SCIENCE INFORMATION TO SUPPORT CONSULTATIONS ON BC CHINOOK SALMON FISHERY MANAGEMENT MEASURES IN 2018

Context

The 2018 draft Integrated Fisheries Management Plans (IFMP) for Pacific Salmon include a number of proposed fisheries management measures for Chinook Salmon (*Oncorhynchus tshawytscha*) in 2018. Fisheries Management has requested that DFO Science provide information (trends in abundance, productivity and current exploitation) for key Chinook Salmon management units to support consultations on potential additional BC Chinook Salmon fishery management measures in 2018.

This Science Response (SR) represents the best available science information on Chinook Salmon at present compiled on a short timeline. Therefore, the data and interpretations presented here are subject to change as new analytical results and information become available.

Background

The wide variation in early life history, age of maturation, ocean distribution, return timing, and other characteristics make Chinook Salmon among the most resilient salmon. However, large-scale patterns of environmental change and increased environmental variability have resulted in broad declines in productivity[1] of Chinook Salmon across their range in recent decades. Potential effects of recent events, such as the persistence of the warm ocean water 'blob' which formed in the North Pacific in 2014 and moved onshore in 2015, and El Niño conditions in early 2016, have lowered expectations for returns of Chinook Salmon in 2018 (PFMC 2018), and reduced returns are expected for several years.

The decline in productivity and abundance of many southern Chinook Salmon stocks started with consecutive large El Niño events in the early and late 1990s. Stock groups such as West Coast Vancouver Island and Strait of Georgia experienced dramatic declines in marine survival rates and resulting productivity. Other stocks such as South Thompson ocean type summer run timing Chinook Salmon showed higher resilience to these changes, but even these stocks have recently shown signs of decline in abundance and productivity. The most recent integrated biological status assessment of Southern BC Chinook Salmon identified 11 out of 15 conservation units (CU) as 'red' (i.e. spawning abundance is likely below the lower biological benchmark) out of 15 CUs for which consensus was reached on an integrated status

[1] Productivity is the intrinsic rate of growth of a population, estimated from the observed relationship between spawners and adult recruits over time.

designation; an additional nine CUs were designated as data deficient and status could not be evaluated for 11 CUs (DFO 2016).

Northern Chinook Salmon stocks, which in the 1990s and 2000s appeared to maintain a higher productivity, are showing more recent declines in abundance and productivity. Recent declines are also apparent for the South Thompson Chinook Salmon and other Fraser stocks, especially the stream type spring and summer timing stocks. In contrast, Southern BC coastal stocks, which had the greatest initial decline in productivity and remained at low levels, have recently exhibited some increases in abundance and marine survival rates. Marine survival rates have increased in east coast Vancouver Island Chinook Salmon, but remain well below average historic levels. Similarly, while recent marine survival rates of West Coast Vancouver Island stocks appear to be near average historic levels, low abundance of local populations remains a concern in areas with relatively minor hatchery supplementation such as Clayoquot Sound.

Dorner et al. (2017) associated the broad pattern of declines in Chinook Salmon productivity, from Alaska to Oregon, with unfavourable large-scale climatic change in the North Pacific Gyre Oscillation and the North Pacific Current as well as increased frequency of large scale events such as El Niño, and in 2014-15, the persistence of warm ocean waters in ‘the blob’. Other researchers such as Ohlberger et al. (2018) suggest that the biological mechanisms behind the decline in productivity also include changes in population demographics, such as younger age-at-maturity, reduced size-at-age, and reduced fecundity of female spawners. Some of these demographic effects are now being observed in BC Chinook Salmon populations (Table 1). Fishery removals of large Chinook Salmon is likely a contributing factor to these demographic changes, as is predation by marine mammals such as seals, sea lions, and killer whales. In addition, degradation of freshwater spawning and rearing habitat likely contributes to the apparent declines in productivity observed across many BC management units.

Key observational data in British Columbia are derived from ‘indicator’ stocks distributed throughout BC. Spawning abundance is estimated for each indicator stock using methods ranging from high precision fence counts to lower precision escapement indicators. Coded Wire Tag (CWT) indicator stocks, generally associated with hatcheries, provide information such as marine survival, fishery exploitation rates, and ocean distribution information. These data are tracked by the Pacific Salmon Commission and results are accessible through the publications of the Chinook Technical Committee. The key Chinook Salmon management units under consideration and associated indicator stock data are summarized in Table 2 The information from these indicator stocks shows regional variation in escapement abundance and marine survival rate trends (Figure 1 and 2). At finer spatial scales, local habitat and ecosystem factors may explain some variations in abundance. In some cases, such as the Cowichan River Chinook Salmon stock, watershed and habitat restoration may be important factors in recent increased productivity and abundance.

