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RECOVERY POTENTIAL ASSESSMENT FOR 11 DESIGNATABLE UNITS OF FRASER RIVER CHINOOK SALMON, *ONCORHYNCHUS TSHAWYTSCHA*, PART 2: ELEMENTS 12 TO 22

Chinook Salmon adult spawning phase. Image credit: Fisheries and Oceans Canada

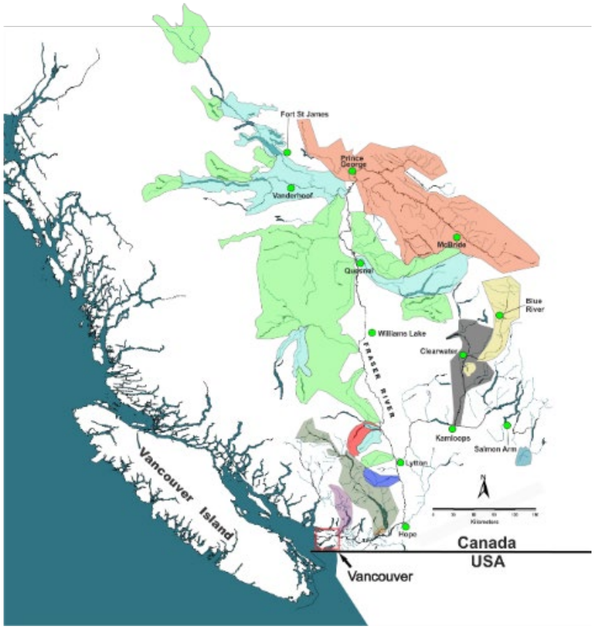

Figure 1. Map of the Fraser River watershed showing the natal areas of the 11 Designatable Units.

Context:

Eleven Designatable Units of southern British Columbia (BC) Chinook Salmon that spawn in the Fraser River drainage were designated as either Threatened or Endangered in November 2018 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Fisheries and Oceans Canada (DFO) Science Branch was asked to complete a Recovery Potential Assessment (RPA) to provide science advice to inform the potential addition of these Fraser populations to Schedule 1 of the Species at Risk Act (SARA). The advice in the RPA will be used to inform both scientific and socio-economic aspects of the listing process, development of a recovery strategy and action plan, support decision making with regards to the issuance of permits or agreements, and the formulation of exemptions and related conditions if listed under SARA. The advice generated via this process will update and/or consolidate any existing advice regarding these populations of southern BC Chinook Salmon.

This Science Advisory Report is from the July 7-9, 2020, October 1, 2020, and March 11-12, 2021 regional peer review on the Recovery Potential Assessment – Fraser River Chinook Salmon (Oncorhynchus tshawytscha) – Eleven Designatable Units (Elements 12 to 22). Additional publications from these meetings will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

July 2021

SUMMARY

- This is the second of two parts of a Recovery Potential Assessment (RPA) for 11 Designatable Units (DUs) of southern British Columbia (BC) Chinook Salmon that spawn in the Fraser River watershed. The primary focus of this portion of the RPA is to propose recovery targets, predict short-term population trends, evaluate mitigation options, and develop an allowable harm assessment.
- DUs were assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in November 2018 (COSEWIC 2019). Four were designated as *Threatened* and seven were designated as *Endangered*. Declining trends in abundance have continued for these DUs since the COSEWIC assessment. The assessed DUs are:
    - Lower Fraser River Ocean Fall - Harrison (DU2)
    - Lower Fraser River Stream Summer - Upper Pitt (DU4)
    - Lower Fraser River Stream Summer (DU5)
    - Middle Fraser River Stream Spring - Nahatlatch (DU7)
    - Middle Fraser River Stream Fall - Portage (DU8)
    - Middle Fraser River Stream Spring (DU9)
    - Middle Fraser River Stream Summer (DU10)
    - Upper Fraser River Stream Spring (DU11)
    - South Thompson Stream Summer - Bessette (DU14)
    - North Thompson Stream Spring (DU16)
    - North Thompson Stream Summer (DU17)
- For each DU two recovery targets were proposed:
    - A **survival** target that approximates conditions such that a DU would not be characterized as *Endangered* or *Threatened* by COSEWIC.
    - A **recovery** target at which the DU's long term persistence is secured.

  Each target was comprised of two benchmarks: generational average spawner abundance and the three-generation trend in spawner abundance.
- For DU2, a 30-year series of spawner and recruitment data (brood years 1984-2013) was used in a population model to estimate recent population parameters. That analysis suggested that population productivity has been variable, but has declined over time.
- For DU2, abundance benchmarks were based on average long-term population productivity. However, alternative approaches for estimating benchmarks when productivity is varying were discussed. For the other DUs a habitat method based on a meta-analysis of data from other populations was used to estimate abundance benchmarks; there is more uncertainty surrounding these benchmarks than those estimated for DU2.
- A projection model was used to simulate DU2 abundances over the next three generations (2020-2031) under the base case assumption that the productivity estimated for the most recent four years for which complete data were available (brood years 2010-2013) and recent United States (US) and Canadian salmon fishery harvest rates (catch years 2009-2015) will continue unchanged into the future. The modelled population was As Likely as Not (33%-66%) to meet the survival target, and Unlikely (10%-33%) to meet the recovery target under base case conditions.
- At base case harvest rates, the projection model predicts that an increase in productivity

over 12 years of at least 40% is required for the model population (DU2) to be Likely (>66%) to reach the survival target; a productivity increase of at least 140% is needed to be Likely to reach the recovery target. Conversely, at base case productivity the projection model predicts that with US harvest rates held constant, a decrease in Canadian salmon harvest rates of at least 90% is required for the model population to be Likely (>66%) to reach the survival target. At the base case productivity with no Canadian salmon harvest, the probability of reaching the recovery target was 41%.

- There were insufficient data for the other ten DUs to conduct an analysis similar to that used for DU2. However, the rate of decline in abundance observed in most of these DUs and the threats identified in Part 1 of the RPA suggests long-term declines in productivity are occurring, and it was judged these DUs are unlikely to reach either the survival or recovery targets in three generations if current conditions continue. For DUs 9, 10, and 11, migration to spawning areas is currently impeded by the Big Bar landslide in the Fraser River and these DUs are likely to suffer greater declines in the short term than the other DUs. Mitigation measures are underway to alleviate the slide but their long-term effectiveness is unknown.
- A preliminary list of mitigation measures was developed that could address threats identified in Part 1 of the RPA. These measures may increase survival or productivity but information was not available to assess their effectiveness, nor their potential to increase the probability of meeting the recovery targets.
- For DU2, under base case values for harvest and productivity, human-induced mortality and other sources of harm identified in the threats assessment should be significantly reduced from base case mortality so as to not jeopardize recovery.
- Many stream-type DUs have experienced more severe declines in abundance than DU2 and some have small populations (<1000 spawners). For DUs 7, 8, and 14, the area of spawning habitat is limited and current populations are very small. As noted above, for DUs 9, 10, and 11, additional concern due to the Big Bar landslide will remain until the impacts from the slide are alleviated. Harm is likely to continue to jeopardize recovery. Therefore, to promote the survival and recovery of these DUs, it is advised that all future and ongoing human-induced harm should be prevented.
- Predicting future changes in salmon productivity and abundance is challenging in the current era of rapidly changing conditions, as there is significant uncertainty in both the future state of natural environments and the ability to mitigate anthropogenic effects. Spawner abundance and productivity should be monitored closely to determine if changes are occurring, and model assumptions, population projections, and science advice should be re-visited as warranted.
- Data to reliably monitor changes in population status exist for DU2, but for most of the other DUs, abundance estimates are less reliable, consistent estimates of exploitation rates are not available, and basic biological attributes of spawning populations are not well known. Increased understanding of these populations is needed for recovery planning.

