



January 2026
Study of Physical Data Gaps to Inform the Implementation
of Nur Rematriation Upstream of Shasta Dam
(AB 211 Drought Grant Agreement Number – Q2396040)



Appendix Q

Life-Cycle Model Report

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Life-Cycle Model Report

Prepared for

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TABLE OF CONTENTS

1	Introduction	1
2	Phase 1	4
2.1	Methods.....	4
2.2	Results	5
3	Phase 2.....	8
3.1	Methods.....	8
3.2	Results	12
3.2.1	Model Runs for Bookend Scenarios.....	12
3.2.2	Model Runs for Reintroduction Rates	14
3.1	Linking Reintroduction Rates to Alternatives.....	20
4	Summary, Caveats, and Potential Additional Evaluations.....	29
4.1	Phase 1	29
4.2	Phase 2	29
4.3	Potential Additional Evaluations	30
5	References	31

TABLES

Table 1	Phase 1 Results of Running Reintroduction Scenarios Under Varying Levels of Reintroduction Quality.....	6
Table 2	Mapping of Design Components to Reintroduction Rates in Alternatives 1 and 3 and Trap and Haul	21

FIGURES

Figure 1	Study Area	3
Figure 2	Winter-Run Chinook Salmon Life-Cycle Model Stages and Transitions	5
Figure 3	Temperature-Dependent Mortality in the Nomtipom Waywaket Below Keswick Dam for Spawning Initiated in Months 5 to 8 (May to August) Used in the WRLCM	6
Figure 4	Phase 1 Model Runs and Confidence Intervals by Varying TDM with a Reintroduction Quality of 0.7 and 0.9	7
Figure 5	Winter-Run Chinook Salmon Life-Cycle Model Flow Chart.....	9

Figure 6	Adult Spawning Dynamics Used in the WRLCM Evaluation of Chinook Salmon of Below Keswick Dam and Winnemem Waywaket Origin Returning to Spawn.....	11
Figure 7	Baseline Winter-Run Life-Cycle Model Run.....	13
Figure 8	Perfect Reintroduction Winter-Run Chinook Salmon Life-Cycle Model Run.....	14
Figure 9	Evaluation of 256 Combinations of the Reintroduction Rates of Adult Attraction, Adult Survival, Juvenile Guidance/Collection, and Juvenile Survival (Variation 1)	18
Figure 10	Evaluation of 256 Combinations of the Reintroduction Rates of Adult Attraction, Adult Survival, Juvenile Guidance/Collection, and Juvenile Survival (Variation 2)	19
Figure 11	Schematic of Alternative 1 for Reintroduction of Chinook Salmon Upstream of Shasta Dam	22
Figure 12	Schematic of Alternative 3 for Reintroduction of Chinook Salmon Upstream Of Shasta Dam	23
Figure 13	Triangular Probability Distributions for the Four Engineering Elements Associated with Adult Collection Under Alternative 3	25
Figure 14	Mapping of 256 combinations of the Design Elements Related to All Four Reintroduction Rates Under Alternative 1	26
Figure 15	Mapping of 256 Combinations of the Design Elements Related to the Adult Reintroduction Rates Under Alternative 3	27
Figure 16	Mapping of 256 Combinations of the Design Elements Related to the Juvenile Reintroduction Rates Under Alternative 3	28

ATTACHMENTS

Attachment 1	Winnemem Waywaket Capacity Estimates
Attachment 2	Description of Alternative Attraction and Collection Rates

ABBREVIATIONS

Background Compendium	<i>Background Compendium and Design Criteria Report for the Feasibility of Volitional Fish Passage above Keswick and Shasta Dams</i>
Consultant Team	Anchor QEA; HDR Engineering, Inc.; U.S. Geological Survey; and QEDA Consulting, LLC
CRR	cohort replacement rate
Feasibility Study	Feasibility Study of Salmon Passage at Shasta and Keswick Dams
M1	first metric
M2	second metric
Nomtipom Waywaket	Winnemem Wintu words for Sacramento River
Project	studies to gather data, compile information, and identify data gaps related to physical and biological conditions in the Study Area
SUS	sustainable under harvest
TDM	temperature-dependent mortality
Winnemem Waywaket	Winnemem Wintu words for McCloud River
WRLCM	Winter-Run Life-Cycle Model

1 Introduction

A team of engineering and fisheries science consultants consisting of Anchor QEA; HDR Engineering, Inc. (HDR); U.S. Geological Survey; and QEDA Consulting, LLC (QEDA) known herein as the "Consultant Team," has received funding from the California Department of Fish and Wildlife to implement studies to gather data, compile information, and identify data gaps related to physical and biological conditions in the Study Area. These studies will be referred to within this document as the "Project." The results of the Project will support an investigation of the feasibility of providing volitional passage for fish, particularly, Chinook Salmon (*Oncorhynchus tshawytscha*), above Keswick and Shasta dams on the Nomtipom Waywaket (also known as the Sacramento River) and into the Winnemem Waywaket (also known as the McCloud River) in northern California. In this document, Chinook Salmon is used to generally describe the species because once connectivity is re-established through reintroduction, fish will adapt to the new environments and could display run timing consistent with multiple runs. It is inclusive of Nur, which the Winnemem Wintu Tribe uses for Chinook Salmon that have been raised by the Tribe. The formal, Evolutionarily Significant Unit-specific name (e.g., Sacramento River winter-run Chinook Salmon) is used when discussing federal Endangered Species Act-listed Chinook Salmon or steelhead (*O. mykiss*). This document is an appendix to the overarching report documenting the results of the Project, which is called the *Background Compendium and Design Criteria Report for the Feasibility of Volitional Fish Passage above Keswick and Shasta Dams* (Background Compendium). This larger report contains additional background information for the Project and this document should be considered within this context.

The Project Study Area extends from the confluence of Cow Creek and the Nomtipom Waywaket and includes the Winnemem Waywaket from Shasta Reservoir to the McCloud Dam (Figure 1). It includes portions of the Winnemem Waywaket; the Nomtipom Waywaket, including Keswick and Shasta dams and reservoirs; Cow Creek; Little Cow Creek; and Dry Creek. These water bodies vary in hydrology, geomorphology, and water quality, with seasonal fluctuations in temperature and flow; these parameters are being measured during this Project to evaluate habitat suitability and passage for salmonids. Understanding these physical conditions is essential to evaluating the feasibility of restoring fish passage to historical spawning and rearing areas upstream of the dams.

The objectives of this document are to identify the level of passage success and survival that adult and juvenile Chinook Salmon would need to achieve under reintroduction scenarios to have an adult spawner abundance equivalent to the historical conditions. This type of analysis necessitates the use of a model to evaluate hypothetical scenarios of reintroduction. The Consultant Team used the Winter-Run Life-Cycle Model (WRLCM), which incorporates temperature-dependent mortality (TDM) into a function that defines egg-to-fry survival. The TDM is itself a model that incorporates spawning distribution and the subsequent temperatures experienced by redds to calculate a monthly thermal

mortality rate (Martin et al. 2017). This technical memorandum describes the analyses that proceeded in two phases. The objectives of Phase 1 of this analysis are as follows:

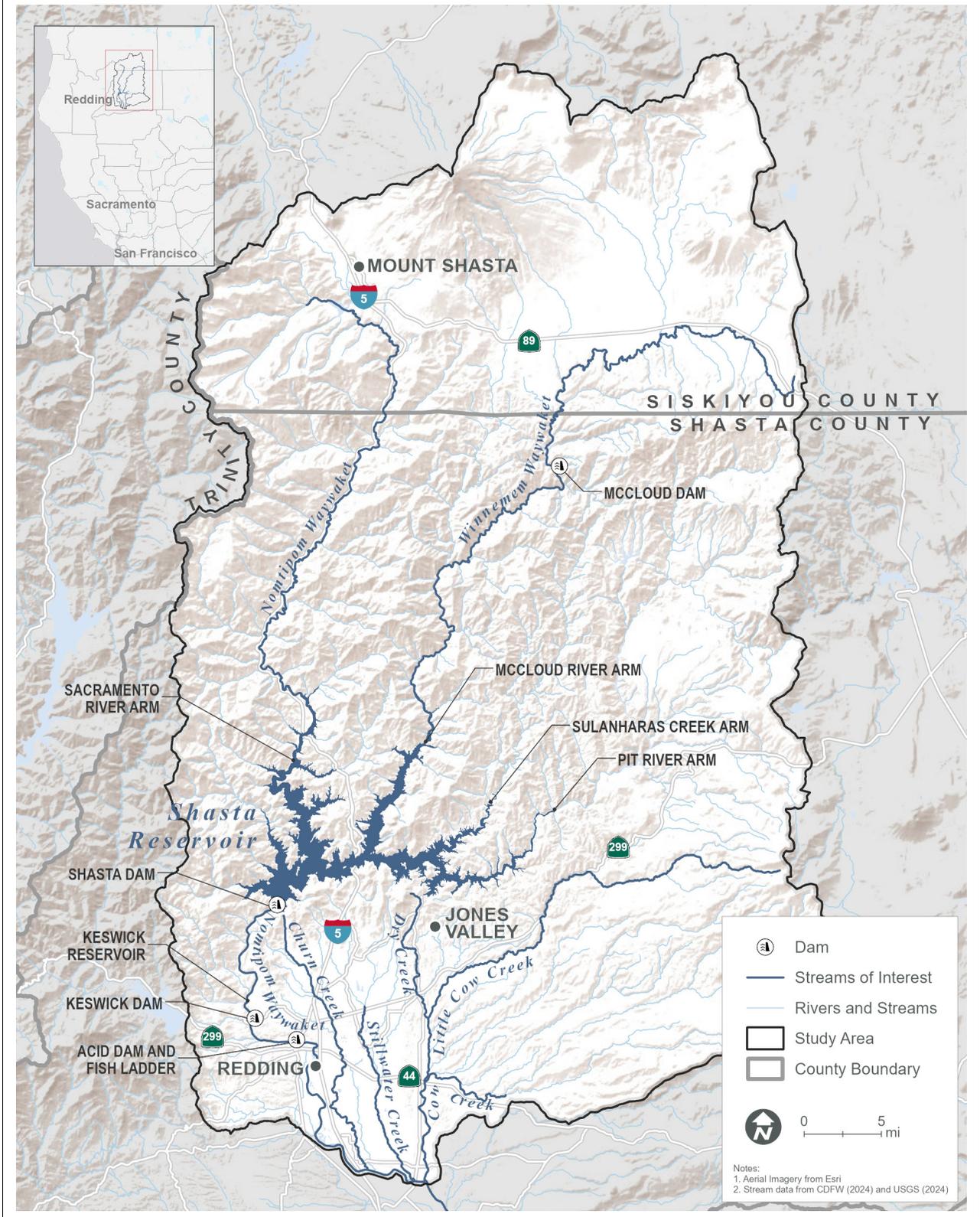
- Evaluate the ability for reintroduction to the Winnemem Waywaket to improve egg-to-fry survival by reducing the TDM being experienced by Sacramento River winter-run Chinook Salmon that currently spawn in the mainstem Nomtipom Waywaket.
- Utilize the WRLCM and the TDM models to evaluate what levels of passage success and survival would be needed for the reintroduction scenarios to be equivalent to the baseline historical conditions. That is, perform the reintroduction action and evaluate the survival and passage rates that would have to occur to match the average abundance of winter-run Chinook Salmon from 1995 to 2020.

