Stikine Sockeye Salmon Management Model: Improving Management Uncertainty

S.E. Miller
J.A. Bednarski

June 2017

**Pacific Salmon Commission
Technical Report No. 38**

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

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For

Pacific Salmon Commission
Joint Transboundary Technical Committee

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Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the report. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$log_{2,}$ etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

TABLE OF CONTENTS

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF APPENDICES

Appendix **Page**

ABSTRACT

Salmon fisheries that harvest Stikine River sockeye salmon, *Oncorhynchus nerka,* in marine waters in Southeast Alaska Districts 106 and 108 and in inriver Canadian fisheries are managed under the Pacific Salmon Treaty. Under this plan, the total allowable catch (TAC) of both natural and enhanced sockeye salmon is currently allocated 50/50 between the countries. The Treaty also dictates that inseason estimates of TAC shall be made using an inseason forecast model developed by the Transboundary Technical Committee, and fishing regimes by both countries shall be based on those estimates. The Stikine Management Model (historical-SMM) has been the agreed to inseason forecast model since about the late 1980s/early 1990s and has been used annually through 2016. Using the historical-SMM as the base model, we developed new inseason prediction models to estimate the terminal run size of sockeye salmon stocks returning to the Stikine River. Model development occurred in two parts: (1) initial model development of terminal and inriver run size models using historical data through 2011, model comparison using Akaike Information Criterion, and managers' preferences, and (2) model testing with inseason data. The percent error is the difference between the inseason estimate of run size and the 'true' postseason, run reconstruction, estimate of run size. Performance of the models was evaluated based on the mean percent error (MPE) and the mean absolute percent error (MAPE). Based on the results of the MPE and MAPE, the preseason forecast of the Tahltan stock was used as a guide for the abundance levels of the terminal Stikine and Tahltan stocks, and a decision tree was created for the managers. The decision tree gives recommended management models based on season (statistical week 26, early, late), stock (terminal Stikine, Tahltan) and relative abundance levels (low, high, average) for inseason management.

Key words: management model, sockeye salmon, Tahltan Lake, Stikine River, Pacific Salmon Treaty, *Oncorhynchus nerka,* decision tree, mean percent error, mean absolute percent error, AICc

INTRODUCTION

Salmon fisheries that harvest Stikine River sockeye salmon, *Oncorhynchus nerka,* in U.S. marine waters of Districts 106 and 108 and in the inriver Canadian fisheries are managed under the Pacific Salmon Treaty (PST) Annex IV, Chapter 1, and the Appendix to Annex IV, Chapter 1 entitled "Understanding on the Joint Enhancement of Transboundary River Sockeye Stocks." Under the terms of the Treaty, total allowable catch (TAC) of both natural and enhanced sockeye salmon is currently allocated 50/50 between the Parties. The Treaty also dictates that inseason estimates of TAC shall be made using an inseason forecast model developed by the Transboundary Technical Committee and fishing regimes by both countries shall be based on those estimates (paragraph 3(a)(1)(i)(b)).

The Stikine Management Model (historical-SMM) was developed in the late 1980s and has been the agreed to inseason forecast model through 2016. The historical-SMM model is based on lower inriver cumulative CPUE and historical run timing. A description of the original historical-SMM is given in the *Transboundary Technical Committee Report: TCTR (88)-2, Salmon Management Plan for the Transboundary Rivers, 1988*. Many subtle changes have been made in the model since the 1988 technical report was written and a new documentation is in progress. The purpose of the model is to aid managers in making weekly harvest decisions to meet Treaty obligations for harvest sharing and conservation of Stikine River sockeye salmon. Therefore, accurate and early inseason estimates of terminal and inriver run size are essential for ensuring Stikine River sockeye salmon escapement goals and harvest sharing obligations are met.

The inseason data sources available to evaluate Stikine River sockeye salmon run size include the U.S. commercial fishery harvest and catch per unit effort (CPUE) data, U.S. inriver subsistence fishery harvest, Canadian inriver commercial harvest, Canadian test fisheries' harvest, First Nation fisheries near Telegraph Creek and other inriver terminal fisheries, and stock composition data of all harvest (Pacific Salmon Commission Joint Transboundary Technical Committee, report TCTR (14)-2, 2014 and unpublished data).

The main goal of this study was to improve the Stikine management model by creating more accurate and earlier inseason estimates of the terminal Stikine River sockeye salmon run size. Managers were interested in models that used both harvest and CPUE data. Since some subdistricts may be closed or subject to a limited season due to a weaker run than forecasted, models used data from both U.S. Districts (106 and 108).

METHODS

The Stikine River is a transboundary river that originates in British Columbia and flows to the ocean near Wrangell, Alaska (Figure 1). For research, monitoring, and management purposes, the Stikine River sockeye salmon run is subdivided into four stock groups: 1) the wild Tahltan stock, which are those fish originating from naturally spawning sockeye salmon in Tahltan Lake; 2) the enhanced Tahltan stock, which are those fish originating from broodstock collected at Tahltan Lake and are subsequently stocked as fry into Tahltan Lake; 3) the Tuya stock, which are those fish originating from broodstock collected at Tahltan Lake and are subsequently stocked as fry into Tuya Lake; and 4) the mainstem stock, which are all other naturally spawning sockeye salmon populations in the Stikine River. The 'Tahltan stock' is comprised of the wild Tahltan and enhanced Tahltan stocks. The 'terminal Stikine River sockeye salmon stock' is comprised of the wild Tahltan, enhanced Tahltan, Tuya, and mainstem stocks.

During the first three to four weeks (statistical weeks 24–27) of the sockeye salmon fishery in the U.S., extended fishing time and midweek openings are based on the preseason forecasts, inseason-fishery harvest estimates, and stock proportion data. The preseason forecast model is a combination of a smolt forecast since 2007 for the Tahltan stock, a recent 5-year average age-specific fry-to-adult survival data for the Tuya stock, and a sibling-based and stock-recruitment prediction for the mainstem stock (Pacific Salmon Commission Joint Transboundary Technical Committee 15(1), 2015). For the remainder of the sockeye salmon season (statistical weeks 27–30), subsequent openings, extended fishing times, and midweek openings are based primarily on inseason estimates produced by the historical-SMM and other agreed upon methods (Pacific Salmon Commission Joint Transboundary Technical Committee, report TCTR (15)-1, 2015).

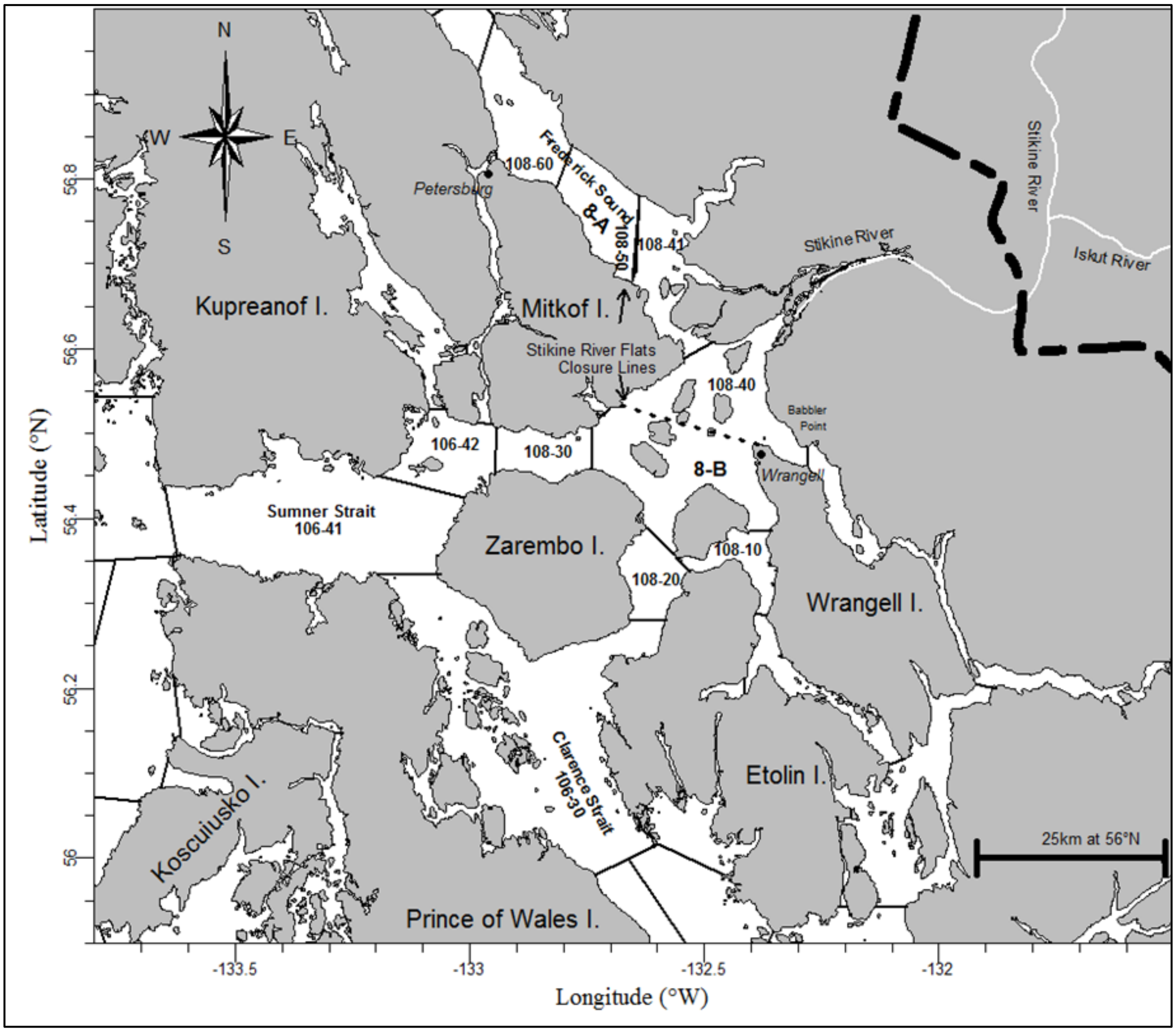

Figure 1. U.S. fishing areas adjacent to the Stikine River in Southeast Alaska. District 8-A includes Subdistricts 108-60, 108-50, and 108-41. District 8-B includes Subdistricts 108-30, 108-40, 108-20, and 108-10. District 108 sockeye salmon areas of higher abundance and consistent effort do not include Subdistricts 108-20 and 108-10 fishing areas or mid-week openings. The Stikine River flats closure line includes waters off the Stikine River west of a line from Babbler Point to Hour Point, north of the Wrangell Island shoreline from Hour Point to Point Highfield, north and east of a line from Point Highfield to the southern end of Liesnoi Island to the southern end of Greys Island to the small island near the eastern entrance of Blind Slough to the nearest point of Mitkof Island, and south and east of a line from the prominent point of Mitkof Island nearest Coney Island to the northern end of Coney Island to a point 500 yards north of Jap Creek on the mainland shore. The dark, dotted line is the U.S./Canadian border.