INTRODUCTION

Rationale for Recovery Potential Assessment

After the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses an aquatic species as *Threatened, Endangered* or *Extirpated*, Fisheries and Oceans Canada (DFO), as the responsible jurisdiction for aquatic species under the *Species at Risk Act* (SARA), undertakes several actions to support implementation of the Act. Many of these actions require scientific information on the current status of the species, threats to its survival and recovery, and the species' potential for recovery. Formulation of this scientific advice has typically been developed through a Recovery Potential Assessment (RPA) following the COSEWIC assessment. This timing allows for the consideration of peer-reviewed scientific analyses into SARA processes, including the decision whether or not to list a species on Schedule 1, and during recovery planning if the species is listed.

In November 2018, COSEWIC (2019) assessed the status of 16 of 28 Chinook Salmon Designatable Units (DUs) in southern British Columbia (BC) that were considered to have received no or little artificial supplementation over the past three generations, or were previously considered by DFO to have insufficient data for assessment. This assessment led to the status assignment of eight DUs as *Endangered*, four as *Threatened*, one as *of Special Concern,* and one as *Not at Risk*. Two DUs were deemed to have insufficient data for assessment. This RPA covers 11 of the DUs assessed by COSEWIC that spawn in the Fraser River drainage, all of which were designated as being either *Threatened* or *Endangered* (Table 1). Each DU covered in this RPA corresponds to a single Wild Salmon Policy Conservation Unit (CU). DUs are widely distributed throughout the Lower (DUs 2, 4, and 5), Middle (DUs 7, 8, 9, and 10), and Upper Fraser rivers (DU11), as well as the North (DUs 16 and 17) and South Thompson rivers (DU 14). Three of the DUs (DUs 2, 7, and 8) have single spawning sites, while the others have spawning sites in multiple river systems.

Table 1. Fraser River Chinook Salmon Designatable Units (DU) covered in this Recovery Potential Assessment (RPA), and their relation to Wild Salmon Policy Conservation Units (CU) and fisheries Management Units (MU). The MU numerical notation refers to the dominant life history type for each DU: 4_2 *and* 5_2 *are stream-type Chinook Salmon where juveniles migrate to sea as yearlings and return at a total (freshwater + marine) age of 4 or 5 years;* 4_1 *is an ocean-type life history where juvenile migrate to sea as subyearlings and primarily return at 4 years total age.*

MU	**CU**	**DU**	**DU Name**	**COSEWIC Status**
Spring 5_2	CK-08	DU7	Middle Fraser River Stream Spring (MFR-Nahatlatch)	Endangered
	CK-10	DU9	Middle Fraser River Stream Spring (MFR-Spring)	Threatened
	CK-12	DU11	Upper Fraser River Stream Spring (UFR-Spring)	Endangered
	CK-18	DU16	North Thompson Stream Spring (NTh-Spring)	Endangered
Summer 5_2	CK-05	DU4	Lower Fraser River Stream Summer (LFR-Upper Pitt)	Endangered
	CK-06	DU5	Lower Fraser River Stream Summer (LFR-Summer)	Threatened
	CK-09	DU8	Middle Fraser River Stream Fall (MFR-Portage)	Endangered
	CK-11	DU10	Middle Fraser River Stream Summer (MFR-Summer)	Threatened
	CK-19	DU17	North Thompson Stream Summer (NTh-Summer)	Endangered
Spring 4_2	CK-16	DU14	South Thompson Stream Summer (STh-Bessette)	Endangered
Fall 4_1	CK-03	DU2	Lower Fraser River Ocean Fall (LFR-Harrison)	Threatened

This is the second of two parts of the RPA for 11 DUs considered in the COSEWIC (2019) assessment. This part of the RPA will cover Elements 12 to 22 of DFO's RPA guidance as outlined in the Terms of Reference. For readability, the 11 elements will be consolidated into four sections: recovery targets, forward projections, evaluation of potential mitigation options, and an assessment of allowable harm. Due to differences in life history type and data availability, much of the advice was developed separately for ocean-type DU 2 and the ten stream-type DUs.

ASSESSMENT

Recovery Targets

Two recovery targets were developed for each DU (Table 2). The first target could result in DUs achieving a *Special Concern* status under the COSEWIC quantitative guidelines, and was called a **survival** target as it is intended to reduce imminent risk of extinction. The second, called the **recovery** target, included benchmarks such that the DU should meet criteria for a *Not at Risk* or *Recovered* status. This approach is consistent with DFO advice on setting SARA recovery targets (DFO 2011). Achieving these targets does not imply that the corresponding status would necessarily be assigned during a COSEWIC review as other aspects (such as the mitigation of ongoing threats) are also likely to be considered.

Each target consisted of an abundance benchmark and a trend benchmark. A DU is considered to have achieved the target if criteria associated with both benchmarks are met. Spawner abundance benchmarks were based on procedures developed for DFO's Wild Salmon Policy (WSP) for the assessment of wild salmon Conservation Units. The abundance benchmark used for the **survival** target was S_{gen}, the spawner abundance that would result in recovery to an upper benchmark in one generation in the absence of fishing mortality. The benchmark used for the **recovery** target was 85% of S_{msy}; here S_{msy} is the spawner abundance that is predicted to result in the long-term maximum sustainable yield. In cases where computed benchmarks were <1,000 spawners, the abundance benchmark was set to 1,000 spawners, following COSEWIC Criterion D for small populations.

Calculation of WSP abundance benchmarks is normally based on an analysis of stock-recruit data. For the DUs being assessed here, such data only exist for DU2. For stream-type DUs, a predictive model based on watershed area was used to compute key stock-recruit parameters needed to derive WSP benchmarks. There is greater uncertainty in these estimates because of the prediction error associated with the habitat-based model.

Values for the trend benchmark were from COSEWIC quantitative guidelines and the rate of change identified depended on the size of the population as identified by the generational abundance benchmarks.

Estimates of S_{gen} and S_{msy} depend partly on the productivity of the DU. Usually abundance benchmarks are calculated using all available data, and are based on average productivity during the period of data availability. If benchmarks are calculated from data from a low-productivity period, S_{msy} is reduced and S_{gen} generally increases, relative to values derived from when productivity is higher. Current DFO practice, within salmon stock assessment, is to not recalculate benchmarks during transitory changes in population productivity. Recalculation of benchmarks may be warranted if a new productivity regime is quantified, documented, and is likely to be persistent.

Productivity of DU2 has been highly variable, and abundance benchmarks for this DU were based on analysis of the full time series of abundance data (brood years 1984-2013) that includes periods of high and low productivity. The estimate of S_{msy} that underpins the benchmarks for DU2 was the WSP benchmark, which has been committed to in the bi-laterally agreed-upon Pacific Salmon Treaty (PST) as an escapement goal for the duration of the current treaty.

For stream-type DUs, abundance benchmarks were derived from a meta-analysis of stock-recruit parameters from historical data from a variety of North American Chinook Salmon populations and are thus based on long-term productivity of all populations included in the original meta-analysis.

