RECOVERY POTENTIAL ASSESSMENT FOR FRASER RIVER SOCKEYE SALMON (*ONCORHYNCHUS NERKA*) – NINE DESIGNATABLE UNITS – PART 1: PROBABILITY OF ACHIEVING RECOVERY TARGETS

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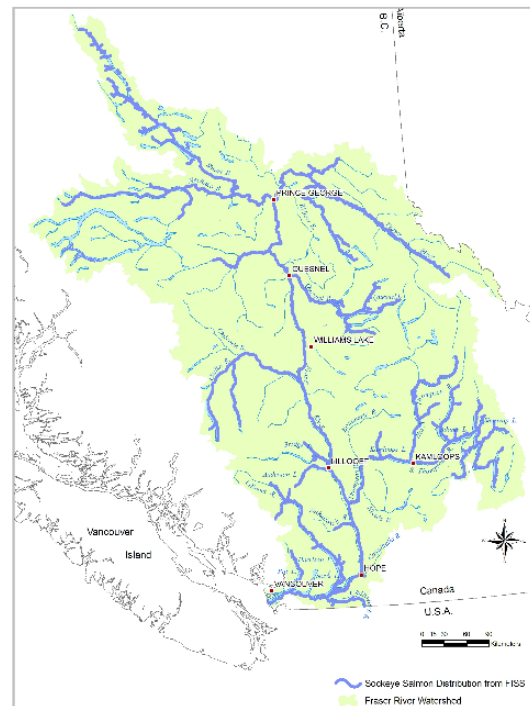*Image credit: Fisheries and Oceans Canada.*

Figure 1. The Fraser River watershed.

Context:

Ten designatable units (DUs) of Fraser Sockeye (Oncorhynchus nerka) were assessed as Endangered or Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2017.

Fisheries and Oceans Canada (DFO) Science Branch was asked to complete a Recovery Potential Assessment (RPA), based on the national RPA guidance, to provide science advice to inform the potential addition of the ten Fraser Sockeye DUs to Schedule 1 of the Species at Risk Act (SARA). The advice in this report, together with the other two Fraser Sockeye reports (Cultus RPA and Habitat, Threats, and Limiting Factors for nine DUs) form the Fraser Sockeye RPA for all ten DUs and may be used to inform both scientific and socioeconomic aspects of the listing process, development of a recovery strategy and action plan, and to support decision making with regards to the issuance of permits or agreements, and the formulation of exemptions and related conditions.

This Science Advisory Report is from the October 7-10, 2019 regional peer review on Recovery Potential Assessment – Fraser River Sockeye Salmon (Oncorhynchus nerka) – Ten Designatable Units. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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SUMMARY

- Ten Designatable Units (DUs) of Sockeye salmon that spawn in the Fraser River watershed in British Columbia were designated as Endangered or Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2017). Nine of them are the subject of this report (DU name followed by common stock name and DU number in parentheses):

    o Endangered: Bowron-ES (Bowron DU2), Takla-Trembleur-EStu (Early Stuart DU20), Harrison (U/S)-L (Weaver DU10), Seton-L (Portage DU17), Quesnel-S (Quesnel DU16), Takla-Trembleur-Stuart-S (Late Stuart DU21), Taseko-ES (Taseko DU22)

    o Threatened: Widgeon-River (Widgeon Slough DU24), North Barriere-ES (Upper Barriere, previously Fennell DU14).

    o The tenth: Cultus-L (Cultus DU6); Endangered, has a separate recovery potential assessment (DFO 2020).

- A further five DUs were categorized as Special Concern[1], and the three with a stock-recruit time series are also included in this analysis: Kamloops-ES (Raft DU11)*, Lillooet-Harrison-L (Birkenhead DU12)*, and Francois-Fraser-S (Stellako DU7)*. The remaining two are: Harrison (D/S)-L (Miscellaneous Lates DU9)* and Nahatlatch-ES (Nahatlatch DU13)*.

- Stock-recruit time series do not exist for two of the DUs (Widgeon Slough and Taseko DU 24, 22) so the type of quantitative analyses conducted for the other DUs were not possible.

- Productivity has been declining since at least the 1990s for all Endangered, Threatened, and Special Concern stocks with stock-recruit time series.

- Two related recovery targets are proposed:

    o Recovery Target #1: approximates the objective for a DU that would not be characterized as Endangered or Threatened by COSEWIC or in the Red biological status of the Wild Salmon Policy (WSP).

    o Recovery Target #2: approximates the objective of COSEWIC for Not At Risk or WSP Green.

- Stock specific stock-recruitment models were used to estimate the percentage of projections that would reach the two recovery targets in three generations (12 years) under scenarios using plausible population dynamics conditions across a range of mortality rates and productivity levels, including recent ones (brood years 2010-2013).

- In the summer of 2019, a large landslide was discovered in the Fraser River mainstem. The Big Bar landslide blocked virtually all of the natural migration of Fraser sockeye until 26-August. Six (Early Stuart, Late Stuart, Bowron, Quesnel, Taseko, and Stellako* DU 20, 21, 2, 22, 7) out of the twelve assessed DUs were affected by the landslide. Of those, Early Stuart, Bowron and Taseko (DU 20, 2, 22) were most affected since they were migrating upstream at a time when passage was completely blocked.

- A method to account for potential impacts of the Big Bar landslide was developed using the very preliminary information available in early August 2019 and used to make the projections.

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[1] Special Concern DUs were not included in the Terms of Reference for this report. However, some of the modeling results showed similar outcomes to the Endangered and Threatened DUs, so they have been included. Special Concern DUs will be identified with an asterisk (*) throughout this report.

- Assuming current productivity levels will continue, the projections were:

  o Unlikely to Very Unlikely (0-33%) to reach Recovery Target #1 even at low mortality rates (e.g., 10% or less) for Early Stuart and Bowron. (DU 20, 2)

  o As Likely As Not (34-65%) to reach Recovery Target #1 at low mortality rates for Upper Barriere, Portage, Weaver, Raft*, Late Stuart and Birkenhead*. (DU 14, 17, 10, 11, 21, 12)

  o Likely or Very Likely (66-100%) to reach Recovery Target #1 at low mortality rates for Quesnel, and Stellako*. (DU 16, 7)

- This report covers elements 12, 13, 15, 19-21 (i.e., quantitative analysis of recovery targets, probability of achieving recovery targets, and mitigation effects) and summarizes how these elements would contribute to element 22 (i.e., allowable harm). **The allowable harm assessment in this document does not include the elements covering habitat, threats, and limiting factors and should not be interpreted as being the final allowable harm statement for these DUs.**

- Recognizing that activities in support of the survival and recovery of a DU (e.g., stock assessment, research, conservation, or mitigation activities) could potentially cause mortalities, all sources of harm should be reduced to the maximum extent possible for Early Stuart and Bowron DUs in order to provide the *best opportunity for the survival* of these DUs. (DU 20, 2)

- Recognizing that activities in support of the survival and recovery of a DU (e.g., stock assessment, research, conservation, or mitigation activities) could potentially cause mortalities (e.g., stock assessment, research, conservation, or mitigation activities), all sources of harm should be reduced to the maximum extent possible for Weaver, Raft*, Birkenhead*, Portage, Late Stuart and Upper Barriere DUs in order to provide the best opportunity for the DUs to meet Recovery Target #1. (DU 10, 11, 12, 17, 21, 14)

- Preliminary results are presented for Quesnel and Stellako* DUs, but no allowable harm statement can be made at this time. Additional information will be available in the next four months to provide empirical estimates of the immediate impacts of the Big Bar landslide and support additional modeling that can be incorporated into the final allowable harm statement. (DU 16, 7)

- For Taseko and Widgeon DUs, the available data does not allow for total allowable harm to be assessed using the methods described in this report. However, using the other small stocks assessed in this report as proxies, all sources of harm should be reduced to the maximum extent possible for Taseko and Widgeon. (DU 22, 24)

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, Special Concern, 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 assessments within SARA processes, including the decision of whether to list or not to list a species on Schedule 1 of SARA, and during the recovery planning phase that follows if the species is listed.

Ten Designatable Units (DUs) of Sockeye salmon that spawn in the Fraser River watershed in British Columbia were designated as Endangered (EN) or Threatened (TH) by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2017). The eight Endangered DUs (common name and DU number in parentheses) are: Bowron-ES (Bowron DU2), Cultus – L (Cultus DU6), Takla-Trembleur-EStu (Early Stuart DU20), Harrison (U/S)-L (Weaver DU10), Seton-L (Portage DU17), Quesnel-S (Quesnel DU16), Takla-Trembleur-Stuart-S (Late Stuart DUD21), and Taseko-ES (Taseko DU22). The two Threatened DUs are: Widgeon-River (Widgeon Slough DU24) and North Barriere-ES (Upper Barriere, previously Fennell DU14). A further five DUs were assessed as Special Concern (SC): Kamloops-ES (Raft* DU11), Lillooet-Harrison-L (Birkenhead* DU12), and Francois-Fraser-S (Stellako* DU7), Harrison (D/S)-L (Misc. Lates* DU9) and Nahatlatch-ES (Nahatlatch* DU13). The RPA of the Endangered Cultus DU is covered in a separate document (DFO 2020). This document covers RPA elements 12, 13, 15, 19-21 (i.e., quantitative analysis of recovery targets, probability of achieving recovery targets, and mitigation effects) and summarizes how these elements would contribute to element 22 (i.e., allowable harm) for the remaining 9 EN/TH DUs and the three SC DUs (i.e., Raft*, Birkenhead*, and Stellako* DU 11, 12, 7) that have a time series of stock-recruit information (DFO 2014). **The allowable harm assessment in this document does not include the elements covering habitat, threats, and limiting factors and should not be interpreted as being the final allowable harm statement for these DUs.**

Summarized rationale for COSEWIC designations of the EN/TH DUs:

- rates of decline greater than 30% (TH) or 50% (EN) applied to:
  - o Bowron, Weaver, Quesnel, Portage, Early Stuart, Late Stuart, and Taseko (DU 2, 10, 16, 17, 20, 21, 22)
- continuing decline in small populations (<2,500) applied to:
  - o Bowron, Upper Barriere, Portage, and Taseko (DU 2, 14, 17, 22)
- population size less than 1,000 applied to:
  - o Portage, Taseko, and Widgeon Slough (DU 17, 22, 24)

ASSESSMENT

This assessment overlapped with the 2019 Fraser Sockeye migration timing, so the last year of adult returns included in the stock-recruit time series was 2018. Preliminary indications are that the 2019 adult return would be the lowest in a time series that began in 1893, with the previous lowest having occurred in 2016. In addition to low abundances, a landslide in the Fraser River near Big Bar created a near complete blockage to the upstream migration of adult Sockeye until late August 2019. Based on the location of the slide and estimates of migration timing, out of the 12 EN/TH/SC DUs covered in this report, the landslide impacted the majority of migrating Early Stuart, Bowron, and Taseko Sockeye (DU 20, 2, 22). Later migrating Late Stuart, Quesnel, and Stellako* (DU 21, 16, 7) fish were also impacted, but potentially to a lesser degree, as water levels had dropped to levels that facilitated some natural migration past the barrier during most of their migration timing. Quantitative estimates of fish arriving to spawning grounds will be

available in early 2020. Delayed impacts (e.g., percent successful spawn, egg fitness, smolt migration success) are unknown at this time.

