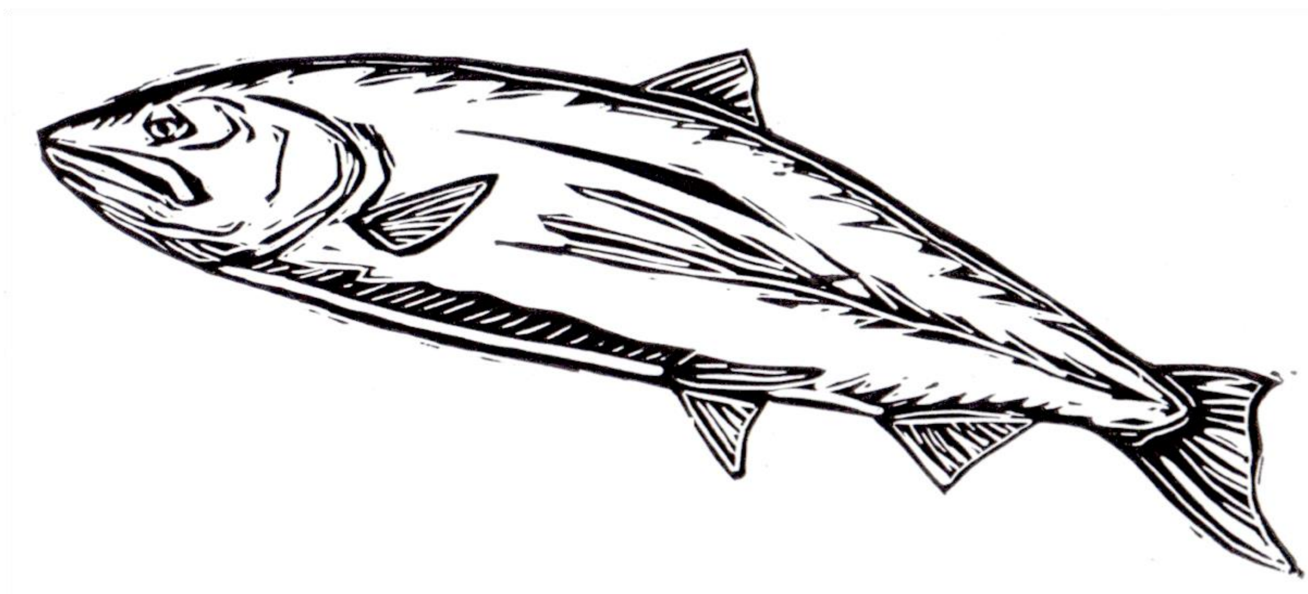
LIFE - CYCLE MODEL FOR UPPER GRANDE RONDE AND CATHERINE CREEK SPRING CHINOOK

EVALUATION OF HABITAT RESTORATION AND POPULATION RECOVERY STRATEGIES

DECEMBER 2018



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Summary

The following describes continued progress toward assessment of Chinook salmon populations and habitat restoration opportunities within the upper Grande Ronde River (UGR) and Catherine Creek (CC) watersheds using a life-cycle modelling (LCM) framework. The work presented here extends LCM development efforts previously initiated by the Columbia River Inter-Tribal Fish Commission (CRITFC) and included as part of the Independent Scientific Advisory Board's (ISAB) 2017 review of LCM efforts in the interior Columbia Basin (chapter 9.f in ISAB 2017). Ultimately, these efforts are intended to provide an analytical tool that will guide long-term restoration and recovery strategies for two threatened Chinook Salmon populations under changing climatic conditions. This effort focuses on two objectives that include: 1) Refinement of LCM parameters and functions to improve model accuracy and efficiency, and 2) leveraging the model to evaluate potential restoration strategies that might increase the viability of these populations under future time horizons that include climate change impacts.

Many of the additions to the 2018 LCM effort make use of novel unpublished population data from the Oregon Department of Fish and Wildlife that allowed us to update almost all life-stage transition parameters with the most up-to-date information. Some of these changes include:

1. Smolt-to-adult (SAR) return rates that are now specific to each population and origin (i.e. natural vs. hatchery).
2. A more realistic approach for modelling current hatchery supplementation operations within the UGR and CC.
3. Expanded incorporation of parameter variability allowing model stochasticity at all stage transitions within the LCM framework.
4. Updates to the model implementation that allow log-normal stochasticity on density-dependent predictions within a Beaverton-Holt framework.

Our updated implementation of the LCM also includes efficiency improvements that significantly decreased the duration necessary to run individual model scenarios. Doing so allowed us to increase the number of stochastic Monte Carlo iterations to 500 for each modelled management scenario.

The updated model was then used to evaluate simulated population dynamics and population extinction risk across restoration and climate scenarios described previously by Justice et al. (2017), as well as within a novel set of restoration scenarios that rely on structural equation models (SEM). Both of these approaches describe the potential impact that restoration actions may have on juvenile Chinook Salmon rearing capacity while also considering impending changes in stream temperature due to climate change. The updated LCM framework also allowed us to evaluate potential population responses (changes in population abundance and extinction risk) under restoration and climate scenarios with and without hatchery supplementation.

ACKNOWLEDGEMENTS

This work was made possible by funding provided by the Bonneville Power Administration (BPA project # 2009-004-00). The life-cycle modelling approach was adapted from previous work by Rishi Sharma (Sharma and others, 2005), and a model implementation refined by the Integrated Status and Effectiveness Monitoring Program (ISEMP [Nahorniak and Armour 2017]).

Casey Justice and Seth White developed the analytical approaches used in the formulation of restoration and recovery scenarios and acquire data used in model parameter development. Nick Weber was responsible for development of the life-cycle modelling software environment, analytical approaches, and final report and figure generation. Nick Bouwes provided analytical oversight during all stages of the project. Pete McHugh and Carl Saunders also contributed to previous life-cycle modelling efforts that greatly informed the current analyses. Data used in the estimation of stage specific parameters was primarily supplied by the Oregon Department of Fish and Wildlife.

SUGGESTED CITATION

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LIFE CYCLE MODEL FRAMEWORK

Several populations of Snake River spring Chinook Salmon are listed under the ESA, including the Upper Grande Ronde and Catherine Creek populations. Both rivers are targeted as high-priority restoration areas in an effort to increase adult abundance to avoid extinction and eventually achieve recovery. To evaluate the benefits of different restoration strategies on long-term population dynamics, we developed a whole life-cycle model to evaluate life-stage specific benefits of restoration and potential changes to adult abundance, one of the primary responses for evaluating the status of ESA listed populations.

Our LCM framework is essentially a density-dependent, stage-structured stochastic projection model that has been adapted from modelling approaches described by Sharma et al. (2005) and implemented by the Integrated Status and Effectiveness Monitoring Program (Nahorniak and Armour 2017). The LCM uses a Beverton-Holt stock recruitment function to simulate the number of individuals surviving from one life-stage (N_i) to the next (N_{i+1}) (after Moussalli and Hilborn 1986) as defined by stage-specific capacity (c_i) and productivity (p_i) parameters:

$$N_{i+1} = \frac{N_i}{\frac{1}{p_i} + \frac{1}{c_i} N_i}$$

Although the functional form of the model implies that density dependence occurs at all stage transitions, density-independent transitions are modeled by setting capacity to an infinitely large value and using empirical estimates of survival (S_i) as the productivity input (p_i). Otherwise, realized survival ($S_i = N_{i+1} / N_i$) is a function of both the capacity and productivity for each modelled life-stage of the population. Within the Beverton-Holt stock-recruit relationship, these parameters form the basis for modelling population responses to restoration and climatic scenarios evaluated for the upper Grande Ronde River and Catherine Creek Chinook populations (see Restoration and Climate Scenarios below).

IMPLEMENTATION ENVIRONMENT

The modelling framework is implemented within the R program for statistical analysis and graphics (R Core Team, 2014). All code and documentation needed to run and customize the model can be found at the following GitHub repository: https://github.com/webernick79/Life-Cycle-Model. The implementation was developed to allow a flexible framework for modelling organism life-cycles using a Beaverton-Holt function and is easily customized to allow an any number of alternative stage transitions. Additionally, the implementation also includes a life-history function that allows the user to specify variability and model stochasticity with respect to bivariate decisions (e.g., age specific maturation probability). Custom components have also been developed that allow easy scaling of parameters as well as routines for implementing and summarizing parameter sensitivity analyses.

MODEL STOCHASTICITY

Our implementation of the LCM framework enables the user to account for parameter and prediction uncertainty, thereby producing a stochastic model that is more reflective of temporal variation in natural processes. Variability can be explicitly specified for individual parameter inputs for p_i and c_i at each stage transition. Although variation around individual parameters is always specified as a standard deviation, the model accounts for different distributional assumptions with respect to parameter type. For example, the model generates values from a beta distribution when p_i

values are < 1 (i.e. survival), and from a positive normal distribution for values of p_i >= 1 (i.e. fecundity) or c_i (capacity). In our model of UGR and CC Chinook, stochasticity was modelled around Beaverton-Holt parameters for density-independent transitions, and/or where data was not available to fit a Beverton-Holt curve (i.e., parr-to-smolt, smolt-to-adult, spawner-to-egg [Appendix 2: Base Model Parameters]).

We used an alternative approach to model stochasticity among life-stage transitions where empirical stock-recruitment data was available and density-dependence was evident or biologically plausible (i.e., adult-to-spawner, egg-to-parr [Appendix 2: Base Model Parameters]). In these cases, the model generates prediction uncertainty based on the residual error associated with a Beaverton-Holt curve fit to available stage-specific data (see example below for Egg to Parr Survival). In this scenario, model parameters for p_i and c_i remain static among model iterations, and uncertainty is modelled on the prediction of N_{i+1} assuming a log-normally distributed residual error. Hilborn and Walters (1992) recommend using a log-normal residual error distribution for stock-recruitment relationships unless there is evidence to the contrary. Model parameters and associated residual error terms are estimated by fitting the log-transformed form of the Beaverton-Holt function to the stage-specific abundance data as suggested by Haddon (2001):

$$ln\left(\frac{N_{i+1}}{N_i}\right) = ln(a) - ln(b + N_i) + \varepsilon$$

where a is equivalent to the asymptotic limit or capacity (c_i) and a/b describes the initial steepness of the curve at low values of N_i or productivity (p_i) within the density dependent relationship, and error (ε) is assumed to be normally distributed with a mean of zero and variance equal to the sum of residual square for error:

$$\varepsilon = N(0, \sigma^2)$$

The LCM then uses the un-transformed form of the Beverton-Holt function to make predictions of N_{i+1} with log-normal residual error following:

$$N_{i+1} = \frac{N_i}{\frac{1}{p_i} + \frac{1}{c_i} N_i} e^{\varepsilon}$$

The model also utilizes a custom function that allows the user to specify variability around the probability associated with bivariate life-history transitions such as choice of life-history strategy (see Parr to Smolt at Lower Granite Dam below) or probability of maturation. In these cases, the mean and standard deviation of the observed data are used to randomly generate probabilities dependent (i.e. sum to 1) for bivariate outcomes using a beta distribution.

BASE MODEL PARAMETERS FOR THE UPPER GRANDE RONDE AND CATHERINE CREEK

In many LCM applications, population stage specific abundance information as well as capacity and productivity parameters are difficult to obtain, as these variables and parameters are rarely estimated as part of routine monitoring programs. However, a combination of entities has been closely monitoring the upper Grande Ronde River (UGR) and Catherine Creek (CC) Chinook populations allowing for estimation of population specific parameters for many life-stages. For over two decades (*ca.* 1993 to present) the Oregon Department of Fish and Wildlife (ODFW), and more recently the Columbia River Inter-Tribal Fish Commission (CRITFC), and other parties have been collecting data needed to estimate spawner, parr, and smolt abundance and/or survival each year. Below, we describe in greater detail the data and assumptions used to parameterize a base LCM used in subsequent modelling investigations of restoration and climate scenario impacts for the UGR and CC Chinook populations. A more concise overview of the parameters used in our LCM parameterization can be found in Appendix 2: Base Model Parameters, however the following discussion is intended to provide a greater understanding of model underpinnings and assist in future efforts to refine and apply this LCM to novel management scenarios.

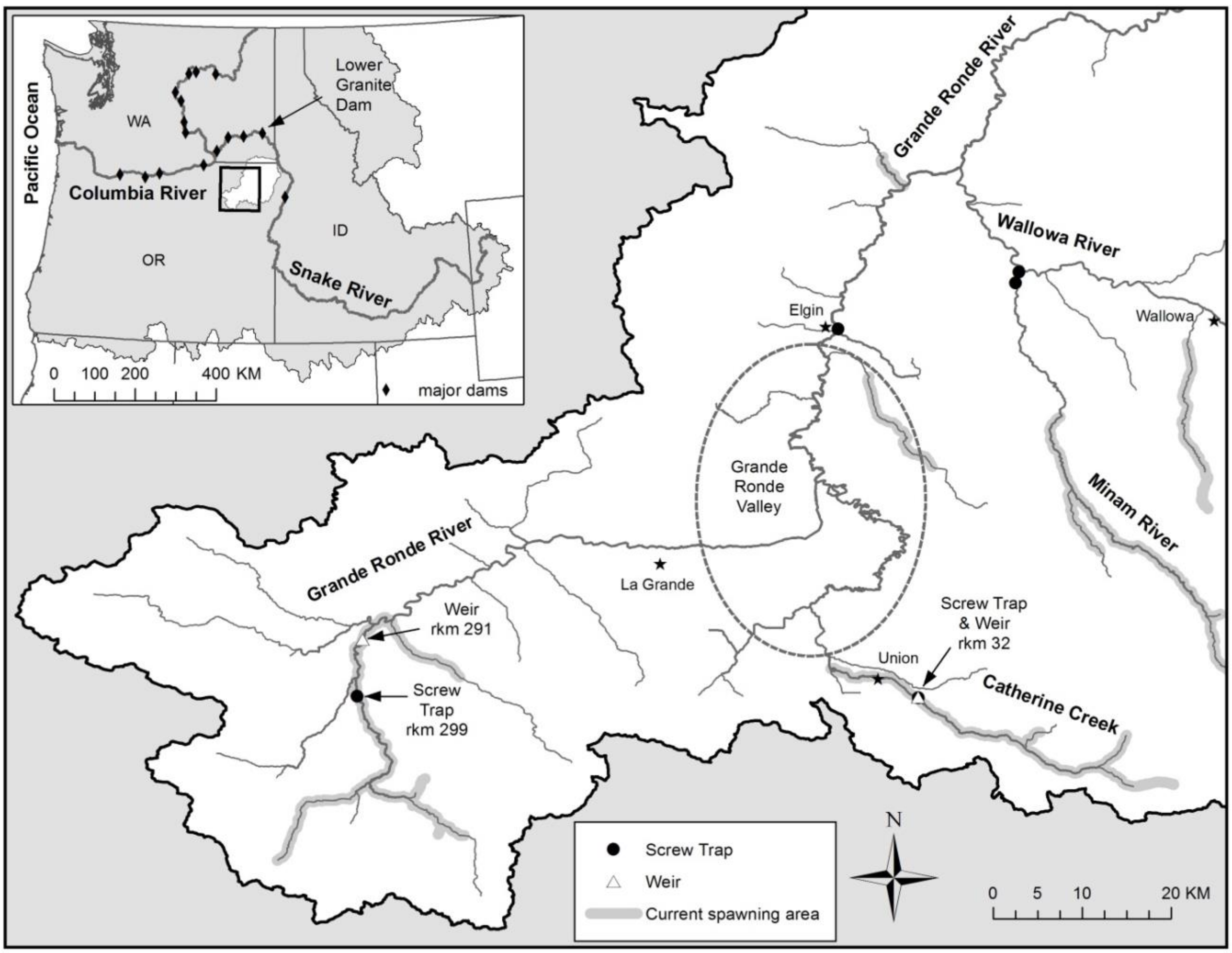

FIGURE 1. OVERVIEW OF THE UPPER GRANDE RONDE RIVER AND CATHERINE CREEK SHOWING MAJOR POINTS OF ACCOUNTING RELEVANT TO DEVELOPMENT OF THE LCM FRAMEWORK INCLUDING ADULT WEIRS, JUVENILE SCREW TRAPS, CURRENT SPAWNING GROUND EXTENT, VALLEY REARING LOCATION, AND LOWER GRANITE DAM.

Model Spatiotemporal Structure

Our LCM framework is structured around data collection efforts within the domain of UGR and CC Chinook Salmon (Figure 1, Figure 6) life-histories where population abundance and survival estimates have been possible. Many of these estimates are a product of field mark-recapture surveys, screw trap operation, and adult weirs operated by ODFW. These efforts include estimates of total parr abundance for each population at a point in late summer, and a subsequent estimate of juvenile abundances exhibiting each of two dominate rearing and migration strategies (i.e. headwaters or valley rearing). PIT-tagging in each tributary also yield annual estimates of total smolts reaching Lower Granite Dam. Additionally, the model uses the best available data to approximate hatchery smolt supplementation abundance and their distinct survival to Lower Granite Dam (LGD). From LGD, our framework accounts for age specific maturation and survival probabilities of natural and hatchery origin smolt to the ocean and back to enumeration of adults at tributary weirs operated on both the UGR and CC. At the adult weir, we model broodstock retention schemas that support hatchery programs specific to each population and their impact on the total population of natural and hatchery origin adults passed to the spawning grounds. Finally, the model invokes a density-dependent survival of adults on the spawning grounds that is informed by redd and carcass surveys that estimate spawner abundances for each population.