Productivity is directly related to sustainable exploitation rates (E_{MSY}); when productivity declines fishery exploitation should be reduced[2]. Chinook Salmon productivity is estimated to have declined about 40% since the early 1980s across all the BC indicator stocks (Riddell et al. 2013). The associated reduction in sustainable exploitation rate depends on the initial

[2] E_{MSY}, or sustainable exploitation rate is derived from the ‘Ricker a’ parameter, an estimate of productivity, by numerical approximation (Hilborn and Walters 1992).

productivity of the stock. In response to declining productivity, marine area fishery catch and exploitation were reduced starting with the first Pacific Salmon Treaty in 1985. In southern BC, total Chinook Salmon catch was reduced by 78% from the early 1980s (Table 3). In northern BC, total marine Chinook Salmon catch was reduced by about 47% from the early 1980s (Table 4). Resulting annual exploitation rates were reduced by an average of 44% for BC CWT indicator stocks (Table 5 and Figure 3). However, for some BC stocks, Dorner et al. (2017) suggest there have been further declines in productivity (i.e. over the last 5 brood years) ranging from about 15 to 66% (Table 6).

Analysis and Response

Fishery Managers requested DFO Science provide and organize available data and other information to address the questions outlined below. These responses will facilitate consultation with First Nations, Industry and other stakeholders in the development of additional fishery management measures that may be required to address declines in Chinook Salmon stock productivity.

Q1. Provide information to determine which stocks require a reduction in fishery exploitation.

Criteria that may be used to determine which stocks may require further management measures to adjust fishery impacts include:

- Recent average exploitation rates relative to estimates of sustainable exploitation (E_{MSY}) given current stock productivity (Table 6);
- Level of recent escapement relative to management goals (Table 7);
- Evidence of recent declines in marine survival rate (Figure 2);
- Identification of other fishery related impacts, such as selective fishing practices, that may be contributing to declines in stock productivity.

A significant issue for these preliminary analyses is that most of the data used to estimate these management parameters are from data-rich stocks. In all cases, there are significant sources of uncertainty with the available data and analysis of management parameters. Further work is required to develop and evaluate stock assessment methods that can be applied to more data limited stocks. Science is currently developing these methods and more complete information to inform data limited assessments and risk-appropriate management responses will be available through future work.

Q2. What tools and information can Science provide to inform trade-offs associated with a range of potential reductions in fishery exploitation rates?

Reductions in fishery exploitation rates to achieve stock rebuilding objectives and fishery objectives inherently involve management choices such as rebuilding times and risk tolerance (i.e., the probability of achieving those objectives). Appropriate tools to inform decisions regarding the trade-offs are not currently available; however development of these tools is already underway within DFO Science. For example, simulations or retrospective analyses can identify benefits and costs associated with a range of fishery reductions and management strategies. Retrospective analysis or simulations will require management input in the form of development of target objectives for evaluation, and the identification of potential management strategies to achieve those objectives. Co-management processes, such as the Southern BC

Chinook Initiative, are recommended as appropriate venues to conduct such management strategy evaluations due to their inclusivity and broad representation.

Q3. What information can Science provide to inform development of management measures if it is determined reductions are required?

Declines as described in the Background section may warrant either reduction in exploitation rates and/or measures to reduce fishery related impacts that may contribute to negative demographic changes in populations (e.g. harvest practices that selectively remove older and larger fish). Strategies for reducing fishing impacts on stocks of concern may include implementing measures such as reductions in total allowable catch or fishing effort; area closures in times when stocks of concern are prevalent; bag limits; size limits; and other gear restrictions (e.g., net mesh size). Once the stocks and targets for potential reductions are identified, more specific input can be provided by Science to inform development of specific management measures. Methods used to assess proposed fishery measures on a by-fishery basis will depend on how proposed reductions are implemented. Science can use data including historical fishery impacts, stock distribution and timing, size at catch and fishing effort to model expected reductions in fishery impacts. However, these plenary models are limited by the available data and information. This limitation is particularly important for data-limited stocks or CUs because the scale of reductions that can be modeled is directly related to the quality of the data inputs; the data are generally inadequate to model finer-scale or incremental reductions in fisheries associated with data-limited management units.