Recent Productivity and Stock Recruitment Models

Stock-specific stock-recruitment models that were specific enough to incorporate recent low productivity levels but general enough to represent a DU's response three generations into the future were identified. The historical productivity patterns represented by estimates of Larkin alphas over time shown in Figure 2- Figure 5 were generated by fitting recursive Bayesian Larkin models to each stock-recruit time series (Larkin 1971, Walters & Staley 1987, Peterman et al. 2003). The DUs with long-term stock-recruit numbers are grouped according to: EN/TH DUs that spawn downstream of the Big Bar landslide (Figure 2); EN/TH DUs that spawn upstream of the Big Bar landslide (Figure 3); SC DUs (Figure 4); and for contrast, the DUs that were designated Not At Risk (Figure 5). For projections, the last four years of alpha estimates were used. The time series of stock-recruit numbers for Taseko and Widgeon Slough are not available. If the stock-recruit numbers were available, Widgeon Slough (DU 22) would be grouped with Figure 2 – EN/TH DUs that spawn downstream of the Big Bar landslide and Taseko (DU 24) would be grouped with Figure 3 – EN/TH DUs that spawn upstream of the Big Bar landslide.
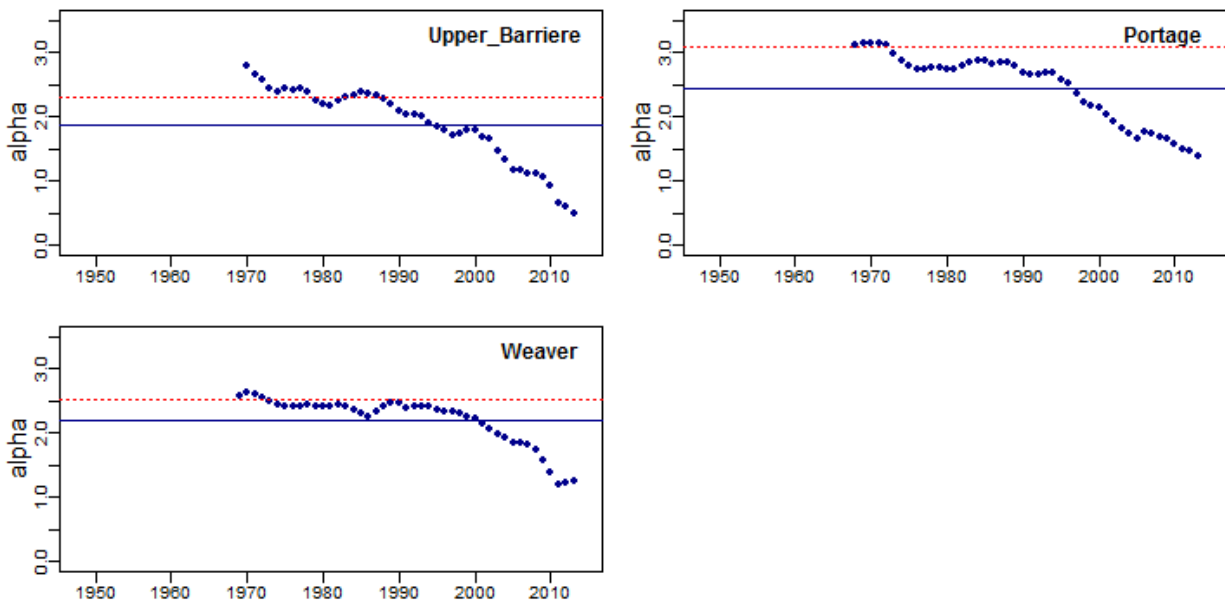
Figure 2. Productivity patterns - Endangered / Threatened DUs that spawn downstream of the Big Bar landslide. Blue points show the medians of annual estimates of the time-varying recursive Bayesian Larkin model alpha parameter value. Solid blue line is the average of all of the time varying alpha median values. Dotted red line is the median alpha estimate from the regular (non-time-varying) Larkin model.
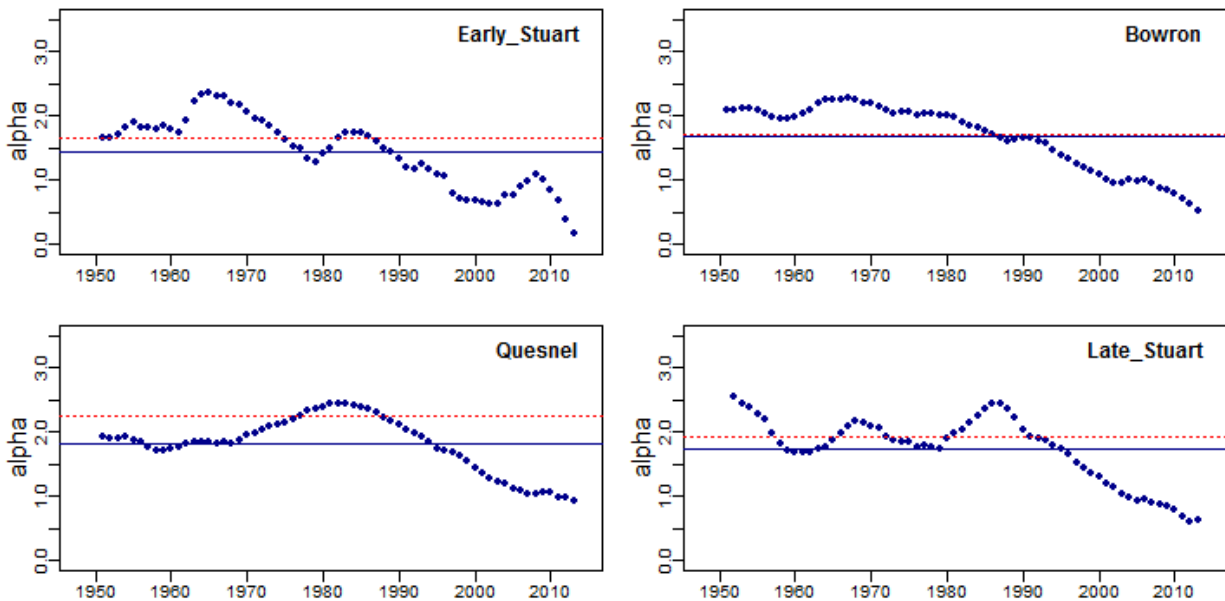
Figure 3. Productivity patterns - Endangered / Threatened DUs that spawn above and are directly affected by the Big Bar landslide. Blue points show the medians of annual estimates of the time-varying recursive Bayesian Larkin model alpha parameter value. Solid blue line is the average of all of the time varying alpha median values. Dotted red line is the median alpha estimate from the regular (non-time-varying) Larkin model.
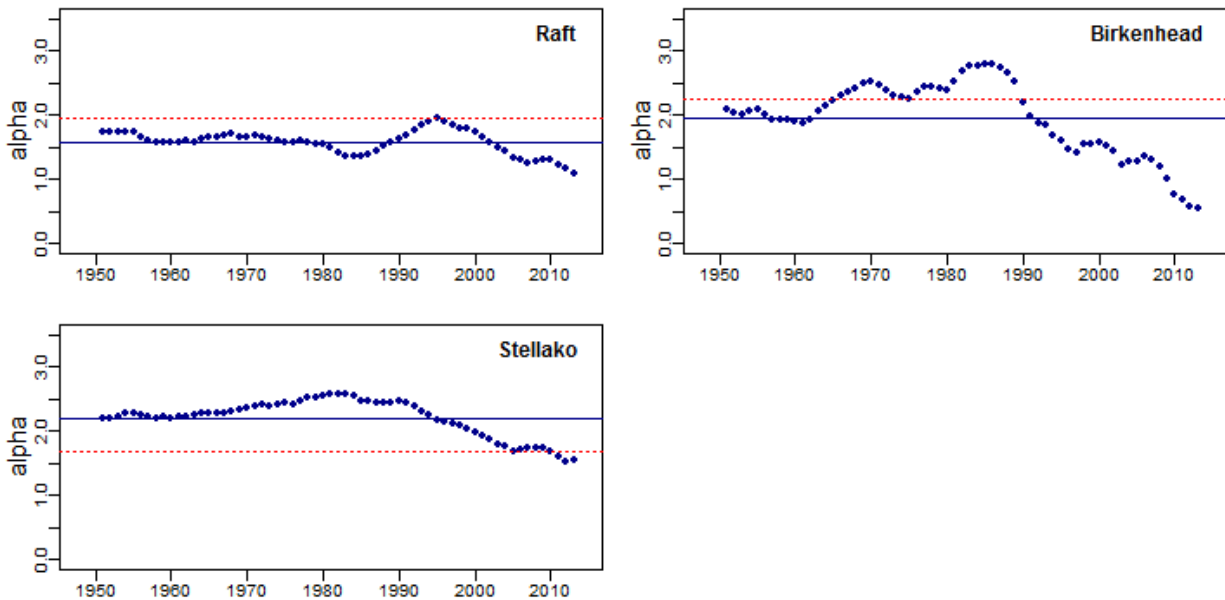
Figure 4. Productivity patterns - Special Concern DUs. Stellako* spawns above the Big Bar landslide. Blue points show the medians of annual estimates of the time-varying recursive Bayesian Larkin model alpha parameter value. Solid blue line is the average of all of the time varying alpha median values. Dotted red line is the median alpha estimate from the regular (non-time-varying) Larkin model.

*Figure 5. Productivity patterns - Not At Risk DUs. Nadina and Chilko spawn above the Big Bar landslide.
Blue points show the medians of annual estimates of the time-varying recursive Bayesian Larkin model
alpha parameter value. Solid blue line is the average of all of the time varying alpha median values.
Dotted red line is the median alpha estimate from the regular (non-time-varying) Larkin model.*
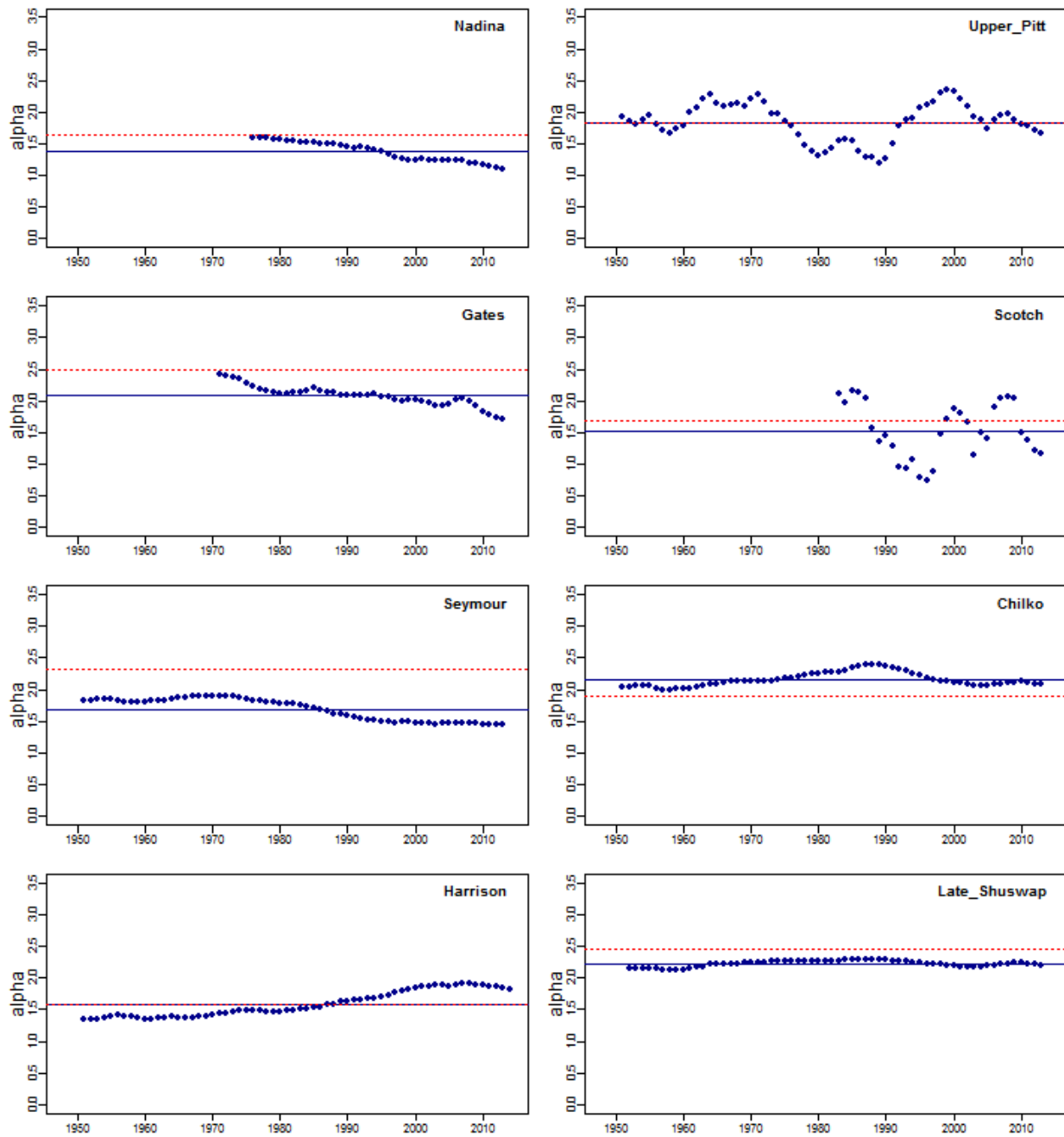
A number of stock-recruitment model forms were compared both in terms of historical performance (via residual patterns) and whether associated projections would result in substantively different outcomes in reaching recovery targets. A single model was chosen if the outcomes were similar based on these two comparisons. Model parameters were averaged if the outcomes were dissimilar. The recursive Bayesian Larkin model was one of the selected model forms for all stocks and was used to generate Figure 2 -Figure 5. Model averaging was implemented by using parameters estimated for all of the selected stock-recruitment models in the forward projections. Table 1 shows the model forms chosen for each stock.