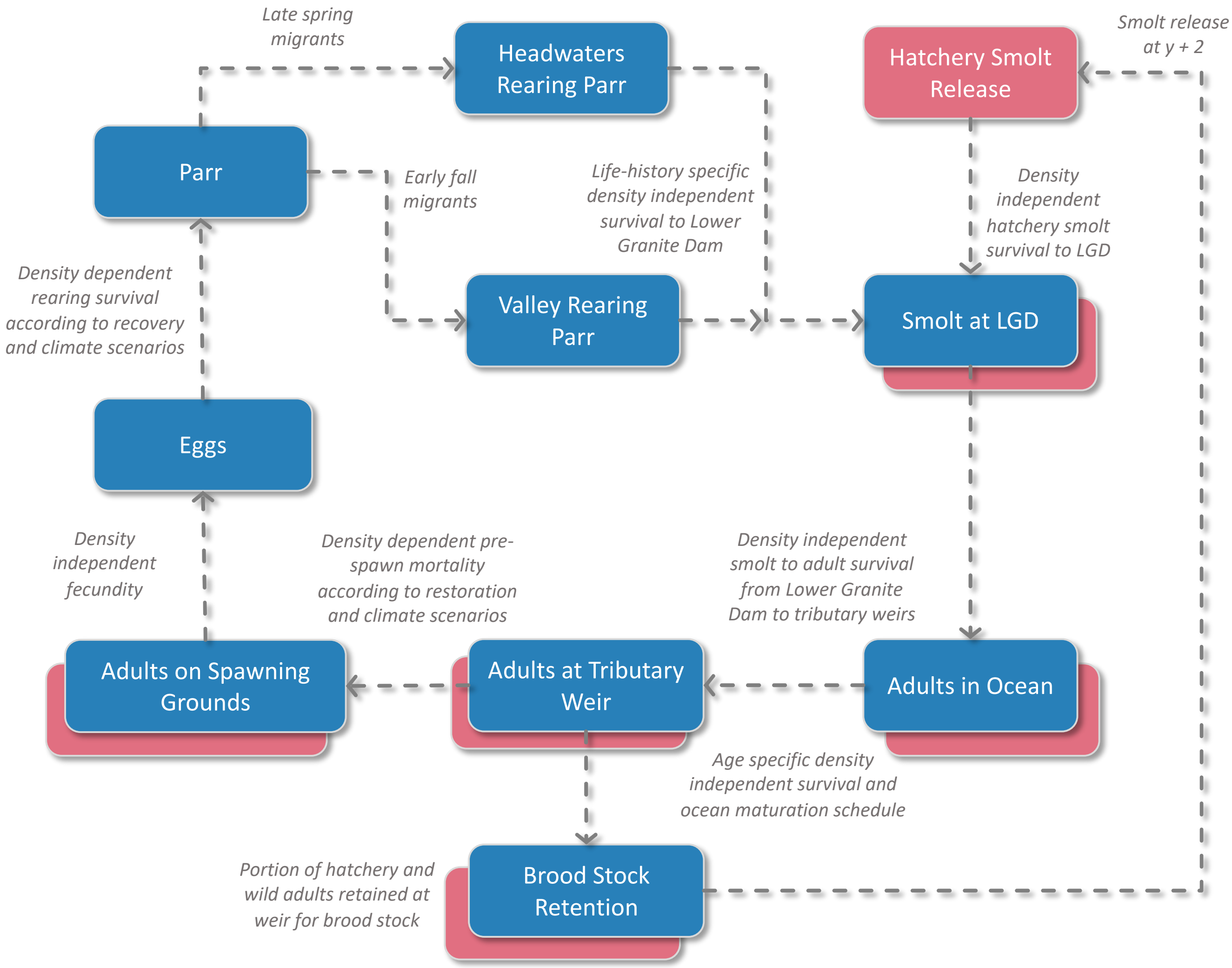

FIGURE 2. CONCEPTUAL DIAGRAM OF THE LIFE CYCLE MODEL (LCM) STRUCTURE. STACKED BOXES REPRESENT STAGES IN WHICH THE MODEL TRACKS NATURAL AND HATCHERY ORIGIN CHINOOK. ALL NATURALLY SPAWNED CHINOOK ARE CONSIDERED OF NATURAL ORIGIN.

EGG TO PARR SURVIVAL

The conversion of eggs to parr has particular importance within our LCM as the restoration and climate scenarios (discussed below) primarily affect juvenile rearing habitat and parr rearing capacity. We modelled this life-stage transition as a density – dependent survival probability using base estimates of p_i and c_i derived by fitting a Beaverton-Holt model to available abundance data (Table 1, Figure 3).

TABLE 1. ESTIMATED ABUNDANCES OF EGGS AND LATE SUMMER PARR USED IN THE DERIVATION OF BEAVERTON-HOLT PARAMETERS FOR EGG TO PARR SURVIVAL.

	Upper Grande Ronde		Catherine Creek	
Brood year	Eggs (N_i)	Summer parr (N_{i+1})	Eggs (N_i)	Summer parr (N_{i+1})
1992	747045	77467	-	-
1993	626369	125620	492284	42334
1994	-	-	53634	10437
1995	-	-	65127	9325
1996	-	-	65127	14878
1997	-	-	137916	38204
1998	-	-	174311	40393
1999	-	-	155156	41091
2000	-	-	93860	40463
2001	-	-	683834	71273
2002	-	-	762369	153078
2003	-	-	766200	151047
2004	-	-	390762	57927
2005	-	-	256677	74225
2006	101522	17113	459720	66043
2007	149409	36297	312227	46474
2008	181973	70212	385016	103336
2009	3913367	227463	367776	24732
2010	1656908	56714	1750767	116382
2011	739383	87176	2130036	77210
2012	605298	23768	1233582	75419
2014	2352234	58770	1890599	65947
2015	2045754	97513	919440	52011

Annual estimates of eggs were based on a conversion of total spawners (from unpublished ODFW spawning surveys) to eggs using fecundity values reported by Van Dyke (2008) for Catherine Creek female spawner to egg equivalence and assuming a 50:50 sex-ratio for spawning adults. Parr abundances were taken from unpublished estimates gleaned from annual mark-recapture electrofishing surveys conducted by ODFW within rearing habitat in each system during late summer and prior to the fall presmolt outmigration exhibited by a portion of the population (see Parr to Smolt at Lower Granite Dam below).

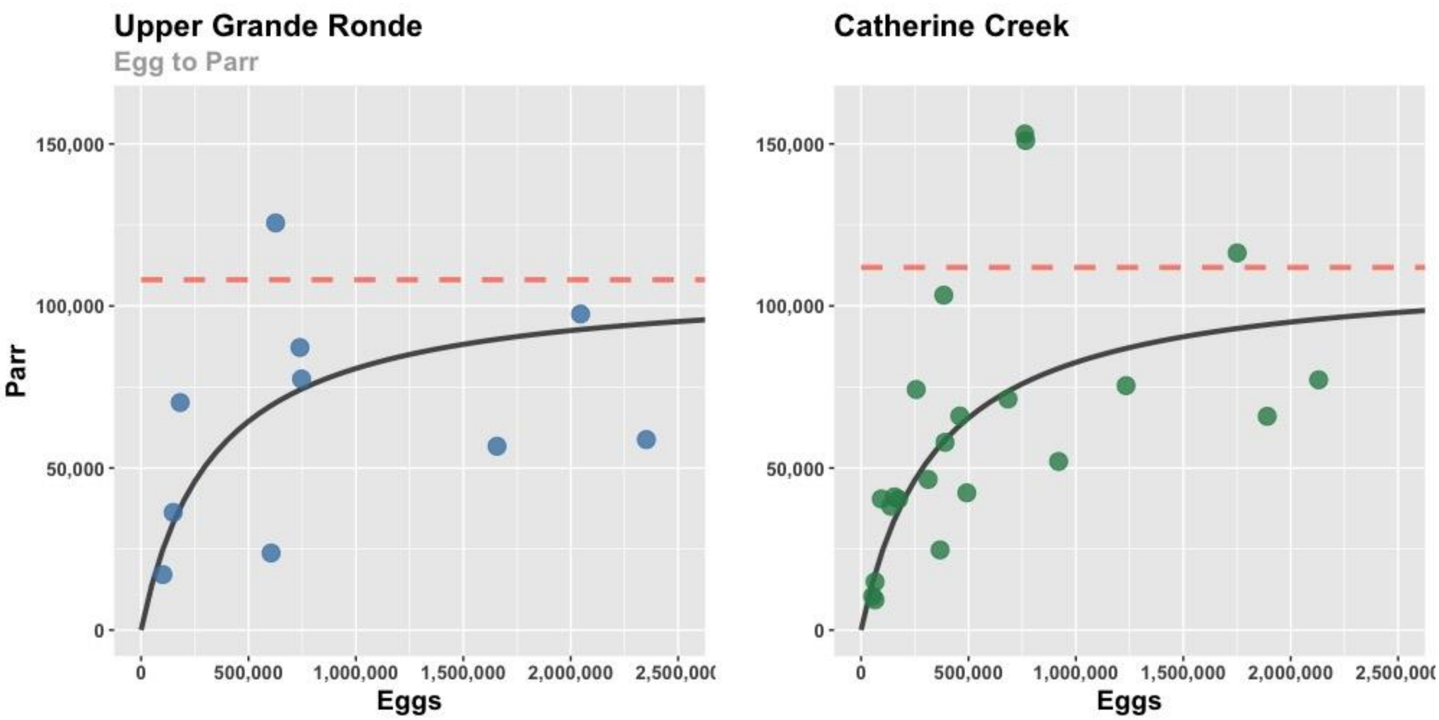

FIGURE 3. BEAVERTON-HOLT FUNCTION FIT TO AVAILABLE ESTIMATES OF EGGS AND SUMMER PARR FOR UPPER GRANDE RONDE AND CATHERINE CREEK CHINOOK. MODEL FITS WERE USED TO GENERATE ESTIMATES OF SURVIVAL AND CAPACITY (DASHED RED LINE) USED IN THE BASE LCM FRAMEWORK.

PARR TO SMOLT AT LOWER GRANITE DAM

In both the UGR and CC watersheds, spawning primarily occurs in headwater and tributary reaches of the Grande Ronde stream network (Figure 1). During the fall of their first year Chinook parr will exhibit one of two distinct rearing life-histories. These include headwaters rearing presmolts that will remain and overwinter within headwaters and tributary reaches prior to smolting the following spring, and valley rearing presmolts that exhibit a fall downstream migration where they winter within valley reaches of the Grande Ronde River. We model the survival of parr from late summer to smolt passing Lower Granite Dam the following year as a density independent survival rate that accounts for different survival rates among these two life-history strategies.

This component of our LCM framework relies on survival and abundance estimates generated by ODFW that are based on mark-resight data gleaned from PIT-tag capture surveys of parr and presmolts, screwtrap operations, and detections of smolt throughout the Columbia hydrosystem (Table 1, Figure 4). Specifically, we rely on survival estimated for three release groups to generate our estimates of parr to LGD smolt survival:

1. *Parr to smolt at LGD* – Cormack-Jolly-Seber (CJS) survival estimate generated from late summer (late July - August) PIT-tag and capture surveys of parr in the headwaters and subsequent detections of individuals throughout the hydrosystem.
2. *Headwaters rearing presmolt to smolt at LGD* – CJS survival estimate generated from late fall/winter (mid November – mid December) PIT-tag capture surveys of presmolt in the headwaters and subsequent detection of individuals throughout the hydrosystem as smolt.
3. *Valley rearing presmolt to smolt at LGD* – CJS survival estimate generated from fall (October – mid November) PIT-tagging of presmolt captured at screw traps as they migrate to valley rearing locations and subsequent detection throughout the hydrosystem as smolt.

TABLE 2. CORMACK JOLLY SEBER ESTIMATES OF SURVIVAL USED TO GENERATE LIFE-HISTORY SPECIFIC SURVIVAL PROBABILITIES FOR PARR THAT EXHIBIT HEADWATERS AND VALLEY REARING LIFE-HISTORIES PRIOR TO SMOLTING AND ARRIVAL AT LOWER GRANITE DAM.

Migratory year	Probability of survival to Lower Granite Dam by tagging group					
	Catherine Creek			Upper Grande Ronde Survival		
	Summer parr	Valley rearing	Headwaters rearing	Summer parr	Valley rearing	Headwaters rearing
1995	0.15	0.24	0.28	0.17	0.23	0.15
1996	0.28	0.36	0.31			
1997	0.18	0.37	0.08			
1998	0.21	0.24	0.28		0.29	0.11
1999	0.16	0.20	0.29		0.27	0.12
2000	0.15	0.21	0.14		0.34	0.13
2001	0.09	0.13	0.08			
2002	0.11	0.15	0.20		0.31	
2003	0.08	0.12	0.15		0.18	
2004	0.07	0.13	0.18		0.16	0.30
2005	0.06	0.12	0.11		0.14	0.21
2006	0.06	0.07	0.13		0.17	0.08
2007	0.04	0.20	0.09		0.24	0.17
2008	0.08	0.15	0.14	0.26	0.34	0.36
2009	0.15	0.27	0.11			
2010	0.11	0.18	0.18	0.24	0.21	0.13
2011	0.13	0.16	0.17	0.13	0.23	0.12
2012	0.12	0.19	0.10	0.08	0.20	0.04
2013	0.05	0.10	0.11	0.10	0.18	0.06
2014	0.09	0.14	0.12	0.10	0.20	0.07
2015	0.06		0.04	0.16	0.09	0.07
2016	0.03	0.06	0.08	0.08	0.12	0.05
2017	0.09	0.15	0.17	0.09	0.17	0.05

One challenge in integrating life-history specific survival rates within our LCM is that survival estimates from late summer parr tagging to fall cannot be generated for each life-history due to insufficient resight of tagged individuals at screw traps in each system. Rather than directly incorporating empirical estimates of parr to presmolt survival into the LCM we developed a correction factor for parr to smolt survival to LGD based on available Cormack-Jolly-Seber estimates of survival for both life-history strategies with the following assumptions:

1. Estimates of survival from late summer parr until fish reach LGD accurately reflect survival rates of all fish in the population. That is, without accounting for life history strategy, all fish experience an average survival rate, and the average of survival rates for each life history strategy is equal to the mean pooled survival for the population as late summer parr to smolts at LGD.
2. Headwaters rearing presmolts experience the same survival rate as valley rearing fish during the short period of time between when fall tagging occurs at the screw trap and fall/winter sampling occurs within the headwaters.

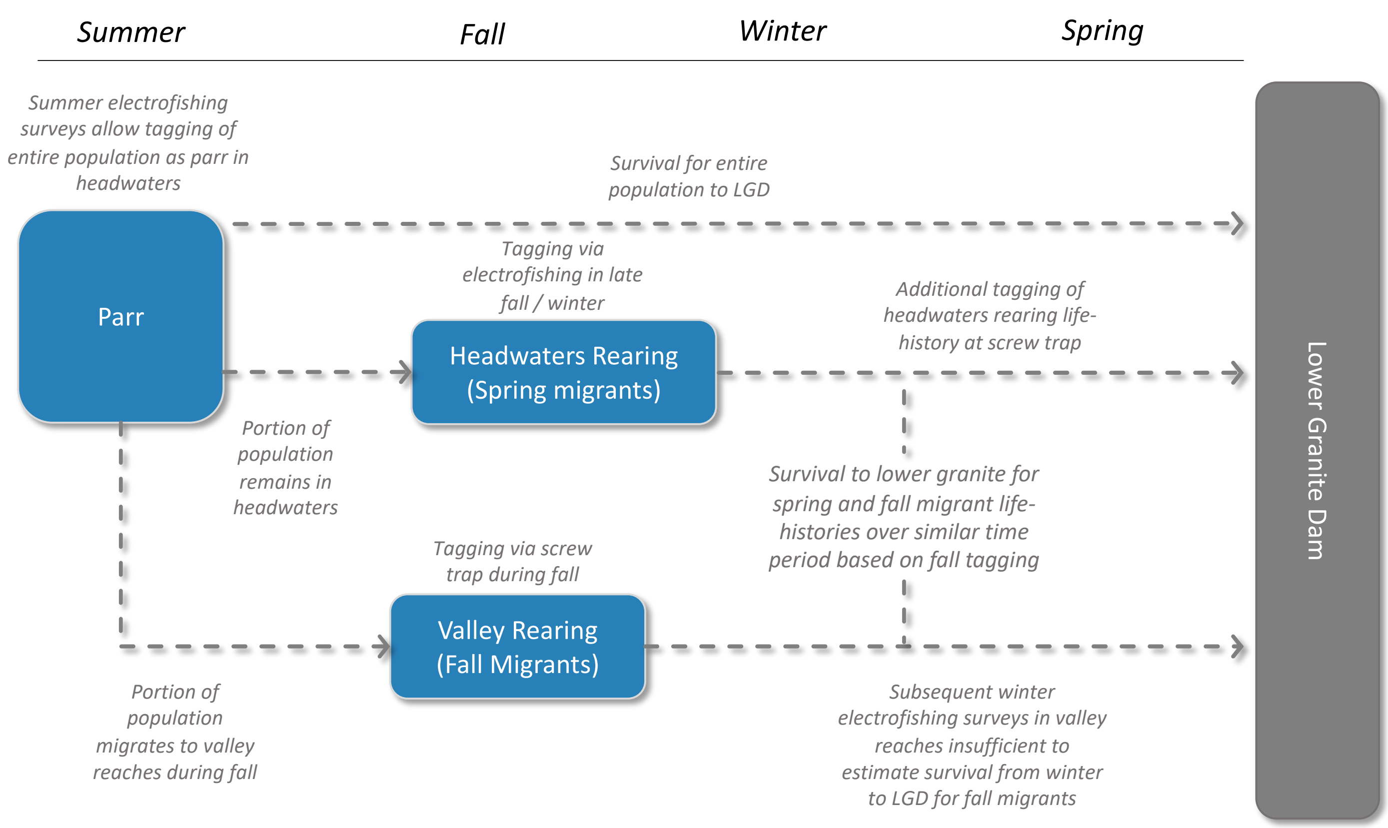

FIGURE 4. VISUAL REPRESENTATION OF JUVENILE LIFE-HISTORIES AND HOW FALL PIT-TAGGING OF HEADWATERS REARING PRESMOLTS VIA ELECTROFISHING AND VALLEY REARING PRESMOLT AT SCREW TRAPS CAN BE USED TO ESTIMATE SURVIVAL TO LOWER GRANITE DAM OVER ROUGHLY EQUIVALENT TIME INTERVALS THUS ACCOUNTING FOR EACH REARING STRATEGY.

Acknowledging these assumptions, we calculated a correction factor that accounts for the different survival rates of each life-history based on the ratio of survival for headwaters rearing presmolts tagged during fall/winter sampling and valley rearing presmolts tagged in the fall at the screwtrap. The ratio was used to adjust the model input of parr survival to smolt at LGD with respect to each life-history (Table 3).

