



APPENDIX A: Population Viability Assessments TECHNICAL STUDY #2 (2023)

Phase 2. Pilot Plan for Experimental Reintroduction of Anadromous Salmon into Upper Columbia River: Proposed Implementation, Monitoring, and Evaluation



The Columbia River Salmon Reintroduction Initiative

BRINGING *the* **SALMON** HOME
kʷ cʷəlkʷ stím iʔ ntytyix
ʔatʔ suʔkiniʔ swaʔmu
Tspelqʷentém re **Sq̓lélten**

Technical Study #2 (2023)

Phase 2. Pilot Plan for Experimental Reintroduction of Anadromous Salmon into Upper Columbia River: Proposed Implementation, Monitoring, and Evaluation

APPENDIX A: POPULATION VIABILITY ASSESSMENTS

The Population Viability Assessment (PVA) models that we used were similar to those used by conservation biologists to evaluate extinction risk (e.g., Emlen 1995, Fieberg and Ellner 2000, Ellner and Fieberg 2003) and in the upper Columbia River (UCUT 2019). The main goal of our PVAs was to determine the level of hatchery effort that would be required to meet a target of 10,000 adults returning to a Salmon Planning Unit (SPU). Two PVAs were used, one each for Chinook and Sockeye salmon, both with parameterization based on life-history data from Okanagan River populations (Figure A1). The Chinook Salmon PVA was based on the Okanagan Summer Chinook PVA that was developed for the Recovery Potential Assessment of Okanagan Chinook Salmon (Mahony et al. 2021). The Sockeye Salmon PVA was developed for the current study and is described below. The development of the Sockeye Salmon PVA was a joint effort between Okanagan Nation Alliance (ONA) and the Columbia River Salmon Reintroduction Initiative Technical Working Group (CRSRI TWG) Experimental Design Subgroup (EDS).

The two PVA formulations have independent parameterizations, and each was separately developed, prioritized different data sources, and featured a different set of underlying assumptions. This approach allowed for species-specific differences to be considered, and allowed the assessment of how fundamental results could vary by PVA formulation.

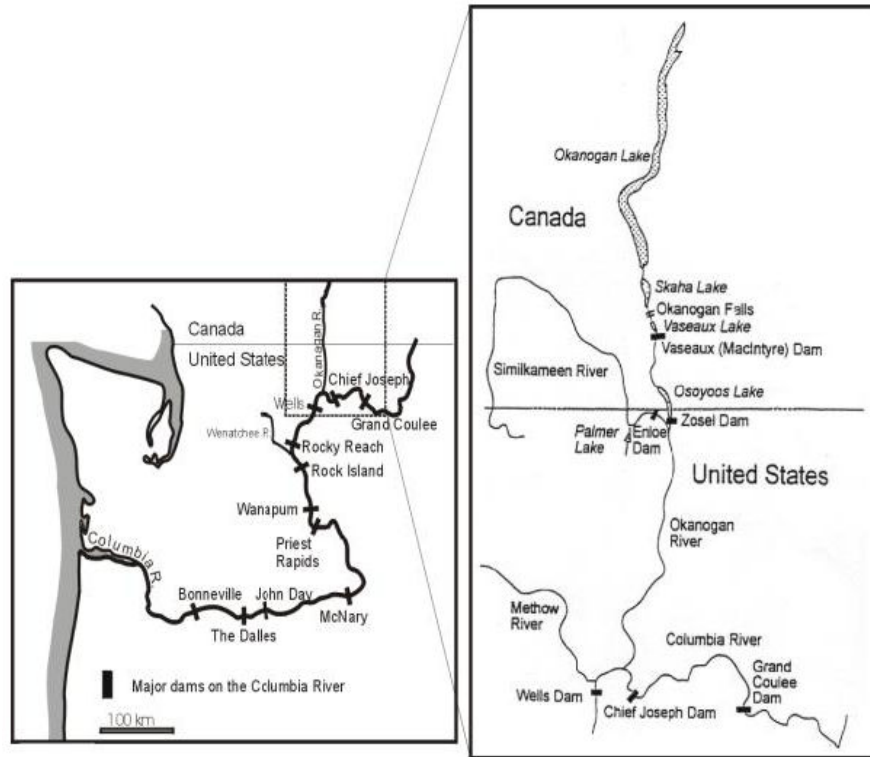


Figure A1. Overview of the location of the Okanogan Chinook and Sockeye salmon populations and related surrogate populations.

Chinook Salmon PVA Formulation

The structure and parameter values used in the Chinook Salmon PVA came primarily from PVA model used in Mahony et al. (2021), with adaptations for the current analysis. Currently, Chinook Salmon hatchery efforts are limited by the lack of a compatible broodstock source. Limitations or variation in hatchery production are not currently known. But to determine scale and variability of possible hatchery production for Chinook Salmon, we used Sockeye Salmon hatchery production scenarios (see Hatchery Scenarios). The Chinook Salmon PVA model developed by Mahony et al. (2021) used a Ricker recruitment curve which features density dependent behaviour. The density dependent function ensured that the number of juvenile recruits per spawner decreased with increasing spawner abundances, due to factors such as spawner competition or density dependent survival effects. However, the formulation developed by Mahony et al. (2021) was for Okanogan Chinook (summer run) Salmon, which is a population that features a small carrying capacity. Its maximum sustainable yield (i.e., highest abundance of juvenile recruits), which occurs at an abundance of half the carrying capacity, was at lower spawning abundances (i.e., $S_{msy} = 2,400$) than will likely be the case for reintroduced Chinook Salmon populations considered here. To understand the impact of this assumption on our PVA, we ran analyses using a series of relaxed carrying capacity assumptions (see Results).

Sockeye Salmon PVA Formulation

The Sockeye Salmon PVA model was developed for this analysis with guidance and input from the CRSRI TWG EDS. The PVA was developed based on literature values published for Okanagan Sockeye Salmon, as well as values provided by expert opinions within the CRSRI TWG EDS. The PVA includes key stochastic elements that represent variation in underlying processes (e.g., survival) as well as uncertainty in estimated quantities (Figure A2).

The PVA breaks down the Sockeye Salmon life history into key steps, including juvenile production (both natural and hatchery outplants), freshwater development, outmigration, ocean survival and maturation, and the adult return migration (Figure A2). Hatchery production considered key limiting steps such as variation in female fecundity and egg-to-fry survival rates within the hatchery complex. Natural reproduction also used a granular stepwise approach with key steps in the natural production of juveniles, including female fecundity and natural egg-to-fry survival rates, as well as overwintering survival rates. Currently, the analysis does not consider the effect of density dependence on natural reproduction of Sockeye Salmon, due to knowledge limitations. That said, these effects, including sensitivity of final results to density dependence assumptions, were investigated within the Chinook Salmon PVA. Juvenile outmigration survival rates were based on yearly in-river survival rates for the Osoyoos stock of Okanagan Sockeye Salmon, with allowances added for the additional mortality expected from SPU transit. Ocean survival processes were selected so that pre-smolt-to-adult survival rates and age-at-return proportions generated by the PVA matched best the available empirical estimates for these quantities and should therefore represent a realistic behaviour for ocean survival and maturation. Finally, return migration and freshwater harvest rates were based on best estimates from harvest and dam counts. Due to the strength of the direct empirical relationship between observed return and harvest size, we used it to predict freshwater harvest within the PVA.

We outline in Table A1 the parameter values used in the Sockeye Salmon PVA, with further details provided in subsequent sections, including analyses used to derive individual parameter values.

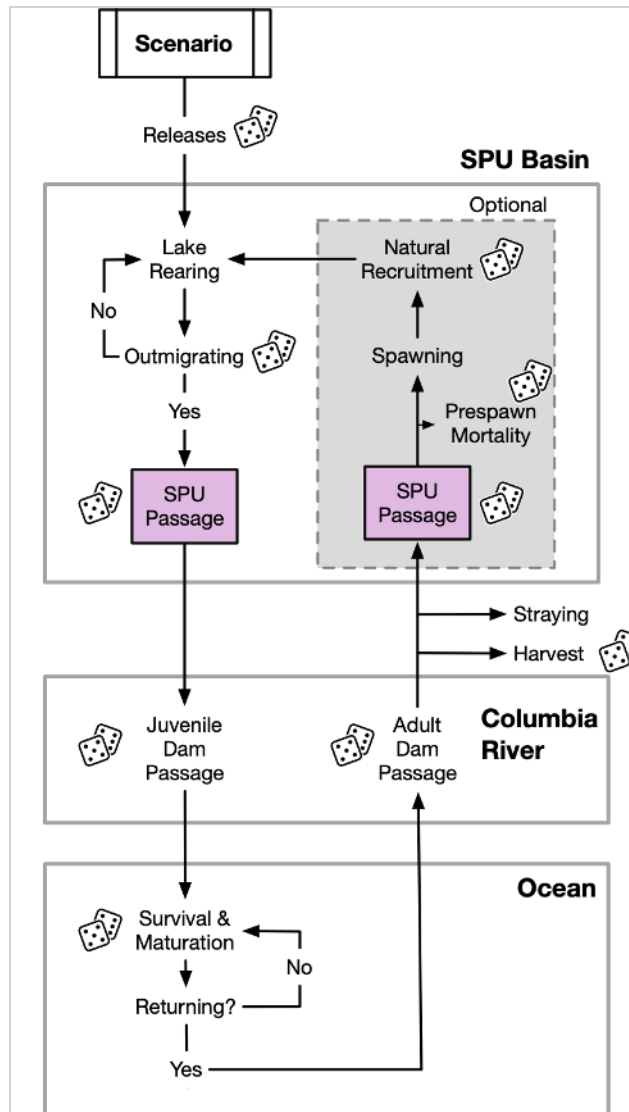


Figure A2. Schematic diagram indicating major lifecycle components and decisions under consideration in the Sockeye Salmon PVA. Dice indicate components that included one or more stochastic elements.