The objectives of Phase 2 of this analysis are as follows:

- Evaluate the reintroduction to the Winnemem Waywaket by winter-run Chinook Salmon that currently spawn in the lower mainstem Nomtipom Waywaket. Conditions in the Winnemem Waywaket can increase egg-to-fry survival, yet adult collection, adult survival, juvenile collection, and juvenile survival are also required to complete the life cycle of fish into the Winnemem Waywaket. Utilize the WRLCM with reintroduction to evaluate these tradeoffs for varying levels of reintroduction rates.
- Identify which combination of reintroduction rates would lead to a population that is equivalent to the baseline conditions (without reintroduction).
- Identify which combination of reintroduction rates would be sustainable given current levels of bycatch of winter-run Chinook Salmon in the ocean fishery.
- Map the reintroduction rates that lead to equivalent population abundance and that may be sustainable under an ocean fishery to the specific design elements under the two volitional alternatives modeled (a fully volitional passage route via Cow Creek (Feasibility Study of Salmon Passage at Shasta and Keswick Dams [Feasibility Study] Alternative 1; Anchor QEA and HDR 2026) and a semi-volitional passage route over Keswick Dam and to the crest of Shasta Dam (Feasibility Study Alternative 3; Anchor QEA and HDR 2026).

Readers should understand that on December 12, 2025, the Consultant Team received an email stating that the Winnemem Wintu Tribe does not endorse these reports (referring to the Background Compendium and appendices and *Alternatives Formulation and Evaluation Report* [Anchor QEA and HDR 2026]).

Figure 1
Study Area



2 Phase 1

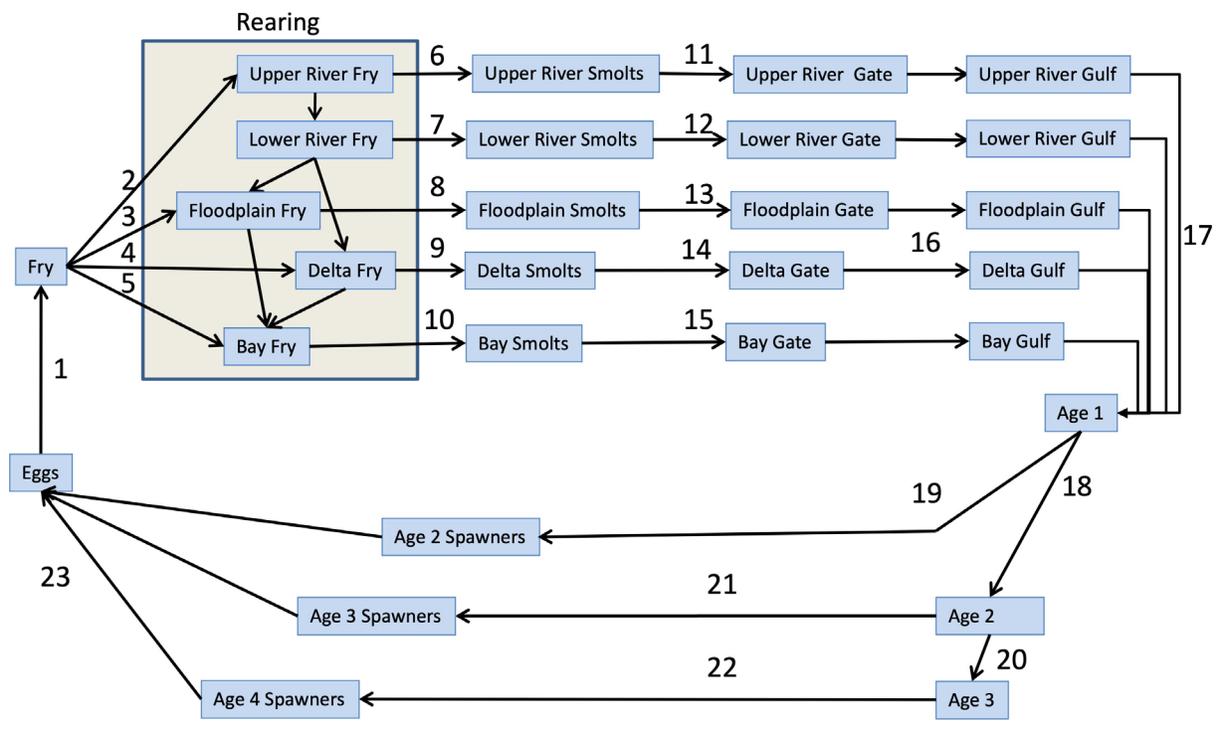
2.1 Methods

A counterfactual analysis, in which the WRLCM was run under a set of conditions from 1995 to 2020, was developed along with a set of scenarios with different levels of survival and passage rates for a hypothetical reintroduction to the Winnemem Waywaket. The WRLCM was utilized for this analysis by varying the amount of TDM under a baseline and under a case where reintroduction was implemented. The WRLCM is a life-cycle model that tracks the abundance of multiple life stages in multiple geographic regions (Figure 2). The stages (boxes) are linked through transition functions that define population vital rates such as survival, movement, or reproduction. The model has a monthly time step in the freshwater life stages and an annual time step in the ocean. Please see Hendrix et al. (2024) for additional details on the WRLCM.

It was assumed that the amount of TDM was 5% and that it only occurred in August in the Winnemem Waywaket. This assumption was based on temperature records on the Winnemem Waywaket that were collected from 2000 to 2010 from a gage near The Nature Conservancy fishing camp. In contrast, the TDM in the Nomtipom Waywaket below Keswick Dam was variable among years (Figure 3). In some years, the TDM values were greater than 0.5, indicating that the majority of eggs deposited in that month succumbed to TDM (e.g., 1977 and 2015). Several scenarios were developed with the following characteristics:

- The reintroduction scenarios start with the adult life stage below Keswick Dam and end with juveniles below Keswick Dam.
- Variable reintroduction quality (i.e., levels of adult to juvenile passage and survival rates). The survival and passage rates over these life stages corresponded to levels of 0.70, 0.75, 0.80, 0.85, and 0.90.
- The WRLCM was run over 1,000 Monte Carlo simulations drawing from the parameter uncertainty.
- For each iteration of the 1,000 simulations, the pairwise differences between the reintroduction action at the specified level and baseline was calculated as $100\% \times (\text{action} - \text{baseline})/\text{baseline}$.

Figure 2
Winter-Run Chinook Salmon Life-Cycle Model Stages and Transitions



Note: The WRLCM consists of stages (boxes) that are connected by transitions that reflect the population vital rates of movement, survival, or reproduction.

2.2 Results

The WRLCM was run for the period 1995 to 2020 and the spawner abundances were compared for the baseline relative to the reintroduction under different levels of quality (i.e., survival and passage rates). The abundance of spawners at a reintroduction quality of 70% was below the baseline spawner abundance, whereas spawner abundance at a reintroduction of 90% was greater than the baseline spawner abundance (Figure 4).

The model simulation results can be summarized by the percent differences in average abundance (1995 to 2020). Under the reintroduction scenarios, the levels of passage and survival for adults below Keswick Dam to juveniles below Keswick Dam would need to be approximately 0.80 to match the abundance levels of winter-run Chinook Salmon spawners in the Nomtipom Waywaket. Passage and survival rates of 0.9 would increase average abundance by 30% over baseline (Table 1).