TABLE 3. ESTIMATES OF TOTAL PARR SURVIVAL AND LIFE-HISTORY SPECIFIC SURVIVAL FOR PARR EXHIBITING FALL MIGRANT (VALLEY REARING) AND WINTER RESIDENT (HEADWATERS REARING) LIFE-HISTORIES. SURVIVAL ESTIMATES ARE BASED ON CJS ESTIMATES OF SURVIVAL FROM ODFW PIT-TAG SURVEYS AND WERE USED TO DEVELOP SURVIVAL CORRECTIONS FOR PARR TO SMOLT SURVIVAL FOR THE BASE MODEL.

	Mean survival				Correction factor		Survival estimate	
Population	Summer parr	Valley rearing	Headwaters rearing	Life-history mean	Valley	Headwaters	Valley	Headwaters
CC	0.11	0.18	0.15	0.16	1.10	0.94	0.12	0.10
UGR	0.14	0.21	0.13	0.17	1.25	0.77	0.18	0.11

HATCHERY SUPPLEMENTATION

The UGR and CC spring Chinook populations are presently supplemented by a target annual release of *ca*. 250K (UGR) and 150K (CC) hatchery-reared smolts released into acclimation ponds near the spawning grounds in both systems.

Adults returning from supplementation releases are meant to home to the spawning grounds and spawn naturally with natural-origin fish. To support an integrated hatchery program, a fraction of natural-origin fish returning to spawn in the wild are retained for spawning in the hatchery. Adult trap weirs situated in both streams are used to manage three aspects of escapement under the supplementation goals: (i) the proportion of the total natural-origin returns retained for the hatchery (P_{NOS-R}) (ii) the proportion of natural spawners of hatchery origin (P_{HOS}), and (iii) the proportion of hatchery broodstock/egg-take of natural origin (P_{NOB}). These supplementation efforts have a strong influence on abundance dynamics in both the UGR and CC populations. Thus, we attempted to implement a broodstock retention and supplementation scheme that approximates this management strategy within the LCM.

A more complete description of the LCM implementation of the broodstock retention program can be found in Appendix 1: Broodstock Retention Approach. But in brief, we developed a target brood retention for each system of 170 and 103 adults for the UGR and CC respectively based on an adult-to-smolt equivalence (assuming a 50:50 sex ratio) of 1,470 smolts per adult (M. McLean, CTUIR, pers. comm.). Based on these retention targets we used unpublished annual records of smolt supplementation release abundances to derive a mean adult-to-smolt conversion factor and standard deviation that were incorporated into the LCM and more accurately represent the natural variability exhibited by the supplementation program on each system. To better approximate the dynamics of current hatchery supplementation management we only used available supplementation release data from years following release year 2001 (brood year 1999) to develop inputs for the LCM (Table 4).

TABLE 4. ANNUAL SMOLT RELEASE ABUNDANCE USED TO PARAMETERIZE THE HATCHERY SUPPLEMENTATION PROGRAM WITHIN THE LCM. SMOLT TO ADULT EQUIVALENCE ASSUMES A TARGET BROOD RETENTION OF 103 ADULTS IN CC AND 170 ADULTS IN THE UGR.

	Catherine Creek		Upper Grande Ronde	
Release year	Total release	Smolt equivalence	Total release	Smolt equivalence
2001	136820	1328	2560*	
2002	180340	1751	151444*	
2003	129684	1259	237036	1394
2004	161868	1572	144919	852
2005	189581	1841	105369	620
2006	68820	668	18901*	
2007	71270	692	139423	820
2008	116882	1135	259932	1529
2009	138842	1348	146552	862
2010	144353	1401	232350	1367
2011	155475	1509	242382	1426
2012	161373	1567	285737	1681
2013			290572	1709

* Indicates years that were omitted from calculation of a mean smolt release equivalent as they did not reflect the current supplementation scheme that includes both the captive and integrative broodstock program.

HATCHERY SMOLT SURVIVAL TO LGD

Hatchery origin smolts experience a shortened survival period from the time of their release until they reach LGD and are released at a larger size relative to natural-origin smolts and were thus modelled separately from their natural counterpart (McCullough et al. 2014). Survival was estimated from PIT-tagged hatchery smolts using a Cormack-Jolly-

Seber model implemented in program MARK as described in Appendix K of McCullough et al. (2014). Survival rates of hatchery smolts from release to LGD were then used to predict the number of hatchery smolts at LGD, a metric needed to estimate smolt-to-adult return rates (SAR) for hatchery fish (Table 5). Hatchery smolt abundance information was taken from Feldhaus et al. (2017).

TABLE 5. ANNUAL ABUNDANCE OF HATCHERY SMOLTS RELEASED AND ESTIMATED HATCHERY SMOLT ABUNDANCE AT LOWER GRANITE DAM USED TO PARAMETERIZE HATCHERY SMOLT SURVIVAL TO LGD.

	Catherine Creek			Upper Grande Ronde		
Migration Year	Smolts released	Smolts at LGD	Survival to LGD	Smolts released	Smolts at LGD	Survival to LGD
2000	37982	16661	0.44	1508	594	0.39
2001	136820	85795	0.63	2559	1302	0.51
2002	180340	146802	0.81	151443	62782	0.41
2003	129684	88599	0.68	237036	105990	0.45
2004	161868	57837	0.36	144919	50891	0.35
2005	189581	61982	0.33	105369	18932	0.18
2006	68820	36135	0.53	18977	12333	0.65
2007	71270	42284	0.59	139423	76982	0.55
2008	116882	88587	0.76	259932	107662	0.41
2009	138842	88687	0.64	146552	73319	0.50
2010	144353	92712	0.64	232349	131046	0.56
2011	155475	97394	0.63	242385	101902	0.42
2012	161373	89539	0.55	285738	132372	0.46

NATURAL AND HATCHERY ORIGIN SMOLT TO ADULT RETURN RATES

Our LCM uses smolt-to-adult return rate (SAR) data to parameterize the marine survival and maturation schedules specific to each population and origin (i.e., natural vs. hatchery). The SAR is taken from unpublished estimates compiled by ODFW of smolt abundance at LGD and estimated abundance and age structure of adults returning to the weir traps within each system. Thus, within our modelling framework, ocean life-stages begin for smolt at LGD and end at weirs in proximity to the spawning grounds within each system (Figure 1).

Table 6. Natural origin SARs based on estimates of smolt at LGD and adult returns to the spawning grounds on each system. Annual returning age structure was obtained via NOAAs Salmon Population Summary (SPS) database system.

	Catherine Creek						Upper Grande Ronde					
				Return age structure						Return age structure		
Brood year	SAR	Smolt at LGD	Adults at weir	Age-3	Age-4	Age-5	SAR	Smolt at LGD	Adults at weir	Age-3	Age-4	Age-5
1992							0.008	11155	92	0%	91%	9%
1993	0.025	6519	163	7%	7%	85%	0.006	21732	127	0%	7%	93%
1994	0.007	2891	21	0%	39%	61%						
1995	0.058	1641	96	11%	90%	0%						
1996	0.027	3139	85	3%	95%	2%	0.018	3162	56	3%	95%	2%
1997	0.072	6131	441	6%	82%	12%	0.014	7337	100	4%	83%	13%
1998	0.070	6099	428	0%	21%	79%	0.039	7436	292	0%	27%	73%
1999	0.023	3763	87	0%	98%	2%						
2000	0.009	5768	53	12%	77%	12%	0.012	4247	53	4%	96%	0%
2001	0.008	5427	46	6%	86%	8%	0.012	1666	20	0%	97%	3%
2002	0.013	11163	144	4%	73%	23%	0.033	1919	64	0%	73%	28%
2003	0.008	8714	68	1%	26%	74%	0.018	2082	37	1%	4%	95%
2004	0.033	3372	112	5%	78%	16%	0.005	13156	71	12%	89%	0%
2005	0.035	3204	113	8%	75%	18%	0.017	5680	98	5%	76%	19%
2006	0.116	5375	625	9%	90%	1%	0.033	4518	150	11%	82%	7%
2007	0.079	7071	557	10%	55%	35%						
2008	0.043	11168	475	7%	84%	9%	0.031	10498	329	22%	65%	13%
2009	0.082	3238	267	28%	56%	16%	0.036	9314	335	11%	69%	19%
2010	0.052	13916	726	5%	93%	2%	0.032	26758	849	6%	88%	6%
2011	0.076	3938	300	17%	67%	16%	0.066	5979	396	22%	72%	5%

Using population specific age structure information from NOAA's Salmon Population Summary (SPS) database (https://www.webapps.nwfsc.noaa.gov/apex/f?p=261:HOME::::::) we decomposed the natural origin SAR return estimates into ocean age specific survival (S1, S2, S3) and maturation probabilities (m1, m2, and m3) that could yield an overall SAR and returning adult age structure on par with the observed data (Table 6). While the observed return-at-age pattern is a function of non-identifiable parameters, the approach used here places constraints on survival and maturation probabilities by age that allow parameter estimation (see McHugh et al. 2017 for an example and rationale). Also note that our model assumes a single SAR representative of an 'average' outmigrant experience and makes no attempt to parse transported vs. in – river individuals; thus, the assumption is the data for 1993-2011 brood years are a reasonable average of future mainstem/ocean conditions. We used an analogous set of hatchery smolt and adult return data (Table 7) to adjust our model for differences in hatchery and natural origin SARs. This was done by scaling the overall SAR for hatchery origin fish based on the ratio of the mean for hatchery and natural SARs for all available data (Table 8).

TABLE 7. HATCHERY ORIGIN SARS BASED ON ESTIMATES OF SMOLT AT LGD AND ADULT RETURNS TO THE SPAWNING GROUNDS ON EACH SYSTEM.

	Catherine Creek			Upper Grande Ronde		
Brood year	SAR	Smolt at LGD	Adults at weir	SAR	Smolt at LGD	Adults at weir
1998	0.025	16661	419	0.008	594	5
1999	0.003	85795	245	0.008	1302	11
2000	0.005	146802	673	0.010	62782	626
2001	0.002	88599	190	0.004	105990	462
2002	0.005	57837	269	0.003	50891	169
2003	0.003	61982	162	0.002	18932	41
2004	0.005	36135	193	0.007	12333	82
2005	0.006	42284	263	0.011	76982	877
2006	0.016	88587	1417	0.027	107662	2856
2007	0.009	88687	763	0.013	73319	976
2008	0.013	92712	1237	0.010	131046	1279
2009	0.003	97394	318	0.006	101902	577
2010	0.008	89539	705	0.010	132372	1346

TABLE 8. RATIO OF NATURAL AND HATCHERY SAR USED TO MODEL HATCHERY SPECIFIC SAR SURVIVAL PROBABILITIES WITHIN THE LCM.

	Mean SAR		
Population	Natural	Hatchery	Correction factor
CC	0.044	0.008	0.17
UGR	0.024	0.009	0.39

SPAWNING GROUNDS SURVIVAL AND CAPACITY

Spawner capacity is used to define the upper limit of the density-dependent pre-spawn survival function for adult fish on the spawning grounds given restoration and climate change scenarios (see Restoration and Climate Scenarios below). For our model, spawning grounds survival refers to the survival rate of adults passed above adult weirs to spawner abundance during late summer. Spawner capacity estimates capitalize on extensive field survey information and associated habitat suitability index (HSI) models to produce a spatially explicit depiction of spawning habitat quality and quantity.

TABLE 9. UNPUBLISHED ESTIMATES FROM ODFW OF ADULT CHINOOK ON THE SPAWNING GROUNDS AND NUMBER OF SPAWNERS IN LATE SUMMER USED TO DEVELOP BASE CASE PARAMETERS FOR THE LCM.

Catherine Creek				Upper Grande Ronde			
Brood year	Spawning grounds	Spawners	Survival	Brood year	Spawning grounds	Spawners	Survival
1987	699	684	0.98	1987	804	707	0.88
1988	727	691	0.95	1988	554	554	1.00
1997	82	72	0.88	1989	3	3	1.00
1998	101	91	0.90	1992	443	394	0.89
1999	88	81	0.92	1998	88	84	0.95
2000	61	54	0.89	2003	185	165	0.89
2001	556	513	0.92	2004	634	586	0.92
2002	462	432	0.94	2009	555	127	0.23
2003	487	424	0.87	2010	2339	2094	0.90
2004	216	216	1.00	2011	1559	1359	0.87
2005	152	146	0.96	2012	718	392	0.55
2006	283	253	0.89	2013	1084	395	0.36
2007	174	174	1.00	2014	1918	1388	0.72
2008	219	219	1.00	2015	1841	1144	0.62
2009	293	281	0.96	2016	239	151	0.63
2010	999	973	0.97	2017	155	99	0.64
2011	1725	1657	0.96				
2012	716	667	0.93				
2013	514	489	0.95				
2014	1101	1059	0.96				
2015	522	514	0.98				
2016	420	364	0.87				
2017	139	139	1.00				

The HSI model relies on habitat information collected by CRITFC and ODFW using the Columbia Habitat Monitoring Protocol (CHaMP 2015) throughout the UGR and CC historic Chinook spawning network. The HSI model uses depth and velocity results from Delft3D hydraulic model runs, as well as geo-referenced field observations of substrate size (i.e., gravel, cobble, etc.) to compute a spawning HSI score for every 10-cm raster cell within each surveyed reach (see Wheaton et al. 2017 for a more in-depth discussion of the HSI approach). HSI scores were then translated into a reach-scale estimate of available spawning habitat, weighted by habitat suitability (i.e. weighted usable area, WUA). The total spawning capacity for a reach was than estimated by dividing the WUA by the average territory size for a spawning Chinook (estimated here as 3.2m^2 for CC and the UGR).

Habitat Suitability Index estimates of reach-scale spawner capacity (estimated as redds) were available for a total of 186 CHaMP survey visits (CC = 81, UGR = 105) that occurred between 2011 and 2015. To obtain an estimate of total spawner capacity for each population domain, reach scale estimates were first divided by survey reach length as a measure of redd density per linear stream distance. Total redd capacity was then estimated by linear extrapolation of mean redd density within strata that correspond to position in the stream network (upper, lower, and valley sections) and channel

size (i.e. tributaries vs mainstem). Finally, capacity estimates for each strata were summed as an estimate of base model spawner capacity for each population (CC = 25,653, UGR = 28,397 [Appendix 2: Base Model Parameters]).

We used an approach similar to those described for egg to parr survival and capacity (see Egg to Parr Survival above) to estimate a survival parameter for use in the base LCM. This involved fitting a Beaverton-Holt function to abundance data at each stage with the capacity parameter fixed to our capacity estimate from the HSI model. This model was fit to unpublished ODFW estimates of annual adults on the spawning grounds to estimates of total spawners obtained through redd and carcass survey data. Fitting the Beaverton-Holt model to the data also yielded an estimate of error that was used to model variability in predicted spawner abundances.

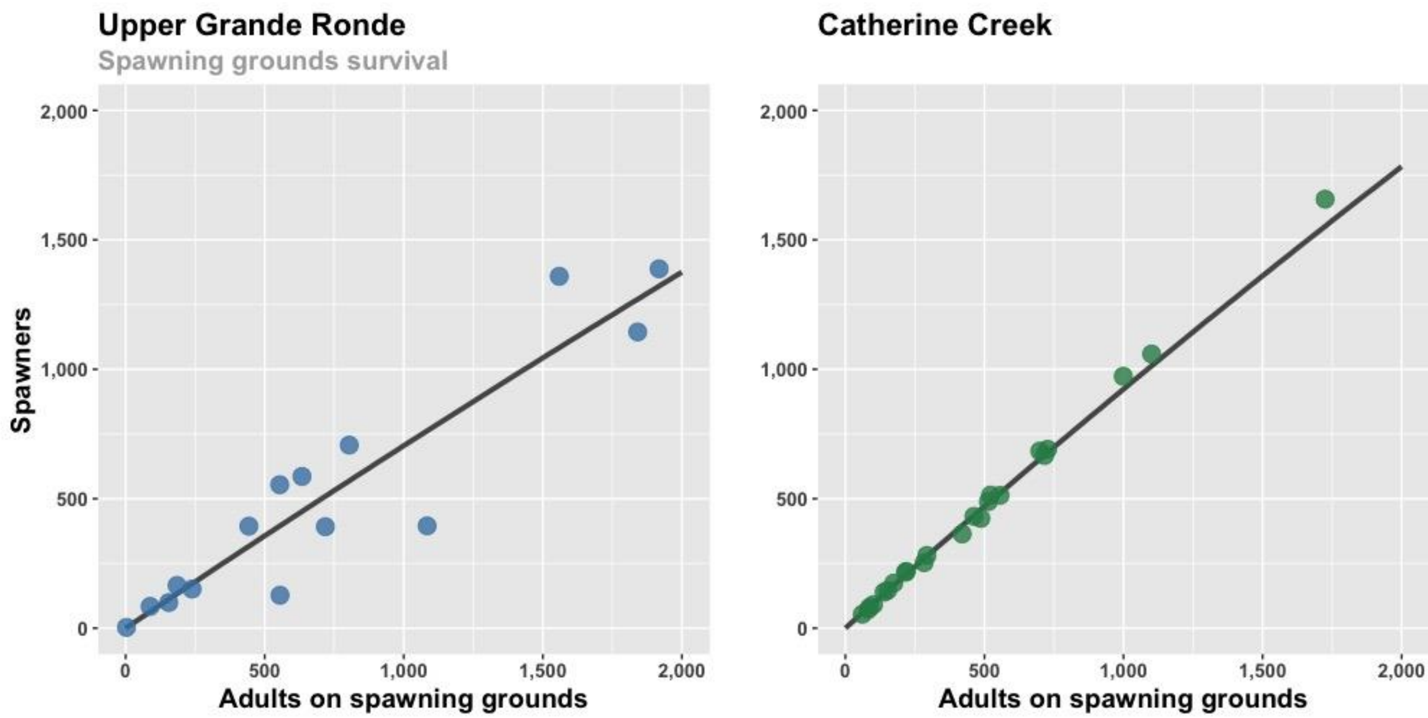

FIGURE 5. BEAVERTON-HOLT MODEL FIT TO ODFW ESTIMATES OF ADULTS PASSED ABOVE ADULT WEIRS AND TOTAL SPAWNING ADULTS IN EACH SYSTEM. NOTE, THAT CARRYING CAPACITY IS NOT SHOWN, AND CURVES APPEAR STRONGLY LINEAR DUE TO SPAWNER CAPACITY ESTIMATES FROM THE HSI MODEL BEING WELL ABOVE THOSE COMMONLY OBSERVED.