Table A1. Parameters used in the Sockeye Salmon PVA.

Component	Parameter Name	Symbol	Type	Value	Notes
Natural Reproduction	Spawner Sex Ratio	$\pi_{i,y}^N$	Stochastic	0.48 (CV 15%)	Proportion of spawners that are female (Howard Stiff, DFO, pers. comm.)
	Spawner Fecundity	$F_{i,y}^N$	Stochastic	2510 (CV 17.3%)	Number of eggs per female spawner (Howard Stiff, DFO, pers. comm.)
	Egg survival	$\phi_{i,y}^{N,1}$	Stochastic	0.036 (CV 48%)	Egg to fry survival rate (Howard Stiff, DFO, pers. comm.)
Hatchery Reproduction	Broodstock	$B_{i,y}$	Stochastic	Variable	Broodstock numbers correspond to hatchery scenarios (see Table A6)
	Sex ratio	$\pi_{i,y}^H$	Stochastic	0.45 (CV 21.1%)	Sex ratio of hatchery broodstock (Ryan Benson, ONA, pers. comm.)
	Fecundity	$F_{i,y}^H$	Stochastic	2063 (CV 8.7%)	Number of eggs per female retrieved from hatchery broodstock (Ryan Benson, ONA, pers. comm.)
	Egg-to-Fry Survival	$\phi_{i,y}^{H,egg}$	Stochastic	0.85 (CV 11.1%)	Egg to fry survival rates for hatchery outplants (Ryan Benson, ONA, pers. comm.)
	Fry-to-yearling Survival	$\phi_{i,y}^{H,1}$	Stochastic	0.183 (CV 40.3%)	Fry to yearling survival rates for hatchery outplants (Ryan Benson, ONA, pers. comm.)
Lake Rearing	Lake Rearing Probability	p_{rear}^a	Deterministic	$\begin{cases} 1 & a = 0 \\ 0.02 & a = 1 \\ 0 & a = 2 \end{cases}$	Probability of lake rearing by fry age. All newly hatched fry reared one year, while only 2% of yearlings were assumed to rear an additional year. All age 2 fry were assumed to migrate.
	Overwinter Survival	$\phi_{i,y}^W$	Stochastic	0.90 (CV 5%)	Probability of surviving over winter in the lake (UCUT 2019).

Component	Parameter Name	Symbol	Type	Value	Notes
Juvenile Migration	Within-basin Survival	$\phi_{i,y}^{\text{basin}}$	Stochastic	0.54 (CV 25%)	Set to be the same survival through the Columbia River system.
	Columbia River Survival	$\phi_{i,y}^{\text{juv,river}}$	Stochastic	0.54 (CV 25%)	See Murauskas et al. (2021)
Ocean Survival and Migration	Early Ocean Survival	ϕ^{EO}	Deterministic	0.2465	Derived, see Table A5
	Yearly Ocean Survival	ϕ^{ocean}	Deterministic	0.85	Derived, see Table A5
	Return Probability	δ^a	Deterministic	$\begin{cases} 0 & a = 2 \\ 0.073 & a = 3 \\ 0.885 & a = 4 \\ 1 & a = 5 \end{cases}$	Probability of returning at age a , see Table A5
	Marine Harvest	M^{ocean}	Deterministic	0.005	Marine harvest currently assumed to be less than 0.5% (Richard Bussanich, ONA, pers. comm.)
Adult Upstream Migration	Freshwater (FW) Harvest Intercept	β_0	Regression	-4.966 (CV 11.2%)	Linear regression intercept estimate (see Figure A5)
	FW Harvest Slope	β_1	Regression	1.191 (CV 4.2%)	Linear regression slope estimate (see Figure A5)
	FW Harvest Residual Error	σ_H	Regression	0.397	Linear regression residual error estimate
	FW Survival	$\phi_{i,y}^{\text{adult}}$		0.890 (CV 9.5%)	Adult freshwater survival during upstream migration, see Figure A6. See also Murauskas et al. (2021)

Juvenile Production

Recruitment of new juveniles into an SPU came from two sources, hatchery releases and, optionally, natural reproduction depending on the simulation scenario being considered (Figure A2).

Natural Origin Juveniles

Natural Reproduction within an SPU was based on reproductive rates estimated within Okanagan Sockeye Salmon stock. First, the total number of spawners ($S_{i,y}^{\text{total}}$) was determined across all returning age classes (i.e., ages $a = 3$ to 5) for each simulation iteration (i) and year (y), for both natural ($E_{i,y}^{N,a}$) and hatchery ($E_{i,y}^{H,a}$) origin escapement (see Table A1 for parameter values):

$$S_{i,y}^{\text{total}} = \left(\sum_{a=3}^5 E_{i,y}^{N,a} + E_{i,y}^{H,a} \right), \quad \text{Equation 1}$$

where age class referred to the post-hatch age.

Once hatchery origin fish returned as adults to reproduce, they were considered to be of natural origin in terms of life history parameterization. The total number of eggs produced was based on the proportion of hatchery broodstock that were female ($\pi_{i,y}^H$) and the fecundity of the hatchery broodstock ($F_{i,y}^H$),

$$e_{i,y}^N = S_{i,y}^{\text{total}} \cdot \pi_{i,y}^H \cdot F_{i,y}^H \quad \text{Equation 2}$$

where $\pi_{i,y}^H \sim N(\mu_{\pi}^H, \sigma_{\pi}^H)$ and $F_{i,y}^H \sim N(\mu_F^H, \sigma_F^H)$ were stochastic elements that varied for each simulation iteration (i) and year (y).

Survival rates from egg to age 0 fry were not available, so survival rates from egg to age 1 were used to estimate age 1 fry, then age 0 fry were back-calculated based on the overwinter survival rate and the probability of rearing. First, the total number of age 1 fry was determined from the number of eggs as

$$f_{i,y+2}^{N,1*} = e_{i,y}^N \cdot \phi_{i,y}^{N,1} \quad \text{Equation 3}$$

where the survival rate $\phi_{i,y}^{N,1} \sim N(\mu_e, \sigma_e)$ was a stochastic component (see Table A1 for parameter values). Then, the number of age 0 fry was back-calculated as

$$f_{i,y+1}^{N,0} = \frac{f_{i,y+2}^{N,1*}}{p_{\text{rear}}^0 \cdot \bar{\phi}_{i,y}^W} \quad \text{Equation 4}$$

where p_{rear}^0 was the probability of rearing at age 0 (i.e., unity, see Table A1) and $\bar{\phi}_{i,y}^W$ was the average overwinter survival rate. The number of age 1 fry, $f_{i,y+2}^{N,1*}$, was not directly retained, but was derived at a later step in the simulator (see Overwintering and Outmigration).

Hatchery Origin Juveniles (i.e., Outplants)

Number of hatchery smolts were determined for each simulation based on capacities and variation that can occur within ONA's hatchery facilities, estimates of survival rates of fry outplants, and the natural migration rates of age-1 smolts. The simulation starts by predicting the number of adults available for broodstock based on the level of hatchery production considered in a scenario.

The number of hatchery-produced age-1 outplanted smolts migrating in year y of iteration i ($S_{i,y}^{H,1}$) was modeled as a function of the number of outplanted age-0 fry ($f_{i,y}^{H,0}$) surviving to the migration period and choosing to migrate. For year (y) in simulation iteration i , the PVA first predicts the number of eggs $e_{i,y}$ harvested for broodstock based on the number of adults collected ($B_{i,y}$), the average proportion of females in natural returns (π_f), and the average adult female fecundity (F) measured as eggs per individual:

$$e_{i,y}^H = B_{i,y} \cdot \pi_{i,y}^H \cdot F_{i,y}^H. \quad \text{Equation 5}$$

where $\pi_{i,y}^H \sim N(\mu_\pi^H, \sigma_\pi^H)$ and $F_{i,y}^H \sim N(\mu_F^H, \sigma_F^H)$ were stochastic components, and where the resulting number of fry outplants ($f_{i,y}^{H,0}$) was computed as

$$f_{i,y}^{H,0} = e_{i,y} \cdot \phi_{i,y}^{H,\text{egg}} \quad \text{Equation 6}$$

with $\phi_{i,y}^{H,\text{egg}} \sim N(\mu_e, \sigma_e)$ being another stochastic component representing egg-to-fry survival rates (see Table A1 for parameter values for all stochastic components). The number of fry that survived the first-year post-release was determined as

$$f_{i,y}^{H,1} = f_{i,y}^{H,0} \cdot \phi_{i,y}^{H,0} \quad \text{Equation 7}$$

where survival rate $\phi_{i,y}^{H,1} \sim N(\mu_\phi^{H,1}, \sigma_\phi^{H,1})$ was stochastic and differed from the corresponding survival rates for natural origin smolts (see Table A1). After surviving their first year post-release, hatchery-released fry share all subsequent life history parameters with their natural-origin counterparts.

Overwintering and Outmigration

Rearing and overwintering survival

On each yearly time step, natural-origin and hatchery-origin fry shared the same common life history parameters, but they were tracked separately within the simulator. For each available fry age class (i.e., ages 0-2) and origin type (i.e., N = Natural, H = Hatchery) the number of fry remaining in the lake to rear for an additional year was determined as

$$f_{i,y+1}^{T,a+1} = f_{i,y}^{T,a} \cdot p_{\text{rear}}^a \cdot \phi_{i,y}^W \quad \text{for } \begin{cases} a \in \{1,2\} & T = H \\ a \in \{0,1,2\} & T = N \end{cases} \quad \text{Equation 8}$$

where p_{rear}^a represented the age class specific probability of rearing (see Table A1) and $\phi_{i,y}^W \sim N(\mu_w, \sigma_w)$ was a stochastic component representing overwinter survival to the next age class (see Table A1 for parameter values). The calculation was done for a different number of age classes depending on whether hatchery- or natural-origin fish were considered, as the first-year survival rates were determined separately for hatchery-origin fish.