Q4. What are the potential metrics/indicators that could be used to assess whether or not objectives have been met? Provide commentary on strengths and weaknesses of proposed assessment methods.

Metrics/indicators that could be used to assess whether or not objectives have been met should be similar to the criteria used to set targets for reduction. That is, for the management units in which management actions are taken, performance metrics could include:

- A reduction in observed exploitation rate to a level consistent with E_{MSY};
- An increase in escapement of indicator stocks within the management unit (i.e., observe rebuilding towards a target);
- An observed reduction in size-selective fishery impacts.

In all cases, the sources of uncertainty associated with potential metrics and data deficiency should be considered and targets set accordingly. The ability to assess the achievement of specific reduction targets post-season on a by-fishery basis is dependent on catch monitoring and sampling programs conducted during the fishing season. Current sampling programs in many fisheries are inadequate to evaluate incremental reductions in fishery impacts and it may be impractical to increase sampling in order to assess incremental reductions. Therefore, the choice of performance metrics/indicators identified on a by-fishery basis that are inconsistent with current stock assessment and catch monitoring frameworks (or highly sensitive to the uncertainty of the available data) may require additional monitoring and sampling programs. As well, many escapement programs produce relatively imprecise estimates of spawning abundance. Finally, detecting measurable improvements associated with fishery actions on annual basis may not be possible given inter-annual variation in environmental conditions that influence marine survival rate and stock abundance.

Conclusions

1. Information and work required to support recommended actions has not been completed. While sources of uncertainty are identified in this preliminary response to inform the decision-making process, these uncertainties have not been presented with sufficient detail to fully understand their impact on the decision-making context. Further work is required to describe uncertainties the data, and evaluate how sensitive the analysis is to the uncertainties.
2. Science, working with other DFO sectors and through various joint technical processes involving First Nations and stakeholders, is currently completing work that will more adequately inform the decision-making context. This work includes developing stock assessment methods that can be applied for more data limited situations, developing robust methods for estimating sustainable exploitation rates, and developing evaluation tools that can be used to inform management trade-offs when setting fishery and stock objectives for rebuilding. There is also a technical review underway to evaluate management actions implemented in 2012 to reduce fishery impacts on Fraser River Chinook Salmon. As this work is completed, the information that Science can provide to managers will be more comprehensive and robust.
3. Ultimately, a more strategic and integrated ecosystem response to address conservation for stocks of concern and inform rebuilding plans is needed. Such a response involves assessment of all potential factors limiting stock productivity, including impacts in freshwater habitat. Particularly when exploitation rates are already reduced and near or below sustainable exploitation rates and stock productivity is low, rebuilding times may be relatively insensitive to reductions in fishery impacts. Efforts that may be directed towards implementing and assessing relatively minor changes in fishery impacts may distract from broader stock assessment activities related to understanding and explaining why stock productivity has declined.

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Sources of information

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Appendix

Table 1. Summary of recent trends in characteristics for Transboundary and BC management units.

Management Unit	Stock	2017 Escapement (relative to 2003-13 avg)	Escapement Trend (3 generations)	Survival (2007-2011 brood year avg relative to 1980-1990 avg)	Generation Time (Decline rate)	Female Length (Trend)	Fecundity (Trend)
Transboundary	Alsek	-62%		Unk	Unk	Unk	Unk
	Taku	-63%		-39%	Declining	Unk	Unk
	Stikine	-53%		Unk	Unk	Unk	Unk
Northern BC	Nass	-72%		Unk	Unk	Unk	Unk
	Skeena (Kitsumkalum)	-72%		-36%	-0.025	Declining age-5 & -6	Unk
Central BC	Atnarko			28%	-0.015	Unk	Unk
Upper Georgia Strait	NEVI (Quinsam)		-58%	-81%	-0.017	Declining age-4 & -5	Declining since 2011
	Big Qualicum		TBD*	-44%	-0.008	Declining age-3 & -4	Declining since 2011
	Puntledge Summers		TBD*	-9%	-0.009	Unk	Unk
Lower Georgia Strait	Cowichan	405%	TBD*	-73%	-0.016	Unk	Stable
	Nanaimo		TBD*				
WCVI	WCVI aggregate	123%	55% North CU***** -18% South CU***** -41% Nootka &Kyuquot CU*****	-73%	stable	Unk	Unk
Fraser Spring 4_2	Fraser Spring 1.2 (Nicola)	-3%	DD*	-55%	stable	Declining, age-4	Unk
Fraser Spring 5_2	Fraser Spring 1.3	-52%	DD*	Unk	Unk	Unk	Unk
Fraser Summer 5_2	Fraser Summer 1.3 (Chilko)	-61%	DD*	Unk	Unk	Declining, age-5	Unk
Fraser Summer 4_1	Fraser Summer 0.3	-24%	-34% Shuswap CU -14% South Thompson CU	-42%	-0.020	Declining age-3, -4, -5	Declining
Fraser Fall 4_1	Fraser Fall	-57%	-51%*****	-45%	-0.016	Declining	Unk