Table 1. Selected model form(s) for each stock.

Model Form	DUs Modelled
recursive Bayesian Larkin model	Early Stuart, Bowron, Portage, Weaver, Raft* (DU 20, 2, 17, 10, 11)
recursive Bayesian Larkin model *and* recursive Bayesian Ricker model	Quesnel, Upper Barriere, Stellako*, Birkenhead* (DU 16, 14, 7, 12)
recursive Bayesian Larkin model *and* non-recursive Bayesian Ricker model using 5 generations of stock-recruitment estimates	Late Stuart (DU 21)

Recovery Targets

Recovery targets are needed to identify appropriate recovery and mitigation measures within SARA processes (DFO 2014). Unlike Cultus Sockeye (DFO 2020), quantitative recovery targets have not been previously identified for any of the EN/TH or SC DUs covered in this paper. Two related recovery targets are proposed for the DUs covered in this RPA:

o Recovery Target #1: approximates the objective for a DU that would not be characterized as Endangered or Threatened by COSEWIC or in the Red biological status of the Wild Salmon Policy (WSP).

o Recovery Target #2: approximates the objective of COSEWIC for Not At Risk or WSP Green.

These are nested Recovery Targets because the first Recovery Target must be reached in order to be considered for meeting the second target. While the Recovery Targets refer to COSEWIC and WSP processes, the computational methods in this paper do not capture the nuances in these expert-driven approaches. Both COSEWIC and WSP status determinations are made during multi-day meetings by subject matter experts. Criteria are outlined in COSEWIC (2018) and Holt et al. (2009), but are not directly translatable into a repeatable algorithm.

Although there is a low probability that a DU categorized as EN/TH could reach Recovery Target #2 in three generations, it is proposed within this RPA as a longer term aspirational

target. Recovery Target #1 is proposed as an intermediate target against which progress can be more easily measured.

Table 2 shows two different pathways, or combinations of criteria, by which a DU can meet each Recovery Target. The determination of the pathway is based on DU abundance. In Path A, DUs that have between 1,000 – 10,000 mature individuals in the last generation must also have an increasing three generation slope. In Path B, DUs that have abundances larger than 10,000 mature individuals can have a three generation decline no greater than 30%. DUs with mature individuals in the last generation that are less than 1,000 or less than the stock-specific WSP S_{gen} benchmark do not meet either Recovery Target. S_{gen} is the "spawner abundance that will result in recovery to S_{MSY} in one generation in the absence of fishing under equilibrium conditions" (Holt et al. 2009). As COSEWIC (2018) does not define a specific methodology to determine when a DU is considered Not At Risk, the WSP upper abundance benchmark was used to identify when a DU reached Recovery Target #2. Table 3 lists the S_{gen} and upper WSP benchmark values used to define the Recovery Target criteria that were adapted from Grant et al. (*in press*). Due to the nested nature of the Recovery Targets, a DU that meets Recovery Target #2 will also meet Recovery Target #1.

Table 2. Criteria used to determine whether projections for a given DU reached Recovery Target #1 and/or #2. Each Recovery Target can be met by two different combinations of criteria (Path A or Path B). Note that Recovery Target #2 uses the same two criteria pathways as Recovery Target #1, but adds one additional criterion. Criteria are designed to approximate, but not exactly match COSEWIC and WSP expert-driven status categorization approaches.

Criteria Questions	Recovery Target #1		Recovery Target #2	
	Path A	*Path B*	*Path A*	*Path B*
Is the average number of mature individuals in the last generation larger than the adapted Sgen value?	Yes	Yes	Yes	Yes
Is the average number of mature individuals in the last generation greater than 1k?	Yes	-	Yes	-
Is the 3 generation slope increasing?	Yes	-	Yes	-
Is the average number of mature individuals in the last generation greater than 10k?	-	Yes	-	Yes
Is the 3 generation slope doing better than a 30% decline?	-	Yes	-	Yes
Is the average number of mature individuals in the last generation larger than the upper WSP abundance benchmark?	-	-	Yes	Yes

Table 3. S_{gen} and upper WSP biological abundance benchmark values adapted from Grant et al. (in press). These values were used as criteria to assess the achievement of Recovery Targets (see Table 2).

Common Name (DU name)	S_{gen}	Upper WSP Biological Benchmark
Early Stuart DU 20 (Takla-Trembleur-EStu)	107,900	350,100
Bowron DU 2 (Bowron-ES)	5,100	19,000
Upper Barriere DU 14 (North Barriere-ES)	600	5,100
Quesnel DU 15 (Quesnel-S)	192,300	1,302,800
Late Stuart DU 21 (Takla-Trembleur-Stuart-S)	126,400	590,400
Raft* DU 11 (Kamloops-ES)	5,000	17,800
Stellako* DU 7 (Francois-Fraser-S)	24,300	122,600
Portage DU 17 (Seton-L)	2,200	13,500
Weaver DU 10 (Harrison (U/S)-L)	10,700	84,600
Birkenhead* DU 12 (Lillooet-Harrison-L)	14,900	79,000

Recovery Potential

To assess recovery potential, DU populations were projected forward for three generations (12 years), and this projection repeated 5,000 times with stochastic variation in parameter values for each scenario. A scenario in this analysis refers to a specific combination of exploitation rate, productivity level and Big Bar landslide impact. Simulation results are presented as the percentage of these projections that meet Recovery Target #1 or #2. The likelihood outcome

categories and descriptions defined by the Intergovernmental Panel on Climate Change (IPCC) (Mastrandrea et al. 2010) are used to facilitate presentation and discussion of results (Table 4).

Table 4. Intergovernmental Panel on Climate Change Likelihood Scale (from Mastrandrea et al 2010)

Term	Likelihood of the Outcome
Virtually Certain	99-100% probability
Very Likely	90-100% probability
Likely	66-100% probability
About As Likely As Not	33-66% probability
Unlikely	0-33% probability
Very Unlikely	0-10% probability
Exceptionally Unlikely	0-1% probability

While human-induced mortality is expressed as an "exploitation rate" in this analysis, it is important to note that: 1) ER was modelled because it is the easiest management lever to change quickly, and 2) the ERs modelled should not be explicitly interpreted as an allowable fisheries exploitation rate on adult salmon. Other factors that are implicitly bundled with, but are not explicitly modelled by the "exploitation rate" include: increased levels of in-river mortality above those modelled; mortalities associated with fishing activities directed at sockeye or other species, including direct and indirect physical and physiological injury (i.e., through release, depredation or gear avoidance); increased natural predation; and habitat impacts on migratory adults. Thus, ER in the scenarios should be interpreted as a combination of direct mortalities from anthropogenic sources (e.g., fishing); increases in mortality from indirect anthropogenic sources (e.g., en-route mortality exacerbated by climate change); and increases in mortality from historical levels of natural mortality (e.g., predation). All factors contributing to mortalities should therefore be considered in addition to ER and productivity when considering allowable harm and overall recovery potential. Note that historical levels of in-river mortality is included in the models for all DUs, in addition to the in-river mortality associated with the Big Bar landslide for DUs that spawn upstream of the blockage.

Recovery Potential – Current Productivity

Table 5 provides a snapshot of the simulation results. For each DU, it shows the maximum exploitation rate that resulted in the DU being categorized as Likely to reach each Recovery Target (i.e., 66% or more of the projections met the Recovery Target criteria). The results in Table 5 are based on current productivity, and the scenario where the Big Bar landslide only impacts the fish returning in 2019 for the DUs that spawn upstream of the landslide (i.e., assumed that the blockage will be removed prior to adults returning in 2020 and no lingering effects). For most DUs, an "NA" is shown, because even at zero exploitation rate the DU was either Unlikely or As Likely As Not to reach a Recovery Target.

Of the EN/TH group, only the simulation results for Quesnel (DU 16) show that the DU is Likely to reach Recovery Target #1 within three generations at current productivity levels and at exploitation rates greater than zero. Late Stuart (DU 21) is Likely to reach Recovery Target #1, but only at a zero exploitation rate. Of the remaining modelled EN/TH DUs: Upper Barriere, Portage and Weaver (DU 14, 17, 10) were As Likely As Not to reach Recovery Target #1; and Early Stuart and Bowron (DU 20, 2) were Unlikely to reach Recovery Target #1 at a zero exploitation rate.

The SC group also shows a wide range of results (Table 5). Raft* (DU 11) is As Likely As Not to reach Recovery Target #1 at current productivity levels in three generations at a zero exploitation rate. Birkenhead* (DU 12) is Likely to meet Recovery Target #1, but only at a zero

exploitation rate. Stellako* (DU 7) is the only DU to meet Recovery Target #2 in three generations at current productivity levels and then only with a maximum exploitation rate of 5%.

Table 5. Summary of simulation results at current productivity. Last four columns: A = the maximum exploitation rate that is associated with a DU being "likely" to reach Recovery Target #1 (i.e., maximum ER that results in 66% of the projections reaching Recovery Target #1); B = the percentage of projections that met Recovery Target #1 with no additional exploitation rate (at current productivity); C = the maximum exploitation rate that is associated with a DU being "likely" to reach Recovery Target #2; D = the percentage of projections that met Recovery Target #2 with no additional exploitation rate.

Common Name	*DU Name and number*	*COSEWIC status*	*spawn above Big Bar*	*A. max ER that meets Recovery Target #1*	*B. % of projections that meet Recovery Target #1 at ER = 0%*	*C. max ER that meets Recovery Target #2*	*D. % of projections that meet Recovery Target #2 at ER = 0%*
Early Stuart	*Takla-Trembleur-Estu* *DU 20*	*EN*	*Y*	*NA*	*3*	*NA*	*0*
Bowron	*Bowron-ES* *DU 2*	*EN*	*Y*	*NA*	*20*	*NA*	*1*
Taseko	*Taseko-ES* *DU 22*	*EN*	*Y*	*not modelled*			
Upper Barriere	*North Barriere-ES* *DU 14*	*TH*	*N*	*NA*	*50*	*NA*	*22*
Quesnel	*Quesnel-S* *DU 16*	*EN*	*Y*	*25*	*85*	*NA*	*16*
Late Stuart	*Takla-Trembleur-Stuart-S* *DU 21*	*EN*	*Y*	*0*	*66*	*NA*	*18*
Widgeon Slough	*Widgeon-River* *DU 24*	*TH*	*N*	*not modelled*			
*Raft**	*Kamloops-ES* *DU 11*	*SC*	*N*	*NA*	*50*	*NA*	*18*

Common Name	DU Name and number	COSEWIC status	spawn above Big Bar	A. max ER that meets Recovery Target #1	B. % of projections that meet Recovery Target #1 at ER = 0%	C. max ER that meets Recovery Target #2	D. % of projections that meet Recovery Target #2 at ER = 0%
Stellako*	Francois-Fraser-S DU 7	SC	Y	55/35	99	5	72
Portage	Seton-L DU 17	EN	N	NA	40	NA	14
Weaver Creek	Harrison (U/S)-L DU 10	EN	N	NA	56	NA	26
Birkenhead*	Lillooet-Harrison-L DU 12)	SC	N	0	67	NA	24

Recovery Potential – Range of Future Productivities

While Table 5 focussed on the likelihood of reaching the Recovery Targets at current productivities, Figure 6 - Figure 15 show the results across a range of exploitation rates and future productivities by DU. For each of these, the number in column B in Table 5 corresponds to a value shown in a single cell in Figure 6 - Figure 15. Using Upper Barriere (DU 14) as an example, the number in column B of Table 5 (i.e., "50") is the same as the number in Figure 6 in the grid on the left (i.e., Recovery Target #1) at the intersection of the bottom row (i.e. "zero exploitation rate") and the column labelled "0" (i.e., current productivity).