Table 2. Survival and recovery targets for each DU. The survival target aims to achieve COSEWIC Special Concern status. The recovery target is designed to achieve Recovered or Not at Risk status. To meet the target, each population must meet both abundance and trend benchmarks. Abundance is based on S_{gen} or 85% S_{msy} for the survival or recovery targets respectively, unless otherwise indicated.

		Survival target		Recovery target	
DU	**DU Short Name**	**Abund.**	**Trend**	**Abund.**	**Trend**
DU2	LFR-Harrison	15,318	< 30% decline	63,808	< 30% decline
DU4	LFR-Upper Pitt	1,000[2]	Positive population growth	1,000[2]	Positive population growth
DU5[1]	LFR-Summer	1,000[2]	Positive population growth	1,285	Positive population growth
DU7	MFR-Nahatlach	1,000[2]	Positive population growth	1,000[2]	Positive population growth
DU8	MFR-Portage	1,000[2]	Positive population growth	1,358	Positive population growth
DU9	MFR-Spring	5,331	Positive population growth	22,216	< 30% decline
DU10	MFR-Summer	5,878	Positive population growth	25,260	< 30% decline
DU11	UFR-Spring	5,273	Positive population growth	24,883	< 30% decline
DU14	STh-Bessett	1,000[2]	Positive population growth	1000[2]	Positive population growth
DU16	NTh-Spring	1,000[2]	Positive population growth	3,865	Positive population growth
DU17	NTh-Summer	1,824	Positive population growth	7,773	Positive population growth

[1] For DU5, the recovery target only represents a target for the sampled systems, not the DU as a whole, as the Lillooet River system is not included in this estimate.

[2] For DUs with an S_{gen} or S_{msy} abundance target of < 1,000, the abundance target was set to a minimum of 1,000 to ensure that COSEWIC Criterion D is exceeded.

The nature of the spawner data available to assess each DU against benchmarks varies. For DU2, extensive effort is made to estimate spawner abundance, and these values are considered unbiased and relatively precise. For the other DUs, spawner data vary in terms of bias and precision. For DUs 4, 5, 7, 14, and 16, only some of the known spawning areas are surveyed. Resulting estimates are likely biased downwards and this bias should be considered when evaluating the DU against abundance benchmarks. The data may be more suitable for the trend indicator under the assumption that all spawning areas in the DU have similar trends and the method of assessment has been stable for the 3-generation time window used for trend calculation. For DUs 9, 10, 11, and 17 most major spawning areas are assessed using helicopter overflights conducted at the peak of spawning; for DU8 a float count is conducted. To convert visual estimates to actual abundances, constant calibration factors are used, which potentially introduces errors as the true relation between observed and actual abundance likely varies by site and year. There is the potential for some additional bias if surveys do not access all spawning areas. In these cases both the trend and abundance indicators can be applied although results should be viewed in the context of the uncertainty in the data.

Near-term Population Projections

The goal of Elements 13 and 15 of the RPA is to project population trajectories over the near term (three generations in this case) using current (or the most recent available) population dynamics parameters, and consider the effects of changing key parameters on population trajectories.

DU2

For DU2, a 30-year time series of population data was used to estimate the current population parameters needed for forward simulations. Three candidate salmon population models were considered for estimating required parameters. These models predict the relation between the number of spawners in a year and the average number of recruits that are expected to be produced by them. However, for any specific year, the observed number of recruits will be the sum of the number predicted by the model for that parent spawner abundance, and an additional random component unrelated to spawner abundance that results from unpredictable environmental events and measurement error.

The models are:

1: Standard Ricker stock-recruit model

This model estimates the relation between recruitment and spawner abundance using 2 parameters (α and β). Alpha (α) is a measure of population productivity at low population size, and β determines the strength of density-dependent processes that cause productivity to decline with increasing abundance. Population productivity is defined as the ratio of the number of recruits (R) to the number of parent spawners (S). It is assumed that parameters remain constant over time. Year-to-year variation in recruitment around the average predicted by the model is assumed to be a random process.

2: Ricker model with auto-correlated environmental variation

As in model 1, this model assumes constant parameters for the Ricker model but year-to-year variation in recruitment can be auto-correlated (i.e., current year may be similar to the previous year). This approach allows for the population to go on “runs” of good or poor productivity, which may mimic longer-term patterns in environmental variation.

3: Ricker model with time-varying alpha

Here, the population productivity parameter, α, is allowed to vary over time in a smoothed pattern, tracking trends in productivity in the data, although there is a component of variation not described by the model due to random processes and measurement errors. The model yields an estimate of α for each year of the stock-recruit data.

The choice of which model to draw parameters from for forward projections was largely based on the performance of each model in describing recent productivity, as the projections are to be based on current population dynamics parameters. A primary diagnostic is the examination of patterns in model residuals (the difference between the model’s prediction and the observed value). Models 1 and 2 were unable to track the decline in productivity that has occurred and productivity residuals showed a trend from more positive values in the older data to more negative in the most recent years. This means that using parameters from these models will tend to over-predict recent productivity relative to what has been observed. Model 3 does track changes in productivity, and the residuals do not show a time trend (Figure 2). Additionally, Model 3 residuals have more desirable properties, as deviations are smaller and appear to vary randomly through time with no discernable pattern.