(Harrison)	age-3, -4, -5

*Denote values obtained from DFO 2016: trends as estimated from a linear trend in $\log_e$(spawner abundances) over 3 generations. TBD denotes CUs for which integrated status evaluation was not possible, DD denotes CUs that were determined to be data deficient. The negative trends are expected to increase with inclusion of data from more recent years.

Table 2. Key observational data used to inform the analysis for Transboundary and BC Chinook management units.

Chinook Management Unit	Life History Type	CWT Indicators	CTC Model Stock	Escapement Indicators
Transboundary	Stream		Transboundary	Alsek, Taku, Stikine
North Coast	Stream	Kitsumkalum	Northern BC	Nass, Skeena, Kitsumkalum
Central BC	Ocean	Atnarko	Central BC	Atnarko
Upper Georgia Strait	Ocean	Quinsam Hatchery	Upper Georgia Strait	
		Puntledge Hatchery	Middle Georgia Strait	
		Big Qualicum Hatchery		
Lower Georgia Strait	Ocean	Cowichan River	Lower Georgia Strait	Cowichan, Nanaimo
West Coast Vancouver Island	Ocean	Robertson Creek Hatchery	WCVI Natural WCVI Hatchery	Aggregate index.
Fraser Spring 4_2	Stream	Nicola River	Fraser Early Springs 1.2	Aggregate (Fraser run reconstruction index)
Fraser Spring 5_2	Stream		Fraser Early Springs 1.3	Aggregate (Fraser run reconstruction index)
Fraser Summer 5_2	Stream		Fraser Early Summers 1.3	Aggregate (Fraser run reconstruction index)
Fraser Summer 4_1	Ocean	Lower Shuswap	Fraser Early Summers 0.3	Aggregate (Fraser run reconstruction index)
Fraser Fall 4_1	Ocean	Harrison River	Fraser Late Natural	Harrison River
		Chilliwack Hatchery	Fraser Late Hatchery	

