river-type life history of smolting in first summer ("zero-check" or 0.2 and 0.3 fish), while about 55% spend one year in freshwater before smolting (1.2 and 1.3 fish) (Figure 5). Recently there have been large annual variations in the proportion of zero check fish in the run, for example 2014 and 2018 where age 0.2 fish comprised nearly 20% of the Canadian commercial harvest compared to the average 4-5% (Figure 20).

4 Annual Capture-Recapture Estimates

4.1 Capture-Recapture Assumptions

This section introduces key assumptions for capture-recapture estimates, summarizes corresponding diagnostics for the Taku Sockeye Salmon data, compares three different estimation methods, and documents the resulting updated abundance estimates for 1984 to 2018.

4.1.1 Overview of Key Assumptions

Schwarz *et al.* (2009) and Boyce and Andel (2014) identify the following key assumptions for an inriver capture-recapture estimate of salmon migrating upstream:

1) *no missing tags*: no tag loss, tag misidentification or non-reporting
2) *no tagging effects*: no difference in subsequent survival, behaviour, movement, or catchability
3) *closed population*: all the same individuals are available for marking and recapture
4) *equal probabilities*: all individuals have the same probability of being tagged and recaptured

These assumptions apply to all variations of the Petersen estimator (Seber 1982) and relate to the difference between assumed and actual probability of applying and then recapturing tags. Any missing tags (1) will create the appearance of a larger population. Tagging effects (2) can bias estimates upwards (e.g., trap shyness) or downwards (e.g., trap happiness). Fish moving into or out of the sampling area (3) between the tagging event and the recapture event can also bias the estimate in either direction. The probability (4) of tagging or recovery can be influenced by many factors (e.g., size selectivity of tagging gear vs. recapture gear). Assumption 4 may be a particular concern for time-stratified estimates in settings like the Taku Sockeye Salmon program, where tags are applied continuously at the fishwheel, but can only be recaptured in discrete fishery openings of variable length.

The Taku Sockeye Working Group conducted a detailed review to determine whether or not these assumptions were being met. Various graphical displays were used to visualize the data and check for violations of assumptions. These included patterns of tag releases and recoveries (over the season, by weekday, time to recovery, proportion recovered) as well as size distributions and age compositions. Some of the diagnostic plots are relevant to multiple assumptions, and each assumption was examined in multiple ways.

This section provides a brief overview of the main diagnostic plots. Some of the year-specific plots are included here as an illustration, but the full set of diagnostics is included in the supplementary material (Pestal et al., in prep).

Subsequent sections evaluate each assumption in turn. Where violations occur, the sources of bias are identified and mitigating measures proposed. Different estimation methods explored in Section 4.2 (Capture-Recapture Estimates) were selected based on these potential sources of bias.

Annual Release & Recovery Profiles

Annual profiles of tag releases and tag recoveries showed two general patterns, which can be illustrated with data from 2017 and 2018 (Figures 11 to 14).

Tags are released continuously. In some years (e.g., 2018), tag releases followed an overall pattern of gradual increase and decrease over the course of the season. However, other years (e.g., 2017) had a pronounced weekly pattern of more releases earlier in the week, which is likely due to a shadow effect of the previous week's downstream and marine fishery openings on daily abundances. Upstream commercial fisheries and associated tag recoveries occur during openings that are typically 1-4 days at the beginning of each week. Tags from each release date are recovered over multiple fishery openings. Tag recovery rates vary over the course of the season.

Differences due to Weekday of Release

The weekday on which tags are released at the fish wheels affects both the proportion recovered and the time to recovery in the Canadian Commercial fishery (Figures 15 and 16).

Given the pattern of continuous tag release at the fish wheels and intermittent recovery due to the pattern of fishery openings generally early in the week (e.g. Fig. 13):

- the proportion of recovered tags decreases later in the week, with lowest proportion recovered from releases between Wednesday and Friday.
- tags released on Sunday and Monday are generally recovered much sooner than tags released later in the week (medians of 3 days vs. 5-6 days).

Distribution of Time to Recovery

Most tag recoveries in the Canadian Commercial fishery occurred within 10 days of release and fish reached the spawning grounds about 20-40 days after passing the fish wheels (Figure 17; top panels). Median time to recovery in the Canadian Commercial fishery differed by a few days between years (e.g., 2009 vs. 2018; bottom panels of Figure 17) .

Secondary Marks

Tag recoveries and observations of secondary marks have generally tracked closely for the time window with the bulk of the run (statistical weeks 28 to 35), with no indication of consistent bias between the two proportions (e.g., see Figure 18 for 2018). In some weeks the tagged proportion was higher, in others the proportion of secondary marks was higher. In some years, like 2016, there was a late-season spike in both tag recoveries and secondary mark observations (Figure 19).

Sampling variability is probably the main cause of observed differences in any given week as well as odd patterns at the beginning or end of the sampling program, given that only a small part of the Canadian Commercial harvest is inspected for secondary marks (Table 3).

Tag recoveries by licence in the Canadian Commercial fisheries (Table 4) show that no individual was consistently at the low end or the high end of the range. Individual values can be affected by sample size and fishing patterns (e.g., how much of the run was fished and on which dates).

Size and Age Composition

Various diagnostics of size distribution, age composition, size-at-age, and sample size were explored (Figures 20 through 26).

The most notable observations are:

- fish in the Canadian commercial harvest have been smaller in recent years (this may due to size-selective harvest)
- sizes of fish have been more variable in recent years (both releases and recoveries)
- size difference between releases and recoveries is more pronounced in years with smaller-sized fish (i.e., recent years)
- overall size in the total Canadian commercial harvest is consistently larger than the size of tagged fish in the Canadian commercial harvest.
- size-at-age has been fairly stable but shows a slight drop in the size of age 5 and age 6 fish and a slight increase in the size of age 4. The sample size of length measures in the Canadian commercial harvest was substantially increased in the early 1990s.

4.1.2 Assumption 1: No missing tags

The Petersen estimate assumes that there is no tag loss, tag misidentification or non-reporting. Should any of these occur, they need to be estimated and adjusted for. Note that this assumption deals with lost or missed *tags* (e.g., if they fall off or are overlooked in the recapture stage), rather than lost *fish* (Assumption 3).

Past studies, operational details, and additional data are available to assess whether these are potential concerns in the Taku Sockeye Salmon capture-recapture program.

Section 2.3.1 describes the tag application. The Canadian Commercial fishery used as the recapture event is close to the tagging site (Sec. 2.3.2) resulting in a very short travel time between the two locations, which reduces the likelihood of tag loss.

Tag Loss Due To Breakage or Shedding

The standard check for tag loss is *double tagging*, where each tagged fish also receives a secondary mark. If the proportion of secondary marks detected is close to the proportion of spaghetti tags, then there is little tag loss. If the proportion of fish with a secondary mark is consistently much higher than the proportion of fish with a primary mark, then there likely is substantial tag loss. Fish that lose their spaghetti tags are readily identifiable by the presence of entrance and exit holes just below the dorsal fin created during tag application; these serve as a secondary mark. Additional secondary marks have been deployed including hole punches to various fins, and clipping of the left axillary appendage.

To gain insight on tag loss, the incidence of secondary marks can be compared with tag recoveries in the recapture sample (the upstream fishery). This has been conducted and reported on at various times during the course of the Taku River Sockeye Salmon capture-recapture program (Kelley et al. 1997, McGregor et al. 1991). For most years, this was conducted concurrent with age-length sampling, with a target sample sizes of 200 fish per week. For some years starting in 2010, a more intensive study was conducted. In these years, an axillary appendage clip served as the secondary mark and directed sampling was conducted.

Table 3 lists annual tag recoveries, secondary mark observations, and corresponding sample sizes.

There were two observed types of annual patterns (Figures 18 and 19). In general, though, secondary mark rates tracked the primary mark rates closely, and there was no consistent bias. There was variability in both weekly estimates, and observed differences were probably due to the smaller sample size in the secondary mark inspections.

Tag Misidentification

The capture-recapture data set for 1984 to 2018 includes over 90,000 records (Sec. 2.2).

Section 2.3.2 describes the quality control steps taken inseason and post-season to reduce the likelihood of tag misidentification. In any data set of this size, some record mismatches and data entry issues are inevitable, but there is no indication of any substantial or consistent problem. Any incomplete records are excluded from both components of the analysis (e.g., if a tag ID has a plausible recapture date but a non-sensical release date, it is excluded from the analysis).

A direct check for tag misreads can be done by subsampling the recovered tags and re-reading them to estimate an error rate. This has not been done for the Taku River Sockeye Salmon capture-recapture program, because the Taku Sockeye Working Group considered it a much lower priority than testing other potential sources of bias. Note that all recovered tags are already re-read three times in the process of getting to a final post season data set.

Tag Non-Reporting

Overlooked or non-reported tags in the Canadian commercial fishery could bias the estimate high (i.e., fewer recovered tags translate into larger estimated abundance), leading to potential concerns due to short-term incentives for non-reporting (i.e., larger inseason run size estimate, leading to larger allowable harvest).

The secondary mark information presented above provides useful insight into not only tags being shed but also potential non-reporting. In general, secondary mark proportion tracks the primary mark proportion closely, and there is no consistent bias.

In addition, we compared tag recovery proportions (tag incidence relative to harvest) for individual harvesters in the years 2014 - 2018 (Table 4). Significant differences in tag recovery proportions among harvesters could indicate non-reporting of tags. Annual proportions are generally very similar across harvesters – and the slight differences observed are likely due to variation in sample size and fishing patterns (e.g., how much of the run was fished and on which dates). Importantly, no individual harvester was a consistently low outlier.

A more direct check for overlooked or unreported tags would be to re-check a subset of the Canadian commercial harvest. This has not been done for the Taku Sockeye Salmon capture-recapture program, because the Taku Sockeye Working Group considers it a much lower priority than testing other potential sources of bias.

Summary - Assumption 1: No missing tags

Missing tags are likely not a major source of bias, based on close proximity between tag application and tag recovery, secondary mark observations, data cross-validation, and observed proportion of tagged fish by harvester.

4.1.3 Assumption 2: No tagging effects

The Petersen estimate assumes that fish handling and the presence of the tag itself do not affect subsequent survival, behaviour, movement or catchability of the tagged fish. It is not possible to test for this directly, because it is not possible to individually track fish that were not handled and tagged.

The time between tag application and recovery can provide some indirect clues. If many fish hold at the tagging site or fall back downstream to rest after handling before continuing their upstream migration (i.e., *sulking*), then tagging probably has an effect on their condition.

Tags released earlier in the week are generally recovered much sooner in the Canadian commercial fishery, but almost all recoveries occur within 10 days (Figure 16).

The annual median time to recapture in the Canadian commercial fishery ranges from 2-4 days (Figure 17). Over 95% of the tags recovered in the Canadian commercial fishery were captured within 10 days in most years, and almost all the recoveries from 1998 to 2018 happened within 15 days of release.

Summary - Assumption 2: No tagging effects

The observed times to recapture indicate that sulk time is not very long *for most of those fish that eventually migrate upstream* and is likely not a major source of bias.

However, there is another aspect to consider; fish that fall back to rest after tagging, but then don't continue upstream to the Canadian commercial fishing area. This could be due to mortality (e.g., predation or handling stress or straying (e.g., river-type stock). These *dropouts* are considered in Assumption 3 below.

4.1.4 Assumption 3: Closed Population

The Petersen estimator assumes that the population of fish does not change between capture and recapture. If a population exhibits no mortality, recruitment, immigration, or emigration, it is called a closed population. Whether any of these mechanisms are likely concerns depends on the specific setting of the capture-recapture program.

Taku Sockeye Salmon are tagged at Canyon Island and recaptured in the Commercial fishery upstream a few days later, with most of the harvest occurring within 5km of the fish wheels, so movement of other fish into the population or recruitment are obviously not issues. However, fish that fall back after tagging and do not later migrate upstream to the Commercial fishing area are effectively lost from the capture-recapture study. Similar to lost, missed or non-reported tags (Assumption 1 above), lost fish could bias the estimate high (i.e., fewer recoveries of tagged fish translates into larger abundance estimates).

Tagged fish drop out (i.e., fail to move upstream) for a variety of reasons related to being handled and tagged at the fish wheels, including, increased exposure to predation, delayed mortality from handling, regurgitation or loss of tags, emigration from the Taku River, tag failure, spawning downstream of Event II (above the U.S./Canada border), and capture in the U.S. fisheries. Dropout rates depend on tagging location, fish condition, fish handling, and annual migration conditions (e.g., Bromaghin and Underwood 2003; Cleary 2003; Underwood et al. 2004; Bromaghin et al. 2007; Liller et al. 2011).

Radio telemetry data from four relevant studies (see Sec. 2.3.6) indicated that a substantial, but variable proportion of radio tagged fish were not detected upstream above the Canadian border (17% to 32%). Assuming that radio tagged fish and spaghetti tagged fish exhibit similar behaviour (i.e., handling procedures are similar, and no additional effect of the radio tag itself), then a substantial proportion of tagged fish "drop out" between capture at the fish wheels and recapture in the fishery.

Summary - Assumption 3: Closed population

Given the telemetry results, dropout of tagged fish is likely a major source of bias and the capture-recapture estimates of Taku River Sockeye Salmon need to be adjusted to account for it.

4.1.5 Assumption 4: Equal probability

The Petersen estimator commonly assumes that all individuals have either (1) the same probability of being tagged, or (2) the same probability of being recaptured, or (3) that there is complete mixing between tagging and recapture. Note that these are three of many possible conditions that make the Petersen estimate unbiased (Carl Schwarz, pers. comm.) Any one of these three conditions leads to unbiased Petersen estimates. For example, if (1) is true (equal tagging probability), then it is not necessary that fish to mix completely or that sampling events have equal probability, as long as there is no differential between tagged and untagged fish.

If, however, these assumptions are not met, then separate estimates need to be calculated for subsets of the data (*stratification*). The individuals *within* each subset are then assumed to have equal probability of tagging or equal probability of recapture. Strata sometimes need to be pooled in these types of designs in order to have sufficient numbers of samples in each stratum (e.g., when a statistical week without tag recoveries is merged with another statistical week).

Two common causes for unequal probabilities in tagging studies of inriver Salmon runs are:

- interactions between inseason patterns of sampling gear, environmental conditions, and run timing,
- size selective gear

Note these effects can differ between tagging and recapture (e.g., fish wheel vs. Canadian commercial gear).

Unequal sampling probability (*heterogeneity*) in the 2 sampling events is the most likely source of biases in the Taku Sockeye Salmon capture-recapture program, and we assessed whether this is a potential concern by examining:

- annual patterns of releases and recoveries
- proportion recovered by date or weekday
- time to recovery
- size distribution of fish tagged at the fish wheels
- size distribution of the tagged fish in the Canadian commercial harvest
- size distribution of the Canadian commercial harvest
- age composition of the Canadian commercial harvest

Patterns of Tagging and Recapture

All years followed a strong pattern with 1 or 2 distinct main peaks of captures over the run (e.g., Figures 11 and 13). Given that almost all fish caught at the fish wheels are tagged (Figure 10), this pattern of tag releases roughly matches run timing, subject to changes in fishwheel capture efficiency (e.g. affected by changing water levels or size distributions). In addition, many years had spikes in tag releases earlier in the week. These within-week release patterns are likely a shadow effect on the daily abundance of fish passing the wheels, caused by the previous week's marine fisheries, which typically occur for 1-4 days at the beginning of the week.

Tags released Saturday to Monday were recovered at higher rates and had a shorter apparent mean time to recovery than tags released mid-week (Figures 15 and 16), but overall the proportion recovered for each release date was fairly stable by week over the course of each season (Figures 12 and 14). This within-week recovery pattern coincides with Canadian commercial fishery openings, which also typically occur for 1-4 days at the beginning of the week.

Size Distributions

The median size of tagged fish recovered in the fishery was consistently larger than the median size of fish tagged at the fish wheels, differing by about 10-15 mm in most years since 2003, but reaching 30-35 mm in 2014 and 2018 (Figure 20). The median size of the total Canadian commercial harvest was usually larger than the median size of tagged fish recovered in the fishery, differing by -10 mm to +20 mm in most years since 2003, but reaching 40mm in 2018 (Figure 21).

The size difference between tag releases and tag recoveries (Figure 22) was statistically significant in all years (p-value <0.05 in a Kolmogorov–Smirnov test of pairwise comparisons), but sample sizes were in the thousands, and the actual differences were generally small (10-15 mm on average, with size records usually rounded to the nearest 10 mm).

Over all years, the mode (i.e., main peak) of the size distributions was very close for fish tagged at the fish wheels, tagged fish harvested in the fishery, and all harvested fish (medians are 545, 560, and 564 mm, respectively; Figure 22). Shapes were similar for the main part of the distributions, but the tag releases also include a sample of smaller fish (<500 mm) that was not reflected in the Canadian commercial harvest. Results for 2018 were notable, because not only were the median sizes different, but the shape of the distributions was also fundamentally different . In 2018, the majority of fish tagged at the fish wheels were smaller than 500 mm, the tag recoveries were almost evenly split between smaller and larger fish (bimodal distribution), and the total Canadian commercial harvest was mostly larger fish. The 2014 pattern was similar to the 2018 pattern, and both were likely due to unusually large proportion of younger fish in those years (age 3 river-types, 0.2 age designation; Figure 23).

Summary - Assumption 4: Equal Probability

Given the observed patterns in Sockeye Salmon run timing curves and the on/off recapture activity due to actively managed fishery openings, the probability of tagging and recapture could vary substantially over the course of a season. The magnitude of resulting bias needs to be assessed by comparing various time-stratified estimates to the pooled Petersen estimate.

The observed differences in size distribution between fish tagged at the Canyon Island fish wheels, tagged fish recaptured in the Canadian Commercial fishery, and the total Canadian Commercial harvest could introduce a substantial bias, which needs to be assessed by comparing various size-stratified estimates to the pooled Petersen estimate.

Variations in age composition and stock composition are related to the observed size differences, but we did not formally account for them in the set of different capture-recapture estimates in the next section. Rather, these are briefly covered in the alternative assessment techniques in Section 5.

4.2 Capture-Recapture Estimates

This section describes three different estimation approaches: Pooled Petersen, time-stratified Petersen, and size-stratified Petersen. All three were implemented in *R* (R Core Team 2019) using the Bayesian Time Stratified Population Analysis System (*BTSPAS*) package (Bonner and Schwarz 2020). Schwarz et al. (2009) and Schwarz (2006) describe the methods in detail. The next sections provide a brief overview.

We also briefly explored stratifying the tag data by fish wheel (FW1, FW2, FW1+2, FW3), but data at this resolution could only be matched up for 2016 to 2018. Using data from FW1 and FW2 individually or together did not reveal any substantial differences or consistent bias. Estimates based on FW3 were lower, but FW3 was only used in 2016 and 2017 as a test of methods and was discontinued in 2018. Results for these explorations are not included in this report.

4.2.1 Pooled Petersen Estimator

The simple pooled Petersen estimator expands the number of released tags by the ratio of untagged/tagged fish in the recapture step. With the Chapman modification to address 0 recoveries, the calculation is:

$$
\begin{aligned}
U_{est} &= (n_1+1)\frac{u_2+1}{(m_2+1)} - 1 \\
se_{U_{est}} &= \sqrt{(n_1+1)(m_2+u_2+1)(n_1-m_2)\frac{u_2}{(m_2+1)^2(m_2+2)}} \\
N_{est} &= (n_1+1)\frac{u_2+m_2+1}{(m_2+1)} - 1 \\
se_{N_{est}} &= se_{U_{est}}
\end{aligned}
$$

where

n_1 = number fish tagged in event I
m_2 = number of tagged fish recaptured in Event II
u_2 = number of untagged fish caught in Event II
N = population size
U = untagged population size

We calculated simple pooled Petersen estimates as the default comparison for other estimation methods.

4.2.2 Bayesian Time-Stratified Petersen Estimator

Simple time-stratified estimators split the tag data into smaller subsets (strata), compute the Petersen estimate for each stratum, and then estimate the total as the sum of the individual stratum estimates. To address patterns in salmon migration, data are typically split by statistical week (e.g., Boyce and Andel 2014), but a finer resolution may be necessary when the recapture event is intermittent (e.g., continuous tag releases at the fishery, but only 1-2 day fishery openings occur every week for recapture). Previous reports (e.g., Boyce and Andel 2014) typically reported time-stratified estimates (by statistical week), implemented with an earlier software package, Stratified Population Analysis System (SPAS; Arnason et al. 1996).

The Bayesian version of the time-stratified estimate takes the analysis further, extrapolating a run-timing curve from the tag data and computing the abundance based on that. Details are available in Sec. 3.4 of Schwarz et al. (2009) and a brief explanation is included below. Note that Bayesian estimates are computationally complex, and can be sensitive to prior assumptions.

We used the BTSPAS package, which is a Bayesian upgrade of *SPAS*. BTSPAS models time-stratified two-sample capture-recapture experiments where releases can be recovered in a number of recovery strata. The input data for BTSPAS is a matrix of releases and recoveries stratified into temporal units (statistical weeks) as illustrated in Table 6, combined with weekly totals as illustrated in Table 7.

In this case, a total of 3,126 tags were released at the fish wheels from statistical weeks 24 to 36. Recoveries occurred in the Canadian commercial harvest from statistical weeks 24 to 38. A total of 444 tags were recovered in the Canadian Commercial fishery, among a harvest of 17,546.

The number of releases varied considerably over the weeks reflecting different numbers of fish passing the fish wheels. Releases from each week were recovered over a number of subsequent weeks. Fishery harvest varied over the weeks, but the total harvest was a reflection of both effort and availability. It is not possible to recover a fish in the week before it is released, and so the lower triangle of recoveries were all zero.

The BTSPAS model consists of three components:

- *Movement model*. The fish tagged in a particular week are often captured in several weeks due to differences in migration timing among fish and artefacts caused by fish tagged at the start or at the end of a week. A non-parametric movement distribution is used, i.e. a simple multinomial distribution where there is a "base" average-distribution, but individual release weeks are allowed to vary slightly from this average-distribution. For example, the base average distribution could be a multinomial with 5 classes (the largest observed) with (estimated) probabilities of [.61, .33, .04, <.01,< .01], i.e. the average distribution of movement has 61% of tagged fish being available for recovery in the same week as released; 33% in the second week after release; 4% in the third week after release etc.]. The actual movement from tags released in a particular week could differ slightly, e.g.. [0.68, 0.25,.06, .01, <.01] but the amount of variation allowed in a particular week of release is dependent on sample size. Release weeks with small sample sizes have very little information to distinguish the travel time distribution for that week from the average distribution of travel times.
- *Recapture model*. The movement model is used to estimate the number of tagged fish that are available to be recaptured by the fishery in a week as a combination of tagged fish from several release weeks and their respective movement probabilities. The total number of tags recovered is modelled as a binomial distribution with a week specific recovery probability. However, the variation in week specific recovery probabilities is constrained to vary around an average. Again, recovery weeks with few tagged fish available and a small harvest provide little information to distinguish a week-specific recovery probability that differs from the average.
- *Run model*. A non-parametric spline is used to model the average shape of the run, i.e. how many fish in total (tagged and untagged) are available for capture in a particular recovery week. Again, individual weeks are allowed to vary above and below the smoothing spline. Weeks with little (or no) recovery effort are modelled as being close to the smoothed spline.

Bayesian methods are used to fit the model to the data. The model is self-adjusting in the sense that where there are weeks with much data, more variation from the averages are allowed compared to weeks with sparse data. The spline is used to interpolate the run for weeks where there is no Canadian commercial harvest (e.g. at the start or end of the run, or even in the middle of a run).

For example, Figure 27 shows a plot of the estimated capture probabilities on the logit scale. The capture probabilities are allowed to vary around the average (solid line), but are forced to zero at the start and end of the study. Figure 28 shows the corresponding plot of the run curve on a log-scale. The plot shows the underlying *spline* fit (dashed line) but individual weeks are allowed to vary around this smooth spline when there is much data. The uncertainty of the run at the start and end is very large because there was no Canadian commercial harvest in these weeks, but the estimated run in these weeks is also small.

In some cases, additional tweaks to the data can be done to "force" the underlying curve to have desirable properties. For example, in some years, the Canadian commercial fishery started late and considerable numbers of fish had already passed upstream. We have no data to estimate the shape of the run before the fishery, but are very confident that it was very small 4 weeks earlier. The input data can be modified slightly to force the run to be close to 0 four weeks before the Canadian commercial fishery started. Of course, the estimated run in weeks prior to the start of the fishery will have poor precision.

Time stratification can be applied at a finer resolution than statistical week. For example, weeks can be split into the 2 parts: the fishery opening at the beginning of the week, and the closed period at the end of the week. This open/close stratification separates out periods with different recapture probabilities (even if they have different lengths), and could potentially further reduce bias related to patterns in recovery.

4.2.3 Size-Stratified Petersen Estimator

Size-stratified estimators simply apply the pooled Petersen estimator twice (see equations in Sec. 4.2.1), once for smaller fish and once for larger fish, then add up the individual estimates. Variances are also additive.

$$\begin{aligned} T_a &= T_s + T_l \\ se_{T_a} &= \sqrt{se_{T_s}{}^2 + se_{T_l}{}^2} \end{aligned}$$

where

T = total inriver abundance (tagged and untagged) for all (*a*), small (*s*), or large fish (*l*)
se = standard error

Note that size-stratified estimates can be sensitive to the cut-off point chosen to categorize small and large fish. We split the tag records based on the n^{th} percentile of the observed size distribution in the Canadian Commercial harvest, examining how results changed for percentiles from 5 to 60.

4.2.4 Dropout Adjustment

Telemetry studies indicated that dropout was likely introducing a substantial positive bias in all versions of the capture-recapture estimates (Sec. 2.3.6), and should be accounted for. The estimated dropout rate and the adjusted Petersen estimator (and associated standard errors) are (Schwarz 2019):

$$\begin{aligned} dr &= 1 - (x/n) \\ se_{dr} &= \sqrt{dr(1-dr)/n} \\ N_{adj} &= N(1-dr) \\ se_{N_{adj}} &= \sqrt{se_N{}^2 se_{dr}{}^2 + se_N{}^2(1-dr)^2 + N^2 se_{dr}{}^2} \\ U_{adj} &= U(1-dr) \\ se_{U_{adj}} &= \sqrt{se_U{}^2 se_{dr}{}^2 + se_U{}^2(1-dr)^2 + U^2 se_{dr}{}^2} \end{aligned}$$

where

n = number fish tracked for drop out
x = number that did NOT fall back
N = estimated population size without adjustment for dropout of tagged fish
U = estimated untagged population size without adjustment for dropout of tagged fish N_{adj} = estimated population size with adjustment for dropout of tagged fish U_{adj} = estimated untagged population size with adjustment for dropout of tagged fish

The same dropout adjustment was applied to the final estimates for all three capture-recapture estimation methods.

The long-term average dropout adjustment was modelled using synthetic values of *n* and *x* that incorporated the weighted average of the results from 1984, 2015, 2017, and the 2018 side project radiotelemetry studies. The side project data for 2018 was used because fish wheel operation was similar to previous years' operations (Bednarski et al. 2019).

Specifically:

All samples combined = 149 dropouts / 587 radio tags
Mean of 4 individual samples = 38 dropouts / 147 radio tags
Scaled-down mean sample for variance estimation = 13 dropouts / 51 radio tags

The observed dropout proportion varies among years; however, there is no year-specific dropout estimates for most of the capture-recapture estimates. Therefore, an imputed dropout proportion for years without radiotelemetry studies must account for the uncertainty in the dropout proportion caused by a small number of fish tagged with radio tags in a particular study and the year-to-year variation in the dropout probability.

The synthetic values address the effect of the implied radio tag sample size on the variance of the adjusted capture-recapture estimate.

We created a "synthetic" set of telemetry data (Figure 29) that represents both sources of uncertainty as follows:

(1) We fit a generalized linear mixed model to the four years of telemetry data with a common mean and a random effect for years. The overall estimated mean dropout probability was approximately 0.25 (SE 0.028). The estimated year-to-year standard deviation in the dropout probability was 0.45.
(2) The total uncertainty that accounts for both year-to-year variation and uncertainty in estimating the mean dropout probability is found as $\sqrt{.045^2 + .028^2} = .054$.
(3) We found synthetic values of n and x such that a telemetry study with these synthetic values matched the mean dropout probability (i.e. $x/n = 0.25$) and matched the combined uncertainty (i.e. $\sqrt{(x/n)(1 - x/n)/n} = .054$), but rounded to integer values. This gives n=51 and x=13.

The BTSPAS model uses these synthetic values when accounting for drop-out in the estimation process.

For dropout adjustments applied to past run abundance estimates, the *Taku Sockeye Working Group* recommended using (Figure 31, Table 8):

- long-term average (synthetic rate) for updated 1984-2016 post-season estimates and for 2019 inseason estimates
- 2017 data for updated 2017 estimates
- 2018 project data for updated 2018 estimates (based on hourly sampling; side project spaghetti tags were also excluded from the inseason and post-season estimates in 2018)

The top panel in Figure 31 shows the time series of annual dropout adjustments. Table 8 lists the specific values.

4.2.5 Estimation Methods Examined

We examined the following estimation approaches:

- pooled Petersen with dropout adjustment (1984-2018)
- statistical week stratified Bayesian estimate with dropout adjustment (1984-2018)
- Open/close stratified Bayesian estimate with dropout adjustment (2003-2018)
- size-stratified estimate using p5 to p60 break point, with dropout adjustment (2003-2018)

4.3 Results

4.3.1 All Estimation Methods

Estimates from all three methods we explored (pooled Petersen, time-stratified Petersen, size-stratified Petersen) differ from previously published estimates. Some of the differences are due to updated methods (BTSPAS vs. SPAS, size stratification). There were, however, additional changes that contributed to the differences:

- *Data Cleaning*: Based on our cross-check of alternative data sources (Sec. 2.2), we made some relatively small changes to the capture-recapture data for some years.
- *Annual Adjustments*: Previously published estimates included year-specific adjustments (e.g., choosing pooled or time-stratified estimate, pooling of strata for the time-stratified estimate).
- *Dropout*: Year-specific adjustment for the estimated proportion of tagged fish that don't pass the border (Sec. 4.2.4).

The first two changes generally had a small and variable effect. The dropout adjustment resulted in substantially lower estimates with wider confidence intervals (i.e., higher uncertainty), regardless of estimation method.

4.3.2 Pooled Petersen Estimates

The relative effect of the 3 changes is illustrated by comparing the pooled new pooled Petersen estimates to the previously published estimates (Figure 30). Pooled Petersen estimates without dropout adjustment were similar to previously published time-stratified estimates, but the dropout adjustment substantially reduced the estimated inriver abundance for all years. Dropout adjustment also increased the corresponding Relative Standard Error (*RSE*) of the estimate (Figure 31). The RSE roughly tripled, from about 3% to about 9%, due to the large uncertainty in the dropout adjustment.

4.3.3 Time-Stratified Estimates

Time-stratified estimates were very similar to the simple pooled Petersen estimate for most years, and both lined up with previously published estimates (Figure 32). For years where the pooled Petersen differed noticeably from the previously published estimates, the time-stratified estimate generally fell closer to the previously published estimate (e.g., early 1990s).

There was no consistent bias in the differences between the estimates, with the time-stratified estimate only about 1% smaller on average (Figure 33). However, there were some years with much larger differences (e.g., 1984, 1992, 2006, 2015), and a recent general increase in the year-to-year variability. Years with larger differences also tended to have much higher uncertainty (i.e., wider posterior distributions) in the time-stratified estimates, indicating a poorer fit.

Time-stratified estimates that further split statistical weeks into open and close strata generally gave estimates very similar to the SW-stratified fits, except with larger uncertainty. In some years where the Bayesian posteriors of the SW-stratified fits indicated poorer fits, the Open/Close fits produced even wider posterior distributions or failed to converge.

4.3.4 Size-Stratified Estimates

Size-stratified estimates were affected by the value chosen to split the tag data into small and large fish (Figure 34). Using different percentiles of the size distribution in the Canadian commercial harvest for size stratification, the percentile with the largest absolute difference between the size-stratified Petersen estimate and the pooled Petersen estimate varied from 5% to 50%, with a median of about 20%. The corresponding absolute percent differences in abundance estimates ranged from about 5% to about 20%, with a median of 10%. If each year's size-stratified estimate were based on the percentile level resulting in the largest difference, then than the pooled Petersen estimate would be 9.5% lower on average (see bottom right panel).

However, the effects of cut-off points at low percentiles were sensitive to annual variation in the sampling and resulted in very small sample sizes for the small-fish component of the size-stratified estimate in some cases. The *Taku Sockeye Working Group* therefore recommended the 30th percentile of the size distribution as the default cut-off point for all years, rather than the 20th percentile that produces the largest absolute difference.

Size-stratified estimates were only available for 2003-2018. For these years, estimates based on size-stratification at the 30th percentile of the Canadian commercial harvest on the abundance estimates followed the same pattern as the simple pooled Petersen estimate, but were consistently lower (Figure 35), with the size-stratified estimate about 6.4% smaller on average (Figure 36). For some years, the difference was very pronounced (e.g., 2014, 2018), and there was a recent general increase in both the magnitude and year-to-year inconsistency between the estimates.

4.4 Recommendations for Post-Season Abundance Estimates

4.4.1 Rationale

For post-season estimates, annual sample sizes and tagging rates have been sufficient to address any potential biases related to patterns in run timing, tag application, and fishery openings (Sec. 4.3). Estimates for the simple pooled Petersen and variations of the Bayesian time-stratified Petersen are generally very close, and the confidence bounds for the pooled Petersen estimate are much more consistent across all years. In contrast, the posterior distributions of the Bayesian time-stratified estimates are very wide and highly skewed for some years.

Size differences between fish caught in the fish wheels (tag application) and fish harvested in the Canadian commercial fishery (tag recovery) vary drastically between years, and can produce a substantial size bias in the pooled Petersen estimate for some years (Sec. 4.3). Based on individual tag records compiled for 2003 to 2018, the bias in estimated abundance ranges from -21.3% to +7.6%, with a mean of -6.4%, when using the 30th percentile of the size distribution in the Canadian commercial fishery as the breakpoint between tag data for small fish and large fish. Note that the annual size composition of the run is related to stock composition, with some stocks and years having smaller, younger returns (Sec. 3).

Based on these results, the *Taku Sockeye Working Group* recommended the following updates to the time series of inriver abundance estimates:

- Adjust all estimates based on an agreed-upon dropout rate estimated from relevant telemetry studies.
- Time stratification of estimates was not warranted.
- Where possible with available size data, use individual year size-stratified pooled Petersen estimates.
- Where size stratification is not possible, use pooled Petersen estimates and adjust them for the average size bias observed in size-stratified estimates.