Figure 3
Temperature-Dependent Mortality in the Nontipom Waywaket Below Keswick Dam for Spawning Initiated in Months 5 to 8 (May to August) Used in the WRLCM

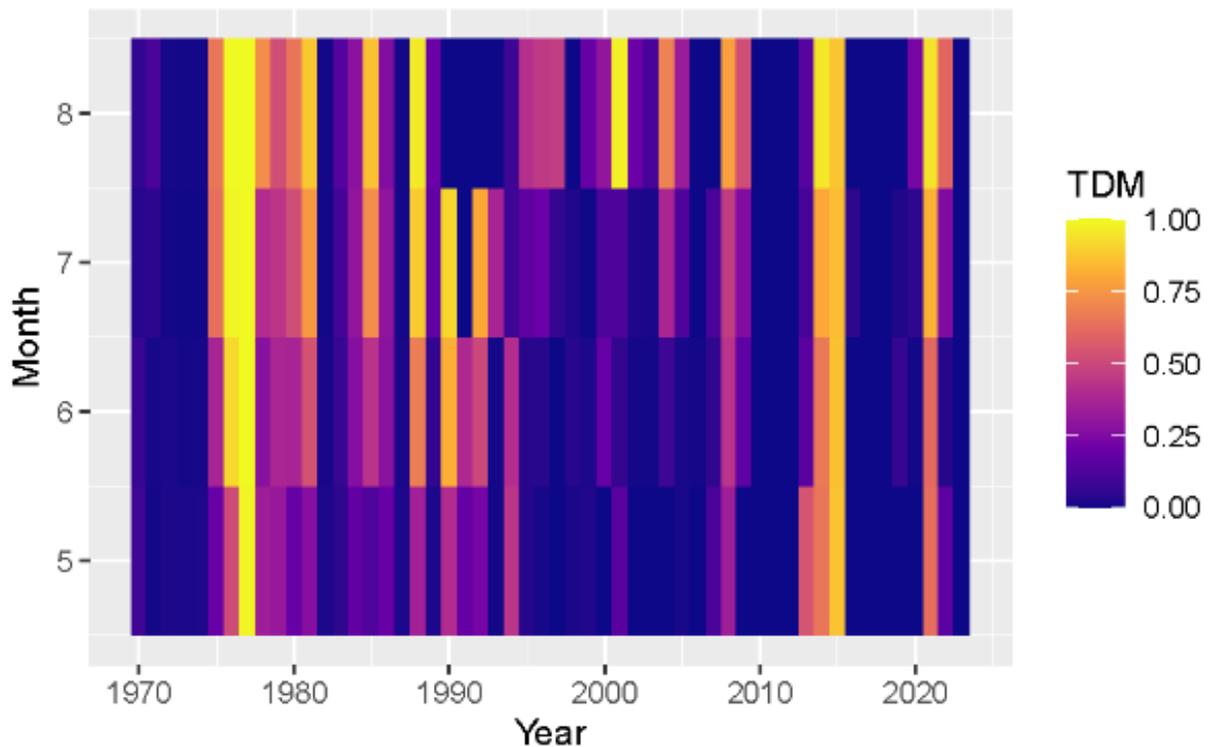
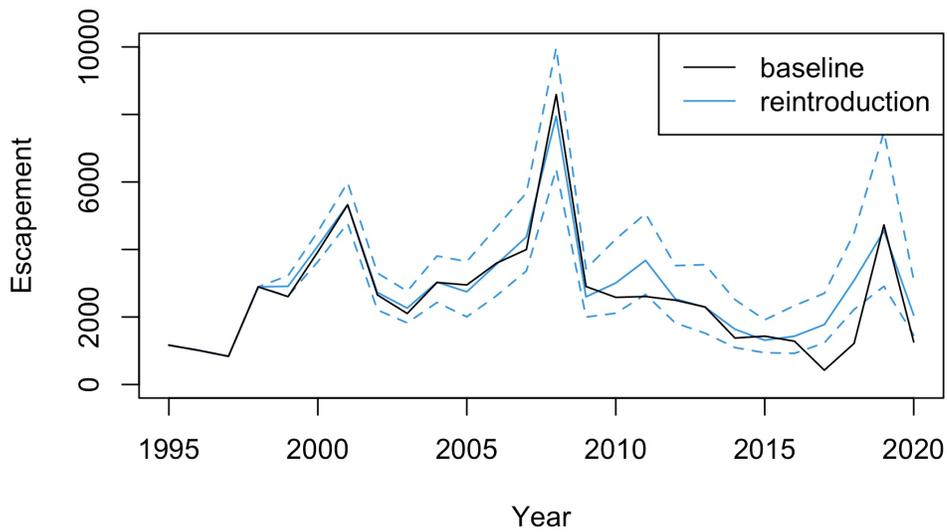
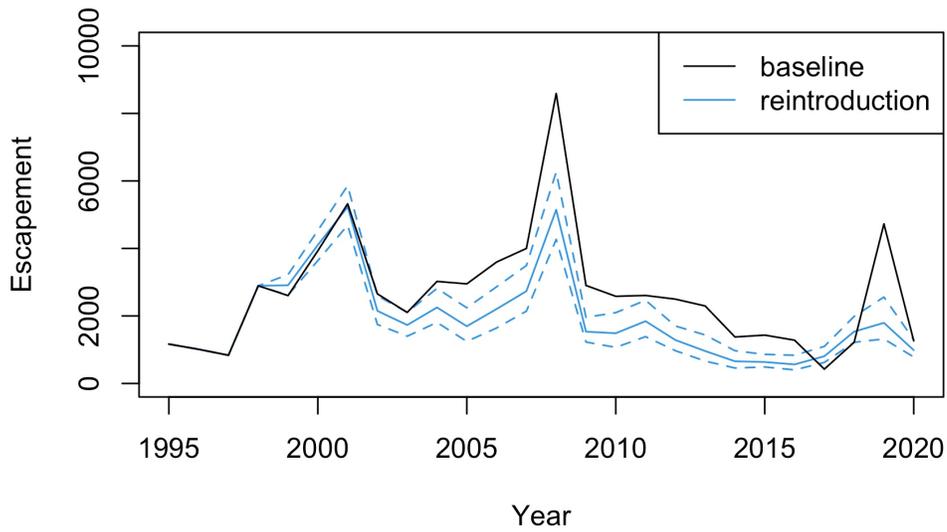


Table 1
Phase 1 Results of Running Reintroduction Scenarios Under Varying Levels of Reintroduction Quality

Level	Median Difference from Baseline (95% Interval)
0.70	-18% (-21%, -15%)
0.75	-8.7% (-11%, -6.1%)
0.80	2.0% (0.0%, 4.0%)
0.85	15% (14%, 16%)
0.90	30% (30%, 31%)

Note:
 "Levels of reintroduction quality" refers to levels of adult to juvenile passage and survival rates.

Figure 4
Phase 1 Model Runs and Confidence Intervals by Varying TDM with a Reintroduction Quality of 0.7 and 0.9



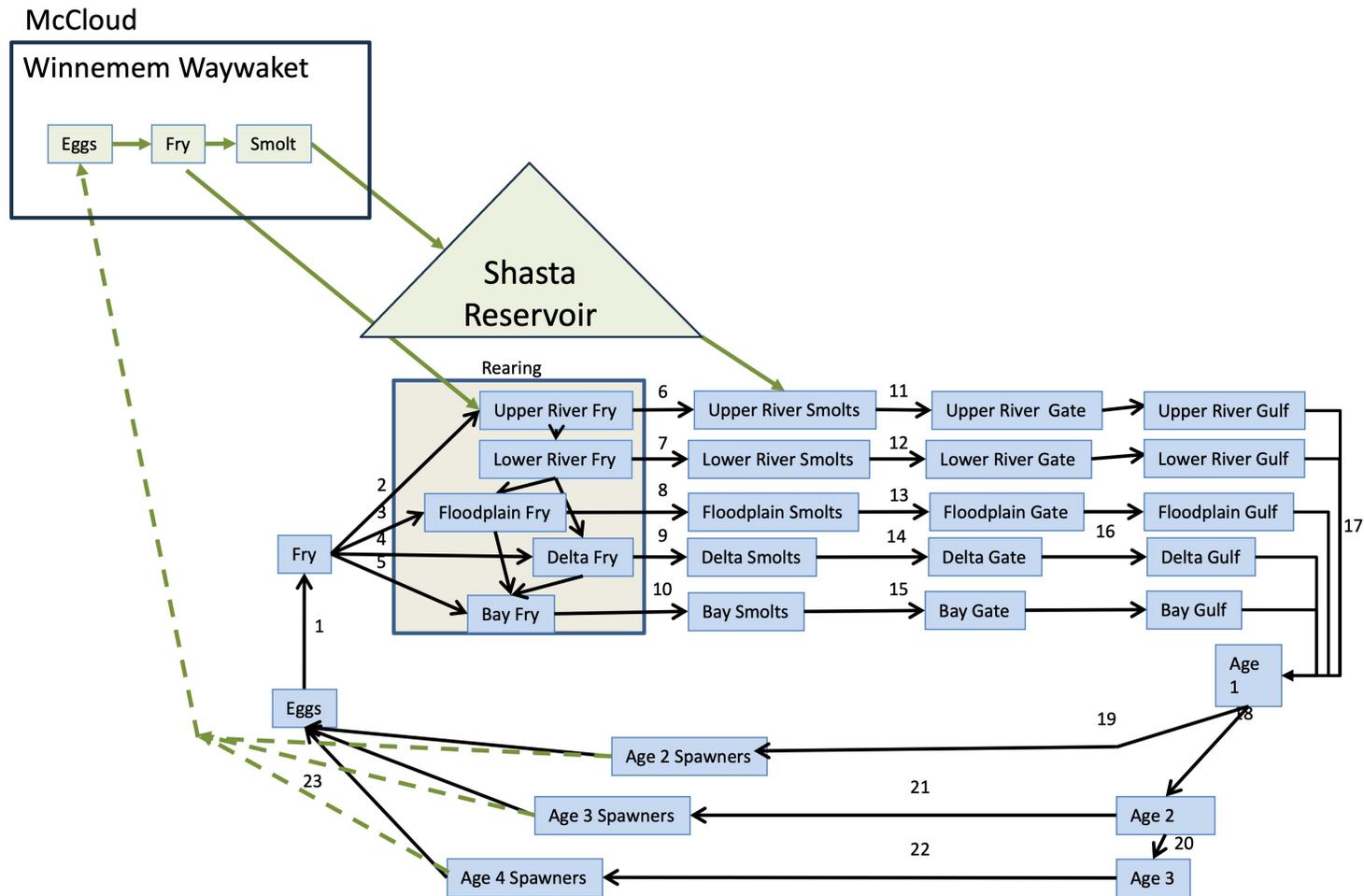
Notes: Phase 1 model runs of median escapement (solid line) and 95% confidence intervals (dashed lines) by varying TDM with a reintroduction quality (i.e., levels of adult to juvenile passage and survival rates) of 0.7 (top) and 0.9 (bottom). The total average population was below the baseline for the reintroduction quality of 0.7 but above the baseline when the quality was approximately 0.8 or higher.