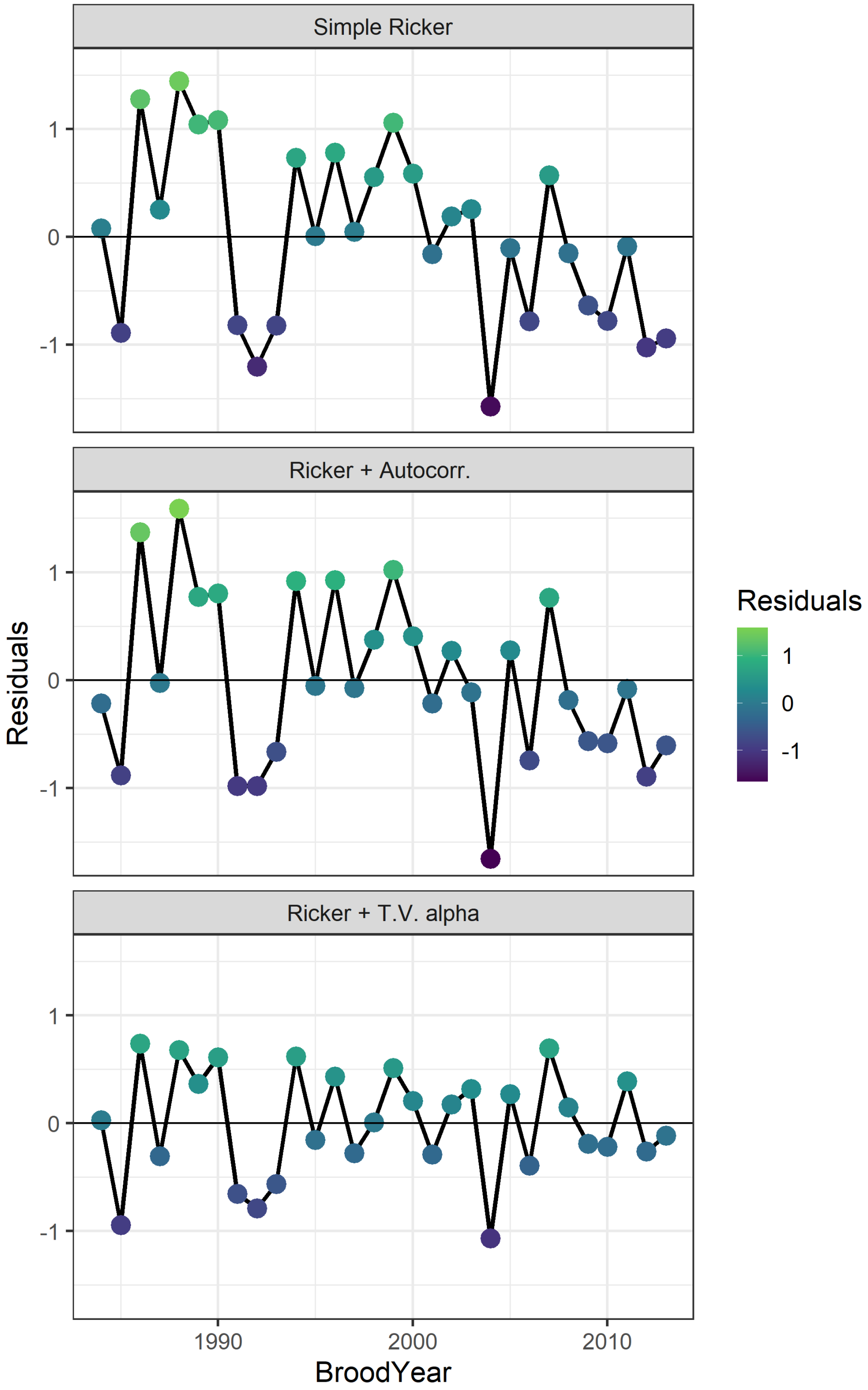

Figure 2. Residuals (observed log(Recruits/Spawner) - predicted log(Recruits/Spawner)) resulting from fitting three different models to DU2 stock and recruitment data for brood years 1984 to 2013.

Models were also compared using Akaike Information Criterion (AIC), a statistic for evaluating the relative suitability of different models. When comparing models of similar quality the AIC criteria will identify the model that best explains the data using the fewest parameters. AIC values for Models 1 and 2 were very similar, but the value for Model 3 was slightly higher, indicating that this model could be a less-preferred option. However, in simulation studies under a variety of patterns of declining productivity, Holt and Michielsens (2020) found that time-varying models provided parameter estimates that were less biased than standard Ricker models, despite AIC model selection criteria that favored the standard Ricker model. They suggested that AIC may not be appropriate for selecting between standard and time-varying Ricker models.

Based on the evaluation of residuals, parameters from Model 3 were chosen for forward simulation. Specifically, the average of the productivity parameter (α) from the four most recent complete cohorts (spawning in 2010-2013) was used in projections, representing current productivity that is lower than the long-term average (Figure 3).

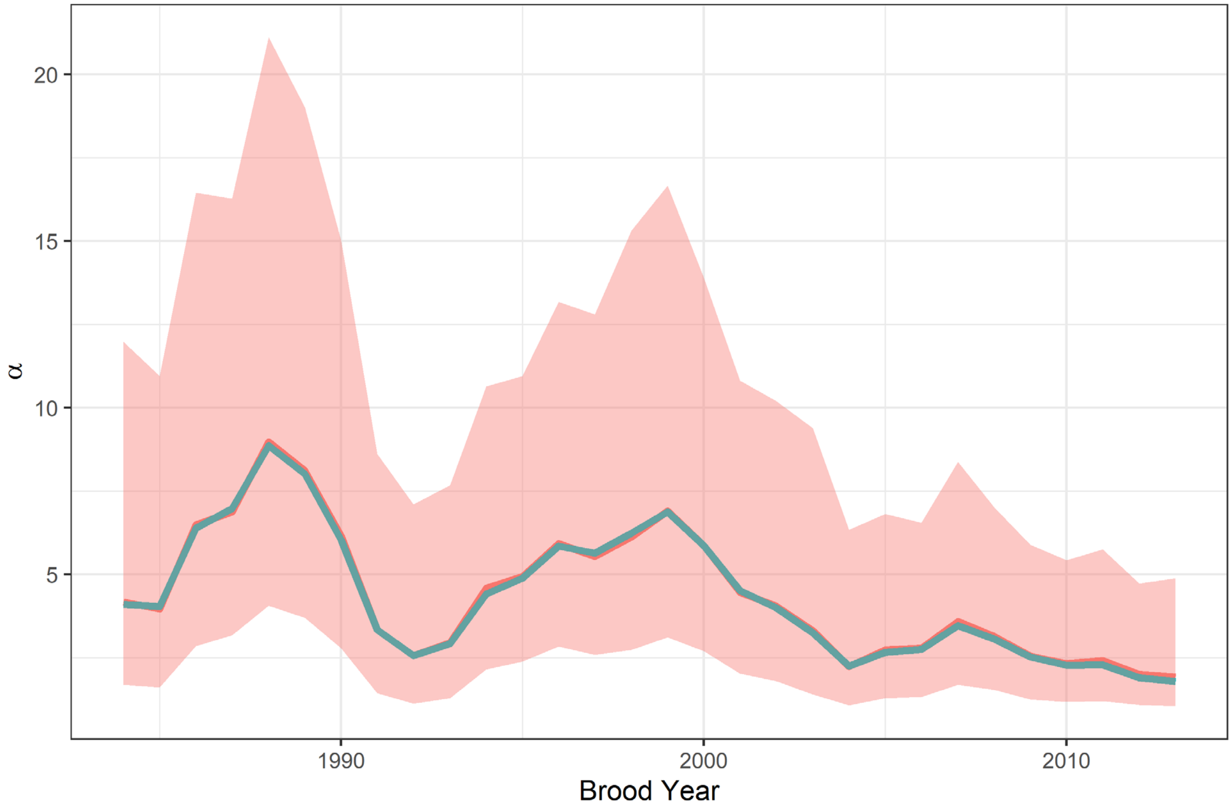

Figure 3. Time series of α estimated by the time-varying Ricker model, with corresponding 95% credible interval. Thick lines show results of two different methods of estimation (red: Bayesian, blue: maximum likelihood).

A forward projection model based on a simple Ricker model was used to estimate spawner population trends for DU2 for 12 years (2020-2031). The model assumed that the average recent productivity for brood years 2010-2013, as estimated by the time-varying productivity model, would continue unchanged. The model contained age-specific harvest rates based on the assumption that recent (2009-2015) levels and patterns of Canadian and US fishery removals would continue unchanged. Harvest rates cannot be readily converted into a single annual exploitation rate because both immature and mature fish are captured in fisheries, but can be approximated as *catch/(catch+escapement)* by year. That computation results in an average total exploitation rate of about 30%, of which the total Canadian exploitation rate is 18%.

Random variation in recruitment, age at maturity, and fishing mortality were included in the model to simulate some of the factors that lead to variation in the number of spawners each year. Uncertainty in estimated population parameters was also incorporated into the projections.

The model predicted that if recent conditions persist, the population (DU2) is most likely to continue to decline slowly (Figure 4) and is As Likely as Not (33-66%) to achieve the survival target (Table 3). This is the result of 49% of simulations having a rate of decline less than the 30% decline benchmark, although 90% of simulations met the survival target abundance benchmark. The model population was predicted to be Unlikely (10-33%) to reach to the recovery target as it infrequently exceeded the abundance benchmark of 63,808 spawners after 12 years.