Spawner Fecundity

Female fecundity for both populations was modelled as 3831 eggs per female based on available estimates provided by Van Dyke (2008) for Catherine Creek chinook.

Table 10. Estimates of eggs per. female for Catherine Creek chinook from Van Dyke (2008).

Year	Fecundity (eggs per. female)
1997	3782
1998	4066
1999	3742
2000	3872
2001	3801
2002	3754
2003	3868
2004	3742
2005	3852

Base Model Validation

Several measures were taken to describe the accuracy of our LCM framework in reproducing UGR and CC population dynamics. This effort relied on an initial visual evaluation of model behavior and progressed to comparisons of modelled freshwater population abundances across life-stages to available data.

Base Model Behavior

We use initial model runs to visualize the behavior of the base model parameters developed for the Upper Grande Ronde and Catherine Creek Chinook Salmon populations. These model runs consisted of 500 iterations of a 150-year model seeded with 10,000 eggs and 5000 natural and hatchery origin smolt. To demonstrate the behavior of each population with and without supplementation we discontinued the supplementation component of each population at year 100.

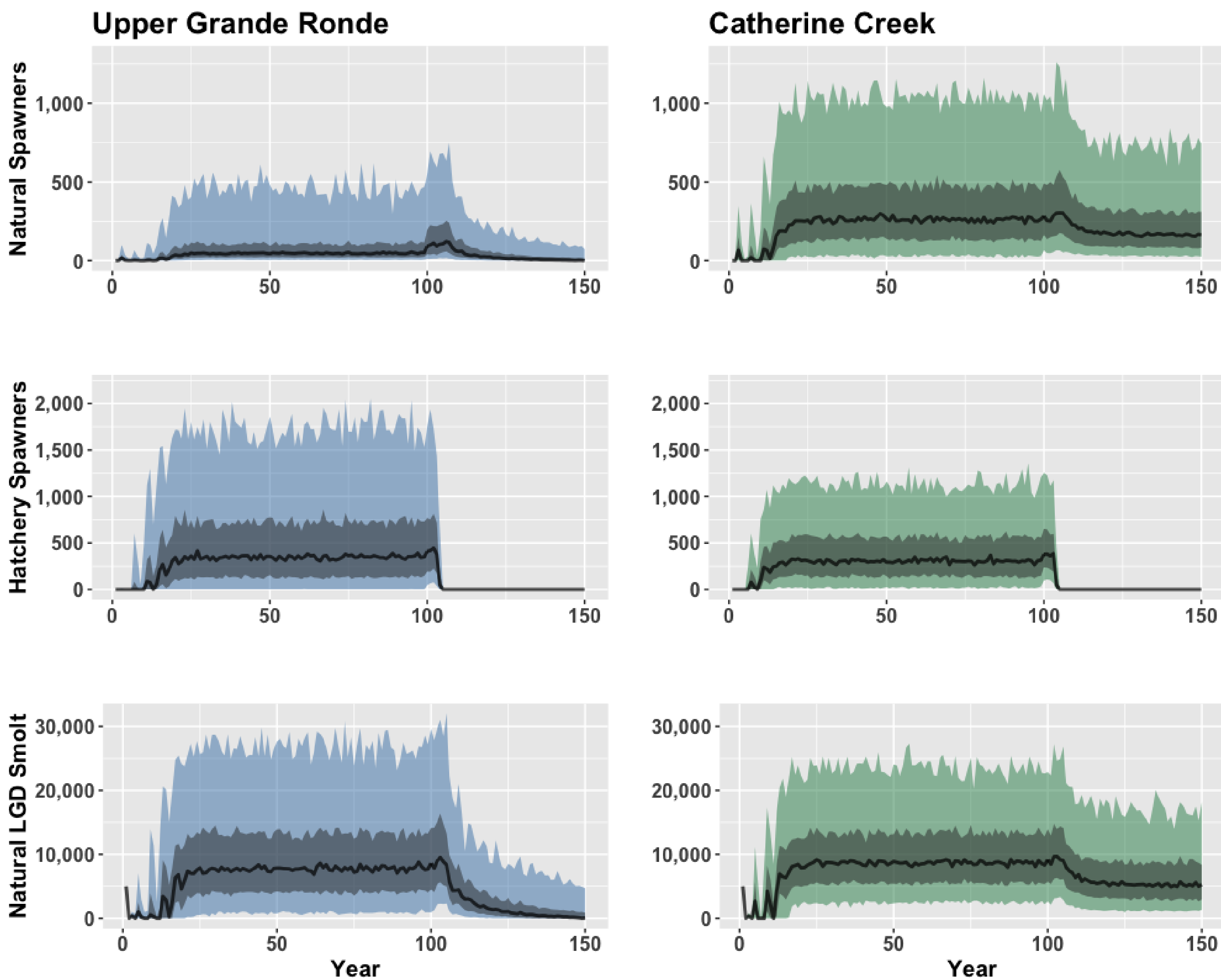

FIGURE 6. VISUAL DEPICTION OF MODEL SIMULATION BEHAVIOR SHOWING MAJOR LIFE-STAGE ABUNDANCE FOR 500 ITERATIONS OF A 150 YEAR MODEL. COLORED REGIONS REPRESENT THE 5TH AND 95TH, GREY REGIONS REPRESENT 25TH AND 75TH, AND BLACK LINES REPRESENT THE MEDIAN POPULATION ABUNDANCE. VISUALIZATIONS ALSO DEMONSTRATES THE IMPACT THAT CEASING HATCHERY SUPPLEMENTATION IN YEAR 100 HAS ON THE TRAJECTORY OF EACH POPULATION.

A visual evaluation of base model behavior (Figure 6Figure 1) showed that populations reach semi-stable equilibrium after approximately 30 years. Thus, we treated the first 40 years of each model run as a burn-in period during model validation and evaluation of restoration and climate change impacts. Modelled population abundances also increase slightly when the hatchery supplementation program is discontinued due to an initial increase of adults reaching the spawning grounds. However, the model suggests that the Upper Grande Ronde would quickly trend toward extinction without hatchery supplementation, while Catherine Creek would reach a new although slightly depressed stable population equilibrium.

Modelled Vs Observed Data

As part of our model validation process we compared available population abundance observations for late-summer parr, hatchery and natural origin smolt reaching LGD, and hatchery and natural origin adults returning to the spawning

grounds (i.e. returning to adult weirs) with the predicted distribution of population abundances for these stages. To develop a modelled dataset for use in validation we sampled the population abundance for each life-stage at year 50 from 500 iterations of a 100 - year run of the base model. Because our base model was parameterized using population data at a point when the hatchery supplementation program on the UGR and CC was being implemented (i.e., brood year 1998 to current), model predictions were only compared to observed data during this time period.

TABLE 11. COMPARISON OF THE MEDIAN POPULATION SIZE FROM OUR MODEL VALIDATION DATASET AND OBSERVED POPULATION ESTIMATES SHOWING THE DIFFERENCE AND RELATIVE DIFFERENCE ACROSS LIFE STAGES AND AMONG NATURAL AND HATCHERY COMPONENTS OF EACH POPULATION.

				Median abundance			
Pop.	Origin	Stage	Location	Observed	Modelled	Obs. - Mod.	Difference
UGR	Natural	Parr	Spawning grounds	58770	61767	2997	5%
		Smolt	Lower Granite Dam	9314	7669	-1645	-18%
		Adult	Returns to spawning grounds	240	143	-97	-40%
	Hatchery	Smolt	Release on spawning grounds	232350	199646	-32705	-14%
		Smolt	Lower Granite Dam	101902	84371	-17532	-17%
		Adult	Returns to spawning grounds	976	565	-412	-42%
CC	Natural	Parr	Spawning grounds	66043	80360	14317	22%
		Smolt	Lower Granite Dam	4657	8819	4162	89%
		Adult	Returns to spawning grounds	388	301	-87	-22%
	Hatchery	Smolt	Release on spawning grounds	141598	131057	-10541	-7%
		Smolt	Lower Granite Dam	88687	74808	-13880	-16%
		Adult	Returns to spawning grounds	705	435	-271	-38%

We assessed the agreement between observed population abundance estimates and model predictions visually in a series of boxplots (Figure 7, Figure 8) that also show raw observed and modelled population observations. We also evaluated the agreement between observed and modelled data in a regression between the median observed and median modelled value of abundance across life-stages (Figure 9, Table 11).

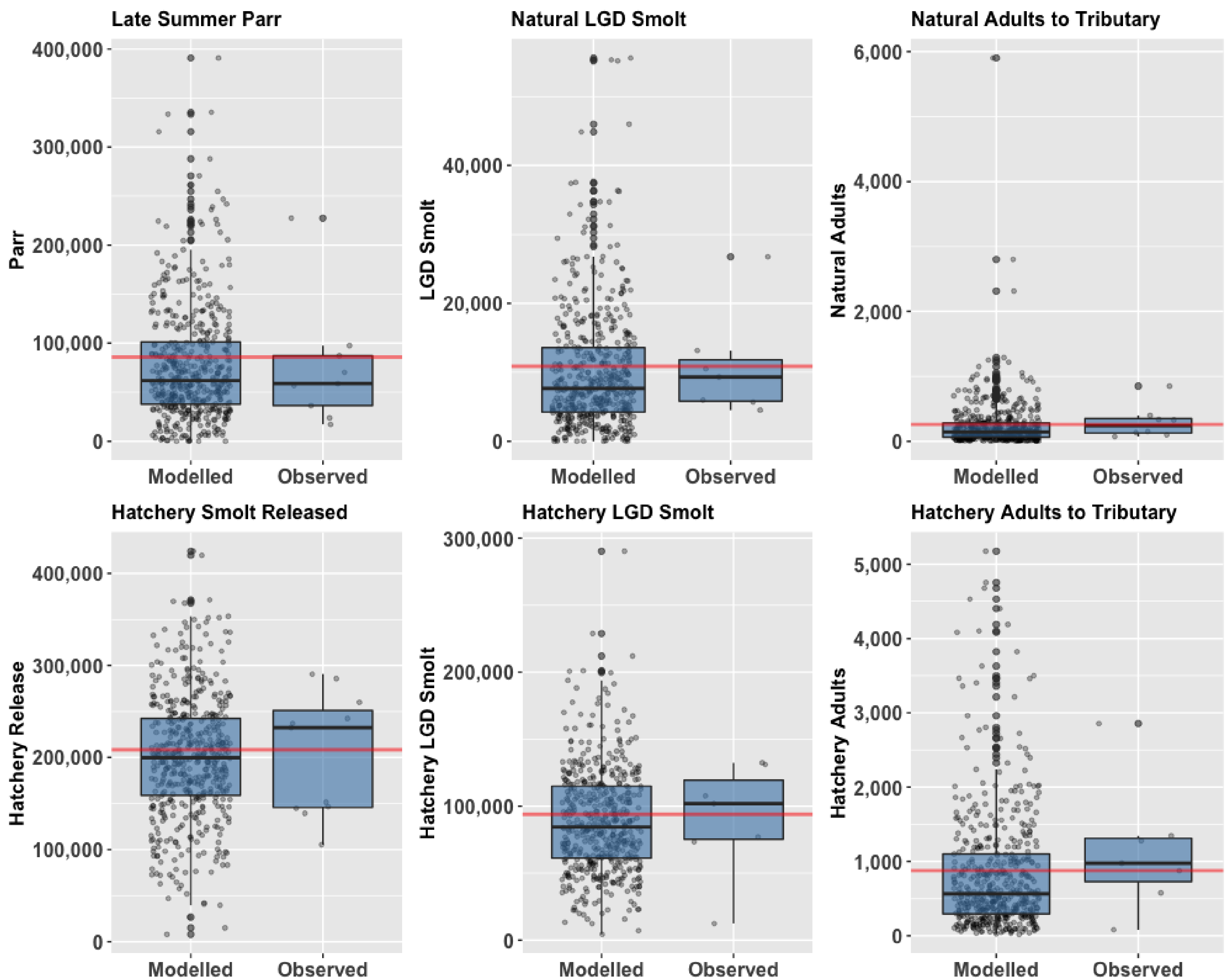

FIGURE 7. VISUAL VALIDATION OF MODEL PERFORMANCE FOR THE UPPER GRANDE RONDE. FIGURES CONTRAST THE DISTRIBUTION OF POPULATION ABUNDANCES FOR LIFE-STAGES AS MODEL PREDICTIONS AND OBSERVED ESTIMATES. THE MODELLED DATA IS BASED ON THE POPULATION ABUNDANCE AT YEAR 50 FROM 500 ITERATIONS OF A BASE MODEL SCENARIO. THE RED LINE SHOWS THE MODEL PREDICTED POPULATION ABUNDANCE AT EACH LIFE-STAGE WHEN MODEL STOCHASTICITY HAS BEEN TURNED OFF (I.E. DETERMINISTIC MODEL PREDICTION).

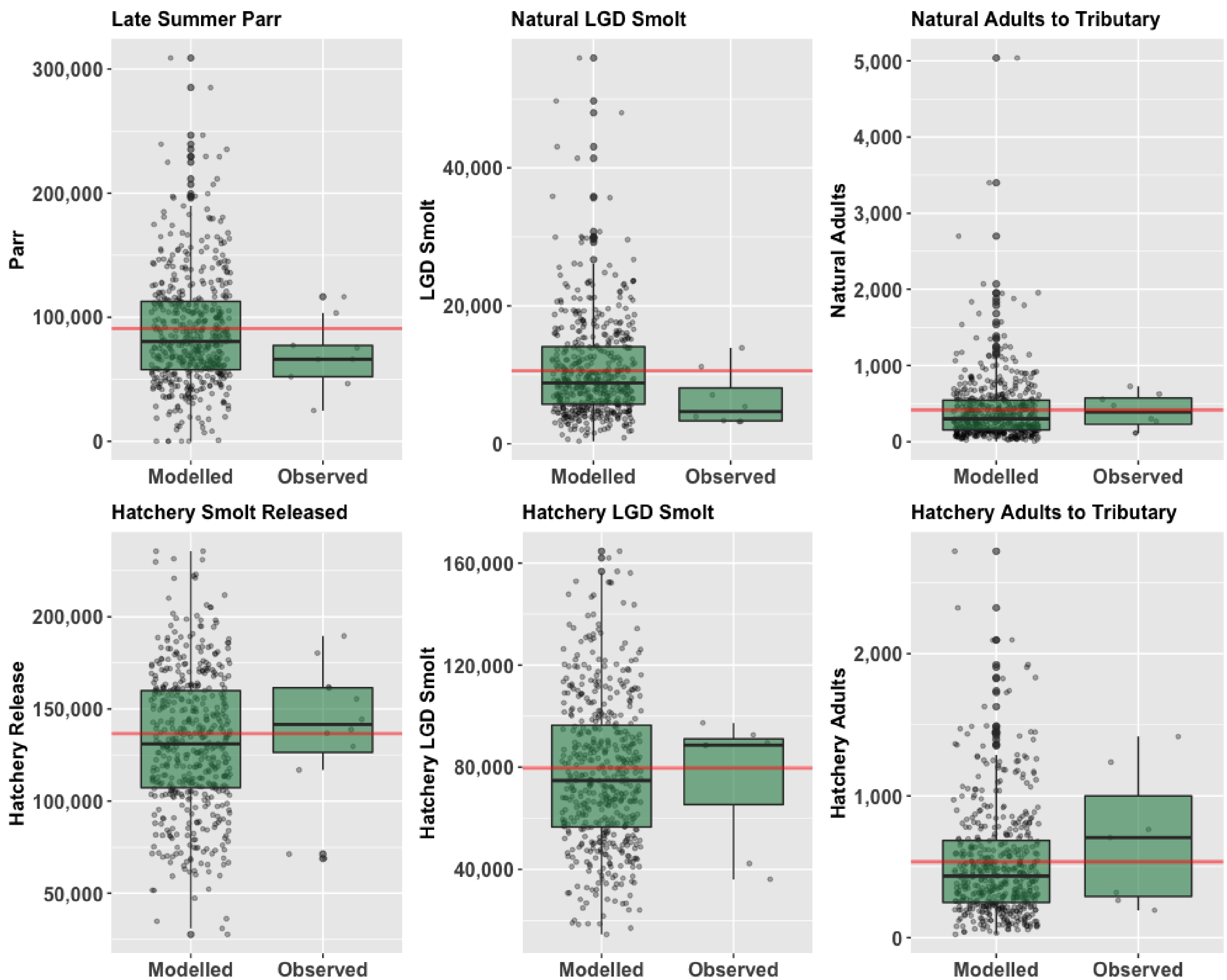

FIGURE 8. VISUAL VALIDATION OF MODEL PERFORMANCE FOR CATHERINE CREEK. FIGURES CONTRAST THE DISTRIBUTION OF POPULATION ABUNDANCES FOR LIFE-STAGES AS MODEL PREDICTIONS AND OBSERVED ESTIMATES. THE MODELLED DATA IS BASED ON THE POPULATION ABUNDANCE AT YEAR 50 FROM 500 ITERATIONS OF A BASE MODEL SCENARIO. THE RED LINE SHOWS THE MODEL PREDICTED POPULATION ABUNDANCE AT EACH LIFE-STAGE WHEN MODEL STOCHASTICITY HAS BEEN TURNED OFF (I.E. DETERMINISTIC MODEL PREDICTION).

Our validation procedures suggested a high correspondence between observed population abundance estimates and those predicted among life-stages by our base model. This statement holds particularly well when evaluating the median values of model - based predictions and observed estimates regardless of population and origin. However, visual validation of raw model predictions does suggest that population abundances within our model occupy a broader range than have been observed for these populations in the years on record. However, one must consider that the observed data available is sparse at best and based on roughly a decade of data collection and population estimation. In contrast, we used 500 individual 100 year model iterations to produce our validation datasets, and given the large variability built into our model framework it is not surprising that our modelled populations occupy a larger space of potential trajectories.