3 Phase 2

3.1 Methods

The Phase 2 approach used the WRLCM with reintroduction to simulate the population trajectory from 1970 to 2020. The role of the WRLCM with reintroduction is to complete the remainder of the life cycle from juveniles in the Nomtipom Waywaket to adults returning to spawn. The reintroduction process provides pathways for adults to reach the Winnemem Waywaket for spawning to occur, and for juveniles to rear and move from the Winnemem Waywaket to the Nomtipom Waywaket (Figure 5). Spawning to juvenile production, egg-to-fry survival, and fry survival functions from the WRLCM are used to model these life-cycle processes in the Winnemem Waywaket.

Figure 5
Winter-Run Chinook Salmon Life-Cycle Model Flow Chart



Note: WRLCM that includes passage for adults to reach the Winnemem Waywaket (dashed green lines), adults to produce juveniles, and for juveniles to return to the Normpom Waywaket through, or around, Shasta Reservoir as fry or smolts (solid green lines).

The adult dynamics include the potential for straying to occur between the reach below Keswick Dam and Winnemem Waywaket-origin Chinook Salmon (Figure 6). In addition, the pathways for adults to reach the Winnemem Waywaket may not be perfect at attracting them, thus the Chinook Salmon of Winnemem Waywaket origin that are not attracted are assumed to spawn in the reach below Keswick Dam.

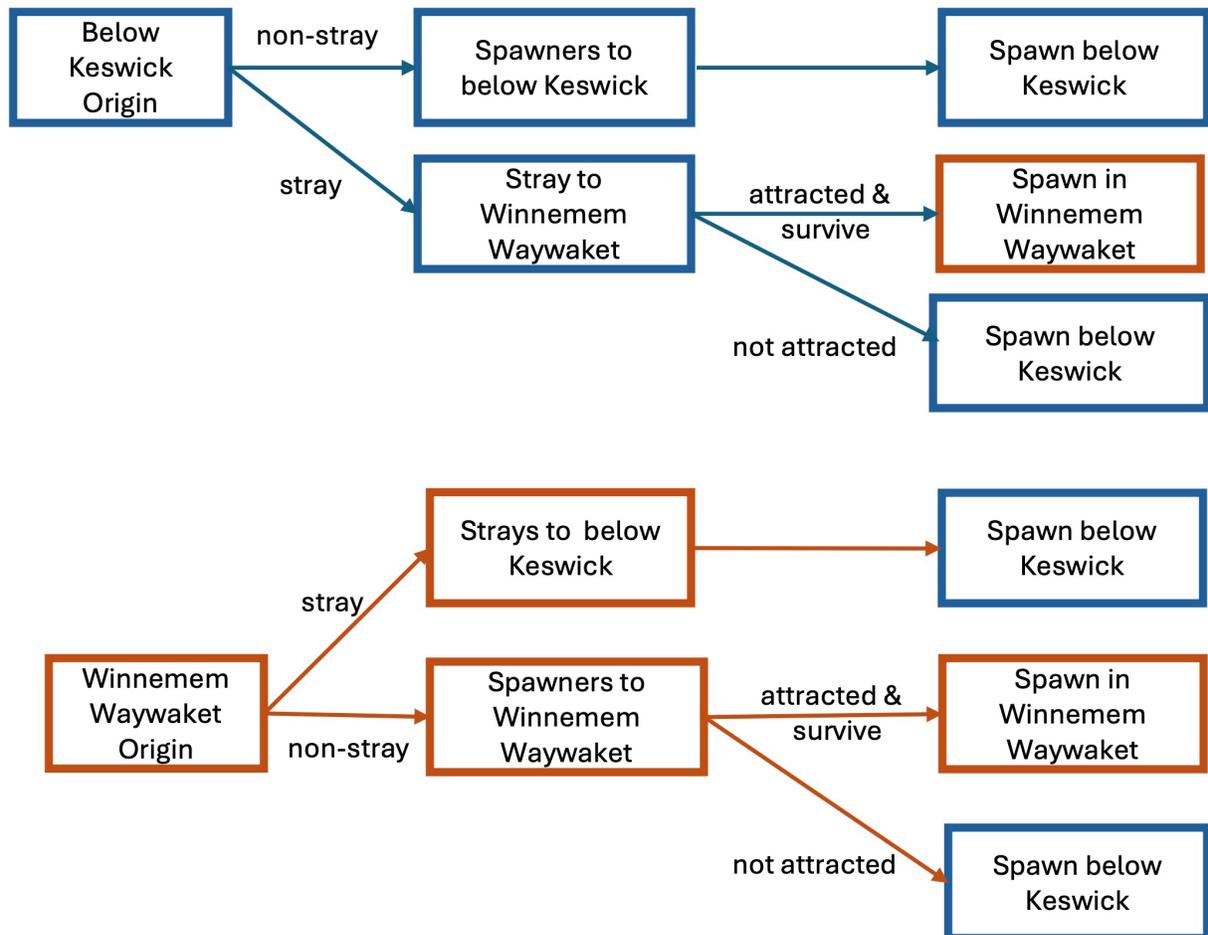
The WRLCM runs were based on conditions from 1970 to 2020, which lead to a 51-year time series for evaluating the performance of the reintroduction alternatives. There are four reintroduction rates that are required to run the reintroduction analyses, and they are defined as follows:

- Adult attraction: The rate at which adult Chinook Salmon heading for Winnemem Waywaket can enter the pathway to that spawning area
- Adult survival: For those Chinook Salmon that are attracted, the proportion that survive through the pathway to the Winnemem Waywaket
- Juvenile guidance or collection: The proportion of juvenile Chinook Salmon that enter the pathway to the Nontipom Waywaket from the Winnemem Waywaket
- Juvenile survival: For those Chinook Salmon that enter the pathway, the proportion that survive from the entrance point to the Nontipom Waywaket

To evaluate the alternatives in the reintroduction, several assumptions were applied to the WRLCM framework

- The initial population abundance was 4,000 spawners, with 70% located below Keswick Dam spawning reach and 30% in the Winnemem Waywaket. For the baseline model run, all 4,000 spawners were located in the spawning reach below Keswick Dam.
- The straying rate between the below Keswick Dam reach and Winnemem Waywaket populations was 10%.
- The out-migration timing of juveniles in the Winnemem Waywaket occurs at a rate of 70% per month after emergence.
- The survival of fry in the Winnemem Waywaket is slightly higher (0.62 per month) than the fry survival in the mainstem Nontipom Waywaket, Yolo bypass, and Delta (0.52 per month).
- The spawner capacity for the Winnemem Waywaket is 4,200 female spawners (Attachment 1).
- Ocean fishery winter-run catch rates in the 1970 to 2020 period reached values of approximately 0.7 in some years. Currently, winter-run catch rates are managed to substantially lower levels, so we adjusted the maximum harvest rates to be 0.2 for age-3 fish and 0.36 for age-4 fish to be consistent with the current winter-run control rule for ocean fishery management (O'Farrell and Satterthwaite 2015).

Figure 6
Adult Spawning Dynamics Used in the WRLCM Evaluation of Chinook Salmon of Below Keswick Dam and Winnemem Waywaket Origin Returning to Spawn



Note: Adult Chinook Salmon follow the pathway that would lead them to their preferred spawning location, which includes straying. Chinook Salmon that are attracted and survive the journey to the Winnemem Waywaket will spawn there. Adult Chinook Salmon from the Winnemem Waywaket that stray, or are not attracted to the Winnemem Waywaket, spawn in the reach below Keswick Dam. Adult Chinook Salmon that stray from the reach below Keswick Dam but are not attracted to the pathway to the Winnemem Waywaket spawn in the reach below Keswick Dam.

To define the baseline condition, which is the population of winter-run Chinook Salmon without reintroduction (lower bookend scenario), we ran the WRLCM under the current physical configuration without pathways to the Winnemem Waywaket. Namely, the baseline condition represented the conditions without the opportunity for reintroduction. There is a period in which the hatchery begins producing juveniles that subsequently return to spawn as adults, and we track these fish in the model as they return and spawn in the reach below Keswick Dam. The baseline differs from the actual historical conditions due to altering the starting abundance and modifying the ocean harvest rates; however, it does represent a reference point from which we can evaluate the

reintroduction under the same set of physical conditions. Finally, the WRLCM run consisted of 100 simulations to incorporate uncertainty in population vital rates (e.g., survival) in the model outcomes.