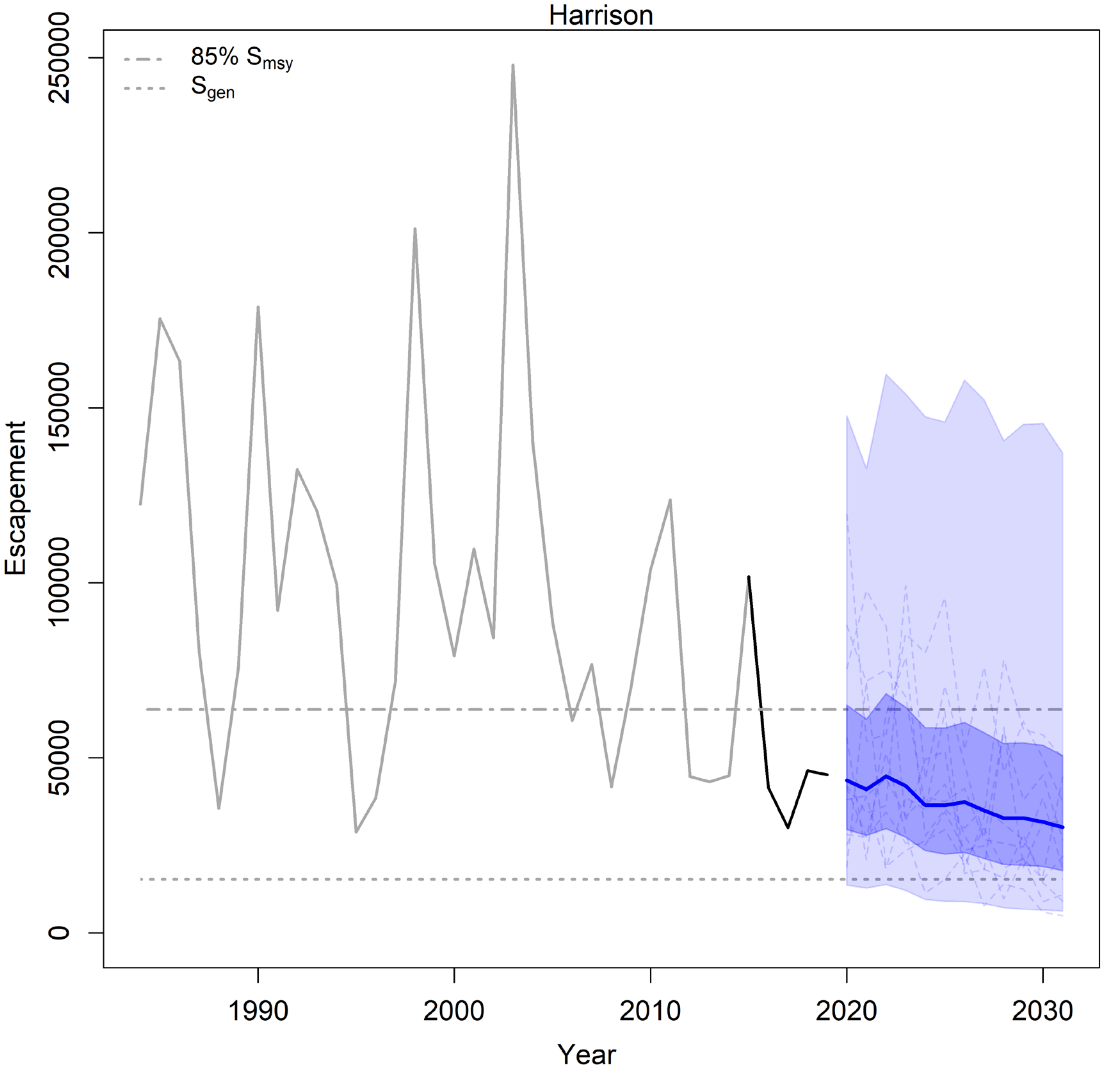

Figure 4. Simulated forward projection of spawner abundance for DU2 for 2020 to 2031 using average productivity from brood years 2010-2013 as estimated by a time-varying productivity model. The median of simulated abundances in each projected year is represented by the dark blue line. The area shaded light blue encloses 95% of simulated abundances (0.025 and 0.975 quantiles), while the dark blue polygon encloses 50% of abundances (0.25 and 0.75 quantiles). The escapement time series from 1984 to 2019 is shown in light grey, and the black overlay highlights years used to initialize the projection model. Dashed lines show outcomes of ten randomly selected individual simulations. Horizontal lines indicate abundance benchmarks for survival (S_{gen}) and recovery targets (85% S_{msy}).

*Table 3. The percent of simulations that meet the survival and recovery targets for DU2, including results for the generational mean abundance and trend benchmarks, and the associated risk category based on the International Panel of Climate Change (IPCC) risk/certainty categories. Note that survival or recovery targets are only considered met for a given simulation trial if **both** abundance and trend benchmarks are met in that trial.*

	Simulations Meeting Target	IPCC Risk Category
Trend benchmark (< 30% decline)	49%	As Likely as Not (33% to 66%)
Survival target abundance benchmark (≥ 15,313)	90%	Very Likely (90%–99%)
Recovery target abundance benchmark (≥ 63,808)	17%	Unlikely (10% to 33%)
Survival Target (trend and abundance benchmarks)	**48%**	**As Likely as Not (33% to 66%)**
Recovery Target (trend and abundance benchmarks)	**16%**	**Unlikely (10% to 33%)**

Sensitivity analyses were used to evaluate the effect of alternative scenarios of productivity and human-induced mortality on the probability of reaching the proposed recovery targets. In these simulations it was assumed that productivity (α) would change in linear increments from the baseline (2010-2013) value to a prescribed increase or decrease over the 12 years of simulation. The range in productivity used in the sensitivity analyses was based on estimated changes in α from the time-varying model where declines of >50% and increases of >150% occurred (Figure 3). Canadian Chinook Salmon fishing mortality was changed from the baseline (2009-2015) for the first year of the simulation and it remained constant thereafter. US exploitation was assumed to remain constant at the 2009-2015 levels. Other sources of human-induced mortality were not quantified or considered; these include incidental mortality in non-salmon fisheries and potentially some impacts of industrial activities in the lower Fraser River and estuary.

Model results indicate that if productivity remains at the base case value, and if Canadian harvest rates decrease by 80% over base case values, DU2 is Likely (66-90%) to be able to meet the survival target in the next three generations (Figure 5). It should be noted that recent (2019 and later) measures to reduce Chinook Salmon harvest may have decreased current harvest rates below the base case; however, estimates of the effects of these measures on harvest rates are not yet available. If productivity increases, the probability of reaching the survival target will increase.

DU2 is not predicted to be Likely to meet the recovery target under any of the harvest rate scenarios at base case productivity levels (Figure 6). Depending on the harvest levels, a productivity increase of 50% to 100% is required for DU2 to be Likely to meet the recovery target.