TERMINAL AND INRIVER RUN SIZE MODELS

Terminal run size is defined as harvests in marine areas inside the terminal Alaskan drift gillnet fisheries in Districts 106 and 108, and U.S. subsistence fishery harvest in the river, plus inriver run size. Inriver run size is defined as all inriver commercial, subsistence, First Nation, and test fishery harvest plus escapement to the spawning grounds along with any broodstock taken. Terminal and inriver run size models by stock (Tahltan stock, Tuya stock, or the terminal Stikine stock), on a natural log scale, were developed using historical cumulative marine and inriver harvest and CPUE data by statistical week, year, and stock (Pacific Salmon Commission Joint Transboundary Technical Committee, report TCTR (14)-2, 2014 and unpublished data) (Table 1). The dependent variable in the models was either terminal run size by stock or inriver run size by stock from 1985–2011, based on the postseason run reconstruction catch and effort tables for 2014 (unpublished data). For the inriver run size models, terminal run size was then based on the inriver run size prediction from the inriver run size model and historical run timing. For all stocks, data was only used up to year 2011 because stock identification methodology changed from postseason analysis using scales to genetics in 2012 (Pacific Salmon Commission Joint Transboundary Technical Committee, report TCTR (12)-1, 2012). Although the models incorporated data from multiple statistical weeks and years, terminal and inriver run size by stock were only enumerated annually.

Table 1. Summary of the data sources available for modeling terminal and inriver run size.

Data	Specifics
U.S. commercial fishery harvest and CPUE	Subdistrict 106-41/42 (Sumner Strait)
U.S. commercial fishery harvest and CPUE	Subdistrict 106-30 (Clarence Strait)
U.S. commercial fishery harvest and CPUE	District 108 (Section 8-A (Frederick Sound) and Section 8-B (Wrangell)
U.S. commercial fishery harvest and CPUE	District 108 sockeye salmon area[a]
U.S. inriver subsistence fishery harvest	
Canadian inriver commercial fisheries	lower river commercial fishery
Canadian inriver commercial fisheries	lower river commercial fishery near Flood Glacier
Canadian inriver commercial fisheries	upper river commercial fishery
Canadian lower river test fishery	
First Nation fisheries near Telegraph Creek	
other inriver terminal fisheries	Tuya test fishery
other inriver terminal fisheries	Excess Salmon to Spawning Requirements (ESSR)
Stock composition data of all harvest[b]	otolith thermal marks, genetics, scale pattern analysis, egg diameter

[a]District 108 sockeye salmon areas of higher abundance and consistent effort (does not include Subdistricts 108-20 and 108-10 fishing areas or mid-week openings).

[b]Stock composition data of enhanced Tahltan and Tuya sockeye salmon in U.S. harvests are based on otolith thermal marks. Inseason stock composition of wild Tahltan and mainstem sockeye salmon in U.S. harvests is based on historical data, while postseason stock composition is based on scale pattern analysis or genetic stock identification. Inseason stock composition of the inriver Canadian harvests is based on egg diameter and otolith thermal marks, while postseason composition is based on egg diameter, age, sex, and otolith analysis (Pacific Salmon Commission Joint Transboundary Technical Committee, report TCTR (15)-1, 2015).

The model dataset for the terminal Stikine and the Tahltan run size in the Subdistrict 106-41/42 fishery included postseason data from years 1985–2006 and 2008–2011 for statistical weeks 25–41. The model dataset for the terminal Stikine and the Tahltan run size in the District 108 fishery included postseason data from years 1986–2000 and 2004–2011 for statistical weeks 25–41. The years 2001–2003 were excluded because the fishery was open late in District 108 to conserve stocks. The model dataset for the Tuya terminal run size in the Subdistrict 106-41/42 fishery included postseason data from years 1995–2004, 2006, and 2008–2011 for statistical weeks 25–41. The model dataset for the Tuya terminal run size in the District 108 fishery included years 1995–2000, 2004, and 2006–2011 for statistical weeks 25–41. Based on the importance of the inseason statistical weeks, statistical weeks 25 and 37–41 were weighted 0.01, statistical weeks 26–31 were weighted 1.0, and statistical weeks 32–36 were weighted 0.25 for all model datasets.

The model dataset for the Stikine inriver run size and the Tahltan inriver run size included postseason data from years 1979–1983 and 1985–2011 for statistical weeks 26–41. The model dataset for the Tuya inriver run size included postseason data from years 1995–2011 and statistical weeks 26–41. Based on the importance of the inseason statistical weeks, statistical weeks 26 and 32–36 were weighted 0.25, statistical weeks 27–31 were weighted 1.0, and statistical weeks 37–41 were weighted 0.01 for all model datasets. The inriver run size models utilized various combinations of inriver historical cumulative harvest and CPUE data by stock (Tahltan stock, Tuya stock, or the terminal Stikine stock).

Model structures for the terminal and inriver run size models included interactions and second order polynomials. Model comparison and selection was based on the small-sample bias-corrected Akaike Information Criterion (AICc) (Akaike 1974; Hurvich and Tsai 1995; Burnham et al. 2011) and the needs of the managers. The AICc measure allows the comparison and rank of multiple competing models; the model with the lowest AICc value represents the 'best approximating' model or 'preferred' model. The 6 best prediction models along with the historical-SMM model, and the preseason forecast model were then tested by incorporating historical, weekly inseason data. Two methods, mean percent error (MPE) and mean absolute percent error (MAPE), were used to compare the 'true' postseason terminal run size with model estimates of inseason terminal run size for each model structure.

MODEL TESTING WITH INSEASON DATA

The terminal and inriver run size models (6 best prediction models, historical-SMM, preseason forecast) were tested by incorporating historical, weekly inseason data, from years 1996–1999, and 2005–2014, into the models. The historical inseason data included estimates of U.S. commercial harvest and CPUE data, weekly U.S. inriver subsistence harvest data, weekly inriver commercial (upper, lower, and flood) and test fishery harvest and CPUE data, inseason thermal otolith stock composition data for Tuya and enhanced Tahltan stocks, and weekly small egg diameter data for test years 1996–1999 and 2005–2014. The inseason data for test years 1996–1999, and 2005–2014 represented low, average, and high abundance years when both District 106 and District 108 were not subject to inseason closures or a protracted season (Figure 2). To determine if a run size was at a low, average, or high abundance level, the average postseason run size was calculated by stock from 1994–2014. A postseason run size that fell within ±10% of the average postseason run size from 1994–2014 was considered an 'average' abundance year. Run sizes that were above the +10% average postseason line or below the -10% average postseason line were the 'high' and 'low' abundance years respectively. Based on the postseason run size, years 1996–1997, 2005–2006, and 2011 were considered high abundance years, while years 1998–1999, 2008, 2010, 2012–2014 were low abundance years, and years 2007 and 2009 were average abundance years for the terminal Stikine stock (Figure 2). The average postseason run size for the terminal Stikine stock from 1994–2014 was 186,188 fish with ±10% equal to 167,569 to 204,807 fish. Based on the postseason run size, years 1996 and 2005–2007 were considered high abundance years, while years 1997–1999, 2008, 2010, and 2012–2014 were low abundance years, and years 2009 and 2011 were considered average abundance years for the Tahltan stock (Figure 2). The average postseason run size for the Tahltan stock from 1994–2014 was 96,338 fish with ±10% equal to 86,704 to 105,972 fish.

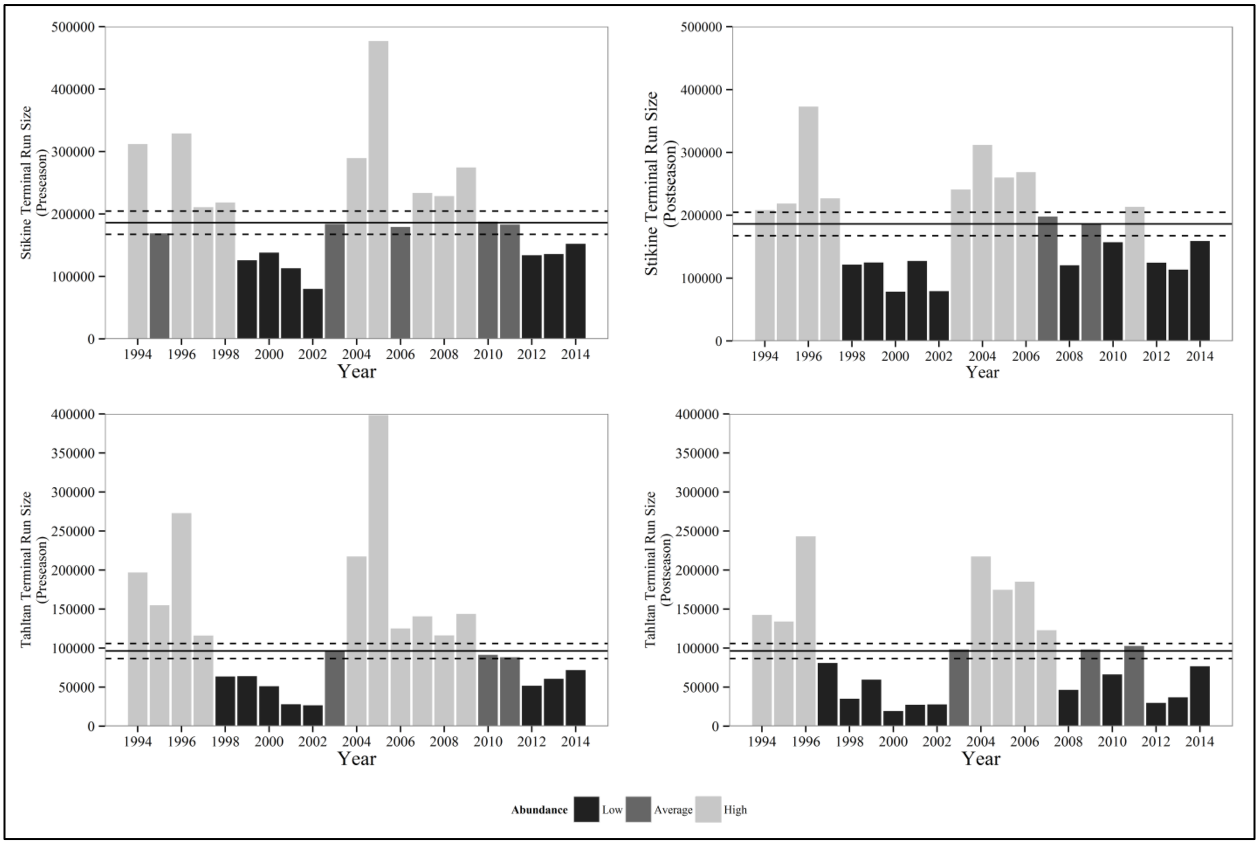

Figure 2. Postseason and preseason run size for the terminal Stikine and Tahltan stocks. Abundance levels are light grey for high abundance, dark grey for low abundance, and medium grey for average abundance. The horizontal line is the average postseason run size, by stock, from 1994–2014. The dotted horizontal lines are +/- 10% of the average postseason run size by stock. A run size that falls within 10% of the average postseason run size from 1994–2014 is considered an average year. Run sizes that are above the +10% line or below the -10% line are the high and low years respectively. For the preseason run sizes only, the horizontal line is the average postseason run size from 1994–2014 for the particular stock. The postseason average was used to determine if the preseason forecast predicts the same run size as the postseason in terms of low, average, or high for the terminal Stikine and Tahltan stocks.

Percent Error Analysis

Two methods, MPE and MAPE, were used to compare the 'true' postseason terminal run size with model estimates of inseason terminal run size for each model structure. Mean error is defined as a measure of both the magnitude and direction of estimator bias; the difference between the generated inseason estimate for the test years (1996–1999, and 2005–2014) by model *j* for statistical week *i* in year *y* and the 'true' postseason run size for each year and statistical week (Walther and Moore, 2005).

Mean error was calculated as,

$$[-(A_y - \hat{Z}_{i,j,y}) / A_y] \text{ x } 100, \qquad (1)$$

where A_y = 'true' postseason terminal run size in year *y* and $\hat{Z}_{i,j,y}$ is the predicted terminal run size for statistical week *i* using model *j* in year ***y*.** MPE provides for a measure of bias; indicating average over- or under-estimates of run size. To assist in examination of the range and distribution of underforecasting (negative MPE) and overforecasting (positive MPE) bar charts were constructed by stock and season. MAPE is calculated as the mean of the absolute values of the percent errors. It yields a measure of overall model performance with over- and under-estimates of run size treated equally (e.g. Ryall 1998). The best models were the models with the lowest MAPE or an MPE value close to zero.