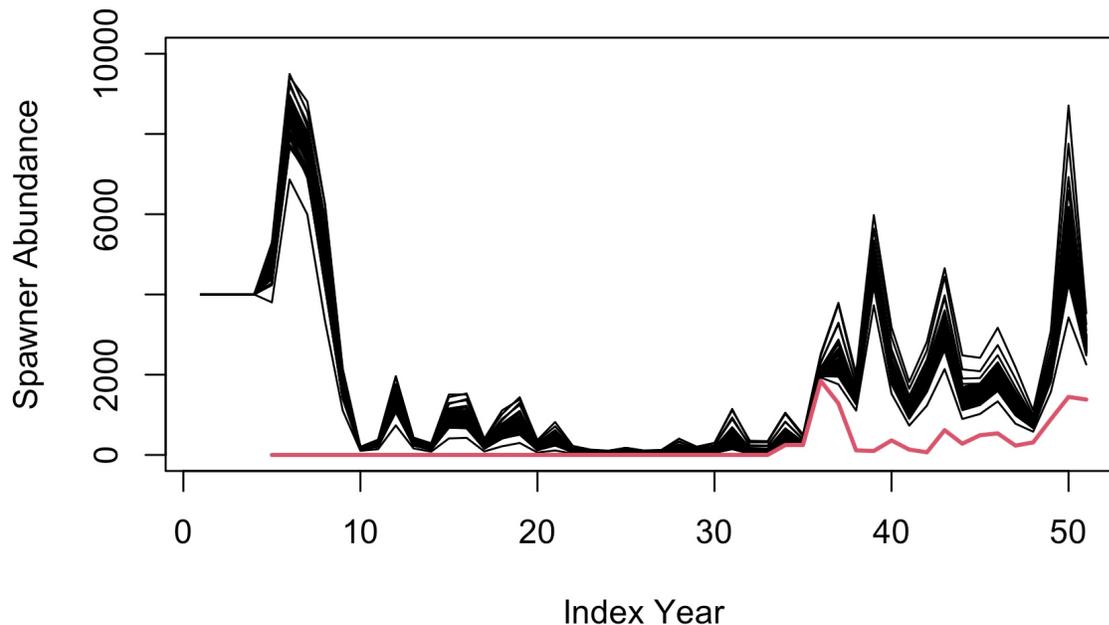
The second model run was a “perfect” reintroduction (upper bookend scenario) in which all the reintroduction rates were set to 1.0. This run represents the theoretical best conditions for reintroduction in terms of the pathway to the Winnemem Waywaket being completely accessible with no additional mortality associated with accessing it relative to the spawning reach below Keswick Dam. Likewise, the juvenile out-migration pathway is completely accessible with no additional mortality associated with their downstream migration.

3.2 Results

3.2.1 *Model Runs for Bookend Scenarios*

Under the baseline (lower bookend scenario), the initial population increases for the first several years after the initial abundance of 4,000 spawners and then declines rapidly due to TDM, reducing survival in the egg-to-fry stage in model index years 9 and 10 (Figure 7). This period corresponded to drought conditions in the late 1970s. While the specific levels of abundance varied among the 100 simulations, the overall pattern was similar (50 simulations were plotted in Figure 7). The population remains below 1,000 spawners until the hatchery release of juveniles in index year 32 return to spawn in index year 35. The population increases and maintains a higher average abundance during index years 35 to 50 due to the production of river spawning adults and consistent hatchery inputs over this period (Figure 7).

Figure 7
Baseline Winter-Run Life-Cycle Model Run



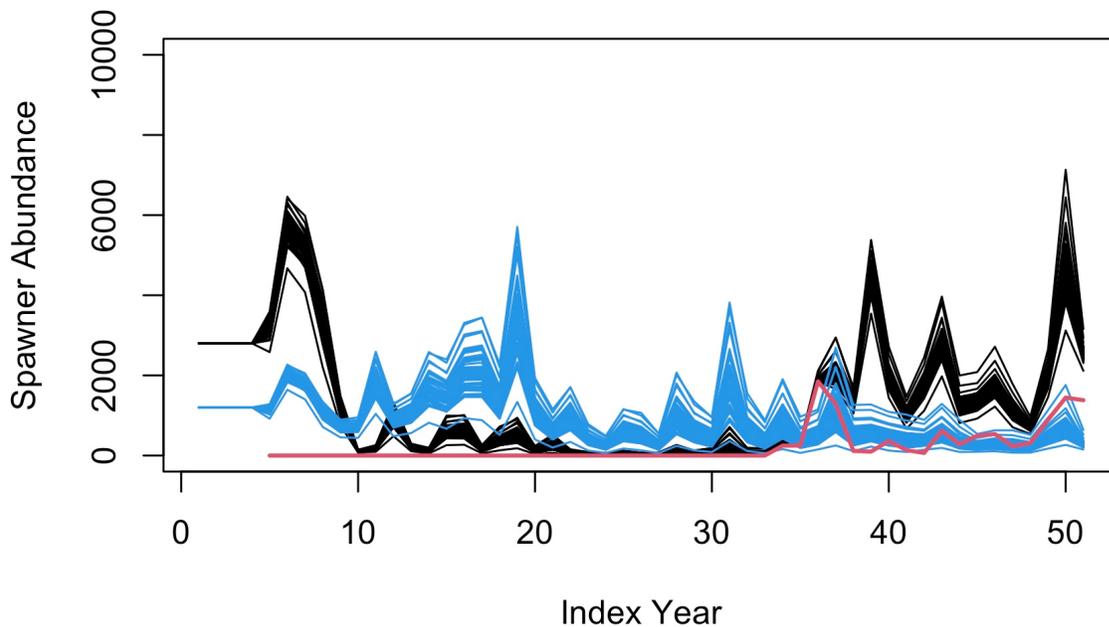
Notes: Baseline (lower bookend scenario) WRLCM run, based on 50 trajectories of the spawner abundance over the 51 years of the modeled time series. Spawner abundance for the spawning reach below Keswick Dam for 50 iterations (black lines) and hatchery-origin spawners (red line).

The perfect model run (upper bookend scenario) showed a similar trend in abundance for the population spawning below Keswick Dam but a distinctly different population trajectory for the Winnemem Waywaket population (Figure 8). The population remains stable over index years 9 to 20 as the Winnemem Waywaket does not experience the same thermal conditions as the population spawning in the reach below Keswick Dam. The Winnemem Waywaket population remains at an abundance higher than the population spawning in the reach below Keswick Dam for model index years 10 to 35. The population spawning in the reach below Keswick Dam surpasses it when the hatchery begins producing spawners that return to the population that spawns below Keswick Dam in model index year 35. The Winnemem Waywaket population declines over the last 15 index years of the time series, driven in part by a reduction in later life stage survival (e.g., smolt and early ocean life stages; (Figure 8).

The time series of abundance values shows how the Winnemem Waywaket population and population spawning below Keswick Dam covary over the modeled time period. For much of the

time series, the Winnemem Waywaket and below Keswick Dam populations are moving out of phase with each other (Figure 8). The two subpopulations are varying asynchronously due to the low correlation in productivities of each subpopulation. The result is a more resilient population overall. This type of portfolio effect has been missing in much of the Chinook Salmon dynamics in the Central Valley (Carlson and Satterthwaite 2011); therefore, it is encouraging to see the potential for these dynamics with reintroduction to the Winnemem Waywaket.

Figure 8
Perfect Reintroduction Winter-Run Chinook Salmon Life-Cycle Model Run



Notes: All collection and survival levels are set to 1.0. Below Keswick spawner abundance (black lines) for 50 simulations and hatchery-origin spawners (red line). Winnemem Waywaket spawner abundance (blue lines) for 50 simulations of the WRLCM with reintroduction

3.2.2 Model Runs for Reintroduction Rates

To evaluate reintroduction rates, the WRLCM with reintroduction was run under multiple possible combinations of adult attraction, adult survival, juvenile guidance/collection and juvenile survival. The approach was to build all combinations of these four reintroduction rates at the levels of (0.8, 0.85, 0.9, and 0.95). This approach resulted in 256 ($4^4 = 256$) combinations and thus 256 distinct runs of the WRLCM with reintroduction. The term “scenario” is used to refer to a specific combination of the

four reintroduction rates. Thus, we used the WRLCM with reintroduction to run 256 scenarios and evaluate each scenario according to the following objectives:

1. The reintroduction rates lead to average total abundance across the Keswick and Winnemem Waywaket populations that are equal to or above the average abundance from the baseline model run.
2. The reintroduction rates meet Objective No. 1 and the combined population has the potential to be sustainable under catch of winter-run Chinook Salmon in ocean fisheries.

3.2.2.1 Metrics

We developed two metrics to identify those scenarios that were consistent with these objectives. The first metric was developed to evaluate the abundance levels of the populations relative to the baseline. The abundance metric uses the abundance of the combined Winnemem Waywaket and below Keswick Dam populations for the reintroduction scenarios due to the adult spawning dynamics being interconnected (e.g., Figure 5).

To calculate the average abundance, we averaged across all simulations of the spawning adults for the model years 10 to 51. Using this time frame allowed the model to equilibrate after the initial abundances. Under the reintroduction, there are two populations being tracked in the model $p = 2$, and we sum across the spawners in each population.

$$\bar{A} = \frac{1}{M \times 42} \times \sum_{j=1}^M \sum_{t=10}^{51} \sum_{p=1}^2 S p_{p,t,j}$$

where $j=1,\dots,M$ is the number of simulations. If the reintroduction increased performance compared to the baseline, the average abundance will be greater than the baseline abundance. The baseline average spawner abundance was calculated from years 10:51 across 100 simulations and the value was 1,084.

To evaluate the probability that the reintroduction scenario would be greater than the baseline across multiple states of nature, we can compare the average abundance in spawners for years 10:51 for each simulation of the WRLCM with reintroduction. That is, how many of the 100 simulations had higher average abundance under reintroduction than under the baseline? Thus, for each simulation, the level of abundance for years 10:51 is

$$A_j = \frac{1}{42} \times \sum_{t=10}^{51} S p_{j,t}$$

which results in a vector of 100 abundance values, one for each simulation.