It is important to emphasize that the entire lower range of future productivities (i.e., 10-50% below current productivity) is considered plausible, given rates of decline in productivity over the past three generations. The range of higher productivities (i.e. 10-30% above current productivity) is presented more as a way to gauge potential effects from mitigation measures as opposed to representing expected near-future productivity trends.

Alternative future productivities are simulated using subsets of the parameter samples for each stock-specific stock-recruitment model, with subsets selected to generate the pre-defined change in the median of the productivity parameter *alpha.*

Future Productivities: DUs that spawn below Big Bar Landslide

Upper Barriere (DU 14, Figure 6), Portage (DU 17, Figure 7), and Weaver (DU 10, Figure 8) Sockeye all spawn below the Big Bar Landslide. At exploitation rates of 10% or less, Upper Barriere and Weaver (DU 14, 10) are As Likely As Not to reach Recovery Target #1 across most of the range of productivities modelled. At exploitation rates of 10% or less, Portage (DU 17) becomes Unlikely to reach Recovery Target #1 as productivity decreases from current values and is As Likely As Not to reach Recovery Target #1 at current or higher productivities.

Figure 6. Effect of varying exploitation rate across alternative productivity scenarios – Upper Barriere (DU 14, North Barriere-ES). These two panels show the simulated performance relative to Recovery Target #1 and Recovery Target #2. Each panel summarizes performance results for simulations in which exploitation rate (along a column) and productivity (along a row) varied in combination. Current productivity is shown in the column labelled "0" productivity change. The numbers in each cell are the percentage of projections out of 5000 that met the Recovery Target. Each cell's colour coding overlays the IPCC probability levels (Table 4) obtained in the results, from Very Likely in dark green to Very Unlikely in dark magenta.
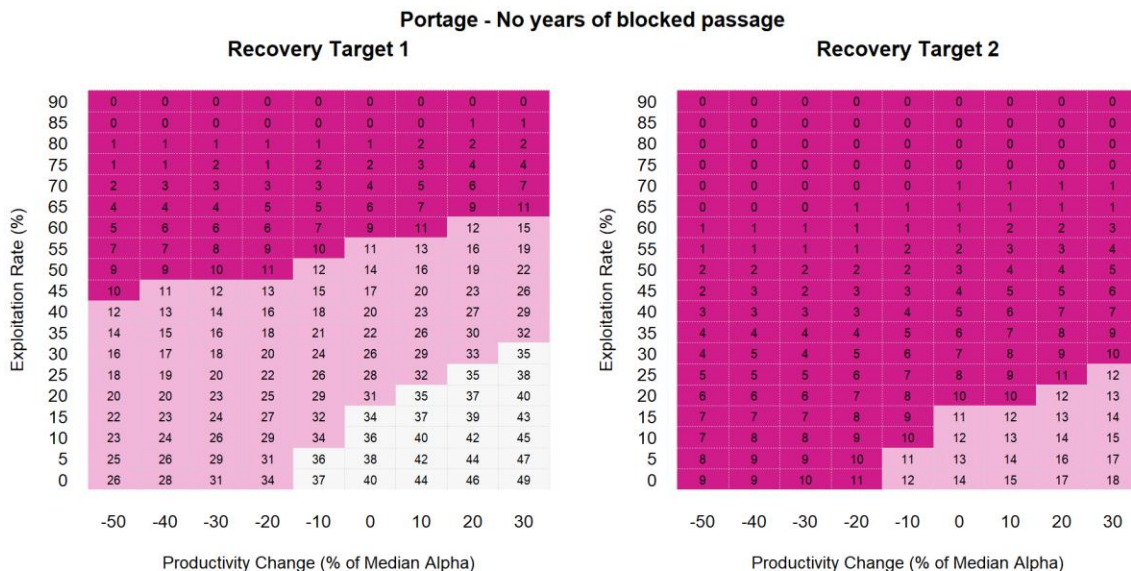
Figure 7. Effect of varying exploitation rate across alternative productivity scenarios – Portage (DU 17, Seton-L). These two panels show the simulated performance relative to Recovery Target #1 and Recovery Target #2. Each panel summarizes performance results for simulations in which exploitation rate (along a column) and productivity (along a row) varied in combination. Current productivity is shown in the column labelled "0" productivity change. The numbers in each cell are the percentage of projections out of 5000 that met the Recovery Target. Each cell's colour coding overlays the IPCC probability levels (Table 4) obtained in the results, from Very Likely in dark green to Very Unlikely in dark magenta.

Weaver Creek - No years of blocked passage

Recovery Target 1

Exploitation Rate (%)	-50	-40	-30	-20	-10	0	10	20	30
90	0	1	1	1	1	1	1	1	1
85	2	2	2	3	3	3	4	4	6
80	4	5	5	6	6	7	7	8	10
75	7	8	8	9	9	10	12	14	16
70	10	10	11	12	13	15	17	19	22
65	13	13	14	16	17	20	22	25	27
60	15	16	17	20	21	24	26	29	32
55	18	19	20	24	25	28	30	33	36
50	21	22	24	27	29	32	34	37	40
45	23	25	27	30	32	35	38	41	43
40	25	27	30	33	35	38	41	44	47
35	27	30	32	35	38	41	44	47	50
30	30	32	34	38	41	44	46	50	52
25	31	35	36	40	43	47	49	52	54
20	34	37	39	42	46	49	51	54	56
15	36	39	41	44	48	51	53	56	58
10	38	41	43	46	50	53	55	57	60
5	39	43	45	48	52	55	57	59	61
0	41	44	47	50	54	56	58	60	62

Productivity Change (% of Median Alpha)

Recovery Target 2

Exploitation Rate (%)	-50	-40	-30	-20	-10	0	10	20	30
90	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	1
75	1	1	1	1	1	1	1	1	2
70	1	1	2	2	2	2	2	2	4
65	2	2	2	3	3	3	4	4	5
60	3	3	4	4	4	5	5	6	7
55	4	5	5	5	6	6	7	8	10
50	5	6	6	7	8	8	9	10	12
45	6	7	8	8	9	10	11	12	14
40	7	8	9	10	10	12	13	14	16
35	8	9	10	11	12	14	15	16	19
30	9	11	12	13	13	16	17	18	21
25	10	12	13	14	15	18	19	20	23
20	12	13	14	16	17	19	20	22	24
15	13	14	16	17	18	21	22	24	26
10	14	16	17	18	20	22	24	25	28
5	15	17	18	20	21	24	25	27	29
0	16	18	19	21	23	26	27	29	31

Productivity Change (% of Median Alpha)

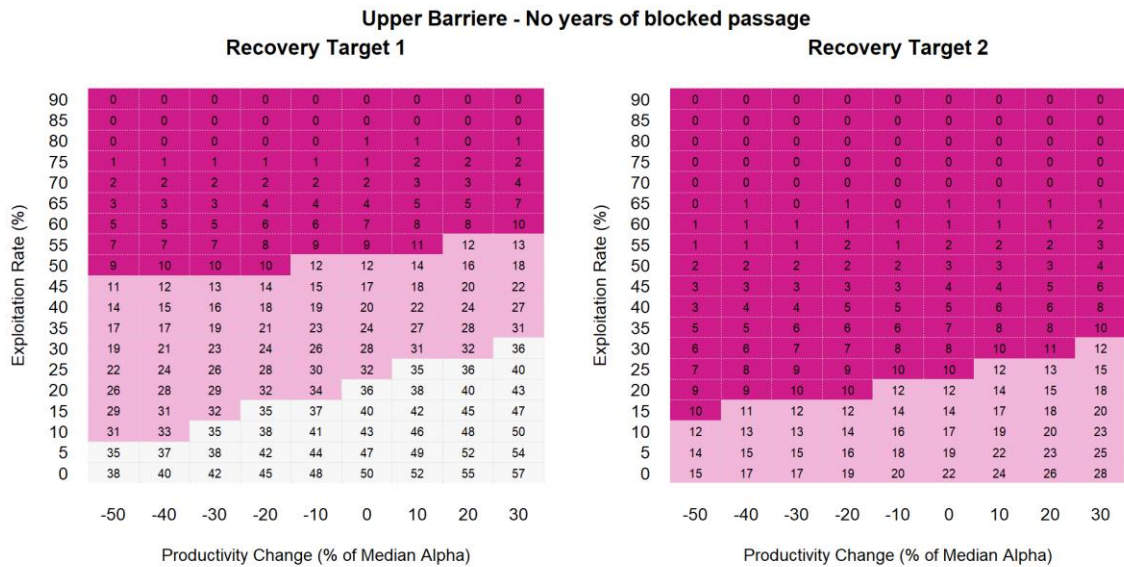*Figure 8. Effect of varying exploitation rate across alternative productivity scenarios – Weaver (DU 10, Harrison (U/S)-L). These two panels show the simulated performance relative to Recovery Target #1 and Recovery Target #2. Each panel summarizes performance results for simulations in which exploitation rate (along a column) and productivity (along a row) varied in combination. Current productivity is shown in the column labelled "0" productivity change. The numbers in each cell are the percentage of projections out of 5000 that met the Recovery Target. Each cell's colour coding overlays the IPCC probability levels (Table 4) obtained in the results, from Very Likely in dark green to Very Unlikely in dark magenta.*
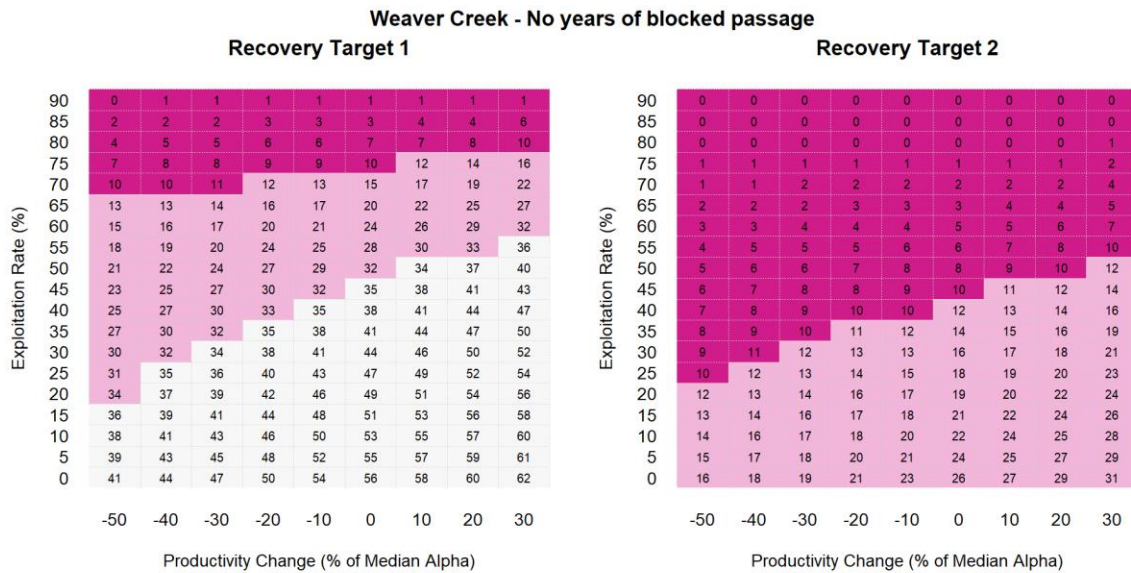
Future Productivities: Endangered and Threatened DUs that spawn above Big Bar Landslide

Early Stuart (DU 20, Figure 9), Bowron (DU 2, Figure 10), Quesnel (DU 16, Figure 11), Late Stuart (DU 21, Figure 12), and Taseko (DU 22, no Figure) Sockeye all need to migrate upstream of the Big Bar landslide to spawn. Preliminary indications are that the modelled impacts on spawners to the grounds using a 99.5% en-route mortality rate result in projected numbers that are similar to observed spawner numbers for Early Stuart and Bowron (DU 20, 2), but overly pessimistic for Quesnel and Late Stuart (DU 16, 21). Additional information for these stocks will be needed prior to making a final allowable harm assessment statement. Specifically, near final spawner estimates and a plan to address the blockage at the Big Bar site will be known early in 2020. Longer term impacts such as the reproductive fitness of 2019 spawners, impacts on the downstream migration of smolts and the migratory and spawning success of Sockeye after remedial work at the Big Bar site is conducted will not be known for several years.