Models were classified into a statistical week 26 forecast, an early season forecast (statistical weeks 27–28), and a late season forecast (statistical weeks 29–33). Models were then evaluated based on postseason abundance level (low, high, average; Figure 2), season (statistical week 26, early, late), and stock (Tahltan, terminal Stikine). The two best models based on the lowest MPE and MAPE were determined, along with any models within 10% of the postseason value, based on abundance level, season, and stock. Years were evaluated separately. For example, both 2013 and 2014 were considered low abundance years. If, hypothetically, Model 5 had a low MAPE in 2013 for the early season (8%) but a high MAPE in 2014 (20%), Model 5 would still be considered a preferred model for a low abundance year since 2013 is within 10% of the postseason value.

Abundance-Based Management Models

If the preseason forecast can accurately place the terminal Stikine stock or Tahltan stock abundance in a similar postseason abundance level (‘low’, ‘average’, ‘high’), then a table of preferred models based on abundance can be used effectively by the manger inseason. For example, in the year 2004, the preseason terminal run forecast of 289,500 fish predicted that it would be a high abundance year for Stikine sockeye salmon since 289,500 is greater than 204,807 (the average postseason run size for the terminal Stikine stock from 1994–2014 plus 10%). The postseason terminal run size confirmed the high abundance level since the final postseason terminal run size estimate was 311,987 fish. In 1998, the preseason terminal run size forecast was 218,500 fish and thus it was predicted that it would be a high abundance year. Unfortunately, it turned out to be a low abundance year since the final postseason terminal run estimate was only 121,448 fish.

Based on the results of model testing with inseason data and the percent error analysis, a decision tree was created to aid managers in inseason management.

RESULTS

TERMINAL AND INRIVER RUN SIZE MODELS

The ‘best approximating’ or ‘preferred’ model structure for *each* data source was determined by the lowest AICc value (Table 2). Some subdistricts may be closed or subject to a limited season due to a weaker run than forecasted, therefore models that used either District 108 or Subdistrict 106-41/42 data were retained. Also, managers were interested in models that used both catch and effort data in separate models; therefore, instead of finding one ‘best’ model (e.g. Model 1 using D106-41/42 cum. catch^2 + SW) based on the lowest AICc value, separate models using similar or correlated data sources were both retained for model testing with inseason data (e.g. Model 1 using D106-41/42 cum. catch^2 + SW and Model 3 using D106-41/42 cum. CPUE^2 + SW were both retained as best models). For example, although the four model structures for Model 1 that used Subdistrict 106-41/42 catch data and the four model structures for Model 3 that used Subdistrict 106-41/42 CPUE data, by stock, could be compared using AICc to determine the best model out of 8 alternative models, managers were interested in models that used both catch and CPUE. Therefore, instead of finding one 'best' model with the lowest AICc value, a Subdistrict 106-41/42 catch model *and* a Subdistrict 106-41/42 CPUE model were both retained and tested using inseason data (Appendices 1–4).

Terminal run size models based on an inriver run size prediction model evaluated only the inriver run size models (Inriver5, Inriver6) using the AICc comparison, not the full terminal run size models (Table 2). For example, Model 5 is the Inriver5 prediction plus run timing model of D108 sockeye area cumulative catch. Therefore, the Inriver5 model, not Model 5, was evaluated based on AICc to determine the best model structure using lower inriver cumulative catch (Table 2).

Table 2. Summary of results for the terminal and inriver run size models for the terminal Stikine and Tahltan stocks. The best fit models using AICc comparison are highlighted. *K* is the number of parameters estimated in the model and *n* is the number of data points. The best approximating model is the model with the lowest AICc value; therefore it has a ΔAICc of zero.

					Terminal Stikine		Tahltan	
Model	Dependent	Independent	K	n	ΔAICc	R^2	ΔAICc	R^2
Model 1	**Terminal**	**D106-41/42 cum. catch^2 + SW**	**20**	**442**	**0**	**0.75**	**0**	**0.84**
Model 1	Terminal	D106-41/42 cum. catch x SW	35	442	17	0.75	10	0.84
Model 1	Terminal	D106-41/42 cum. catch^2 x SW	52	442	45	0.75	47	0.84
Model 1	Terminal	D106-41/42 cum. catch + SW	19	442	91	0.69	80	0.81
Model 2	**Terminal**	**D108 cum. catch^2 + SW**	**20**	**391**	**0**	**0.71**	**0**	**0.77**
Model 2	Terminal	D108 cum. catch^2 x SW	52	391	11	0.74	32	0.78
Model 2	Terminal	D108 cum. catch x SW	35	391	59	0.68	120	0.70
Model 2	Terminal	D108 cum. catch + SW	19	391	102	0.63	126	0.69
Model 3	**Terminal**	**D106-41/42 cum. CPUE^2 + SW**	**20**	**442**	**0**	**0.71**	**0**	**0.83**
Model 3	Terminal	D106-41/42 cum. CPUE^2 x SW	52	442	70	0.69	70	0.81
Model 3	Terminal	D106-41/42 cum. CPUE x SW	35	442	70	0.67	88	0.80
Model 3	Terminal	D106-41/42 cum. CPUE + SW	19	442	72	0.66	92	0.78
Model 4	**Terminal**	**D108 cum. CPUE^2 + SW**	**20**	**391**	**0**	**0.55**	**0**	**0.78**
Model 4	Terminal	D108 cum. CPUE x SW	35	391	10	0.56	40	0.77
Model 4	Terminal	D108 cum. CPUE + SW	19	391	32	0.51	48	0.75
Model 4	Terminal	D108 cum. CPUE^2 x SW	52	391	35	0.56	71	0.77
Inriver5	**Inriver**	**lower inriver cum. catch x SW**	**33**	**512**	**0**	**0.51**	**0**	**0.66**
Inriver5	Inriver	lower inriver cum. catch^2 + SW	19	512	20	0.47	22	0.63
Inriver5	Inriver	lower inriver cum. catch^2 x SW	49	512	33	0.5	32	0.65
Inriver5	Inriver	lower inriver cum. catch + SW	18	512	240	0.19	341	0.31
Inriver6	**Inriver**	**lower inriver cum. CPUE^2 + SW**	**19**	**512**	**0**	**0.44**	**0**	**0.65**
Inriver6	Inriver	lower inriver cum. CPUE x SW	33	512	14	0.44	11	0.65
Inriver6	Inriver	lower inriver cum. CPUE + SW	18	512	33	0.4	71	0.59
Inriver6	Inriver	lower inriver cum. CPUE^2 x SW	49	512	40	0.43	42	0.64

The Tuya data was not as informative as the Tahltan or terminal Stikine data (most of the data was clustered at high CPUE and high catch values); therefore the best model structures for the Tahltan and terminal Stikine stocks were used for the Tuya stock. The Tuya stock are those fish originating from broodstock collected at Tahltan Lake and are subsequently stocked as fry into Tuya Lake. Therefore, the Tuya stock comingles with the Tahltan stock and shows similar run timing and distribution as the Tahltan stock (Pacific Salmon Commission Joint Transboundary Technical Committee 12(1), 2012).

The best models for both the terminal Stikine stock and the Tahltan stock were second order polynomial regression models (Models 1–4) and run timing models based on the inriver run size prediction (Models 5–6) (Table 3). Model 7, the historical-SMM, is currently used for inseason management. Inseason run size predictions are by statistical week (26–33) and by stock (terminal Stikine, Tahltan, Tuya, mainstem). Although the inseason run size predictions are calculated weekly, the predictions only pertain to a *final* terminal run size; they are not an estimate of cumulative run size to date or weekly run size. Also, there is no model for the mainstem stock. The inseason run size prediction for the mainstem stock is always the inseason prediction for the terminal Stikine stock in statistical week i minus the inseason prediction for the Tuya stock and Tahltan stock in statistical week i.

Table 3. Descriptions of the best inriver run size models (Inriver1–Inriver6) and the best terminal run size models (Model 1–Model 7; preseason forecast) for the Tahltan and terminal Stikine stocks.

Model	Description
Inriver1	Model1 prediction minus U.S. cumulative catch with historical run timing
Model1[ab]	cumulative catch D106-41/42
Inriver2	Model2 prediction minus U.S. cumulative catch with historical run timing
Model2[ab]	cumulative catch D108 sockeye salmon area
Inriver3	Model3 prediction minus U.S. cumulative catch with historical run timing
Model3[ab]	cumulative CPUE D106-41/42
Inriver4	Model4 prediction minus U.S. cumulative catch with historical run timing
Model4[ab]	cumulative CPUE D108 sockeye salmon area
Inriver5[c]	lower inriver cumulative catch
Model5[a]	Inriver5 prediction plus run timing model of D108 sockeye area cumulative catch
Inriver6[b]	lower inriver cumulative CPUE
Model6[a]	Inriver6 prediction plus run timing of D108 sockeye area cumulative catch
Inriver7	lower inriver cumulative CPUE
Model7 (historical-SMM)[d]	Inriver7 prediction plus run timing of D108 cumulative catch
Preseason forecast	Smolt forecast since 2007 (Tahltan stock), age-specific fry-to-adult survival (Tuya stock), sibling-based and stock-recruitment analysis (mainstem stock)

[a]Tahltan stock (≤98,000 or >98,000 in the D106-41/42 fishery, and <46,000 or >175,000 or 46,000≤ x ≤175,000 in the D108 fishery).
[b]Second order polynomial regression model (see Table 2)
[c]ANCOVA model (see Table 2)
[d]Tuya stock correction factor included (based on equation 6); <40,000 or >80,000 or 40,000≤ x ≤80,000 trigger sizes.

The first four inseason terminal run size models (Models 1–4) have a similar model structure (Table 3),

$$\ln(\hat{Z}_{i,j}) = \alpha + \beta_1 \ln(X_{i-1,j}) + \beta_2 \ln(X_{i-1,j}^2) + \sum_{k=1}^{11} \gamma_k (D_{ik}) + \varepsilon_i;\ i = 26,...,36. \quad (2)$$

In this model structure, $\hat{Z}$ is the predicted terminal run size estimated from data source *j* and for time period *i*, α is the intercept for statistical week 25, β is the slope of the regression line, γ is the adjustment to the intercept based on the statistical week of the prediction, D_{ik} is a set of eleven indicator variables to represent the statistical weeks in the study (statistical weeks 26 through 36), and *X* is data from data source *j* through time period *i*-1 (e.g. Tremblay et al. 1998, and Rodríguez et al. 1993). The four data sources for the inseason model are either: (1) cumulative commercial harvest of Subdistrict 106-41/42 through statistical weeks *i*-1 (Model 1); (2) cumulative commercial harvest of the District 108 sockeye salmon area through statistical weeks *i*-1 (Model 2); (3) cumulative commercial CPUE of Subdistrict 106-41/42 through statistical weeks *i*-1 (Model 3); or (4) cumulative commercial CPUE of the District 108 sockeye salmon area through statistical weeks *i*-1 (Model 4) (Table 3).