The probability of a scenario being greater than the average baseline can be calculated as the proportion of the simulations in which the average scenario abundance for years 10:51 for simulation j is greater than the average baseline abundance.

$$\Pr(A_s \geq \bar{A}_b) = \frac{1}{M} \sum_{j=1}^M I(A_{s,j} - \bar{A}_b)$$

where $I(x)$ is the indicator function that evaluates to 1 when $x \geq 0$. The first metric (M1) that we used to evaluate the reintroduction scenarios is the probability that the combined abundance of spawners under the reintroduction is greater than the baseline average.

$$M1_s = \Pr(A_s \geq \bar{A}_b)$$

The second metric is based on population productivity to categorize the scenarios. The cohort replacement rate (CRR) is a quantity that reflects the ability of the population to replace itself and therefore provides an index on the sustainability of the population. The CRR is defined as:

$$CRR_t = \frac{\sum_{sex=1}^2 \sum_{a=2}^4 R_{sex,a+t}}{Sp_t}$$

where spawners from brood year t Sp_t generate adults that return in the absence of harvest at age a in year $a+t$, R_{a+t} . Both sexes are tracked in the CRR metric. When we have multiple populations that are interacting due to potential straying between them, then we calculate the CRR for all of the populations by summing across both populations.

$$CRR_t = \frac{\sum_{p=1}^2 \sum_{sex=1}^2 \sum_{a=2}^4 R_{p,sex,a+t}}{\sum_{p=1}^2 Sp_{p,t}}$$

A quantity that is related to the CRR is a metric that reflects the probability that the population would be sustainable under harvest (SUS). The SUS metric removes fish due to harvest and evaluates whether the population is still sustainable. The SUS metric is calculated for a year t as:

$$SUS_t = \frac{\sum_{p=1}^2 \sum_{sex=1}^2 \sum_{a=2}^4 (1 - H_a) R_{p,sex,a+t}}{\sum_{p=1}^2 Sp_{p,t}}$$

where H_a is the harvest rate at age a and the equation is otherwise equivalent to the CRR equation. The second metric (M2) is whether the average SUS value is greater than 1.0 and it is calculated as:

$$M2_s = \overline{SUS}_s$$

We used the metrics defined above to filter each of the 256 scenarios. The following tiers were constructed to place each of the scenarios into one of the following tiers:

- Tier 1: The average abundance of the reintroduction was less than or equal to the average baseline abundance with a probability of ≤ 0.5 , i.e., $M1s \leq 0.5$.
- Tier 2: The average abundance of the reintroduction was greater than the average baseline abundance with a probability of > 0.5 , i.e., $M1s > 0.5$.
- Tier 3: All scenarios in Tier 1 and in addition the average sustainability metric was greater than 1.0, i.e. $M2s > 1.0$.

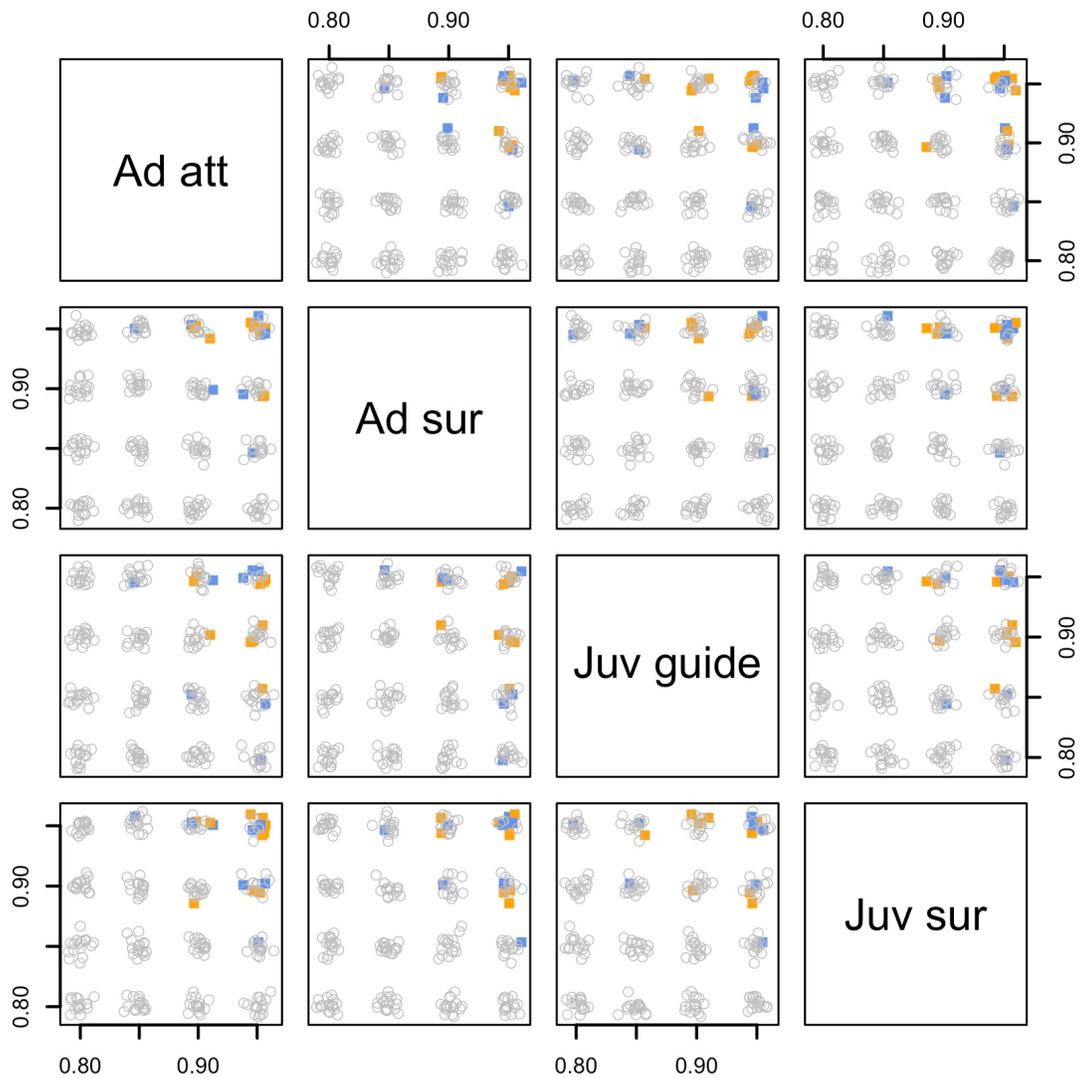
3.2.2.2 Results for Reintroduction Rates

Running the 256 combinations resulted in a tier designation for all combinations of the four levels of the four rates (the adult attraction, adult survival, juvenile guidance/collection, and juvenile survival). To visualize the relationships among a 4D parameter space, we plotted all pairwise combinations among the four reintroduction rates (Figure 9). The diagonal indicates the reintroduction rate that is being plotted on that row and column. For example, the second column and first row plots the tier values of adult attraction versus adult survival. This plot is equivalent to the second row and first column, which also plots the tier values of adult attraction and adult survival.

Each panel shows the results of the 256 combinations with coloring to identify whether that combination (along with the values from the two other rates) resulted in Tier 1, Tier 2, or Tier 3 outcomes. The majority of the reintroduction rate scenarios were in Tier 1, which corresponded to the probability of average abundance under the scenario below the baseline (Figure 9). For adult attraction, adult survival, juvenile guidance/collection, and juvenile survival, the patterns in non-Tier 1 outcomes were similar; Tier 2 and Tier 3 outcomes were associated with the upper right corner of the panel. The upper right corner is where the highest rates were operating in combination to create higher abundance (Tier 2) and productivity (Tier 3) outcomes (Figure 9). Generally, most of the Tier 2 and Tier 3 outcomes were at reintroduction rates of 0.90 to 0.95; however, there were not many combinations that lead to those tiers (Figure 9).