4.4.2 Implementation

With currently available data, this yields a dropout-adjusted time series for all years, with size-adjusted estimates for 1984-2002, and size-stratified estimates for 2003-2018.

Dropout rate observed across the four relevant telemetry studies was assumed to be representative of long-term average dropout (Sec. 2.3.6), resulting in a synthetic dropout rate of $dr = 13/51 = 25.5\%$ applied for 1984-2016. For 2017 and 2018, the year-specific telemetry results were used (32.1% and 14.6% respectively).

In some cases, adjustments to estimates of abundance for dropout are done using custom BTSPAS extensions built for this project (Sec. 11.3), but in other cases it is applied afterwards (e.g., the size-stratified Petersen estimates) using a stand-alone function (Sec. 11.2). The same dropout adjustment was selected for the weekly inseason estimates in 2019 (Sec. 6.3). In all cases, both the estimate and its uncertainty are adjusted using the equations in Sec. 4.2.4.

The pooled Petersen estimates for 1984-2002 were further adjusted using the average bias from the size-stratified estimates for 2003-2018 (-6.4%). Only the estimates are adjusted and no adjustments to the associated uncertainty were made. The pooled Petersen estimates from 2003-2018 included year specific (p30) size stratification in the estimate.

4.4.3 Updated Abundance Estimates

Table 8 summarizes the updated estimates of inriver run size. Figures 39 and 40 show the time series of annual differences between the updated estimates, the previously published estimates, and the previous estimates adjusted for dropout and size bias. Previous estimates shown here are the capture-recapture estimates, not the final values used at the time which included expansions to account for portions of the run missed by the capture-recapture study in some years.

On average, the updated estimates are about 30% lower than the previously published estimates (Figure 40), with most of the difference due to adjusting for dropout rate (-25.5% for most years), and most of the remainder due to adjusting for size bias (-6.4% on average). In addition, small annual differences are due to revisions of the source data.

The updated abundance estimates in Table 8 should be used for future analyses (e.g., escapement goal estimation).

5 Exploration of Alternative Asssesment Techniques

5.1 Rationale for Exploring Alternative Techniques

In addition to reviewing the current capture-recapture program to make improvements and minimize potential bias, an additional objective of the Taku Sockeye Working Group was to investigate alternative or complementary stock assessment techniques. The current method relies on the Canadian commercial fishery to be operating as the recapture portion (event II) of the study, and as demonstrated by recent Chinook Salmon conservation concerns, this may not be possible in all years; runs can become too low or budgets too restrictive to deliver a suitable test/assessment fishery. Therefore it is prudent to investigate options that could inform, support, or replace the current method, and test these options in years where comparisons are possible, in order to avoid a scenario where an untested method is employed without prior review. Even if no changes are made to the current program, alternative assessment methods can provide verification or a check on results.

The Taku Sockeye Working Group conducted a literature review to examine various stock assessment techniques employed in Sockeye Salmon stock assessment across their range. There are a variety of techniques employed and methods vary depending on region, river size, and agency preference based on cost or practicality of application.

Capture-recapture methods are widely used for Sockeye Salmon stock assessment throughout southeast Alaska, Yukon and northwestern British Columbia. Fish wheel capture methods are employed coast-wide from the Fraser River (experimental) north through the Nass and Taku rivers, to several large river systems in Alaska including the Chilkat, Kuskokwim, Tanana, and Kantishna rivers (Cleary and Bromaghin. 2001, Kerkvliet et al. 2004, Schaberg et al. 2010). Typically, the lower portion of large river systems (i.e. Canyon Island in the Taku River) are most suitable for fish wheels that require a particular array of hydrological conditions to be effective (Kelley et al. 1997, McGregor et al. 1991). There is still much debate concerning the variable catch efficiency of fish wheels throughout the salmon run period (Willette et al. 2016). Recapture methods can be variable as well, depending on the logistics of specific river systems. The core Taku River Sockeye Salmon assessment to date has relied on recaptures in the Canadian commercial fishery, but recoveries are also made in headwater enumeration and sampling projects, which can provide another look at run abundance. This headwater recapture method is widely used in Taku River Chinook Salmon abundance estimation (e.g., Jones et al. 2010).

As discussed previously (see Section 4.2.4) in relation to the Taku River, when trying to generate accurate abundance estimates, the bias caused by dropout following initial capture in a capture-recapture study (often caused by gear or handling stress) needs to be determined. The Taku Sockeye Working Group reviewed several investigations undertaken to examine these biases (e.g., Bromaghin and Underwood 2003; Cleary 2003; Underwood et al. 2004; Bromaghin et al. 2007; Liller et al. 2011). Relevant studies are summarized in Table 2.

Genetic methods are becoming increasingly useful for estimating Sockeye Salmon run abundance. These tools can be employed once a genetic stock identification (GSI) baseline has been established for the various component stocks of a large river system stock aggregate (Hess et al. 2014, Eskelin et al. 2013). The most common method employed is a ratio-based expansion method, sometimes called a reverse capture-recapture, where known escapements of a genetically distinct population (or group of populations) can be expanded from genetically determined proportions of those stocks or populations in a lower river sample. This method or similar has been applied to abundance estimates of Sockeye Salmon on the Yentna River (Willette et al. 2016), Yukon River Chinook Salmon (Hamazaki and DeCovich 2014), and Alsek River Chinook and Sockeye Salmon stocks (Gazey 2010). GSI methods are rapidly evolving, but processing time and distance from a laboratory can currently make inseason use limited, and the expansion method currently requires end of season population enumeration data (weir counts).

Hydro-acoustics (sonar) is another method of stock assessment widely used to derive Sockeye Salmon run abundance estimates (Mulligan and Kieser 1986, Willette et al. 2012). Sonar is widely deployed from large river systems with turbid water where techniques that rely on weirs and visual observation of salmon are less applicable to more typical weir sites with direct enumeration of adult Sockeye Salmon escapement into a lake (Carlson et al. 1998). Sonar estimates have been compared with and validated by capture-recapture methods conducted using radio tags, fish wheels, and weirs to estimate Sockeye Salmon abundance (Yanusz et al. 2011). Large river systems like the Taku River which have large co-migrating runs of various salmon species can pose significant challenges to Sockeye Salmon enumeration by sonar due to species apportionment requirements.

5.2 Pooled Petersen Estimates Based on Headwater Weir Counts

5.2.1 Background

Headwater fish inspection and tag recovery data are the primary input for Taku River Chinook Salmon abundance estimates (Jones et al. 2010), which rely on angling and carcass sampling on up to seven Taku River headwater tributaries. This model could also potentially apply to Taku River Sockeye Salmon, or at least provide a cross-verification for the primary capture-recapture study. To assess potential this we examined the most recent five years of assessment program data.

Spaghetti tags applied to Taku River Sockeye Salmon at the Canyon Island fish wheels, as part of the primary capture-recapture study, are also recovered in headwater areas, principally at counting weirs situated at the outlets of Little Trapper, Tatsamenie, Kuthai, and King Salmon lakes. All Sockeye Salmon are inspected for tags as they pass through the weirs (the orange tags are highly visible), and a subset of tags are physically recovered. Over the past five years, the number of fish inspected for tags in headwater projects (24,578 fish) is comparable to the number inspected in the lower river fisheries (24,770 fish).

Tag loss is a potential issue when conducting tag recovery (Event II) significant distances from the marking location. The closest weir to the fish wheels, King Salmon, is over 70 river kilometers (rkm) away and the farthest, Tatsamenie, is over 200 rkm away.

As with the fishery sampling, a subset of fish transiting the weirs are inspected for tag loss. Tagging needle scars are clearly visible at all locations, and in some years a secondary mark in the form of an axillary appendage clip has been applied at the time of tagging. The inspection is concurrent with ASL sampling and typically has involved 700-800 fish per project, as escapements permitted; in 2018 a video system was used for enumeration at Kuthai and King Salmon lakes and permitted inspection for tag loss. Results ranged from 0.0% to 3.4%. Appendix 5 includes a summary counts, tag recoveries, and estimated tag loss by weir for 2014 to 2018.

5.2.2 Methods

Pooled Petersen estimates of Taku River Sockeye Salmon inriver abundance were generated using headwater tag recovery data, weir counts, and the number of tags available upstream of fisheries. Tag loss estimates were used to adjust the number of recoveries. Downstream removals (i.e. harvests) were added to the estimates to quantify inriver abundance for comparison with inriver run abundance estimates from the primary capture-recapture study based on fishery data. The number of marks out was not adjusted by drop-out or catchability by size for either the fishery-based or headwater-based estimates.

The upper panels of Figure 42 show the number of fish inspected and the proportion marked. Appendix 4 contains the details for each year’s abundance estimates.

In order to use headwater-based capture-recapture as a Taku River Sockeye Salmon abundance estimation tool, either tag application (adjusted by fishery tag removals) would have to be proportional with respect to individual stock abundance or the recovery efforts would have to be random. To assess tag availability at the different sites, the marked fraction of inspected fish was examined across tributaries for each year. Homogeneity would indicate that tag application less fishery removals was not biased across the tributaries examined.

Abundance estimates were also generated using a subset of the headwater data, specifically that from Tatsamenie Lake and Little Trapper Lakes weirs. There is a high degree of confidence in these data sets, and marked fractions passed homogeneity tests for three of the five years (2014, 2016, and 2018).

5.2.3 Results

In all years, the proportion of tagged fish differed significantly between the four lakes, with p-values in Fisher's Exact test well below 0.05 (Table 13). Marked fractions varied by as much as 14.5% in a particular year (see Kuthai Lake and King Salmon Lake data for 2018, however note small sample size, n=13, at Kuthai Lake). Dissimilarities in the marked fractions among fish inspected in the different tributaries indicate that the Petersen estimator based on data pooled across these tributaries is not a consistent estimator for the capture-recapture experiment with this data set.

Table 14 lists annual estimates for 2013-2017. Figure 42 compares the headwater-based estimates to the fishery-based estimates, using either all weirs or only Tatsamenie and Little Trapper.

The headwater-based estimates are substantially larger than the fishery-based estimates in 3 of the 5 years we tested. The Tatsamenie/Little Trapper estimate more closely matches the fishery-based estimate (Mean Percent Error = 19%) than the All Weir estimate (MPE = 26%).

It is also notable that the two years where both headwater-based estimates are very similar to the fishery-based estimates have also been identified as unusual earlier in the report (larger proportion of younger river-type fish spawning in the mainstem; Figure 22)

Overall, results point to potential non-random marking and/or non-random tag removal in downstream fisheries, i.e. differential mark application/removal by stock. Differential mortality of tagged/untagged fish due to migration obstacles, predation, a combination thereof, or other factors could also be issues contributing to bias. In order to address non-random tag availability, headwater sampling would have to be conducted in a random manner and be expanded to include river spawners.

5.2.4 Recommendations

Event II data from existing weir programs is easily obtained and provides insight on the capture-recapture program in general. It is recommended that inspection and tag recovery continue at the weir projects and that focus on quantifying tag loss be increased, with more rigorous data quality assurance procedures implemented. In order to use headwater tag information to estimate drainage-wide abundance, an expansion of sampling efforts to include river spawning populations would be required.

5.3 Estimates Based on Genetic Stock ID

5.3.1 Background

Since 2008, GSI data have been collected from Taku River Sockeye Salmon harvested in the Canadian inriver commercial gillnet fishery to meet PST harvest allocation criteria. Although these data have not been gathered with the intent of abundance estimation, the data were investigated to determine their suitability as a potential post-season abundance estimator. Even if genetic samples could be shipped and processed rapidly during the season, GSI-based estimates cannot currently be used for inseason estimates of Taku River Sockeye Salmon, because they rely on end of season weir counts.

Abundance estimates based on GSI could potentially avoid sources of bias that affect most capture-recapture estimates, because they don't rely on two capture events with different gear types, and they don't involve assumptions about mixing of marked and unmarked fish. However, they do introduce new potential sources of bias, including uncertainty in stock assignments, and they do not account for any natural mortality that might occur between the fishery and the weirs. Similar to the traditional capture-recapture method which requires the assumption that fish wheel CPUE is representative of the run, GSI methods assume the weekly stock composition and CPUE of the genetic sample method (Canadian commercial fishery in this case) reflects the actual weekly abundance of fish at the fishery.

Two considerations make the Taku River system a promising setting for GSI-based estimates:

- Life-history types: Finer genetic resolution of Sockeye Salmon stocks can be more uncertain, but larger groupings are reliably differentiated. Samples of Taku River Sockeye Salmon can be assigned to lake-type or river-type life history with much higher confidence than their assignments to individual stocks so uncertainty can be substantially reduced.
- Population enumeration: Most Taku River lake-type Sockeye Salmon stocks are currently enumerated, providing a reliable expansion factor for the stock proportions as the lake-type group comprises up to half of the annual run.

5.3.2 Methods

This exploratory analysis used an R implementation of the expansion approach currently used by DFO Stock Assessment for the Alsek River, which was reverse engineered from a spreadsheet implementation developed by Gazey (2010). The R code is included in Section 12.5. The analytical approach to GSI ratio-based expansion is currently being reviewed by a group of statistical experts under the coordination of Dr. Carl Schwarz.

Briefly, the calculation has the following steps:

- weekly run weight = CPUE in the Canadian commercial fishery
- weighted proportion Lake Type = Sum(weekly Prop Lake Type * weekly run weight)
- Escapement = Weir Counts / Weighted Prop Lake Type
- inriver Run Size = Escapement + CDN Comm Harvest+ FSC Harvest+ Test Harvest

Data used include:

- annual totals of weir counts, FSC harvest, and test fishery harvest (Table 16)
- weekly proportion of lake type stocks in the Canadian commercial fishery, genetic sample size, and commercial harvest(e.g. Table 17)

We calculated two versions of the GSI-based run size estimate, one based on all monitored lake-type stocks (King Salmon, Kuthai, Little Trapper, and Tatsamenie lakes), and one based on Tatsamenie and Little Trapper lake stocks only. The two approaches were due to the possibility that early run fish (Kuthai and King Salmon stocks) were not sampled appropriately in all years due to their early season run timing which coincides with early season fishery restrictions related to Sockeye Salmon conservation concerns (Kuthai) and Chinook Salmon conservation concerns. There are also concerns as Kuthai and King Salmon stocks have both been experiencing passage challenges in recent years and not all returning fish in the stocks are escaping. Both of these issues could confound estimation.

5.3.3 Results

In general, the GSI-based estimates track reasonably well with the large scale abundance patterns observed in the traditional capture-recapture method (Figure 43), but the GSI-based estimates are consistently lower by about 20% on average (Figure 44).

For several years, the two GSI-based estimates are close to each other (2009-2011, 2016). The estimate using only Tatsamenie and Little Trapper stocks is generally higher than the All Weir stocks estimate, with large differences in some years (2008, 2013-2015, 2018). In a few years, one or the other GSI-based estimate is very close to the capture-recapture based estimate (All Weirs in 2011, Tats/LTrapper in 2013 and 2014)

5.3.4 Recommendations

GSI-based estimates are a potentially informative addition to the annual post-season Taku River Sockeye Salmon assessment process. The fact that they were close to the traditional capture-recapture estimate for some years and quite different in other years highlights that they are sensitive to different sources of bias, and a more thorough exploration may be able to identify the conditions under which one type of estimate may be more appropriate than the other.

Priorities for further exploration include:

- *Analytical Method*: Continue to liaise with biostatistical group working on a review of analytical tools for GSI-based estimation.
- *Sample Collection*: Compare genetic stock composition determined from the Canadian commercial fishery with stock composition determined from the fish wheels to determine if bias exists between the traditional capture-recapture index and the fishery. We know there can be size bias between these two methods (see Sec. 4.3.4), and this could be correlated with stocks, particularly the smaller-sized King Salmon Lake stock and the Mainstem stocks in years with high proportions of age 0.2 fish (Figure 20). As the fish wheels are currently considered an unbiased sample in proportion to the run for the traditional capture-recapture, perhaps genetic samples from the fish wheels would be best suited to a comparable GSI-based expansion.
- *Uncertainty*: formally incorporate uncertainty into the GSI-based estimate. A simple first step could be to bootstrap the weekly stock proportions. A more thorough look could include a Bayesian version of the expansion step.
- *Stock ID*: review the accuracy and precision of the stock assignments for Lake type vs. river type, and for subgroups (e.g. Tatsamenie/Little Trapper vs other lakes). Bias in stock composition estimates due to the genetic baseline might be adjusted using the rubias software (Moran and Anderson 2018).
- *Inriver mortality*: Inriver mortality is currently built into escapement goals, and a different index could potentially require a re-evaluation of escapement goals or an estimation of inriver natural mortality between the traditional capture–recapture experiment and the weirs, however studies have found that inriver natural mortality is low for fish already migrating (e.g., Spencer et al. 2009)

6 Inseason Abundance Estimates

6.1 Context

Abundance of Taku River Sockeye Salmon is estimated weekly inseason in order to implement abundance-based management as directed by the PST. Specifically: "The management of U.S. and Canadian fisheries shall be based on weekly estimates of the TAC [Total Allowable Catch] of wild sockeye salmon" (Chapter 1(b)i(D)). TAC is estimated from projections of run abundance which are determined by expanding weekly capture–recapture estimates plus Taku River Sockeye harvests in D11 to a season total using historical average run timing. Initial inseason management relies on the pre-season forecast of run size, and inseason estimates are used once capture-recapture data is sufficiently robust, typically after 2-3 weeks of fishing.

6.2 Rationale

Inseason estimates rely on less data than postseason estimates, especially early in the season, and are therefore more sensitive to patterns of Sockeye Salmon migration, fish wheel operation, and openings in the Canadian commercial fishery. Therefore, the *Taku Sockeye Working Group* recommended using time-stratified estimates as the default for weekly inseason estimates, as in previous years, but to change the implementation to the Bayesian version. Simple pooled Petersen estimates are also computed as a cross-check, and the weekly inseason update may report either or both the estimates, depending on the Bayesian fit and other considerations.

Size data from the fish wheels and Canadian commercial fishery are not available with a quick enough turn-around during the season to allow for size-stratified estimates. The average size bias correction calculated for 2003-2018 is -6.4%. Given other sources of uncertainty, the *Taku Sockeye Working Group* recommended not to include this average size bias adjustment in the 2019 inseason estimates, but identified options for inseason size-bias adjustments as a priority for future work (Sec. 7.5)

6.3 Implementation

Dropout rate observed across several relevant telemetry studies is assumed to be representative of long-term average dropout (Sec. 2.3.6), resulting in a synthetic dropout rate of $dr = 13/51 = 25.5\%$. This is handled internally in the custom BTSPAS extensions built for this project (Sec. 11.3), using the equations in Sec. 4.2.4. The same dropout adjustment was selected as the long-term average drop-out adjustment for the updated post-season estimates (Sec. 4.4.2).

6.4 2019 Weekly Inseason Abundance Estimates

The 2019 season was the first real-time test of the new Bayesian software package (Bonner and Schwarz 2020) for inseason estimation.

Weekly estimates of inriver run-to-date differed between methods but converged as the season progressed (Figure 41). Early in the season, the Bayesian time-stratified estimate was much lower than the pooled Petersen estimate. While this created interpretation challenges during the season, the observation can be explained. It is due to some tagged fish not being available to the Canadian commercial fishery (have not yet moved to the fishery) leading to a positive bias in the pooled Petersen estimator.

The estimates converged over time, and the final post-season estimates for the two methods are basically identical.

7 Conclusions

7.1 Annual Capture-Recapture Estimates of Inriver Abundance

The main source of bias in past estimates of Taku River Sockeye Salmon inriver abundance is the variable proportion of tagged fish that do not continue migrating upstream to the Canadian Commercial fishery where there is a potential for tag recovery (i.e., *dropout*). Adjusting for dropout decreases the abundance estimate and increases the uncertainty (i.e., lower estimated abundance, wider confidence intervals). A second source of bias is the difference in size distribution between fish captured at the fish wheels for tagging and fish captured in the Canadian commercial fishery for the recapture step. Size bias has a smaller effect on average than dropout but can be substantial in years with an unusually high proportion of small, young river-type fish (e.g., 2014, 2018). Size bias generally decreases the estimates. The temporal open/close nature of the Canadian commercial fishery combined with tagged fish sulking could also potentially bias estimates. Retrospective analysis showed that time stratification of past estimates was not warranted, but may be applicable to future estimates.

Table 8 summarizes the updated post-season estimates of inriver abundance for 1984-2018, using these adjustments. On average, the updated estimates are about 30% lower than the previously published estimates (Figure 37), with most of the difference due to adjusting for dropout rate (-25.5% for all years other than 2017 and 2018), and most of the remainder due to adjusting for size bias (-6.4% on average). In addition, small annual differences are due to revisions of the source data.

Moving forward, the Taku Sockeye Working Group makes the following recommendations for Taku River Sockeye Salmon stock assessment:

- Continue to conduct Taku River Sockeye Salmon abundance estimation using capture-recapture methods; applying tags at Canyon Island with fish wheels and recovering tagged fish in the Canadian commercial fishery.
- Continue to implement changes and improve fish wheel operation and fish handling techniques (as per Bednarski et al 2019) to minimize stress on fish with intent to reduce dropout rate and lower mortality of handled fish.
- In-season abundance estimates should include an adjustment for dropout by applying the relevant average dropout rate.
- All post-season estimates should include an adjustment for dropout using the year specific dropout rate determined from telemetry (when available) or by applying the relevant average dropout rate.
- Continue to conduct Taku River sockeye salmon telemetry studies through 2022 to further refine variability in dropout rate, both using the historical method (prior to 2018) and revised method (2018 and beyond (Bednarski et al 2019)) of fish handling at the fish wheels.
- In years where postseason time stratified abundance estimates differ from pooled Petersen abundance estimates, consider use of time stratified abundance estimates.
- In years where postseason size stratified abundance estimates differ from unstratified pooled Petersen abundance estimates, consider use of size stratified abundance estimates .

7.2 Alternative Assessment Techniques

Given that the basic information required for headwater-based estimates is being collected as part of the current program, these estimates can be useful as a quick cross-check of the primary capture-recapture estimates. However, more intensive escapement sampling, especially of the Mainstem stock, would be necessary to make this approach more defensible.

Genetic stock identification data are also being collected as part of the current program. These data have promise as a post-season run size cross-check, or potential replacement assessment method should substantive changes to the existing program or run sizes occur. Potential biases are currently being investigated, and the analytical tools are currently being reviewed. Once complete, this method would at minimum require a simple test fishery in the lower river and escapement counts to generate a robust post-season run estimate. The Taku Sockeye Working Group recommends that GSI samples continue to be collected from the fisheries, and that samples continue to be collected from the fish wheels in proportion to the run to inform potential biases in both fish wheel stock selectivity and the Canadian commercial fishery.

The *Taku Sockeye Working Group* briefly discussed hydro-acoustic stock assessment techniques for Sockeye Salmon enumeration on the Taku River, but concluded that the likely challenges (e.g. species identification of co-migrating salmon) could outweigh the potential benefits, so therefore did not conduct any in-depth explorations.

7.3 Inseason Estimates of Run-To-Date

As part of this project, the inseason run size estimation process switched over to the BTSPAS package with custom extensions incorporating an estimate of dropout (Bonner and Schwarz 2020). Early in the season, this resulted in some interpretation challenges of the Bayesian estimates due to small sample size, however the estimates became more robust as the season developed, but clear guidelines for interpretation should be developed prior to the next season. The *Taku Sockeye Working Group* recommended that this approach be continued in future seasons incorporating experience gained from future work (Section 7.5).

7.4 Program Implementation

In addition to the *Taku Sockeye Working Group* review of the capture-recapture data and estimates, there was a parallel process to review and update the operational plan for the assessment program. Significant operational changes started in 2018 (Andel et al. 2018) and were fully implemented in 2019 (Bednarski et al. 2019). Many aspects of the program have been modified, particularly fish wheel operations (e.g., timing of daily operation, frequency of checks, secondary marks, radio tag deployment strategies, etc.).

In addition, the operational plan also incorporated lessons learned during the compilation and cross-check of historical tag data and established clearer data management protocols.

7.5 Priorities for Future Work

The *Taku Sockeye Working Group* identified the following priorities for future work related to the implementation and evaluation of the stock-assessment program:

Capture-Recapture Estimates

- explore potential mechanistic models for predicting dropout rate (e.g. water level, water temperature).
- explore homogeneity in dropout within seasons.
- explore potential inseason adjustments for size bias in extreme years (e.g., years like 2018).
- test how Bayesian inseason estimates would have performed in past years. A preliminary exploration was done as part of this project but should be completed and written up.
- after several years of implementing the Bayesian time-stratified inseason estimates, review annual estimate convergence and develop interpretation guidelines for the early part of the season.
- for size stratification, explore using the actual length of the fish as an individual-covariate (rather than stratifying into two size categories) to investigate the general shape of the selectivity curve using methods proposed by Huggins (1989) to see if this related to effects of harvest gear or fish wheel effects.
- investigate postseason size stratification in BTSPAS estimate.
- Investigate the late-season recovery rate spikes observed in some years (e.g. Figure 19).
- given the observed dropout rates in studies to date, explore options for reducing mortality associated with either general fish wheel operation or the specific capture-recapture study while

retaining sufficient statistical power in the study design. The key factor determining statistical power is the number of recovered tags, which can be adjusted by varying either the number of tags released or the level of recovery effort. As a rule of thumb (Carl Schwarz, pers. comm.), reducing the RSE by half requires four times as many tag recoveries. Conversely, reducing tag recoveries by half will roughly increase the RSE 1.4 times ($\sqrt{2}$). Recovery effort in the Canadian commercial fishery is linked to abundance and fishery openings, and can't be adjusted for study design purposes. However, the number of tags released could be modified, with details depending on the most likely source of observed mortality. If it is fish wheel operations, then the active period of the wheels could be reduced. If it is tag application or tag effects, then a smaller proportion of the sampled fish could be tagged.

Alternative Assessment Techniques

- continue coordinating and improving the Taku Sockeye Salmon genetic baselines
- explore new statistical approaches for the GSI-based estimate
- continue exploring headwater-based estimates
- explore potential relationship between CPUE (fish wheel and fishery) and abundance incorporating water level

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9 Tables

Table 1 Summary of Available Tag Data

Year	Tags Released	Tags Recovered	Prop Recovered	Matched Size Obs	Prop Size Obs
1992	0	10	NA	NA	NA
1993	0	950	NA	NA	NA
1994	0	1822	NA	NA	NA
1995	0	1913	NA	NA	NA
1996	0	2221	NA	NA	NA
1997	0	479	NA	NA	NA
1998	3819	1329	0.35	NA	NA
1999	4288	1333	0.31	NA	NA
2000	5401	2004	0.37	NA	NA
2001	0	2375	NA	NA	NA
2002	5377	1776	0.33	NA	NA
2003	5461	1718	0.31	5444	0.997
2004	5659	1431	0.25	5650	0.998
2005	3619	995	0.27	3611	0.998
2006	4931	1721	0.35	4906	0.995
2007	7066	2138	0.30	7059	0.999
2008	3444	1038	0.30	3439	0.999
2009	3143	724	0.23	3142	1.000
2010	2941	807	0.27	2940	1.000
2011	3408	1031	0.30	3406	0.999
2012	4126	1377	0.33	4110	0.996
2013	4100	1349	0.33	4059	0.990
2014	4895	1128	0.23	4888	0.999
2015	4623	950	0.21	4619	0.999
2016	6232	2179	0.35	6210	0.996
2017	5720	2292	0.40	5687	0.994
2018	3322	792	0.24	3307	0.995

This table shows the number of quality-controlled individual tag records that could be compiled from available data sources (Sec. 2.2). In some years, individual tag recovery data is available from the Canadian commercial fishery, but no matching release data for the fish wheels is available. For 1984-1997 (excluding 1986) and 2001, the capture-recapture estimates were based on summary matrices by statistical week that were extracted from hard-copies of annual reports, scanned, and cross-verified. Figure 10 plots these time series.

Over 3,000 tags were released annually, with some years as high as 6,000 - 7,000 tags. The number of tags varied with abundance (Fig. 10). 20% to 40% of the tags were recovered in either the Canadian commercial Fishery or the spawning ground sampling. From 2003 onward, matched size measurements are available for almost all of the tagged fish (>99%).

Table 2 Dropout rates observed in Sockeye Salmon telemetry studies

Study	Gear	Holding	Processing	Dropout
Transboundary - Taku River 2018 (ADF&G 2018 Unpubl.)	Fish wheels at Canyon Island	Up to 1 hour holding time	Several minutes processing time after removal	17% Total drop-out (14% in side project with longer holding time)
Transboundary - Taku River 2017 (ADF&G 2017 Unpubl.)	Fish wheels at Canyon Island	Several hours, up to 16 hour holding time	Not specified	32% Total drop-out
Transboundary - Taku River 2015 (TRT and Northern Fund)	Fish wheels at Canyon Island.	An hour to several hours holding time	Handling time not recorded	17% Total drop-out
Transboundary - Taku River 1984, 1986 (Eiler et al. 1992)	Fish wheels at Canyon Island	An hour to several hours holding time	Handling time not recorded	16-20% Total drop-out
Transboundary - Stikine River 2006 (Smith et al. 2007)	Set gillnets	Not specified	tags applied immediately upon capture.	4% to 15% depending on week of capture
Transboundary - Alsek River 2009 (Smith et al. 2009)	Set gillnets	Immediate removal from net	1 to 2 minutes processing time after removal	9.5% in 2002, 5.1% in 2003, Note: later tagged fish had higher drop-out rate
Southern BC - Lower Fraser River 2008 (Robichaud et al. 2009)	Fish wheel operating near Mission bridge pylon	Variable	Comparison made between holding times	25% to 35% for tagged sockeye, 24% to 37% for radio tagged sockeye (all run-timing groups combined). This figure includes a small fishery removal
North Coast BC - Nass River 2016 (Cleveland et al. 2017)	Seine	Not specified	Handling time not specified but fish were processed upon capture	26% total drop-out of which 16% disappeared and 10% stayed at sea
Alaska - Susitna River 2007 (Yanusz et al. 2011)	Fish wheels	Any sockeye that was held in basket in-between visits was released without radio tag	Handling time was reduced in 2007 by tagging fish as they were caught, instead of allowing fish to collect in the fish wheel live box	8% drop-out

Table contributed by Dr. Paul Vecsei. Supplementary materials also cover other salmon species.

Table 3 Overview of Secondary Mark Recoveries

Year	Comm Harvest	Comm Recoveries	Inspected	2ary Mark	Perc Tagged	Perc 2ary Mark	Difference	Ratio
2002	31053	1228	1648	39	3.95	2.37	1.58	1.67
2003	32933	928	1823	26	2.82	1.43	1.39	1.97
2004	20148	900	1886	67	4.47	3.55	0.92	1.26
2005	21696	592	2361	27	2.73	1.14	1.59	2.39
2006	21099	659	2136	34	3.12	1.59	1.53	1.96
2007	16714	1307	2089	126	7.82	6.03	1.79	1.30
2008	19294	624	1998	45	3.23	2.25	0.98	1.44
2009	10951	392	1863	65	3.58	3.49	0.09	1.03
2010	20211	504	4153	143	2.49	3.44	-0.95	0.72
2011	24029	665	6484	147	2.77	2.27	0.50	1.22
2012	30059	865	2310	73	2.88	3.16	-0.28	0.91
2013	25125	929	2219	108	3.70	4.87	-1.17	0.76
2014	17645	820	2292	104	4.65	4.54	0.11	1.02
2015	19753	679	2281	53	3.44	2.32	1.12	1.48
2016	37301	1135	2466	80	3.04	3.24	-0.20	0.94
2017	30209	1243	2400	104	4.11	4.33	-0.22	0.95
2018	17974	471	2227	42	2.62	1.89	0.73	1.39

Tagged fish are also fin clipped as a secondary mark. This table compares annual total catches (*Comm Harvest*) and tag recoveries in the Canadian Commercial Fishery (*Comm Recoveries*) to the number of secondary marks (*2ary Mark*) observed and the number of fish inspected for secondary marks (*Inspected*).

Differences are mostly within $\pm$ 1%, but given the small numbers these differences can still correspond to large proportional differences (e.g., in 2003, the proportion of tags was almost double the proportion of secondary marks). However, the key observation is that in most years (13/17) the tagged proportion is higher than the secondary mark proportion. In 2 out of the 4 years where secondary mark proportion exceeds the tagged proportion, the difference is very small (2016, 2017). Overall, there is little indication of substantial tag loss between release at the fish wheels and recovery in the Canadian Commercial fishery a few days later.

Table 4 Annual Tag Recoveries By Cdn Comm Licence

Label/ID	Proportion 2014	Label/ID	Proportion 2015	Label/ID	Proportion 2016	Label/ID	Proportion 2017	Label/ID	Proportion 2018
WtMn	4.66	WtMn	3.45	WtMn	3.04	WtMn	4.12	WtMn	2.63
Mean	4.60	Mean	3.55	Mean	3.16	Mean	4.32	Mean	2.57
Median	4.54	Median	3.36	Median	2.95	Median	4.30	Median	2.56
B	4.40	I	2.64	L	2.75	C	3.39	B	2.30
C	4.42	C	2.89	E	2.89	E	3.53	E	2.30
D	4.42	J	3.23	D	2.94	B	3.68	H	2.50
E	4.50	D	3.28	C	2.96	D	4.20	O	2.52
F	4.58	E	3.44	H	3.53	M	4.28	M	2.61
G	4.77	B	3.61	I	3.86	N	4.32	C	2.63
H	4.83	H	3.95			H	4.42	D	2.74
I	4.92	G	5.37			I	4.81	I	2.93
						L	5.06		
						O	5.48		

Values are the proportion of tagged fish in the harvest (i.e. number of returned tags divided by reported harvest). Values are only shown for licences with harvest larger than 250 fish in a given year. Mean and median values include only the listed values, but the weighted mean (*WtMn*) includes all values, weighted by harvest. Licences are identified by the same label across years.

No individual is consistently at the low end or the high end of the range. For example, licence B had the lowest proportion of tags in 2014 and 2018, the 3rd lowest in 2017, and the 3rd highest in 2015. Note that individual values can be affected by sample size and fishing patterns (e.g., how much of the run was fished and on which dates).