In models Inriver1–Inriver4, the cumulative U.S. commercial (Districts 106 and 108) and subsistence harvest through statistical weeks *i*-1, divided by the cumulative District 108 historical run timing through statistical weeks *i*-1, is subtracted from the terminal run size estimate (Models 1–4) from statistical week *i* (Table 3). The weekly run fraction is based on historical cumulative CPUE in the District 108 fishery. For example, if Model 1 predicts that the terminal run size is 87,700 Stikine River sockeye salmon for statistical week 32, the cumulative U.S. commercial and subsistence harvest through statistical week 31 is 6,870 fish, and the sum of the weekly run fraction is 92%, then the Inriver1 model would predict 80,233 fish (87,700-(6,870/0.92)) for statistical week 32.

Models 5–7 all have the same structure,

$$\hat{Z}_{i,j} = \frac{I_{i,m} + (X_{i-1,j} / Y_{i-1})}{0.9} + \varepsilon_i; i = 26,...,36., \quad (3)$$

where $I_{i,m}$ is the exponentiated projected inriver run estimate for model *m* for time period *i* added to the data from data source *j* through the time period *i*-1 $(X_{i-1,j})$ divided by the cumulative District 108 historical run timing through statistical weeks *i*-1 (Y_{i-1}). The data sources *j* for the inseason model are either: (1) cumulative commercial harvest of the District 108 sockeye salmon area through statistical weeks *i*-1 (Model 5, Model 6); or (2) cumulative commercial harvest of District 108 through statistical weeks *i*-1 (Model 7). The projected harvest in District 108 or the District 108 sockeye salmon area is based on an assumed 90% contribution of terminal Stikine sockeye salmon to the cumulative harvest (Pacific Salmon Commission Joint Transboundary Technical Committee, report TCTR (15)-1, 2015) (Table 3).

The Inriver5 model is based on an analysis of covariance (ANCOVA) model,

$$\ln(\hat{I}_{\text{i,Inriver5}}) = \alpha + \beta \ln(X_{i-1}) + \sum_{k=1}^{10} \gamma_k (D_{ik}) + \sum_{k=1}^{10} \delta_k (\ln X_{i-1} D_{ik}) + \varepsilon_i;\ \ i = 27,...,36, \quad (4)$$

where X is the cumulative inriver commercial harvest through statistical weeks i-1 on a natural logarithm scale, D_{ik} is a set of ten indicator variables to represent the statistical weeks in the study, and δ is an interaction term. The Inriver6 model ($I_{i,\text{Inriver6}}$) is a second order polynomial regression model using cumulative CPUE of the lower inriver commercial fishery through statistical weeks i-1 (similar to equation 2). The Inriver7 model ($I_{i,\text{Inriver7}}$) uses the observed historical data, runs two regressions of stock specific cumulative CPUE by statistical week (i) across years for the lower inriver commercial fishery against annual inriver run size by stock and year (based on run reconstructions). One is a simple linear regression and the other is a simple linear regression through the origin. For each regression, the inriver run size is only available by year, not statistical week. The weekly intercept (β_0) and slope (β_1) of this regression are then used in a regression to predict inriver run size by stock,

$$I_{i,\text{Inriver7}} = \beta_{0(i-1)} + \beta_{1(i-1)} X_{(i-1)}, \tag{5}$$

where X is the cumulative CPUE of the lower inriver commercial fishery through statistical weeks i-1. If the estimate of terminal Stikine run size for the prior statistical week (i-1) is < 90,000 fish then the regression model through the origin is used for the inriver run size prediction.

TRIGGER POINTS

A trigger point is an abundance level that *triggers* the use of a different stock proportion in the inseason management model. The inseason management model estimates the Tahltan and mainstem stock proportions in District 106-41/42 and 108 harvests from historical postseason scale pattern analysis based on triggers of run size; the stock proportions for the Tahltan and mainstem stock used each week depend upon whether the Tahltan and mainstem run are judged to be below average, average, or above average based on the model output.

The six best prediction models for the terminal run size differed in trigger points for the Tahltan and mainstem stocks (Table 4). In Models 1–6 and Model 7 (historical-SMM), weekly proportions of Tahltan and mainstem stock fish in the D108, D106-41/42, and D106-30 drift gillnet fisheries are (1) modeled based on abundance (low, high, average) using historical data and based on the inseason run size prediction from the model output (trigger points), (2) an average of historical data across all years, or (3) an average of historical data by abundance (low, high, average) based on the inseason run size prediction from the model output (trigger points) (Table 4). If the proportions are based on the inseason run size prediction of the mainstem stock or Tahltan stock from the model output, then the weekly inseason model prediction is used as the trigger point. If the model predicts a high abundance level, average historical proportions from high abundance years are used. If the model predicts a low abundance level, average historical proportions from low abundance years are used. If the model predicts an average abundance year, all historical proportion data are averaged and used in the model.

For the historical-SMM model (Model 7), if the inseason prediction of the run size of the Tahltan stock is high (>80,000 fish), then the average weekly Tahltan stock composition during years with a high run size (>80,000 fish) are used in the historical-SMM model for the Tahltan stock composition. If the inseason prediction of the run size of the Tahltan stock is low (<40,000 fish) then the average weekly Tahltan stock composition during years with a low run size (<40,000 fish) are used in the historical-SMM model for the Tahltan stock composition. Finally, if the inseason prediction of the terminal run size of the Tahltan stock is average (≥40,000 fish ≤80,000 fish) then the average weekly Tahltan stock composition across all historical years of data is used in the historical-SMM model for the Tahltan stock composition. The same trigger points are

Table 4. Descriptions of the method and trigger points used to incorporate historical proportions by stock and fishery for Model 1–Model 7. If the row for trigger points is blank, a trigger size is not used to determine the proportion of Tahltan or mainstem stock fish based on historical data; instead the average across all historical data is used.

Stock, District or Subdistrict	Models	Trigger points	Method
wild Tahltan; D106-41/42	Model 1-Model 6	≤98,000 or >98,000	Modeled
wild Tahltan; D108	Model 1-Model 6	<46,000 or >175,000 or 46,000≤ x ≤175,000	Modeled
wild Tahltan; D106-30	Model 1-Model 6		Average
mainstem; D106-41/42	Model 1-Model 6		Average
mainstem; D108	Model 1-Model 6		Average
mainstem; D106-30	Model 1-Model 6		Average
wild Tahltan; D106-41/42[a]	Model 7	<40,000 or >80,000 or 40,000≤ x ≤80,000	Average based on trigger points
wild Tahltan; D108[a]	Model 7	<40,000 or >80,000 or 40,000≤ x ≤80,000	Average based on trigger points
wild Tahltan; D106-30[a]	Model 7		Average
mainstem; D106-41/42[a]	Model 7	<40,000 or >80,000 or 40,000≤ x ≤80,000	Average based on trigger points
mainstem; D108[a]	Model 7	<40,000 or >80,000 or 40,000≤ x ≤80,000	Average based on trigger points
mainstem; D106-30[a]	Model 7		Average

[a]Tuya stock correction included based on equation 6.

used for the mainstem stock proportions for District 108 and Subdistrict 106-41/42. The Tuya stock correction factor,

$$p_{s_1} = \frac{p_{s_1}}{1 - p_{s_2}}, \tag{6}$$

where p_{s_1} is either the Tahltan stock composition or the mainstem stock composition, and p_{s_2} is the Tuya stock composition, was incorporated into the mainstem and Tahltan stock proportions for the historical-SMM model only.

Similar to the historical-SMM model, the trigger points for the Tahltan stock (≤98,000 fish or >98,000 fish in the Subdistrict 106-41/42 fishery, and <46,000 fish or >175,000 fish or 46,000≤ x ≤175,000 fish in the D108 fishery) were used for Models 1–6 (Table 4). The trigger points were determined by graphing the historical Tahltan proportions by statistical week and finding natural breaks in the data.

MODEL TESTING WITH INSEASON DATA

Abundance-Based Management Models

From 1994–2014, the preseason forecast and postseason terminal Stikine stock run size estimate were similar (low, average, high) 57% of the time (Figure 2). Years 1995, 1998, 2003, 2006–2011 were the exception. Although the preseason forecast was extremely accurate (within 5%) in years 1999, 2002, and 2014, the percent error has ranged from an underestimate of 33% in 2006 to an overestimate of 90% in 2008 for the terminal Stikine stock. Therefore, it is not a consistent source for an accurate forecast. If the ‘average’ preseason forecasts are disregarded, and only the preseason forecasts that are either ‘high’ or ‘low’ are considered, the preseason forecast is a little more accurate (75%).

From years 1994–2014, the preseason Tahltan forecast and the postseason Tahltan stock run size estimate were similar (low, average, high) 81% of the time (Figure 2). Years 1997, and 2008–2010 were the exception. The preseason forecast was within 5% of the postseason run size in years 2001–2004 and the percent error ranged from an underestimate of 32% in year 2006 to an overestimate of 166% in year 2000 for the Tahltan stock.

Percent error analysis (terminal Stikine stock)

Statistical Week 26

During a low abundance year, the preseason model, and Models 1–6 were preferred for the terminal Stikine stock for statistical week 26 (Figure 3; Appendix 5). During a high abundance year, only the preseason model was preferred. During an average abundance year, Model 3 and Model 5 were preferred. Data was not available until statistical week 26 during year 2009. Therefore, an inseason forecast was not available until statistical week 27. So the MPE and MAPE analysis for an ‘average’ year was only based on year 2007 for all models and the preseason forecast in year 2009.

Data was not available until statistical week 26 during the average abundance year 2009, the high abundance years 1996 and 2011, and the low abundance years 1998, 1999, and 2010. Therefore, an inseason forecast was not available until statistical week 27. So the MPE and MAPE analysis for these years was only based on the preseason forecast. A model prediction was not available for Model 7 during statistical week 26 for all years.

Early Season (Statistical weeks 27–28)

During a low abundance year, the preseason model, Models 1–5, and Model 7 were preferred in the early season for the terminal Stikine stock (Figure 4; Appendix 5). During a high abundance year, the preseason model was preferred. During an average abundance year, Model 3, Model 5 and Model 7 were preferred in the early season.