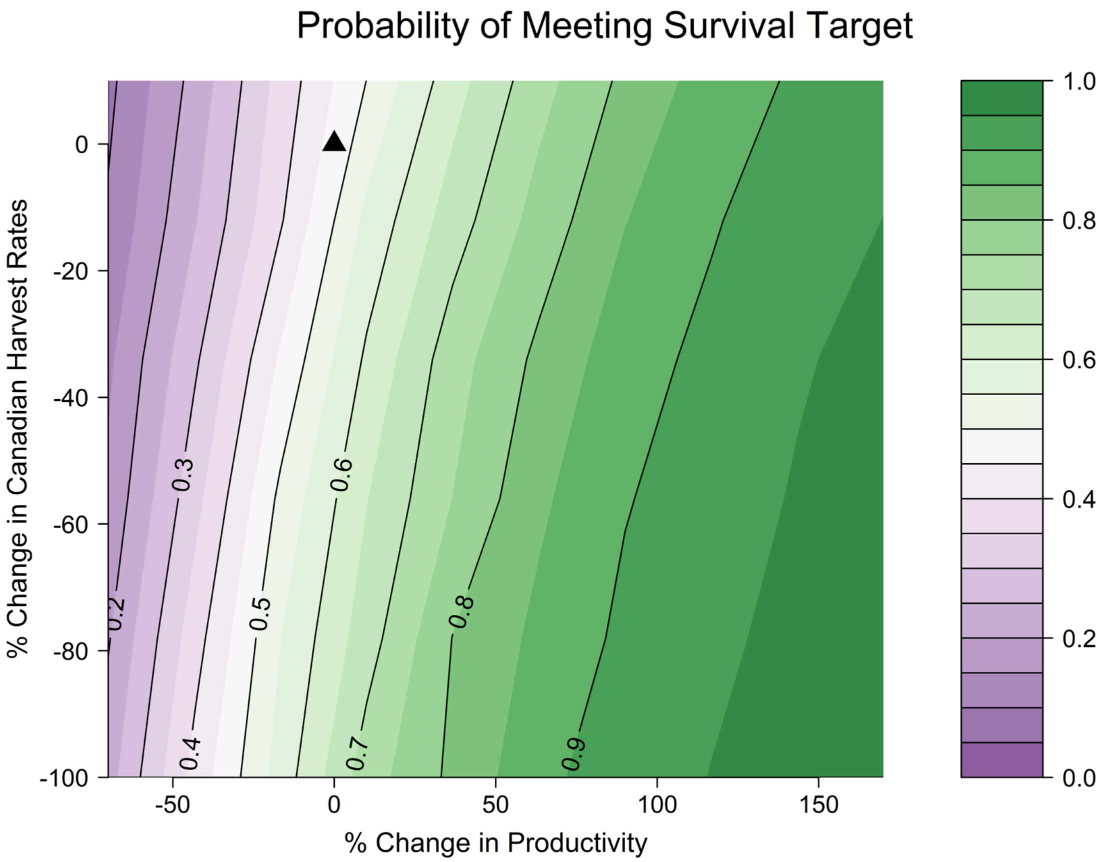

Figure 5. Heat map showing model results for the probability of reaching the ***survival*** *target under changing productivity and percent changes in Canadian harvest rates for DU2. Meeting the survival target requires an average spawner abundance in the last generation greater than 15,313 and a decline in spawner abundance over three generations of less than 30%. The triangle indicates base case conditions. Productivity is assumed to change linearly over the 12 year simulation from the base case value to the indicated percent change from the base case value. Percent reductions in Canadian harvest rates are based on the base case harvest rate (2009-2015) and are assumed to occur instantaneously in the first year and remain constant afterwards.*

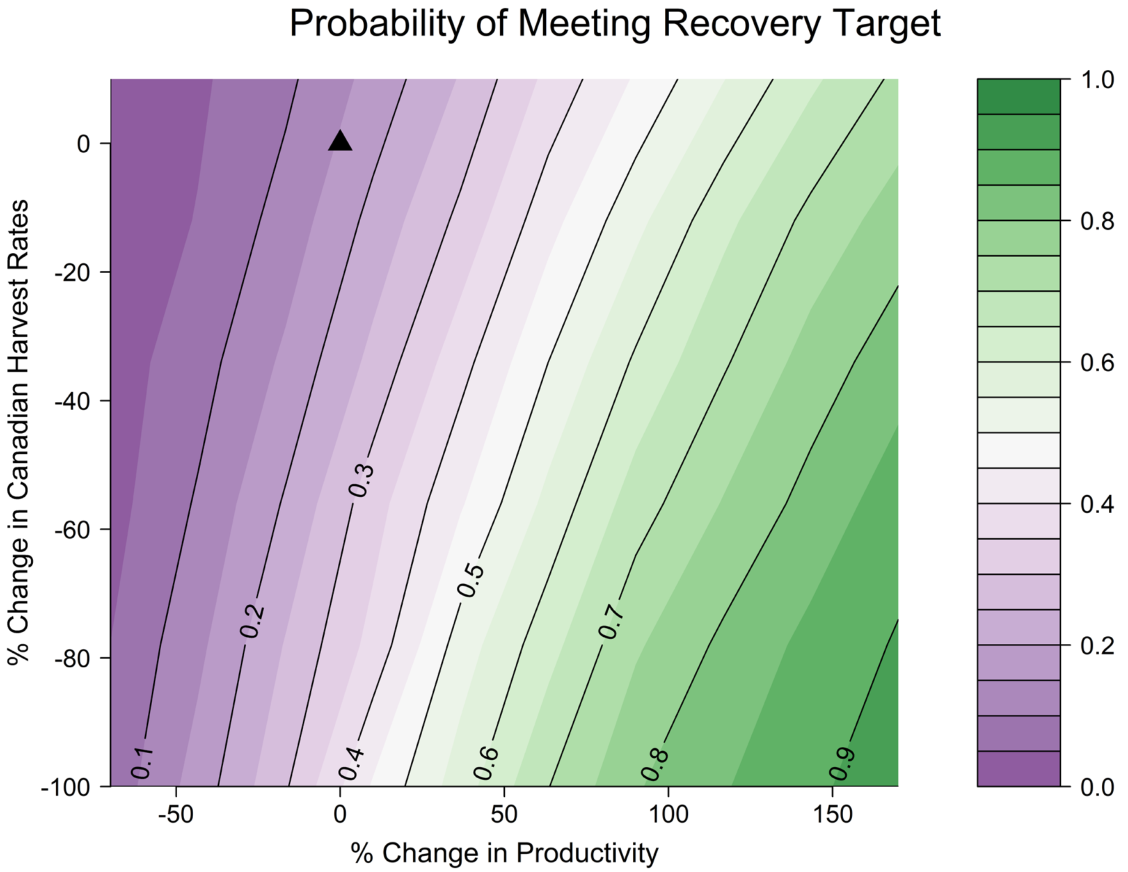

Figure 6. As in Figure 5, except showing the probability of reaching the ***recovery*** *target for DU2. The triangle indicates base case conditions. Meeting the Recovery Target requires an average spawner abundance in the last generation greater than 63,808 and a decline over three generations of less than 30%.*

Predicting future changes in salmon productivity and abundance is challenging in a period of rapidly changing conditions in both freshwater and marine environments. Many, but not all, Chinook Salmon populations have declined in abundance as a result of changes in productivity, and long-term changes in size, age at maturity and fecundity have been observed. For DU2, productivity has generally declined over the period of record, but it also has alternated between periods of higher and lower productivity. It is unknown what trend in productivity will occur in the future. Scenarios of increased productivity can be viewed as cases where productivity increases naturally, or is increased through effective mitigation measures. Conversely, if threats continue unabated or if mitigation measures take many years to be effective, productivity could remain below average or decline further in the future. The effect of these scenarios on the probability of meeting survival or recovery targets can be explored with the heat maps.