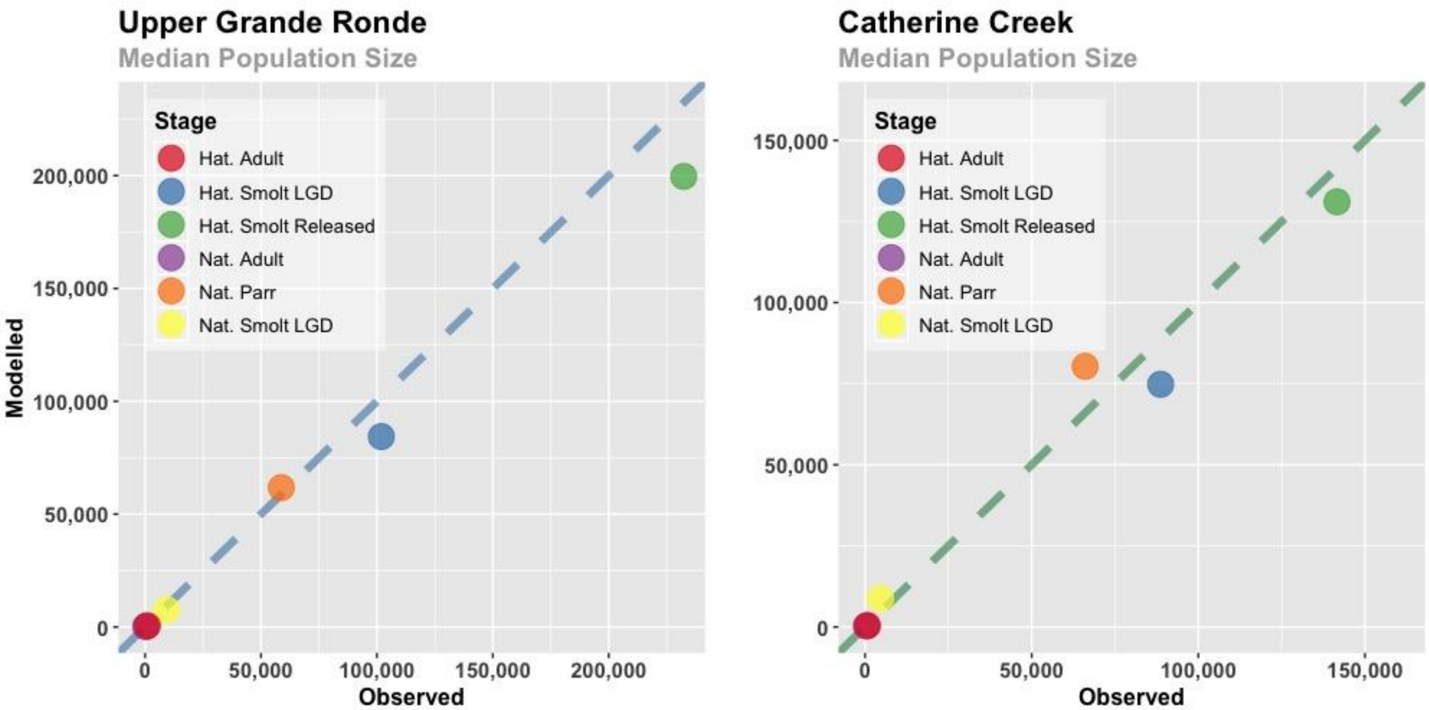

FIGURE 9. VISUAL VALIDATION OF MODEL ACCURACY BETWEEN OBSERVED AND MODEL PREDICTED POPULATION ABUNDANCES FOR NATURALLY (NAT.) AND HATCHERY (HAT.) REARED COMPONENTS OF THE POPULATION.

RESTORATION AND CLIMATE SCENARIOS

Following validation of the base model parameterization (hereafter 'Curr' for current condition), the LCM modelling framework was used to investigate Chinook population performance in the UGR and CC according to an array of restoration and climatic scenarios (Table 12, Table 14). These scenarios are based on two separate modelling frameworks developed by CRITFC that consider how future climate and restoration trajectories may impact the availability of juvenile rearing and adult spawning grounds habitat within the UGR and CC. More specific information on these restoration and climate modelling frameworks evaluated here can be found within Justice et al. (2017 [hereafter 'Justice Scenarios']), and in unpublished reports describing a Structural Equation Modelling (hereafter 'SEM Scenarios') approach that relates changes to instream habitat in the form of increased pool density to the capacity of juvenile Chinook in each system.

JUSTICE SCENARIOS

Restoration and climate modelling presented in work by Justice et al. (2017) evaluates the impacts of alternative temperature/habitat futures that include the effects of global warming manifested as increased streamflow and hydrological change in the presence of habitat restoration (i.e., Table 12, scenarios 'Clim', 'ClimVeg', 'ClimVegWid'). These alternative futures are expressed in terms of proportional changes to freshwater rearing capacity from the base model, which are invoked within our LCM at the egg to parr stage transition.

TABLE 12. SCENARIOS MODELED AFTER JUSTICE ET AL. (2017). FOR LCM INPUTS, EACH SCENARIO IS REPRESENTED AS A PROPORTION INCREASE OR DECREASE IN SUMMER PARR REARING AND SPAWNER CAPACITY.

Scenario abbreviation	Description
Curr	Baseline model calibrated using 2010 temperature, climate, vegetation, and hydrologic conditions
Clim	Air temperature and streamflow set to 2080s climate projections.
ClimVeg	2080s climate projections and vegetation set to potential cover and height at 75 years.
ClimVegWid	2080s climate projections, vegetation set to potential cover and height at 75 years, and channel width set to historic conditions.

We also extended the Justice et al. alternative temperature futures to include impacts to prespawn habitat suitable for survival of adult Chinook on the spawning grounds during summer. This was done by proportionally adjusting spawner capacity (from the base model) based on the relative change in spawning habitat availability. Under each scenario, spawning habitat was considered unsuitable if modelled daily August mean temperature (available from Norwest 2080's stream temperature dataset: https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html) exceeded an upper threshold of 17.2 °C considered lethal for adult Chinook. This threshold was based on the observation that 95% of the salmon redds in the upper Grande Ronde River occurred in areas with water temperatures below 17.2 °C (Tom Cooney, NOAA, pers. comm.).

TABLE 13. PROPORTIONAL INCREASE/DECREASE AND ABSOLUTE CAPACITY ESTIMATES USED UNDER EACH RESTORATION AND CLIMATE SCENARIO FOR THE UPPER GRANDE RONDE (UGR) AND CATHERINE CREEK (CC) CHINOOK POPULATIONS UNDER THE JUSTICE ET AL. (2017) HABITAT FRAMEWORK.

		Parr capacity		Spawner capacity	
Population	Scenario abbreviation	% change	input	% change	input
UGR	Curr	0%	108087	0%	28397
	Clim	-53%	50801	-60%	11491
	ClimVeg	63%	176181	0%	28484
	ClimVegWid	114%	231306	10%	31264
CC	Curr	0%	111897	0%	25653
	Clim	-36%	71614	-36%	16399
	ClimVeg	20%	134276	-1%	25523
	ClimVegWid	37%	226992	1%	25955

SEM Scenarios

Similar to the Justice scenarios, the SEM scenarios consider future restoration and climatic conditions for the UGR and CC and associated impacts to the quantity and quality of juvenile rearing and adult summer habitat (Table 14). Again, these scenarios account for climate change in the absence of restoration ('Clim') as well as when restoration results in increased riparian vegetation ('ClimVeg75') and/or creation of pool habitat ('ClimPools', 'ClimPoolsVeg'). As with the Justice scenarios, the availability of habitat with summer temperatures suitable for survival of pre-spawn adult Chinook were also modelled as proportional changes in spawner capacity. Also, because our primary management question is whether the proposed restoration actions can decrease extinction risk for these we only evaluate the SEM scenarios when the supplementation has been discontinued in year 40.

Table 14. Scenarios modeled after Justice et al. (2017). For LCM inputs, each scenario is represented as a proportion increase or decrease in summer parr rearing and spawner capacity.

Scenario Abbreviation	Description
Curr	Baseline model calibrated using 2010 temperature, climate, vegetation, and hydrologic conditions
Clim	Air temperature and streamflow set to 2080s climate projections.
ClimVeg	2080s climate projections and vegetation set to potential cover and height at 75 years.
ClimPoolsVeg	2080s climate projections, vegetation set to potential cover and height at 75 years, and restoration resulting in increase in pool habitat.

Table 15. Proportional increase/decrease and absolute capacity estimates used under each restoration and climate scenario for the Upper Grande Ronde (UGR) and Catherine Creek (CC) Chinook populations under the structural equation modelling scenarios.

		Parr capacity		Spawner capacity	
Population	Scenario abbreviation	% change	input	% change	input
UGR	Curr	0%	108087	0%	28397
	Clim	-58%	45397	-60%	11491
	ClimPools	-53%	50801	-60%	11491
	ClimVeg75	3%	111654	0%	28484
	ClimPoolsVeg	13%	122138	0%	28484
CC	Curr	0%	111897	0%	25653
	Clim	-39%	68257	-36%	16399
	ClimPools	7%	120177	-36%	16399
	ClimVeg75	-3%	108876	-1%	25523
	ClimPoolsVeg	58%	176797	-1%	25523

LCM Simulation Methods

We used the model to simulate trajectories for each population under each scenario over a 50 - year period (90 years minus a 40 year burn in) within 500 Monte Carlo model iterations. All model iterations were seeded with 10000 eggs and 1000 natural and hatchery origin smolt at LGD. Each scenario was run using the current hatchery supplementation scheme, as well as under a "cease supplementation" scenario in which hatchery supplementation is turned off in year 40.

We summarized the potential outcome of each scenario expressed as the median abundance of natural spawners over each 50 – year model iteration, and as the probability of quasi-extinction risk (pQER) for the population. A model run was considered at risk of quasi-extinction if at any point in the 50 - year simulation the spawning population remained below 50 for 4 consecutive years. pQER was calculated as the proportion of the 500 model iterations that the population reached the quasi extinction threshold at any point. pQER was only calculated for scenario simulations in which supplementation was discontinued as the hatchery supplementation programs ensures future viability of the populations.

LCM Scenario Results and Discussion

Several significant changes to the LCM framework introduced here (as opposed to chapter 9.f in ISAB 2017) increases the realism and utility of the model to assess recovery potential for upper Grande Ronde River and Catherine Creek Chinook Salmon in a LCM context. Specifically, accounting for spawner capacity in addition to parr improves the model's ability to represent the impact of each restoration and climatic scenario on total life-cycle productivity. Further, accounting for life-history dependent presmolt survival probabilities, natural and hatchery origin SAR rates, and more accurately representing the supplementation scheme and survival of hatchery smolts all contribute to a model that better reflects the population and management dynamics within these systems. Changes made to the variance structure of stochastic model components should also improve our confidence in the LCM's ability to forecast future trajectories for the UGR and CC Chinook populations, and estimate probabilities associated with future population viability under different restoration and management scenarios.

Outcomes for the Justice and SEM restoration and climate scenarios are presented in Figures 10 – 15 and Tables 14 – 15 and demonstrate a number of considerations relevant to future recovery and restoration planning in these systems. For both populations, proportional changes in parr and spawner carrying capacity reflected in the Justice and SEM scenarios translated into increased natural spawner abundances on a rank order basis. However, the magnitude of the population response did not increase/decrease on a one-to-one basis to the capacity changes under each scenario. Productivity responses (i.e. increase/decrease) were generally more pronounced within the UGR, which may be due to several factors. Within the UGR, current temperature regimes throughout much of the spawning and rearing network are commonly very near the upper temperature threshold for Chinook. Additionally, returns of natural origin spawners to the UGR have been much lower than those observed within CC, and these low values are more sensitive to proportional changes in productivity.

Running the restoration and climate change scenarios with and without supplementation also has the potential to inform future management for these systems. For example, even under the base (i.e., 'Curr') population conditions, our model suggests that CC has a relatively low extinction risk 0.032 that would increase to roughly 0.12 in the face of climate change even when no restoration was implemented (i.e. 'Clim'). On the other hand, our simulation results

suggest that extinction risk is certain for the UGR in the absence of supplementation, and that under the most aggressive restoration scenario (i.e. 'ClimVegWid') extinction risk could be lowered to roughly 0.78. While we do not attempt to make broad management recommendations here, the hope is that these model outcomes can be used to optimize future investment in restoration and hatchery supplementation programs that support viable natural populations in these systems.

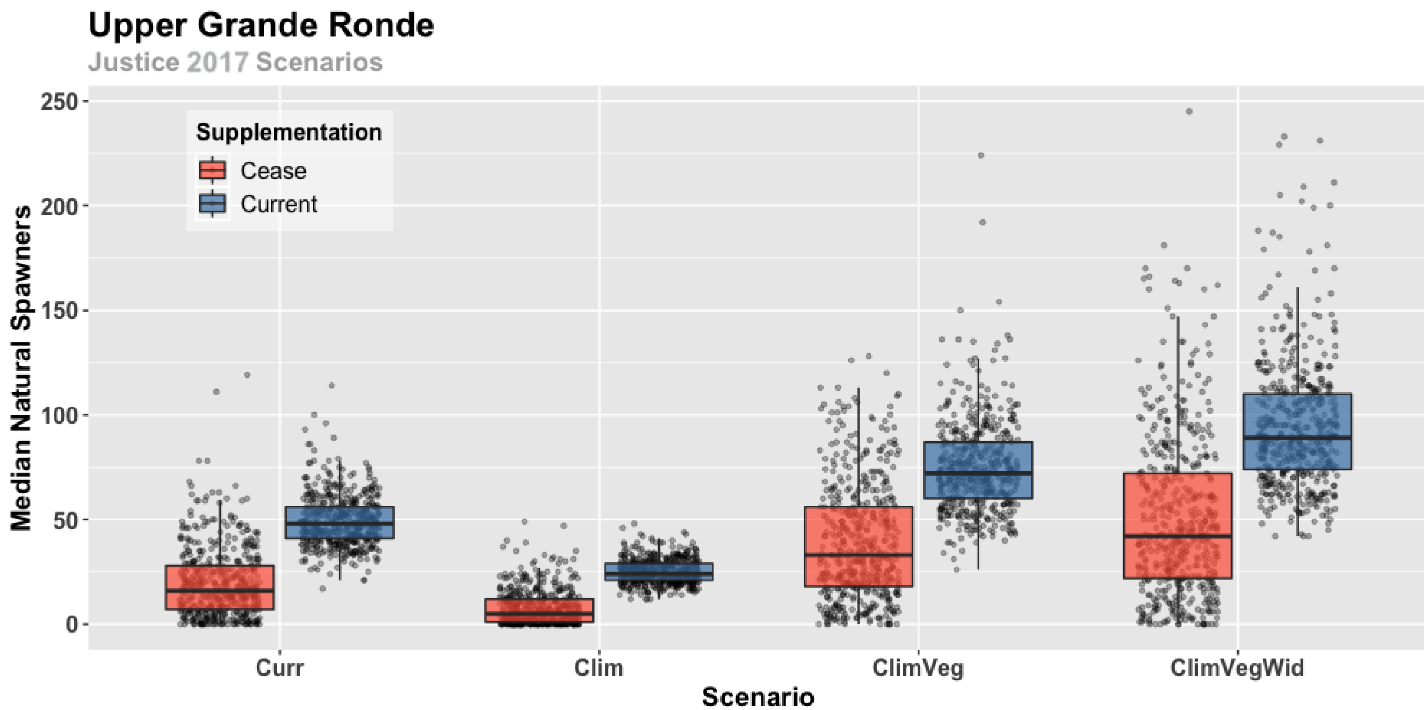

FIGURE 10. BOXPLOTS SHOWING THE DISTRIBUTION OF THE MEDIAN POPULATION SIZE FOR UPPER GRANDE RONDE NATURAL ORIGIN SPAWNING CHINOOK FOR RESTORATION AND CLIMATE SCENARIOS DESCRIBED BY JUSTICE ET AL. 2017. MODEL RUNS AT CURRENT SUPPLEMENTATION AND WITH SUPPLEMENTATION DISCONTINUED ARE SHOWN. JITTERED POINTS SHOW THE MEDIAN VALUE FOR EACH OF 500 MODEL RUNS.