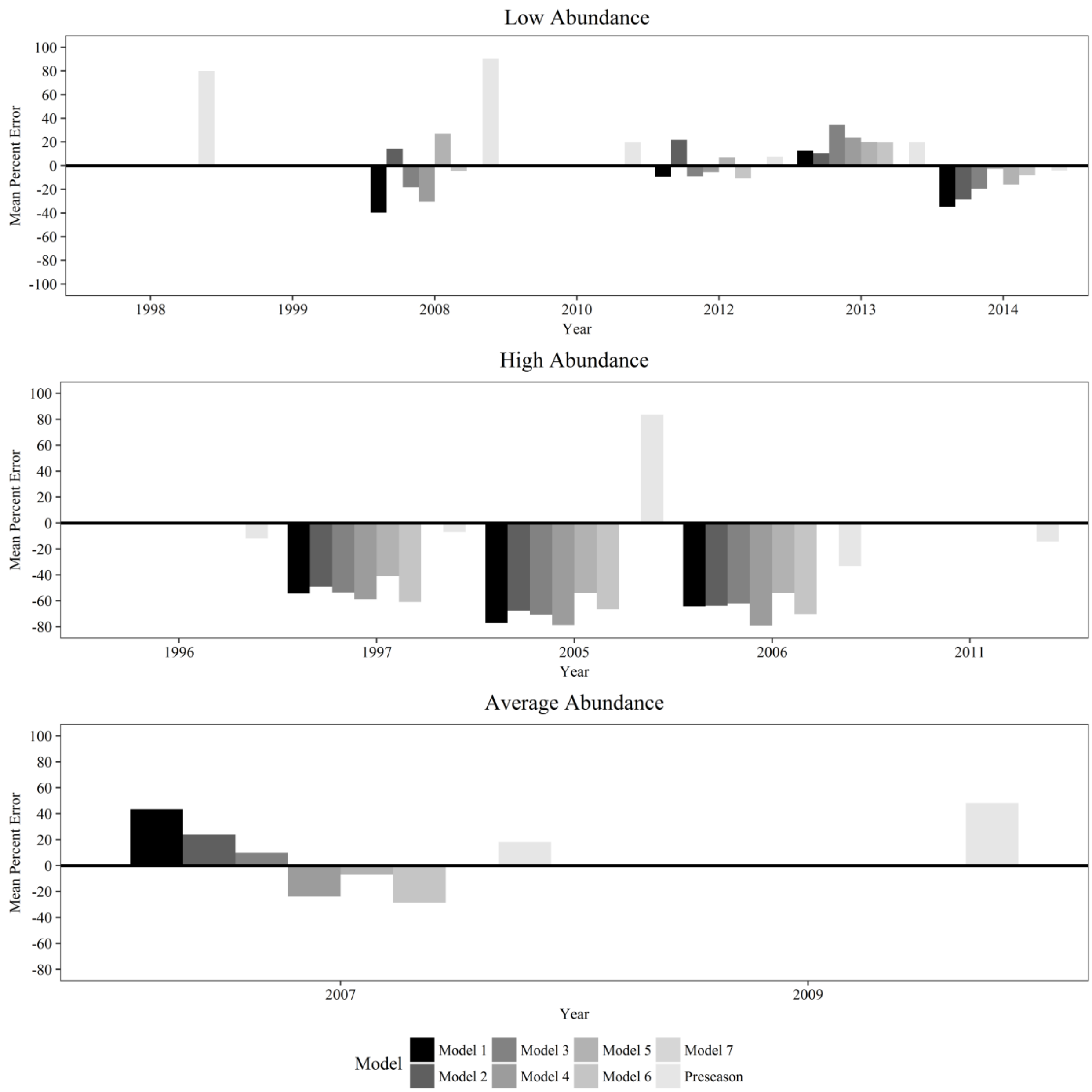

Figure 3. Mean Percent Error (MPE) of various models used to predict total run size of Stikine River sockeye salmon for test years 1996–1999, and 2005–2014 during statistical week 26. Model 1 (Subdistrict 106-41/42 cumulative catch model), Model 2 (District 108 sockeye area cumulative catch model), Model 3 (Subdistrict 106-41/42 cumulative CPUE model), Model 4 (District 108 sockeye area cumulative CPUE model), Model 5 (inriver cumulative catch model using historical run timing), Model 6 (inriver cumulative CPUE model using historical run timing), and Model 7 (historical run timing model). Years 1998, 1999, 2008, 2010, and 2012–2014 were considered low abundance years, years 1996, 1997, 2005, 2006, and 2011 were considered high abundance years, and 2007 and 2009 were considered average abundance years for the terminal Stikine stock.

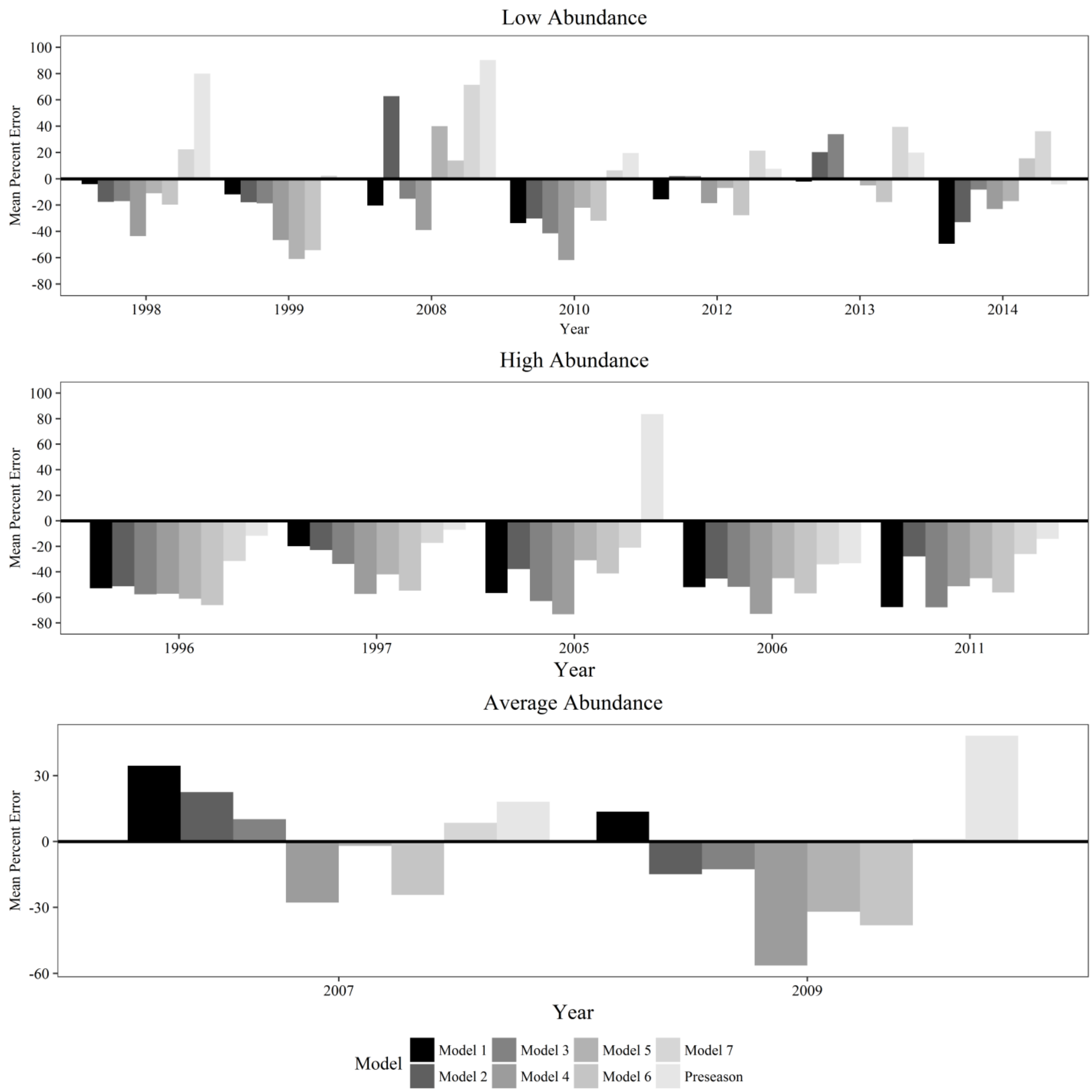

Figure 4. Mean Percent Error (MPE) of various models used to predict total run size of Stikine River sockeye salmon for test years 1996–1999, and 2005–2014 during the early season (statistical weeks 27–28). Model 1 (Subdistrict 106-41/42 cumulative catch model), Model 2 (District 108 sockeye area cumulative catch model), Model 3 (Subdistrict 106-41/42 cumulative CPUE model), Model 4 (District 108 sockeye area cumulative CPUE model), Model 5 (inriver cumulative catch model using historical run timing), Model 6 (inriver cumulative CPUE model using historical run timing), and Model 7 (historical run timing model). Years 1998, 1999, 2008, 2010, and 2012–2014 were considered low abundance years, years 1996, 1997, 2005, 2006, and 2011 were considered high abundance years, and 2007 and 2009 were considered average abundance years for the terminal Stikine stock.

Late Season (Statistical weeks 29+)

During a low abundance year, the preseason model, Models 1–3, and Models 5–7 were preferred in the early season for the terminal Stikine stock (Appendix 5). During a high abundance year, the preseason model, Model 2, and Model 7 were preferred. During an average abundance year, Model 1, Model 3, Model 5, and Model 7 were preferred in the late season.

Percent error analysis (Tahltan stock)

Statistical Week 26

During a low abundance year, the preseason model, Model 4, and Model 6 were preferred for the Tahltan stock for statistical week 26 (Appendix 6). During a high abundance year, Model 2 and Model 3 were preferred and, during an average abundance year, the preseason model was preferred for statistical week 26.

Data were not available until statistical week 26 during the average abundance years 2009 and 2011, the high abundance year 1996, and the low abundance years 1998, 1999, and 2010. Therefore, an inseason forecast was not available until statistical week 27. So the MPE and MAPE analysis for these years was only based on the preseason forecast. A model prediction was not available for Model 7 during statistical week 26 for all years.

Early season (Statistical weeks 27–28)

During a low abundance year, the preseason model, Model 1, and Model 5 were preferred in the early season for the Tahltan stock. Model 2, Model 6, and Model 7 were also preferred based on the MPE analysis only (Appendix 6). During a high abundance year, Model 3, Model 5, and Model 7 were preferred. During an average abundance year, the preseason model and Model 7 were preferred in the early season.

Late season (Statistical weeks 29+)

During a low abundance year, the preseason model, Model 1, Model 2, Model 4, and Model 6 were preferred in the late season for the Tahltan stock (Appendix 6). Model 5 was also preferred based on the MPE. During a high abundance year, Model 3, Model 5, and Model 7 were preferred. Model 6 was also preferred based on the MPE. During an average abundance year, Model 5 and Model 7 were preferred in the late season.

DISCUSSION

Managers are interested in accurate and early inseason estimates of terminal run size. The sockeye salmon fishing season in U.S. waters can open, by regulation, as early as 1200 hours on Monday of statistical week 24, although the initial opening is delayed a week if the preseason forecast of Stikine River sockeye salmon is low or average (Pacific Salmon Commission Joint Transboundary Technical Committee 15(1), 2015). The inseason predictions for Models 1–4 usually begin at statistical week 27 (based on data from statistical weeks 24–26) since they are based on U.S. commercial fisheries in Districts 106 and 108, before the terminal Stikine stocks enter the river. If predictions are not available for statistical week 27 (or earlier weeks), the preseason forecast takes precedent.

Models 5–7 are based on the lower inriver commercial CPUE or catch data, and otolith data. Otolith samples from Canadian inriver fisheries are processed in Juneau Alaska at the Alaska Department of Fish and Game Mark, Tag, and Age Laboratory. Due to the extra days of transporting samples and inriver commercial fisheries lagging behind the U.S. commercial fisheries, the data and thus the predictions based on inriver data are lagged a week or two. Therefore, although Models 5–7 may accurately predict the terminal run for certain stocks, seasons, and run sizes, these models are based on fewer weeks of data or are not available due to the absence of fishing data.

This analysis did not result in one model that proved to be the most accurate and consistent for a stock, season, and run size. Rather, a range of models were plausible. No model is 'right,' rather each model is a guide for the manager based on his or her years of experience managing the fishery. Models 1–6 are an improvement from the preseason forecast and from the historical-SMM (Model 7), and are another 'tool' for the management of the Stikine River fishery for sockeye salmon.

Overall, the preseason forecast for the terminal Stikine stock run size is not a consistent source for an accurate abundance level forecast ('low', 'average', 'high') or a point estimate forecast. The preseason Tahltan stock run size and postseason terminal Stikine stock run size estimates had similar abundance levels 71% of the time (data from 1994–2014). However, the preseason Tahltan stock run size was predicted to be average in years 2003, 2010, and 2011; but, the terminal Stikine stock postseason run size estimates were high in years 2003 and 2011, and low in 2010. While the preseason Tahltan stock run size forecast predicted a high abundance level in years 2007–2009, the terminal Stikine stock postseason run size estimate was average in years 2007 and 2009, and low in 2008. Therefore, the preseason forecast for the Tahltan stock run size is a better predictor of postseason run size abundance level for the terminal Stikine stock than the preseason forecast for the terminal Stikine stock, but not a point estimate forecast.