Stream-type DUs

Quantitative modelling was attempted but was considered unreliable for the other ten DUs as stock-recruit and exploitation rate data were insufficient. It was noted that most DUs had experienced significant declines in spawner abundance in the past three generations, despite efforts to reduce harvest. Although the effectiveness of recent harvest rate restrictions are difficult to quantify, trends in Fraser River populations, and trends in other stream-type Chinook Salmon populations points to a decline in productivity being the main driver of reduced spawner abundance. Given the ongoing declines in abundance, it was judged unlikely that these populations will reach the survival target in the next three generations if current conditions continue.

Adult spawners from DUs 9, 10, and 11 must also migrate upstream past the landslide that occurred in 2019 in the Fraser River at Big Bar in order to reach their spawning grounds. Although some fish have been observed to pass the slide, it is likely that the failure of others to reach spawning areas will contribute to declines in abundance for these DUs until the effects of the slide are mitigated and at least a full generation of Chinook Salmon are able reach their spawning areas unimpeded.

Mitigation Of Threats and Alternatives to Activities

The 11 Chinook Salmon DUs that are the subject of this RPA make use of a vast array of habitats, including much of the Fraser River watershed, the Fraser River estuary, and nearshore and offshore marine habitats. In freshwater, there is diversity in the watersheds they use, both ecologically and due to the nature and severity of anthropogenic and natural threats to DU persistence. Consequently, a large number of potential threats were identified in Part 1 of the RPA, and relative rankings of threats for each DU were developed, mainly based on judgments of the effect of the threat on exposed populations.

Elements 16-21 of the RPA guidelines require an inventory of feasible mitigation measures and alternatives for activities identified as threats in Part 1, and if possible, an evaluation of potential effects those mitigation measures may have on achieving recovery targets.

In this RPA, an initial identification of mitigations of threats and alternatives to activities was conducted and a high-level inventory of activities that could potentially address significant threats was developed. It is recognized that many of the threats that were identified are challenging to mitigate because they occur across large landscapes, result in cumulative effects, and are exacerbated by climate change. Many mitigation measures may be local in scope and of limited effect. We consider each threat and associated mitigation action individually, however, all have the potential to interact in a cumulative manner. Thus, the impact of cumulative effects across threats should be considered in decision making.

A full assessment of mitigation options will require DU-specific analysis due to the diversity in ecosystems, life histories, and range of threats. In most cases, it will not be possible to quantitatively evaluate the possible benefits of mitigation measures on productivity or survivorship due to the lack of basic life history and habitat use information and population data.

Hatchery production can be used to increase adult abundance and can offset the effects of many threats, but as it not a direct mitigation to an identified threat it was not included in the table. Hatcheries can play an important role in the preservation of critically endangered populations by preventing imminent extinction, but hatchery fish spawning in the wild are not included in WSP or COSEWIC assessments of status and therefore may play a more limited role in recovery.

Table 4 below identifies a range of mitigation measures and alternatives to actions in relation to the threats identified in Part 1 of the RPA. Threat categories are provided by the generic COSEWIC threats calculator. A brief description of each threat in the context of Chinook Salmon is provided along with the most likely pathway of effect on DU status. Here “habitat” refers to fish habitat as defined in the *Fisheries Act.* No attempt has been made to prioritize mitigation options by DU; however, the threat tables in DFO (2020) contain DU-specific ratings for each threat that may provide some guidance. Mitigation options will vary in their potential to affect recovery, as well as their cost and feasibility; these factors are also not considered here, and will likely have to be part of a DU-specific analysis.

Table 4. Potential mitigation strategies and alternative actions to address threats to Chinook Salmon DUs that were identified in Part 1 of the RPA.

COSEWIC Major threat category	***Threat category description***	***Likely pathway(s)***	***Mitigation options***	***Notes***
Residential and commercial development	• Footprints of residential, commercial, and recreational development	• Loss or degradation of habitat	• Manage ongoing and future development to minimize effects and ensure success of offsetting to prevent loss of habitat	-
Agriculture & aquaculture	• Footprints of agriculture, horticulture, and aquaculture	• Loss or degradation of habitat • Competitive interactions of hatchery-released fish with wild fish	• Manage ongoing and future development to minimize effects on habitat. • Transition to closed containment aquaculture • Modify hatchery strategies to minimize negative interactions with wild populations.	This would include hatchery production both inside and outside the Fraser River watershed as interactions are possible in the marine environment. Conservation hatcheries can play a role in increasing the abundance of diminished populations.
Energy production & mining	• Footprints and extraction activities from mining (e.g. gravel extraction, placer mining, etc.).	• Loss or degradation of habitat	• Manage ongoing and future development to minimize effects on habitat and ensure success of offsetting to prevent loss of habitat	-
Transportation & service corridors	• Footprints from roads, railroads, utility and service lines, and shipping lanes	• Loss or degradation of habitat • Reductions in connectivity	• Manage ongoing and future development to minimize effects on habitat and ensure success of offsetting to prevent loss of habitat and habitat connectivity • Maintain and enhance connectivity by maintaining existing structures and replacing those that are not functioning	-
Biological resource use	• Logging and wood harvest in riparian areas, transport of logs via rivers • Fishing	• Loss or degradation of habitat • Direct and indirect mortality • Harvest, and other mortality resulting from harvesting activities	• Ensure that forest harvest is designed to minimize effects on riparian habitat. • Restore riparian habitats to accelerate natural processes. • Manage the use of log transport to minimize impacts on water quality and habitat. • Reduce fishing mortality rates • Modify fishing practices to reduce non-target mortality • Enhance education to increase compliance with conservation measures	This category is for use of biota in riparian and aquatic habitats. Fishing effects are transboundary and are associated with mixed stocks and mixed species

COSEWIC Major threat category	*Threat category description*	*Likely pathway(s)*	*Mitigation options*	*Notes*
Human intrusions & disturbance	• Recreational activities (e.g. ATVs in streams, jet boats, etc.)	• Loss or degradation of habitat • Direct and indirect mortality • Alteration of behaviour	• Manage access to water and allowable activities to minimize impacts • Increased education on best practices	-
Natural systems modifications	• Fire and fire suppression • Dams and water Management • Modifications to catchment surfaces, forestry, and linear development	• Loss or degradation of habitat • Direct and indirect mortality • Alteration of behaviour or performance	• Ensure forestry and other activities in watersheds minimize impacts to aquatic habitats and reforestation, reclamation and restoration activities are effective. • Use strategic measures to reduce incidence of large forest fires • Manage ongoing and future development of surface and groundwater resources, including implementation of environmental flows • Decommission or remove dams or other barriers, and maintain fish passage infrastructure for adults and juveniles (fishways, fish ladders, etc.) • Adaptively manage water in the face of climate change and increased variability • Manage ongoing and future linear developments by imitating more natural waterways, reconnecting off-channel habitat, removing or restoring old developments, and set and monitor water quality and sediment targets	-