At all modelled combinations of exploitation rate and productivity, Early Stuart (DU 20) is Very Unlikely to Exceptionally Unlikely to reach Recovery Target #1. At exploitation rates of 10% or less, Bowron (DU 2) is Unlikely to Very Unlikely to reach Recovery Target #1 and Quesnel (DU 16) is Likely to reach Recovery Target #1 across most of the range of productivities modelled. At exploitation rates of 5% or less and with increasing productivities, Late Stuart (DU 21) is Likely to reach Recovery Target #1. As productivity decreases below current levels and at exploitation rates of 10% or less, Late Stuart is As Likely As Not to reach Recovery Target #1.

Early Stuart - 1 year blocked passage (2019)

Recovery Target 1

Recovery Target 2

Figure 9. Effect of varying exploitation rate across alternative productivity scenarios – Early Stuart (DU 20, Takla-Trembleur-EStu). These two panels show the simulated performance relative to Recovery Target #1 and Recovery Target #2. Each panel summarizes performance results for simulations in which exploitation rate (along a column) and productivity (along a row) varied in combination. Current productivity is shown in the column labelled "0" productivity change. The numbers in each cell are the percentage of projections out of 5000 that met the Recovery Target. Each cell's colour coding overlays the IPCC probability levels (Table 4) obtained in the results, from Very Likely in dark green to Very Unlikely in dark magenta.

Bowron - 1 year blocked passage (2019)

Recovery Target 1
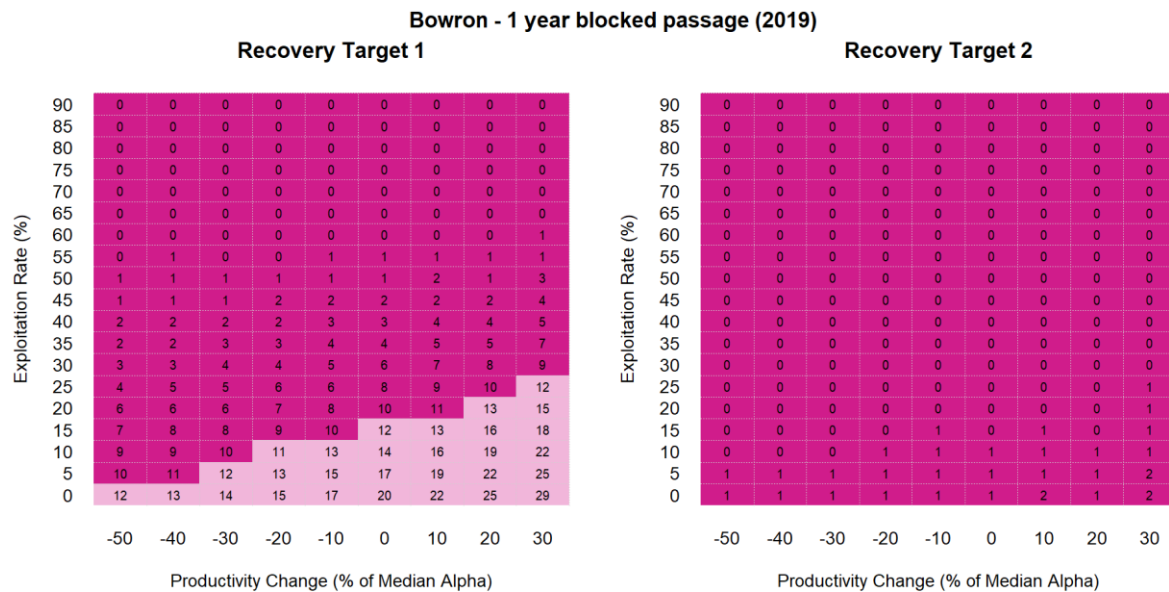
Recovery Target 2

Figure 10. Effect of varying exploitation rate across alternative productivity scenarios – Bowron (DU 2, Bowron-ES). These two panels show the simulated performance relative to Recovery Target #1 and Recovery Target #2. Each panel summarizes performance results for simulations in which exploitation rate (along a column) and productivity (along a row) varied in combination. Current productivity is shown in the column labelled "0" productivity change. The numbers in each cell are the percentage of projections out of 5000 that met the Recovery Target. Each cell's colour coding overlays the IPCC probability levels (Table 4) obtained in the results, from Very Likely in dark green to Very Unlikely in dark magenta.
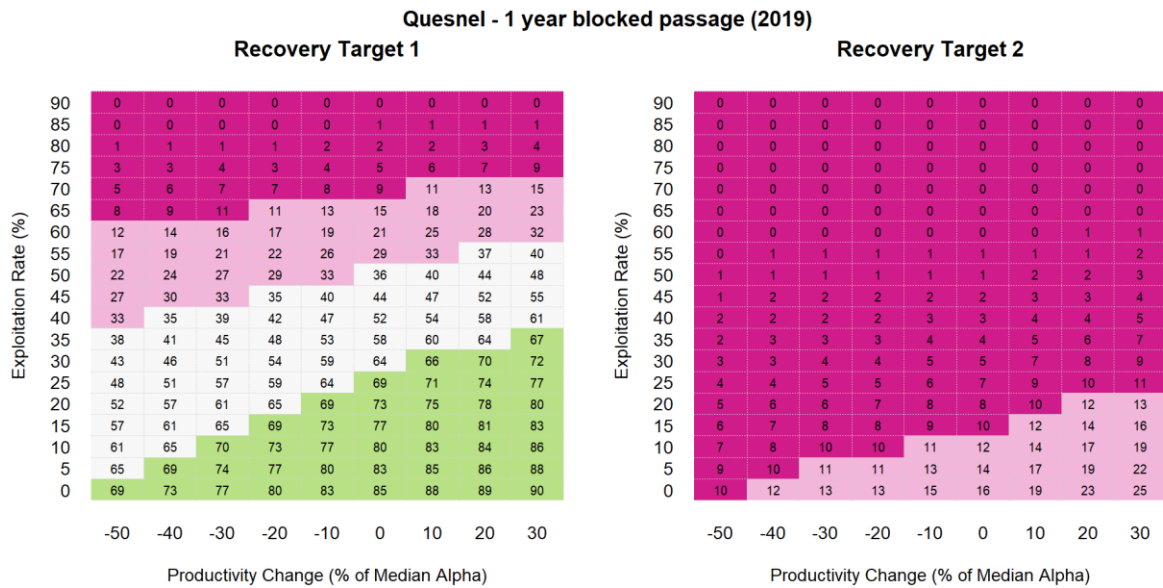
Figure 11. Effect of varying exploitation rate across alternative productivity scenarios – Quesnel (DU 16, Quesnel-S). These two panels show the simulated performance relative to Recovery Target #1 and Recovery Target #2. Each panel summarizes performance results for simulations in which exploitation rate (along a column) and productivity (along a row) varied in combination. Current productivity is shown in the column labelled "0" productivity change. The numbers in each cell are the percentage of projections out of 5000 that met the Recovery Target. Each cell's colour coding overlays the IPCC probability levels (Table 4) obtained in the results, from Very Likely in dark green to Very Unlikely in dark magenta.
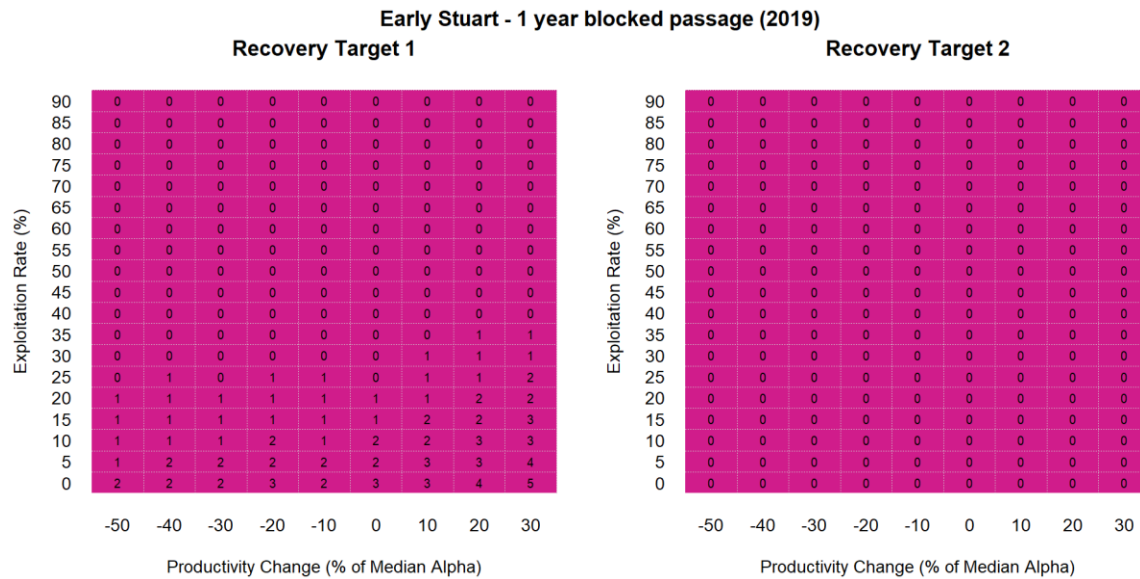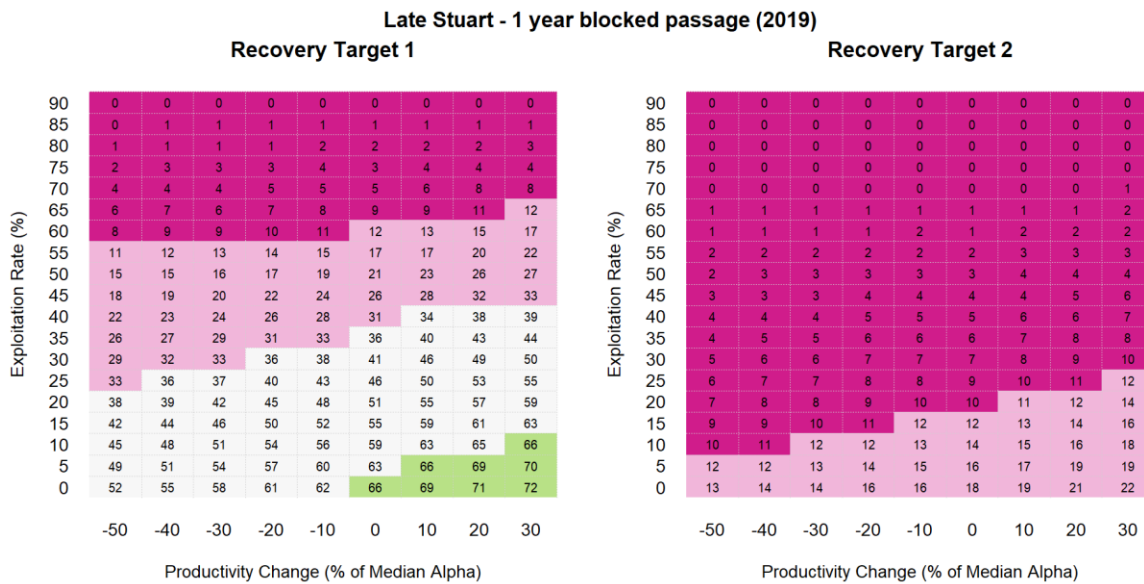

Figure 12. Effect of varying exploitation rate across alternative productivity scenarios – Late Stuart (DU 21, Takla-Trembleur-Stuart-S). These two panels show the simulated performance relative to Recovery Target #1 and Recovery Target #2. Each panel summarizes performance results for simulations in which exploitation rate (along a column) and productivity (along a row) varied in combination. Current productivity is shown in the column labelled "0" productivity change. The numbers in each cell are the percentage of projections out of 5000 that met the Recovery Target. Each cell's colour coding overlays the IPCC probability levels (Table 4) obtained in the results, from Very Likely in dark green to Very Unlikely in dark magenta.

Future Productivities: Special Concern DUs

Raft* (DU 11, Figure 13), Birkenhead* (DU 12, Figure 14) and Stellako* (DU 7, Figure 15) Sockeye were designated as Special Concern by COSEWIC in 2017. As stock-recruit estimates are available for these DUs and their performances against Recovery Target #1 were similar to that achieved by the EN/TH DUs, particularly for Raft* and Birkenhead* (DU 11, 12), their results are included in this report. Of the Special Concern DUs, Stellako* (DU 7) spawns upstream of the Big Bar landslide and so the caveats in the previous section pertaining to interpretation of results also apply. Two other DUs (Harrison (D/S)-L (DU 9, Miscellaneous Lates)* and Nahatlatch-ES (DU 13, Nahatlatch)*) were also designated as Special Concern, but do not have stock-recruit estimates, and are not included in this report.