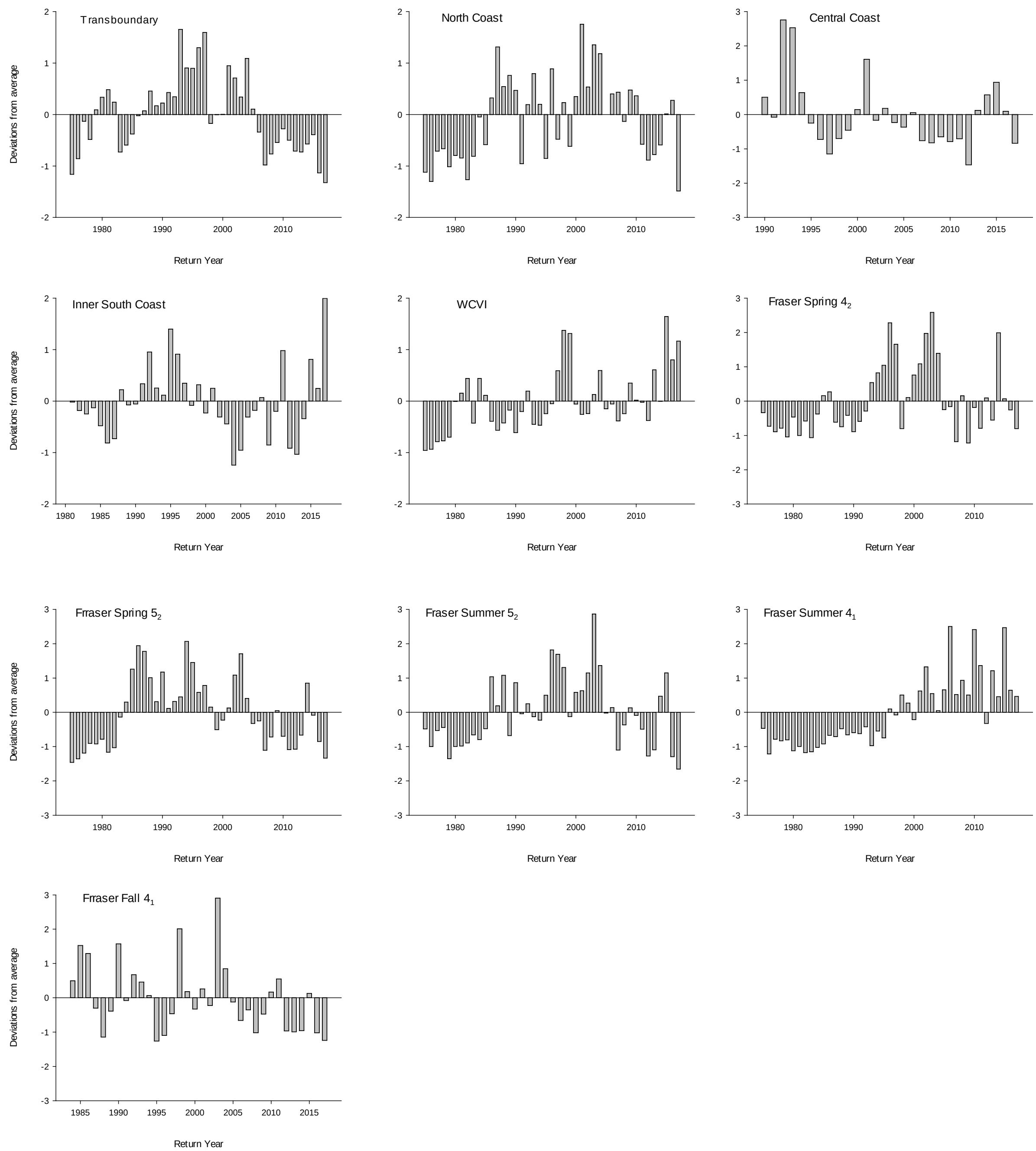

Figure 1. Trends in escapement based on average deviations (Z-scores) for 10 Chinook management units, 1975-2017. Stocks included in the analysis are Alsek, Taku, Stikine, Nass, Skeena, Kitsumkalum, WCVI-aggregate, Cowichan, Fraser Spring 4_2, Spring $5_{2,}$ Summer 5_2 and Summer 4_1 aggregates and Harrison (Fraser Fall 4_1). Note x-axis is not consistent throughout figure panels.