COSEWIC Major threat category	***Threat category description***	***Likely pathway(s)***	***Mitigation options***	***Notes***
Invasive & other problematic species & genes	• Aquatic invasive species (AIS), introduced pathogens and viruses, problematic native species (e.g. pinnipeds, parasites, and disease), interbreeding with hatchery-origin fish	• Loss or degradation of habitat • Alteration of behaviour • Predation and competition • Increased prevalence of disease • Reduced genetic diversity and maladaption	• Prevention of introduction of AIS and spread through management, monitoring and education. Suppression or removal of AIS. • Monitoring and treatment of pathogens in aquaculture, transition to land-based aquaculture; treatment of aquaculture effluent. Manage predator populations or habitat features they depend on. • Manage hatchery production and practices to minimize effects on natural breeding population of negative fitness consequences	Predation rates on different life stages are poorly understood and temporal changes have not been quantified. Additional research is required on the efficacy of ecosystem management approaches, including direct applicability of predator population reductions, as a mitigation measure.
Pollution	• Introduction of exotic and/or excess materials or energy from point and nonpoint sources, including nutrients, toxic chemicals, and/or sediments from urban, commercial, agricultural, and forestry activities	• Reduced performance, stress, mortality	• Manage ongoing and future activities/developments that contribute to pollution, improve waste water management and monitoring, increase enforcement of best practices for water quality • Remediation of contaminated legacy sites	-
Geological events	• Avalanches and landslides	• Reductions in passage • Increased mortality • Alterations to habitat	• Increase fish passage infrastructure for adults and juveniles where required • Maintain existing infrastructure • Proactively identify areas that are at risk of landslides and implement monitoring	-
Climate change & severe weather	• Changes in freshwater and marine environments, and increasing frequency of severe climate events	• Degradation of habitat suitability • Direct and indirect mortality • May exacerbate effects of other threats	• Follow guidelines from the recent Paris Accord and International Panel on Climate Change reports • Proactively manage habitats and populations so that they are resilient and may adapt to future changes, including maintaining biodiversity of populations	Adaptive management is required for all mitigation activities in the context of climate change and the increased frequency of severe weather events

Allowable Harm Assessment

DU2

Part 1 of the RPA identified numerous threats facing DU2, and indicated a continued downward trend in observed abundances. Outcomes from the modelling indicate that at 2009-2015 catch-year average Canadian harvest rate levels, DU2 is likely to continue to decline in abundance and is unlikely to reach the recovery target in three generations if the productivity persists at base case levels, even if Canadian harvest is greatly reduced. The probability of reaching the lower survival target is higher, particularly when harvest is reduced. The probability of reaching either target increases if population productivity increases from the base case at rates similar to what has been observed in the past.

Considering the impact from all activities in the allowable harm assessment is vital because any additional impacts from the various threats not directly modelled will further hinder recovery. **The results from both the modelling and the threats assessment suggest that under model base case productivity, human-induced mortality and other sources of harm identified in the threats assessment should be significantly reduced from base case levels so as to not jeopardize recovery**. There is greater uncertainty in our understanding of allowable harm on habitat, and the effects of harm to habitat on recovery outcomes could not be quantified. The impact of any activities on survival and recovery outcomes should be evaluated on a case-by-case basis, and considered in the broader context of cumulative impacts on recovery. Activities that are in support of the survival or recovery of the species that may result in mortalities, but will have a net positive effect on the population, should be allowed. As the productivity of this population has exhibited large fluctuations in the recent past, abundances and productivity should be continually monitored to determine if progress towards recovery is sufficient to warrant a re-assessment of allowable harm.

Stream-type DUs

Quantitative forward projections were not considered for the remaining ten DUs due to the uncertainty resulting from the quality of the relative escapement data and lack of reliable exploitation rate estimates. Therefore, the allowable harm assessment is based on the threats assessment from Part 1, recent trends in relative abundance, and the possible future trajectory of these populations based on qualitative assessments. The results of the threats workshop from Part 1 indicated that all DUs were considered to be at High-Extreme or Extreme risk, due to the severity and number of threats that each of the DUs are facing (DFO 2020). Alleviating many of these threats will be difficult given the widespread nature of them, especially as many are exacerbated by climate change, posing a risk of extinction for these DUs within the next three generations.

There is considerable uncertainty about the future trajectory of these populations, but based on the qualitative assessment these populations were considered to be at greater risk, and the potential for recovery is less likely than for DU2. It is likely that many of the assessed threats pose a more serious risk to these stream-type DUs than compared to DU2, as stream-type populations rely on freshwater habitat for more of their life cycle than ocean-type stocks. Most stream-type DUs have experienced more severe declines in relative abundance compared to DU2 and many are currently extremely small. Based on this information and the allowable harm assessment for DU2, a precautionary approach is suggested unless sufficient increases in abundance are confirmed due to mitigation measures or changes in natural conditions. **Harm is likely to continue to jeopardize recovery. Therefore, to promote the survival and recovery of these DUs, it is advised that all future and ongoing human-induced harm should be prevented.** As with DU2, it is important to note that there are some activities in support of survival or recovery that may result in mortalities, but should be allowed if they result in a positive effect on survival or recovery.

For DUs 7, 8, and 14, there is additional concern due to the limited area of the spawning habitat and small population sizes.

For DUs 9, 10, and 11, additional concern due to the increased threat risk from the Big Bar landslide will remain until the impacts from the slide are alleviated.

Sources of Uncertainty

- Uncertainties regarding species biology, habitat, and the significance of threats to population declines are identified in Part 1 (DFO 2020).
- Uncertainty about the number of spawners in each DU (both in terms of bias and precision, and changes to these over time) needs to be considered when comparing abundance data to quantitative benchmarks, as benchmarks and data may not be directly comparable.
- Abundance benchmarks for recovery targets of stream-type DUs are based on a habitat-based model and are subject to greater uncertainty compared to those developed from stock-recruitment analysis (DU2).
- Predicting future changes in productivity of salmon populations is difficult and any modelling may underestimate the range in possible outcomes as a result of surprise events or unanticipated changes in environmental conditions.
- It is unclear which of the threats are key drivers of current population status. Additional DU-specific analysis of factors that have led to the current population status is required as this will likely be used to prioritize recovery measures. This includes the estimation of fishing mortality for many DUs.
- There is considerable uncertainty about the effectiveness of measures listed in Table 4 in promoting survival and recovery at the DU level.

FUTURE RECOMMENDATIONS

- Further development of survival and recovery targets should consider the spatial distribution of spawners within some DUs. While the use of stock-recruit modelling to develop benchmarks is appropriate when most or all spawners are part of a single panmictic breeding population, some DUs include a number of river systems spread over a large area, and it is unlikely that there is significant interchange of spawners among rivers to impact demographic processes. In these cases, the implications of DU-level abundance targets on the distribution and diversity of populations within the DU should be considered.
- Threatened and endangered salmon populations often have declining trends in productivity. Protocols for both the development of recovery benchmarks and forward projections should be developed to further guide Science for the analysis of populations where productivity has declined and future trends in productivity are unknown.
- Better information is needed to evaluate the conservation status of the stream-type DUs. The RPA revealed the information currently available was inadequate to characterize productivity and change in biological attributes of these DUs.
- Alternative methods for population projections need to be developed for salmon DUs that do not have stock and recruitment data.

- The projection models used here and any future models used for the analysis of DU2 and any Chinook population dynamics need to be further verified through simulation testing and sensitivity analysis. Open access code that underpins models will also further their ability to be reviewed, shared, and developed for future processes.
- Methods to evaluate mitigation measures at the DU level are needed. In some cases, quantitative modelling may be feasible, but in most situations a blend of quantitative analysis and structured expert assessment may be required.
- The degree to which the supply of suitable habitat meets the needs for each DU (Element 14) was not assessed. Further work to assess habitat supply at the DU level would inform recovery planning and prioritization of threat mitigation activities.

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SOURCES OF INFORMATION

This Science Advisory Report is from the 7-9 July 2020, 1 October 2020, and 11-12 March 2021 regional peer review on Recovery Potential Assessment – Fraser River Chinook Salmon (*Oncorhynchus tshawytscha*) – Eleven Designatable Units (Elements 12-22). Additional publications from these meetings will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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