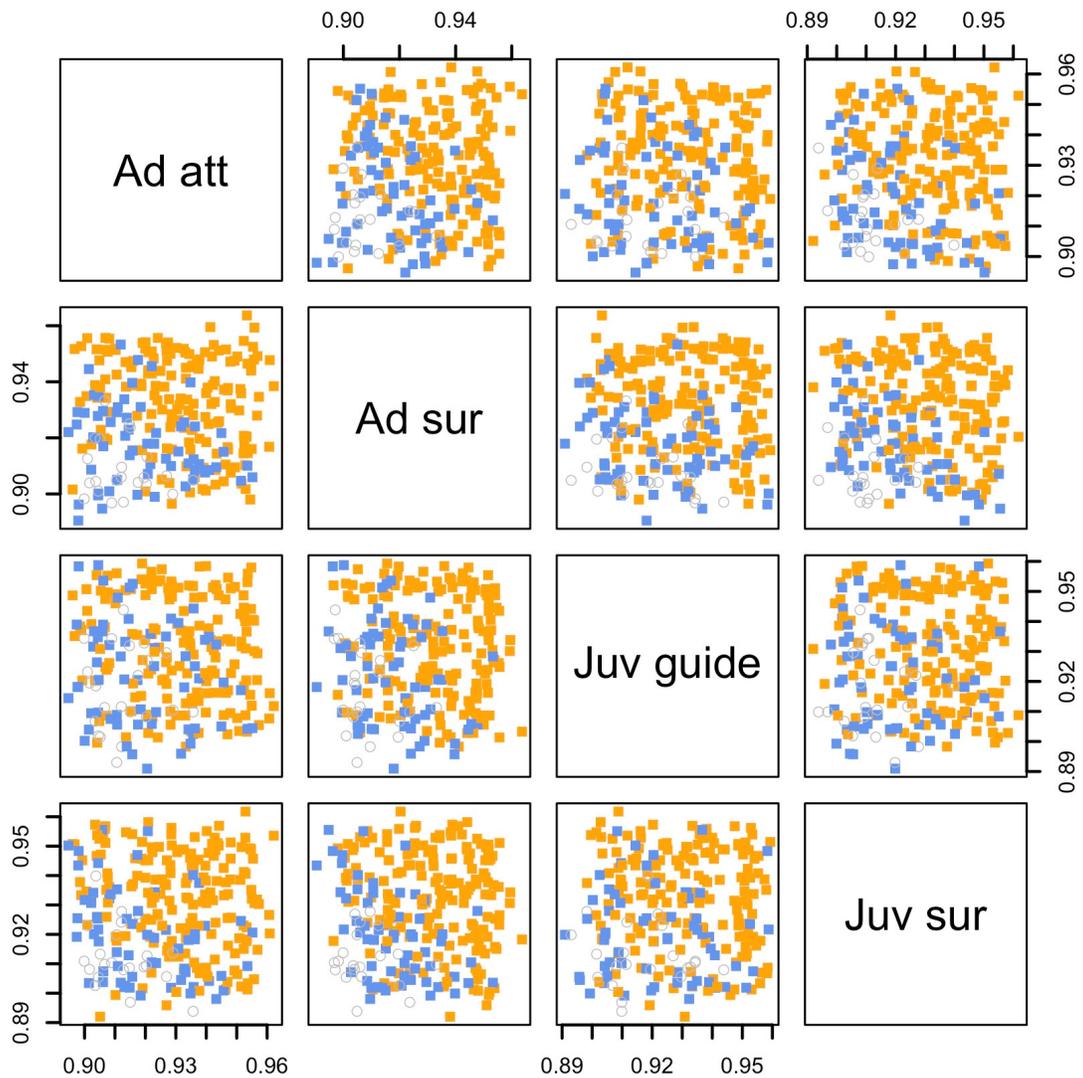
To evaluate this range of reintroduction rates more fully, we reran the WRLCM with reintroduction under a new set of combinations for the four reintroduction rates at four levels in the range of 0.90 to 0.95 (0.905, 0.920, 0.935, and 0.950). The second set of values provided a better view of the regions in which Tier 2 and Tier 3 results diverge (Figure 10). Generally, values of the reintroduction rates greater than 0.92 resulted in Tier 3 outcomes, whereas values below 0.92 resulted in Tier 2 and some Tier 1 outcomes.

Figure 9
Evaluation of 256 Combinations of the Reintroduction Rates of Adult Attraction, Adult Survival, Juvenile Guidance/Collection, and Juvenile Survival (Variation 1)



Notes: Evaluation of 256 combinations of the reintroduction rates of adult attraction (Ad att), adult survival (Ad sur), juvenile guidance/collection (Juv guide), and juvenile survival (Juv sur). Gray circles indicate Tier 1 combinations, blue squares indicate Tier 2 combinations, and the orange squares indicate Tier 3 combinations. Combinations at design points (0.80, 0.85, 0.90, and 0.95) have been jittered to facilitate the visualization.

Figure 10
Evaluation of 256 Combinations of the Reintroduction Rates of Adult Attraction, Adult Survival, Juvenile Guidance/Collection, and Juvenile Survival (Variation 2)



Notes: Evaluation of 256 combinations of the reintroduction rates of adult attraction (Ad att), adult survival (Ad sur), juvenile guidance/collection (Juv guide), and juvenile survival (Juv sur). Gray circles indicate Tier 1 combinations, blue squares indicate Tier 2 combinations, and the orange squares indicate Tier 3 combinations. Combinations at design points (0.905, 0.920, 0.935, and 0.95) have been jittered to facilitate the visualization

3.1 Linking Reintroduction Rates to Alternatives

There are two volitional or semi-volitional alternatives that are being considered in this analysis, Alternative 1 and Alternative 3 from the Feasibility Study (Anchor QEA and HDR 2026).

In Alternative 1, adult Chinook Salmon returning to the Nomtipom Waywaket enter Cow Creek and continue up Dry Creek to the crest of the natural channel where they enter a constructed channel that terminates in the Winnemem Waywaket (Figure 11). The adults spawn in the Winnemem Waywaket and produce juveniles in which the egg-to-fry mortality is minimized due to the generally cool stream temperatures. Juveniles in the Winnemem Waywaket are then guided into the constructed channel that returns them to the natural channel and then the Nomtipom Waywaket via a similar route as the adults (Figure 11).

In Alternative 3, adults pass through a ladder at Keswick Dam and enter Keswick Reservoir and migrate upstream to Shasta Dam, where they are guided by a structure into a technical fish ladder that takes them to the Shasta Dam crest (Figure 12). They pass through a temperature-controlled acclimation and release structure and are released into Shasta Reservoir, where they migrate to the Winnemem Waywaket to spawn. Juveniles are routed into a collection facility and taken to Shasta Dam where they are released into the lower sections of the technical fish ladder, enter Keswick Reservoir, travel through the Keswick Reservoir, and pass through the Keswick Dam and into the Nomtipom Waywaket below the dam (Figure 12).

Each of the design elements under each of the alternatives (e.g., Figures 11 and 12) can be mapped to one of the reintroduction rates of adult attraction, adult survival, juvenile guidance/collection, or juvenile survival. There is also another option called “trap and haul” that is provided as a point of comparison. We provide the mapping of the reintroduction rates to the design elements under each of the alternatives and trap and haul (Table 2).

Table 2
Mapping of Design Components to Reintroduction Rates in Alternatives 1 and 3 and Trap and Haul

Reintroduction Rate	Alternative 1	Alternative 3	Trap and Haul
Adult Attraction	<ul style="list-style-type: none"> • Proportion of adults into Cow Creek 	<ul style="list-style-type: none"> • Percent of adults through the Keswick fish ladder • Percent through Keswick Reservoir • Percent into guidance structure • Percent to Shasta Dam crest 	<ul style="list-style-type: none"> • Percent of adults through the Keswick fish ladder • Percent through Keswick Reservoir • Percent into guidance structure • Percent through ladder at Shasta Dam
Adult Survival	<ul style="list-style-type: none"> • Percent of adults to top of natural channel • Percent of adults through constructed channel into the Winnemem Waywaket 	<ul style="list-style-type: none"> • Percent through temperature control structure • Percent through Shasta Reservoir 	<ul style="list-style-type: none"> • Percent through sorting facility • Percent survive trucking
Juvenile Guidance	<ul style="list-style-type: none"> • Percent through guidance structure into constructed channel 	<ul style="list-style-type: none"> • Percent through collection facility on the Winnemem Waywaket 	<ul style="list-style-type: none"> • Percent through collection facility on the Winnemem Waywaket
Juvenile Survival	<ul style="list-style-type: none"> • Percent of juveniles through constructed channel and into the Nomtipom Waywaket 	<ul style="list-style-type: none"> • Percent survive trucking to Shasta Dam • Percent survive sorting facility • Percent to Keswick Dam • Percent through surface flow outlet 	<ul style="list-style-type: none"> • Percent survive trucking to Shasta Dam • Percent survive sorting facility • Percent to Keswick Dam • Percent through surface flow outlet

Figure 11
Schematic of Alternative 1 for Reintroduction of Chinook Salmon Upstream of Shasta Dam