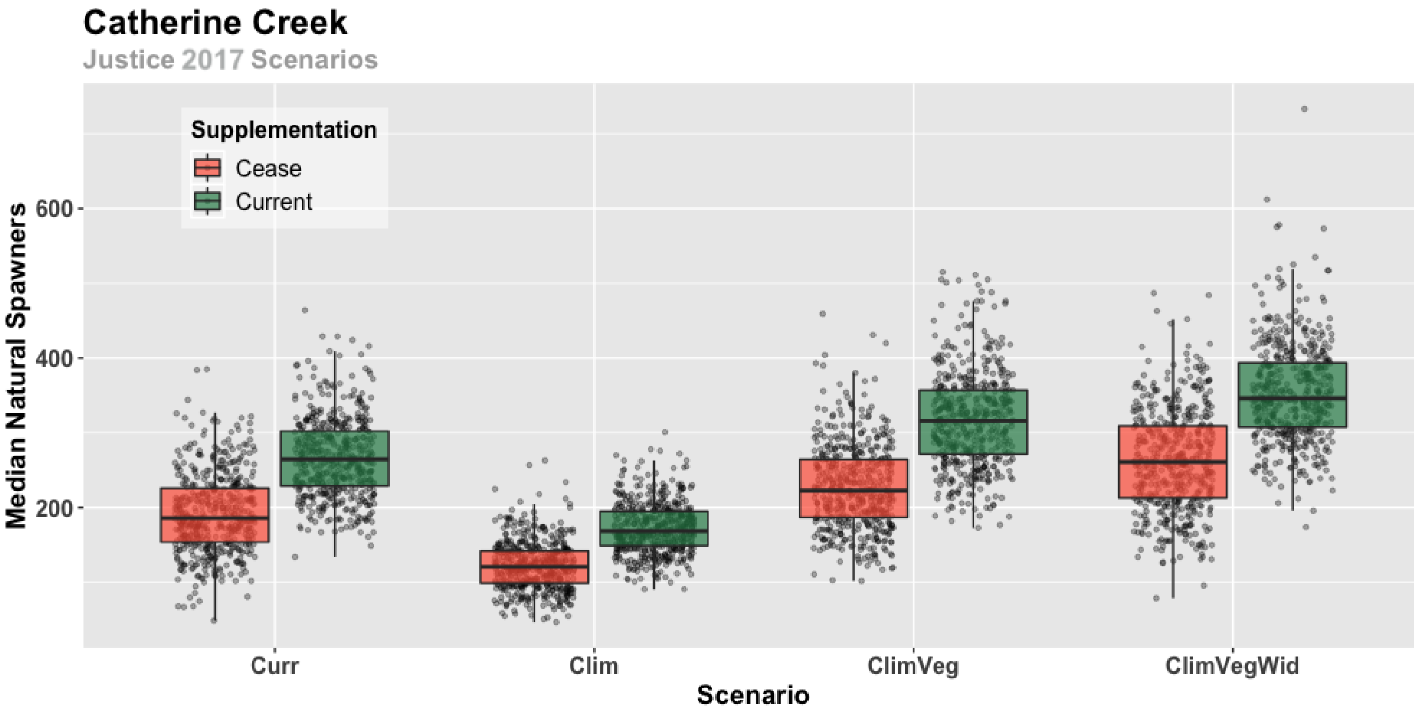

FIGURE 11. BOXPLOTS SHOWING THE DISTRIBUTION OF THE MEDIAN POPULATION SIZE FOR CATHERINE CREEK NATURAL ORIGIN SPAWNING CHINOOK FOR RESTORATION AND CLIMATE SCENARIOS DESCRIBED BY JUSTICE ET AL. 2017. MODEL RUNS AT CURRENT SUPPLEMENTATION AND WITH SUPPLEMENTATION DISCONTINUED ARE SHOWN. JITTERED POINTS SHOW THE MEDIAN VALUE FOR EACH OF 500 MODEL RUNS.

TABLE 16. MEDIAN POPULATION SIZE OF NATURAL ORIGIN SPAWNING CHINOOK FOR 500 MODEL ITERATIONS OF RESTORATION SCENARIOS DESCRIBED BY JUSTICE ET AL. 2017. ALSO SHOWING RELATIVE DIFFERENCE OF EACH SCENARIO TO THE CURRENT CONDITIONS ('CURR') IN MODEL RUNS AT CURRENT HATCHERY SUPPLEMENTATION AND WHEN SUPPLEMENTATION IS DISCONTINUED.

		Current Supplementation		Cease Supplementation		
Pop	Scenario	Median natural spawners	Relative to Curr	Median natural spawners	Relative to Curr	pQER
UGR	Curr	48	-	16	-	0.972
	Clim	24	-50%	5	-69%	1
	ClimVeg	72	50%	33	106%	0.872
	ClimVegWid	89	85%	42	163%	0.784
CC	Curr	265	-	186	-	0.032
	Clim	169	-36%	121	-35%	0.118
	ClimVeg	316	19%	223	20%	0.004
	ClimVegWid	346	31%	261	40%	0.01

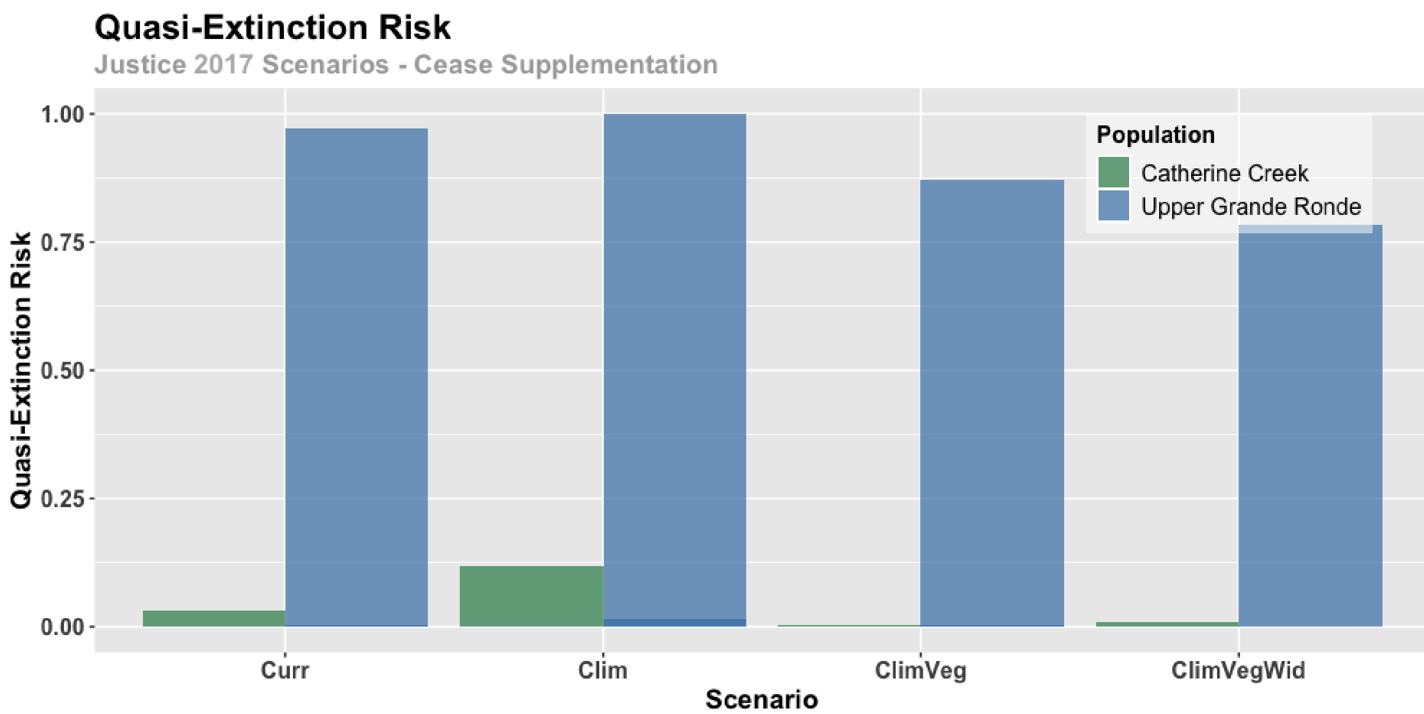

FIGURE 12. QUASI – EXTINCTION RISK (PQER) UNDER EACH RESTORATION AND CLIMATE SCENARIO FOR THE UPPER GRAND RONDE AND CATHERINE CREEK CHINOOK POPULATIONS FOR RESTORATION AND CLIMATE SCENARIOS DESCRIBED BY JUSTICE ET AL. 2017.

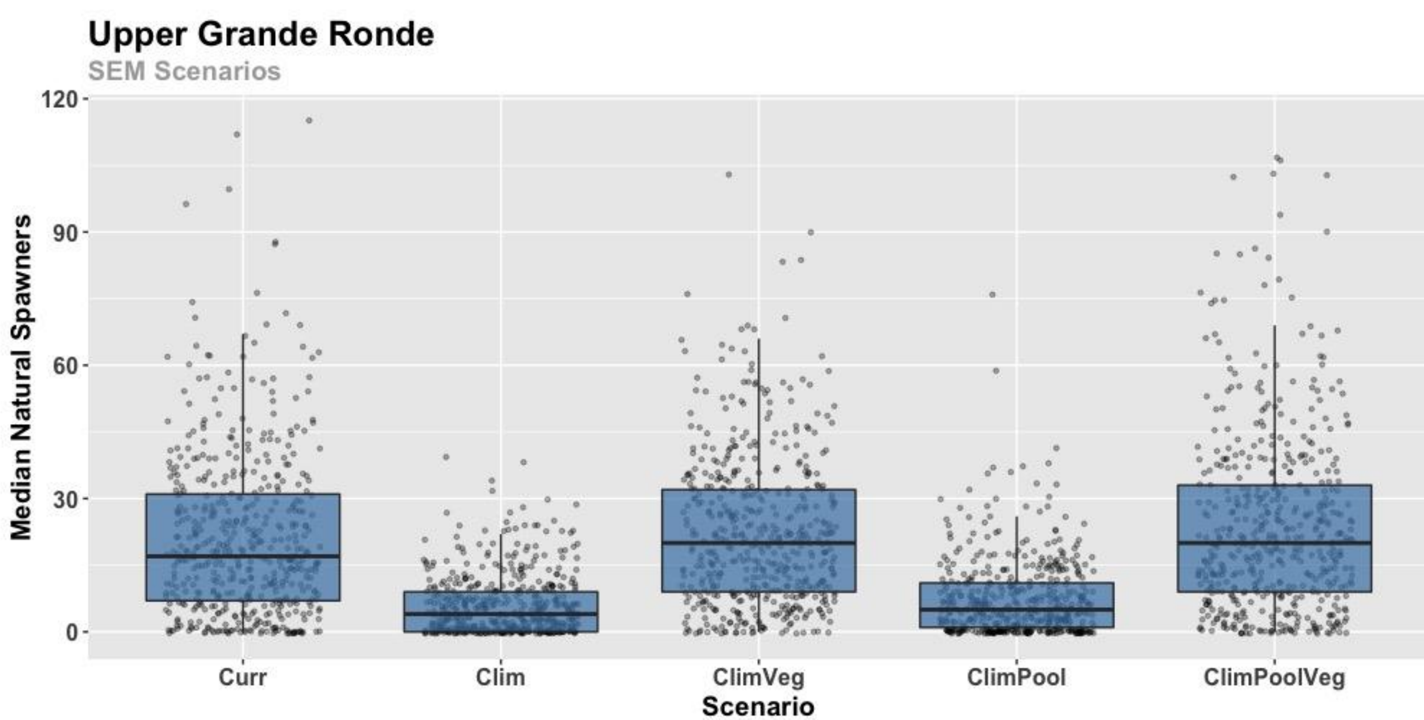

FIGURE 13. MEDIAN POPULATION SIZE OF UPPER GRANDE RONDE NATURAL ORIGIN SPAWNING CHINOOK BASED ON RESTORATION AND CLIMATE SCENARIOS DESCRIBED BY THE STRUCTURAL EQUATION MODEL RELATIONSHIPS. MEDIAN POPULATION SIZE IS FROM 500 MODEL SIMULATIONS AND ASSUMES DISCONTINUATION OF HATCHERY SUPPLEMENTATION.

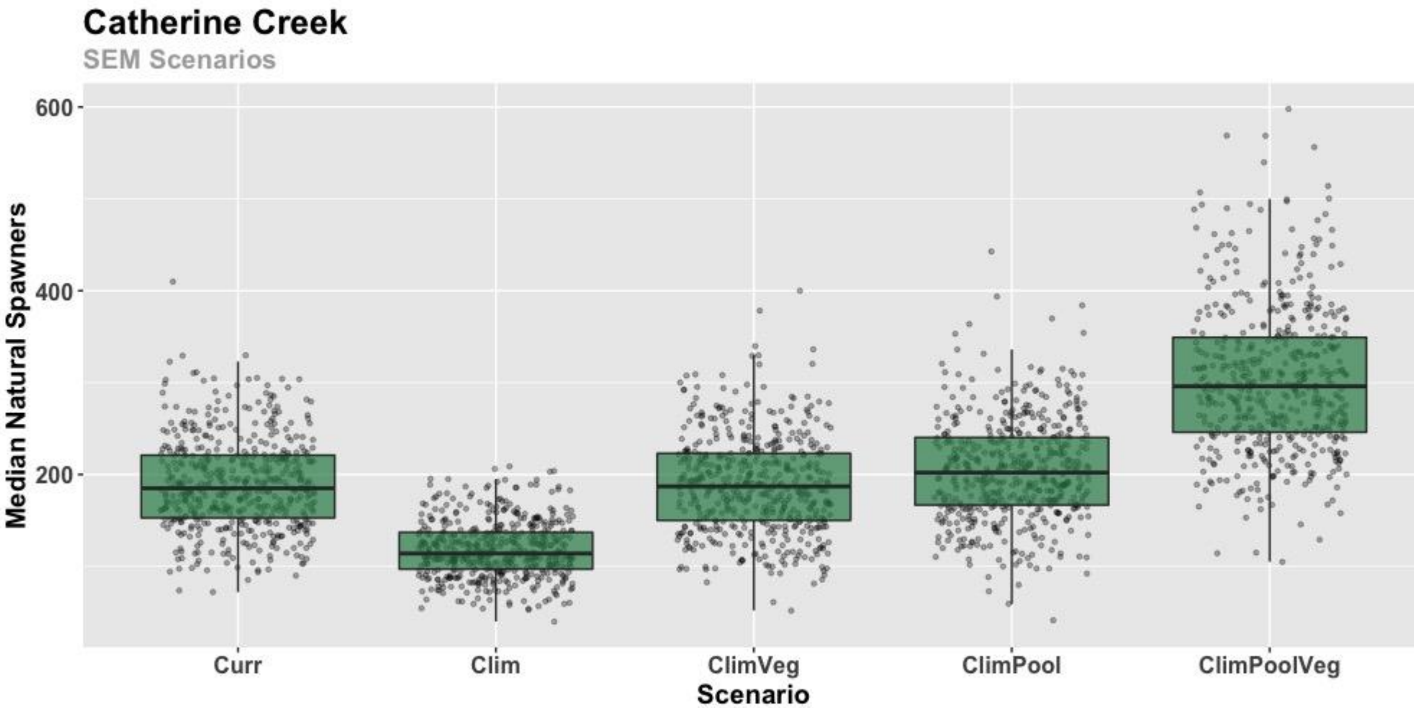

FIGURE 14. MEDIAN POPULATION SIZE OF CATHERINE CREEK NATURAL ORIGIN SPAWNING CHINOOK BASED ON RESTORATION AND CLIMATE SCENARIOS DESCRIBED BY THE STRUCTURAL EQUATION MODEL RELATIONSHIPS. MEDIAN POPULATION SIZE IS FROM 500 MODEL SIMULATIONS AND ASSUMES DISCONTINUATION OF HATCHERY SUPPLEMENTATION.

TABLE 17. MEDIAN POPULATION SIZE OF NATURAL ORIGIN SPAWNING CHINOOK FOR 500 MODEL ITERATIONS OF RESTORATION SCENARIOS DESCRIBED BY THE SEM SCENARIOS. ALSO SHOWING RELATIVE DIFFERENCE OF EACH SCENARIO TO THE CURRENT CONDITIONS ('CURR') AND QUASI EXTINCTION RISK (PQER).

		Cease Supplementation		
Population	Scenario	Median Natural Spawners	Relative to Curr	QER
UGR	Curr	17	-	0.968
	Clim	4	-76%	1
	ClimVeg	20	18%	0.982
	ClimPool	5	-71%	0.998
	ClimPoolVeg	20	18%	0.952
CC	Curr	185	-	0.028
	Clim	114	-38%	0.15
	ClimVeg	187	1%	0.04
	ClimPool	202	9%	0.022
	ClimPoolVeg	296	60%	0.002

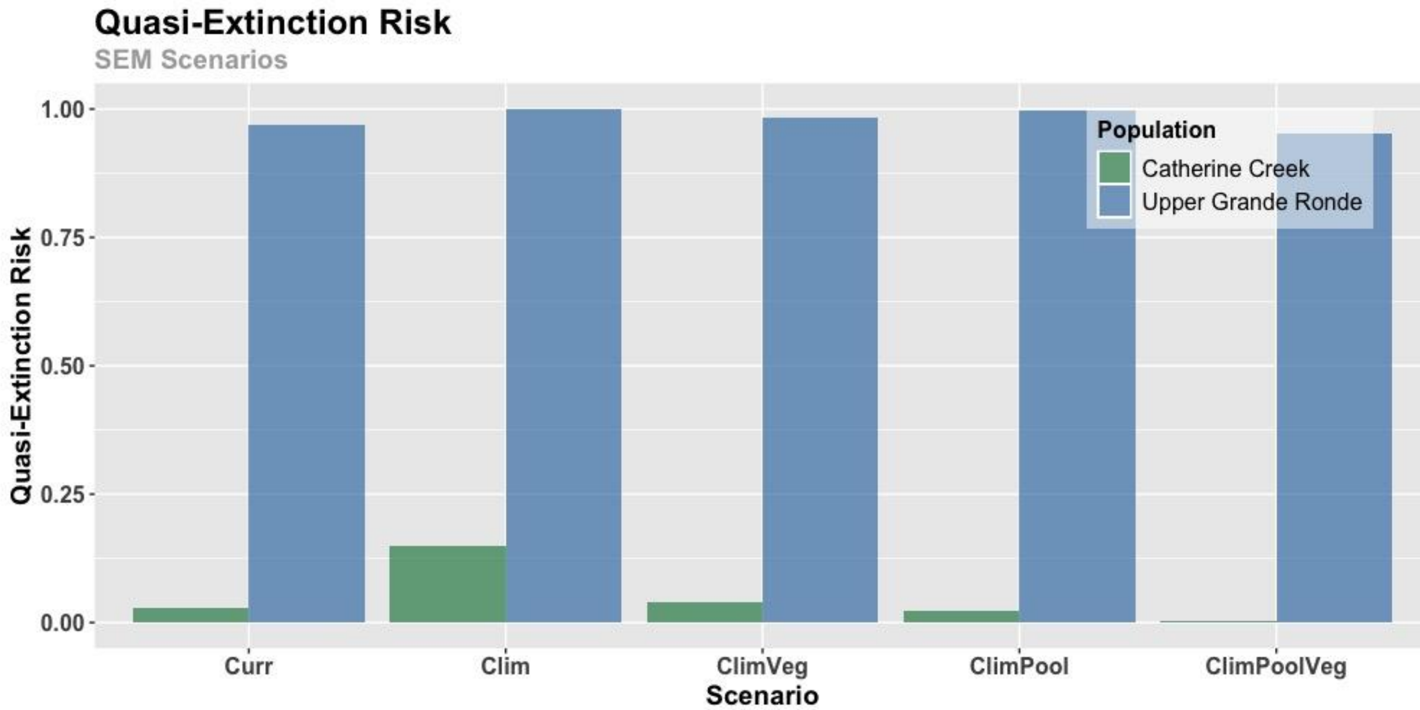

FIGURE 15. QUASI EXTINCTION RISK BASED ON RESTORATION AND CLIMATE SCENARIOS FROM THE STRUCTURAL EQUATION MODEL ANALYSIS FOR THE UPPER GRANDE RONDE AND CATHERINE CREEK CHINOOK POPULATIONS.