The number of fry outmigrating as smolts occurring in the next time step was therefore determined as

$$s_{i,y+1}^{T,a+1} = f_{i,y}^{T,a} \cdot (1 - p_{\text{rear}}^a) \cdot \phi_{i,y}^W \text{ for } \begin{cases} a \in \{1,2\} & T = H \\ a \in \{0,1,2\} & T = N \end{cases} \quad \text{Equation 9}$$

where $\phi_{i,y}^W$ was the same stochastic component used in Equation 8, representing overwinter survival to the next age class. Note that no age-2 juveniles were expected to rear for another year in a lake (see Table A1), so all individuals were forced to outmigrate by this age class (i.e., no age-3 freshwater fish were permitted).

Juvenile Outmigration

Survival rate of outmigrating smolts through the hydrosystem was determined in two steps: 1) survival through the SPU basin downstream through Chief Joseph Dam and into Wells Pool; then 2) downstream survival through the middle and lower Columbia River. Survival through the SPU basin to Wells Pool was determined as

$$s_{i,y}^{T,a,\text{basin}} = s_{i,y}^{T,a} \cdot \phi_{i,y}^{\text{basin}} \text{ for } T \in \{N, H\}, a \in \{0,1,2\} \quad \text{Equation 10}$$

where $\phi_{i,y}^{\text{basin}} \sim N(\mu_{\text{basin}}, \sigma_{\text{basin}})$ was a stochastic component representing survival and was shared across age classes. Downstream survival through the Columbia River was then represented as

$$s_{i,y}^{T,a,\text{ocean}} = s_{i,y}^{T,a,\text{basin}} \cdot \phi_{i,y}^{\text{juv,river}} \text{ for } T \in \{N, H\}, a \in \{0,1,2\} \quad \text{Equation 11}$$

where $\phi_{i,y}^{\text{juv,river}} \sim N(\mu_{\text{river}}^{\text{juv}}, \sigma_{\text{river}}^{\text{juv}})$ was a stochastic component representing survival and $s_{i,y+1}^{T,a,\text{ocean}}$ represented the number of smolts entering the ocean for a given origin type and age class.

The juvenile in-river survival through the Columbia River ($\phi_{i,y}^{\text{juv,river}}$) was based on the Osoyoos stock estimates from Murauskas et al. (2021), which resulted in an average survival of about 54% with a CV of 24% (see Table A3). The Osoyoos stock represented a reasonable approximation due to its relative proximity to the Columbia River.

Within-basin survival ($\phi_{i,y}^{\text{basin}}$) was expected to vary by SPU, yet SPU-specific values are currently unknown. Mortality associated with reservoir transit and dam passage through an SPU can be ballparked based on estimated rates of dam passage survival and estimates of percent loss per kilometre for reservoir transit. Potential within-basin survival for SPU 5 (Arrow Lakes Reservoir – Revelstoke Reach) was estimated under five different juvenile survival scenarios (Table A3). Juveniles migrating from SPU 5

Table A2. Release group survival rates for Osoyoos stocks estimated by Murauskas et al. (2021). Brackets indicate standard error.

Year	Osoyoos Lake	Osoyoos Lake at Haynes Point Campground	Osoyoos Lake Narrows Highway 3 Bridge
2013			0.50 (0.12)
2014			0.44 (0.05)
2015			0.54 (0.22)
2016	0.51 (0.09)		0.51 (0.10)
2017	0.59 (0.07)		0.97 (0.29)
2018	0.35 (0.08)	0.61 (0.09)	
2019	0.54 (0.09)		

Table A3. Range of estimated juvenile within-basin survival rates based on different assumptions.

SPU Juvenile Survival Scenario	Within-Basin Survival ($\phi_{i,y}^{\text{basin}}$)	SPU to Bonneville Survival ($\phi_{i,y}^{\text{basin}} \cdot \phi_{i,y}^{\text{juv.river}}$)
Status Quo (Worst Case) with 0.25% loss per km	4.6%	2.5%
Status Quo (Worst Case)	7.8%	4.2%
Status Quo (Best Case)	17.6%	9.5%
Improved Dam Passage	39.3%	21.2%
Improved Dam Passage w/ higher per km survival	51.0%	27.5%

would need to transit 520 km and pass three dams (i.e., Hugh Keenleyside, Grand Coulee, and Chief Joseph dams) in order to reach Wells Pool. A 0.15% loss per kilometer of reservoir travel has been used to model transit loss in salmon (e.g., UCUT 2019) suggesting that only 48.5% of outmigrating smolts will survive the 520 km distance. Dam passage survival will also be expected to be lower compared to the middle and lower Columbia River dams which feature juvenile passage facilities. Hugh Keenleyside may be expected to have juvenile dam passage survival rates ranging from 85% to 90%, as for other low head dams in the lower Columbia basin (USACE 2002, NPCC 2016, CPC 2021). Juvenile survival rates are estimated at 44% to 55% for Grand Coulee Dam, and 44% to 88% for Chief Joseph Dam (UCUT 2019). Combining the per kilometre losses with the current dam passage rates represents a ‘status quo’ scenario where no facility improvements are put in place. Using the lower and upper end of the estimated dam passage survival rates provides worst- and best-case scenarios of 7.8% and 17.6% survival respectively (Table A3). A 0.25% loss per kilometre of reservoir travel has also been suggested (UCUT 2019) and when combined with the worst-case ‘status quo’ provides a lower bound estimate of

4.6% for within-basin survival to Well Pool (Table A3). It is unlikely that large-scale salmon reintroduction programs will progress in isolation without any improvement to juvenile dam passage facilities. If the addition of juvenile passage facilities increases dam passage survival rate to 95% for each dam, then within-basin juvenile survival to Wells Pool increases to 39.3% (Table A3). Finally, the estimate of 0.15% loss per kilometer of reservoir loss may be over represent mortality in this exercise (it was based on the middle and lower Columbia River passage and includes multiple dam passages, whereas dam passage survival was already considered, separately from the per km rate, in the current exercise). Reducing the per kilometre loss rate to 0.10%, and considering 95% dam passage survival rates, further increases within-basin survival rate to 51% to Wells Pool (and to 27.5% survival rate from the SPU to Bonneville; Table A3).

The above in-river survival rates can be compared to published rates for other stocks. For example, marked Osoyoos (Okanagan) Sockeye Salmon had an average survival rate of approximately 54% over 758 km of travel to Bonneville Dam (Murauskas et al. 2021). The Skaha stock (Okanagan Sockeye Salmon) travelled distances that were about 45 km longer, and passed through one additional dam as compared to the Osoyoos stock, and the resulting migration survival rate to the ocean was approximately 41% (as compared to 54%; Murauskas et al. 2021). These rates are comparable to our 'improved dam passage' scenarios (Table A3), although they are still higher than our rates given shorter migration distances. Our 'status quo' scenarios have substantially lower survival rates which could potentially inhibit successful reintroduction efforts. For the purpose of the PVA analysis, we considered mainly the 'Improved Dam Passage w/ higher per km survival' scenario (27.5% SPU to Bonneville survival rate) as it represented the best-case scenario with facility improvements and may represent a more realistic approximation of the environment that may be available once full reintroduction efforts take place. That said, status quo scenarios represent current conditions and should be considered as part of an assessment of whether or not dam passage facilities will be required. In order to consider these options, a sensitivity analysis was conducted to determine the relative impact of juvenile survival rates on reintroduction efforts.

Ocean Survival and Maturation

There are few direct estimates of ocean survival, maturation, or return processes for Okanagan Sockeye Salmon. However, estimates of these parameters, or combinations of parameters, could be determined based on empirical observations of smolt-to-adult return ratios (SARs), known in-river migration survival rates, and observed return-at-age proportion, with some simplifying assumptions. The system could be broken down into a series of state transitions with known and unknown parameters (Figure A3). Known parameters such as observed SARs, migration survival rates, harvest rates, and observed return-at-age proportions could be used to determine likely values for unknown ocean process parameters (i.e., for the parameters in blue font in Figure A3).