Table 5 Size Comparison of Releases, Recoveries, and Escapement

Year	Rel	CommRec	Esc	DiffRelRec	DiffRelEsc
2003	560	575	575	-15	-15
2004	555	565	550	-10	5
2005	550	560	520	-10	30
2006	550	560	550	-10	0
2007	555	570	570	-15	-15
2008	570	580	580	-10	-10
2009	560	570	570	-10	-10
2010	525	540	510	-15	15
2011	560	565	570	-5	-10
2012	535	550	525	-15	10
2013	565	575	580	-10	-15
2014	480	515	500	-35	-20
2015	535	555	530	-20	5
2016	520	535	520	-15	0
2017	550	560	555	-10	-5
2018	470	500	488	-30	-18

Median Mid-eye to Fork length (mm) of all tagged fish (*Rel*), tagged fish recovered in the Canadian Commercial fishery (*CommRec*), and tagged fish recovered on the spawning grounds (*Esc*).

Sizes are mostly recorded in 5 mm increments, and in most years the median sizes are within 1-2 increments of each other. However, there is a persistent bias towards recovery of larger fish in the Canadian Commercial fishery (*DiffRelRec* < 0 in all years). Two years have a much larger size difference (2014, 2018), which is linked to age composition and stock composition (more river-type fish, which tend to return younger and smaller). Figure 22 plots the size distributions.

Table 6 Illustration of release-recovery matrix for Bayesian time-stratified estimate - 2018

SW_Rel	Num_Rel	SW24	SW25	SW26	SW27	SW28	SW29	SW30	SW31	SW32	SW33	SW34	SW35	SW36	SW37	SW38	SW39	SW40
24	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	17	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	161	0	0	0	9	1	0	0	0	0	0	0	0	0	0	0	0	0
27	476	0	0	0	3	31	1	0	0	0	0	0	0	0	0	0	0	0
28	474	0	0	0	0	46	32	0	0	0	0	0	0	0	0	0	0	0
29	833	0	0	0	0	0	74	52	2	1	0	1	0	0	0	1	0	0
30	539	0	0	0	0	0	0	75	32	1	0	1	0	0	0	0	0	0
31	292	0	0	0	0	0	0	0	29	11	5	0	0	0	0	0	0	0
32	93	0	0	0	0	0	0	0	0	1	4	1	0	0	0	0	0	0
33	113	0	0	0	0	0	0	0	0	0	0	12	1	0	0	0	0	0
34	52	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0
35	65	0	0	0	0	0	0	0	0	0	0	0	6	4	0	0	0	0
36	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

For time-stratified estimates, tag releases and recoveries are split by time period. This illustration uses statistical weeks (SW) as the time window. Each row corresponds to a SW where tags were released at the fish wheels and shows the number of tags releases in a week (*Num_Rel*) as well as the number of tags recovered in the Canadian Commercial fishery in each subsequent week (*SW24* to *SW40*). Based on this matrix and the weekly total in Table 7 , *BTSPAS* (Sec. 4.2.2) estimates capture probabilities (Fig. 27) and fits a smoothed run timing curve (Fig. 28) to compute an abundance estimate.

Table 7 Illustration of input totals for Bayesian time-stratified estimate - 2018

	Recaptures	Unmarked	Total
SW24	1	0	1
SW25	1	0	1
SW26	2	250	252
SW27	12	607	619
SW28	78	2092	2170
SW29	107	2617	2724
SW30	127	6147	6274
SW31	63	2359	2422
SW32	14	727	741
SW33	9	582	591
SW34	17	1184	1201
SW35	8	544	552
SW36	4	313	317
SW37	0	82	82
SW38	1	29	30
SW39	0	11	11
SW40	0	2	2
Total	444	17546	17990

The second input for the time-stratified estimates are weekly totals of recovered tags and unmarked fish in the Canadian Commercial fishery. For context, refer to Table 6.

Table 8 Summary of Updated Abundance Estimates for 1984-2018

Year	EstType	Data	UpdatedEst	SE	CV	PubEstAdj	DrAdj	SzAdj	PubEst
1984	PPSizeAdj	matrix	88,272	8,689	9.8%	93,027	-0.255	-0.064	133,414
1985	PPSizeAdj	matrix	84,479	8,573	10.1%	82,391	-0.255	-0.064	118,160
1986									
1987	PPSizeAdj	matrix	56,362	5,386	9.6%	61,050	-0.255	-0.064	87,554
1988	PPSizeAdj	matrix	55,580	5,466	9.8%	60,405	-0.255	-0.064	86,629
1989	PPSizeAdj	matrix	80,997	7,605	9.4%	69,356	-0.255	-0.064	99,467
1990	PPSizeAdj	matrix	75,801	6,981	9.2%	81,850	-0.255	-0.064	117,385
1991	PPSizeAdj	matrix	104,895	9,899	9.4%	107,223	-0.255	-0.064	153,773
1992	PPSizeAdj	matrix	99,643	9,121	9.2%	112,961	-0.255	-0.064	162,003
1993	PPSizeAdj	matrix	92,933	8,351	9%	96,589	-0.255	-0.064	138,523
1994	PPSizeAdj	matrix	90,128	8,231	9.1%	90,032	-0.255	-0.064	129,119
1995	PPSizeAdj	matrix	104,242	9,531	9.1%	101,290	-0.255	-0.064	145,264
1996	PPSizeAdj	matrix	97,477	8,788	9%	92,265	-0.255	-0.064	132,322
1997	PPSizeAdj	matrix	73,255	6,697	9.1%	65,416	-0.255	-0.064	93,816
1998	PPSizeAdj	matrix	64,755	6,069	9.4%	62,750	-0.255	-0.064	89,992
1999	PPSizeAdj	matrix	83,588	7,886	9.4%	79,285	-0.255	-0.064	113,706
2000	PPSizeAdj	matrix	83,190	7,583	9.1%	80,670	-0.255	-0.064	115,693
2001	PPSizeAdj	matrix	132,502	12,049	9.1%	134,049	-0.255	-0.064	192,245
2002	PPSizeAdj	matrix	94,605	8,637	9.1%	94,295	-0.255	-0.064	135,233
2003	SumSize	master	133,593	12,338	9.2%	134,847	-0.255	-0.064	193,390
2004	SumSize	master	85,257	7,828	9.2%	88,587	-0.255	-0.064	127,047
2005	SumSize	master	87,496	8,521	9.7%	99,122	-0.255	-0.064	142,155
2006	SumSize	master	106,545	10,175	9.6%	116,862	-0.255	-0.064	167,597
2007	SumSize	master	60,320	5,352	8.9%	73,085	-0.255	-0.064	104,815
2008	SumSize	master	78,031	7,647	9.8%	58,622	-0.255	-0.064	84,073

Table continues on next page…

This table compares updated estimates to previously published estimates. For each year it lists the estimation method (*EstType*), data source (*Data*), estimate (*UpdatedEst*), standard deviation (*SE*), coefficient of variation (*CV*), previously published estimate adjusted for average dropout and size bias (*PubEstAdj*), average dropout adjustment (*DrAdj*), average size bias adjustment (*SzAdj*), and previously published estimate (*PubEst*).

All updated estimates are adjusted for dropout rate. Estimates of type *SumSize* account for size bias by combining separate Petersen estimates for small and large fish, while *PPSizeAdj* denotes simple Petersen estimates that were adjusted afterwards using the average size bias from the *SumSize* estimates. Section 4.4.2 describes the adjustments for dropout and size bias. Estimates are based on either the annual table of releases and recoveries by statistical week (*matrix*), or the newly compiled master files of individual tag details (*master*) where available. For comparison the originally published estimates are also listed. Note that these are the unexpanded original estimates. Table 9 shows the annual expansion factors used at the time and the corresponding expanded estimats. Figures 37 and 38 plot these time series.

Table 8 continued

Year	EstType	Data	UpdatedEst	SE	CV	PubEstAdj	DrAdj	SzAdj	PubEst
2009	SumSize	master	59,817	6,237	10.4%	57,894	-0.255	-0.064	83,028
2010	SumSize	master	80,747	8,034	9.9%	71,999	-0.255	-0.064	103,257
2011	SumSize	master	82,116	7,741	9.4%	97,568	-0.255	-0.064	139,926
2012	SumSize	master	102,670	9,534	9.3%	108,490	-0.255	-0.064	155,590
2013	SumSize	master	88,535	8,506	9.6%	67,586	-0.255	-0.064	96,928
2014	SumSize	master	68,532	6,357	9.3%	76,690	-0.255	-0.064	109,984
2015	SumSize	master	102,506	10,262	10%	104,929	-0.255	-0.064	150,483
2016	SumSize	master	146,294	13,284	9.1%	149,114	-0.255	-0.064	213,851
2017	SumSize	master	91,164	5,030	5.5%	87,979	-0.321	-0.064	138,518
2018	SumSize	master	84,806	5,206	6.1%	108,135	-0.146	-0.064	135,351

Table 9 Comparison of updated abundance estimates to expanded and unexpanded previously published estimates.

Year	UpdatedEst	PubEst_Adj	PubEst	ExpFactor	PubEst_ExpAdj	PubEst_Exp
1984	88,272	93,027	133,414	0.056	98,494	141,254
1985	84,479	82,391	118,160	0.047	86,445	123,974
1986						
1987	56,362	61,050	87,554	0.088	66,955	96,023
1988	55,580	60,405	86,629	0.065	64,597	92,641
1989	80,997	69,356	99,467	0.128	79,537	114,068
1990	75,801	81,850	117,385	0.002	81,981	117,573
1991	104,895	107,223	153,773	0.007	107,990	154,873
1992	99,643	112,961	162,003	0.032	116,708	167,376
1993	92,933	96,589	138,523	0.026	99,117	142,148
1994	90,128	90,032	129,119	0.019	91,748	131,580
1995	104,242	101,290	145,264	0.008	102,117	146,450
1996	97,477	92,265	132,322	0.017	93,889	134,651
1997	73,255	65,416	93,816	0.017	66,547	95,438
1998	64,755	62,750	89,992	0.000	62,750	89,992
1999	83,588	79,285	113,706	0.000	79,285	113,706
2000	83,190	80,670	115,693	0.000	80,670	115,693
2001	132,502	134,049	192,245	0.000	134,049	192,245
2002	94,605	94,295	135,233	0.000	94,295	135,233
2003	133,593	134,847	193,390	0.000	134,847	193,390
2004	85,257	88,587	127,047	0.000	88,587	127,047
2005	87,496	99,122	142,155	0.000	99,122	142,155
2006	106,545	116,862	167,597	0.000	116,862	167,597
2007	60,320	73,085	104,815	0.002	73,223	105,012
2008	78,031	58,622	84,073	0.040	61,059	87,568

Table continues on next page…

The first 3 columns are replicated from Table 8. For the previously published estimates, expansion factors were identified annually to account for incomplete coverage of the run based on fish wheel CPUE.

Table 9 continued

Year	UpdatedEst	PubEst_Adj	PubEst	ExpFactor	PubEst_ExpAdj	PubEst_Exp
2009	59,817	57,894	83,028	0.001	57,942	83,097
2010	80,747	71,999	103,257	0.053	76,023	109,028
2011	82,116	97,568	139,926	0.000	97,568	139,926
2012	102,670	108,490	155,590	0.008	109,387	156,877
2013	88,535	67,586	96,928	0.089	74,156	106,350
2014	68,532	76,690	109,984	0.000	76,690	109,984
2015	102,506	104,929	150,483	0.012	106,246	152,372
2016	146,294	149,114	213,851	0.000	149,114	213,851
2017	91,164	87,979	138,518	0.002	88,155	138,796
2018	84,806	108,135	135,351	0.012	109,448	136,995

Table 10 Weir Counts of Sockeye Salmon entering 4 Lakes

Year	KingSalmon	Kuthai	LittleTrapper	Tatsamenie
1980		1,658		
1981		2,299		
1983			7,402	
1984			13,084	
1985			14,889	
1986			13,820	
1987			12,007	
1988			10,637	
1989			9,606	
1990			9,443	
1991			22,942	
1992		1,457	14,372	
1993		6,312	17,432	
1994		5,427	13,438	
1995		3,310	11,524	5,780
1996		4,243	5,483	10,381
1997		5,746	5,924	8,363
1998		1,934	8,717	5,997
1999		10,042	11,805	2,104
2000		4,096	11,551	7,575
2001		1,663	16,860	22,575
2002		7,697	7,973	5,495
2003		7,769	31,227	4,515
2004	5,005	1,578	9,613	1,951
2005	1,046	6,004	16,009	3,372
2006	2,177	1,015	25,265	22,475
2007	5	204	7,153	11,187
2008	888	1,547	3,831	8,976
2009	1,100	1,442	5,552	2,032
2010	2,977	1,626	3,387	3,513
2011	2,899	811	3,809	7,880
2012	6,913	182	10,015	15,605
2013	470	1,195	4,840	10,246
2014	1,061	208	6,707	2,106
2015	1,683	341	13,253	1,537
2016	6,404	1,476	7,594	32,934
2017	439	299	6,376	27,237
2018	3,180	13	8,249	5,086

Weir counts include natural spawners and broodstock.

Table 11 Illustration of Inputs for Headwater-Based Estimates - 2018

Variable	Tatsamenie	Kuthai	King Salmon	L. Trapper
Fish Inspected for Tag Loss	800	13	3,180	320
Tag Loss Identified	0	0	9	1
% Tag Loss	0.00%	0.00%	0.30%	0.30%
Fish Inspected at Weir	3,104	13	3,375	8,249
Marks Identified	96	2	32	185
Perc Marked	3.1%	15.4%	0.9%	2.2%

Inputs for headwater-based estimates include tag recoveries at the weir (*Perc Marked*) and observed tag loss. Observations can be combined for 2 or more weirs.

Sample sizes and tag recoveries differ between weirs, but 3 of the 4 weirs have large sample sizes (> 3,000 fish inspected) and recovery rates of 1-3%, making them potentially useful for Petersen estimates.

Table 12 lists sample sizes and tag recoveries for 2014-2018.

Table 12 Sample Sizes and % Tagged in 4 Lake Stocks 2014-2018

Year	Variable	Tatsamenie	Kuthai	King Salmon	L. Trapper	Overall
2014	Fish Inspected	2,105	155	1,061	6,607	9,928
2014	Marks Identified	105	1	28	307	441
2014	Perc Marked	5.0%	0.6%	2.6%	4.6%	4.4%
2015	Fish Inspected	1,536	341	1,683	13,257	16,817
2015	Marks Identified	50	1	18	241	310
2015	Perc Marked	3.3%	0.3%	1.1%	1.8%	1.8%
2016	Fish Inspected	32,934	1,476	6,404	7,771	48,585
2016	Marks Identified	880	21	54	191	1,146
2016	Perc Marked	2.7%	1.4%	0.8%	2.5%	2.4%
2017	Fish Inspected	25,528	299	439	6,552	32,818
2017	Marks Identified	872	5	52	154	1,083
2017	Perc Marked	3.4%	1.7%	11.8%	2.4%	3.3%
2018	Fish Inspected	3,104	13	3,375	8,249	14,741
2018	Marks Identified	96	2	32	185	315
2018	Perc Marked	3.1%	15.4%	0.9%	2.2%	2.1%

For three of the four lakes, the number of inspected fish was consistently large (thousands to tens of thousands), but the percentage of tagged fish in those samples was highly variable between lakes.

Fisher's Exact Test was used on each year's 2x4 contingency table to check whether the proportion of tagged fish observed at in the four lake stocks are similar to each other. Table 13 summarizes the results.

Table 13 Fisher's Exact Test for Homogeneity of Tag Proportions in Headwater Samples

Year	p.value	SimilarProp
2014	8.86e-04	FALSE
2015	1.45e-05	FALSE
2016	0.00e+00	FALSE
2017	0.00e+00	FALSE
2018	0.00e+00	FALSE

In all years, the proportion of tagged fish differed significantly between the four lakes, with p-values well below 0.05.

Table 14 Headwater-Based Capture-Recapture Estimates

Year	EstType	Tags	Inspected	Recovered	AbdEst	Harvest	InRiver
2014	All Weirs	4,069	9,928	441	91,428	17,867	109,295
2015	All Weirs	4,019	16,817	310	217,390	19,881	237,271
2016	All Weirs	5,164	48,585	1,146	218,802	37,624	256,426
2017	All Weirs	4,469	32,818	1,083	135,310	30,524	165,834
2018	All Weirs	2,682	14,741	315	125,300	17,988	143,288
2014	Tats&LTrapper	3,159	8,712	412	66,666	17,867	84,533
2015	Tats&LTrapper	4,019	14,793	291	203,671	19,881	223,552
2016	Tats&LTrapper	5,164	40,705	1,071	196,157	37,624	233,781
2017	Tats&LTrapper	4,469	32,080	1,026	139,630	30,524	170,154
2018	Tats&LTrapper	2,682	11,353	281	108,077	17,988	126,065

Pooled Petersen estimates of Taku River inriver abundance 2014-2018 based on data from four headwater weirs, using input values presented in this section. Headwater recoveries incorporate site/year specific tag loss estimates ranging from 0 - 3.4%, but are not adjusted for dropout rate.

Table 15 Fishery-Based Capture-Recapture Estimates

Year	Tags	Inspected	Recovered	InRiver
2014	4,896	17,867	827	105,676
2015	4,703	19,872	684	136,471
2016	6,270	37,615	1,106	213,089
2017	5,712	30,524	1,252	139,177
2018	3,126	17,974	444	126,310

Pooled Petersen estimates of Taku River inriver abundance 2014-2018 based on tags recovered in the Canadian Commercial fishery, using input values presented in this section. Note: values differ slightly from Table 8 due to use of different estimators (e.g. Darroch vs. Pooled Petersen).

Table 16 Harvest and Weir Counts used in GSI-based estimates

Year	Lake Type All Weirs	Lake Type Tats & LTrapper	Lake Type Tats Only	FSC Harvest	Test Harvest
2008	15242	12807	8976	215	10
2009	10126	7584	2032	106	174
2010	11503	6900	3513	184	297
2011	15399	11689	7880	124	521
2012	32715	25620	15605	169	6
2013	16751	15086	10246	99	0
2014	10082	8813	2106	219	8
2015	16814	14790	1537	85	49
2016	48408	40528	32934	191	123
2017	34351	33613	27237	229	0
2018	16528	13335	5086	13	0

Annual total of weir counts for either all 4 weirs, or 2 of the 4 weirs (Tatsamenie and Little Trapper), or Tatsamenie only are one component of the GSI-based abundance estimates. Table 17 has the context.

Table 17 Illustration of strata data for GSI-based estimate - All Weirs 2018

StatWeek	RunWeight	PropLake	DNASamples	Harvest
SW20-26	0.077	0.698	72	252
SW27	0.058	0.711	87	619
SW28	0.139	0.586	124	2170
SW29	0.166	0.457	172	2724
SW30	0.239	0.383	197	6274
SW31	0.134	0.403	174	2422
SW32	0.043	0.498	89	741
SW33	0.045	0.568	30	591
SW34	0.061	0.375	75	1201
SW35	0.022	0.450	49	552
SW36-40	0.015	0.472	114	428

StatWeek identifies the statistical weeks included in each stratum. *RunWeights* are standardized weights based on CPUE at the Canyon Island fish wheels. *PropLake* is the proportion of DNA samples from the Canadian Commercial fishery that was matched to one of the lake-type baseline groups (Tatsamenie, Little Trapper, Kuthai, King Salmon). The number of DNA samples and harvest are also for the Canadian Commercial fishery.

Table 18 Comparison of GSI-based estimate to Capture-Recapture Estimates

Year	GSI_All	GSI_TatsLTr	CREst	DiffAll	DiffTatsLTr	PercDiffAll	PercDiffTatsLTr
2008	45724	51453	78031	32307	26579	41	34
2009	42213	40036	59818	17605	19782	29	33
2010	61970	55585	80747	18777	25162	23	31
2011	68294	63207	82117	13823	18910	17	23
2012	102092	107971	102671	578	-5300	1	-5
2013	53230	54350	88536	35305	34185	40	39
2014	48692	67704	68533	19840	829	29	1
2015	86593	103482	102506	15913	-975	16	-1
2016	119057	120360	146294	27238	25934	19	18
2017	79888	84896	91164	11276	6268	12	7
2018	52062	62708	84807	32745	22098	39	26

Estimates of inriver river run based on genetic stock identification (*GSI*) at the Canyon Island fish wheels expand the weir counts from either all weirs (*All*) or only Tatsamenie and Little Trapper (*TatsLTr*). *CREst* is the capture-recapture estimate using tag recoveries from the Canadian commercial fishery including adjustments for dropout and size bias (Table 8). Figure 43 shows the pattern over time.

For most years, the GSI-based estimates are 20-40% lower than the capture-recapture estimates, but in several years one or both GSI-based estimates match the capture-recapture estimates closely (2012, 2014, 2015, 2017).

10 Figures

Figure 1 Taku watershed topographical map.

Map provided by Kathy Smikrud (ADFG).

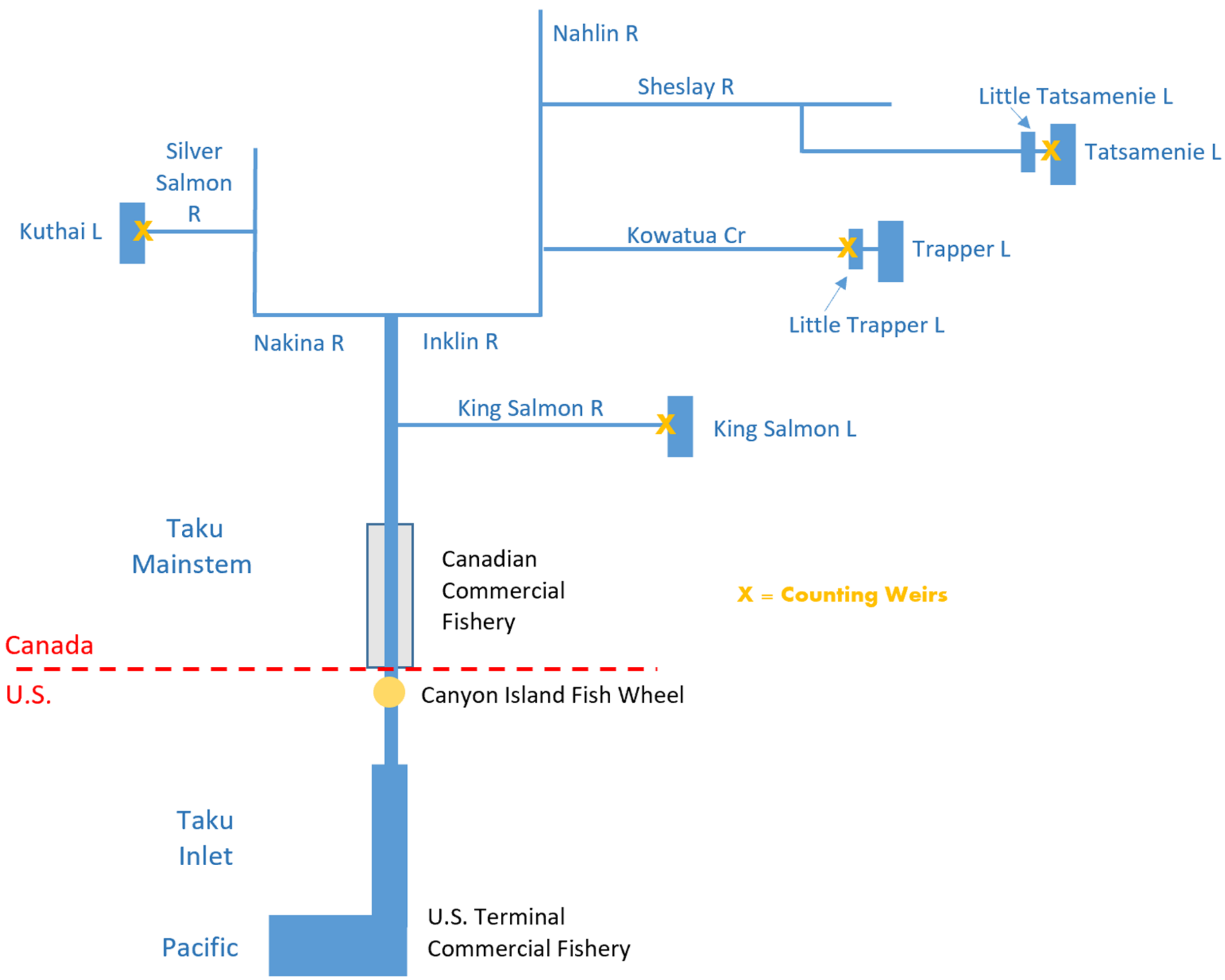


Figure 2 Overview of Taku River Sockeye Salmon stock structure and stock assessment.

This figure is a high level diagram of key features relevant to this paper, and does not capture all the details. Rather, it is a simple overview of how the stocks and assessment components are connected.

The U.S. terminal Commercial fishery intercepts Taku River Sockeye Salmon in Taku inlet and the lower Taku River. The run is sampled and tagged just below the Canadian border at the Canyon Island fish wheels. Tag recaptures in the Canadian Commercial fishery just above the border are the main source of abundance information. Each of the 4 main lake-type stocks is enumerated with a counting weir, but river-type mainstem spawners are currently not surveyed.

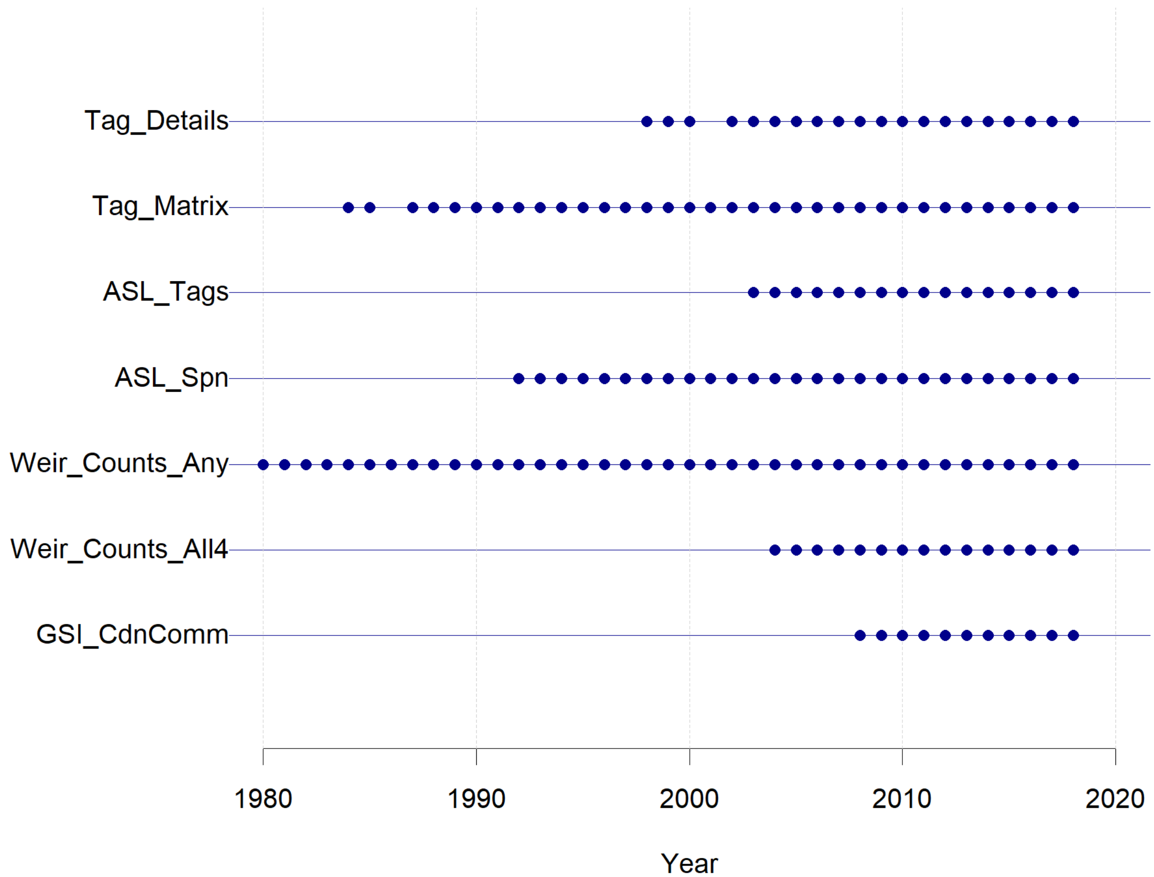


Figure 3 Overview of Available Data after Quality Control

This figure summarizes the available data after quality control (Section 2.2). Points mark the years where records are available, but details vary by data set. *Tag_Details* marks any year with at least 1 valid record with individiual tag id. *Tag_Matrix* shows the years for which annual summary tables of releases and recoveries could be constructed or tracked down in paper records. *ASL_Tags* shows the years for which at least 1 Age/Size/Length (ASL) record could be matched to a tag ID, and *ASL_Spn* shows the same for spawning ground surveys. *Weir_Counts_Any* shows years where weir counts for at least 1 of the 4 lakes is available, while *Weir_Counts_All4* identifies years with a complete set of 4 weir counts. *GSI_Cdn_Comm* shows years for which annual genetics-based estimates of stock composition are available for the Canadian commercial fishery.

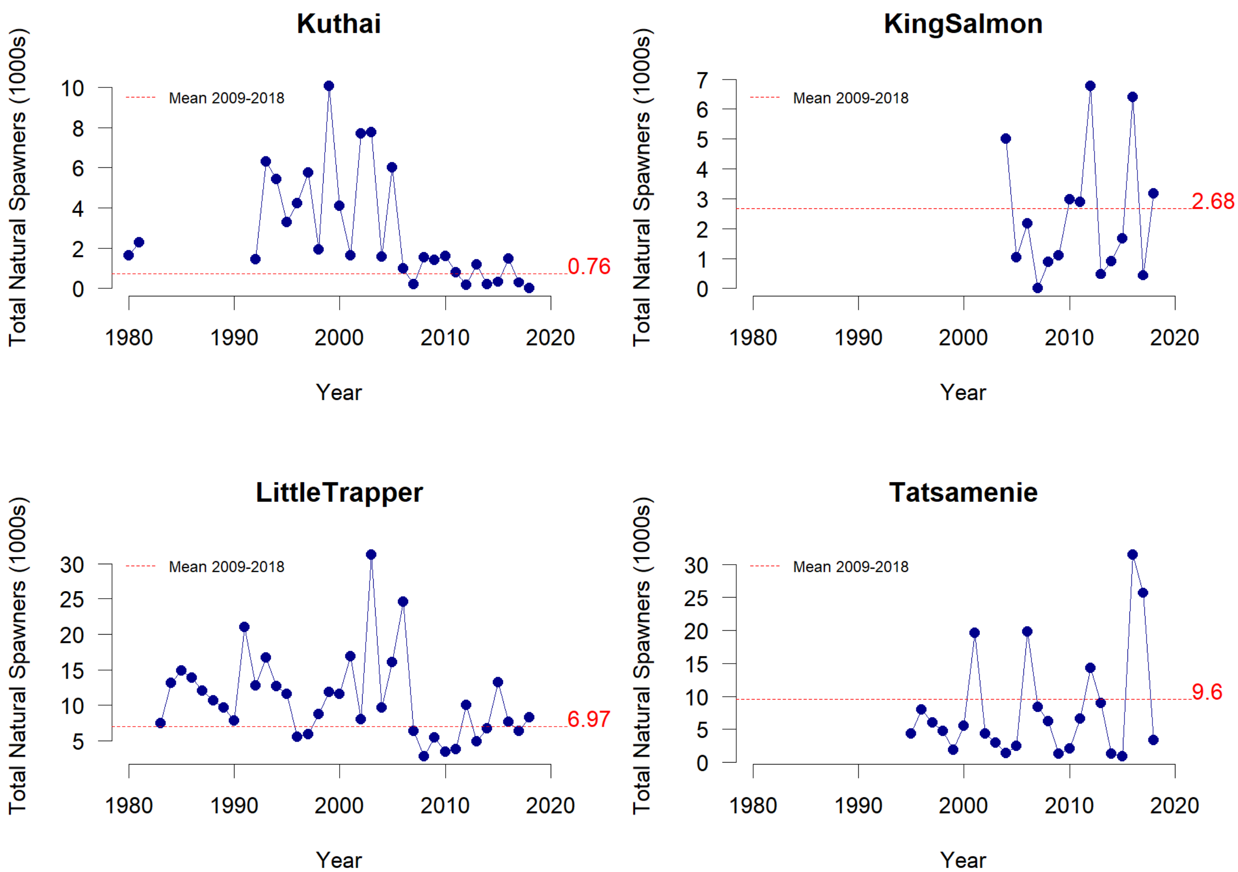


Figure 4 Natural Spawner Abundance in 4 Lake Stocks

Natural spawner abundance is calculated as total weir count minus broodstock take and includes both wild and enhanced fish. Tatsamenie is the largest of the 4 stocks with a median abundance of almost 10,000 over 2009-2018. Two of the 4 stocks have highly variable abundances (King Salmon, Tatsamenie). However, recent abundances for the other 2 stocks (Kuthai, Little Trapper) are much lower than in earlier years.