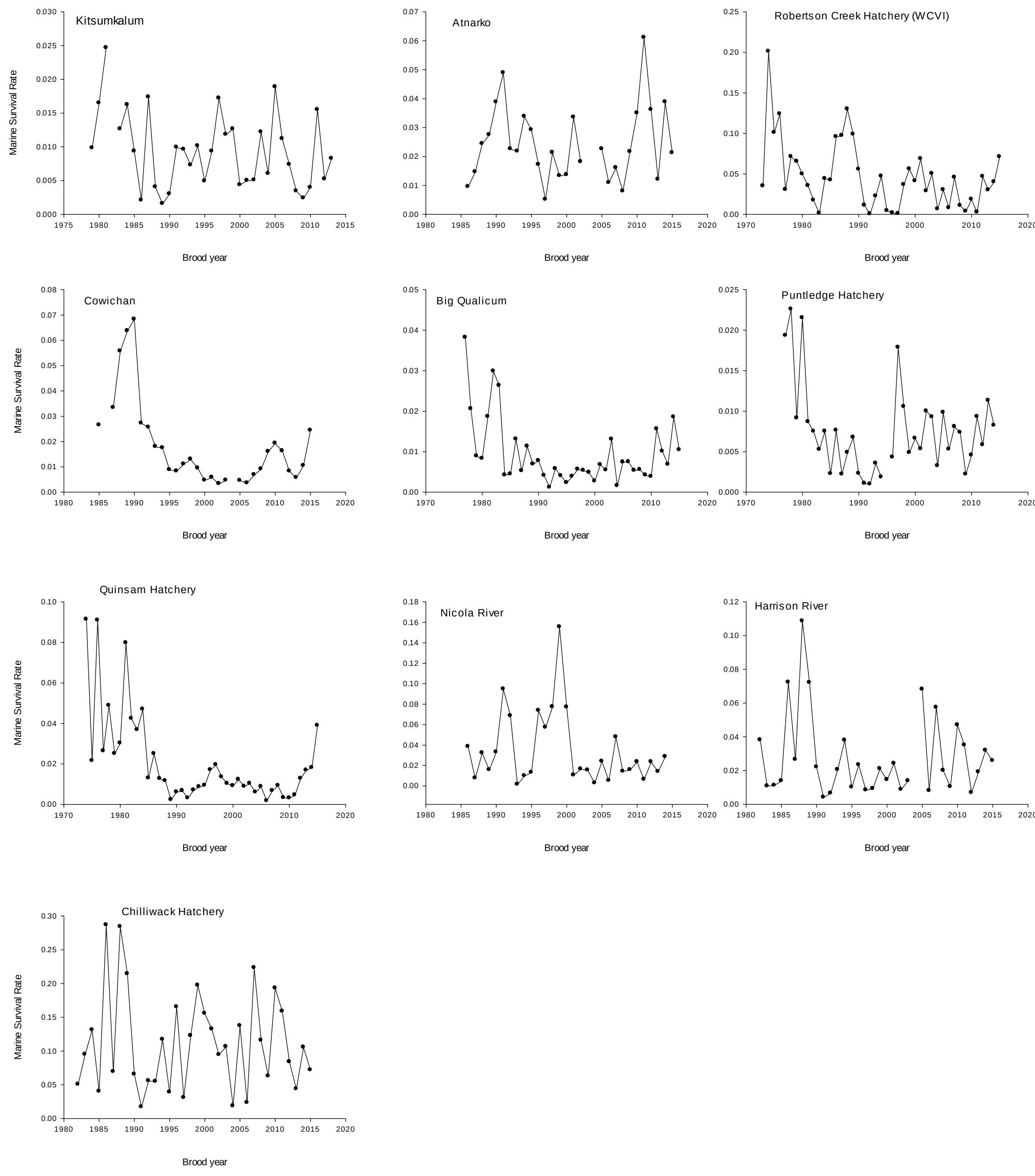

Figure 2. Trends in brood year marine survival rate to age 2 estimated from coded-wire-tag indicator stocks across BC. Note: marine survival rate scale (y-axis) is not consistent throughout figure panels. Incomplete brood-year data is depicted from 2011 to 2015, and is based on model estimates.