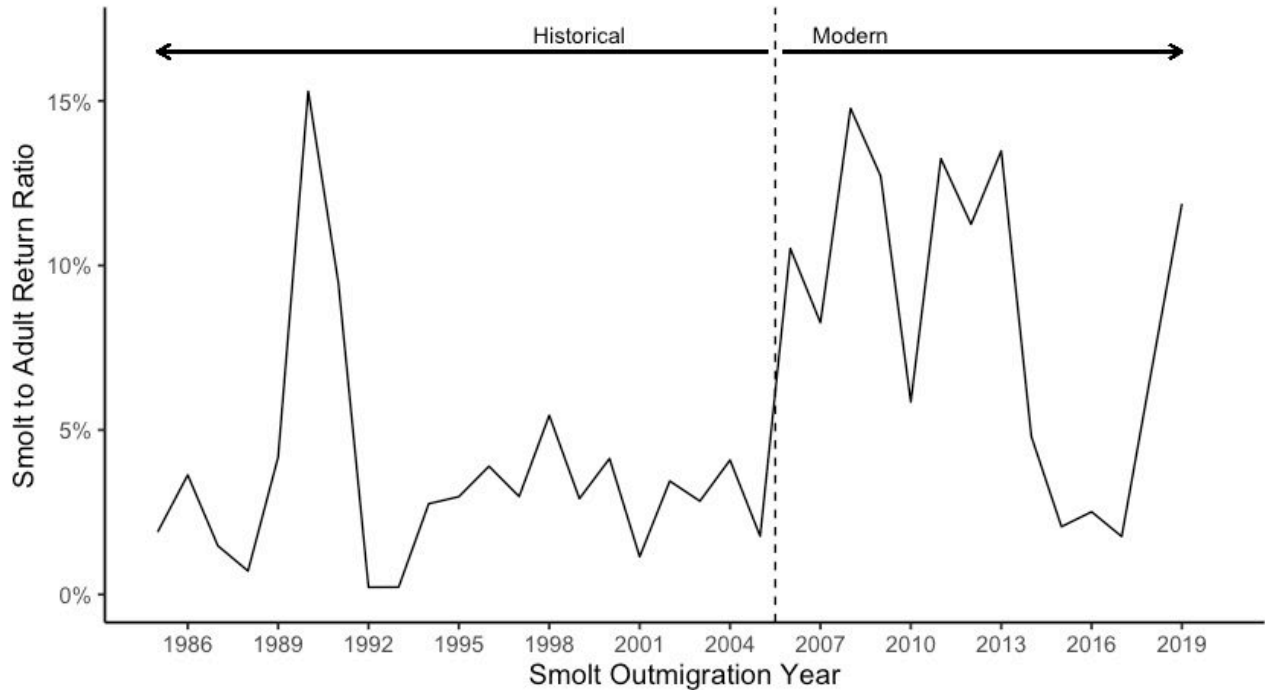


Figure A4. Historical and modern fall-winter pre-smolt to adult return (mouth of Bonneville Dam) ratios for the Osoyoos stock of Okanagan Sockeye Salmon. Data provided by Howard Stiff (DFO).

Table A4. Estimates of smolt to adult return ratio for the Osoyoos stock of Okanagan Sockeye Salmon by epoch. The ‘Modern’ epoch corresponds to the recent period with improvements to both the physical environment and water management.

Epoch	Years	Average	SD	CV
Historical	1985-2005	4.34%	4.03%	92.8%
Modern	2006-present	9.91%	5.66%	57.2%
All Periods Combined	1985-present	6.67%	5.46%	82.1%

The second point of constraint was the observed return-at-age proportions, which, along with the yearly ocean survival (i.e., constant yearly survival after the early ocean period), provide a way to estimate the probability of returning each year, conditional on surviving and not returning in a previous year (i.e., δ^a in Figure A3). This provided a way to include age structuring in the adult returns.

Estimates for unknown ocean processes were produced solving a series of equations representing the survival processes and using gradient methods. This produced estimates of unknown ocean parameters that resulted in the observed SARs and the observed return-at-age proportions (see Table A5). This did

not imply that estimates of unknown quantities were uniquely identifiable, only that values used for unknown quantities produced a behaviour that matched empirical SARs and observed return-at-age proportions based on the estimated proportion of smolts returning at each age class.

By dividing ocean survival into early ocean survival and yearly survival thereafter, parameter values were determined that would produce modern SAR values (Table A4)

$$\begin{aligned}
 R^3 &= \phi^{\text{winter}} \cdot \phi^{\text{river}} \cdot \phi^{\text{EO}} \cdot \phi^{\text{ocean}} \cdot \delta^3 \cdot (1 - M^{\text{ocean}}) \\
 R^4 &= \phi^{\text{winter}} \cdot \phi^{\text{river}} \cdot \phi^{\text{EO}} \cdot (\phi^{\text{ocean}})^2 (1 - \delta^3) \cdot \delta^4 \cdot (1 - M^{\text{ocean}}) \\
 R^5 &= \phi^{\text{winter}} \cdot \phi^{\text{river}} \cdot \phi^{\text{EO}} \cdot (\phi^{\text{ocean}})^2 (1 - \delta^3) \cdot (1 - \delta^4) \cdot (1 - M^{\text{ocean}})
 \end{aligned}
 \tag{Equation 12}$$

where R^a represented the proportion of juvenile cohort exiting the Columbia basin and returning as an adult of age a , and where ϕ^{winter} represented overwintering survival from pre-smolt to outmigration (see Table A1 and Table A5), ϕ^{river} (0.54 see Table A3 and Table A5) represented survival through the Columbia River, ϕ^{EO} represented the first year of ocean survival (which is unknown), ϕ^{ocean} represented yearly ocean survival thereafter (also unknown), and δ^3 and δ^4 represented the probability of returning at age 3 and age 4, respectively (also unknown). The M^{ocean} parameter represented ocean mortality associated with in-ocean harvest that was assumed to occur during the return year (see Table A1 and Table A5).

While the return proportions were not directly observable, estimates could be normalized to produce estimates of the return-at-age proportions (α^a) by comparing the proportion of an age class return relative to the total proportion of smolts returning (i.e., total returns), where total returns were determined as

$$T_{\text{return}} = R^3 + R^4 + R^5, \tag{Equation 13}$$

and the realized returns-at-age proportion were determined as

$$\alpha^a = R^a / T_{\text{return}} \text{ for } a \in \{3,4,5\}. \tag{Equation 14}$$

Furthermore, the total proportion of smolts returning could be directly compared to the observed SAR estimates:

$$SAR = T_{\text{return}} \tag{Equation 15}$$

The estimates for unknown quantities were determined by using gradient methods to solve a series of equations (Equation 12 to Equation 15) using known elements (i.e., $\phi_{\text{juv}}^{\text{river}}$, α^3 , α^4 , α^5 , SAR, $\phi_{\text{adult}}^{\text{river}}$, M^{ocean} , and M^{river}) and determining values for unknown quantities that produced values for SAR and return proportions that were consistent with observed values (Table A5).

Simulator Implementation

Using the estimated parameters for in-ocean process (i.e., ϕ^{EO} , ϕ^{ocean} , δ^3 , and δ^4), survival of natural- and hatchery-origin smolts were simulated. The first year of survival in the ocean (i.e., early ocean

survival) was shared for all cohorts, with the number of smolts entering the ocean that survived the first ocean year and remaining in the ocean determined as

$$A_{i,y}^{T,a} = S_{i,y-1}^{T,a-1,\text{ocean}} \cdot \phi^{\text{EO}} \cdot (1 - \delta^a) \text{ for } T \in \{N, H\} \text{ and } a \in \{2,3\}, \quad \text{Equation 16}$$

and with the number of smolts surviving and returning to freshwater reproduce determined as

$$R_{i,y}^{T,a} = S_{i,y-1}^{T,a-1,\text{ocean}} \cdot \phi^{\text{EO}} \cdot (\delta^a) \cdot (1 - M^{\text{ocean}}) \text{ for } T \in \{N, H\} \text{ and } a \in \{2,3\}. \quad \text{Equation 17}$$

where $S_{i,y}^{T,a,\text{ocean}}$ was number of smolts of a given origin type ($T \in \{N, H\}$) and age a ($a \in \{2,3\}$) was the age after the survival step. The shared survival rate ϕ^{EO} represented early ocean survival rate, and δ^a represented the return probability at a given age after surviving from the previous age class to age class a (see Table A5). For individuals surviving to a total age of two, the corresponding return probability, δ^2 , was fixed to zero, indicating returns only occurred for fish that had total age greater than two. Finally, the mortality rate from ocean harvest was represented by M^{ocean} , with $R_{i,y}^{T,a}$ representing the number of individuals of a particular age and rearing type entering the freshwater during the return migration.

For individuals that survived and remained in the ocean for another year, subsequent ocean survival was determined for each year using a shared yearly ocean survival rate (ϕ^{ocean}), with the number surviving and remaining in the ocean determined as

$$A_{i,y}^{T,a} = A_{i,y-1}^{T,a-1} \cdot \phi^{\text{ocean}} \cdot (1 - \delta^a) \text{ for } T \in \{N, H\} \text{ and } a \in \{3,4,5\}, \quad \text{Equation 18}$$

and the number of individuals surviving and returning to spawn determined as

$$R_{i,y}^{T,a} = A_{i,y-1}^{T,a-1} \cdot \phi^{\text{ocean}} \cdot (\delta^a) \cdot (1 - M^{\text{ocean}}) \text{ for } T \in \{N, H\} \text{ and } a \in \{3,4,5\}, \quad \text{Equation 19}$$

where $A_{i,y-1}^{T,a-1}$ represented the number of individuals in the ocean in the previous time step. All age 5 fish were assumed to return (i.e., δ^5 was fixed to one). For returning individuals, M^{ocean} represented mortality associated with ocean harvest, and $R_{i,y}^{T,a}$ represented the number of individuals of a particular age and rearing type entering the freshwater.

Table A5. Summary of known values and ocean process parameters that were solved based on known values.

Description	Symbol	Known Value	Solved Value	Reference
In-river survival	$\phi_{\text{juv}}^{\text{river}}$	0.540	-	Table A3
Early ocean survival	ϕ^{EO}	–	0.2465	
Yearly Ocean survival	ϕ^{ocean}	–	0.85	
Probability of returning at age 2	δ^2	–	0	Constrained
Probability of returning at age 3	δ^3	–	0.073	
Probability of returning at age 4	δ^4	–	0.885	
Probability of returning at age 5	δ^5	–	1	Constrained
Proportion of returns at age 3	α^3	0.086	–	Howard Stiff, DFO, pers. comm.
Proportion of returns at age 4	α^4	0.820	–	Howard Stiff, DFO, pers. comm.
Proportion of returns at age 5	α^5	0.093	–	Howard Stiff, DFO, pers. comm.
Ocean harvest mortality	M^{ocean}	0.05	–	Table A1
Adult upstream survival	$\phi_{\text{adult}}^{\text{river}}$	0.890	–	Figure A6
Average in-river harvest mortality	M^{river}	0.050	–	Figure A5
Pre-smolt to adult return ratio	SAR	0.067		Table A4; Figure A4

Return Migration

For individuals returning to spawn, multiple sources of mortality were considered, including freshwater harvest and in-river mortalities. Marine harvest was already considered in Equations 17 and 19, which determined the number of adults returning to freshwater.