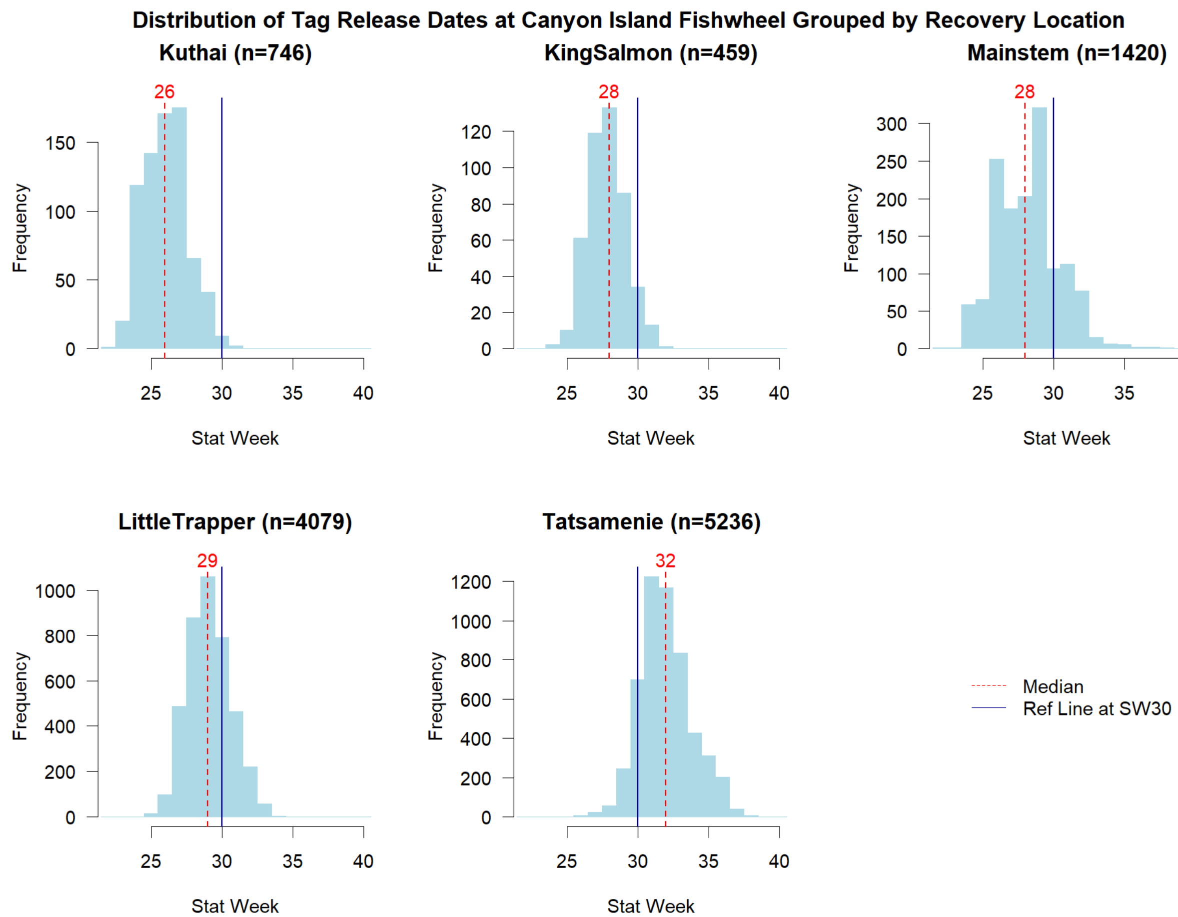


Figure 5 Index of Run Timing at Canyon Island Fish Wheel

Histograms show the distribution of release dates by statistical week for all tags recovered in each location from 2003 to 2018. Mainstem recoveries are collected as part of the ASL sampling (Section 3.3.

The 5 stocks return in a consistent sequence, with Kuthai earliest (median = Statistical Week 26), Tatsamenie latest (SW 32), and the other 3 overlapping with median dates at the fish wheels around SW 28-29.

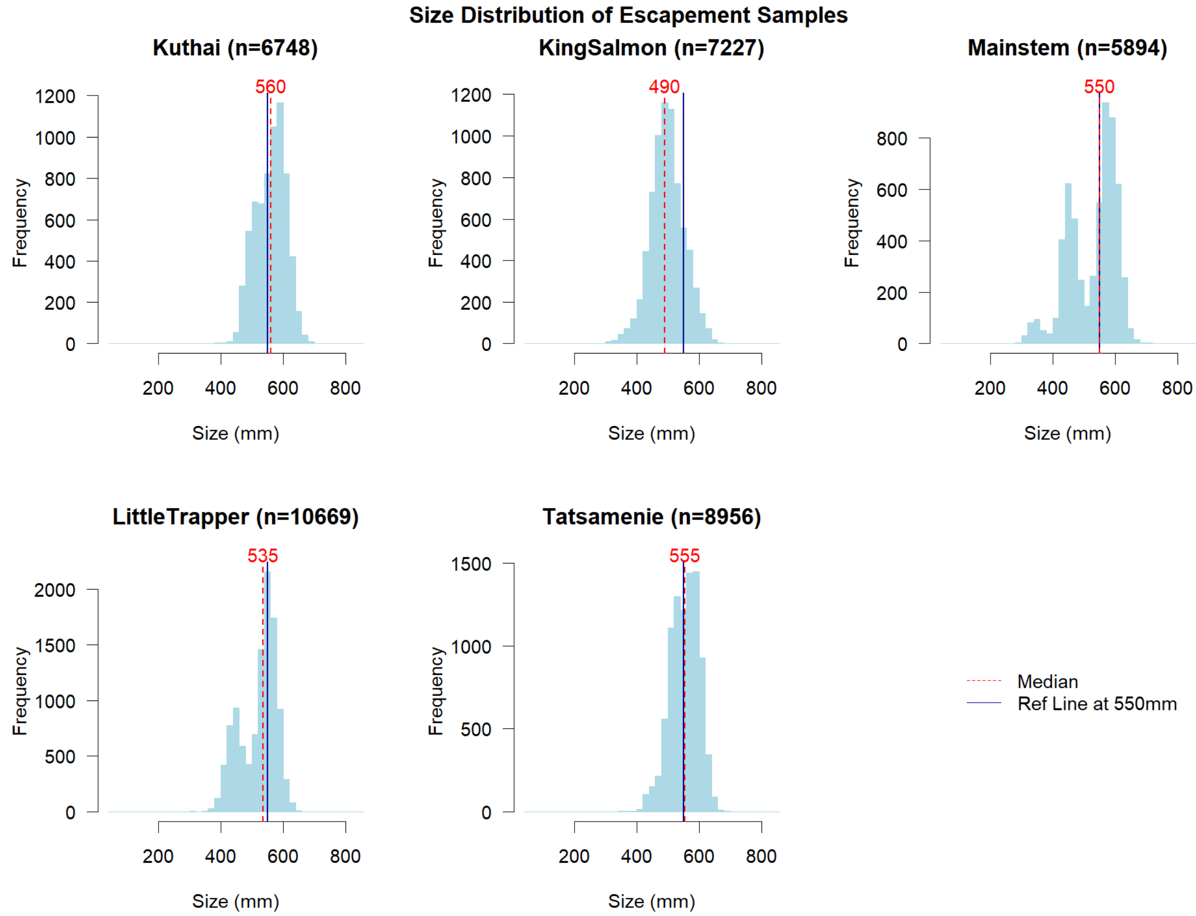


Figure 6 Size Distribution by Spawning Stock

Histograms show the distribution of mid-eye to fork sizes (mm) for all tags recovered in each location. Consistent sampling of all stocks was done from 2003 to 2012, but samples for individual locations are available for different time periods (Kuthai: 1992,1993, 1998, 2001 - 2017; King Salmon: 2003 - 2018; Mainstem: 1993, 2001, 2003 - 2012; Little Trapper: 1992 - 2018; Tatsamenie: 1996 - 2018;). Section 3.3 describes ASL sampling for the Mainstem (river-type) stock.

Median size is essentially identical for 3 of the 5 stocks (550-560 mm), but smaller for Little Trapper (535 mm), and much smaller for King Salmon (495 mm). Two of the stocks (Mainstem, Little Trapper) have bimodal size distributions, with a substantial component of smaller fish in some years.

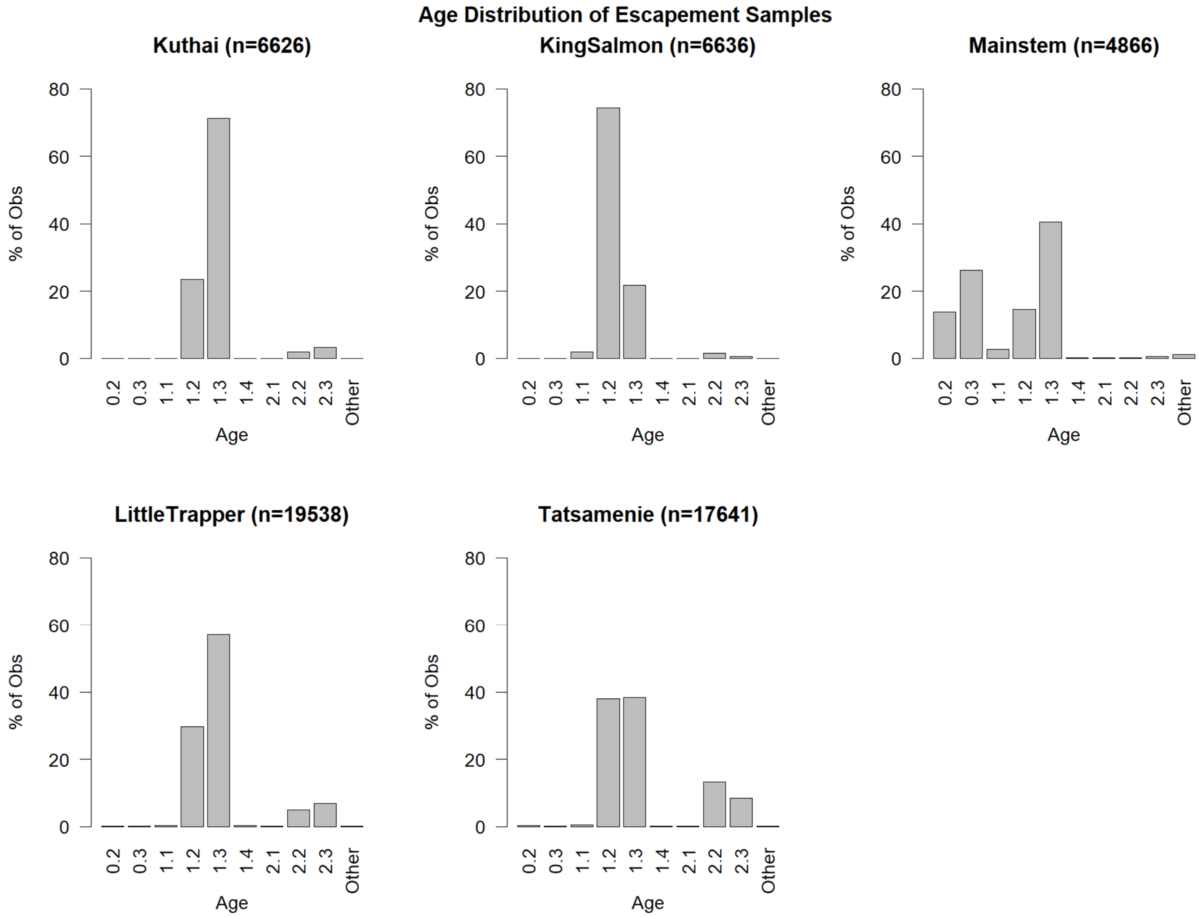


Figure 7 Age Composition By Spawning Stock

Histograms show the age composition for all tags recovered in each location. Sample years as per Figure 6. The *Mainstem* grouping includes samples from Dudidontu RIver, Hackett River, Nahlin River, Nakina, Taku River Mainstem, and Tulsequah River. Ages are reported using the European system which lists the number of winters spent in freshwater and ocean environments. For example, *1.3* denotes a 5-year old fish with 1 winter in freshwater and 3 winters in the ocean.

Most fish in the lake-type stocks return as 4 or 5 year olds (1.2, 1.3, 2.2), whereas nearly half of the mainstem spawners return younger (0.2, 0.3).

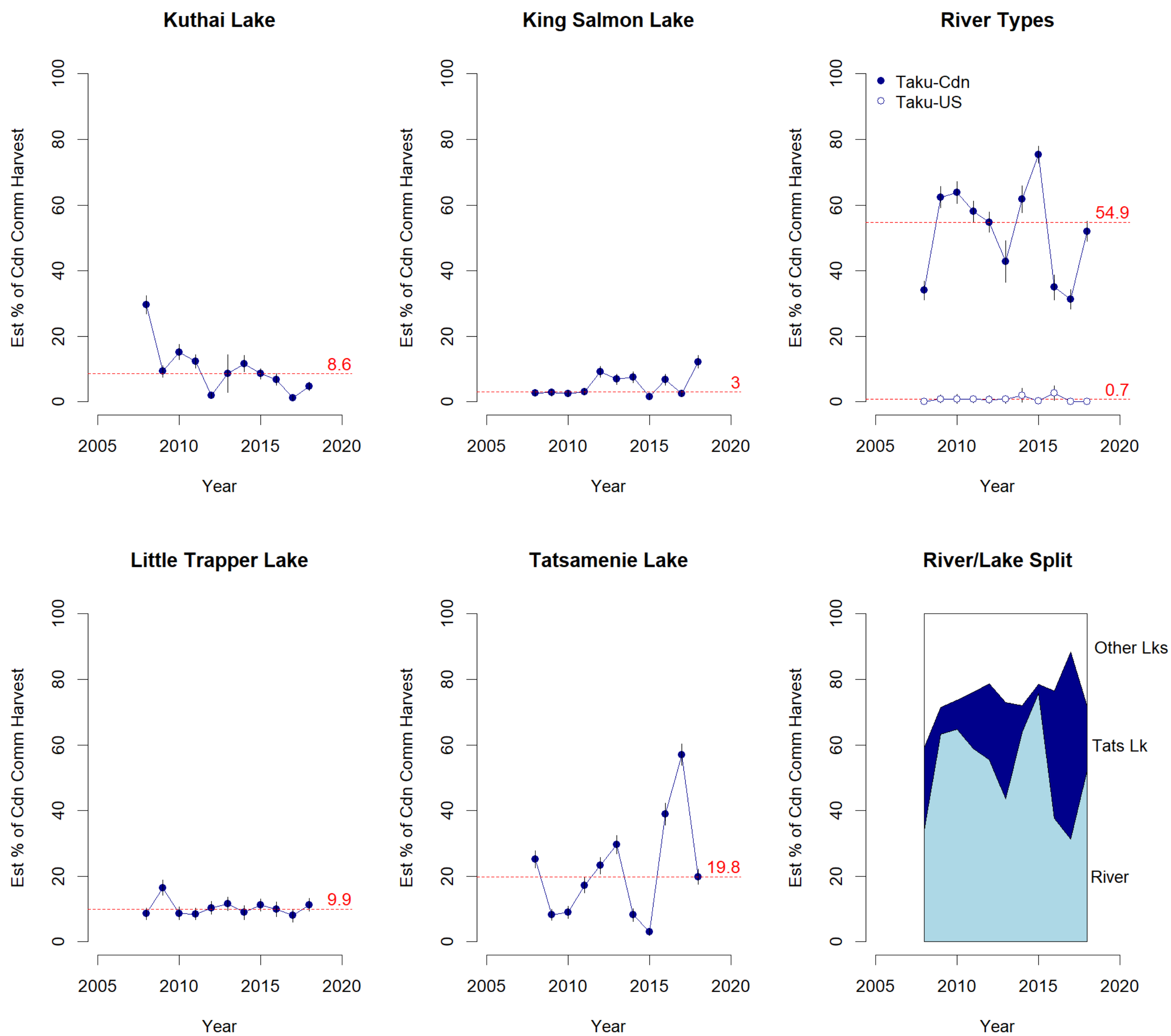


Figure 8 Annual Stock Composition of Cdn Commercial Harvest based on Genetic Stock Identification

Each time series shows the estimate, as well as whiskers for ± 2 SE, and the median % for 2008-2018.

Most of the harvest is assigned to river-type fish (median = 56%). Lake-type fish rearing in Tatsamenie Lake account for the majority of the remaining harvest (median = 20%). The relative contribution of river-type fish and Tatsamenie Lake fish is highly variable, but together these 2 stocks consistently account for about 3/4 of the total abundance (bottom right panel).

Figure 9 Spaghetti Tagged Sockeye Salmon at Canyon Island Fish Wheel

Fish are tagged with clearly visible spaghetti tags at the Canyon Island fish wheels. Section 2.3.1 describes the tags and how they are applied.

Image provided by Aaron Foos (DFO).

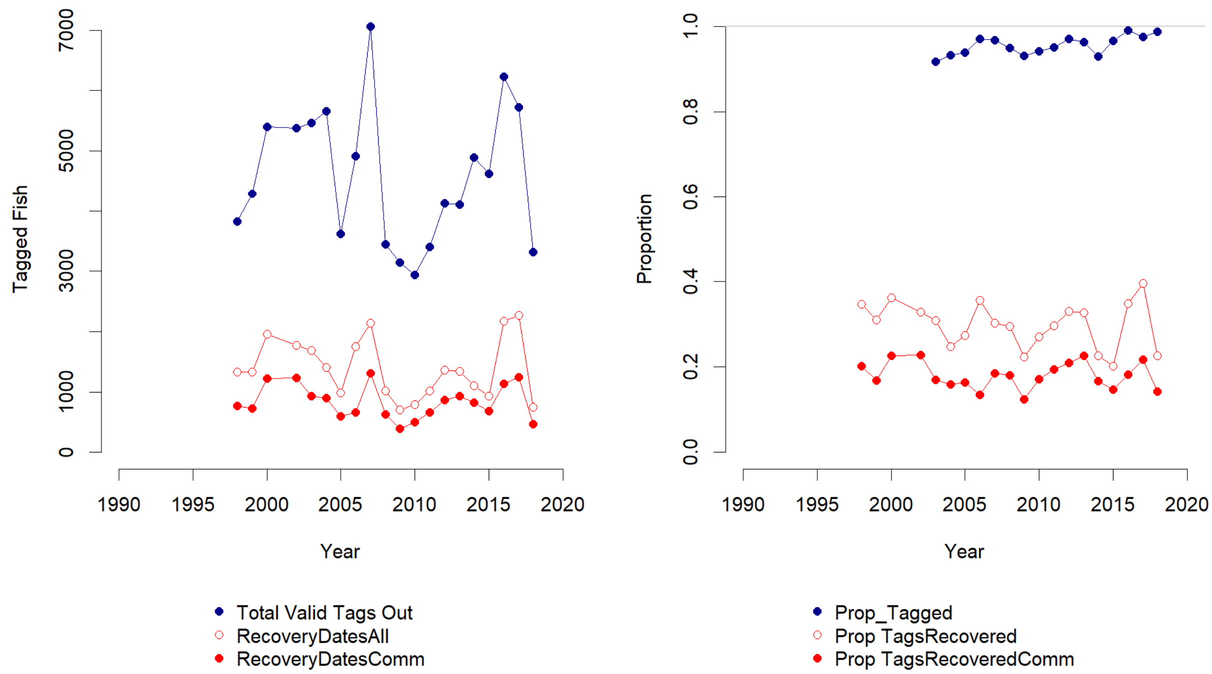


Figure 10 Summary of Tagging Data

The total number of valid tag records has varied over time (blue line,left panel), but part of that variability is due to changing annual abundances. Almost all of the fish sampled at the fish wheels were tagged (blue line, right panel). About 20% of tags were recovered in the Canadian Commercial fishery and about 10% were recovered in escapement sampling. Table 1 lists the corresponding values.

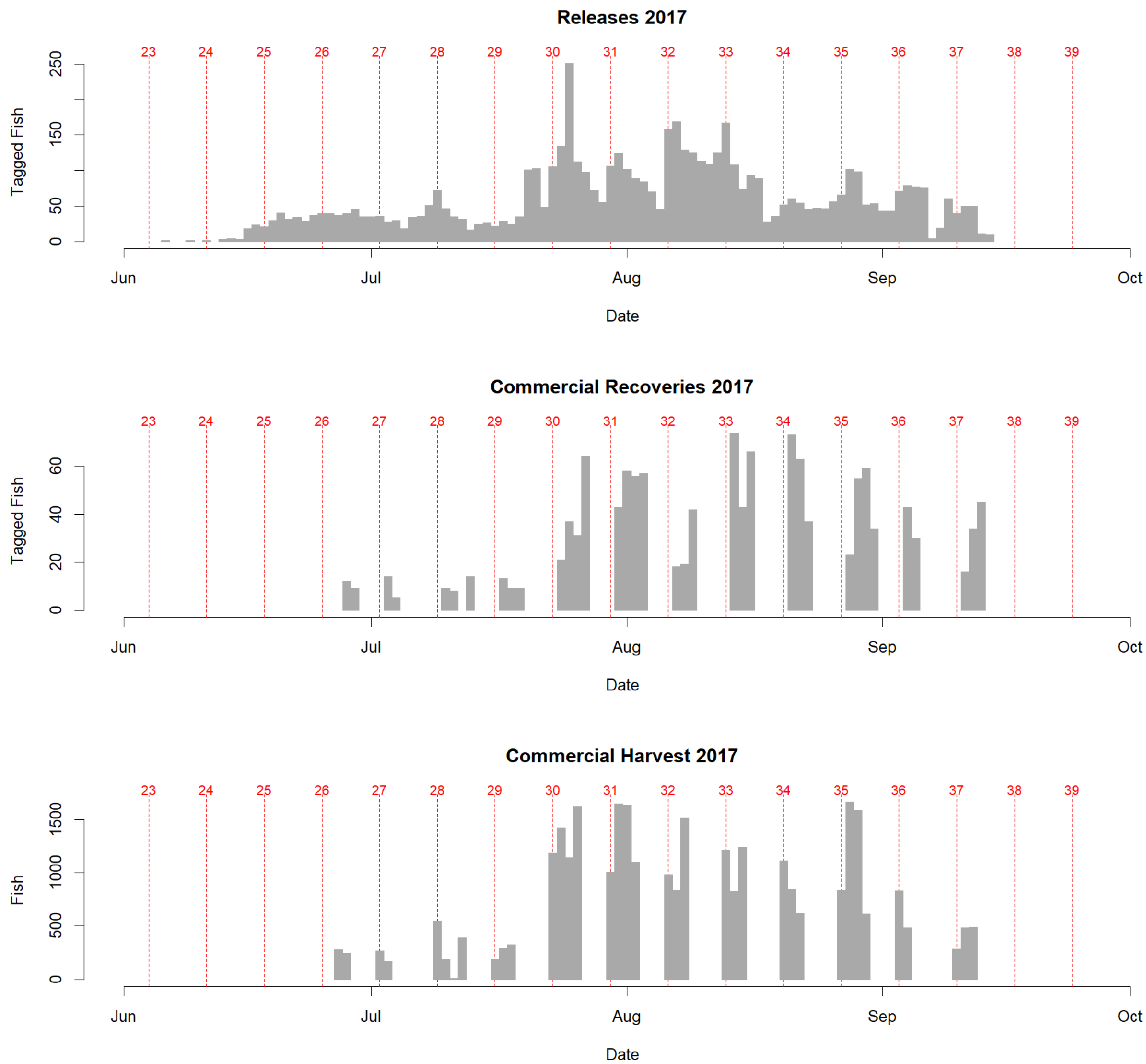
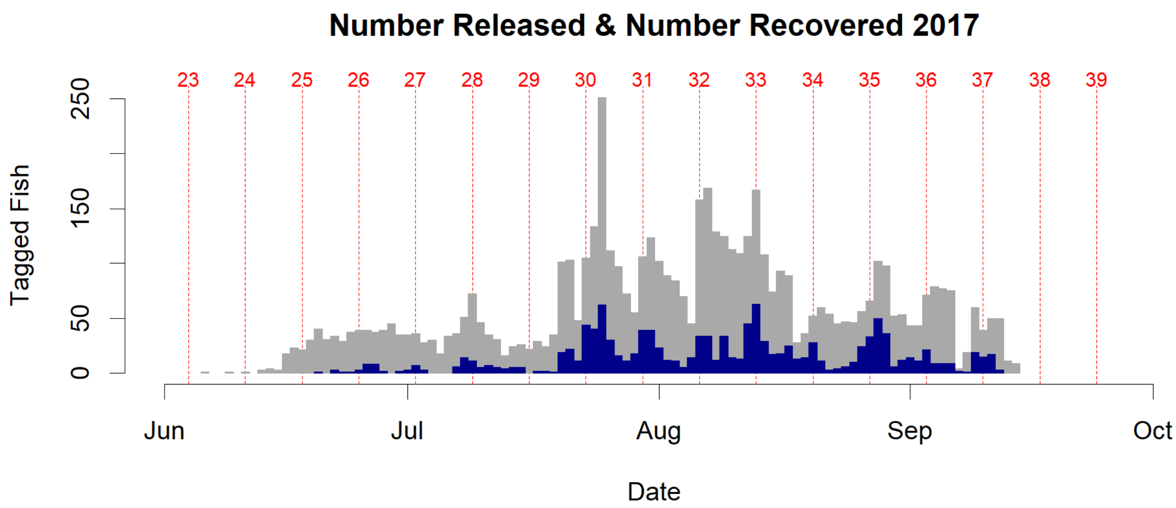


Figure 11 2017 Pattern of Releases and Recoveries

This figure illustrates one of two typical patterns of tag releases and Canadian commercial recoveries. Red vertical lines mark the first day of each statistical week (Sunday). Tags are released continuously, but with some weekly pattern of more releases earlier in the week, which is likely due to a shadow effect of the previous week's downstream and marine fishery openings on daily abundances. Upstream commercial fisheries and associated tag recoveries occur during openings that are typically 1-4 days at the beginning of each week.



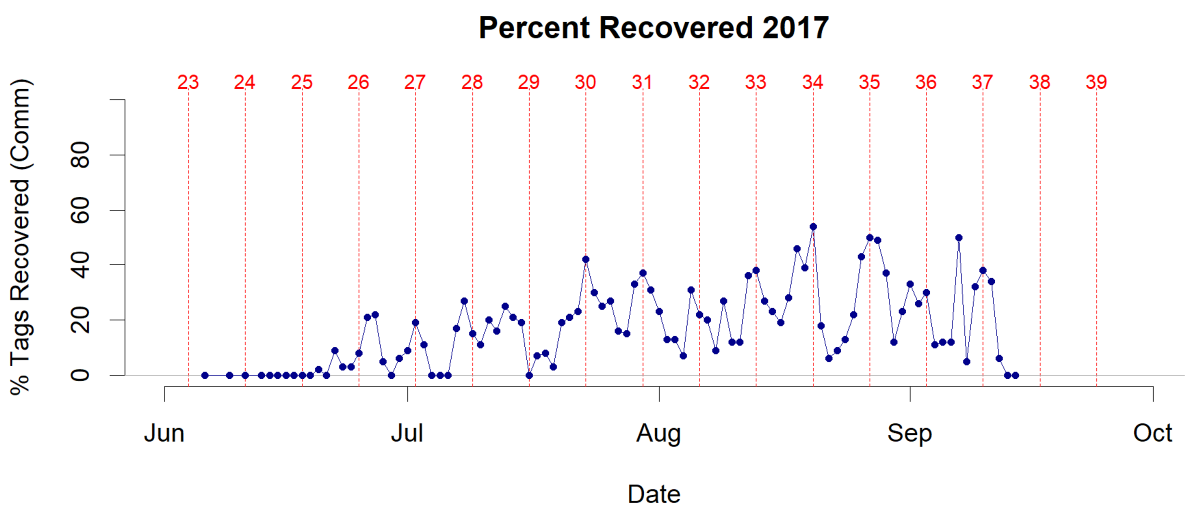


Figure 12 2017 Pattern of Releases and Recoveries matched by Date of Release

This figure illustrates the pattern of releases and recoveries *aligned by release date*. Red vertical lines mark the first day of each statistical week (Sunday). The pattern of releases is the same as in Fig. 11, but tags from each release date are recovered over multiple fishery openings. Figure 17 shows the distribution of time until recovery in the Canadian Commercial fishery.

The proportion of tags that is recovered varies over the course of the season and by weekday. Subsequent figures show the patterns by week day.

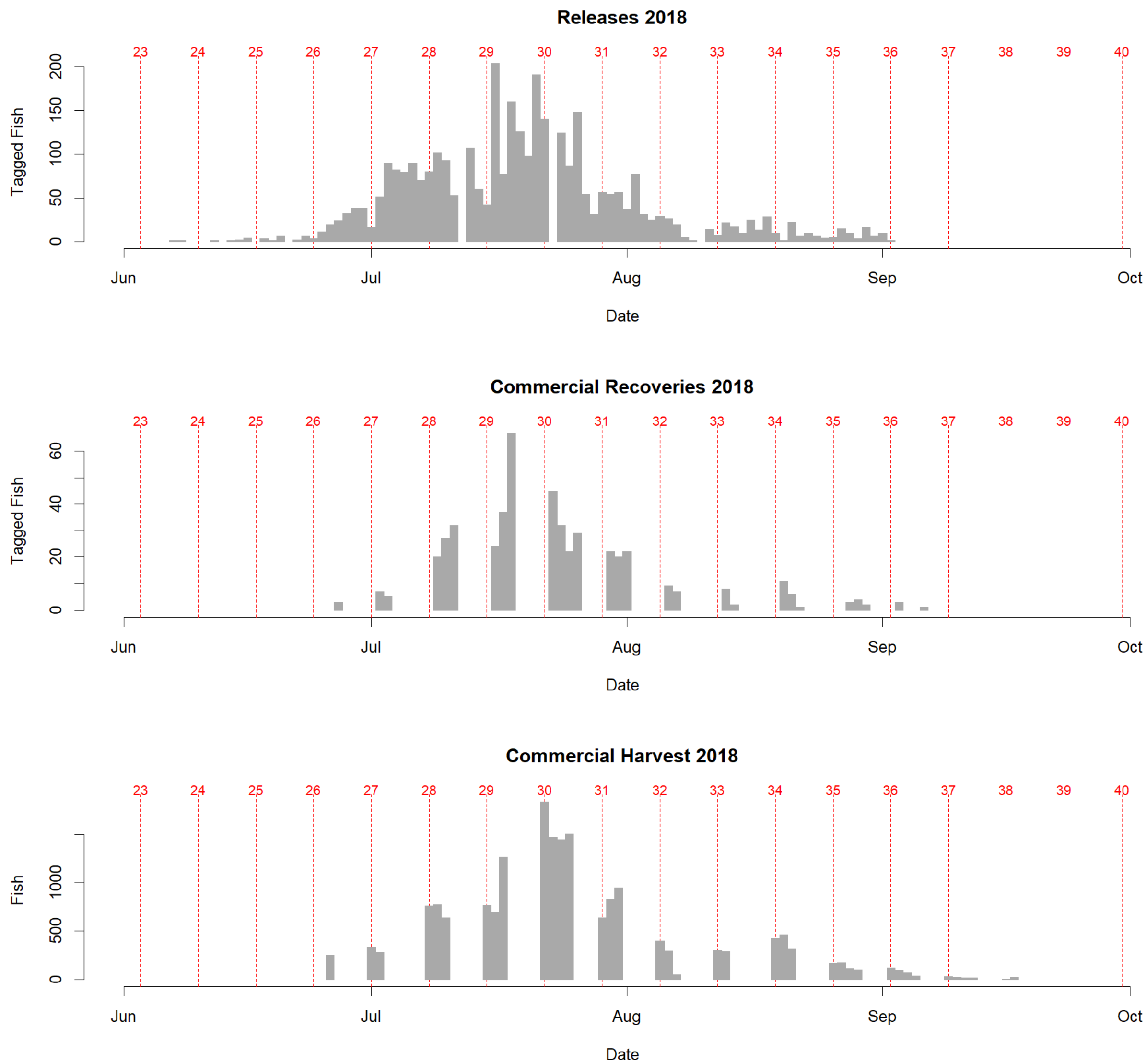


Figure 13 2018 Pattern of Releases and Recoveries

This figure illustrates the second of two typical patterns of tag releases and Canadian commercial recoveries. Red vertical lines mark the first day of each statistical week (Sunday). Tags are released continuously and tag releases follow a fairly smooth run timing curve. Commercial fisheries and associated tag recoveries occur during 1-4 day openings at the beginning of each week.

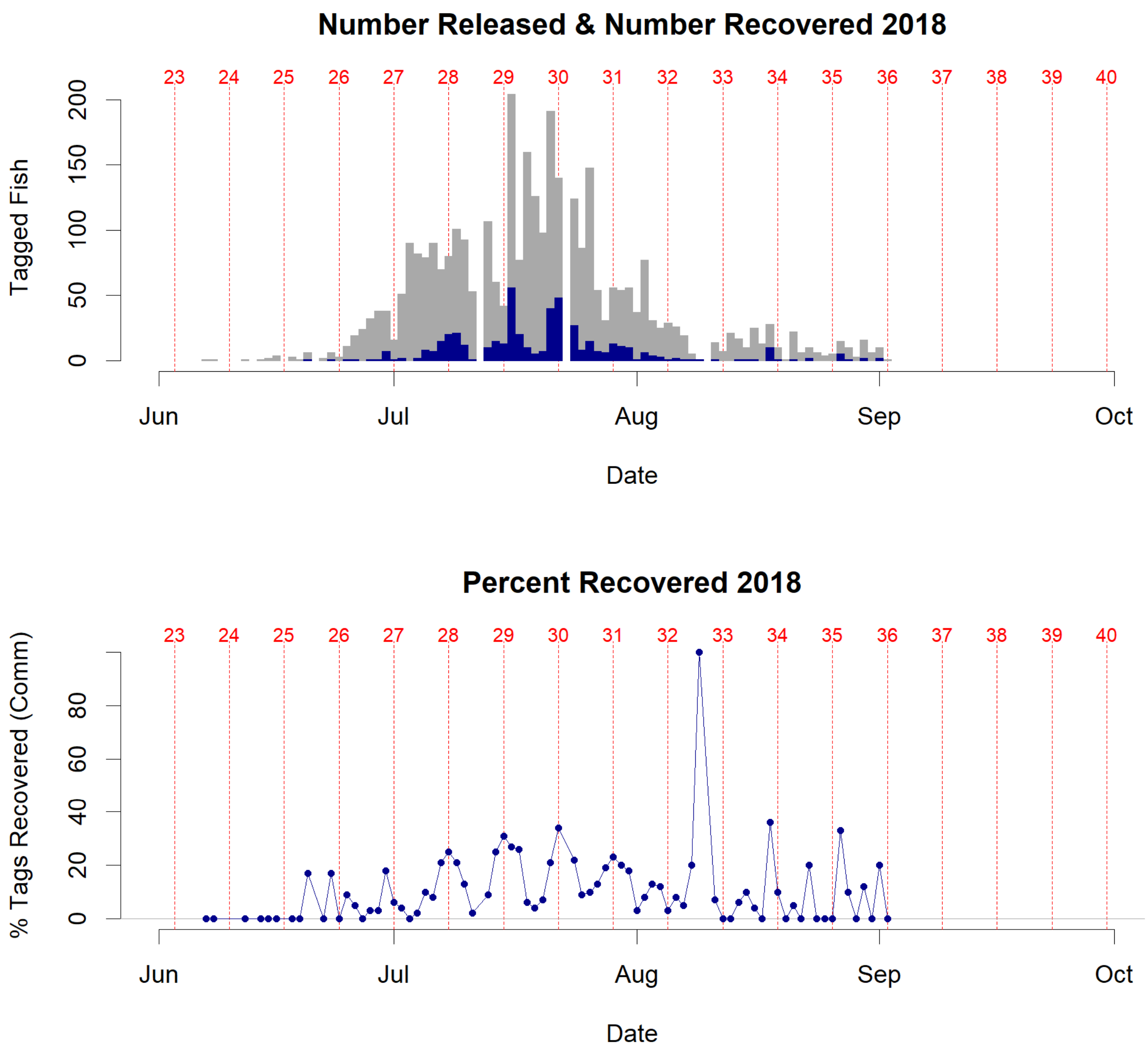


Figure 14 2018 Pattern of Releases and Recoveries matched by Date of Release

See Figure 12 for description.