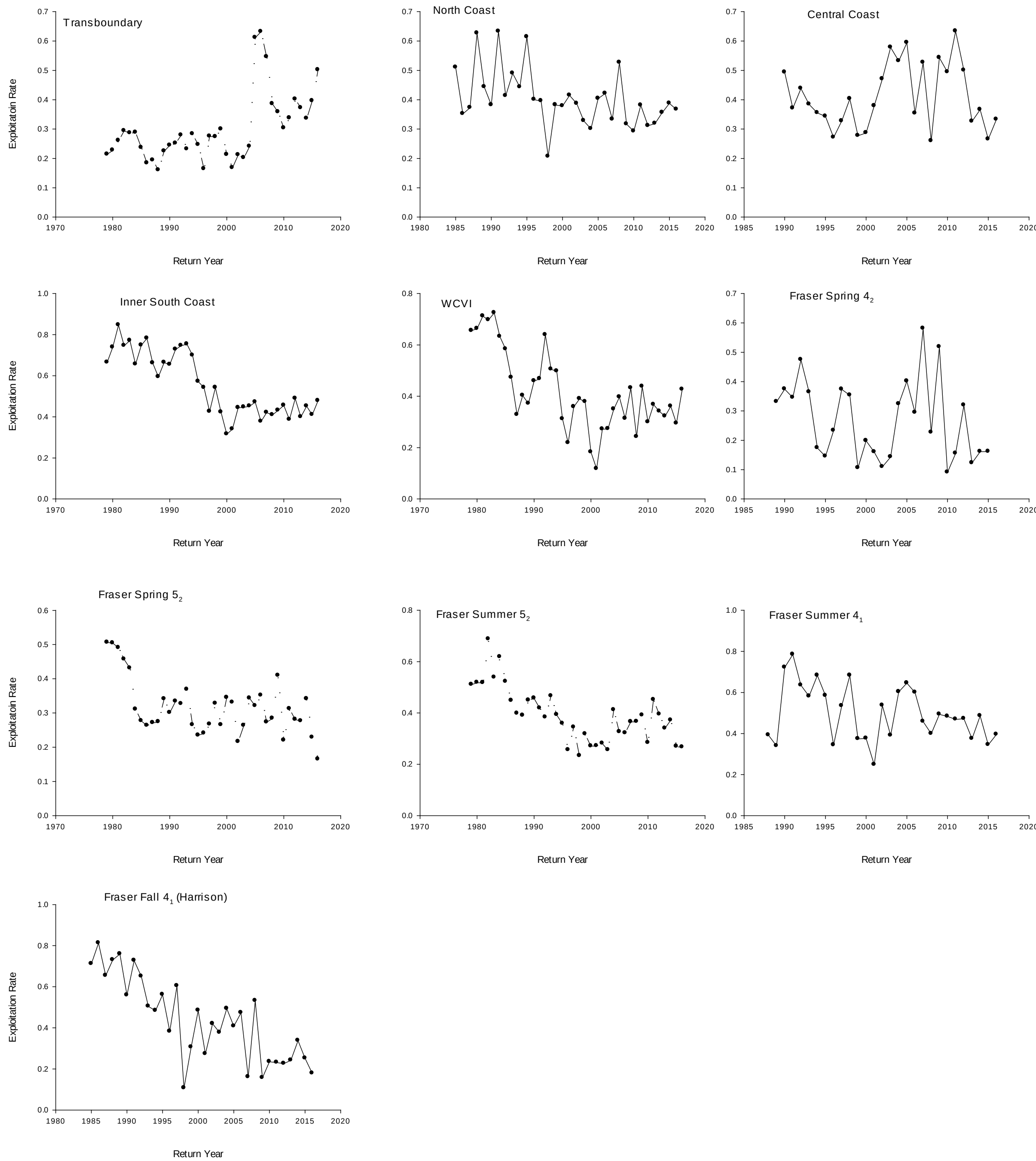

Figure 3. Trends in annual in exploitation rate for Transboundary and BC Chinook management units. The exploitation rate represents total mortality (i.e. includes estimated mortality from releases as well as landed catch). For some management units with more than one CWT indicator, annual observations are averaged. For the Transboundary, Fraser Spring 5_2 and Summer 5_2 management units, the trend represents modelled output from the CTC coast-wide chinook model (dashed lines). The estimates include age 2 fish.

Table 1. Estimated landed catch of Chinook in Southern BC marine fisheries, 1975 – 2016.

Catch Years	SBC ISBM First Nations marine	SBC ISBM Net	SBC ISBM Sport	SBC ISBM Troll	WCVI AABM Troll	-WCVI AABM Sport	Total Catch	% Change Relative to 1975-84
1975 to 84:	No Est	73,170	365,639	214,393	511,790	No Est	1,164,992	
1985 to 98:	404	34,710	190,295	26,300	221,065	6,208	478,982	-59%
1999 to 08:	764	10,713	97,896	425	104,817	37,729	252,344	-78%
2009 to 16:	1,340	11,229	104,275	0	81,596	58,494	256,934	-78%

Table 2. Estimated landed catch of Chinook in Northern BC marine fisheries, 1975 - 2016.

Catch Years	NBC ISBM First Nations	NBC ISBM Net	NBC ISBM Sport	NBC ISBM Troll	NBC AABM Sport and Troll	Total Catch	% Change Relative to 1975-84
1975 to 84:	14,564	60,489	10,100	101,221	167,571	353,945	
1985 to 98:	27,038	40,090	14,148	26,594	154,977	262,847	-26%
1999 to 08:	23,310	18,431	18,055	256	144,532	204,584	-42%
2009 to 16:	14,529	6,797	19,523	0	146,369	187,218	-47%

Table 3. Estimated catch year annual exploitation rates (20011-2016) for Transboundary and BC Chinook management units relative to historic levels (1980-1989). Annual exploitation rate estimates represent total mortality (i.e. include estimated release mortality). For some management units, estimates are modelled outputs form the Chinook Technical Committee coast-wide model. All estimates include Age 2 fish.