Freshwater Harvest

Freshwater harvest was calculated from an empirical relationship in the form of a linear regression model that predicted number of returning upper Columbia River Sockeye Salmon based on the number of Okanagan Sockeye Salmon returns (Figure A5a). This represents in-river harvest from approximately the mouth of the Columbia River to Wells Pool. The linear regression was of the form:

$$\ln(H_y^{\text{river}}) = \beta_0 + \beta_1 \cdot \ln(R_y) + \epsilon_y \quad \text{Equation 20}$$

where R_y represented the number of Okanagan Sockeye Salmon returns in year y , H_y^{river} represented the corresponding in-river harvest, β_0 and β_1 represented the regression coefficients, and $\epsilon_y \sim N(0, \sigma_H)$ represented the random error term associated with observed harvest. The relationship was significant ($P < 0.0001$) with log returns explaining approximately 96% of the variation in log harvest (Figure A5). The single relationship also naturally predicted changes in overall harvest rates over time that were observed in the system (Figure A5b). Regression coefficients estimates were $\widehat{\beta}_0 = -4.083$ (SE: 0.456) and $\widehat{\beta}_1 = 1.093$ (SE: 0.041) for the intercept and slope, respectively.

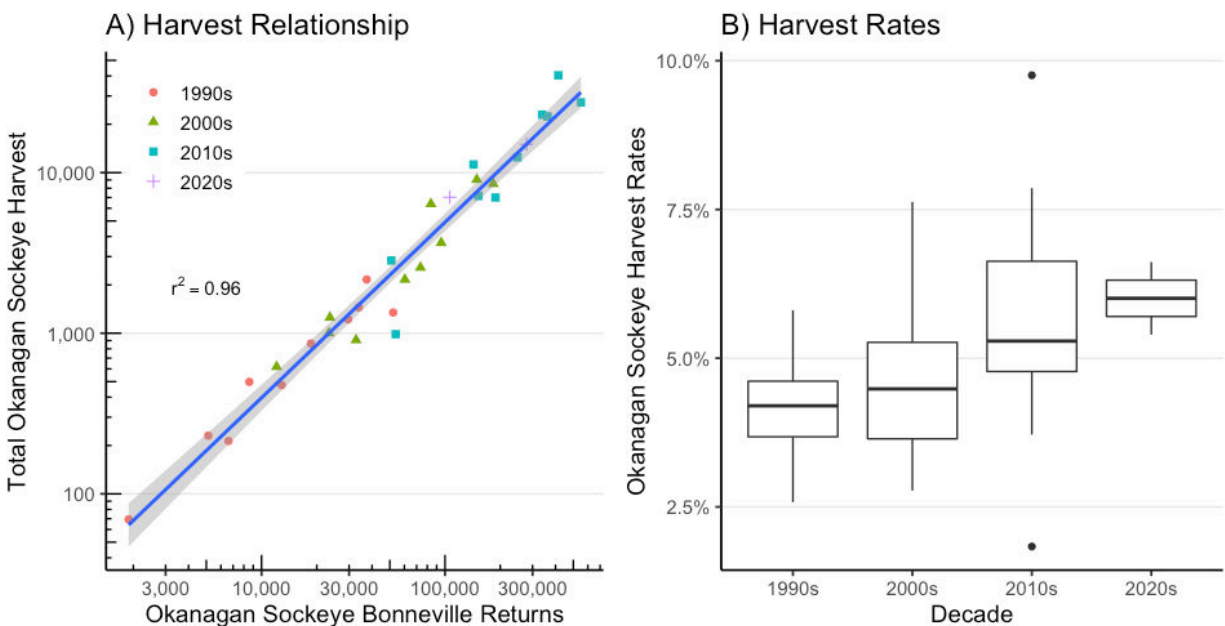


Figure A5. Relationship between estimated Okanagan Sockeye Salmon returns at Bonneville Dam and subsequent freshwater harvest (A), and distribution of estimated harvest rates by decade (B). Data provided by Howard Stiff (DFO).

Freshwater Survival

Adult upstream survival rates were based on estimates of survival by comparing counts at Wells Pool to estimated returns to the ‘mouth of the Columbia’ (i.e., Bonneville Dam) after adjusting for harvest (Figure A6). Resulting naïve estimates of upstream survival showed consistent survival rates across four decades of about 0.89 (CV 9.5%) from Bonneville Dam to Wells Pool (Figure A1).

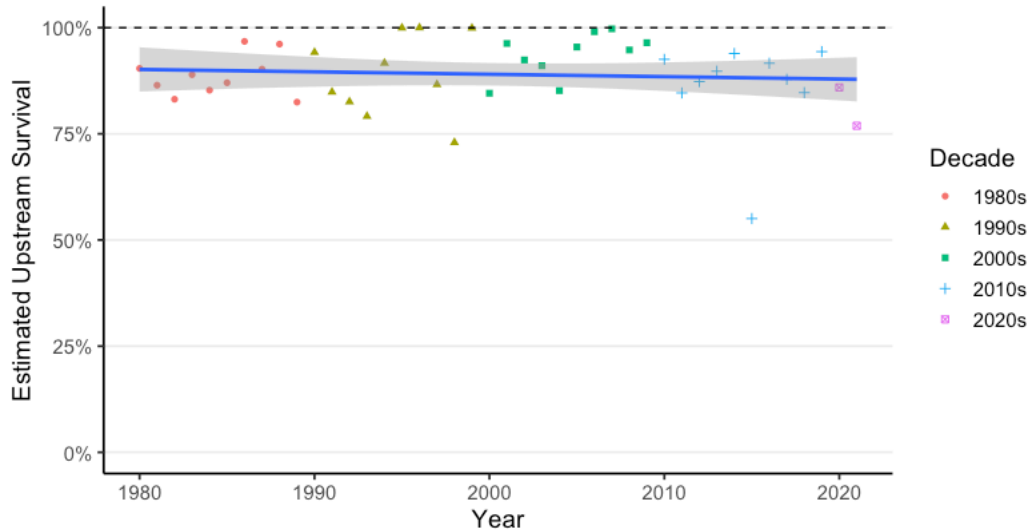


Figure A6. Estimated upstream survival rates based on yearly estimates of the ratio between estimated returns to the mouth of the Columbia and abundances at Wells Pool, after removing estimated in-river harvest. Data provided by Howard Stiff (DFO).

Simulation Implementation

The freshwater survival and harvest mortality were computed over two migration segments, from the ‘mouth of the Columbia’ (i.e., Bonneville Dam) to Wells Pool, and from second Wells Pool to the hypothetical spawning area in an SPU. Within each of these segments both harvest mortality and natural mortality was considered, with harvest based on the in-river harvest relationship observed from Bonneville Dam to Wells Pool (i.e., Figure A5a). Harvest mortality rate within each segment was determined by first predicting the total harvest based on the size of returns entering the segment, then the harvest prediction was converted to a harvest rate. Because the same in-river harvest relationship was used for both segments, harvest pressure from Wells Pool to the SPU spawning area was assumed to be identical to in-river harvest pressure experienced below Wells Dam.

Harvest rates within a migration segment were computed by first predicting the total harvest based on return abundance observed at the start of the segment, and then by converting it to a harvest rate. For year y in simulation iteration i , simulated harvest ($H_{i,y}^S$) within a migration segment was predicted as a combination of the mean response with error:

$$H_{i,y}^s = \exp \left(\ln(\overline{H}_{i,y}) + \omega_{i,y}^{\text{reg}} + \omega_{i,y}^{\text{obs}} \right) \quad \text{Equation 21}$$

where $\overline{H}_{i,y}$ represented the mean harvest predicted by Equation 20, and $R_{i,y}^{T,a}$ from Equations 17 and 19 combined to represent R_y in Equation 20. The terms $\omega_{i,y}^{\text{reg}}$ and $\omega_{i,y}^{\text{obs}}$ were error draws representing uncertainty associated with the regression estimates and the observation process, where

$$\omega_{i,y}^{\text{reg}} \sim N(0, \text{SE}_{\text{pred}})$$

and

$$\text{Equation 22}$$

$$\omega_{i,y}^{\text{obs}} \sim N(0, \widehat{\sigma}_{\text{obs}})$$

where SE_{pred} represented the standard error associated with the mean prediction and $\widehat{\sigma}_{\text{obs}}$ represented the estimates of the residual error from the regression model. The realized harvest mortality within a return migration segment was therefore computed as

$$M_{i,y}^{\text{river}} = \frac{H_{i,y}^s}{\sum_{a=3}^5 R_{i,y}^{N,a} + R_{i,y}^{H,a}} \quad \text{Equation 23}$$

where the denominator (i.e., $\sum_{a=3}^5 R_{i,y}^{N,a} + R_{i,y}^{H,a}$) represented the total return size at the start of the segment, which combined returns across available age classes and rearing types.

Once the harvest rate had been determined in a migration segment, the number of returns that escaped to the end of the segment, $E_{i,y}^{T,a}$, for a given rearing type and age was computed as

$$E_{i,y}^{T,a} = R_{i,y}^{T,a} \cdot (1 - M_{i,y}^{\text{river}}) \cdot \phi_{i,y}^{\text{adult}} \quad \text{for } T \in \{N, H\} \text{ and } a \in \{3,4,5\}, \quad \text{Equation 24}$$

where $M_{i,y}^{\text{river}}$ was in-river mortality from harvest (i.e., Equation 23) and $\phi_{i,y}^{\text{adult}}$ was the adult migration survival rate, which was stochastic and disturbed as $\phi_{i,y}^{\text{adult}} \sim N(\mu^{\text{adult}}, \sigma^{\text{adult}})$ (see Table A1 for parameter values).