Overall, the preseason forecast for the Tahltan stock run size is a consistent source for an accurate abundance level forecast ('low', 'average', 'high'), but not a point estimate forecast for the Tahltan stock. The preseason Tahltan forecast and the postseason Tahltan stock run size estimate were similar 81% of the time.

For the terminal and inriver run size models, data was only used up to year 2011 for all stocks because stock identification methodology changed from postseason analysis using scales to genetics in 2012. Since 2012, after the fishing season, genetic stock identification has been used to recalculate weekly contributions of wild Tahltan and mainstem sockeye stocks in the commercial fisheries in each subsection of District 106 (Clarence Strait and Sumner Strait) and District 108. Genetic stock identification will be used in all subsequent years to replace scale pattern analysis; genetic stock identification is an improvement over scale pattern analysis techniques that are logistically difficult, labor intensive, and more expensive (Gilk-Baumer and Oliver, 2013). Therefore, if Models 1–6 are updated in the future, they should be reanalyzed using all historical data through 2016.

RECOMMENDATIONS FOR INSEASON MANAGEMENT

The recommendations for the managers for inseason management include;

Follow the recommended models in Table 3 and the decision trees in Appendix 5 and Appendix 6 for inseason management. Some subdistricts may be closed or subject to a limited season due to a weaker run than forecasted. Therefore, based on timing and performance of the inseason fisheries, the manager must use his or her expertise to determine which of the preferred models in the decision tree most likely represents the 'true' abundance of the Stikine River terminal stocks. Based on model testing with inseason data using historical data, Appendix 7 also guides the manager in determining if the model is more likely to over or underestimate the 'true' run size.

Although the fisheries are mixed stock fisheries, the U.S. manager is more likely to rely on inseason predictions from Models 1–4 because they are based on U.S. commercial fisheries in districts 106 and 108, before the terminal Stikine stocks enter the river. These models provide earlier estimates of terminal run size. The Canadian manager is more likely to rely on Models 5–7 which are based on the lower inriver commercial CPUE or catch data, and stock composition data from otoliths, and assume that all fish caught inriver are Stikine River bound fish. By the time adequate data is incorporated into the inriver models (Models 5–7), the U.S. fishery is winding down. Therefore, although Models 5–7 may accurately predict the terminal run for certain stocks, seasons, and run sizes, these models are based on fewer weeks of data or are not available to the U.S. manager due to the absence of inriver fishing data.

The managers should use the preseason Tahltan stock size forecast as a guide for the run size of the terminal Stikine and Tahltan stocks (low, average, or high) for statistical week 26 models. After statistical week 26, if a model predicts a different inseason run size than the Tahltan preseason forecast, the managers should change the strategy to a different abundance level based on the decision tree. For example, if the preseason model suggests that the run size of the Tahltan stock is average, use Model 3 or Model 5 inseason during statistical week 26 (Appendix 5) to predict the terminal Stikine stock run size. If Model 3 and Model 5 predict the abundance of the terminal Stikine stock to be low, then for statistical weeks 27–28, use the preseason model, Models 1–5, or Model 7 for the inseason prediction.

The historical-SMM model is written in Microsoft Excel 2010. There are 1000s of links to data sheets within the workbook and outside the workbook. Each year these links need to be updated and checked for accuracy. Since the historical-SMM is based on a simple linear regression, by updating the links, the model automatically uses the current data to update the model. Although this creates more room for errors through incorrect links or 'broken' links (links that no longer reference a formula or data), the model is updated each year with the current data. Although the inseason data is updated each year, the parameters for Models 1–6 are static. The models have more complicated structures that cannot be automatically updated by adding a few cells to the worksheet and changing a few formulas as the historical-SMM. To update the parameters based on data after 2011, Models 1–6 would have to be rerun and models structures would have to be compared by AICc. Therefore, Models 1–6 would be more efficiently run in a software program such as the R language (http://cran.r-project.org).

Part of this project included general updates to the historical-SMM model including adding additional data, correcting cell links and formulas. This has greatly improved the historical model performance and was an important result of this analysis. Two additional years of model testing (2015 and 2016) have provided some insight into recent performance of Models 1–7 and the preseason forecast model (Appendix 8). Based on the preseason forecast and the postseason run size, the year 2015 was considered an average year for the terminal Stikine and a low year for the Tahltan stock, while the year 2016 was considered a high year for both the terminal Stikine and for the Tahltan stock. Based on both MPE and MAPE, in the last 5 years the preseason forecast is a better predictor of postseason run size than Models 1–7, and should be revisited as an inseason guide to managers.

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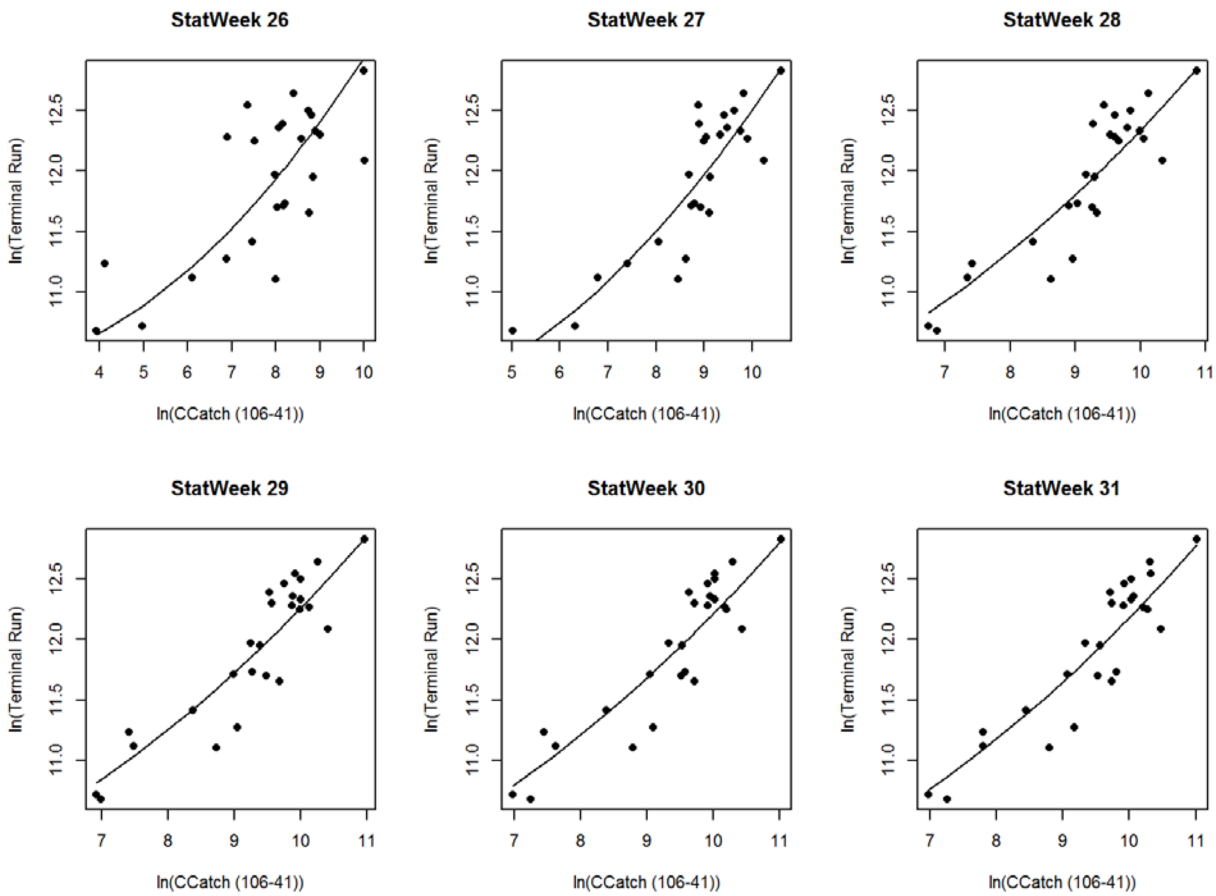
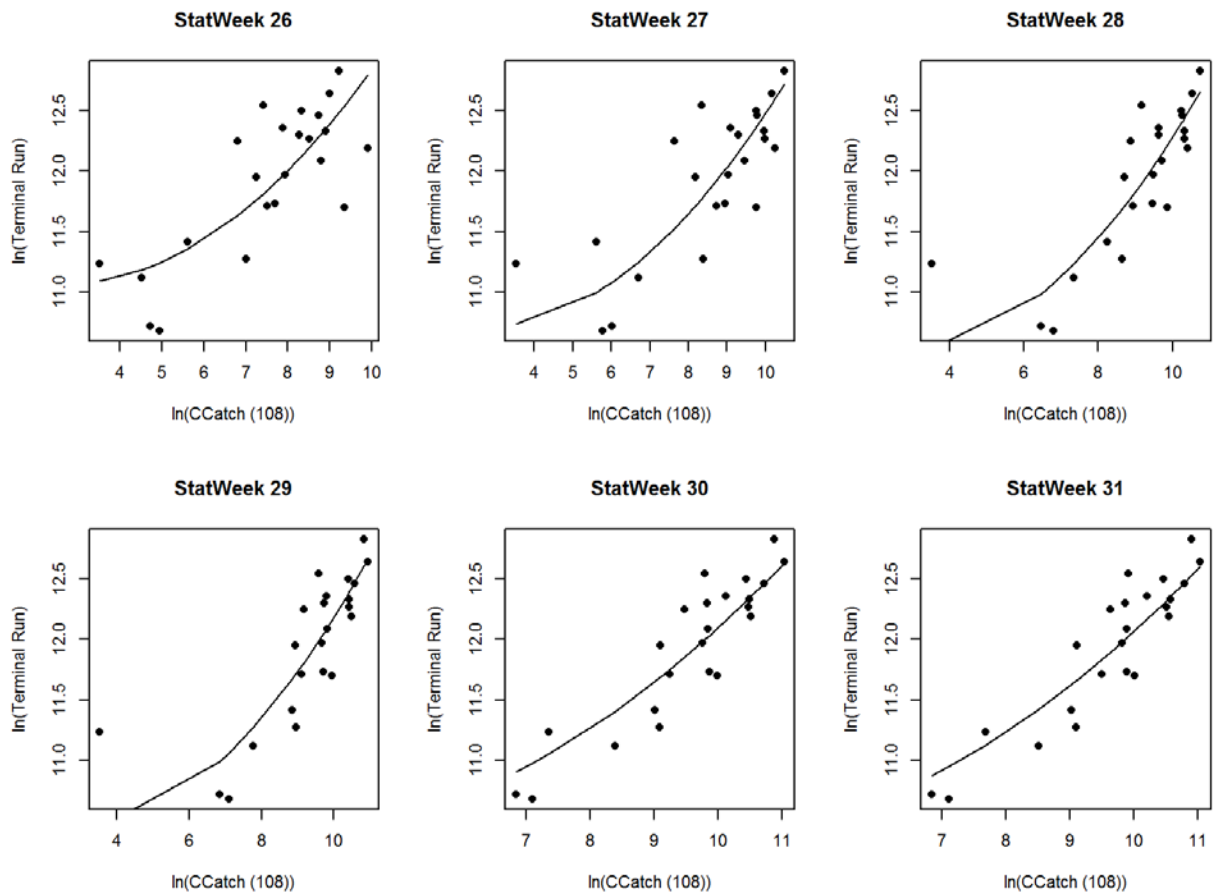
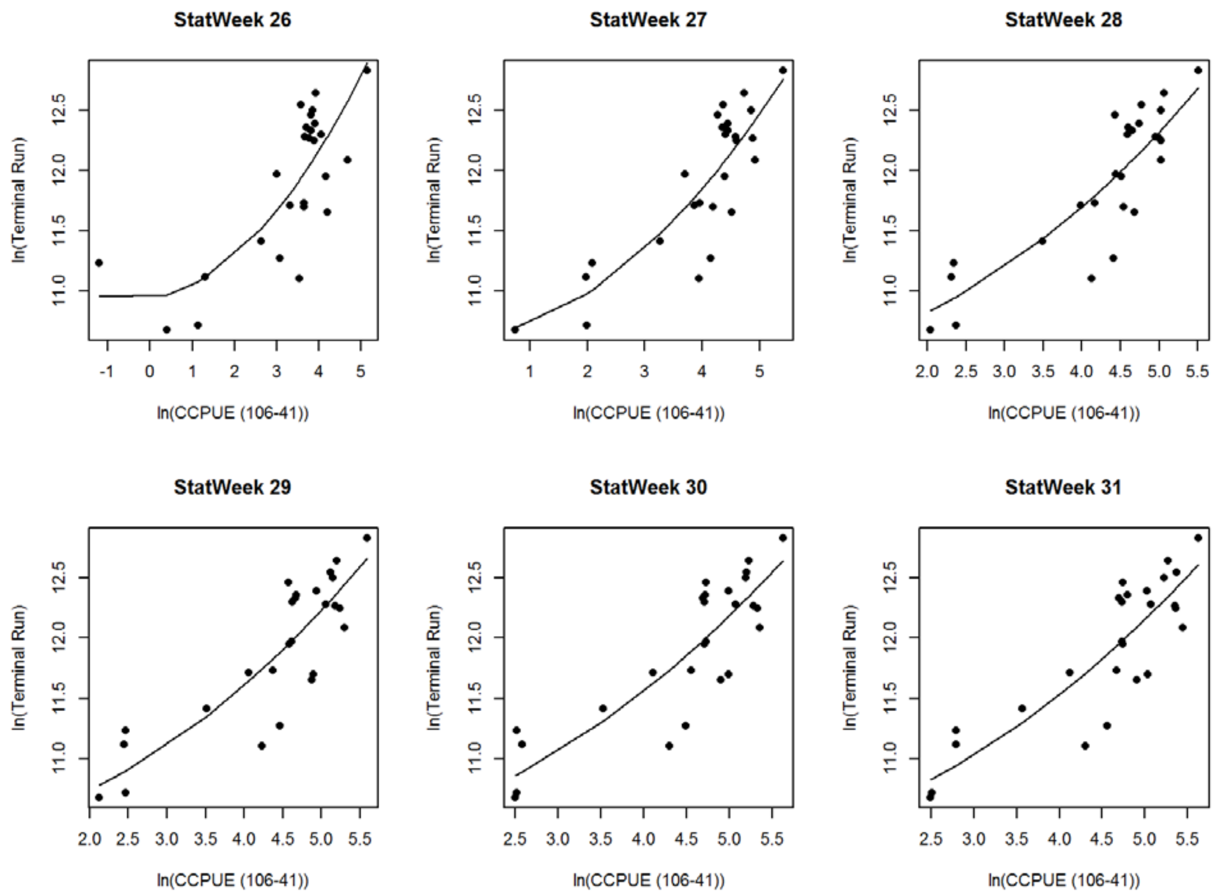
APPENDICES