Management Unit	CWT Indicator Stock / Model Stock	Average ER 1980-89	Average ER 2011-2016	% Change
Transboundary	*CTC Model Output*	*24%*	*39%*	66%
Northern BC	Kitsumkalum River	46%	35%	-23%
Central BC	Atnarko River	n/a	40%	n/a
Upper Georgia Strait	Phillips*			
	Big Qualicum Hatchery	76%	43%	-43%
	Puntledge Hatchery	66%	37%	-43%
	Quinsam Hatchery	73%	38%	-48%
Lower Georgia Strait	Cowichan River	79%	55%	-30%
	Nanaimo River*			
WCVI	Robertson Creek Hatchery	56%	35%	-37%
Fraser Spring 4_2	Nicola River	33%	18%	-44%
Fraser Spring 5_2	*CTC Model Output*	*36%*	*26%*	*-28%*
Fraser Summer 5_2	*CTC Model Output*	*51%*	*35%*	*-31%*
Fraser Summer 4_1	Lower Shuswap River	37%	42%	16%
	Mid Shuswap	n/a	46%	n/a
Fraser Fall 4_1	Harrison River	73%	24%	-67%

* denotes ER calculations from previous year's assessment

Table 6. Summary of the intrinsic productivity (Ricker.a) and sustainable exploitation rates (EMSY) for select management units based on Dorner et al.'s (2017) Chinook productivity analysis for their full time series and for the recent 5 brood years up to 2008 for B.C. stocks. Also displayed are recent CWT exploitation rates or modelled (italicized) for Transboundary and BC chinook management units. Further work is required to estimate long term and recent productivity for several BC management units following the method applied by Dorner et al. (2017).

Management Unit	Indicator Stock	Long term prod. (Ricker a)	Recent prod. (Ricker a)	Relative Change in prod.	Long term E_{MSY}	Recent E_{MSY}	Relative change E_{MSY}	Average ER (2011 – 16)
Transboundary	Alsek	0.74	0.25	-66%	33%	12%	-64%	
	Stikine	1.45	1.50	3%	58%	59%	2%	*39%*
	Taku	0.94	0.70	-26%	41%	31%	-23%	
Northern BC	Kitsumkalum	1.51	1.28	-15%	60%	53%	-12%	35%
Central BC	Atnarko*		2.24		76%	40%		40%
Upper Georgia Strait	Phillips							
	Big Qualicum							43%
	Puntledge							37%
	Quinsam							38%
Lower Georgia Strait	Cowichan							58%
	Nanaimo							
WCVI	Robertson Creek							35%
Fraser Spring 4_2	Nicola	1.6	1.59	-1%	62%	62%	0%	18%
Fraser Spring 5_2								*26%*
Fraser Summer 5_2	Fraser Early							*35%*
Fraser Summer 4_1	Shuswap							42% to 46%
Fraser Fall 4_1	Harrison	1.18	0.59	-50%	49%	27%	-45%	24%

*Atnarko productivity analysis is a S-R assessment that has 1 alpha parameter which is different from the method used by Dorner et al (2017).

Table 7. Escapement for indicator stocks relative to management goals (estimated spawners producing maximum sustained yield (S_{MSY}) for Transboundary and BC management units. Note in all cases there is significant uncertainty in the estimated S_{MSY} values and for most management units the estimates are preliminary and require further review.

Management Unit	Stock	Abundance Levels			Escapement		
		Lower	Upper	Type	Long-term AVG	Last 5 Years	2017
Transboundary	Alsek	3,500	5,300	S_{MSY}	8,586	3,672	1,740
	Stikine	19,000	36,000	S_{MSY}	39,843	18,304	8,754
	Taku	14,000	28,000	S_{MSY}	24,635	15,997	7,206
Northern BC	Nass	16,500		S_{MSY}	17,344	11,411	4,984
	Kitsumkalum	8,621		S_{MSY}	14,377	14,396	4,943
Central BC	Atnarko	5,009		S_{MSY}	9,307	10,127	5,464
Inner S. Coast	Cowichan	6,500		S_{MSY}	5,870	9,394	24,609
WCVI	*Aggregate*	15,000		S_{MSY}	11,304	17,727	17,163
Fraser Spring 4_2	*Aggregate*	22,146		S_{MSY}	10,693	11,317	5,105
Fraser Spring 5_2	*Aggregate*	42,165		S_{MSY}	18,916	23,805	8,154
Fraser Summer 5_2	*Aggregate*	23,567		S_{MSY}	16,070	20,047	6,459
Fraser Summer 4_1	*Aggregate*	120,000	322,000	S_{MSY}	63,006	111,950	84,470
Fraser Fall 4_1	Harrison	75,100	98,500	S_{MSY}	94,958	50,791	29,799

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