At exploitation rates of 10% or less, Raft* (DU 11) is As Likely As Not to reach Recovery Target #1 when productivities range from current to increased levels. As productivity drops, Raft* becomes Unlikely to reach Recovery Target #1. At exploitation rates of 10% or less, Birkenhead* (DU 12) is As Likely As Not to reach Recovery Target #1 until productivity increases above the current level. At exploitation rates of 10% or less, Stellako* (DU 7) is the only DU to be Very Likely to reach Recovery Target #1 in three generations across the entire range of productivities modelled. Stellako* is also the only DU to be Likely to reach Recovery Target #2 in three generations in any scenario.

Raft - No years of blocked passage

Recovery Target 1

Exploitation Rate (%) vs. Productivity Change (% of Median Alpha)

Exploitation Rate (%)	-50	-40	-30	-20	-10	0	10	20	30
90	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	1	1	1
65	1	1	1	1	1	1	2	2	3
60	1	1	2	2	2	3	3	4	6
55	2	2	3	3	3	5	6	8	10
50	4	4	5	5	6	8	9	12	15
45	6	6	7	8	9	11	13	17	20
40	8	9	10	11	13	15	18	22	26
35	10	12	12	14	16	19	23	28	32
30	13	14	15	18	20	23	28	33	38
25	16	17	18	21	24	28	33	38	43
20	18	20	21	25	29	33	38	44	48
15	21	23	24	29	33	38	43	48	52
10	24	26	27	32	37	42	48	52	57
5	26	29	31	36	41	46	52	56	60
0	29	31	35	39	45	50	56	59	64

Recovery Target 2

Exploitation Rate (%) vs. Productivity Change (% of Median Alpha)

Exploitation Rate (%)	-50	-40	-30	-20	-10	0	10	20	30
90	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	1	0	1
45	0	0	0	1	1	1	1	1	2
40	1	1	1	1	1	2	2	2	4
35	2	1	2	2	2	3	3	4	6
30	2	2	3	3	3	4	5	6	8
25	3	3	4	4	4	6	7	9	10
20	4	4	5	6	6	8	10	12	14
15	5	6	7	7	8	10	12	15	17
10	7	7	8	10	10	13	15	18	20
5	8	9	10	12	13	15	18	21	24
0	10	10	11	14	15	18	21	24	27

Figure 13. Effect of varying exploitation rate across alternative productivity scenarios – Raft (DU 11, Kamloops-ES). These two panels show the simulated performance relative to Recovery Target #1 and Recovery Target #2. Each panel summarizes performance results for simulations in which exploitation rate (along a column) and productivity (along a row) varied in combination. Current productivity is shown in the column labelled "0" productivity change. The numbers in each cell are the percentage of projections out of 5000 that met the Recovery Target. Each cell's colour coding overlays the IPCC probability levels (Table 4) obtained in the results, from Very Likely in dark green to Very Unlikely in dark magenta.*

Birkenhead - No years of blocked passage

Recovery Target 1

Exploitation Rate (%)	-50	-40	-30	-20	-10	0	10	20	30
90	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0
80	1	1	1	1	1	1	1	1	1
75	2	2	2	2	2	2	3	3	3
70	3	4	4	4	4	5	5	6	6
65	6	6	6	7	7	9	9	10	11
60	9	9	10	11	11	13	14	15	16
55	12	13	14	15	16	17	19	21	23
50	16	18	18	20	20	23	25	26	29
45	20	22	23	24	26	28	30	32	34
40	24	26	28	30	31	33	35	37	40
35	28	31	32	35	36	39	41	43	45
30	33	35	36	40	41	43	46	47	50
25	37	40	41	44	45	48	50	52	54
20	41	44	46	48	51	52	55	57	59
15	45	48	50	53	55	56	59	61	63
10	49	51	54	57	59	60	63	65	66
5	53	55	58	60	63	64	67	68	70
0	57	58	61	64	67	67	70	71	73

Productivity Change (% of Median Alpha)

Recovery Target 2

Exploitation Rate (%)	-50	-40	-30	-20	-10	0	10	20	30
90	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	1	1
60	1	1	1	1	1	1	1	1	1
55	1	1	1	1	1	1	2	2	2
50	2	2	2	2	2	3	3	3	3
45	3	3	3	3	3	4	4	5	5
40	4	4	4	4	4	5	6	6	7
35	5	5	5	6	6	7	8	8	8
30	6	7	7	7	7	9	10	10	11
25	8	8	9	9	10	11	12	13	14
20	10	10	11	11	12	14	15	15	17
15	11	12	13	14	14	16	18	18	20
10	13	14	15	16	17	19	20	21	23
5	15	16	17	18	20	21	23	24	26
0	17	18	20	21	22	24	26	27	29

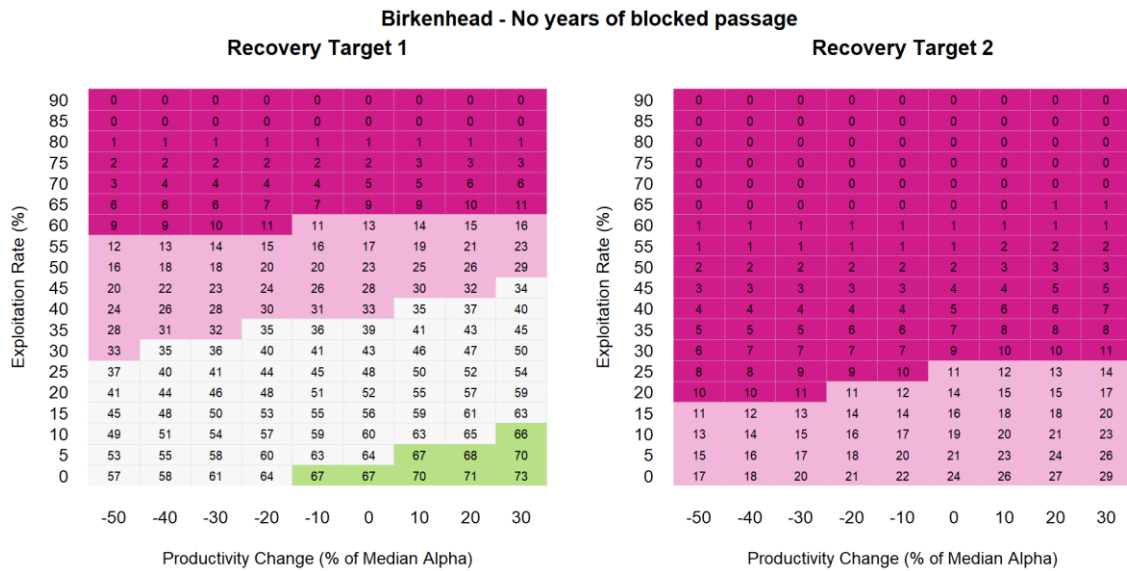Productivity Change (% of Median Alpha)

Figure 14. Effect of varying exploitation rate across alternative productivity scenarios – Birkenhead* (DU 12, Lillooet-Harrison-L). These two panels show the simulated performance relative to Recovery Target #1 and Recovery Target #2. Each panel summarizes performance results for simulations in which exploitation rate (along a column) and productivity (along a row) varied in combination. Current productivity is shown in the column labelled "0" productivity change. The numbers in each cell are the percentage of projections out of 5000 that met the Recovery Target. Each cell's colour coding overlays the IPCC probability levels (Table 4) obtained in the results, from Very Likely in dark green to Very Unlikely in dark magenta.
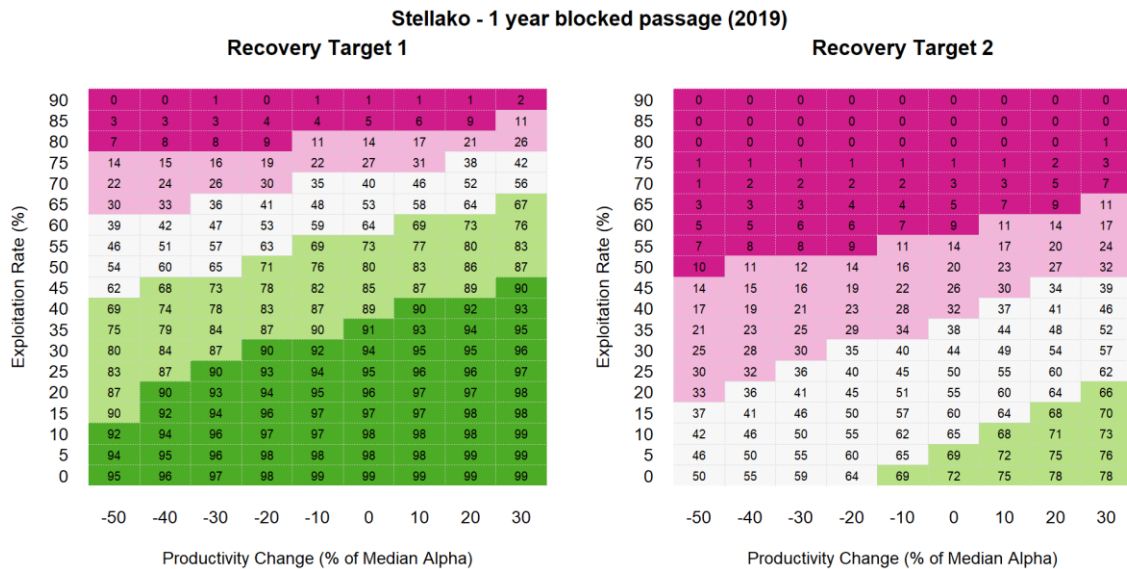
Stellako - 1 year blocked passage (2019)

Recovery Target 1

Exploitation Rate (%)	-50	-40	-30	-20	-10	0	10	20	30
90	0	0	1	0	1	1	1	1	2
85	3	3	3	4	4	5	6	9	11
80	7	8	8	9	11	14	17	21	26
75	14	15	16	19	22	27	31	38	42
70	22	24	26	30	35	40	46	52	56
65	30	33	36	41	48	53	58	64	67
60	39	42	47	53	59	64	69	73	76
55	46	51	57	63	69	73	77	80	83
50	54	60	65	71	76	80	83	86	87
45	62	68	73	78	82	85	87	89	90
40	69	74	78	83	87	89	90	92	93
35	75	79	84	87	90	91	93	94	95
30	80	84	87	90	92	94	95	95	96
25	83	87	90	93	94	95	96	96	97
20	87	90	93	94	95	96	97	97	98
15	90	92	94	96	97	97	97	98	98
10	92	94	96	97	97	98	98	98	99
5	94	95	96	98	98	98	98	99	99
0	95	96	97	98	99	99	99	99	99

Productivity Change (% of Median Alpha)

Recovery Target 2

Exploitation Rate (%)	-50	-40	-30	-20	-10	0	10	20	30
90	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	1
75	1	1	1	1	1	1	1	2	3
70	1	2	2	2	2	3	3	5	7
65	3	3	3	4	4	5	7	9	11
60	5	5	6	6	7	9	11	14	17
55	7	8	8	9	11	14	17	20	24
50	10	11	12	14	16	20	23	27	32
45	14	15	16	19	22	26	30	34	39
40	17	19	21	23	28	32	37	41	46
35	21	23	25	29	34	38	44	48	52
30	25	28	30	35	40	44	49	54	57
25	30	32	36	40	45	50	55	60	62
20	33	36	41	45	51	55	60	64	66
15	37	41	46	50	57	60	64	68	70
10	42	46	50	55	62	65	68	71	73
5	46	50	55	60	65	69	72	75	76
0	50	55	59	64	69	72	75	78	78

Productivity Change (% of Median Alpha)

Figure 15. Effect of varying exploitation rate across alternative productivity scenarios – Stellako* (DU 7) Francois-Fraser-S). These two panels show the simulated performance relative to Recovery Target #1 and Recovery Target #2. Each panel summarizes performance results for simulations in which exploitation rate (along a column) and productivity (along a row) varied in combination. Current productivity is shown in the column labelled "0" productivity change. The numbers in each cell are the percentage of projections out of 5000 that met the Recovery Target. Each cell's colour coding overlays the IPCC probability levels (Table 4) obtained in the results, from Very Likely in dark green to Very Unlikely in dark magenta.