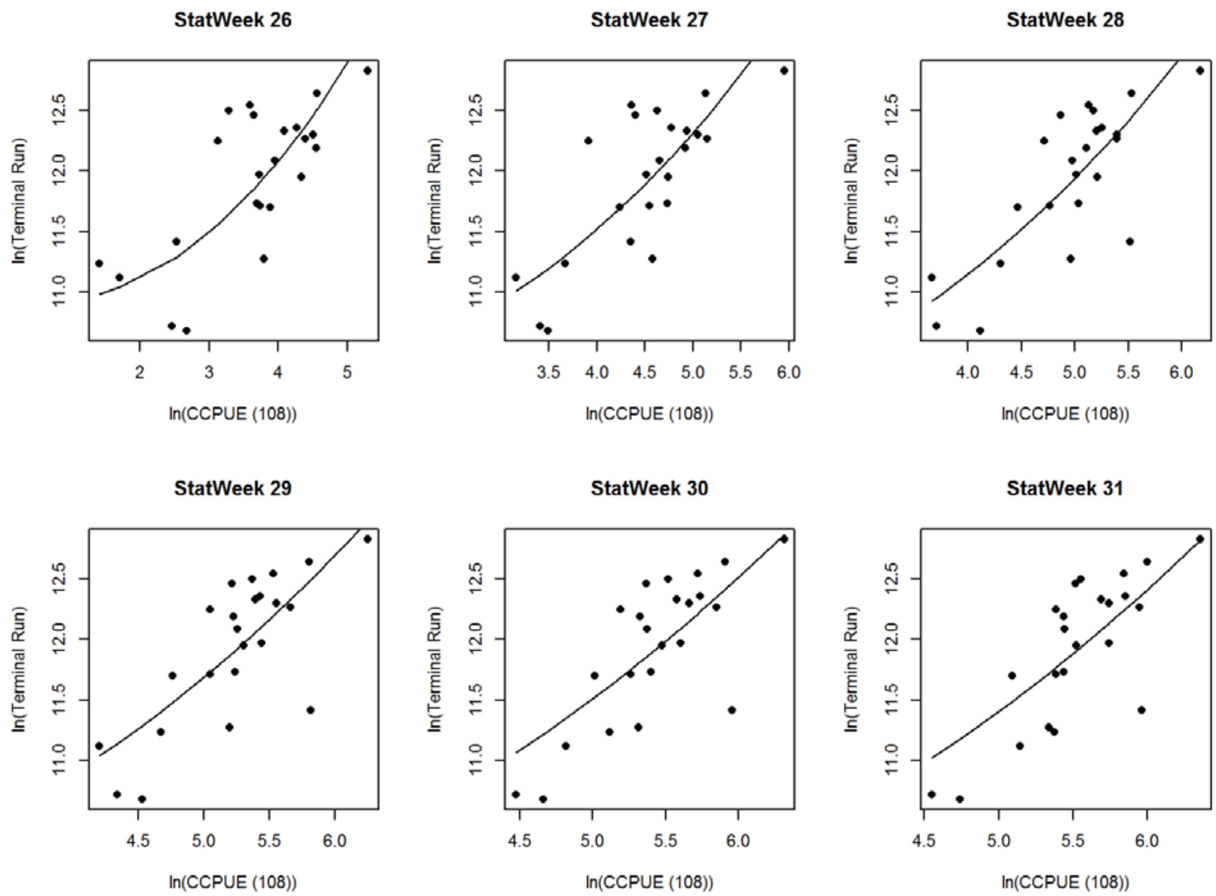
Appendix 1. Model 1 fit by statistical week on a natural log scale. The model is a second order polynomial regression model. The y-axis is the terminal Stikine run size and the x-axis is cumulative catch in Subdistrict 106-41/42.



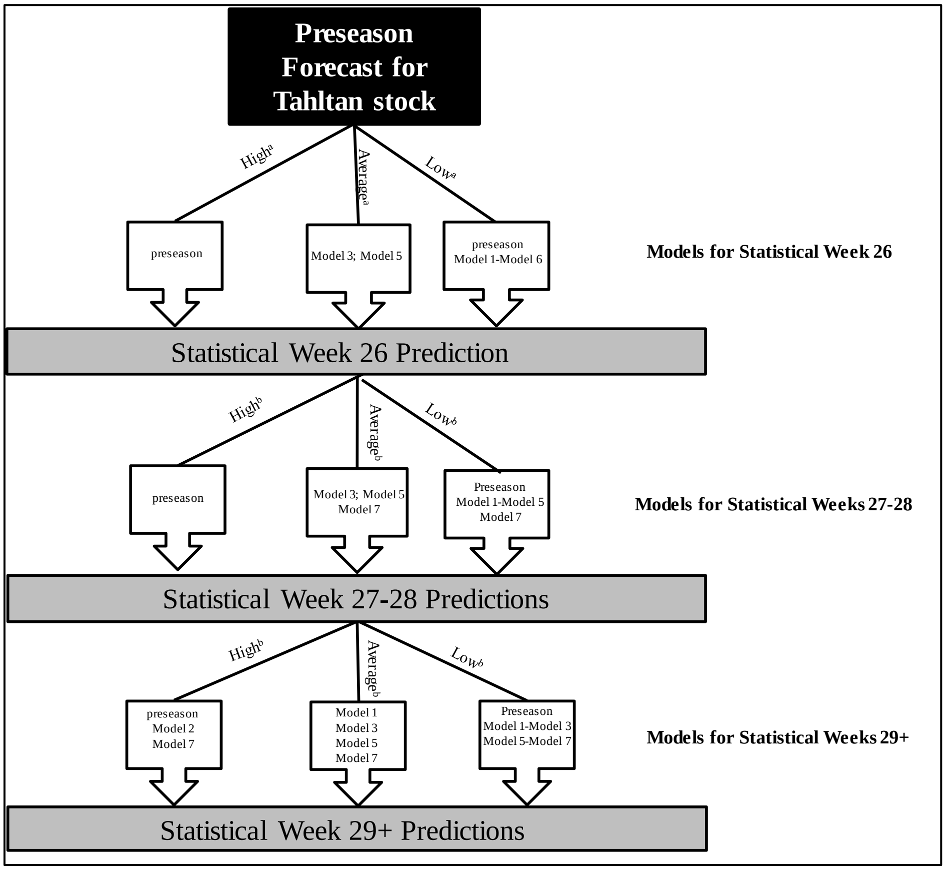
Appendix 2. Model 2 fit by statistical week on a natural log scale. The model is a second order polynomial regression model. The y-axis is the terminal Stikine run size and the x-axis is cumulative catch in District 108.



Appendix 3. Model 3 fit by statistical week on a natural log scale. The model is a second order polynomial regression model. The y-axis is the terminal Stikine run size and the x-axis is cumulative CPUE in Subdistrict 106-41/42.

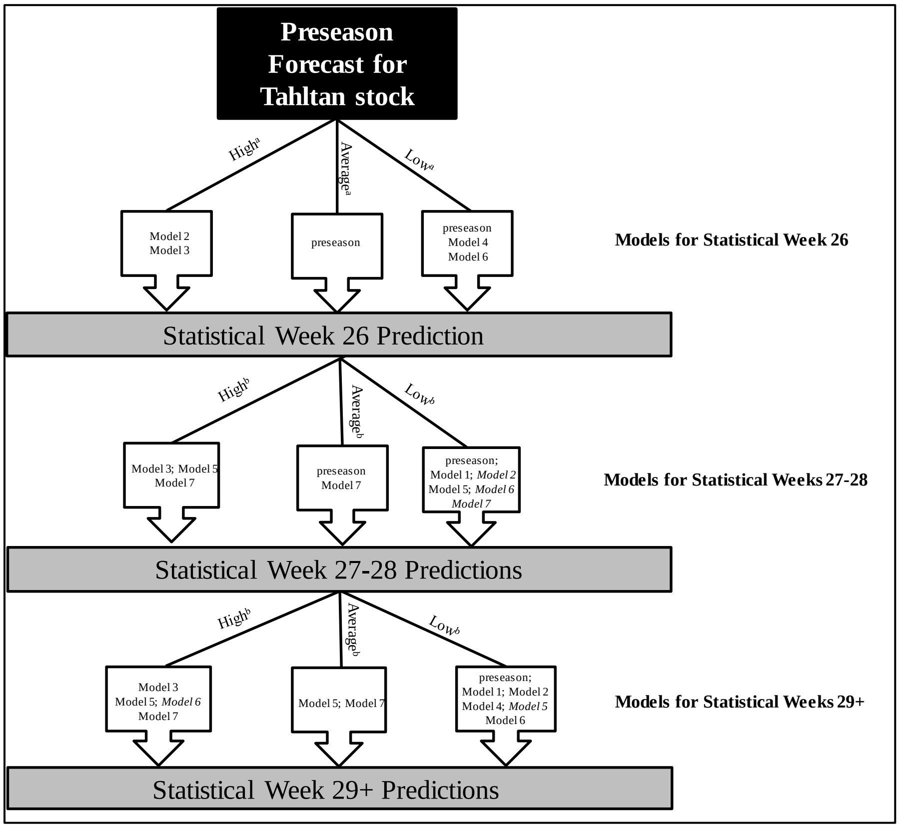


Appendix 4. Model 4 fit by statistical week on a natural log scale. The model is a second order polynomial regression model. The y-axis is the terminal Stikine run size and the x-axis is cumulative CPUE in District 108.