At the end of the first segment (i.e., Wells Pool) the number escaping for an age and rearing type (i.e., $E_{i,y}^{T,a}$) was used to predict harvest mortality (i.e., Equations 21 to 23), and the corresponding return number was used when computing the in-river harvest and mortality rates (i.e., Equation 23) which were used to compute the final escapement abundance to the SPU spawning area (i.e., Equation 24). The total number of spawners was then determined by summing SPU escapement across age class and rearing types (see Equation 1), and used for natural reproduction (i.e., Equations 2 to 4).

Modelling Assumptions

The PVA analysis represents best available information at the time of the analysis, which should be revised in the future as better information becomes available. On a fundamental level, each parameter value, and any estimate of uncertainty/variation, represents an assumption that the values were

accurate and representative of both current and future conditions. This makes the implicit assumption that key life history parameters will not deviate substantively in the near future, which may not be the case. For example, global climate change impacts may be regional and stock specific, making explicit predictions more difficult (Martins et al. 2012). Furthermore, while analyses did consider the potential effect of uncertainty and stochasticity on results, the analyses did not consider the possibility of long-term temporal trends in life history parameters, for example nutrient enrichment or habitat restoration could improve long-term productivity, while environmental disturbances or degradation could reduce productivity over time.

In terms of explicit life history parameter values, life history processes occurring in a SPU were highly speculative and should be validated with empirical studies, and analyses should be revisited in the future as more information becomes available. Some notable examples include spawner productivity, system carrying capacity (which was not directly considered in the Sockeye Salmon analysis), and migration rates within an SPU. Successful natural reproduction was found to be a critical component to a successful reintroduction program. Current analyses were generated using Okanagan Salmon as a proxy, which will need to be validated with empirical studies and results reassessed once that information becomes available. For juvenile and adult migration between Bonneville and Wells Pool, information was available, but above Wells Pool life history processes were speculative. Sensitivity analyses on within-basin juvenile survival rates demonstrated that different assumptions on key processes could result in very different levels of expected adult returns. Furthermore, analyses assumed that juvenile passage facilities will be available during reintroduction efforts, which may not be the case. Adult survival and harvest rates were also speculative based on observed rates in the middle and lower Columbia River. These rates will also need to be validated with empirical studies and assume that adult passage facilities will be available during reintroduction efforts. Finally, ocean survival rates were based on rates estimated for Okanagan Salmon, which assumes reintroduced stocks will experience similar ocean conditions, which may also not be the case and will need to be validated with empirical studies.

Hatchery Scenarios

To determine the type of hatchery input required to produce a given range of returning adults, multiple PVA runs were performed, each with a different level of hatchery outplants into the SPU. The runs ('Scenarios') specified the level (and variation) in broodstock collected for the hatchery program, which resulted in a corresponding level and variation that would be expected for Sockeye Salmon outplants (Table A6). Variability in broodstock procurement was provided for full hatchery scenario (i.e., 1M) by ONA hatchery manager (Ryan Benson, DFO pers. comm.) and was linearly scaled down for smaller output levels.

Scenarios were broken into two main approaches, one set of scenarios used a constant level of hatchery output for the full 50 years of the simulation, and the other set of scenarios started with an initial hatchery effort, and then changed to a different (reduced) level of hatchery effort after the establishment of natural reproductions. The latter set of scenarios therefore represented the possibility of balancing the cost of high initial hatchery effort with reduced effort in later years.

Hatchery outplant schedules that maintained a constant level of yearly hatchery fry outplants over time included 100,000 (i.e., 100K), 250,000 (i.e., 250K), 500,000 (i.e., 500K) and 1,000,000 (i.e., 1M) outplants per year, providing a range of hatchery outputs that vary from lower levels that can be generated by current ONA hatchery facilities with a high probability (i.e., 100K) to very high production rates (i.e., 1M) that may require hatchery facility expansions.

The second set of scenarios used hatchery productivity scenarios that considered approaches with high initial output that were reduced over time (i.e., ‘500K + 100K’, ‘1M + 100K’, and ‘1M + 250K’ scenarios). The intent was to consider using an initial period of higher hatchery to establish the population, followed by a reduction in hatchery effort intended to help maintain the population. The ‘1M +100K’ and ‘1M + 250K’ scenarios maintained 1,000,000 outplants per year for the first 12 years followed by a reduction to either 100K or 250K thereafter, representing a strategy with an intense but shorter initial release schedule. The ‘500K + 100K’ scenario maintained 500K outplants for the first 30 years followed by 100,000 outplants per year afterwards, representing a more moderate initial release schedule maintained for a longer duration.

Table A6. Hatchery settings used for the Sockeye Salmon and Chinook Salmon hatchery scenarios.

Approach	Scenario	Broodstock	Fry Outplants	Notes
Constant Effort	100K	124 (CV 1.6%)	100,000 (CV 26%)	
	250K	310 (CV 4.0%)	250,000 (CV 26%)	
	500K	620 (CV 8.0%)	500,000 (CV 27%)	
	1M	1240 (CV 16%)	1,000,000 (CV 30%)	
Variable Effort	500K + 100K	620 (CV 8.0%)	500,000 (CV 27%)	500K for the first 30 years, then 100 K there after
		124 (CV 1.6%)	100,000 (CV 25%)	
	1M + 100K	1240 (CV 16%)	1,000,000 (30 %)	1M for the first 12 years, then 100 K there after
124 (CV 1.6%)		100,000 (CV 26%)		
1M + 250K	1M + 250K	1240 (CV 16%)	1,000,000 (CV 30%)	1M for the first 12 years, then 250 K there after
		310 (CV 4.0%)	250,000 (CV 26%)	

Results and Conclusions

For each PVA analysis under a given hatchery productivity scenario (Table A6), a total of 10,000 simulation iterations were conducted. Each iteration had a different stochastic outcome (i.e., differing survival rates and corresponding number of returning adults) that, when combined, produced a distribution of simulation results (i.e., the potential range of outcomes, e.g., Figure A7). Because many stochastic processes are multiplicative, the variation at one lifecycle stage produced a wide range of ‘starting values’ for the next model step, which compounded by producing an even larger range of

outcomes for the subsequent step. This variability between simulation iterations was summarized by reporting the 2.5% and 97.5% percentiles from the 10,000 total simulations, thus representing the 'plausible' range of results that could be observed at a given time point under a given scenario of hatchery production (Figure A7).

Sockeye Salmon hatchery productivity scenarios produced average returns that ranged from 500 to 5,000 adults, while the Chinook Salmon scenarios produced lower average returns ranging from just under 200 to just under 2000 adults, depending on the productivity scenario (Figure A7). Hatchery scenarios for both species used the same level and variation in hatchery outplants, with the lower Chinook Salmon returns being primary due to higher expected ocean mortality rate (i.e., harvest and natural). Results also indicated that a sizable variation in year-to-year returns could also be expected, with 95% of simulated returns covering nearly an order of magnitude variation (e.g., 200 to 2000) for a given hatchery scenario. None of the hatchery scenarios under consideration generated enough returns to meet a hypothetical target of 10,000 returning adults. The only exception was Sockeye Salmon under the 1M scenario (i.e., average yearly outplants of 1,000,000 fry), which could occasionally meet this target, but only in about 6% of simulated years.

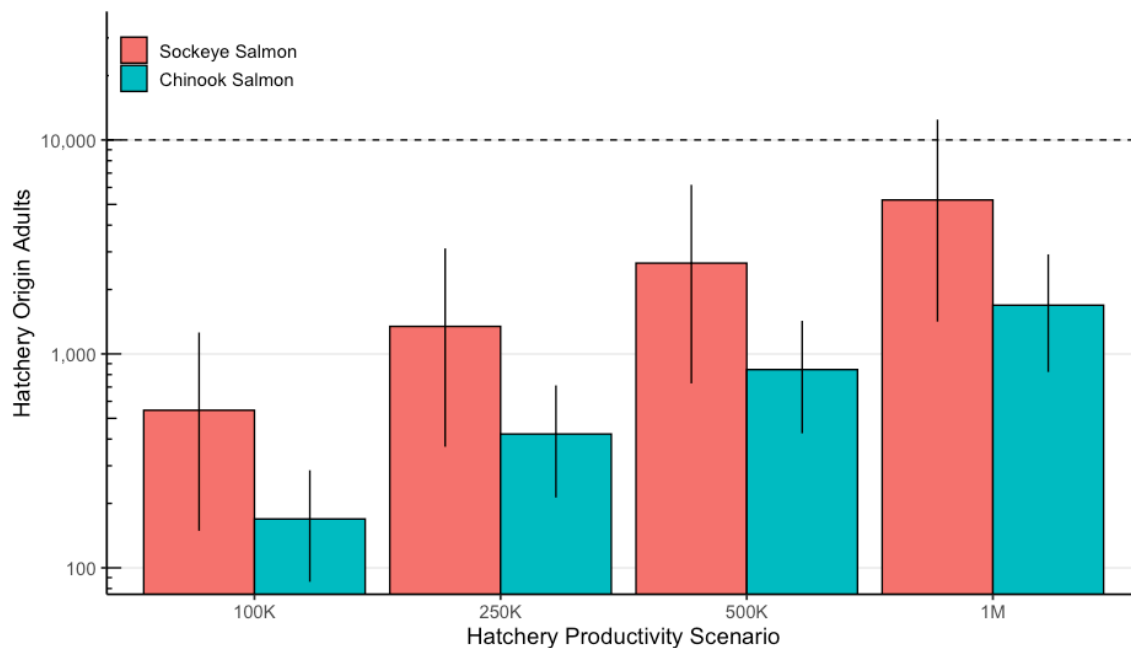


Figure A7. Expected number of Sockeye and Chinook salmon hatchery-origin adults returning under different levels of hatchery productivity of yearly fry outplants. Abundance is displayed on the logarithmic scale; error bars indicate the 2.5% and 97.5% percentiles.