Model Sensitivity

As an extension to our modelling of future population trajectories under restoration and climatic conditions, we also conducted a sensitivity analysis for our LCM framework for both the UGR and CC base LCM parameterizations. This extension is included here for a number of reasons. First, our modelling scenarios only focused on manipulating capacity, and we sought to contrast model performance by comparing manipulations of capacity to increases and decreases directly to productivity (i.e. survival). Second, all of our LCM scenarios manipulated capacity simultaneously at two life-stages which did not allow us to attribute population responses to an individual life-stage. Additionally, modelling scenarios manipulated parameters at just two stage transitions (i.e. egg to parr and spawning grounds survival), and we wanted to contrast the sensitivity of the model over a broader scope within our populations.

For our sensitivity analysis we manipulated productivity parameters for all freshwater life-stages as well as smolt-to-adult survival. The analysis also included capacity but focused only on those stages in which density dependent survival was modelled within our restoration scenarios, namely egg-to-parr survival and adult survival on the spawning grounds. Starting with the base model for each population, we increased and decreased a single target parameter from -30% to +30% at 10% increments while holding all others constant (Table 18). These values were chosen as they produced a realistic range of parameter rate changes that could be expected as a result of management actions and it allowed a normalized means to make comparisons of model sensitivity among parameters. At each increment the model was run for 500 iterations, over which pQER and the percent change in natural origin spawner abundance from the base parameter value was calculated. Again, because our broader aim is to provide results that are relevant to establishing viable populations with hatchery supplementation discontinued, we conducted the model sensitivity analysis with supplementation turned off at year 40. We present the results of our sensitivity analysis visually in a series of plots that compare the proportional increase or decrease in natural spawners and pQER from the base model for each population (Figure 16, Figure 17).

TABLE 18. BASE (I.E. CURR) MODEL PARAMETER VALUES FOR CAPACITY AND PRODUCTIVITY ACROSS LIFE-STAGES INCLUDED IN THE SENSITIVITY ANALYSIS. ALSO SHOWING ACTUAL VALUES USED FOR EACH LIFE-STAGE IN SENSITIVITY SIMULATIONS FROM -30% TO %30.

Population	Parameter	Life Stage	Base Value	Sensitivity analysis values						
				-30%	-20%	-10%	0%	10%	20%	30%
CC	p_i	Adult Spawning Grounds	0.96	0.67	0.77	0.86	0.96	1.00	1.00	1.00
	p_i	Egg - Parr	0.32	0.22	0.26	0.29	0.32	0.35	0.38	0.42
	p_i	Headwaters Rearing - LGD Smolt	0.10	0.07	0.08	0.09	0.10	0.11	0.12	0.13
	p_i	Valley Rearing - LGD Smolt	0.12	0.08	0.10	0.11	0.12	0.13	0.14	0.16
	p_i	LGD Smolt - Tributary Adult Age 1	0.060	0.042	0.048	0.054	0.060	0.066	0.072	0.078
	p_i	Ocean Age 1 - Tributary Adult Age 2	0.66	0.46	0.53	0.59	0.66	0.73	0.79	0.86
	p_i	Ocean Age 2 - Tributary Adult Age 3	0.61	0.43	0.49	0.55	0.61	0.67	0.73	0.79
	c_i	Egg - Parr Capacity	111897	78328	89518	100707	111897	123087	134276	145466
	c_i	Adult Spawning Grounds Capacity	25653	17957	20522	23088	25653	28218	30784	33349
UGR	p_i	Adult Spawning Grounds	0.73	0.51	0.58	0.66	0.73	0.80	0.88	0.95
	p_i	Egg - Parr	0.32	0.22	0.26	0.29	0.32	0.35	0.38	0.42
	p_i	Headwaters Rearing - LGD Smolt	0.11	0.08	0.09	0.10	0.11	0.12	0.13	0.14
	p_i	Valley Rearing - LGD Smolt	0.18	0.13	0.14	0.16	0.18	0.20	0.22	0.23
	p_i	LGD Smolt - Tributary Adult Age 1	0.04	0.03	0.03	0.04	0.04	0.04	0.05	0.05
	p_i	Ocean Age 1 - Tributary Adult Age 2	0.63	0.44	0.50	0.57	0.63	0.69	0.76	0.82
	p_i	Ocean Age 2 - Tributary Adult Age 3	0.52	0.36	0.42	0.47	0.52	0.57	0.62	0.68
	c_i	Egg - Parr Capacity	108087	75661	86470	97278	108087	118896	129704	140513
	c_i	Adult Spawning Grounds Capacity	28387	19871	22710	25548	28387	31226	34064	36903

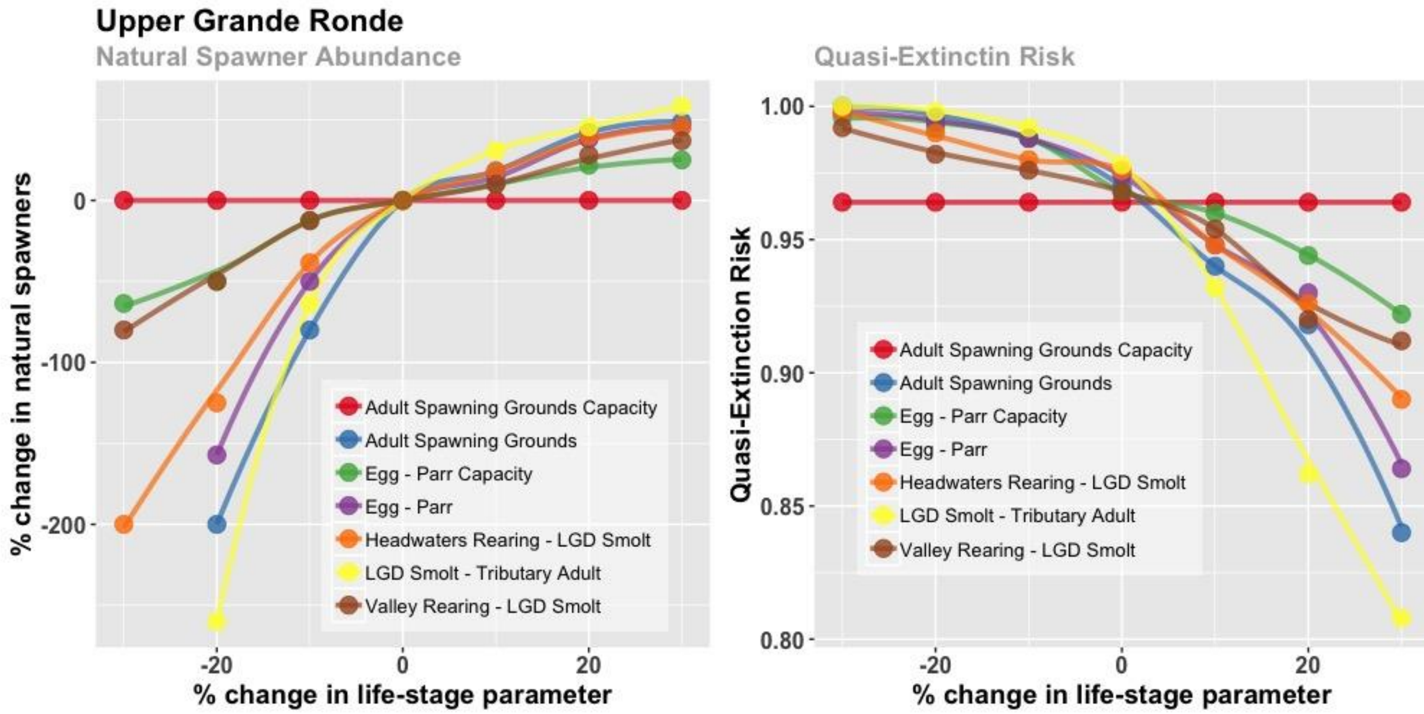

FIGURE 16. RESULTS OF THE SENSITIVITY ANALYSIS FOR THE UPPER GRANDE RONDE. LEFT PANEL SHOWS THE PERCENT CHANGE IN NATURAL SPAWNERS FROM THE BASE MODEL FOR SIMULATIONS THAT MANIPULATED LIFE-STAGE SURVIVAL AND CAPACITY FROM -30% TO +30%. RIGHT PANEL SHOWS HOW CHANGES TO SURVIVAL AND CAPACITY RESULT IN PROPORTIONAL CHANGES IN PQER. NOTE, THAT THE % CHANGE IN NATURAL ORIGIN SPAWNERS AT %-30 WAS REMOVED FOR SOME LIFE-STAGES AS THEY GREATLY INFLUENCED PRESENTATION OF THE FIGURE. LINES REPRESENTING CAPACITY ARE LABELLED AS SUCH WITHIN THE LEGEND WITH OTHER LINES REPRESENTING PRODUCTIVITY PARAMETERS.

Although our sensitivity analysis was based on proportional shifts among parameters, accurate interpretation of sensitivity results should be interpreted relative to the absolute parameter values used in this analysis. However, we do believe that the sensitivity exercise presented here demonstrates important model dynamics and may also have relevance to optimization of future management and restoration of the UGR and CC Chinook populations and habitat.

Based on this analysis, our LCM framework appears more sensitivity to changes in survival parameters rather than capacity. Both populations appeared largely insensitive to changes in spawner capacity (availability of temperature-suitable habitat for adults during summer). This result may be an artifact of spawner capacity estimates used within the base model that are orders of magnitude above those on record for these populations. Manipulation of the survival parameter for adults on the spawning grounds had large impacts to the viability of each population, especially within the UGR model where current survival rates for spawners in the system are lower than that of CC. Sensitivity of the model populations of egg-to-parr survival and capacity followed a similar pattern, with proportional changes to survival rather than capacity having a larger effect on spawner returns and pQER.

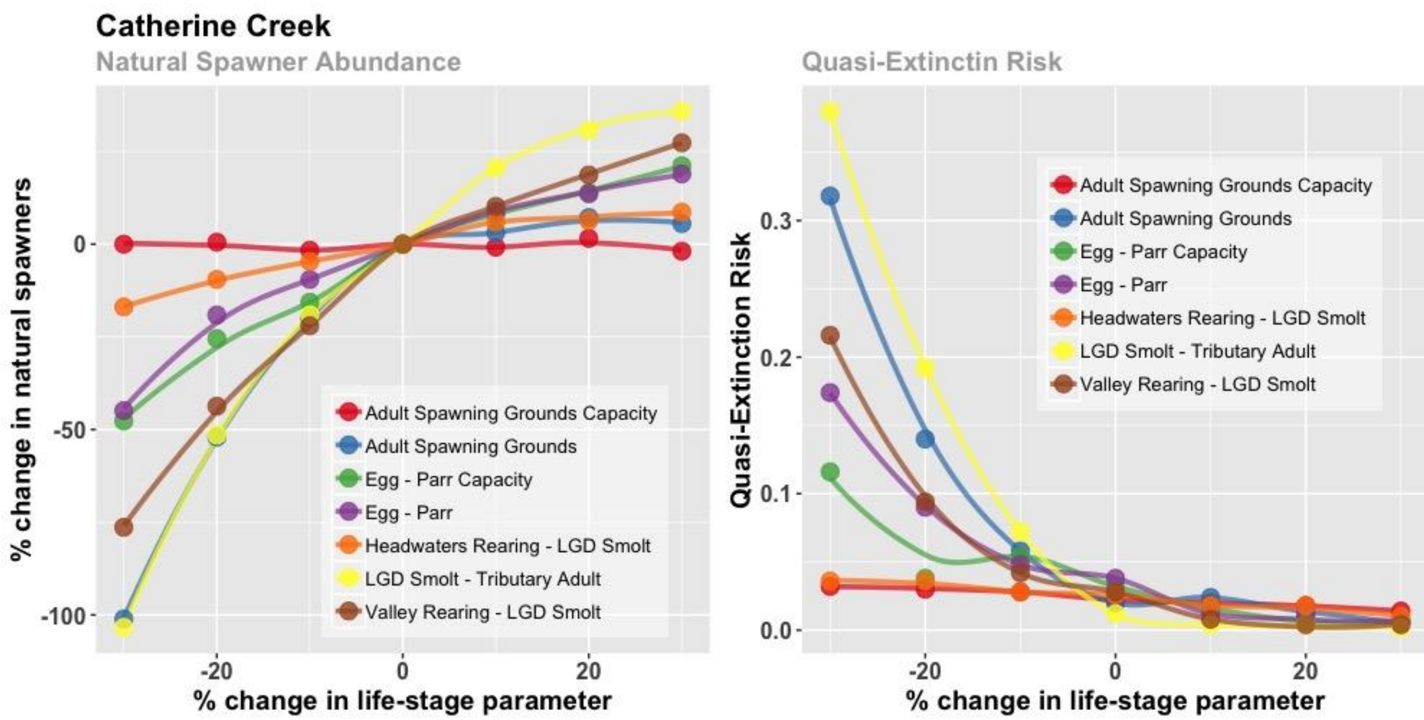

FIGURE 17. RESULTS OF THE SENSITIVITY ANALYSIS FOR CATHERINE CREEK. LEFT PANEL SHOWS THE PERCENT CHANGE IN NATURAL SPAWNERS FROM THE BASE MODEL FOR SIMULATIONS THAT MANIPULATED LIFE-STAGE SURVIVAL AND CAPACITY FROM -30% TO +30%. RIGHT PANEL SHOWS HOW CHANGES TO SURVIVAL AND CAPACITY RESULT IN PROPORTIONAL CHANGES IN PQER. LINES SHOWING CAPACITY ARE LABELLED AS SUCH WITHIN THE LEGEND WITH OTHER LINES REPRESENTING PRODUCTIVITY PARAMETERS.

Our sensitivity analysis also showed that both populations were most sensitive to increases and decreases in survival as smolt from LGD until their return as adults to the spawning grounds (i.e. the SAR). Sensitivity of our populations at this life stage is not surprising as the first - year survival input within our LCM framework (S1) are the lowest for any stage transition (0.04 and 0.07 for the UGR and CC, respectively). However, this is not to say that increases or decreases to freshwater life-stages were completely drowned by the response of the populations to outmigration and ocean survival. Indeed, survival at other life-stage transitions, such as spawning grounds survival and winter survival of rearing presmolt also appear to impact the viability of each population over the range of values considered here.

Manipulation of the presmolt survival parameters for each life-history strategy provided additional insight that may inform prioritization of restoration actions within these systems. For example, the sensitivity analysis suggested that within CC, improvements in headwaters rearing presmolt survival would result in almost no gain in adult returns, while the same improvement for valley rearing presmolt could potentially increase adult returns by greater than 25%. This type of result demonstrates the utility of an LCM and how a sensitivity analysis can be used to direct investments in habitat restoration that targets a specific life-stage.

Discussion and Future Analytical Considerations

The model and analytical framework presented here provides novel insights concerning the dynamics of UGR and CC Chinook, and it is our intention that this work be used to guide future population management and prioritization of habitat restoration, as a well as providing a basis for future life cycle models for these populations. One of the major strengths of our LCM framework lies in efforts taken to model the dynamic interaction between the natural and hatchery component of each population, including the complexities and variability associated with the hatchery supplementation program. Indeed, our model validation suggests that our base model parameterization could accurately represent each of these components of the UGR and CC Chinook populations. This modelling framework allowed us to evaluate the viability of each population according to alternative futures where the hatchery supplementation program has been discontinued.

With this framework in place, we evaluated the future viability of each population according to two modelling approaches (i.e. Justice and SEM) that link future restoration and climate impacts to freshwater habitat quantity and quality. Our evaluation suggested that without aggressive riparian and channel restoration, predicted climate change impacts to stream temperature regimes will result in almost certain extinction of Chinook within the UGR if hatchery supplementation is curtailed. In contrast, our modelling suggests that even without hatchery supplementation, climate change will push CC Chinook toward a moderate extinction risk, and that restoration efforts could be invested to ensure the future long-term viability of this population.

While the LCM results and sensitivity analysis we present here stand alone as being informative to future management of these populations, we believe the real strength of this work resides in the development of a flexible modelling framework and set of base model parameters that can be applied to future management questions and future analysis of population trajectories. To this end, we offer a number of suggestions for further refinement of the LCM that might increase the effectiveness of these efforts:

Link habitat change to survival – Currently, the Justice and SEM scenarios that we evaluated rely on models describing the relationship between climate and habitat restoration impacts to capacity during freshwater life-stages. In reality, these habitat changes would also likely directly influence survival rates. Incorporating this interaction within future LCM scenario analyses may be informative to evaluate the effectiveness of alternative management decisions. This may be especially true for populations such as the UGR and CC which may be under-seeded due to poor hydrosystem and ocean survival.

Adult capacity on the spawning grounds – Within the current framework, estimated spawner capacities are obtained via a habitat suitability index (HSI) approach that relies on a standard redd size and the distribution of suitable substrate and velocity characteristics. Although these estimates (CC = 25,653, UGR = 28,397) may theoretically reflect a total spawner capacity based on available spawning habitat, they are an order of magnitude greater than the range of adults observed on the spawning grounds in either system system (see Table 6 and Table 7). This disparity may suggest that these systems are largely under-seeded and that survival on the spawning grounds is indeed density independent. Alternatively, the disparity may indicate that the HSI model does not capture habitat characteristics that would limit over-summer adult survival. Nevertheless, the model framework, which allows for manipulation of both spawner productivity (i.e., pre-spawn survival) and capacity, provides model users the flexibility to adjust these parameters according to density dependent or independent processesas new estimates become available.

Parameter resolution within the SAR – Our current base model implements survival through the hydrosystem and ocean at a course resolution spanning from the passage of smolt at LGD until their return as adults to the spawning grounds in

each tributary (i.e., CC and UGR). Although we do use age specific survival and maturation probabilities within our model, adding additional stage transitions at key points within the outmigration and return as adults would allow the model to account for future changes to passage management and/or potential scenarios based on ocean survival.