Figure 15 Proportion of Tags Recovered in Cdn Commercial Fishery by Weekday of Release - 2016 to 2018

This figure illustrates the typical pattern of tag recoveries in the Canadian Commercial fishery by weekday of tag release. The proportion of recovered tags decreases later in the week, with lowest proportion recovered from releases between Wednesday and Friday. This is due to a combination of openings in the Canadian Commercial fishery at the beginning of each week, and travel time from the fish wheels.

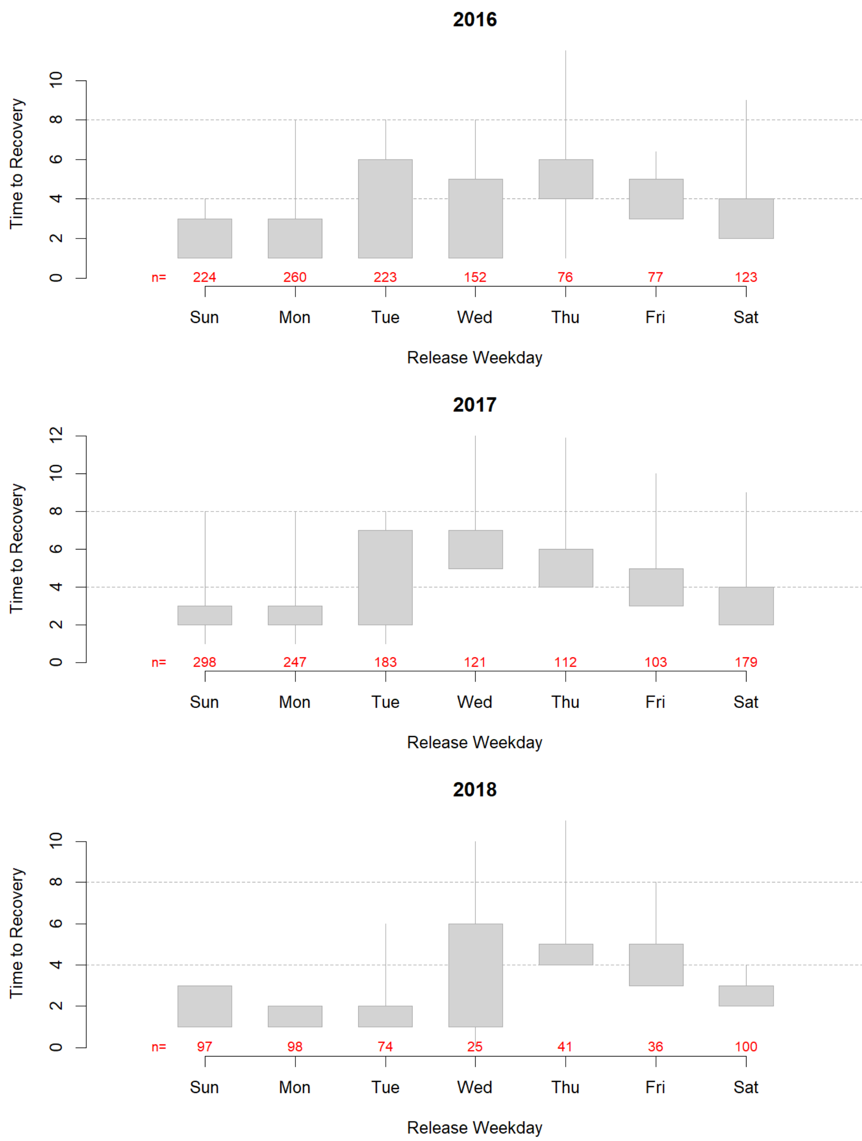


Figure 16 Time to Recovery in Cdn Commercial Fishery by Weekday of Release

This figure illustrates the typical pattern of time elapsed between tag release and recovery in the Canadian Commercial fishery. The boxes show the range capturing half of the observations (25th to 75th percentile) and the whiskers show the range capturing 80% of the observations (10th to 90th percentile).

Given the pattern of continuous tag release at the fish wheels and intermittent recovery due to the pattern in fishery openings (e.g. Fig. 13), tags released on Sunday and Monday are generally recovered much sooner (75% of tag recoveries within 1 to 3 days) than tags released later in the week (75% of tag recoveries within 5-6 days).

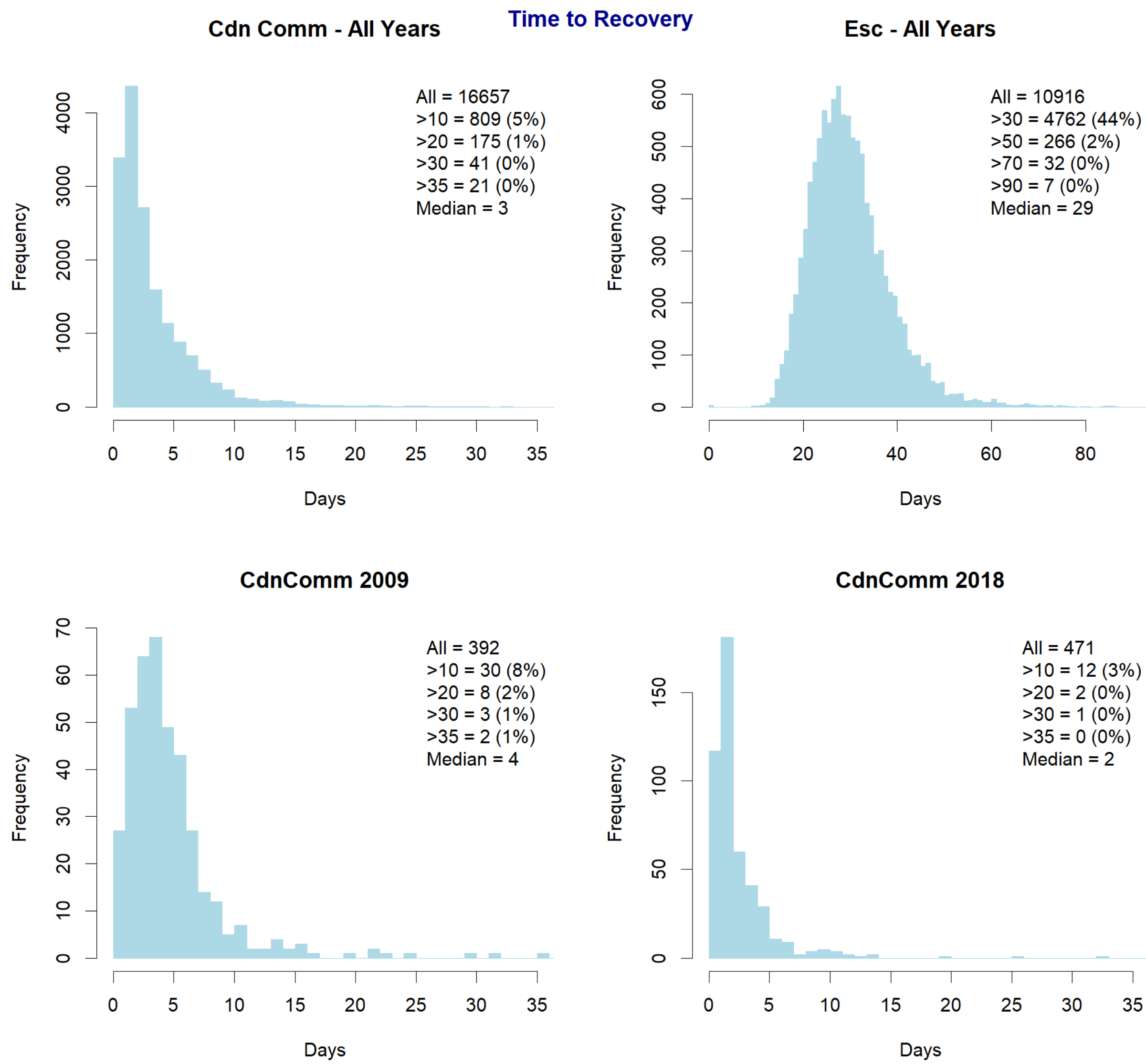


Figure 17 Comparison of Time to Recovery

The historical distributions of time from tag release to recovery show that most tag recoveries in the Canadian Commercial fishery occur within 10 days of release (median = 3) and that fish reach the spawning grounds about 20-40 days after passing the fish wheels (median = 29). Note, however, that migration time and distance differs between stocks (Fig. 2). Time to recovery in the Canadian Commercial fishery also differs between years. The bottom panels show two examples, with median time to recovery of 4 days in 2009 and 2 days in 2018. Improved operational plans were implemented beginning in 2018 to reduce the amount of time fish were held before tagging.

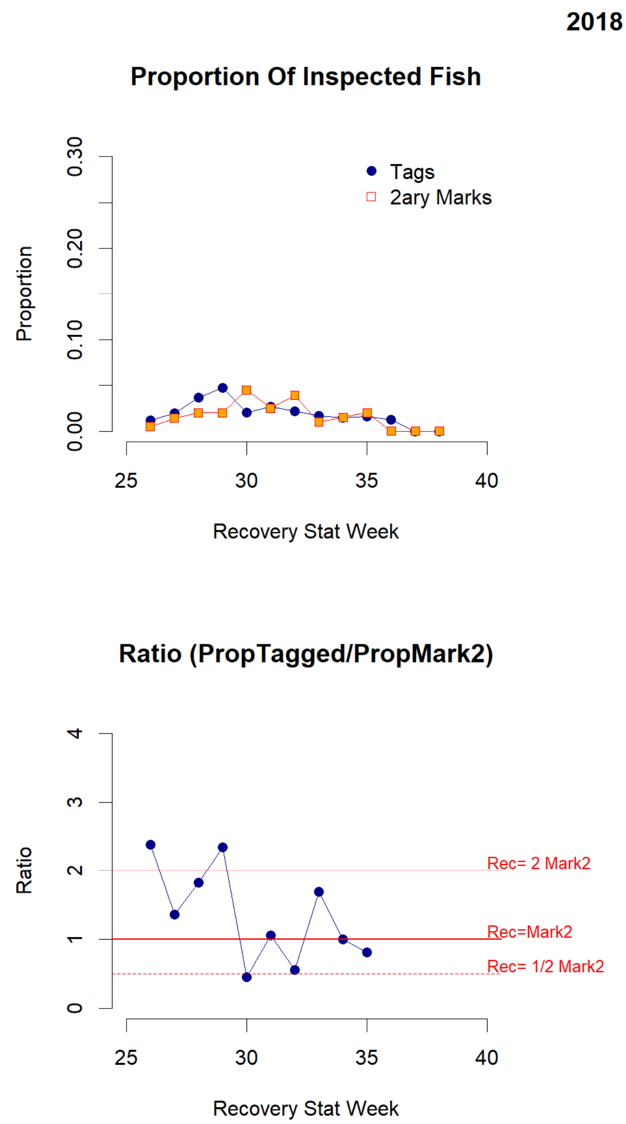


Figure 18 Illustration of Annual Pattern in Tag Recoveries and Secondary Marks - 2018

This figure shows 1 of 2 typical patterns in tag recoveries and observations of secondary marks, with the two proportions tracking closely for the time window with the bulk of the run (statistical weeks 28 to 35) and no indication of consistent bias between the two. In some weeks the tagged proportion is higher, in others the proportion of secondary marks is higher. Sampling variability is probably the main cause of observed differences in any given week, given that only a small part of the Canadian Commercial harvest is inspected for secondary marks (Table 3).

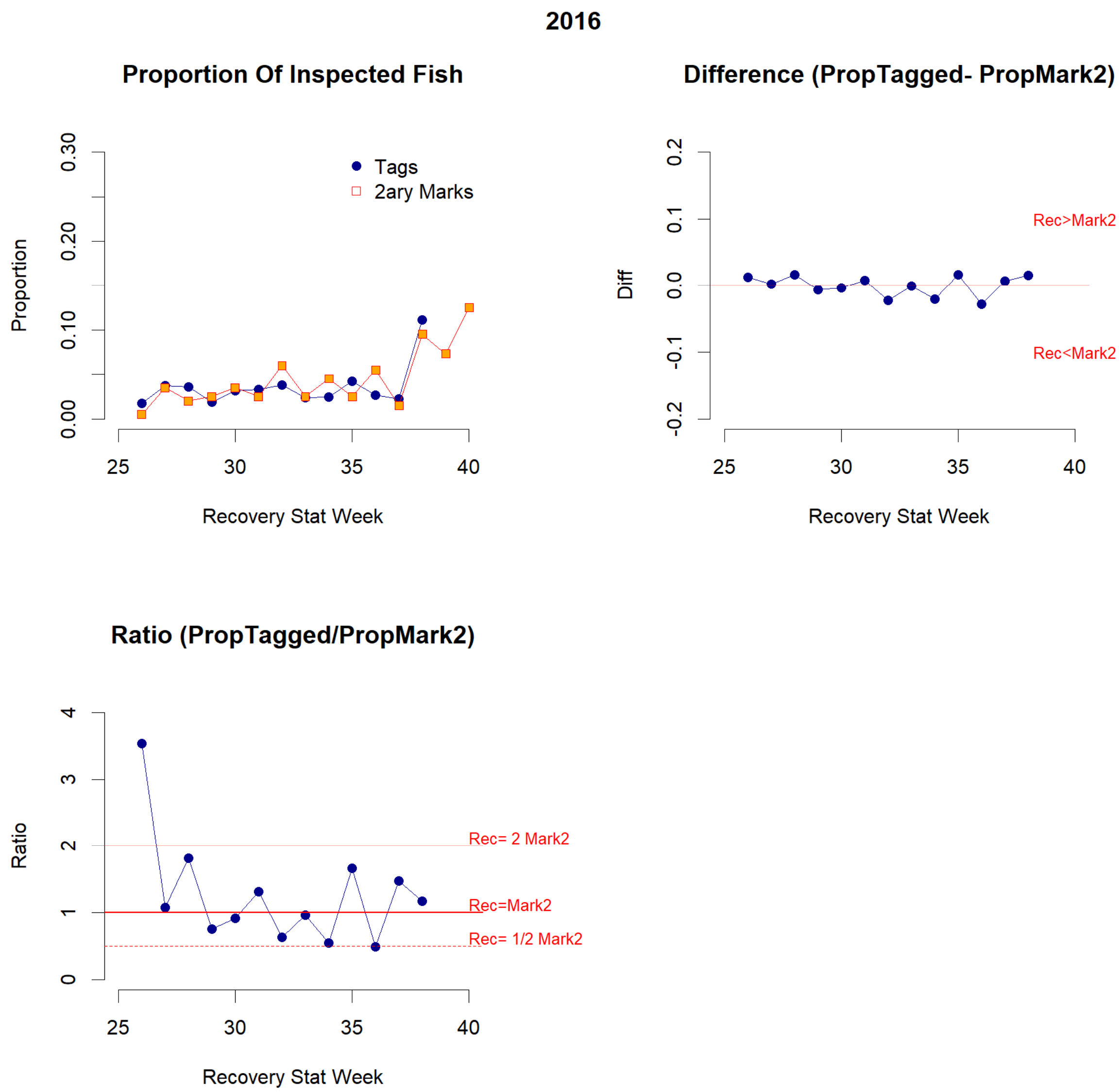


Figure 19 Illustration of Annual Pattern in Tag Recoveries and Secondary Marks - 2016

See Fig. 18 for description.

This is the second of 2 typical patterns in tag recoveries and observations of secondary marks, with the proportion of secondary marks observed higher than the proportion of tagged fish, and a late-season spike in both tag recoveries and secondary mark observations. As in Fig. 18, this is probably due to the much smaller sample sizes of the secondary mark inspections, as listed in Table 3.

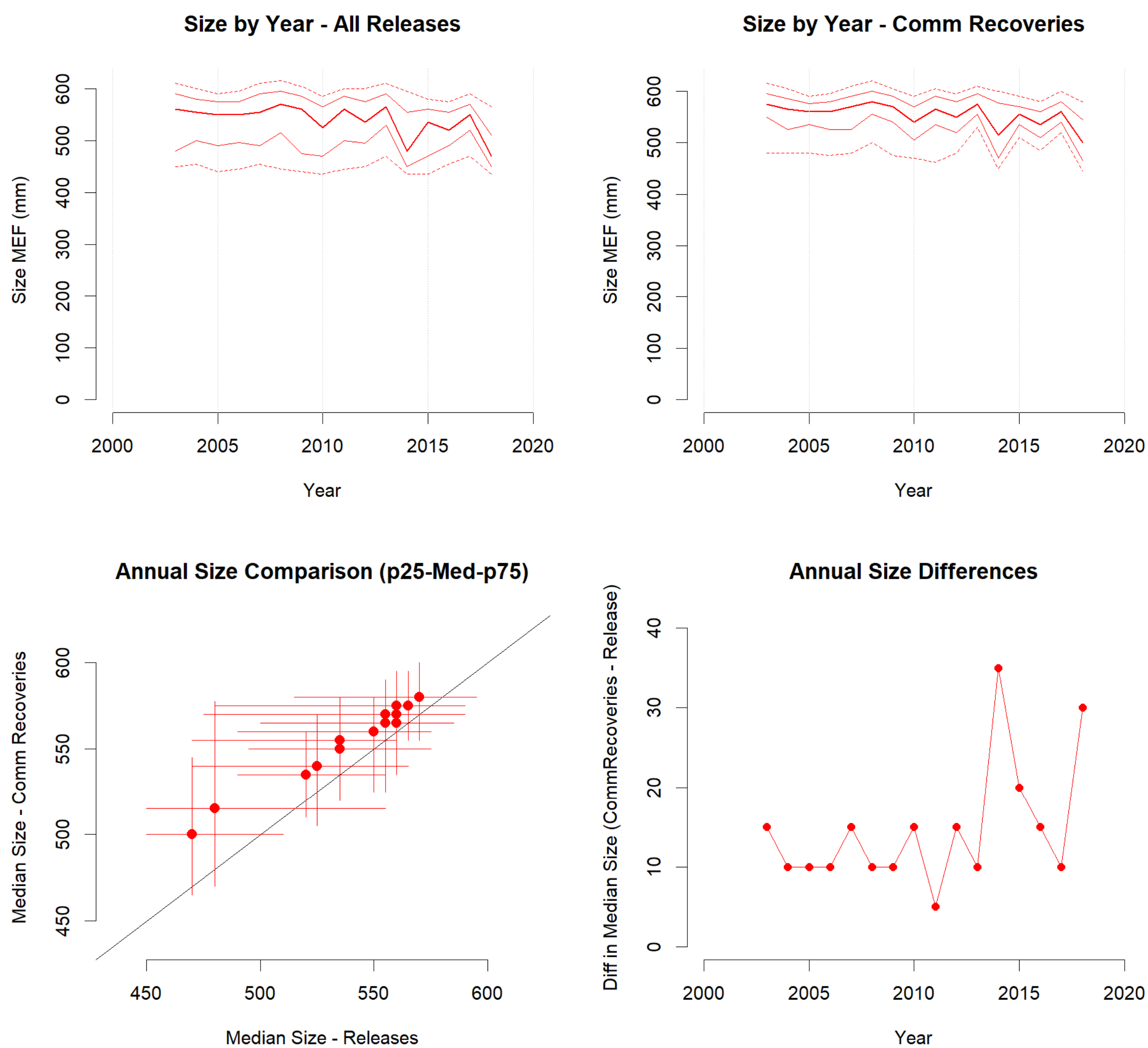


Figure 20 Size Distribution by Year - Releases vs. Recoveries

Annual size distributions of fish tagged at Canyon Island fish wheels and tagged fish recovered in the Canadian Commercial fishery. Top panels show the time series in median mideye-to-fork length (mm) with bands for 10th, 25th, 75th, and 90th percentiles. Bottom left panel compares the annual distributions, and bottom bright panel shows the pattern of differences in median sizes.

Fish size has gradually decreased over time in both the releases and recoveries (which may be related to choices of commercial fishing gear), and 2 years have a notable drop in size (2014, 2018). Tagged fish released at the fish wheels are consistently smaller than tagged fish recovered in the Canadian commercial fishery, but differences are small in most years (10-15 mm). However, in some years where the size distribution of the run has a larger component of smaller, younger fish (i.e. 2014 and 2018), the size difference between releases and recoveries is much larger (30-35 mm).

Table 5 lists the annual median values. Figure 22 shows the shape of the distributions.

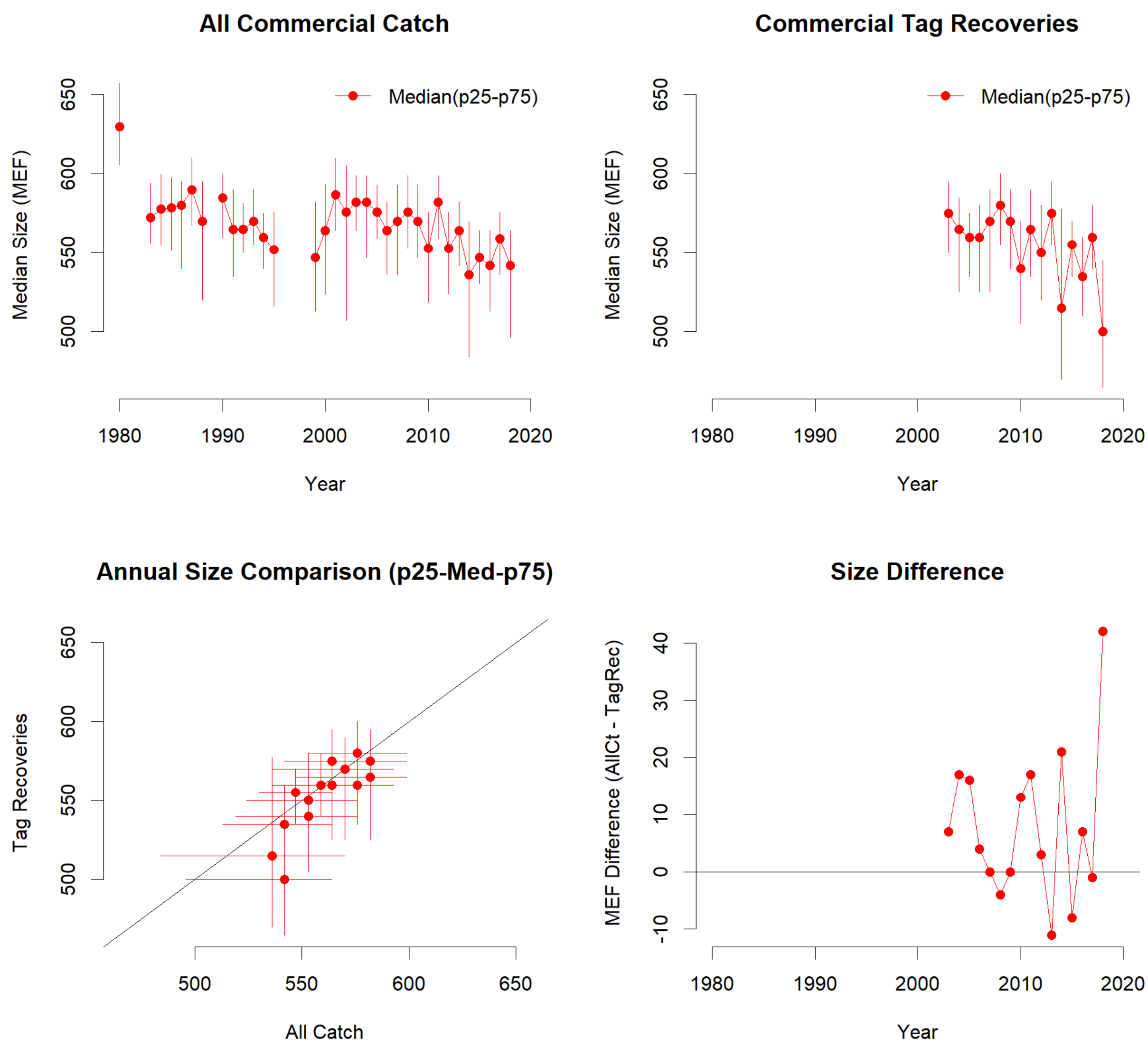


Figure 21 Size Distribution by Year - Tag Recoveries vs. All Harvest

Annual size distributions of fish caught in the Canadian Commercial fishery and the subset of harvest with a tag. See Fig. 20 for a description of plots.

Fish size has gradually decreased over time in both overall harvest and tag recoveries (which may be related to choices of commercial fishing gear). Tagged fish are 10-15 mm smaller than the overall harvest on average in most years, but in 2018 the difference in median size was 40 mm (due to a strong return of smaller, younger fish).

Table 5 lists the annual median values. Figure 22 shows the shape of the distributions.

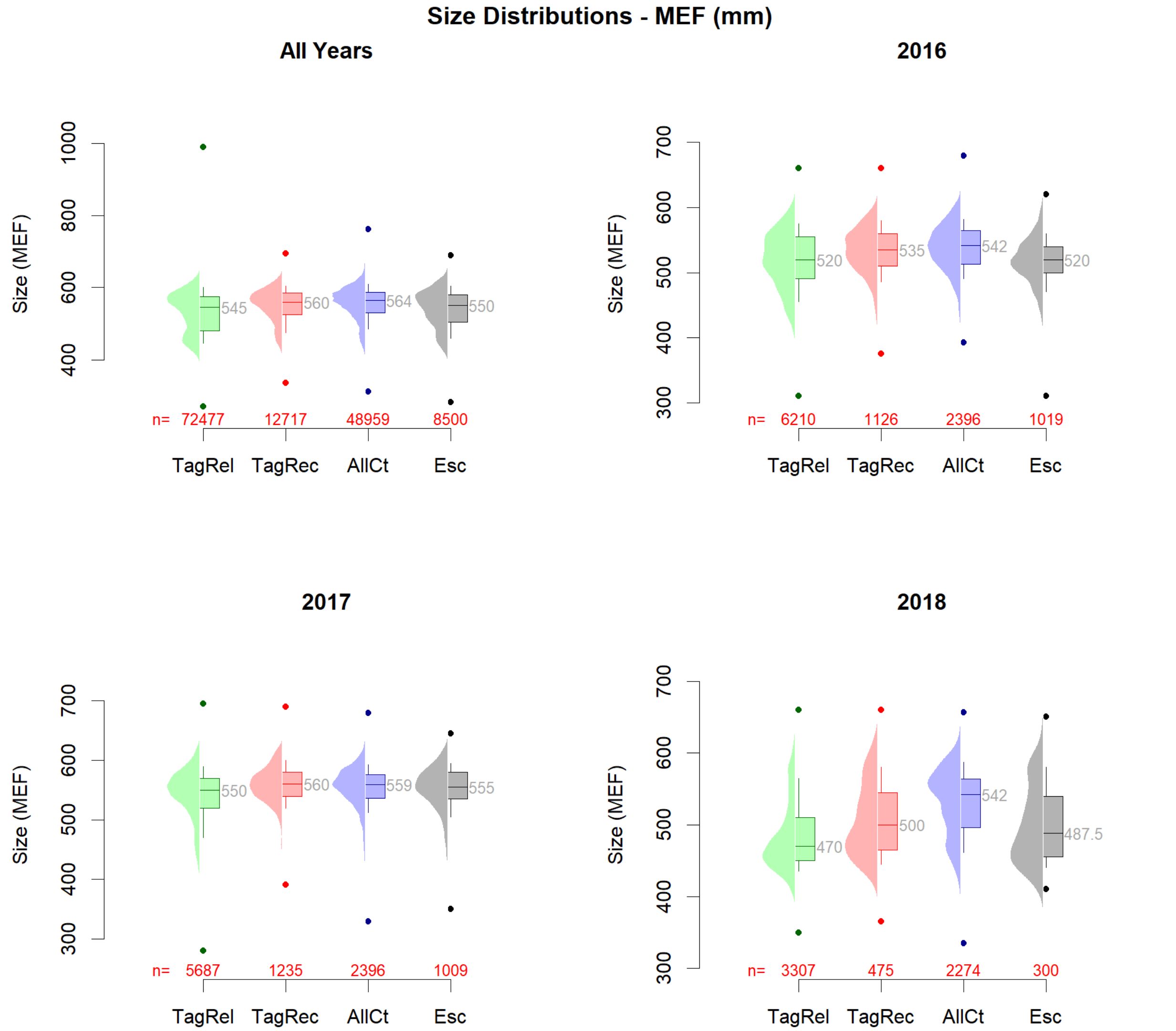


Figure 22 Size Distributions for Comm Recoveries vs. All Harvests

Each panel shows the distribution of Mideye-to-Fork length (mm) for tagged fish released at Canyon Island fish wheels (*TagRel*), tagged fish recovered in the Canadian Commercial fishery (*TagRec*), the entire harvest in the fishery (*AllCt*), and on the spawning grounds (*Esc*). For each sample, the plot shows standard boxplot (right half) and a violin plot (left half) to highlight the median, quartiles, and shape of the distribution. Points above and below mark the largest and smallest observations. Numbers below show the sample size.

Over all years of data (top left), median size and distribution shape are very similar for all 4 samples, but the fish wheels capture more of the small component of the run (<500 mm). Note that fish smaller than 350 mm are not tagged at the fish wheels. However, the distributions differ substantially between years. The remaining panels show annual size distributions for 2016 to 2018 as illustrations. Distributions for all 4 samples were basically identical in 2017. Distributions were wider, and fish were smaller in 2016. In 2018, the median size of fish tagged at the fish wheels (470 mm) was much smaller than the size of tagged fish in the Canadian commercial catch (500 mm), which in turn was much smaller than the size of the overall catch (542 mm). The distribution of overall catch is also skewed in the opposite direction of the tagged fish at the fish wheels, in the catch, and on the spawning grounds.

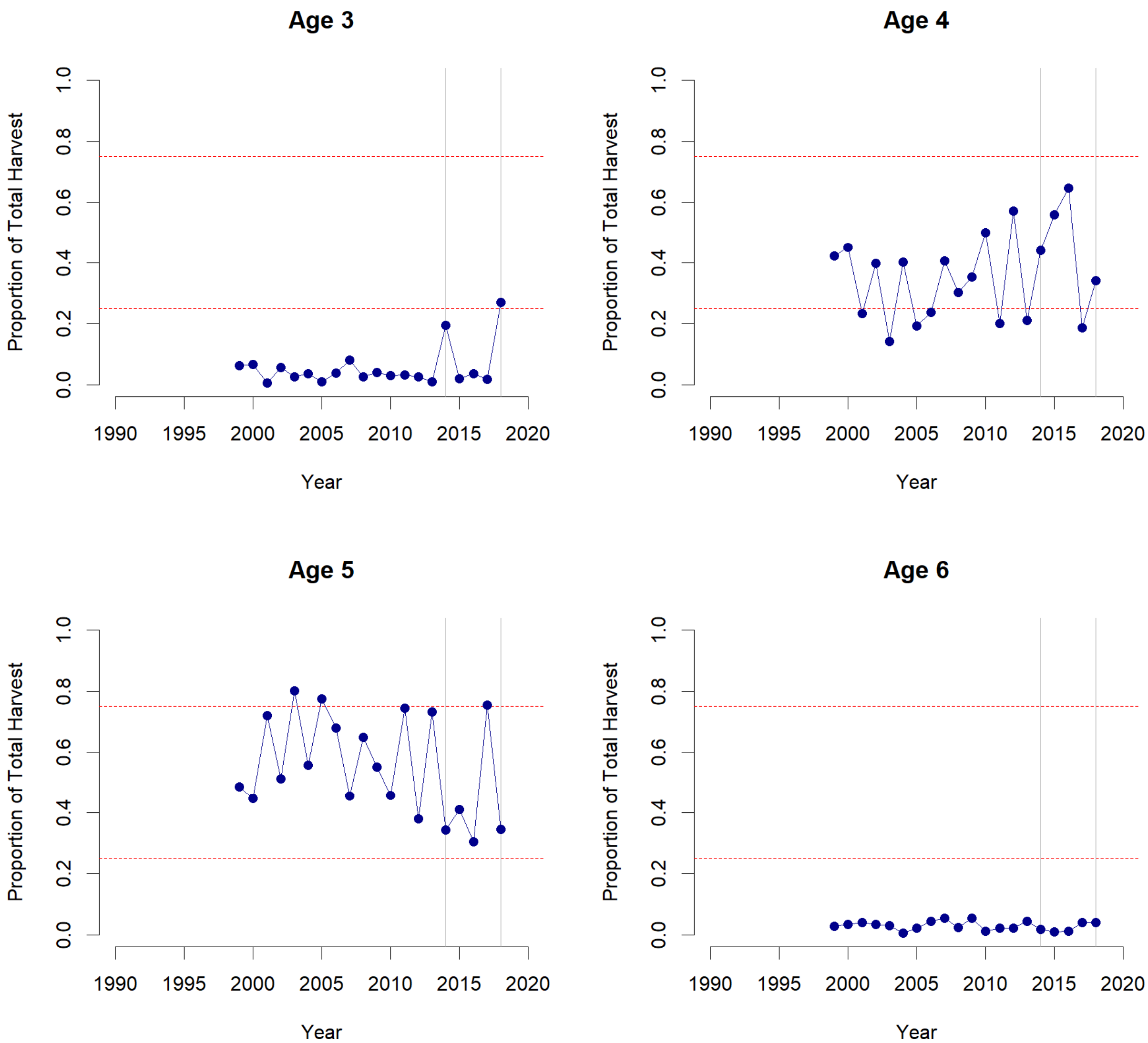


Figure 23 Age Composition in Cdn Commercial Harvest

Each panel shows time series of the proportion one age group contributes to the Canadian Commercial harvest, with age groups combining various age classes (e.g., age 5 includes age classes 1.3, 2.2, and 3.1).

Most of the catch generally consists of 4-yr old and 5-yr old fish, with the predominant age group switching back and forth between the two, and the proportion of 4yr olds gradually increasing in recent years. There are very few 6-yr olds, and in most years the proportion of 3-yr olds is small (<10%). However, in some years there is a substantial component of 3-yr olds (2014, 2018).