Including natural-origin adults in the simulation produced more total adult returns, especially for Sockeye Salmon outplants, with many scenarios producing average returns above the return target (Figure A8; leftmost column). For Sockeye Salmon, average returns exceeded the target within 12 years under large hatchery release schedules (e.g., 1M), with all scenarios producing average returns that exceeded the return target by 50 years. The results were different for Chinook Salmon, with many scenarios producing returns that were lower than the return target.

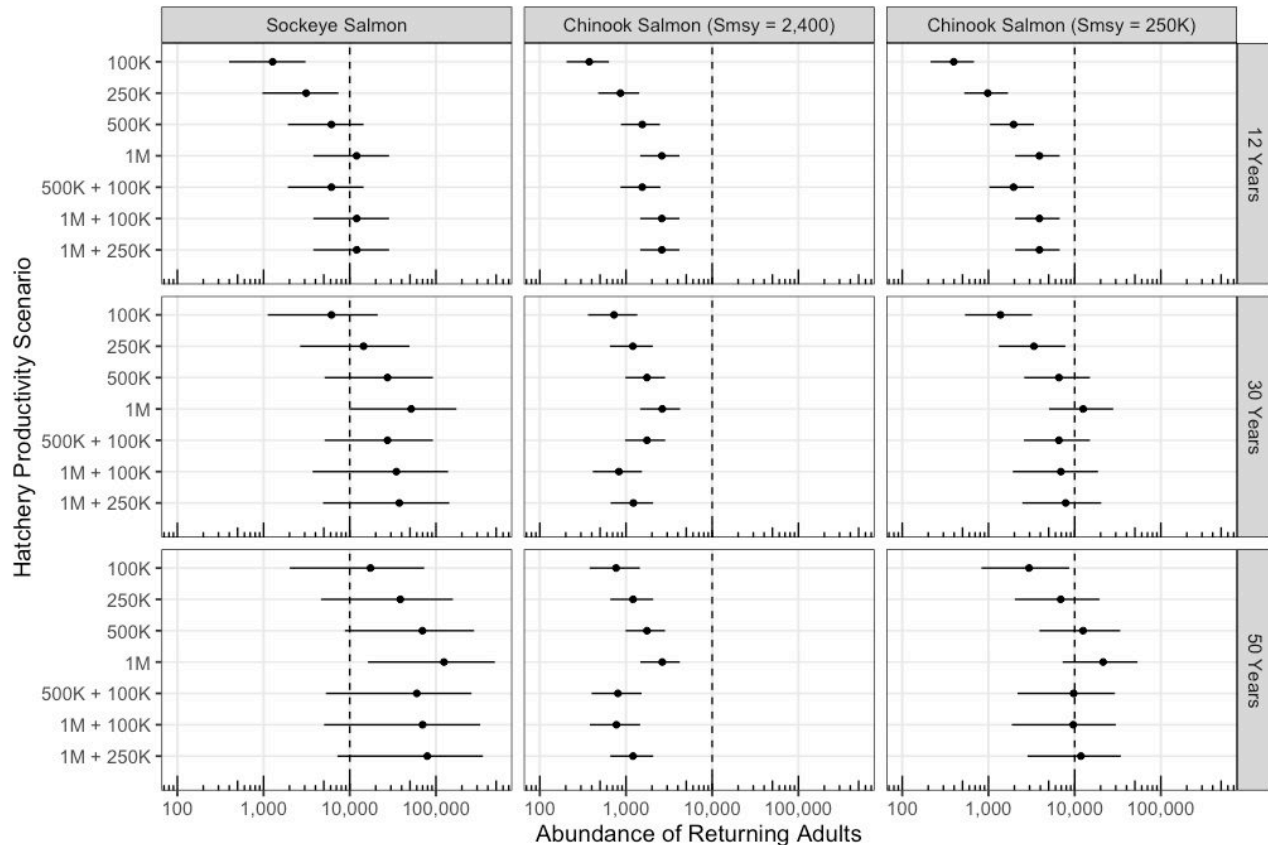


Figure A8. Summary of natural- and hatchery-origin adult returns of Sockeye and Chinook salmon under different hatchery production scenarios and over different time horizons. The 100K, 250K, 500K and 1M scenarios maintained a constant hatchery fry production over a given time frame. The ‘500K + 100K’ scenario maintained 500K production for the first 30 years followed by 100K per year for remaining years. The ‘1M + 100K’ and ‘1M + 250K’ scenarios maintained 1M production for the first 12 years followed by 100K or 250K thereafter. Left column indicates Sockeye Salmon returns, while right column indicates Chinook Salmon returns. Abundance is displayed on the logarithmic scale; error bars indicate the 2.5% and 97.5% percentiles.

The Chinook Salmon PVA model included a density dependent function, where the effective number of juveniles produced per spawner decreased with increases in spawning stock sizes. For the default configuration of the Chinook Salmon PVA model, the largest number of recruits would be produced at a spawner abundance of 2,400 (i.e., S_{msy}), indicating a relatively small carrying capacity (i.e., S_{msy} represents half the carrying capacity). Therefore, including natural reproduction produced only small gains, with no scenarios coming close to meeting the adult return target, given that the target exceeded the carrying capacity. Relaxing the assumption to an S_{msy} of 250,000 (i.e., a carrying capacity of 500,000 spawners – a highly productive area) greatly increased the number of adult returns with the average number of returns exceeding the target for three hatchery productivity scenarios (i.e., 500K, 1M and 1M + 250K) on the longer 50-year time scale. This result is not surprising and indicates the importance of determining the carrying capacity and natural production capacity of an SPU.

Scenarios also differed in the variability of expected returns by species, hatchery outplant approach, and time horizon. Generally, shorter time horizons produced less-variable results, as there was a reduction in the number of stochastic elements involved in the calculation and therefore less of an opportunity for simulation iterations to deviate. This follows general properties of simulation projections, where projections over shorter time periods generally have less uncertainty as compared to projections over longer time periods. Variability in returns were also generally higher for the Sockeye Salmon PVA as compared to the Chinook Salmon PVA, although Chinook Salmon PVA runs that featured a higher assumed S_{msy} value also showed higher variability relative to runs with a lower S_{msy} value. This is primarily the result of PVA formulation, as the Sockeye Salmon PVA included more sources of variation in the formulation than the Chinook Salmon PVA (this was primarily the result of best available information at the time of the PVA formulation). Finally, hatchery outplant scenarios that featured reductions in hatchery production after establishment of the population generally saw slightly larger uncertainty in the number of returning adults for periods after the reduction, as compared to corresponding scenarios that maintained production (Figure A8). This was driven by a larger variation in natural production as compared to hatchery production, which was generally more stable. Without the stabilizing influence of hatchery production, the higher uncertainty in natural productivity resulted in more variability in the numbers of returning adults.

For Chinook Salmon, these results considered two extremes in carrying capacity, and the effects of intermediate carrying capacities and time horizons on adult returns was explored further for Chinook Salmon PVA (Figure A9). On shorter time horizons, the carrying capacity assumption had a much smaller effect relative to number of hatchery outplants (e.g., 12 years; Figure A9) as hatchery-origin fish still dominated returns. On longer time horizons (e.g., 30 and 50 years), there was more separation between simulations with lower assumed S_{msy} values and simulations with larger S_{msy} values, with the largest separation occurring at 50 years. This indicates that carrying capacity assumptions have little impact on short-term projections but become increasingly important for long-term projections. Currently, the Sockeye Salmon PVA does not include a density dependent component, therefore longer-term projections (e.g., 30 and 50 years) represent a best-case scenario where density dependence has not yet become a limiting factor.

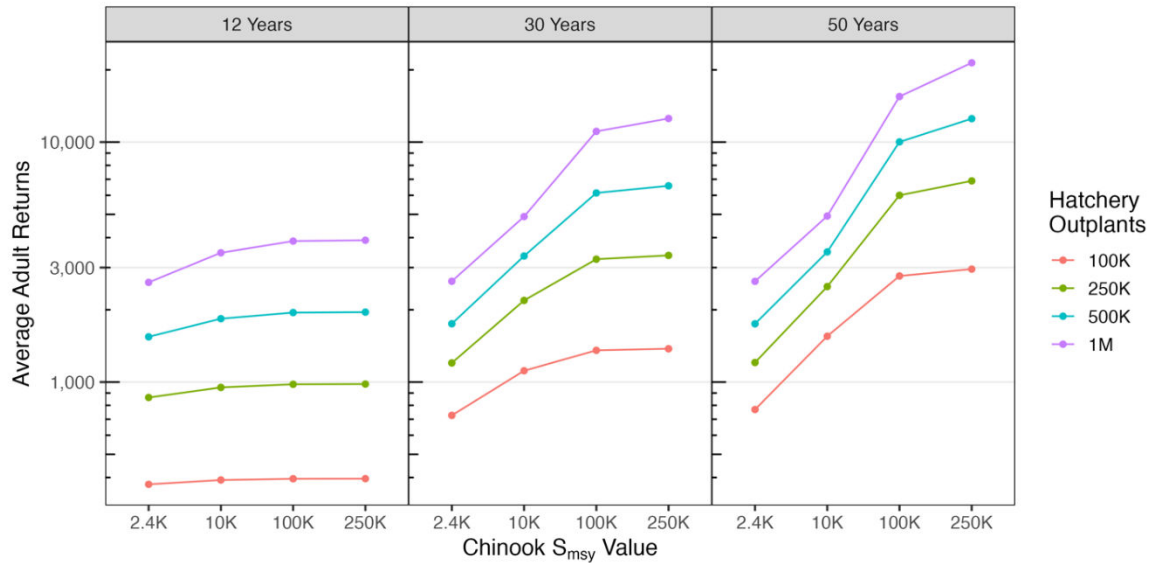


Figure A9. Variation in the number of Chinook Salmon adult returns under differing S_{msy} assumptions over differing time horizons.