Mitigation Assessment Methodology for Big Bar Landslide

Due to the timing of this report, an assessment of mitigation measures for the Big Bar landslide could not be included because decisions about site remediation cannot be made until winter, when water levels drop sufficiently to properly assess the site. However, a methodology for assessing potential outcomes was proposed and demonstrated in this report using a hypothetical fishway installation scenario. In addition, sensitivity analyses were presented in which the 99.5% Big Bar mortality persisted for two to four years. The sensitivity analysis results helps to cast light on the importance of protecting the dominant cycle year for cyclic stocks (2021 for Late Stuart (DU 21) and 2022 for Early Stuart and Quesnel (DU 20, 16)) and the cumulative effect of catastrophic mortality for multiple years in a row.

Figure 16 - Figure 19 in the appendix show the results of this analysis.

Allowable Harm Assessment: PART ONE

This report covers elements 12, 13, 15, 19-21 of the Recovery Potential Assessment Terms of Reference (i.e., quantitative analysis of recovery targets, probability of achieving recovery targets, and mitigation effects) and summarizes how these elements would contribute to element 22 (i.e., allowable harm). **The allowable harm assessment in this document does not include the elements covering habitat, threats, and limiting factors and should not be interpreted as being the final allowable harm statement for these DUs.**

Recognizing that activities in support of the survival and recovery of a DU (e.g., stock assessment, research, conservation, or mitigation activities) can result in possible mortalities, all sources of harm should be reduced to the maximum extent possible for Early Stuart and Bowron DUs in order to provide the best opportunity for the survival of these DUs. These DUs were Unlikely to reach Recovery Target #1 in three generations even at the most optimistic scenario modelled of 30% increase in productivity and zero exploitation rate. In addition, the timing and location of the 2019 migration blockage due to the Big Bar landslide overlapped nearly entirely with the upstream migration of these two DUs. (DU 20, 2)

Recognizing that activities in support of the survival and recovery of a DU (e.g., stock assessment, research, conservation, or mitigation activities) can result in possible mortalities, all sources of harm should be reduced to the maximum extent possible for Weaver, Raft*, Birkenhead*, Portage, Late Stuart and Upper Barriere DUs in order to provide the best opportunity for the DUs to meet Recovery Target #1 (DU 10, 11, 12, 17, 21, 14). These DUs were all As Likely As Not to reach Recovery Target #1 across a wide range of modelled future productivities at low to zero exploitation rates. Some DUs, such as Portage and Raft* (DU 17, 11), became Unlikely to reach Recovery Target #1 as productivity decreased, while others such as Late Stuart and Birkenhead* (DU 21, 12) became Likely to reach Recovery Target #1 as productivity increased.

Preliminary results are presented for Quesnel and Stellako* DUs (DU 16, 7) , however, no allowable harm statement can be made at this time. Additional information will be available in the next four months which will provide empirical estimates of the impacts of the Big Bar landslide and support additional modeling that can be incorporated into the final allowable harm statement.

For Taseko and Widgeon DUs (DU 22, 24), the available data does not allow for allowable harm to be assessed using the methods described in this report. However, using the other small stocks assessed as proxies, and taking into account expected impacts to Taseko (DU 22) from

the Big Bar landslide, all sources of harm should be reduced to the maximum extent possible for Taseko and Widgeon.

Sources of Uncertainty

- Projections of future productivity ranges are based on historical relationships between spawning stock and recruitment. How representative these historical relationships are of the future in a changing global climate is unknown.

- There is uncertainty associated with the estimation of run size, exploitation rate, spawning escapement, and in-river mortality. This uncertainty is inherently larger for smaller stocks as lower precision spawning ground estimation methods are used for escapements that are anticipated to be less than 75,000 fish and smaller stocks by definition are encountered less frequently in test fisheries resulting in smaller sample sizes.

- Modelled exploitation rates did not included implementation error and will result in the appearance of probabilities of recovery being overly certain. Implementation error should be included in models when assessing management measures.

- The impacts of Big Bar landslide are unknown. The immediate effect on the number of successful spawners to the grounds will be known early in 2020. The longer term effects on individual fitness, population structure, and future mortalities of adult and juvenile fish due to passage impediment will not be known in the near term.

Research Recommendations

Several suggestions for future research are:

- Improve knowledge of DU-specific survival at each life history stage – this will allow for parsing out of marine versus freshwater mortality rates which will improve the evaluation of potential mitigation measures.

- Further investigate DU-specific stock-recruitment models – by improving the representation of the longer term biological behavior of each DU, this could result in recovery assessments that are more representative of each DU.

- Develop guidelines for recovery targets for cyclic DUs – creating recovery targets that are responsive to the cyclic nature of some Fraser Sockeye DUs could result in recovery assessments that are more appropriate for these DUs.

- Monitor the longer term effects of the Big Bar landslide, including changes in pre-spawn mortality, age composition, individual fitness, overall population structure, and migration success of adults and juveniles. The collection of this information is vital to inform all future quantitative evaluation of Fraser Sockeye, including recovery success. Without it, any projections of Fraser Sockeye populations will be based on assumptions that are not supported by empirical evidence.

- Investigate DU-specific variability in age composition – assumptions about age composition will affect modelled recovery outcomes for DUs that are directly impacted by large scale events such as the Big Bar landslide.

- Conduct climate change vulnerability assessments for each DU – this will identify which DUs are the most vulnerable to changes in climate and why. This will help identify and prioritize research, mitigation measures, and management actions.

- Incorporate biological models with climate models – this work would inform which future productivity scenarios are more likely to occur and allow recovery assessments to narrow in on a range of potential future outcomes.

OTHER CONSIDERATIONS

- The assessment in this report was conducted at the individual DU level. However, management of fisheries occurs at the stock management unit level for Fraser Sockeye and the DUs are also affected by fisheries targeting Chinook and Pink salmon. Similarly, interpretation and implementation of advice in this report should take into account both the narrow (individual DU) as well as the wider (SMU level and cross species) scope.

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Wor	Catarina	DFO Science
Xu	Yi	DFO Science

SOURCES OF INFORMATION

This Science Advisory Report is from the October 7-10, 2019 regional peer review on Recovery Potential Assessment – Fraser River Sockeye Salmon (*Oncorhynchus nerka*) – Ten Designatable Units. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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APPENDIX – BIG BAR SCENARIOS

This appendix provides projections for the four modelled EN and TH DUs that spawn above the Big Bar landslide. The time series of stock-recruit estimates required to model Taseko (DU 22) is not available.

The "Fishway" panel in the following figures represent a hypothetical scenario, in which the use of explosives to clear the obstruction during the first winter was not feasible. Plans are instead made to install a fishway, but it will take three winters to complete. Larger rocks are manipulated in the first winter to ease fish passage, which reduces the mortality rate from 99.5% in 2019 to 80% in 2020. In the second winter, additional rock manipulations decrease the mortality rate further to 75%. After the third winter, the fishway is fully functional and the mortality rate associated with passage through the Big Bar site drops to 20%. Note that there is additional DU-specific mortality being applied on top of the mortality associated with passing the Big Bar site.