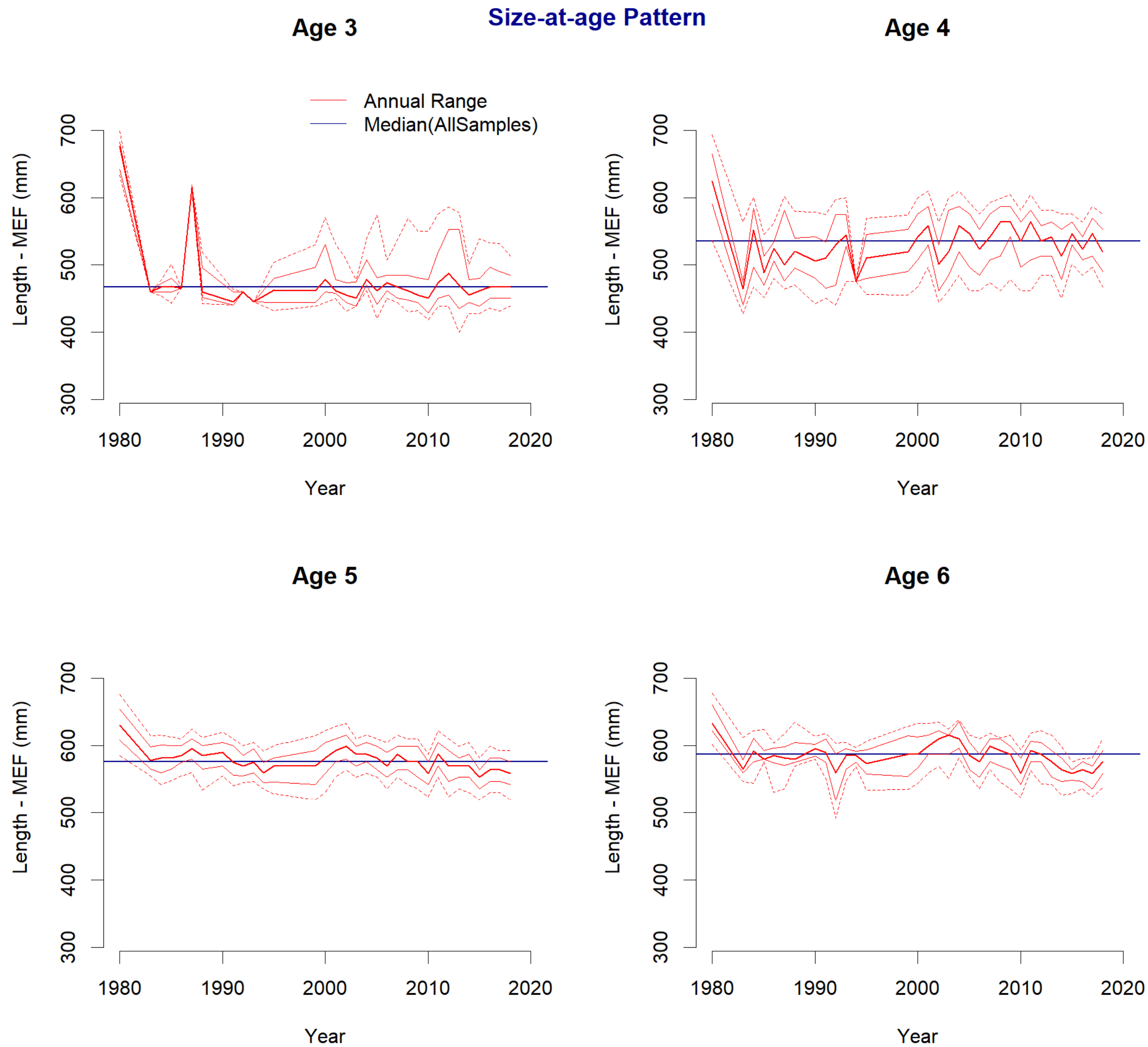


Figure 24 Annual Size-At-Age Range Over Time

Annual size distributions fish caught in the Canadian Commercial fishery, separated by age group. Age groups as per Fig. 23. Each panel shows the time series in median mideye-to-fork length (mm) with bands for 10th, 25th, 75th, and 90th percentiles. Fig. 25 is a comparison plot of the medians and Fig. 25 shows the corresponding sample sizes. The commentary below covers all 3 figures.

Size-at-age is more variable within years (i.e., wider bands) and between years (i.e., spikier median) for younger fish (age 3 and 4), and the median size has generally increased in recent years (coinciding with a shift from age 5 to age 4 fish, see Fig. 23). Earlier estimates are very noisy, especially for the younger fish (age 3 and 4), because sample sizes were very small in the 1980s and early 1990s.

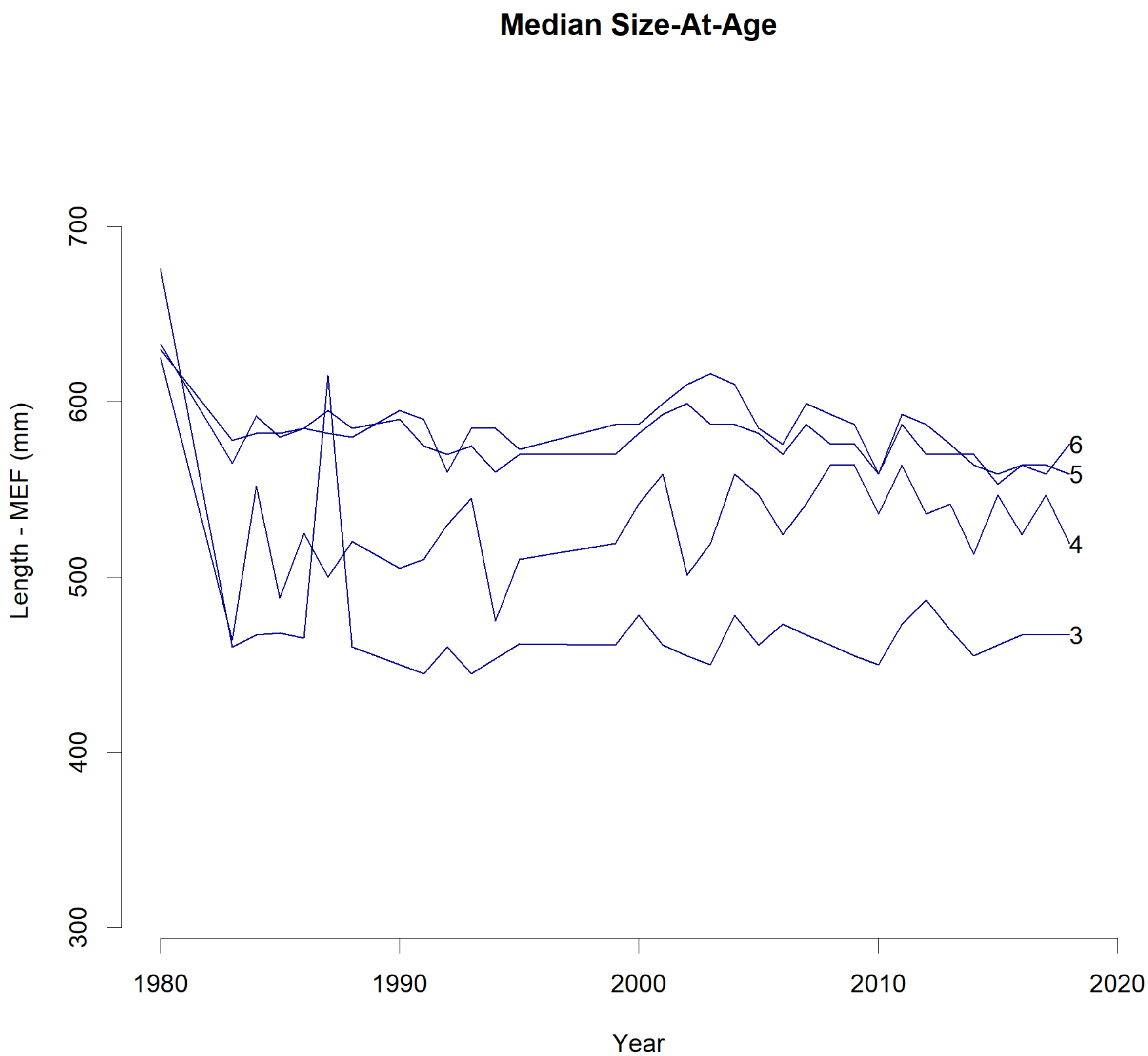


Figure 25 Median Size-At-Age Over Time

See description for Fig. 24.

Figure 26 Size-At-Age Sample Size By Year

See description for Fig. 24.

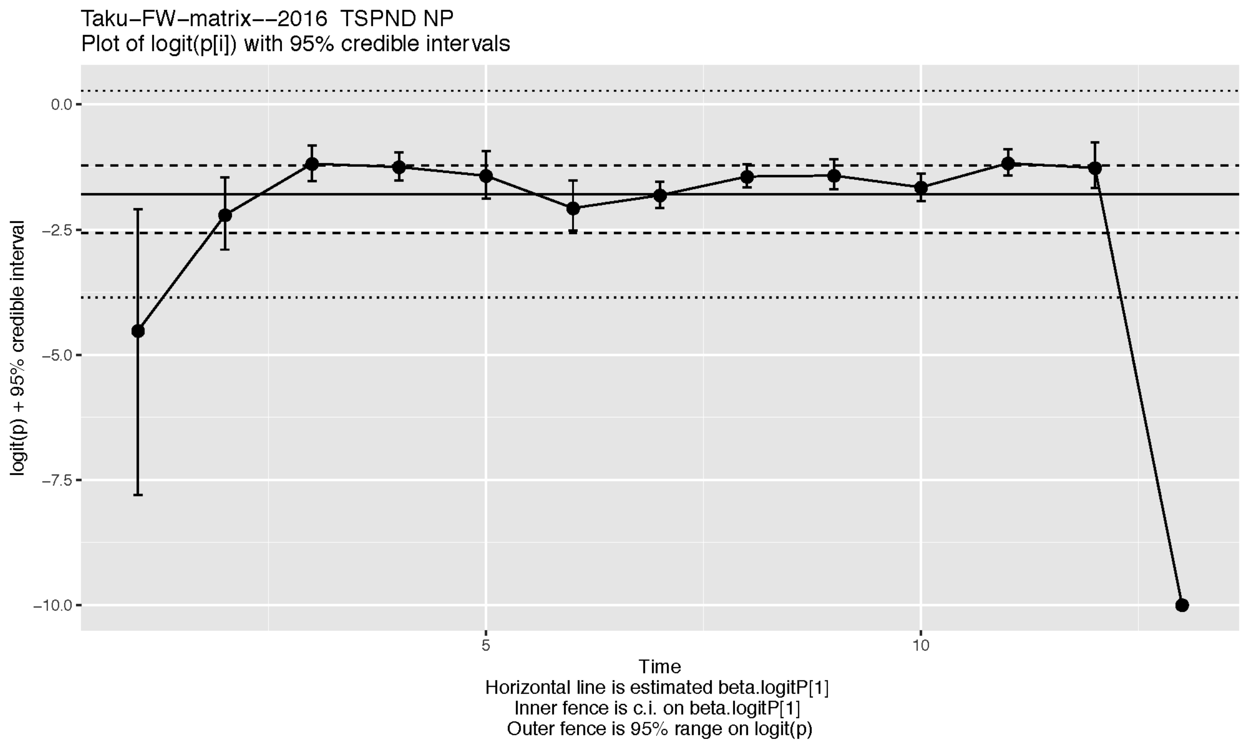


Figure 27 Illustration of fitted capture probability generated by BTSPAS

Fitted capture probability (on the logit scale) based on illustrative data from Tables 6 and 7. Time period 1 on the plot corresponds to statistical week 24. Estimates of the recapture probability are very poor at the start and end of the study when few fish are available to be recaptured and effort was low. The solid line is the average capture probability (on the logit scale) and the inner dashed lines are 95% credible intervals on this probability. The outer dashed lines are 95% probability intervals for individual capture probabilities.

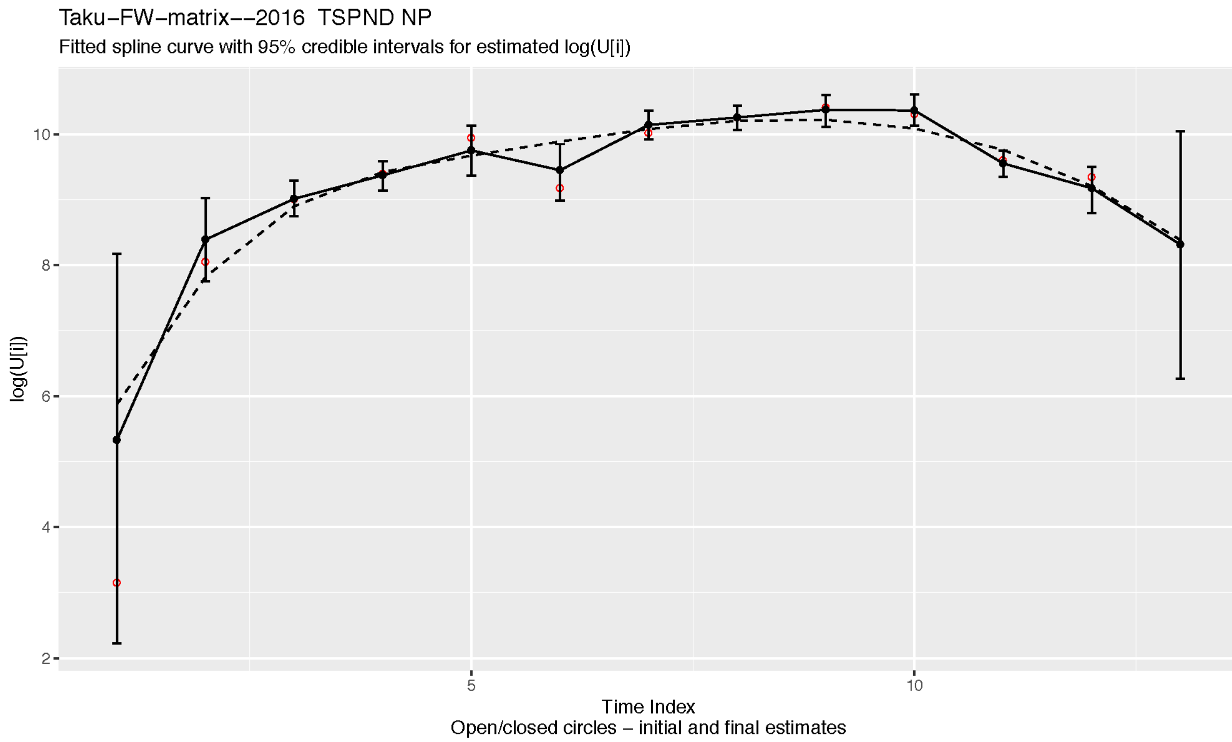


Figure 28 Illustration of fitted run curve generated by BTSPAS

Fitted run curve generated by BTSPAS using the illustrative data of Tables 6 and 7. Time period 1 on the plot corresponds to statistical week 24. The dashed line is the fitted spline curve for the number of unmarked fish (on the natural logarithmic scale) passing the Canadian commercial fishery in each week; the solid line are the actual weekly estimates. Estimates have high uncertainty at the start and end of the study when few fish are available to be recaptured and fishing effort is low.

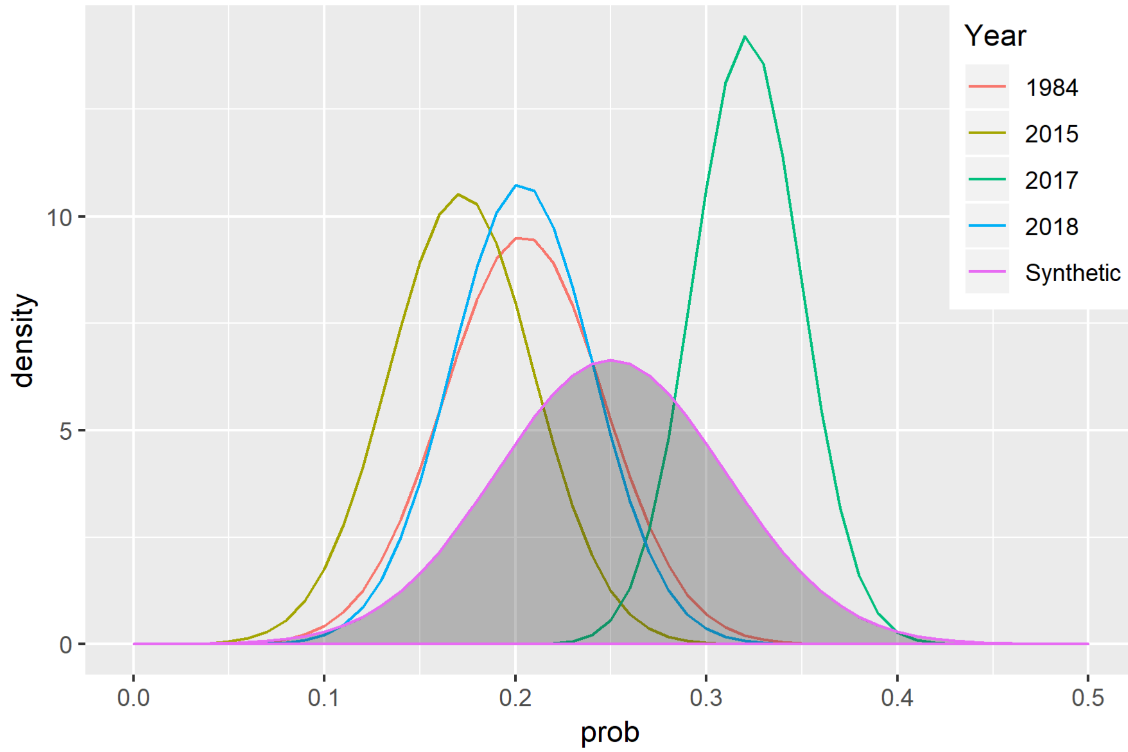


Figure 29 Illustration of dropout rate likelihood functions

Illustration of the likelihood functions for the 4 years of radio-telemetry studies to estimate the dropout probability and the final "synthetic" likelihood function. The "synthetic" likelihood uses values of x (fish that drop out) and n (synthetic sample size) to capture the uncertainty in the dropout probability in each radio-telemetry study and the year-to-year variation in the dropout probability. Details in Section 4.2.4.

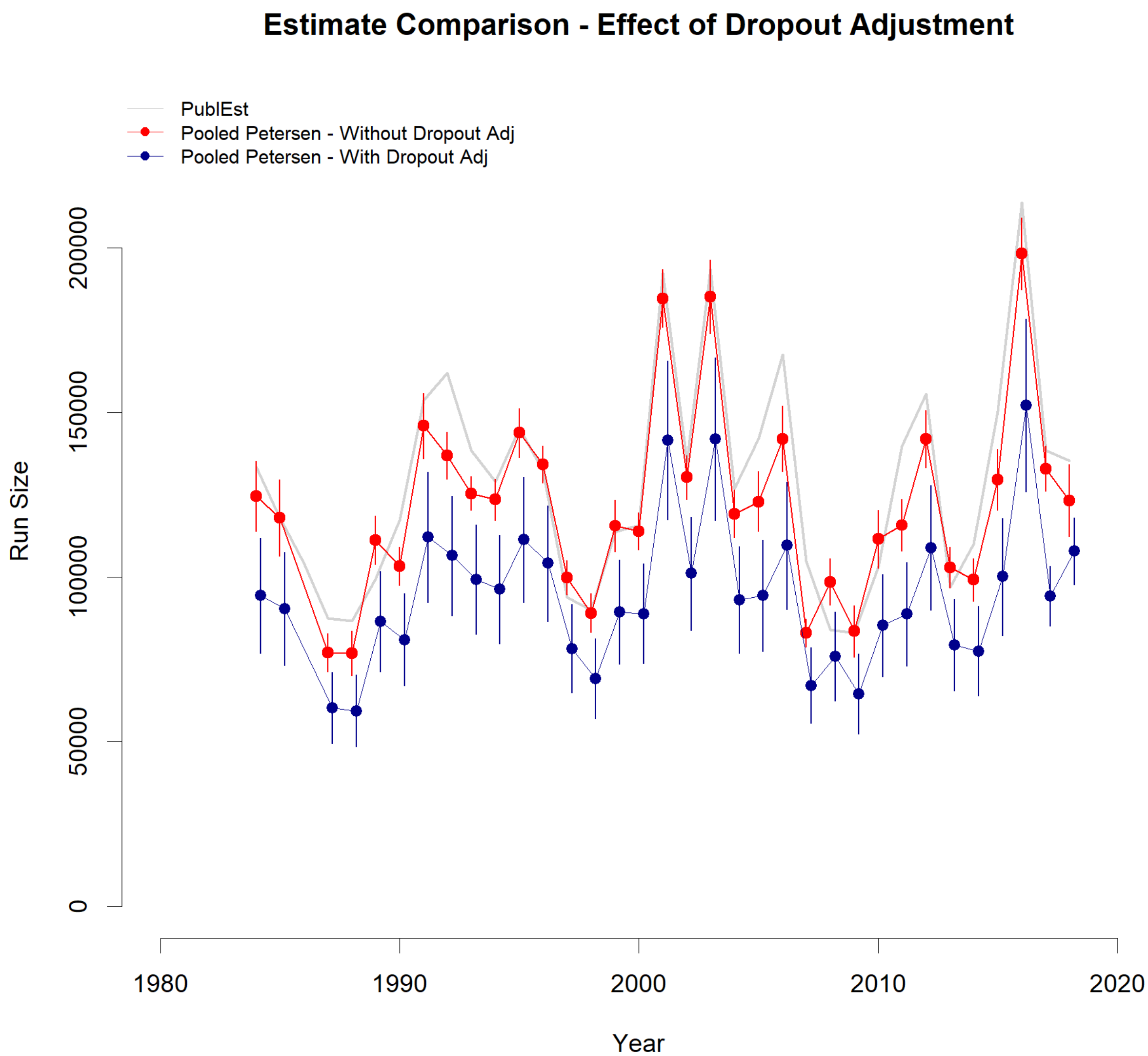


Figure 30 Comparison of Pooled Petersen Estimate of InRiver Abundance with and without Dropout Adjustment

This plot compares 3 alternative estimates of annual inriver abundance. Error bars show ± 2 SE. Previously published estimates are from the annual capture-recapture reports (e.g., Boyce and Andel 2014, TTC 2019a), and values are listed in Table 8. Sec. 4.2 describes the pooled Petersen estimate. Sec. 4.2.4 describes the dropout adjustment and Fig. 31 shows the dropout adjustments that were applied.

The 3 estimates track closely in terms of the pattern over time, but the dropout adjusted estimate is substantially lower. Error bars are mostly quite narrow, reflecting the large total annual sample size of tags and high proportion of recoveries (Table 1).

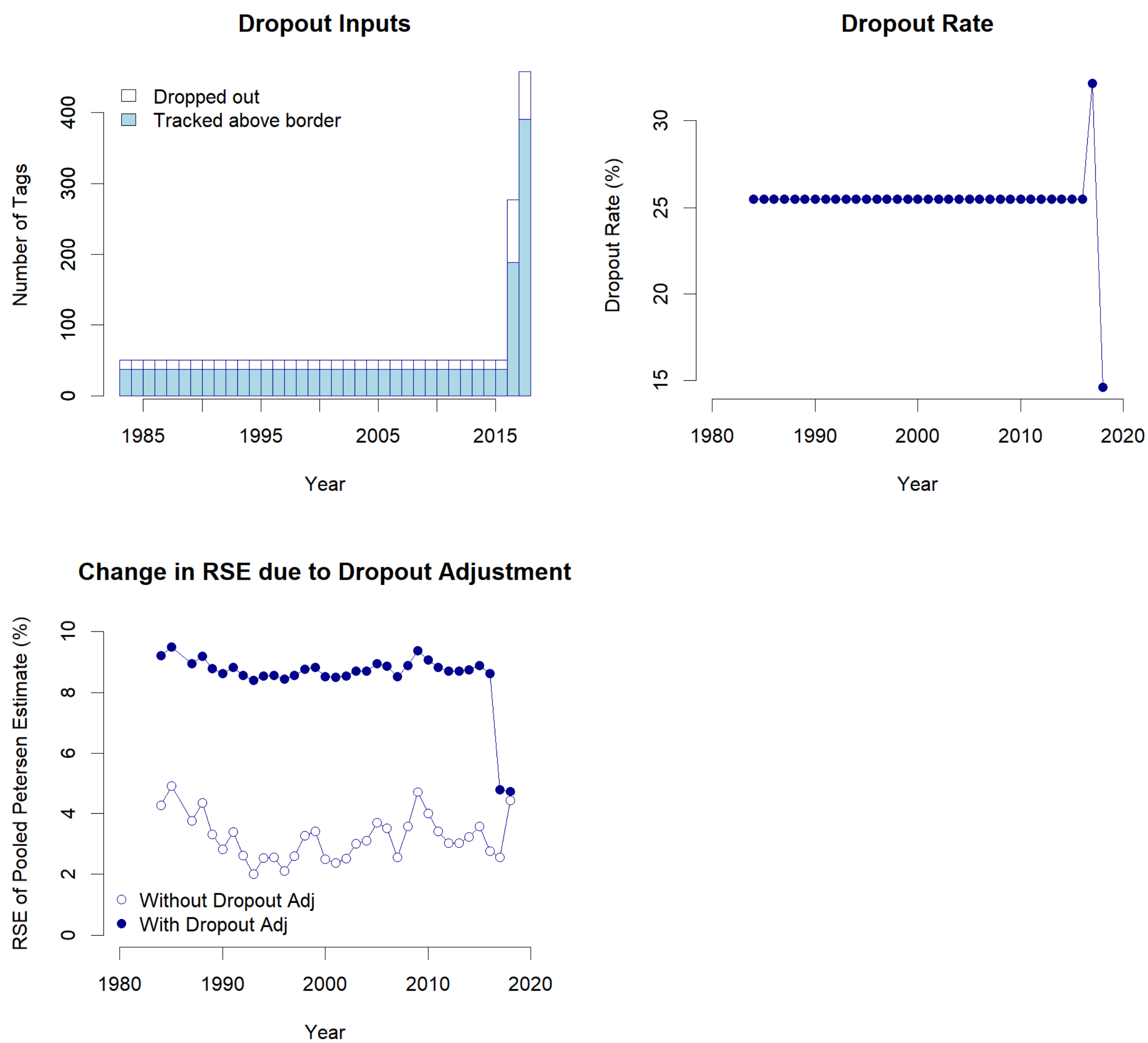


Figure 31 Dropout inputs and effect on RSE of Pooled Petersen Estimate of InRiver Abundance

For most years the dropout adjustment uses the synthetic data of 13/51 = 25.5%, capturing the average across several telemetry studies with a synthetic sample size to reflect both year-to-year variation and uncertainty within a year from small number of fish radio tagged in the studies. Figure 29 shows how the variation implied by the synthetic data captures these sources of variation. For 2017 and 2018, dropout adjustment uses the telemetry results for those years. Section 4.2.4 describes the details. Dropout adjustment also affects the coefficient of Variation (CV) of the annual estimates, with smaller telemetry sample sizes resulting in larger CV (i.e., wider error bars on the estimate).

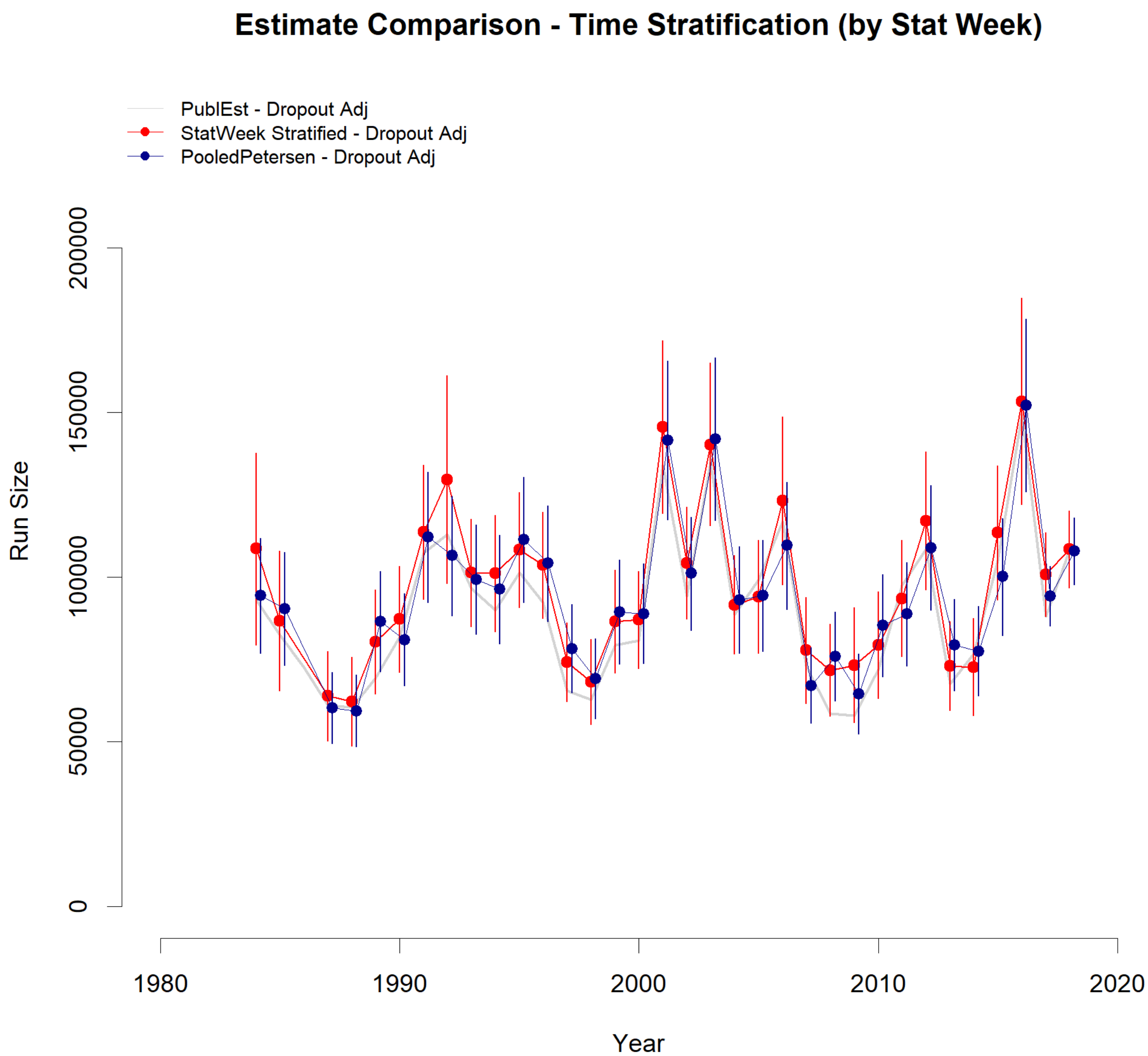


Figure 32 Comparison of Time-Stratified and Pooled Petersen Estimate of InRiver Abundance

This plot compares 3 alternative estimates of annual inriver abundance. Error bars show ± 2 SE. Previously published estimates are from the annual capture-recapture reports (e.g., Boyce and Andel 2014, TTC 2019a), and values are listed in Table 8. Sec. 4.2 describes the pooled Petersen estimate and the Bayesian estimates stratified by statistical week. All 3 estimates are adjusted for dropout, as described in Sec. 4.2.4.

All 3 estimates are very close in most years.

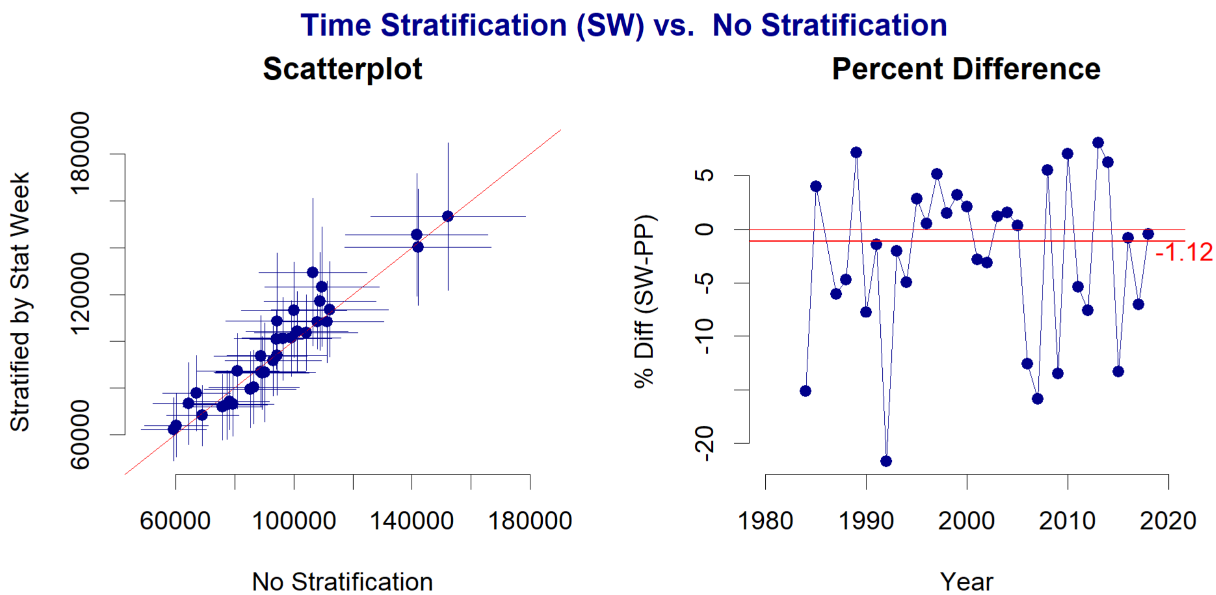


Figure 33 Pattern of Differences between Time-Stratified (SW) and Pooled Petersen Estimate of Inriver Abundance

Estimate details as per Fig. 32. Time-stratified estimates tend to be higher than the pooled estimates, but median difference is small (1%), and the direction of the discrepancy switches back and forth frequently in recent years. However, time-stratified estimates tended to be consistently larger than pooled estimates in the 1980s and early 1990s, and then consistently smaller from the mid-1990s to the mid-2000s.