Finally, to consider the impact of juvenile within-basin survival rates and the necessity of juvenile passage facilities, the Sockeye Salmon PVA analyses were re-run across the range of within-basin survival rates indicated in Table A3. Overall higher within-basin juvenile survival produced higher adult returns, with a larger separation occurring over longer timescales (Figure A10 and Figure A11). The two highest juvenile within-basin survival rates featured improved dam facilities and produced adult returns that were fairly comparable with respect to meeting or surpassing the adult return target in many of the simulation iterations. By contrast, juvenile survival scenarios without out juvenile passage facilities produced substantively lower adult returns with many simulation iterations resulting in fewer than one thousand returning adults, and with no simulation iterations meeting the adult return target. That said, all survival values used to model juvenile survival rates upstream of Wells Pool are speculative and need to be confirmed via empirical study, since the values considered resulted in large differences in the expected number returning adults, especially over longer time frames.

Next Steps

The current PVA analyses are preliminary, designed primarily to help determine the order of magnitude of hatchery effort that may be required for a successful re-introduction experiment. It was not intended to be completely prescriptive in the hatchery effort required, but simply identify whether currently available hatchery facilities would be able to generate juveniles on a sufficient scale (e.g., 100K versus 1 M per year) for re-introduction work. It was the intent of the authors to revisit and re-run this analysis during the course of the re-introduction effort as more information becomes available through future studies and experiments. Some critical components to be revisited include juvenile density dependent effects on both Chinook and Sockeye Salmon. Currently, the density dependence in the Chinook Salmon

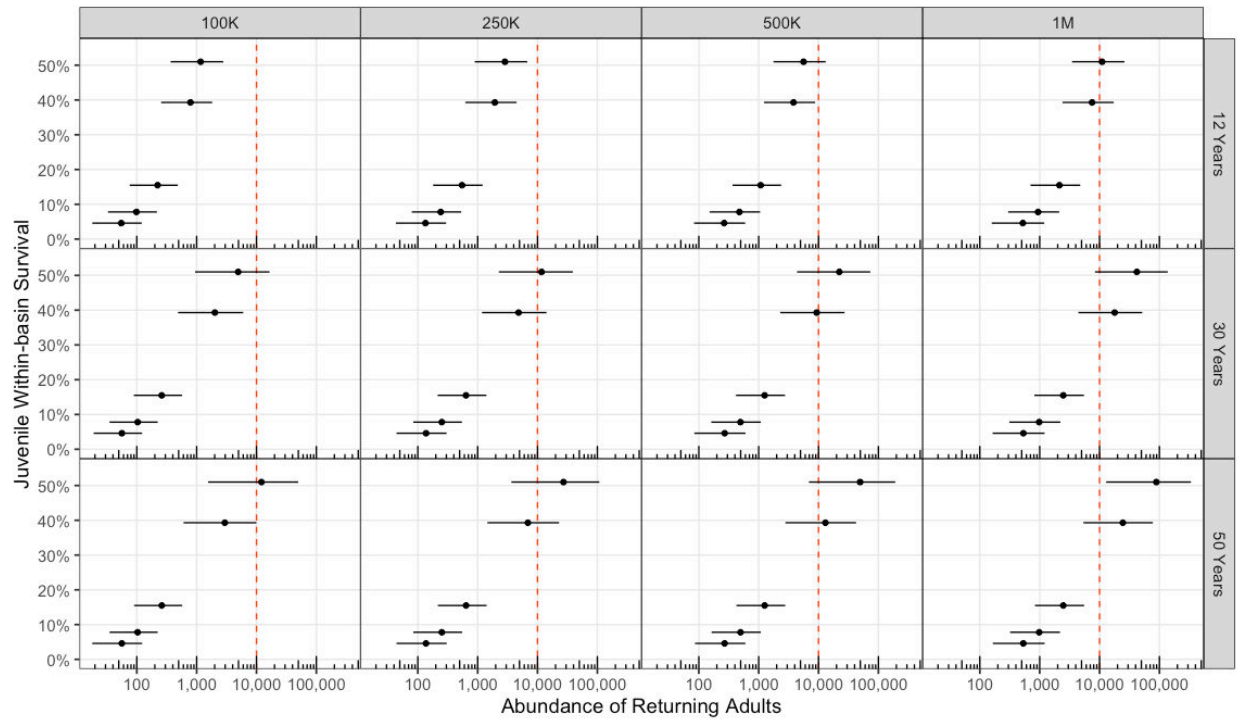


Figure A10. Summary of natural- and hatchery-origin adult returns of Sockeye Salmon under different juvenile within-basin survival rates across differing constant hatchery production scenarios and over different time horizons. Columns indicated one of the 100K, 250K, 500K and 1M constant hatchery fry outplant scenarios, with rows indicating time horizon. Abundance is displayed on the logarithmic scale; error bars indicate the 2.5% and 97.5% percentiles.

PVA made heavy assumptions, while the Sockeye Salmon PVA did not include a density dependency function. Work is currently underway on both components, and the density dependence assumptions will be revisited in future PVA analyses as information such as habitat productivity becomes available. Information on early fry survival was also lacking in the Sockeye Salmon PVA and may be available through additional analyses of the Okanagan acoustic-trawl-surveys, which will be included in future versions of the Sockeye Salmon PVA. Stochasticity in the ocean survival and maturation processes were also likely under-represented and will be re-examined in future analyses, e.g., variation in the observed SAR values will be better represented in future analyses. Harvest rates above McNary, including within an SPU were also a large unknown, harvest and mortality in the lower portion of the river were repeated to represent these sources, but this can and should be refined in future analyses. Finally, the impacts of climate change will also need to be incorporated into future PVA analyses, these include impacts on the ocean survival and maturation processes as well as potential impacts on adult freshwater survival rates.

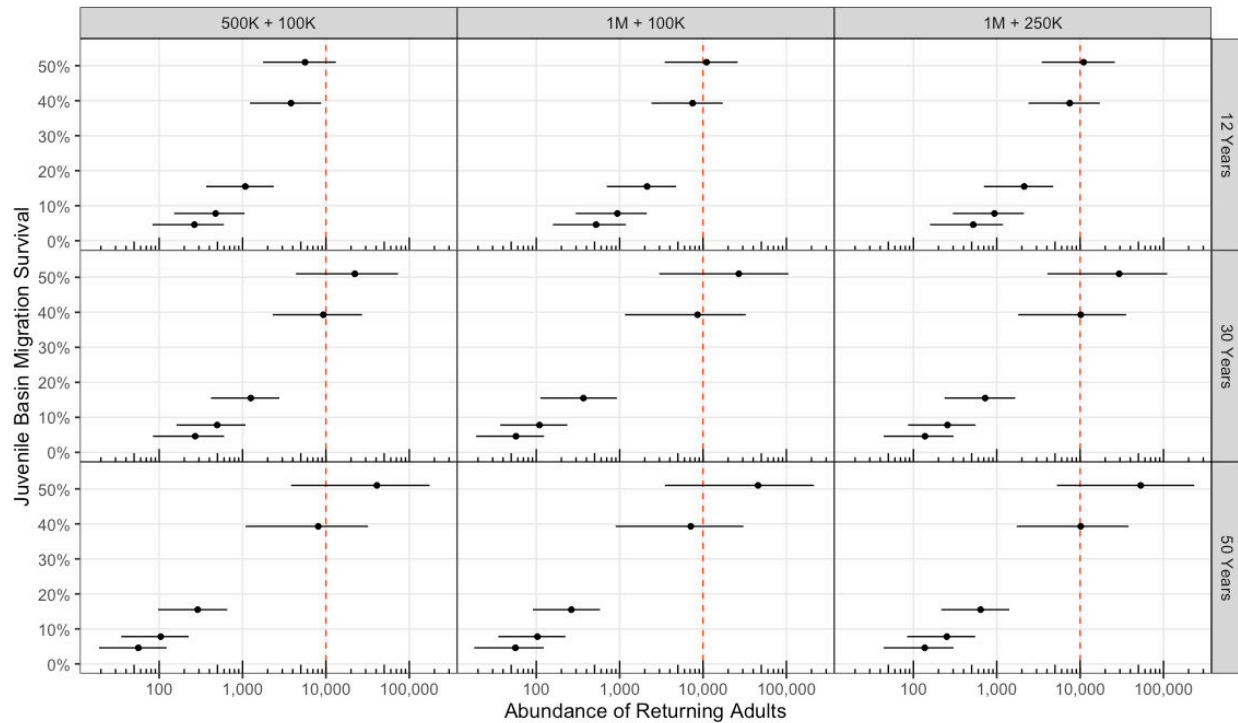


Figure A11. Summary of natural- and hatchery-origin adult returns of Sockeye Salmon under different juvenile within-basin survival rates across differing variable hatchery production scenarios and over different time horizons. The ‘500K + 100K’ scenario maintained 500K production for the first 30 years followed by 100K per year for remaining years. The ‘1M + 100K’ and ‘1M + 250K’ scenarios maintained 1M production for the first 12 years followed by 100K or 250K thereafter. Columns indicate hatchery scenario while rows indicate time horizon. Abundance is displayed on the logarithmic scale; error bars indicate the 2.5% and 97.5% percentiles.

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