The other figures represent sensitivity analyses designed to show the impact of multiple years of catastrophic mortality (99.5%) on top of the 2019 migration impediment year, to demonstrate the impact if the landslide was not cleared.
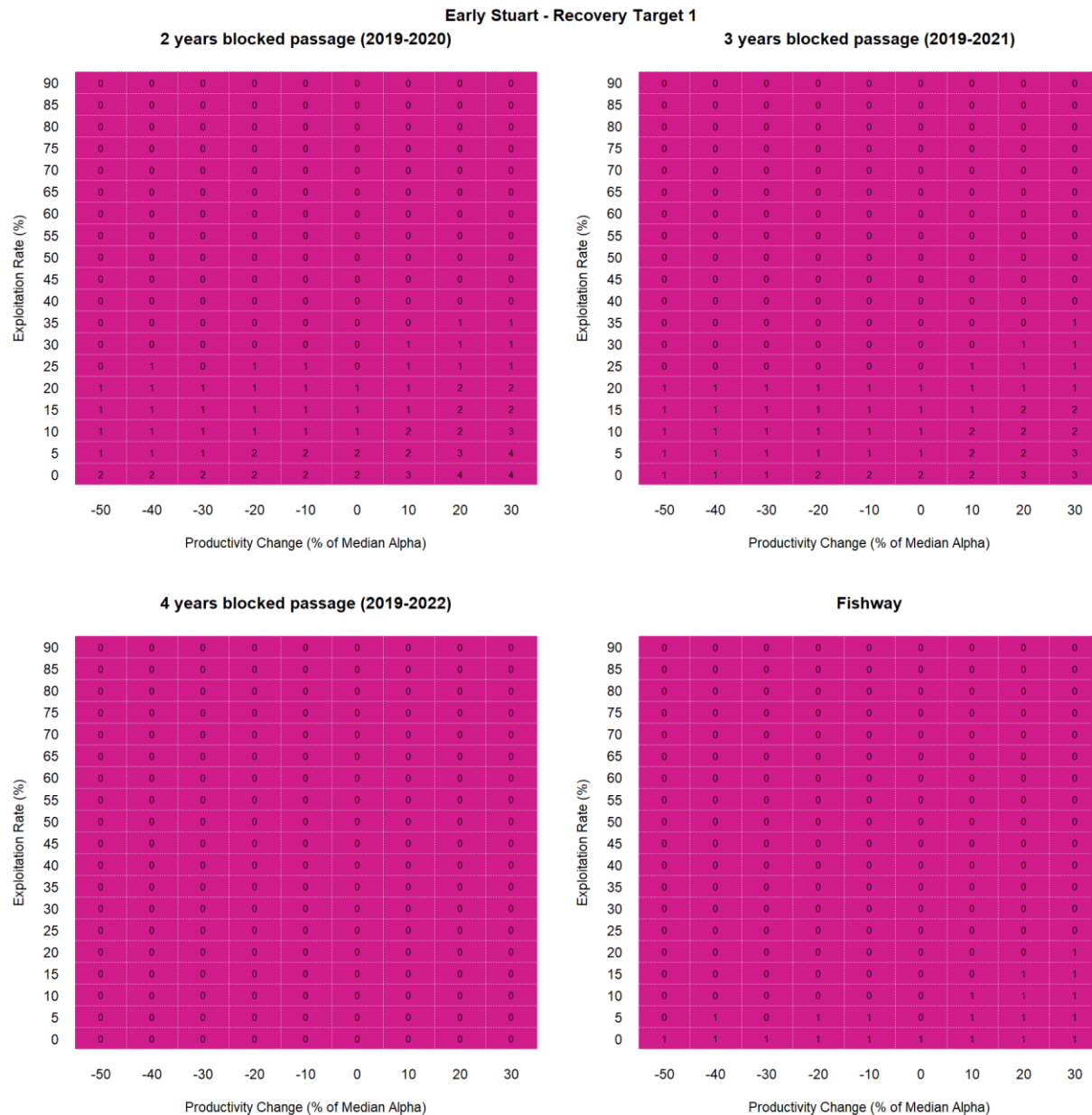
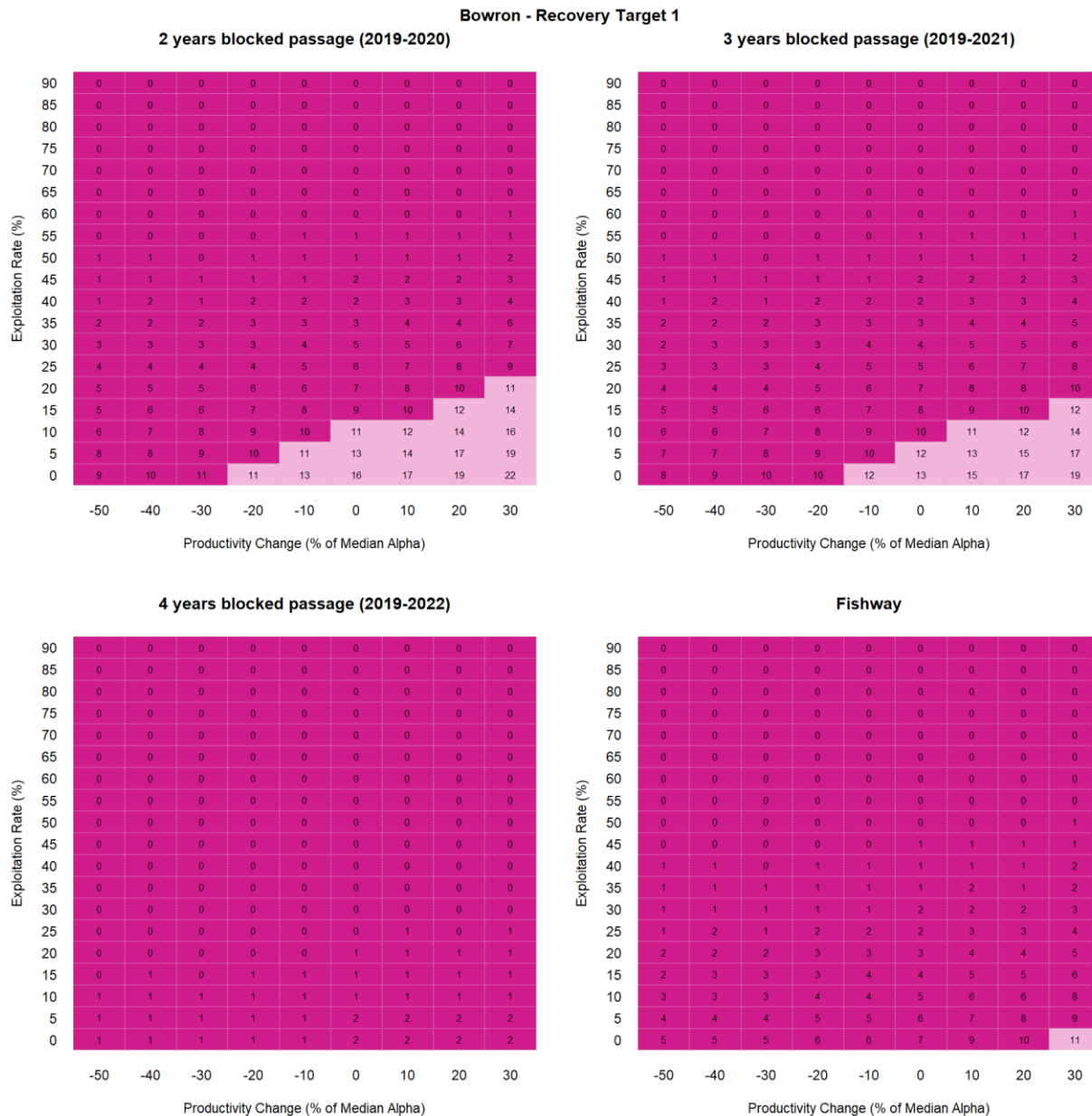Figure 16. Effect of varying exploitation rate across alternative productivities in combination with alternative Big Bar impact scenarios - Early Stuart (DU 20, Takla-Trembleur-EStu). Each panel shows simulated performance relative to Recovery Target #1 under one of the alternative Big Bar landslide scenarios. Grid layout is the same as the figures in the main report. The 2, 3, and 4 years blocked passage panels are sensitivity analyses showing the effect of additional years of Big Bar impacts, and the "Fishway" panel shows the hypothetical fishway scenario as described at the beginning of this appendix.
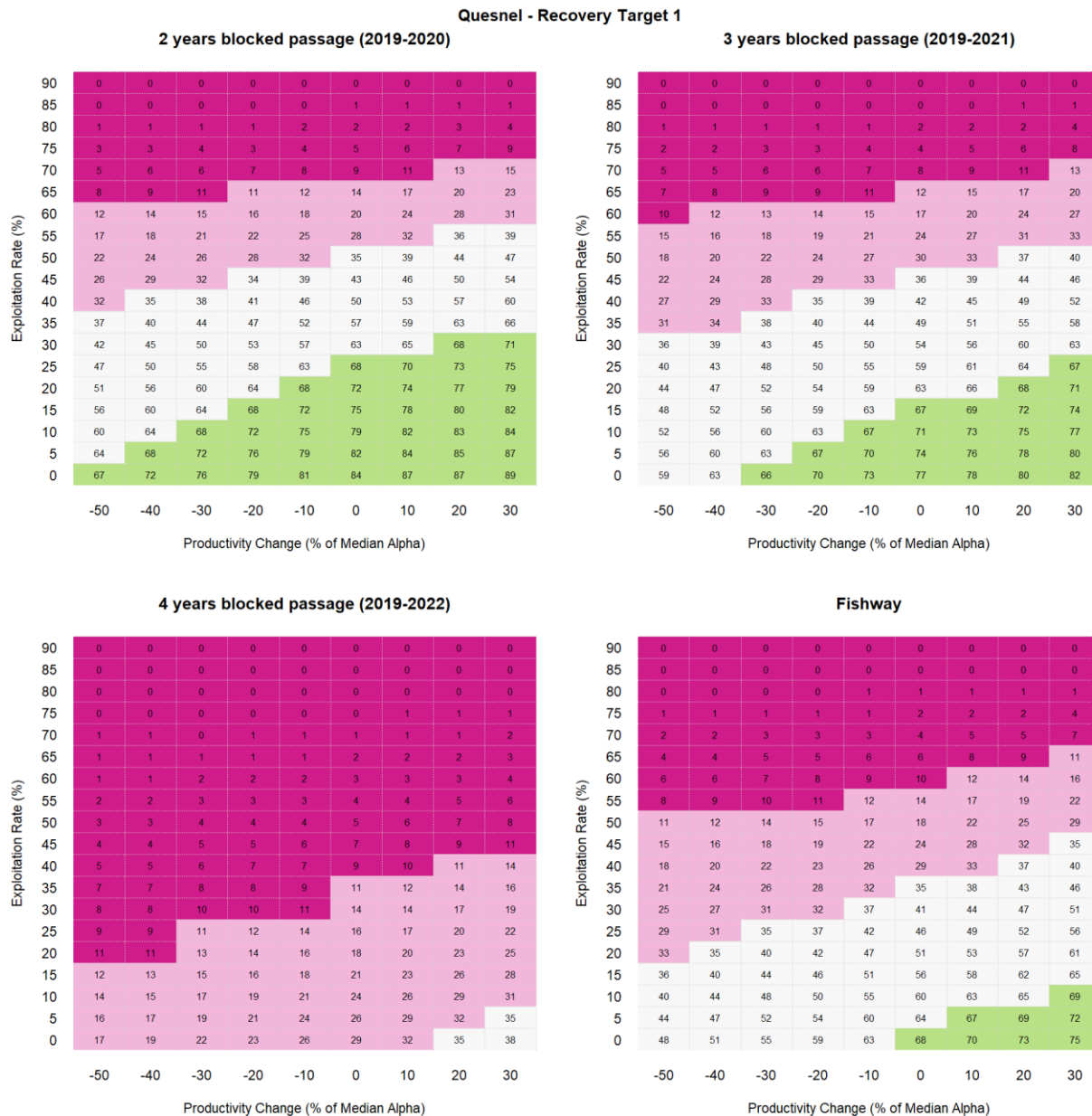
Bowron - Recovery Target 1

Figure 17. Effect of varying exploitation rate across alternative productivities in combination with alternative Big Bar impact scenarios – Bowron (DU 2, Bowron-ES). Each panel shows simulated performance relative to Recovery Target #1 under one of the alternative Big Bar landslide scenarios. Grid layout is the same as the figures in the main report. The 2, 3, and 4 years blocked passage panels are sensitivity analyses showing the effect of additional years of Big Bar impacts, and the "Fishway" panel shows the hypothetical fishway scenario as described at the beginning of this appendix.
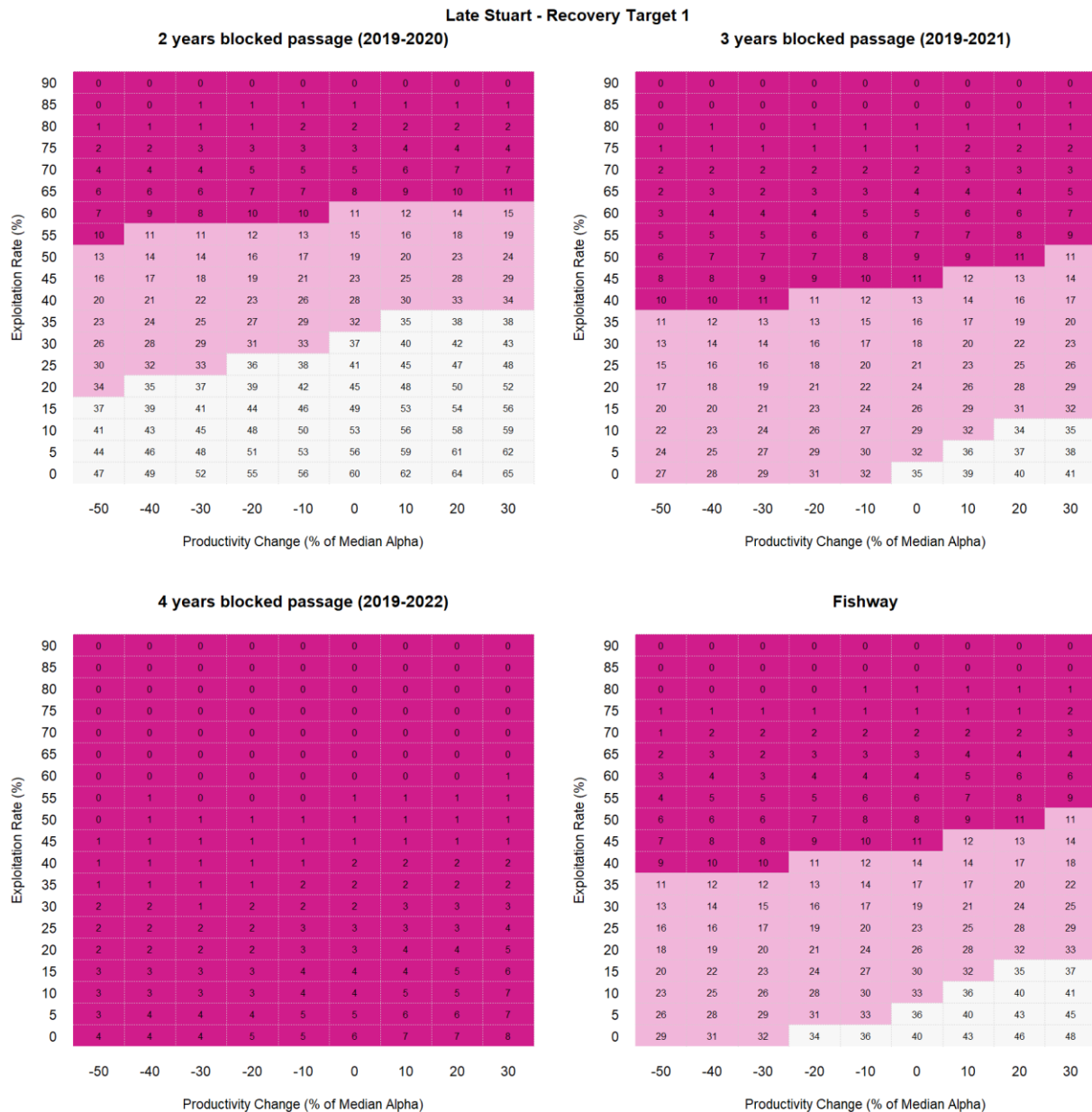
Quesnel - Recovery Target 1

Figure 18. Effect of varying exploitation rate across alternative productivities in combination with alternative Big Bar impact scenarios – Quesnel (DU 16, Quesnel-S). Each panel shows simulated performance relative to Recovery Target #1 under one of the alternative Big Bar landslide scenarios. Grid layout is the same as the figures in the main report. The 2, 3, and 4 years blocked passage panels are sensitivity analyses showing the effect of additional years of Big Bar impacts, and the "Fishway" panel shows the hypothetical fishway scenario as described at the beginning of this appendix.

Figure 19. Effect of varying exploitation rate across alternative productivities in combination with alternative Big Bar impact scenarios - Late Stuart (DU 21, Takla-Trembleur-Stuart-S). Each panel shows simulated performance relative to Recovery Target #1 under one of the alternative Big Bar landslide scenarios. Grid layout is the same as the figures in the main report. The 2, 3, and 4 years blocked passage panels are sensitivity analyses showing the effect of additional years of Big Bar impacts, and the "Fishway" panel shows the hypothetical fishway scenario as described at the beginning of this appendix.

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