[a]abundance level of the Tahltan stock based on the preseason model forecast
[b]abundance level of the terminal Stikine stock based on the inseason model output

Appendix 5. Decision tree for the terminal Stikine stock. The abundance is based on the average postseason run size from 1994–2014 (96,338) for the Tahltan stock. If the preseason forecast for the Tahltan stock is within ±10% of the average postseason Tahltan stock run size (between 105,972 and 86,704) then the Tahltan and terminal Stikine run size are considered average. If the preseason forecast for the Tahltan stock is greater than 105,972, then the Tahltan and terminal Stikine run size are considered high. If the preseason forecast for the Tahltan stock is less than 86,704, then the Tahltan and terminal Stikine run size are considered low. After statistical week 26, the run size level (average, low, high) depends on the model output of the terminal Stikine stock and is compared to the postseason run size from 1994–2014 for the Stikine stock. The average postseason run size for the terminal Stikine stock is 186,188. If the run size from the model output(s) for statistical weeks 27+ are within ±10% of the average postseason terminal Stikine stock run size (between 167,569 and 204,807) then the run size is considered average. If the run size from the model output(s) for statistical weeks 27+ is greater than 204,807, then the run size is considered high. If the run size from the model output(s) for statistical weeks 27+ is less than 167,569, then the run size is considered low.



[a]abundance level of the Tahltan stock based on the preseason model forecast
[b]abundance level of the Tahltan stock based on the inseason model output

Appendix 6. Decision tree for the Tahltan stock. The abundance is based on the average postseason run size from 1994–2014 (96,338 fish) for the Tahltan stock. If the preseason forecast is within ±10% of the average postseason Tahltan stock run size (between 105,972 and 86,704 fish) then the run size is considered average. If the preseason forecast for the Tahltan stock is greater than 105,972 fish, then the run size is considered high. If the preseason forecast for the Tahltan stock is less than 86,704 fish, then the run size is considered low. After statistical week 26, the run size level (average, low, high) depends on the model output of the Tahltan stock, not the preseason forecast run size.

Appendix 7. Mean percent error (MPE) and mean absolute percent error (MAPE) by stock, season, and abundance level. The two preferred models by MPE and MAPE along with models within ±10% of the postseason run size, with the corresponding percent error, are shown. The season 'SW26' is statistical week 26. Abundance is based on the postseason run size by stock. For the terminal Stikine stock, data was not available until statistical week 26 during the average abundance year 2009, the high abundance years 1996 and 2011, and the low abundance years 1998, 1999, and 2010. Therefore, an inseason forecast was not available until statistical week 27. So the MPE and MAPE analysis for these years was only based on the preseason forecast. For the Tahltan stock, data were not available until statistical week 26 during the average abundance years 2009 and 2011, the high abundance year 1996, and the low abundance years 1998, 1999, and 2010. Therefore, an inseason forecast was not available until statistical week 27. So the MPE and MAPE analysis for these years was only based on the preseason forecast. A model prediction was not available for Model 7 during statistical week 26 for all years and stocks.

Stock	Season	Abundance	Method	Model(MPE or MAPE)
terminal Stikine	SW26	average	MPE	Model 3(10%); Model 5(-7%)
terminal Stikine	SW26	high	MPE	Preseason(-12%,-7%)
terminal Stikine	SW26	low	MPE	Preseason(-4%,1%,8%); Model 1(-9%); Model 2(10%); Model 3(-9%); Model 4(-6%,-3%); Model 5(7%); Model 6(-8%,-5%)
terminal Stikine	early	average	MPE	Model 3(10%); Model 5(-2%); Model 7(1%,8%)
terminal Stikine	early	high	MPE	Preseason(-12%,-7%)
terminal Stikine	early	low	MPE	Preseason(-4%,1%); Model 1(-4%,-2%); Model 2(2%);Model 3(-8%,2%); Model 4(1%); Model 5(-7%,-5%); Model 7(2%,6%)
terminal Stikine	late	average	MPE	Model 1(2%); Model 3(3%); Model 5(2%); Model 7(-5%,0%)
terminal Stikine	late	high	MPE	Preseason(-7%); Model 2(-7%,-5%); Model 7(-6%,1%)
terminal Stikine	late	low	MPE	Preseason(-4%,1%,8%); Model 1(-8%,5%); Model 2(-8%,-4%,-3%,0%,3%); Model 3(-6%,-5%,1%); Model 5(-5%,-1%,1%,3%); Model 6(0%,1%); Model 7(10%)
Tahltan	SW26	average	MPE	Preseason(-14%, 47%)
Tahltan	SW26	high	MPE	Model 2(10%); Model 3(-4%)
Tahltan	SW26	low	MPE	Preseason(-7%, 8%); Model 4(3%); Model 6(-10%)
Tahltan	early	average	MPE	Preseason(-14%); Model 7(-12%)
Tahltan	early	high	MPE	Model 3(2%); Model 5(-8%); Model 7(-9%, 4%)
Tahltan	early	low	MPE	Preseason(-7%,8%); Model 1(1%,5%); Model 2(-1%); Model 5(-2%,1%,6%); Model 6(-2%); Model 7(7%)
Tahltan	late	average	MPE	Model 5(-9%); Model 7(-6%,-3%)
Tahltan	late	high	MPE	Model 3(-1%); Model 5(-9%); Model 6(7%); Model 7(-6%,1%)
Tahltan	late	low	MPE	Preseason(-7%,8%); Model 1(-3%,0%,1%); Model 2(-4%); Model 4(3%,6%); Model 5(-4%); Model 6(-4%,3%,4%,7%)

Appendix 7. Continued.

terminal Stikine	SW26	average	MAPE	Model 3(10%); Model 5(7%)
terminal Stikine	SW26	high	MAPE	Preseason(7%,12%)
terminal Stikine	SW26	low	MAPE	Preseason(1%,4%,8%); Model 1(9%); Model 2(10%); Model 3(9%); Model 4(3%,6%); Model 5(7%);Model 6(5%,8%)
terminal Stikine	early	average	MAPE	Model 3(10%); Model 5(3%); Model 7(7%,8%)
terminal Stikine	early	high	MAPE	Preseason(7%,12%)
terminal Stikine	early	low	MAPE	Preseason(1%,4%,8%); Model 1(2%,6%); Model 2(2%); Model 3(3%,8%); Model 4(4%); Model 5(7%,8%); Model 7(3%)
terminal Stikine	late	average	MAPE	Model 1(2%); Model 3(3%); Model 5(2%); Model 7(3%,5%)
terminal Stikine	late	high	MAPE	Preseason(7%); Model 2(5%,7%); Model 7(4%,6%)
terminal Stikine	late	low	MAPE	Preseason(1%,4%,8%); Model 1(6%,8%); Model 2(2%,3%,4%,8%); Model 3(2%,5%,6%); Model 5(4%,5%) ;Model 6(2%); Model 7(10%)
Tahltan	SW26	average	MAPE	Preseason (14%, 47%)
Tahltan	SW26	high	MAPE	Model 2(10%); Model 3(4%)
Tahltan	SW26	low	MAPE	Preseason(7%,8%); Model 4(3%); Model 6(10%)
Tahltan	early	average	MAPE	Preseason(14%); Model 7(12%)
Tahltan	early	high	MAPE	Model 3(6%); Model 5(8%); Model 7(5%,9%)
Tahltan	early	low	MAPE	Preseason(7%,8%); Model 1(1%,5%); Model 5(2%)
Tahltan	late	average	MAPE	Model 5(9%); Model 7(3%,8%)
Tahltan	late	high	MAPE	Model 3(1%); Model 5(9%); Model 7(1%,8%)
Tahltan	late	low	MAPE	Preseason(7%,8%); Model 1(1%,3%); Model 2(4%,10%); Model 4(6%); Model 6(7%)

Appendix 8. Mean percent error (MPE) and mean absolute percent error (MAPE) by stock, season, and abundance level. The two preferred models by MPE and MAPE along with models within ±10% of the postseason run size, with the corresponding percent error, are shown. The season 'SW26' is statistical week 26. Abundance is based on the postseason run size by stock. A model prediction was not available for Model 7 during statistical week 26 for all years.

		Statistical		*SFMM Catch (new trigger)*			*SFMM CPUE (new trigger)*		*SMM-Historical (with Tuya correction)*		
Stock	Year	Week	Method	Model1	Model2	Model5	Model3	Model4	Model6	Model7	Preseason
Stikine	2016	26	MPE	-62%	-45%	-44%	-58%	-63%	-57%		-11%
	2016	27–28	MPE	-60%	-30%	-29%	-54%	-32%	-46%	-38%	-11%
	2016	29–33	MPE	-50%	-24%	-11%	-41%	-31%	-28%	-17%	-11%
	2015	26	MPE	-47%	-58%	-46%	-46%	-74%	-60%		-2%
	2015	27–28	MPE	-38%	-51%	-42%	-33%	-66%	-45%	-35%	-2%
	2015	29–33	MPE	-25%	-36%	-16%	-18%	-50%	-8%	-1%	-2%
Tahltan	2016	26	MPE	-77%	-59%	-65%	-73%	-72%	-79%		-17%
	2016	27–28	MPE	-76%	-40%	-36%	-72%	-34%	-55%	-46%	-17%
	2016	29–33	MPE	-70%	-32%	-9%	-65%	-34%	-16%	-10%	-17%
	2015	26	MPE	-57%	-68%	-62%	-55%	-79%	-77%		10%
	2015	27–28	MPE	-52%	-63%	-56%	-49%	-73%	-62%	-47%	10%
	2015	29–33	MPE	-47%	-44%	-9%	-45%	-52%	10%	15%	10%
Stikine	2016	26	MAPE	62%	45%	44%	58%	63%	57%		11%
	2016	27–28	MAPE	60%	30%	29%	54%	32%	46%	38%	11%
	2016	29–33	MAPE	50%	24%	11%	41%	31%	28%	18%	11%
	2015	26	MAPE	47%	58%	46%	46%	74%	60%		2%
	2015	27–28	MAPE	38%	51%	42%	33%	66%	45%	35%	2%
	2015	29–33	MAPE	25%	36%	16%	18%	50%	9%	10%	2%
Tahltan	2016	26	MAPE	77%	59%	65%	73%	72%	79%		17%
	2016	27–28	MAPE	76%	40%	36%	72%	34%	55%	46%	17%
	2016	29–33	MAPE	70%	32%	9%	65%	34%	16%	13%	17%
	2015	26	MAPE	57%	68%	62%	55%	79%	77%		10%
	2015	27–28	MAPE	52%	63%	56%	49%	73%	62%	47%	10%
	2015	29–33	MAPE	47%	44%	10%	45%	52%	18%	17%	10%