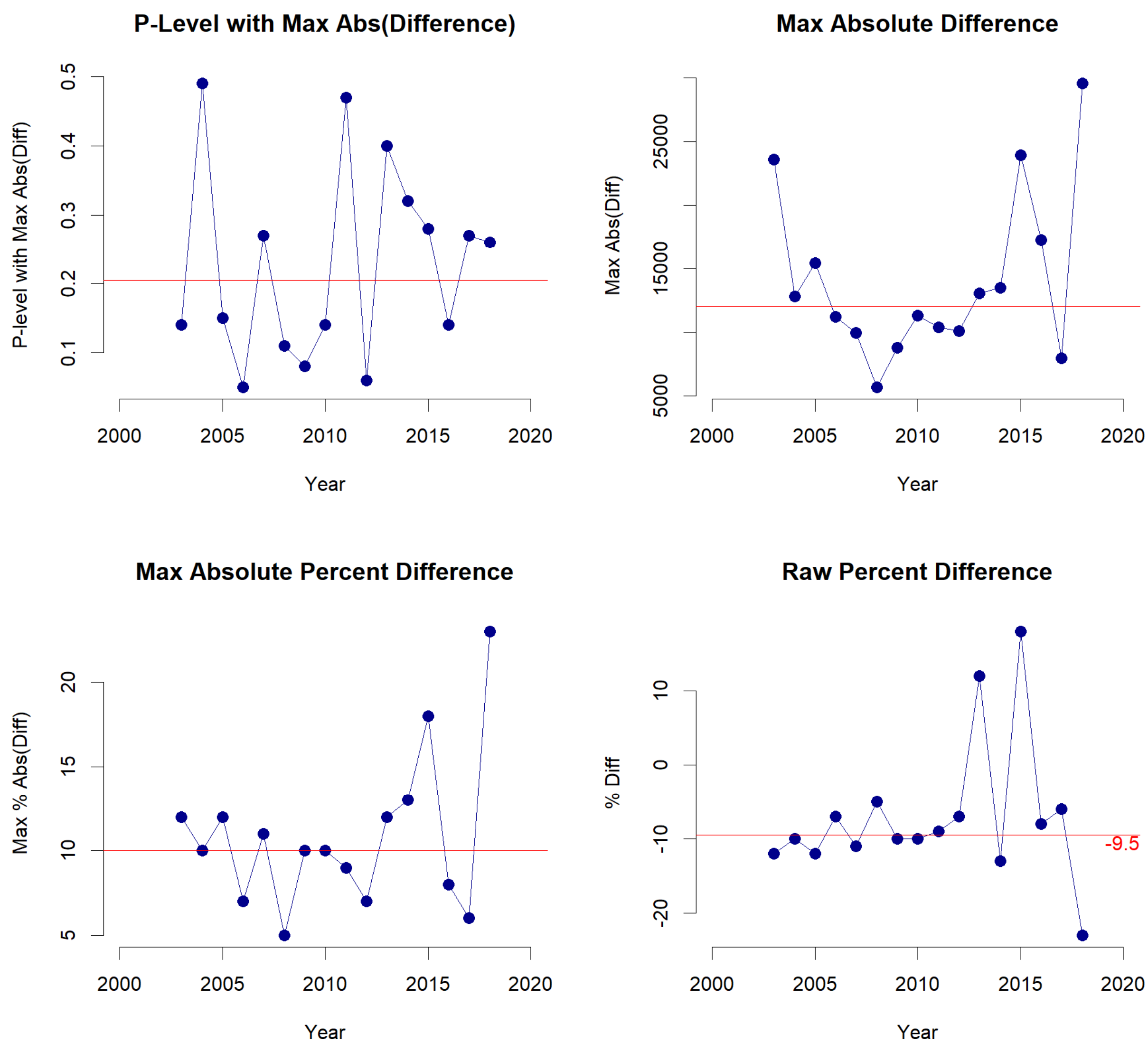


Figure 34 Effect of Different Cut-off Points for Size-Stratified Petersen Estimate of Inriver Abundance

Size-stratified estimates combine separate Petersen estimates for small and large fish, to correct for the observed differences in size distribution between fish tagged at the fish wheels and fish harvested in the Canadian Commercial fishery. The cut-off points used to split the tag data into small and large fish determines sample sizes and recovery proportions, and can affect the combined abundance estimate. Sec. 4.2 describes methods. Cut-off points at various percentiles of the size distribution of the Canadian Commercial catch were tested.

The top left panel shows the percentile (*p-level*) that resulted in the largest absolute difference between the size-stratified estimate and the pooled Petersen estimate. Corresponding differences between estimates were substantial in some years, with the largest absolute difference about 30,000 fish (~ 25%). Using the p-level with largest difference each year results in a long-term median difference of -9.5% (i.e size- stratified estimates are about 10% smaller than the pooled estimates).

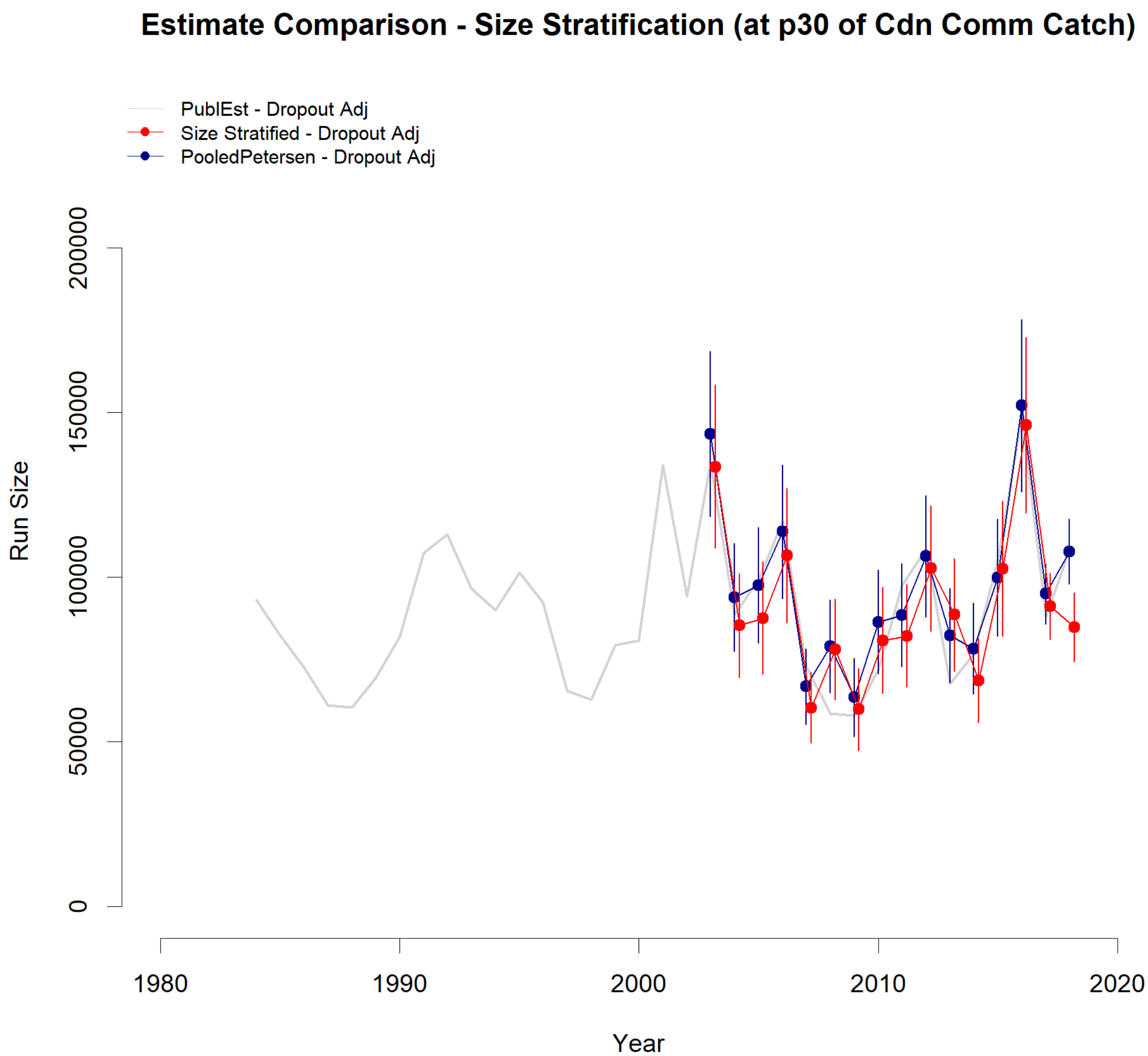


Figure 35 Comparison of Size-Stratified and Pooled Petersen Estimate of Inriver Abundance

This plot compares 3 alternative estimates of annual inriver abundance. Error bars show ± 2 SE. Previously published estimates are from the annual capture-recapture reports (e.g., Boyce and Andel 2014, TTC 2019a), and values are listed in Table 8. Sec. 4.2 describes the pooled Petersen estimate and the size-stratified estimates. All 3 estimates are adjusted for dropout, as described in Sec. 4.2.4.

Size-stratified estimates are only available for 2003-2018, because tag records could not be matched to size data for the earlier years. Size-stratified and pooled estimates match closely in most years, but the size-stratified estimate is consistently lower, and substantially lower in some years (2014, 2018).

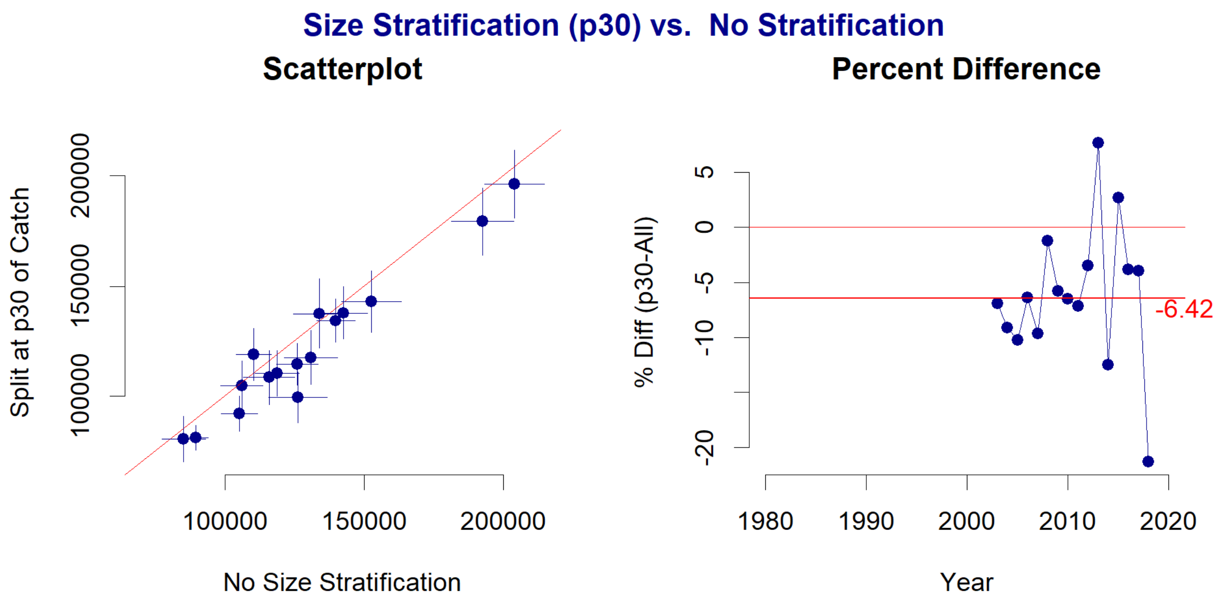


Figure 36 Pattern of Differences between Size-Stratified and Pooled Petersen Estimate of Inriver Abundance

Estimates as per Fig. 35.

There is a consistent bias, with the size-stratified estimate about 6.4% smaller on average. For some years, the difference is very pronounced (2014, 2018), and there is a recent general increase in both the magnitude and year-to-year inconsistency between the estimates.

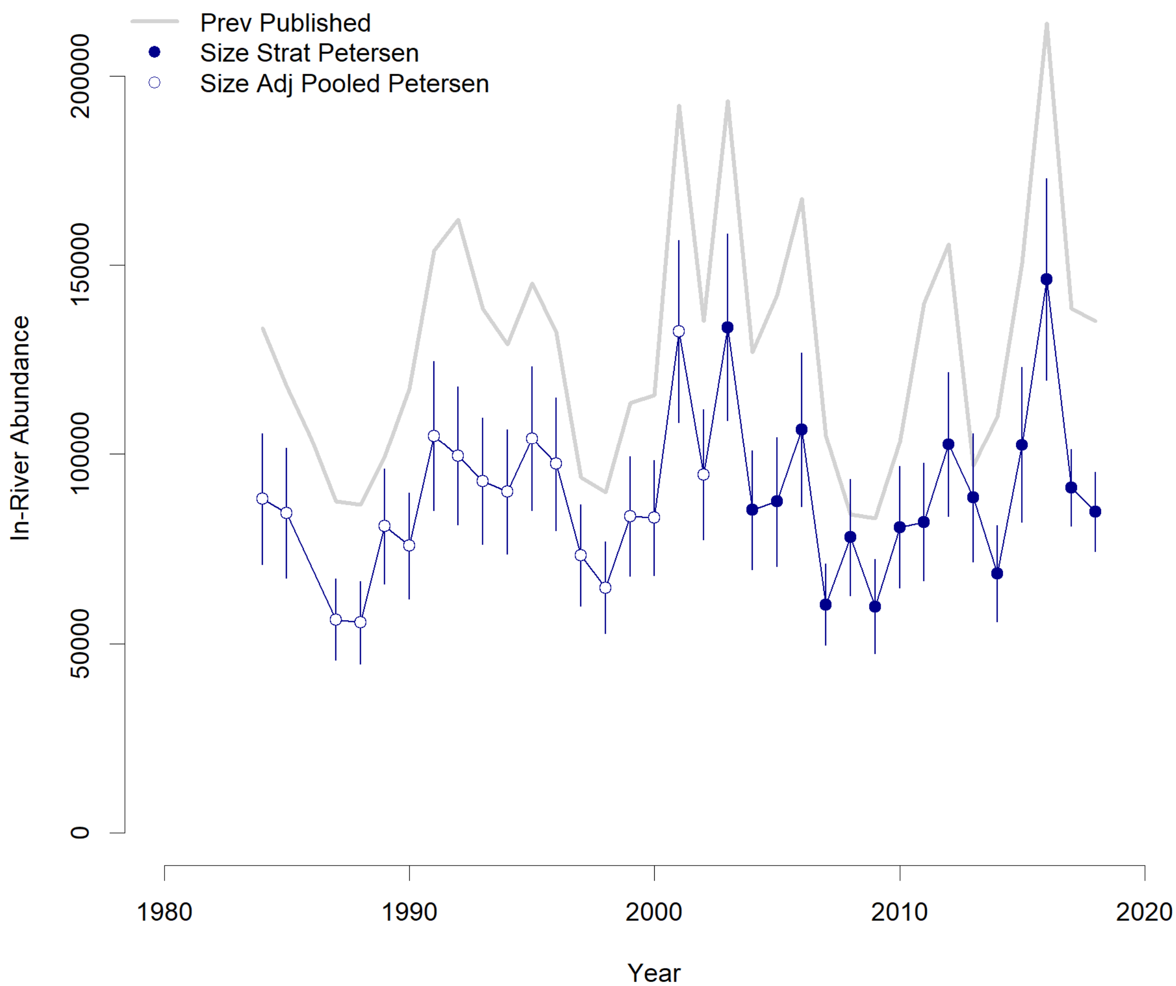


Figure 37 Comparison of Updated Estimates to Previously Published Estimates of Inriver Abundance

Previously published estimates are from the annual capture-recapture reports (e.g., Boyce and Andel 2014). Updated estimates are based on pooled Petersen estimate or size-stratified Petersen estimates, and include adjustments for dropout and size bias (see Sect. 4.4.2). Error bars show ± 2 SE. Table 8 lists the corresponding values.

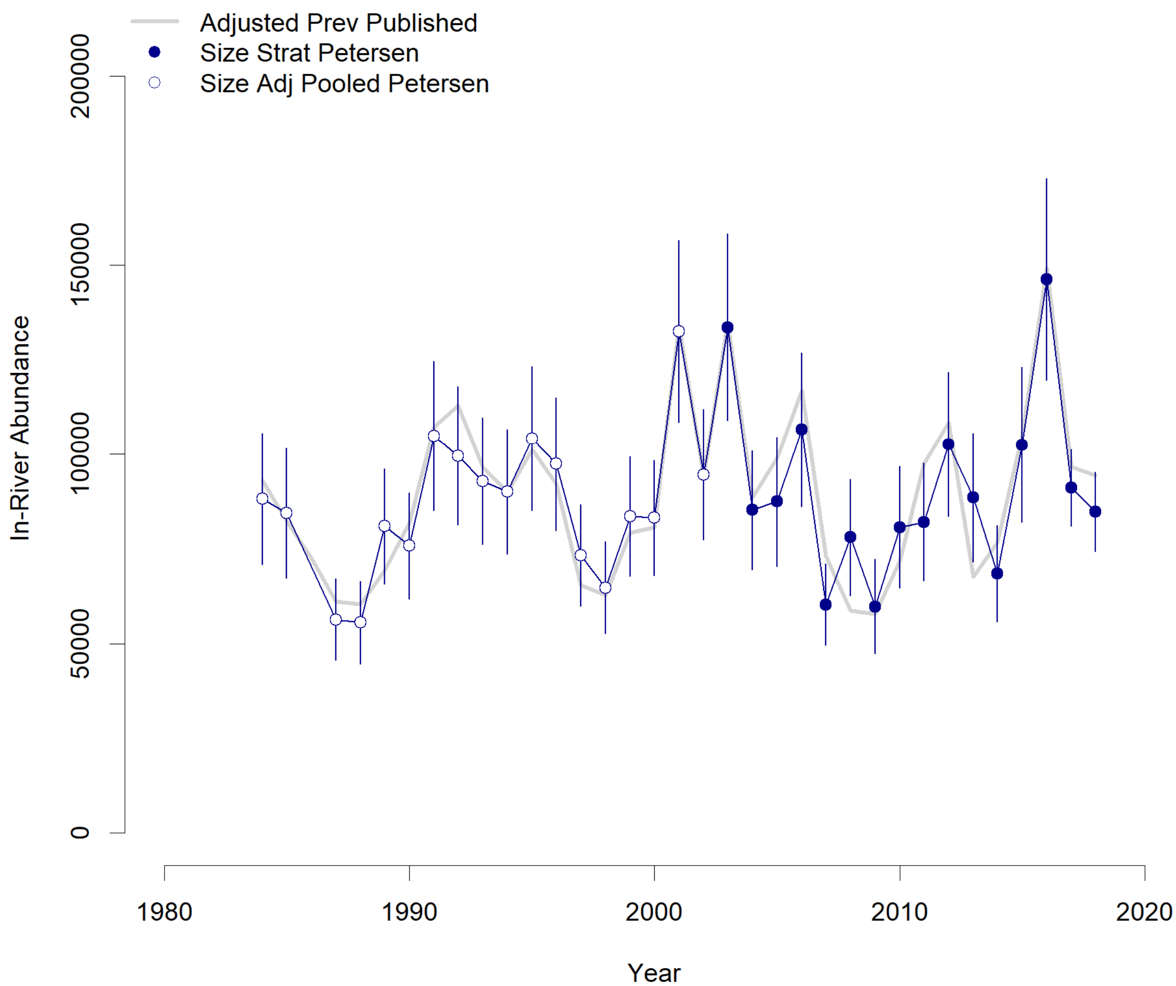


Figure 38 Comparison of Updated Estimates to Adjusted Previously Published Estimates of Inriver Abundance

Previously published estimates are from the annual capture-recapture reports (e.g., Boyce and Andel 2014). Updated estimates are based on pooled Petersen estimate or size-stratified Petersen estimates. All 3 estimates include adjustments for dropout and size bias (see Sect. 4.4.2). Error bars show ± 2 SE. Table 8 lists the corresponding values.

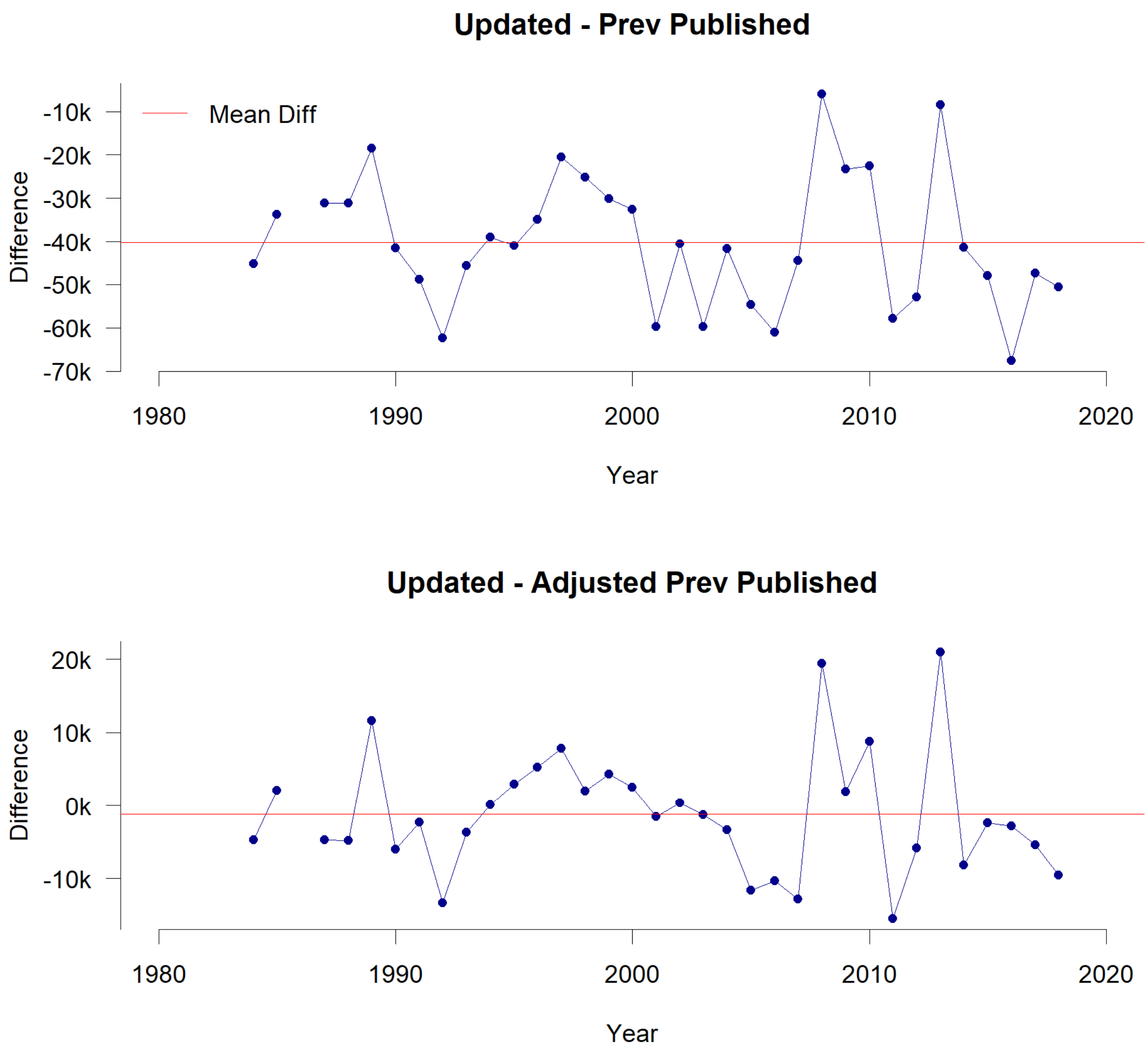


Figure 39 Difference Between Updated Estimates and Previously Published Estimates of Inriver Abundance

Estimate details as per Figures 37 and 38.

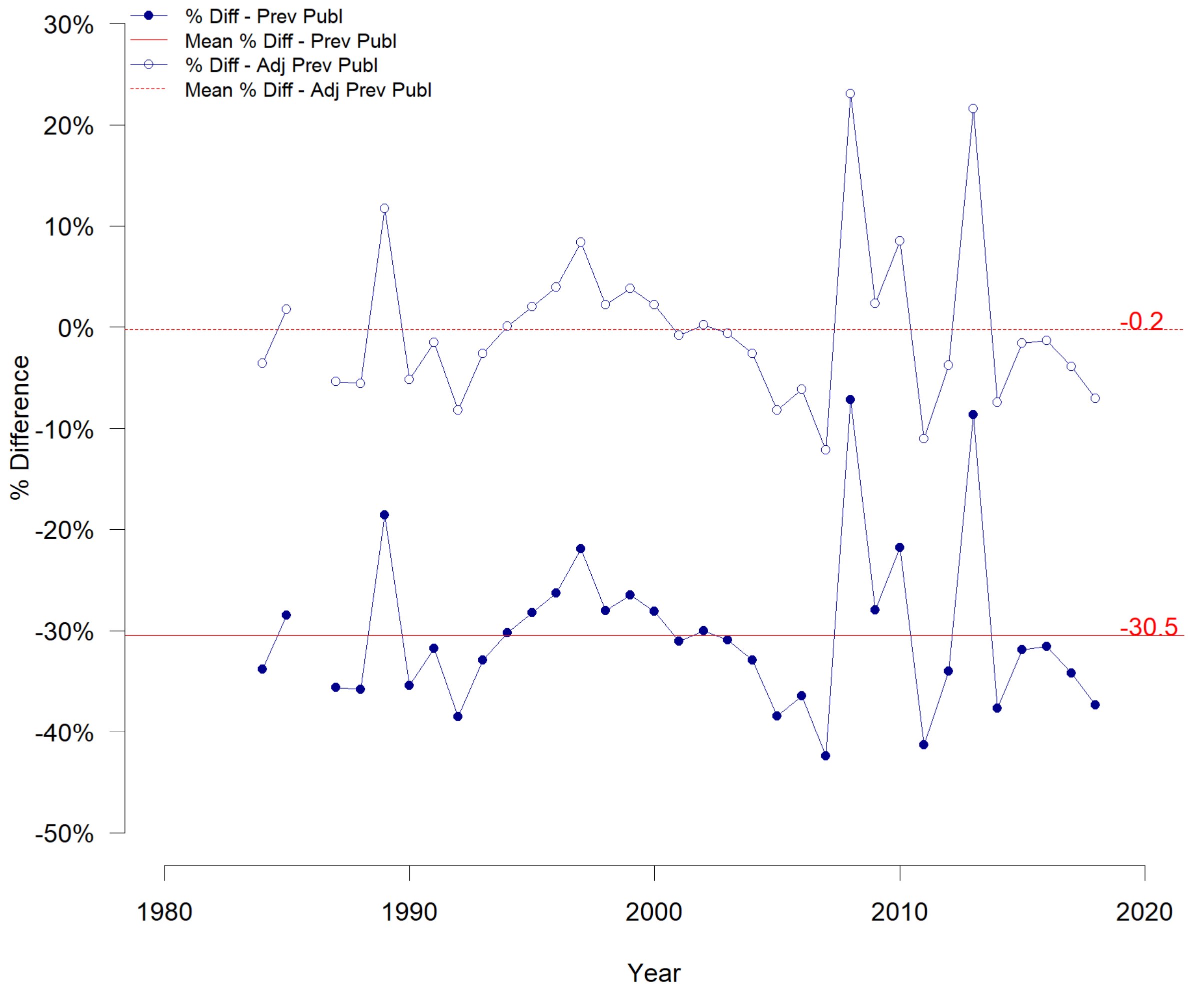


Figure 40 Percent Difference Between Updated Estimates and Previously Published Estimates of Inriver Abundance

Estimate details as per Figures 37 and 38.

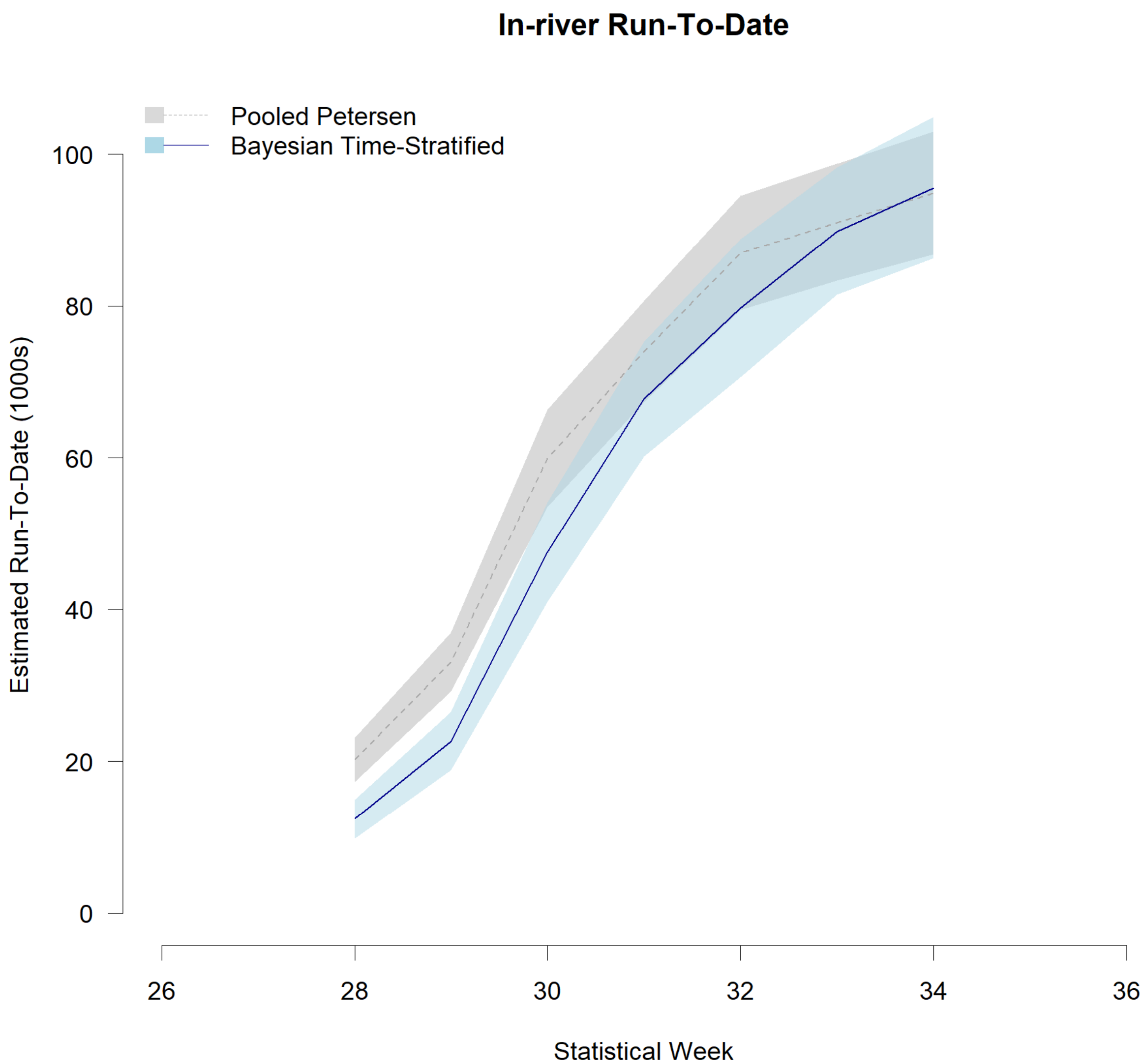


Figure 41 Weekly inseason estimates of inriver abundance for 2019

Inseason estimates are computed at the end of each statistical week using data from the start of the season. A pooled Petersen estimate and the Bayesian Time-Stratified (BTSPAS) estimate are shown. The pooled Petersen estimate will tend to have a positive bias because some fish released late in the week at the fishwheel will not have had time to migrate to the recapture event at the Canadian commercial fishery. By the end of the season, both estimates will converge.

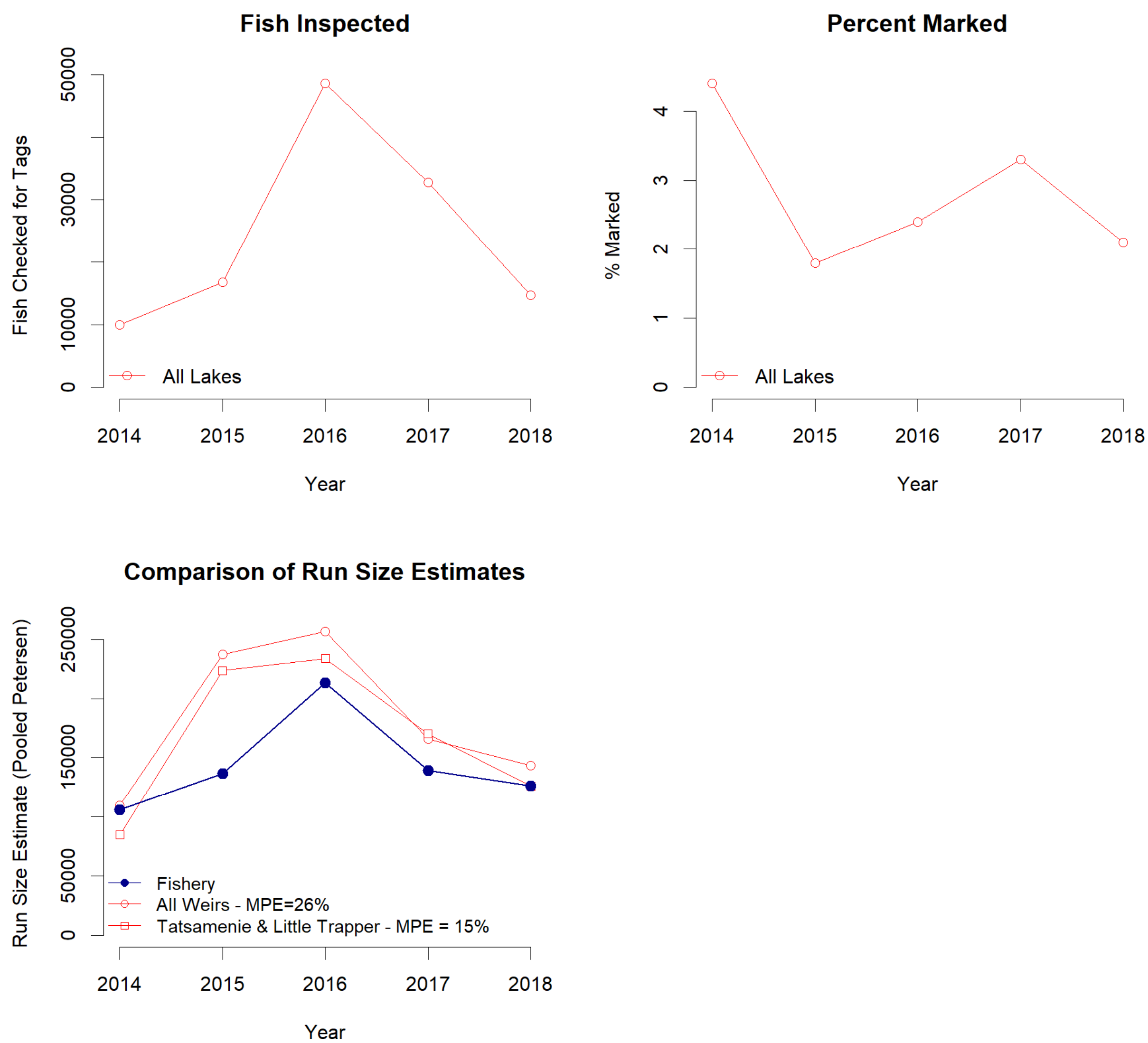


Figure 42 Diagnostics For Headwater Run Estimates

These plots present basic input data (fish inspected, percent marked) and results for pooled Petersen estimates at four headwater lakes, namely Kuthai, King Salmon, Little Trapper and Tatsamenie lakes from 2014 to 2018. The last plot also shows results for a sub-set of the lakes. The number of marks out was not adjusted by drop-out or size for either the fishery-based or headwater-based estimates.