Presmolt survival to LGD – Currently, recapture information following the parr life-stage occurs at time intervals that do not allow direct estimation of overwinter survival of presmolt rearing in headwater or valley reaches. Because of this, our LCM models presmolt survival from Summer parr to smolts at LGD adjusted for each life-history using a correction factor (see Parr to Smolt at Lower Granite Dam). Future LCM effort could emphasize the development of a more direct estimation approach, or acquisition of data that would allow a direct estimate of overwinter survival for parr exhibiting each rearing life-history strategy (i.e. headwaters or valley rearing) exclusive of survival during outmigration to LGD. This would allow the modelling framework to more directly assess the impacts that management and restoration of freshwater rearing habitat may have on the viability the UGR and CC chinook populations.

APPENDIX 1: BROODSTOCK RETENTION APPROACH

The supplementation program currently operated as part of Chinook management on the UGR and CC strongly influences the dynamics of these populations. We took the following measures in order to best represent this management strategy within the LCM framework. In order to implement the supplementation scheme, we made several simplifying assumptions that allowed us to model a mixed hatchery-natural broodstock population similar to the programs currently implemented within the UGR and CC:

1. All hatchery-reared fish are produced from supplementation fish captured in the wild and reared according to conventional hatchery practices; thus, no captive broodstock component was modelled due to its largely discontinued status and potential life history differences.
2. To model a feedback between total adult returns and adults eligible for retention as broodstock we assumed a target brood retention for each system of 170 and 103 adults for the UGR and CC respectively based on an adult-to-smolt equivalence (assuming a 50:50 sex ratio) of 1,470 smolts per adult (M. McLean, CTUIR, pers. comm.).

CATHERINE CREEK

In CC, the adult trapping operations span the entire run and management of hatchery and natural fish on the spawning grounds and as broodstock follows a 'sliding scale' framework (Carmichael et al. 2011). Under this framework target levels for the proportion of natural and hatchery origin spawners, and the proportion of natural origin broodstock vary across three levels of run size (Table 19).

TABLE 19. SLIDING SCALE FRAMEWORK USED IN MANAGEMENT OF THE INTEGRATED HATCHERY PROGRAM FOR CATHERINE CREEK SUPPLEMENTATION (ADAPTED FROM CARMICHAEL ET AL. 2011).

Total run size (H & N)	Max. % natural retained as broodstock	% hatchery above weir	Min. % natural origin broodstock
< 250	40%	-	-
251 - 500	20%	< 70%	> 20%
> 500	< 20%	< 50%	> 30%

While this rule set is straightforward, there are cases for which it is impossible to meet all constraints simultaneously, which made implementing it within the LCM code somewhat complicated. Consider a case in which returns fall between 250 and 500 but are almost exclusively of hatchery origin. In this case, it's quite likely that egg take needs will not be met if weir management strictly follows the sliding scale natural origin broodstock constraints; nor is it clear what passage goals (to spawning grounds) should be in cases for which returns exceed the upper abundance threshold but are composed predominantly of hatchery origin returns. Thus, we chose to implement a simplified interpretation of the CC sliding scale in which the ruleset specifying the proportion of natural origin spawners will always be met (if possible given the run size), and the remaining target for broodstock retention will be made up of hatchery origin adults. Under our interpretation, no attempt was made to constrain the modeled supplementation program based on the stated hatchery constraints set for the composition of the run above the weir as doing so introduced additional coding complications (i.e., due to exceptions and circular dependencies), and was virtually impossible to meet under the current modelled population demographics.

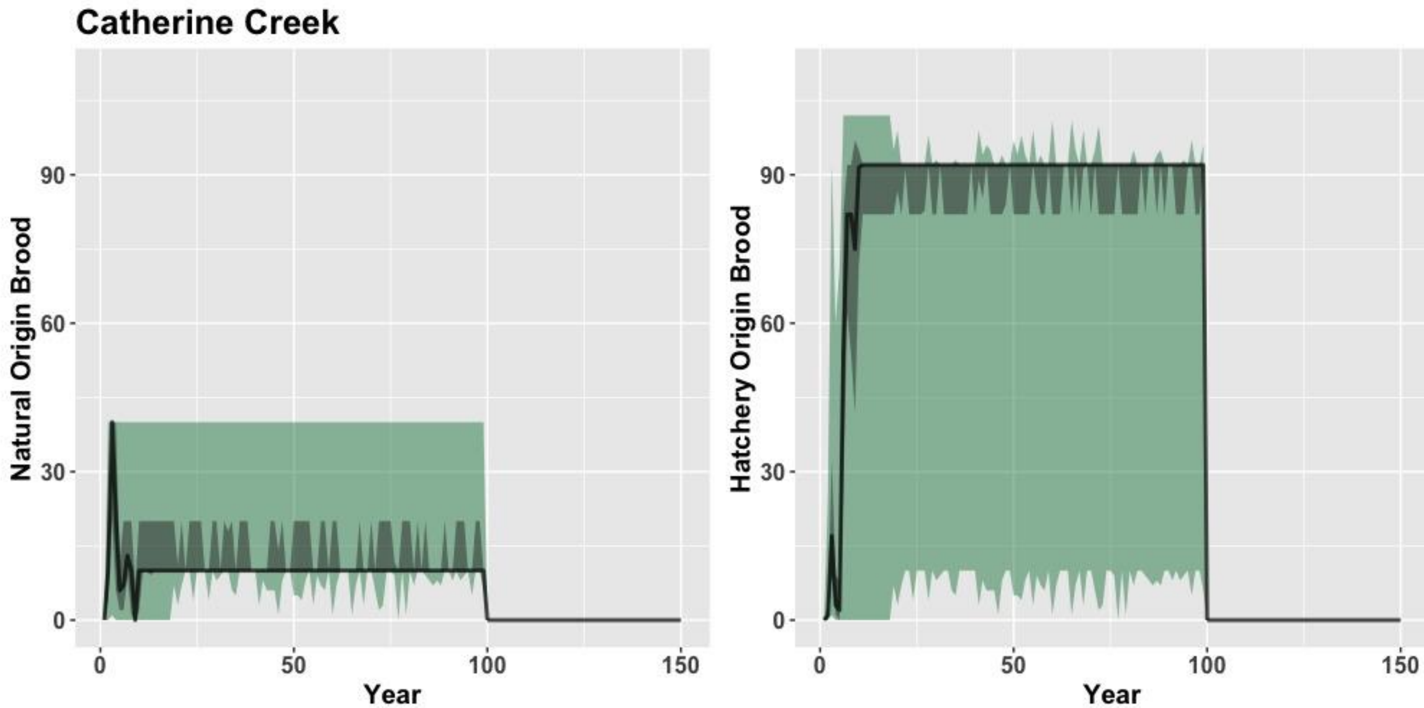

FIGURE 18. BROODSTOCK RETENTION FOR CATHERINE CREEK SUPPLEMENTATION MANAGEMENT DISCONTINUED IN YEAR 100. BLACK LINE SHOWS MEDIAN, GRAY SHADED REGION SHOWS 25TH AND 75TH PERCENTILES, AND GREEN SHADED REGION SHOWS MAXIMUM AND MINIMUM NUMBER OF NATURAL (LEFT) AND HATCHERY (RIGHT) ORIGIN ADULT CHINOOK RETAINED FOR BROODSTOCK.

UPPER GRANDE RONDE RIVER

In the Upper Grande Ronde (rule type = 5 in input files), the management of HOS/NOS on the spawning grounds and HOB/NOB at the hatchery is less formalized than in Catherine Creek, due to the fact that the weir is typically pulled before the majority of the run makes its way through to the spawning grounds and because its supplementation program is generally less restrictive. The main constraint imposed on weir/program management is that no more than 50% of the natural run can be retained for hatchery broodstock.

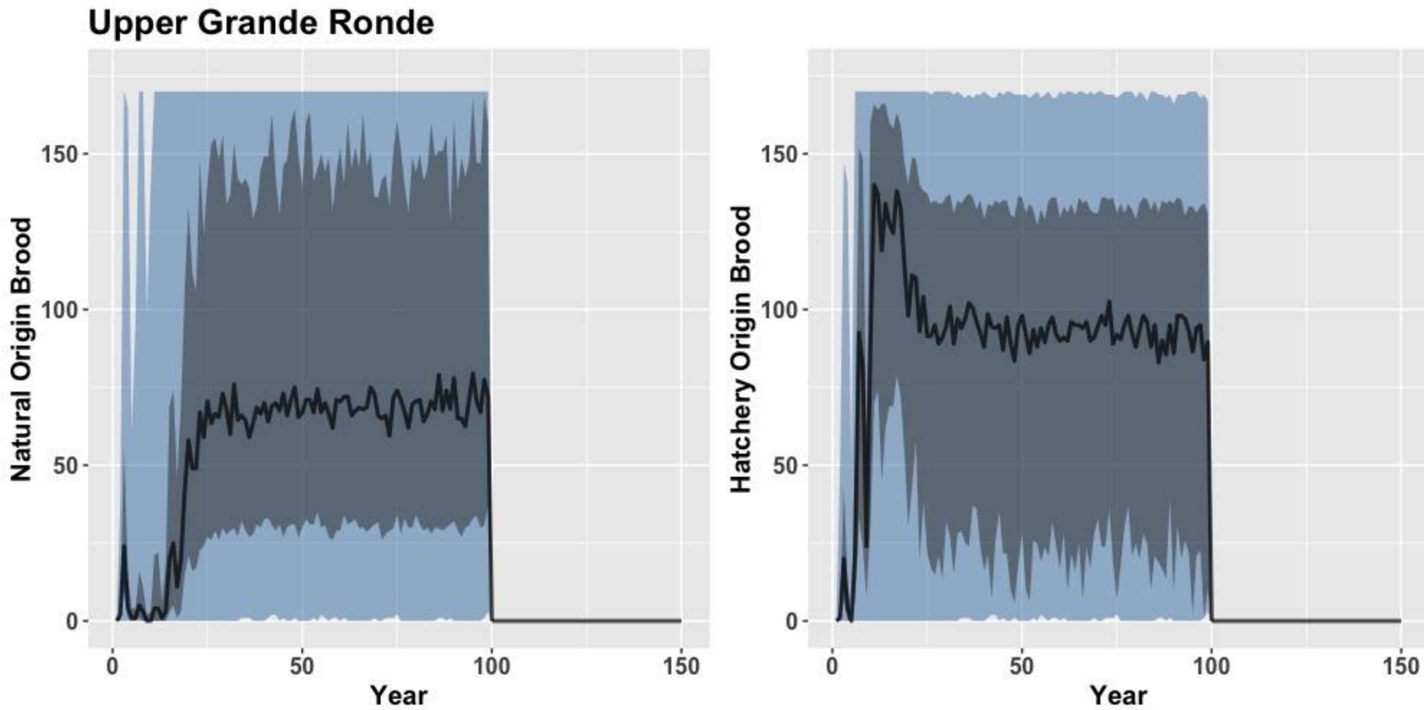

FIGURE 19. BROODSTOCK RETENTION FOR THE UPPER GRANDE RONDE SUPPLEMENTATION MANAGEMENT DISCONTINUED IN YEAR 100. BLACK LINE SHOWS MEDIAN, GRAY SHADED REGION SHOWS 25TH AND 75TH PERCENTILES, AND BLUE SHADED REGION SHOWS MAXIMUM AND MINIMUM NUMBER OF NATURAL (LEFT) AND HATCHERY (RIGHT) ORIGIN ADULT CHINOOK RETAINED FOR BROODSTOCK.

Appendix 2: Base Model Parameters

Table 20. Survival, fecundity, life-history, and stochastic parameters used in the base LCM for the UGR and CC populations. Stochastic parameters are expressed as a standard deviations and also list the distribution used by the model to generate prediction or parameter uncertainty.

Life-stage(s)	Parameters	Value(s)	Stochasticity	Comments
Egg to parr	Density dependent survival from egg-to-parr	UGR = 0.32 CC = 0.32	Log-normal UGR = 0.54 CC = 0.41	Survival and capacity derived from Beaverton-Holt fit between annual estimate of eggs (converted from redds) and late summer parr. Stochastic component is a standard deviation calculated on the model fit (sse) to the log-transformed data.
	Parr capacity	UGR = 108,087 CC = 111,897		
Parr to smolt at LGD	Headwaters rearing presmolt	UGR = 0.72 CC =0.23	Beta UGR = 0.17 CC = 0.11	Probability of late summer parr life-history as fall migrant and valley rearing vs. spring migrant and headwater rearing based on ratio of population estimate. Stochasticity is modelled as beta distribution and is shared between each life-history.
	Valley rearing presmolt	UGR = 0.28 CC =0.77		
	Smolt survival to LGD headwaters rearing	UGR = 0.11 CC = 0.10	Beta UGR = 0.7 CC = 0.6	Density independent survival for parr to smolt at LGD specific to each life-history. Stochasticity modelled as beta distribution on survival.
	Valley rearing	UGR = 0.18 CC = 0.12		
Hatchery smolt release to smolt at LGD	Survival from release as smolt to smolt at LGD	UGR = 0.45 CC = 0.58	Beta UGR = 0.12 CC = 0.14	Density independent survival from release of hatchery smolts within each tributary to smolt at LGD.
LGD Smolt to adult at tributary weir (spawning grounds)	Ocean age maturation probability	Age 1, 2, 3 UGR = 0.03, 0.64, 1 CC = 0.05, 0.68, 1	Beta Age 1, 2, 3 UGR = 0.03, 0.31, 0 CC = 0.03, 0.28, 0	Probability of maturation at ocean age. Maturation schedule is shared among natural and hatchery origin Chinook.
	Annual survival rate by ocean age	Age 1, 2, 3 *Natural origin* UGR = 0.04, 0.63, 0.52 CC = 0.07, 0.66, 0.61 *Hatchery origin*	Beta Age 1, 2, 3 UGR = 0.03, 0.21, 0.27 CC = 0.04, 0.17, 0.16	Survival by ocean age. Note, decreased survival for hatchery origin fish is only applied in the year returning to spawn to account for a proportional difference in natural vs. hatchery SAR. Overall SAR for populations: UGR = 0.024, CC = 0.047.

		UGR = 0.02, 0.24, 0.20 CC = 0.01, 0.11, 0.10		
Adult survival on spawning grounds (passage at weir to spawner)	Summer survival on the spawning grounds	UGR = 0.73 CC = 0.96	Log-normal UGR = 0.39 CC = 0.05	Density dependent survival of adults on the spawning grounds after being passed at the tributary weir and derived based on Beaverton-Holt model fit to ODFW estimates of abundance. Capacity is estimate from habitat data expanded to the population using habitat suitability index (HSI) modelling approach.
	Spawner capacity	UGR = 28397 CC = 25653		
Spawner to egg	Female spawner to egg fecundity	3831	Normal 102	Female spawner to egg fecundity assuming a 50:50 sex ratio for adult spawning Chinook. Estimate comes from CC data and is used for both populations.
Brood to hatchery smolt	Conversion of brood to smolt at release	UGR = 1226 CC = 1339	Normal UGR = 398 CC = 366	Based on ODFW smolt supplementation records and is composite of integrated and captive brood.

REFERENCES

Carmichael and coauthors. 2011. Catherine Creek spring Chinook salmon hatchery progam review. Oregon Department of Fish and Wildlife report to Lower Snake Comp. Program. https://www.fws.gov/lsnakecomplan/Reports/ODFW/Eval/CatherineCreekSpringChinookSalmonHatcheryReviewFINAL.pdf

CHaMP (Columbia Habitat Monitoring Program). 2015, May 15. Scientific Protocol for Salmonid Habitat Surveys within the Columbia Habitat Monitoring Program. Prepared by the Columbia Habitat Monitoring Program. https://www.champmonitoring.org.

Feldhaus, J. W., T. L. Hoffnagele, D. L. Eddy, and K. N. Ressel. 2017. Lower Snake River compensation plan: Oregon spring Chinook Salmon evaluation studies 2014 annual progress report. Page 68. Oregon Department of Fish and Wildlife, Salem, OR.

Hadden, M. 2011. Modelling and Quantitative Methods in Fisheries. Second Edition. CRC Press. Boca Raton, FL.

Independent Scientific Advisory Board. 2017. Review of NOAA Fisheries' Interior Columbia Basin Life-Cycle Modeling. ISAB 2017-1. https://www.nwcouncil.org/media/7491311/isab-2017-1-noaalifecyclemodelreview22sep.pdf

Justice, C., White, S.M., McCullough, D.A., Graves, D.S., Blanchard, M.R., 2017. Can stream and riparian restoration offset climate change impacts to salmon populations? Journal of Environmental Management 188, 212-227.

Justice, C. 2013. Factors influencing body size and survival of juvenile Chinook salmon migrants in the Upper Grande Ronde River basin. Technical Report. Columbia River Inter-Tribal Fish Commission

McHugh, P., and coauthors. 2017. Linking models across scales to assess the viability and restoration potential of a threatened population of steelhead (Oncorhynchus mykiss) in the Middle Fork John Day River, Oregon, USA. Ecological Modelling 355.

Moussalli, E., and R. Hilborn. 1986. Optimal Stock Size and Harvest Rate in Multistage Life-History Models. Canadian Journal of Fisheries and Aquatic Sciences 43(1):135-141.

Nahorniak, M., and M. Armour. 2017. ISEMP Watershed Model. https://github.com/SouthForkResearch/CHaMP-ISEMP-Life-Cycle-Model/wiki

R Core Team, 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Sharma, R., A. B. Cooper, and R. Hilborn. 2005. A quantitative framework for the analysis of habitat and hatchery practices on Pacific salmon. Ecological Modelling 183(2-3):231-250.

Wheaton, J. M., N. Bouwes, P. McHugh, C. Saunders, S. Bangen, P. Bailey, M. Nahorniak, E. Wall, and C. E. Jordan. 2017. Upscaling site-scale ecohydraulic models to inform salmonid population-level life cycle modeling and restoration actions - Lessons from the Columbia River Basin. Earth Surface Processes and Landforms 12(5):1510–25.