Headwater-based estimates were very close to fishery-based capture-recapture estimates in 2014 and 2018. In other years they were higher by a moderate or substantial amount.

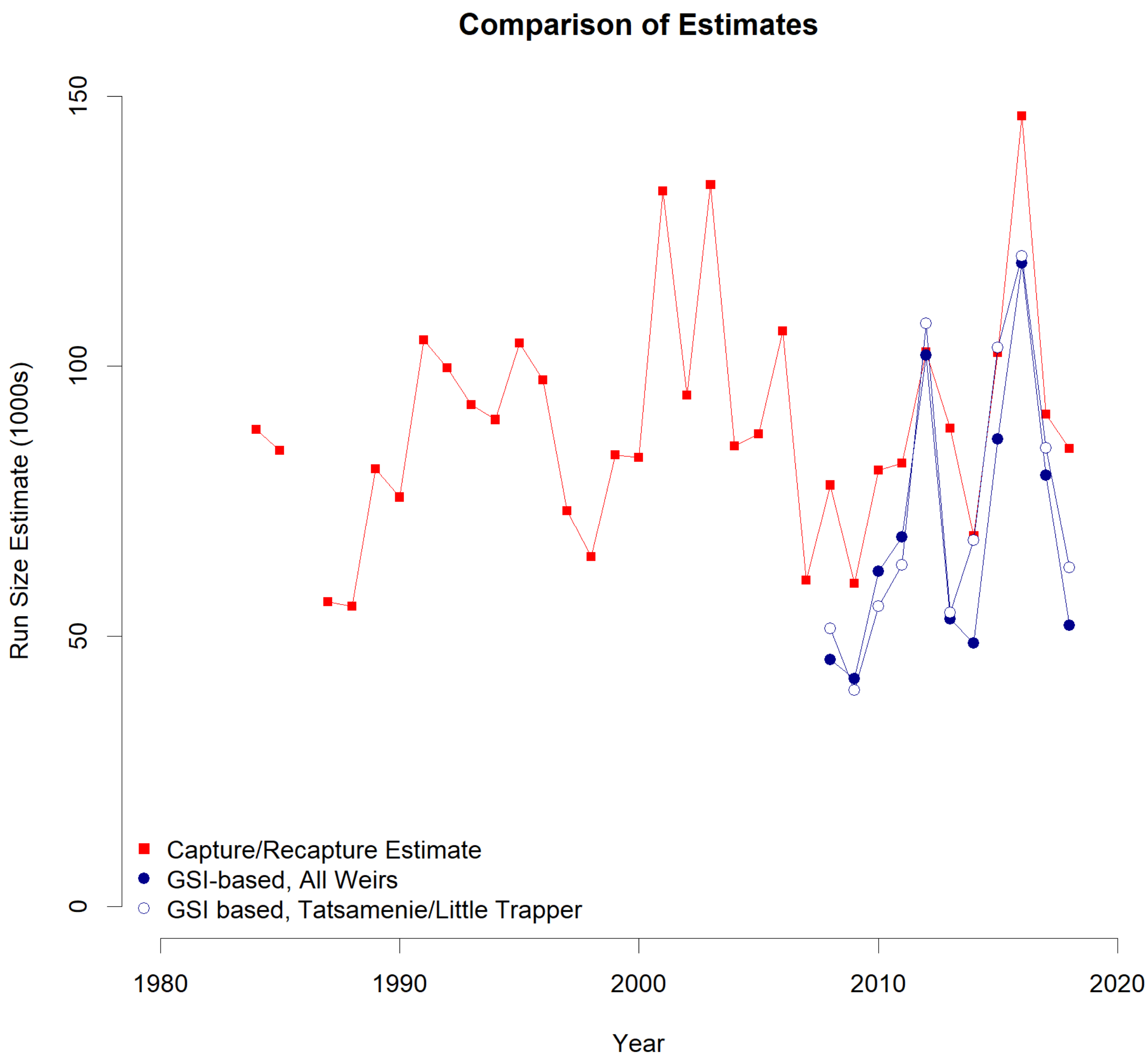


Figure 43 Comparison of Run Size Estimates based on Capture-Recapture vs. GSI

This plot compares 3 alternative estimates of annual inriver abundance. The capture/recapture estimates are the updated run size estimates based on various methods, as listed in Table 8. The genetic stock identification (GSI) based estimates are expansions of escapement estimates (weir counts) from either all 4 weirs or only Tatsamenie and Little Trapper weirs, using stock composition from the Canadian commercial fishery. Table 18 lists the values. Sec. 5.3 describes the methods.

GSI-based estimates tend to be lower than the capture-recapture estimates, and the two alternative GSI-based estimates can differ substantially from each other in some years.

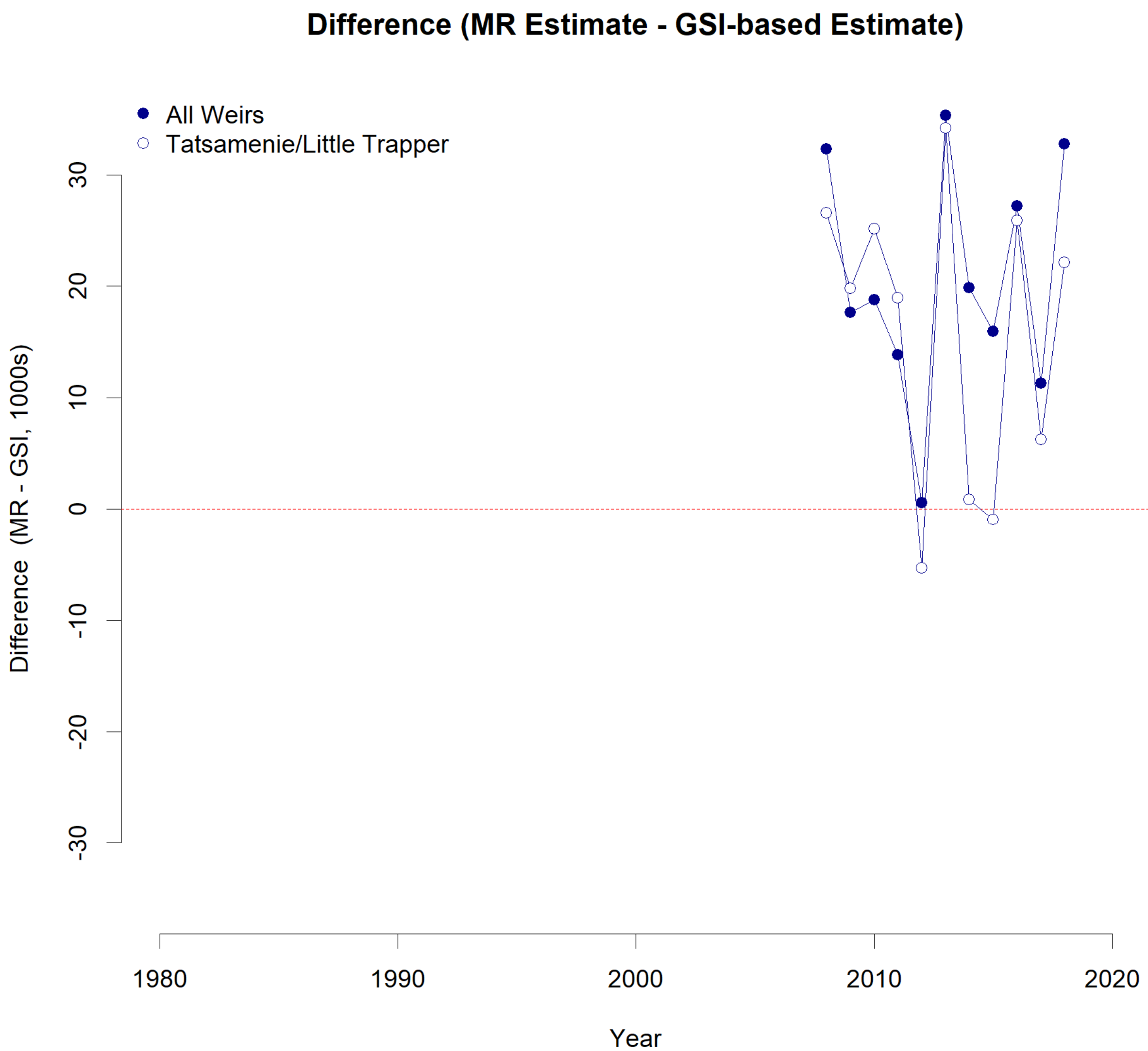


Figure 44 Difference between Run Size Estimates based on Mark-Recapture vs. GSI

Estimates as per Fig. 43.

For most years, the GSI-based estimates are 20-40% lower than the capture-recapture estimates, but in several years one or both GSI-based estimates match the capture-recapture estimates closely (2012, 2014, 2015, 2017).

11 Appendix 1: Custom Functions and Script Examples

11.1 Simple Petersen Estimate

Function from the *BTSPAS* package (Bonner and Schwarz 2020) that computes the Petersen estimator (Chapman correction applied) for the number of UNTAGGED animals given n1, m2, and u2. To find the estimate of abundance, you need to add back n1+u2 animals.

```
SimplePetersen <- function(n1, m2, u2){
    U.est <- (n1 + 1) * (u2 + 1)/(m2 + 1) - 1
    U.se <- sqrt((n1 + 1) * (m2 + u2 + 1) * (n1 - m2) * (u2)/(m2 +
        1)^2/(m2 + 2))
    N.est <- (n1 + 1) * (u2 + m2 + 1)/(m2 + 1) - 1
    N.se <- U.se
    data.frame(U.est = U.est, U.se = U.se, N.est = N.est, N.se = N.se,
        stringsAsFactors = FALSE)
    }
```

Vectorized wrapper function to generate a total estimate

```
SimplePetersenMod <- function(n1,m2,u2){
        unmarked <- SimplePetersen(n1,m2,u2)
        total <- unmarked
        total[,1] <- total[,1] + n1
        if(length(n1==1)){ out.obj <- c(n1=n1,m2=m2,u2=u2,
                                          round(unlist(total)) )}
        if(length(n1>=1)){ out.obj <- cbind(n1=n1,m2=m2,u2=u2,
                                         est=round(total$N.est),
                                         se=round(total$N.se)) }


        return(out.obj)
        }
```

Example

```
> SimplePetersenMod(c(200,400,NA), c(10,20,40), c(300,600,900))
      n1 m2  u2   est   se
[1,] 200 10 300  5682 1567
[2,] 400 20 600 11857 2419
[3,]  NA 40 900    NA   NA
```

11.2 Dropout Adjustment

Stand-alone implementation of the code from function *TimeStratPetersenNonDiagErrorNPMarkAvail_fit.R* in the *BTSPAS Extensions* (Schwarz 2019).

```
dropout.adj <- function(Abd,SE_Abd,tags_dropped, tags_total){

dr <- tags_dropped/tags_total
se_dr <- sqrt(dr*(1-dr)/tags_total)
Abd_adj <- Abd * (1-dr)
SE_Abd_Adj  <- sqrt(SE_Abd^2 * se_dr^2+
                     SE_Abd^2 * (1-dr)^2 +
                     Abd^2 * se_dr^2)

out.vec <- c(Abd_adj,SE_Abd_Adj)
names(out.vec) <- c("Abd_adj","SE_Abd_Adj")

return(out.vec)

}
```

Example

```
> test.out <- SimplePetersenMod(n1 = 2454, m2 = 266, u2 = 4985.2)
> test.out
       n1  m2     u2   est   se
[1,] 2454 266 4985.2 48292 2713
> dropout.adj(Abd=test.out[,"est"],SE_Abd =test.out[,"se"] ,tags_dropped =24,
tags_total = 118)
   Abd_adj SE_Abd_Adj
  38469.90    2807.68
```

11.3 Bayesian Time-Stratified Salmon Population Analysis Software (BTSPAS)

This project used the *BTSPAS* package (Bonner and Schwarz 2014) and custom extensions (Schwarz 2019). The following code loads all the required components.

```
# packages for loading other packages
require(RCurl)
require(devtools)

# check that the source is available
# (i.e., have internet connection and correct website)

url.check <- url.exists("https://raw.githubusercontent.com/cschwarz-stat-sfu-
ca/taku/master/FUNCTIONS_BTSPAS_Wrappers.R")

if(!url.check){warning("Verify URL for BTSPAS extensions");stop()}

if(url.check){

# load the custom extensions
devtools::source_url("https://raw.githubusercontent.com/cschwarz-stat-sfu-
ca/taku/master/FUNCTIONS_BTSPAS_Wrappers.R")

# get the BTSPAS package
devtools::install_github("cschwarz-stat-sfu-ca/BTSPAS", dependencies = TRUE,
                        build_vignettes = TRUE, force=TRUE)


# load BTSPAS, dependencies, and packages required for custom extensions
library(BTSPAS)
library(ggplot2)
library(plyr)
library(readxl)
library(tibble)
```

11.4 Data Cleaning Steps & Functions

Data cleaning used the following custom functions, which are document below:

- statweek.calc(): custom function that converts a text string with a date (e.g., "2017-06-22") into the corresponding statweek
- date.calc(): custom function that converts a year, stat week and day (e.g., year = 2017,week = 32, day = 5) into a text string with a date.
- .isleapyear(): custom function that checks if a year is a leap year. This is used in the functions above to adjust stat week conversion.
- weekdays(): base R function that converts a date to a weekday. This is used in statweek.calc() to get the day of the stat week. The stat weeks are set to start on Sunday. This function is also used to split the stat weeks into "half-weeks", with Sun-Wed = 1 and Thu-Sat = 2 (e.g., Tue of week 27 is stored as 27_1 in the "halfweek"" data field.)
- fixDate(): custom function that takes any dates in a format the other functions don't recognize (i.e., "9/24/2010") and converts it to the corresponding text string (i.e., "2010-09-24")
- extractYear(): custom function to extract a numeric year value from a text string with a date (e.g., "2010-09-24" -> 2010)

Cleaning of all records included the following steps:

- convert blanks and NA text strings to NA values.
- treat any 0 or 99 values as valid numbers
- fix all date formats to YYYY-MM-DD using *fixDate()*

Cleaning of the recovery records also included the following:

- change to NA any end dates that were "0:00" and now show up as "1900-01-00" or that were "-" or "U"
- change to NA any end dates that are earlier than the start dates
- change to NA any date values that are not in the "year" of the earlier column (i.e., if "year" and date disagree, then keep the year and drop the date)
- change any end date that's NA to be the day after the start date
- where dates are not available, but a stat week and day are included, calculate Start.Date and End.Date using *date.calc()*
- calculate recovery date as the mid-point between Start.Date and End.Date where they are both available

Record merging then went through the following sequence:

- extract all the unique Year_Tag values from all the inputs
- for each Year_Tag:
- count the number of appearances in each data file
- flag valid releases as any record that shows up exactly once (no duplicates) in 1 or more of the release files and has 5 or 6 digits in the tag ID number.
- flag valid recoveries as any record that is a valid release and shows up in the recoveries file exactly once.
- extract matching supplemental data from other source files (e.g., age, size, length, radio tag data)
- flag for review any records where sources disagree (e.g., size differs between recovery file and radio tag file)
- resolve merge conflicts based on priority rules for each variable (e.g., in case of size mismatches, use post-season release data over recoveries data)

```
# Stat week calculation are using this :
# https://stackoverflow.com/questions/17286983/
#     calculate-statistical-week-starting-1st-january-as-used-in-fisheries-
data

ufmt <- function(x) as.numeric(format(as.Date(x), "%U"))

statweek.calc <- function(date.in){
# date.in is text string (or vector of strings) in date format (e.g., "2013-
01-02")
  date.use <- as.Date(date.in)
  stat.week <- ufmt(date.use) - ufmt(cut(date.use , "year")) + 1
  return(stat.week)
  }


.isleapyear <- function(year){
  # http://rss.acs.unt.edu/Rdoc/library/fame/html/isLeapYear.html
  ifelse(year%%4 == 0 & (year%%100 != 0 | year%%400 == 0),TRUE,FALSE)
}


date.calc <- function(year,week,day){
# year , week, and day are numerical values (or vectors of equal length)
# for example: year = 2012, week = 26, day = 4
# the function then calculates the date for the 4th day of the 26th stat week
in 2012

if( length(unique(c(length(year) ,length(week),length(day))))>1){warning("all
inputs must have same length!");stop()}

date.out <- rep(NA,length(year))

for(i in 1:length(year)){

    all.dates <- seq(as.Date(paste0(year[i],"-01-01")),
as.Date(paste0(year[i],"-12-31")), by = "day")      #produce all days of the
year
    all.weekdays <- weekdays(all.dates)
    sun.flag <- all.weekdays == "Sunday"

    if(sun.flag[1]){ adj.value <- 0 }
              # if Jan 1 is a Sunday, then that day starts stat week 1
    if(!sun.flag[1]){  adj.value <- 1  }
              # if Jan 1 is NOT a Sunday, then the first Sunday is the start
of stat week 2

    sun.vec <- all.dates[sun.flag]
```

```
    wk.vec <- (1:length(sun.vec)) + adj.value

    if(!is.na(week[i])){
                date.calc.out<- as.character(as.Date(sun.vec[wk.vec ==
week[i]] + day[i]-1 ) )
                      # need -1 because Sun is already 1

                # don't need this anymore, because checking for NA above
                if(length(date.calc.out)==1) {date.out[i] <-
date.calc.out}
                if(length(date.calc.out)!=1)     {print("---------
");print(year[i]);print(week[i]);print(day[i]);print(date.calc);stop()}
            }

    if(is.na(week[i])){date.out[i] <- NA}
    }
  return(date.out)
}


fixDate <- function(x){
# x is a vector with various text strings,
# some in proper date format like "2010-09-24" , others in
# unrecognizable format like "9/24/2010"
# this function finds and fixes the unrecognizable ones
    fix.idx <- grepl("/",x)
    x.out <- x
    x.out[fix.idx] <- as.character(as.Date(x.out[fix.idx],format = "%m/%d/%Y"
))

        # need to convert to character, else get number output instead of
date
        # https://stackoverflow.com/questions/39458989/
        #           why-is-as-date-is-being-returned-as-type-double
    return(x.out)
}

extractYear <- function(x){
# x is a vector with text strings of standard date format like "2010-09-25"
    x.out <- as.numeric(format(as.Date(x, format="%Y-%m-%d"),"%Y"))
    return(x.out)
    }


# Worked Examples
statweek.calc(date.in="2016-08-17")
date.calc(year=2016,week=34,day=4)
fixDate(c("7/29/2003","9/20/2003","9/21/2003" ))
extractYear(c("2003-08-10","2003-08-11","2003-08-12"))
```

11.5 Expansion of GSI-Based Stock Proportions

Replicating Gazey (2010) GSI Worksheet (As Adapted by DFO StAd)

```
estimateRun.GSI <- function(weekly.table, totals.list,
                      settings=list(EffSampleCoeffA=0.5,EffSampleCoeffB=0)){

# weekly.table has 1 row for each stat week (or stat week agg) and
# columns with run weights, prop lake type etc)
# totals.list has elements for NumLakeTypeAboveFishery, FSCCatch, TestCatch


out.table <- weekly.table

# add standardized run weights
out.table <- cbind(out.table,
              RunWeight.Std = out.table$RunWeight/sum(out.table$RunWeight))

# Calculate total escapement above Cdn fishery and total Cdn comm catch
# crossprod() in R is the equivalent to sumproduct in Excel
out.list <- c(totals.list,list(EscAboveCdnFishery =  as.vector(
totals.list$NumLakeTypeAboveFishery /
crossprod(out.table$PropLakeTypeCdnComm, out.table$RunWeight.Std) )))
out.list <- c(out.list,list(CdnCommCatch =  sum(out.table$CdnCommCatch)))

# Calculate Escapement above Cdn fishery by week
out.table <- cbind(out.table,EscAboveCdnFishery = out.list$EscAboveCdnFishery
* out.table$RunWeight.Std)

# Calculate Effective Sample
out.table <- cbind(out.table,EffectiveSample =
out.table$ProcessedDNASamplesCdnComm * (settings$EffSampleCoeffA +
out.table$PropLakeTypeCdnComm * settings$EffSampleCoeffB)  )

# Calculate SE for the weekly proportion
out.table <- cbind(out.table,SDProp =  NA)
eff.sample.idx <- out.table$EffectiveSample  > 0
out.table[eff.sample.idx,"SDProp"] <-  sqrt(
out.table[eff.sample.idx,"PropLakeTypeCdnComm"] * (1-
out.table[eff.sample.idx,"PropLakeTypeCdnComm"]) /
out.table[eff.sample.idx,"EffectiveSample"])
out.table[!eff.sample.idx,"SDProp"] <- 0

# Calculate weighted SE for the weekly proportion
out.table <- cbind(out.table,SDPropWt =  out.table$SDProp *
out.table$RunWeight.Std )
```

```
# calculate total weighted SE for the proportion and for the total escapement
sd.prop.wt <- sqrt(sum(out.table$SDPropWt^2))
sd.esc <- as.vector(out.list$EscAboveCdnFishery * sd.prop.wt  /
crossprod(out.table$PropLakeTypeCdnComm, out.table$RunWeight.Std) )
out.list <- c(out.list,list(SDEsc = sd.esc))

# calculate weekly SE
out.table <- cbind(out.table,SDEsc =  out.table$RunWeight.Std * sd.esc )

# calculate confidence intervals for escapement
probs.use <- c(0.05,0.1,0.25,0.5,0.75,0.9,0.95)
esc.ci <- qnorm(probs.use , mean = out.list$EscAboveCdnFishery, sd = sd.esc)
names(esc.ci) <- paste("p",probs.use * 100,sep="")
out.list <- c(out.list,list(EscCI = esc.ci))


# calculate run size
run.out <- out.list$EscAboveCdnFishery +  out.list$CdnCommCatch +
out.list$FSCCatch + out.list$TestCatch
run.out

run.out.ci <- esc.ci +  out.list$CdnCommCatch + out.list$FSCCatch +
out.list$TestCatch
out.list <- c(out.list,list(RunCI = run.out.ci))


# calculate Cdn harvest rate
out.table <- cbind(out.table,HRCdnComm = out.table$CdnCommCatch /
(out.table$CdnCommCatch+out.table$EscAboveCdnFishery))


# create output object
out.obj <- list(Run.GSI = run.out,Totals = out.list, Weekly = out.table)

return(out.obj)
} # end function estimateRun.GSI()
```

12 Appendix 2: Expert Reviews

12.1 Review by Robert Clark

Scientific Review of the Taku River Sockeye Salmon Assessment Program for Canadian-origin Taku River Sockeye Salmon

Presented to the Pacific Salmon Commission, Transboundary Rivers Panel
January 14, 2020
by

Mr. Robert A. Clark, Consulting Fisheries Scientist
149 Beverly Drive, Sagle ID 83860

Background

As part of the 2019 renegotiated Pacific Salmon Treaty, Transboundary Rivers (TBR) Chapter 1, Parties to the Transboundary Rivers Panel (Panel) specified that an expert review of the Taku River sockeye salmon assessment program be conducted prior to the 2020 fishing season. In addition, they specified that a maximum sustainable yield (MSY) goal be developed for Canadian-origin Taku River sockeye salmon and submitted for review and potential bilateral approval prior to the 2020 fishing season. Specifically, paragraphs 3(b)(i)B and 3(b) (i)C of Chapter 1 state:

> (B) The Parties shall develop a joint technical report and submit it through the Parties' respective review mechanisms with the aim of establishing a bilaterally approved maximum sustainable yield (MSY) goal for Taku River sockeye salmon prior to the 2020 fishing season.
>
> (C) The Taku River sockeye salmon assessment program will be reviewed by two experts (one selected by each Party) in mark recovery estimation techniques. The Parties shall instruct these experts to make a joint recommendation to the Parties concerning improvements to the existing program including how to address inherent mark-recovery assumptions with an aim to minimize potential bias prior to the 2020 fishing season.

In February of 2018, I was asked by the U.S. TBR Panel Chair to review the Taku River sockeye salmon assessment program and the MSY goal as the U.S. expert. As part of my review and as a current member of the Transboundary Technical Committee, I participated in most of the Taku Sockeye Working Group meetings on these topics. This report is a summary of my findings and recommendations. Given the nature of the stock assessment review and its relevance to development of the MSY goal, I present my findings and recommendations of the stock assessment review first.

Mark-Recapture (M-R) Review Summary

- The Taku Sockeye Working Group developed and implemented reasonable methods of run reconstruction using available stock assessment data from 1984 to the present. **I recommend that the "revised" historic run reconstructed values be used to develop an escapement goal and methods of adjustment to M-R abundance estimates should continue into the future.** I agree with recommendations made by the Taku Sockeye Working Group on estimation of dropout rate as well as adjustments to abundance due to dropout, use of weighted age compositions, choice of M-R model, and the effect of size selectivity on abundance estimates. The Taku Sockeye Working Group did an excellent job of examining M-R data to assess the validity of assumptions necessary for accurate estimation of abundance.
- Methods of stock assessment and analysis should continue to be refined as more information concerning assumptions used in the historic run reconstruction becomes available, such as:

    - fishwheel-related dropout rate and improvements in fish handling at the fishwheels during the M-R experiment,
    - size selectivity induced during M-R experiment, and
    - time varying capture probabilities and/or catchability induced during the M-R experiment.
- I recommend that the stock assessment continue to consider use of time stratified estimates in the annual run reconstruction if large differences between BTSPAS timestratified and pooled estimates are apparent (e.g., point estimates differ by 10% or more and both estimates are reasonably precise).
- I also recommend that the stock assessment use size-stratified estimates of abundance when large differences in estimated abundances are found (e.g., point estimates differ by 10% or more and both estimates are reasonably precise). In terms of where to break the M-R data into strata, I suggest that stock assessments utilize a Kolmogorov-Smirnov test to determine the size of the optimum stratum break (i.e., maximizes between stratum differences in capture probability) instead of using a fixed 30th percentile as was done in the historic run reconstruction.
- As reported by the Taku Sockeye Working Group, the radiotelemetry-based estimate of fishwheel dropout rate is moderately variable between years and this was a major source of uncertainty in the annually reconstructed abundances. I recommend that 2-3 additional years of radio-telemetry be conducted to further refine variability in dropout rate, with the potential of revising the dropout rate as necessary.
- I also recommend that stock assessment continue to use the revised (in 2018) method of handling fish to be marked at the fishwheels as well as conducting side experiments to further refine the estimate of historic (prior to 2018) dropout rate.
- Although primarily relevant to the spawner-recruitment analysis, I recommend that stock assessment attempt to refine estimates of earliest years (1980- 1983 and 1986) of the run reconstruction by examining additional sources of available stock assessment and fishery information, including information from the Stikine River sockeye salmon stocks assessment program.

12.2 Review by Dr. Carl Schwarz

Scientific Review of the Taku River Sockeye Salmon Assessment Program for Canadian-origin Taku River Sockeye Salmon

Carl James Schwarz
StatMathComp Consulting
Professor Emeritus Simon Fraser University

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Introduction

Since February of 2018, I have been a member of a Transboundary Technical Committee tasked to review the Taku River sockeye salmon assessment program and the MSY goal. I participated in most of the Taku Sockeye Working Group meetings on these topics. This report is a review of the findings and recommendations.

This Taku Sockeye Working Group first created a run-reconstruction using existing data from 1984 to the present based mostly on capture-recapture data (Paper 1 in prep). This data was then used in a spawner-recruit model to estimate MSY (DFO 2019, Paper 2).

In the rest of the document, **a number of suggestions for future work are made in bold.**

Capture-Recapture Methods Review (Paper 1)

The Taku Sockeye Working Group created a run reconstruction using available stock assessment data from 1984 to the present. This group very carefully assessed the data and methods used to develop run estimates.

Capture-recapture data since program inception in 1984 was compiled, cross-verified, and subjected to a battery of tests to identify sources of potential bias and compare different estimation approaches.

Section 2 of the paper describes how capture-recapture data from 1984 to the present was collected from a number of sources and extensive quality control was applied to obtain an up-to-date dataset. This appears to be carefully done and the "cleaned" data will be valuable for future updates.

Post-Season estimation

As noted in the document (Paper 1, Section 4.1), there are a number of critical assumptions that must be satisfied to ensure that estimates of abundance are unbiased. For this study the two key assumptions are homogeneity of capture probabilities among fish and no drop-out of tagged fish.

Heterogeneity in capture-probabilities could be related to temporal artefacts of the study (fish wheel does not tag fish with a constant probability and/or harvest does not operate continuously). The report computed estimates with three levels of temporal stratification

- Half-week stratification to account for periods where the harvest is not operating;
- Weekly stratification to account for heterogeneity in tag application probabilities (e.g. due to fishwheel saturation) and recovery probabilities (harvest gear saturation);
- No stratification (Pooled Petersen estimators)

The report showed that the estimates are all very similar (Paper 1, Figures 29 and 30) with no consistent difference and so it was decided that temporal stratification will not be needed. I suspect this is because the fish wheel is tagging at a near constant probability which implies that the pooled-Petersen will be unbiased. **Consequently, changes to the fish wheel operations in the future should be reviewed carefully to ensure that this continues**.

Size-based heterogeneity was investigated by creating a small/large fish size category using different size cutoffs (based on percentiles of the fish length distribution). This analysis showed a consistent bias except for two years (Paper 1, Figures 31 to 33). **The reasons why the bias was quite different for these two years is unknown, and bears further investigation**. Based on this analysis, the Pooled-Petersen estimate for years where individual length data is not available are reduced by a fixed percentage (but no additional adjustment to the uncertainty is made for the uncertainty of this percentage reduction). **This analysis can be extended by using the actual length of the fish as a individual-covariate (rather than stratifying into two size categories) to investigate the general shape of the selectivity curve using methods proposed by Huggins (1989) to see if this related to effects of harvest gear or fish wheel effects.**

Drop-out effects are large but not well estimated. There are only a small number of years where radio-tagged fish were released and followed (Paper 1, Section 2.3.6) and estimates of year-specific drop-out probability are available. For other years, a synthetic-estimate that incorporates year-to-year variation in the drop-out probability and uncertainty in the estimated drop-out probability is used. Consequently, the uncertainty about the abundance estimate has been increased substantially. The effects of drop-out are substantial (Paper 1, Figures 34, 35, and 37). The high year-to-year variation in the drop-out probability is worrisome. Presumably fish wheel operations are fairly constant from year-to-year so the variation in the drop-out probability across years must be related to environmental factors such as flow which is not under control of the survey. Similarly, it is not clear if the drop-out probability is equal across weeks within a year. **A carefully designed, long-term study would be needed to understand the drop-out process and to provide year-specific estimates of dropout for the future and to see if dropout is homogeneous within a season.**

The report mentions adjustments to the data to account for the fish wheel starting late or the run extending past the end of the harvest (Paper 1, Section 4.2.2) or to force the run curve to go to 0 at the start and end of the season (Paper 1, Table 5). **This is a useful "trick" and should be added to the BTSPAS documentation so that future users have a reference and example**.[1] It is not possible to adjust the pooled-Petersen estimates in a similar fashion.

<u>Alternate estimates</u>

Two alternate estimators are briefly discussed.

First is a pooled-Petersen estimator based on weir counts (Paper 1, Section 5; Headwater estimates). If the assumption that the fish wheel is tagging at an approximately equal proportion over the run is satisfied, then any sampling upstream (e.g. weir sampling) can be used to estimate total abundance. Figure 39 (Paper 1) showed that Headwater estimates are consistently larger than the fishery- based estimator, but no adjustment for drop out or size stratification has yet to be applied. This likely will bring the estimates into closer alignment. It is not necessary to make adjustments for in-river harvest, but it will be necessary to make adjustments for tag-loss given the larger distance that the fish must swim.

This (drop-out and size-bias adjusted) method should be continued as a cross-check on the in-river harvest estimator.

A combined estimator could be developed that would incorporate the weir data with the harvest data, but given the already very good precision from the harvest data, this is a low priority item.

Second is a reverse-time capture-recapture estimator based on genetic stock ID and a method developed by Gazey (2010). ADFG (unpublished document) reviewed the method of Gazey (2010) and noted some critical assumptions that must be made. As well, the statistical basis for the estimator needs to be more fully developed and estimates of uncertainty are needed.

Again, this is lower priority item for development.

[1] This section was written by myself and during the review I realized that better documentation is needed. It is on my list for the next update to BTSPAS.

Inseason estimation

Section 6 of Paper 1 describes in-season estimation methods using the Bayesian time-stratified estimator and the pooled-Petersen estimator (Paper 1, Figure 38). It was noticed that the pooled-Petersen estimate tended to be larger than the time-stratified estimate and this artefact is attributed to not all tags being available for capture (due to the distribution of travel times) by the harvest when the in-season estimates are computed leading to a positive bias in the pooled-Petersen estimator. Both methods converged to similar values by the end of the season (as expected). The report briefly mentions some issues with small sample sizes in the early weeks that made it difficult to use time-stratified estimators.

The methodology is appropriate, but the reported uncertainty is likely an underestimate because the critical assumption of homogenous drop-out probability across the season has not been investigated in enough detail. This again suggests that a long-term study to investigate drop-out is needed.

References

Huggins, R. M. (1989). On the Statistical Analysis of Capture Experiments. *Biometrika* 76, 133–40. https://doi.org/10.1093/biomet/76.1.133.

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