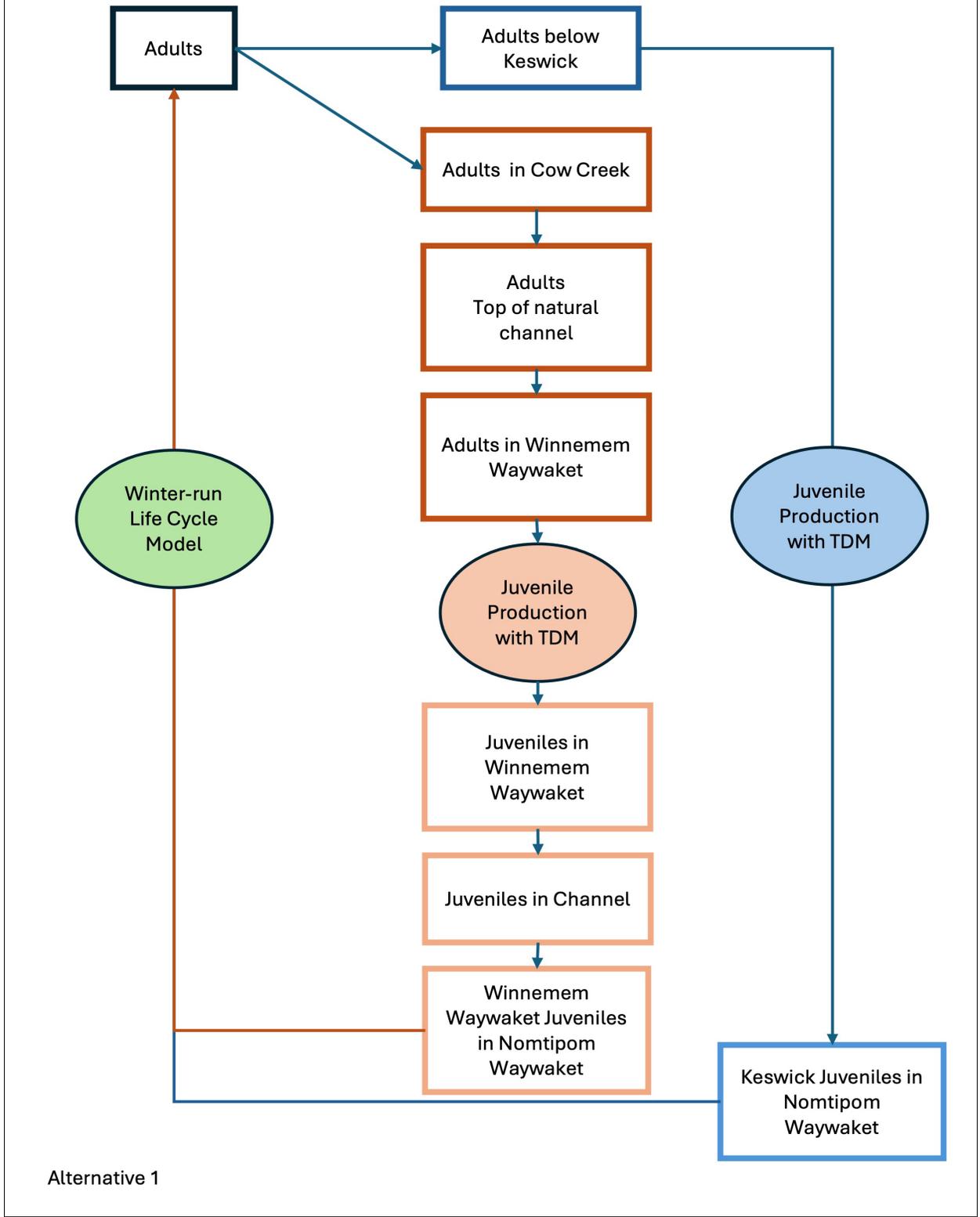
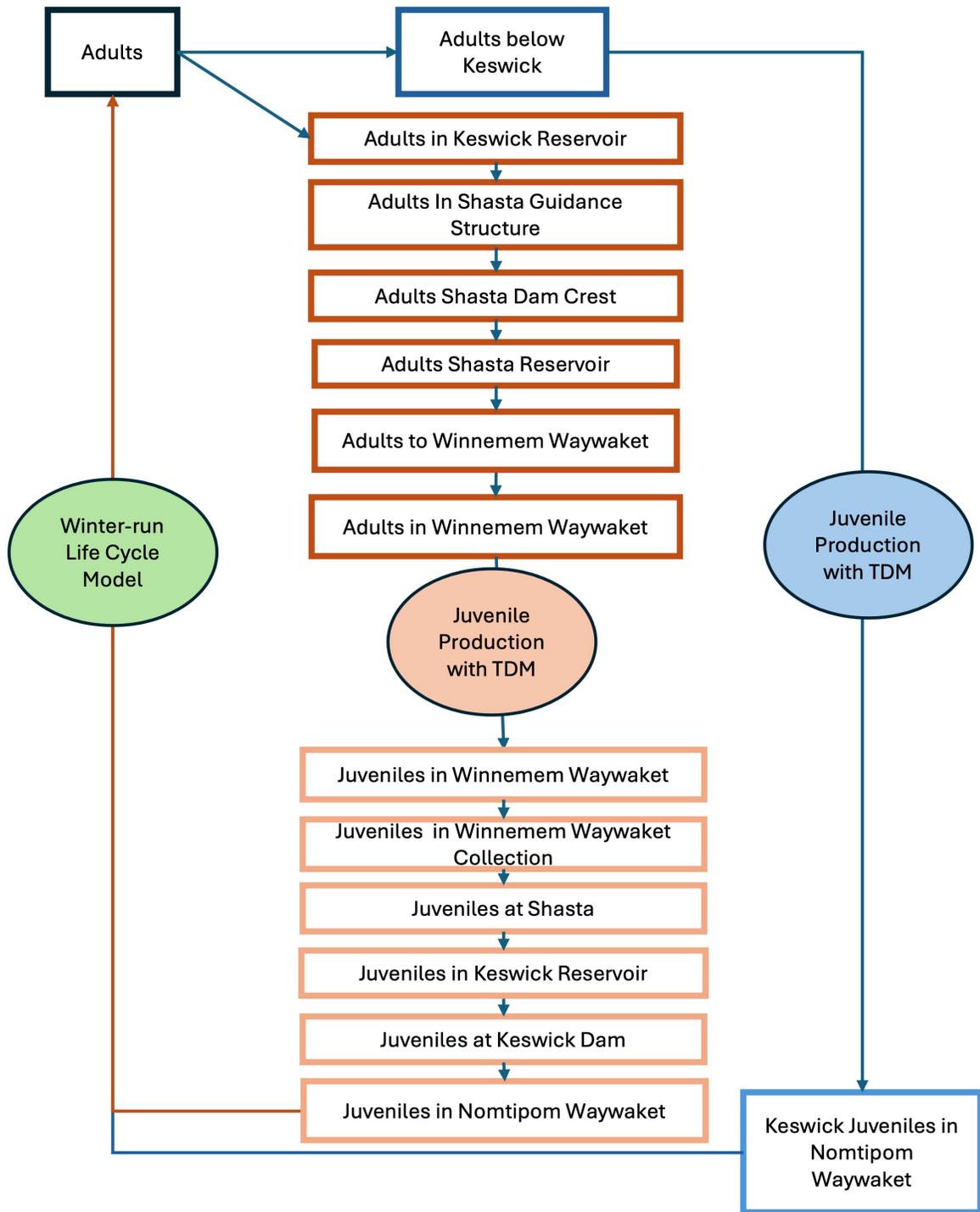


Figure 12
Schematic of Alternative 3 for Reintroduction of Chinook Salmon Upstream Of Shasta Dam



Alternative 3

For each of the design elements, low, most likely, and high values can be provided to reflect the expected performance of these elements. For example, the expected proportions of Chinook Salmon attracted to the ladder at the Keswick Dam can be described with a low value of 0.90, most likely value of 0.95, and high value of 0.98 (Figure 13). Similarly, other design elements may be described with their own set of low, most likely, and high values, such as for Keswick Reservoir passage, Shasta attraction, and Shasta ladder passage (Figure 13).

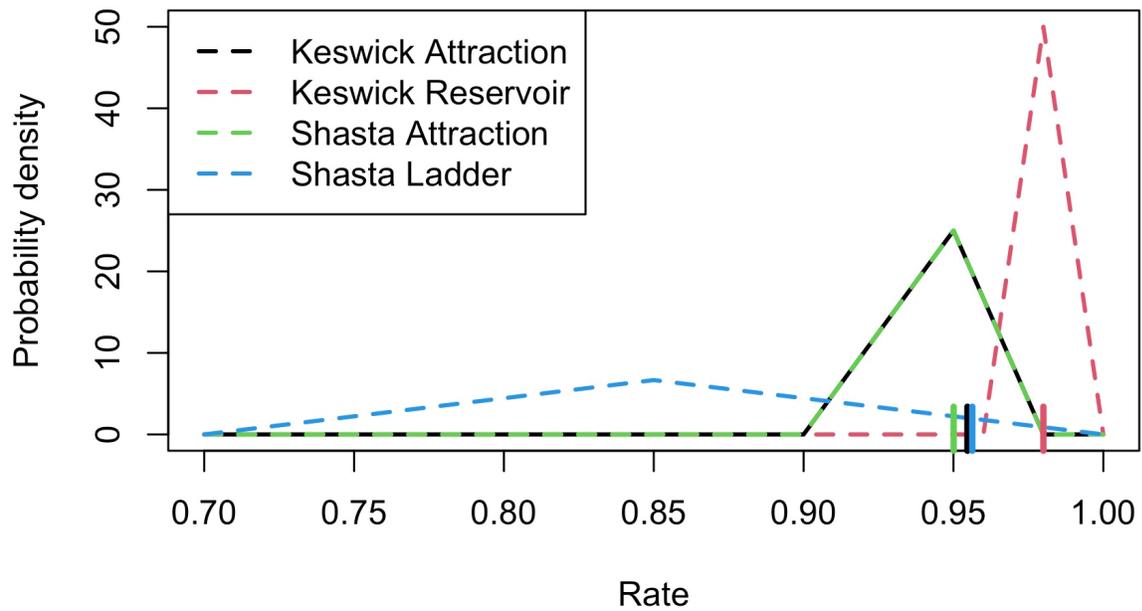
There are many combinations of design elements that can equate to the biological rate that they affect. For example, under Alternative 3, the adult collection rate is a combination of the following design elements: percent of adults through the Keswick fish ladder, percent through Keswick Reservoir, and percent into guidance structure (Table 2). In order to identify the most likely combination of each of the design elements that equate to a biological rate, we used a triangular distribution to reflect the low, mid, and maximum values for each of the design elements. (See Attachment 2 for details on the estimated ranges for each design element under Alternatives 1 and 3.)

In Figure 13, the triangular distributions are plotted for each of the design elements that contribute to adult collection under Alternative 3. There is a unique solution to the optimization problem that maximizes the total probability across all distributions subject to a constraint that the product of the element values must equal the biological rate. For example, given an overall adult collection rate of 0.85, the most likely combination of the four underlying design elements is represented by the colored bars (rugs) on the x-axis in Figure 13. In a similar way, the most likely combination can be calculated for any value of the adult collection that is within the range of the combinations of the underlying elements. We used this approach to map the design element values in each of the alternatives to the biological rates that were then applied in the life-cycle model.

Under Alternative 1, the reintroduction rates map almost directly to the design elements; however, under Alternative 3 there are multiple design elements under each reintroduction rate (Table 2). The result of applying the adult collection reintroduction rate to the design elements under Alternative 3 are plotted in Figure 14. The dependence structure among the design elements is apparent in the relationships between the adult attraction elements (overall pattern of points running from lower left to upper right corner). There is some variation among the bivariate plots, but in general the elements at levels greater than 0.96 lead to Tier 2 and Tier 3 outcomes (Figure 14). The combinations for all design elements across all reintroduction rates for Alternative 3 are provided in Figure 15 for design elements related to adult reintroduction rates and Figure 16 for design elements related to juvenile reintroduction rates. The same general patterns are apparent under Alternative 3, with rates in the range 0.95 to 0.98 leading to Tier 3 and Tier 2 outcomes with lower rates resulting in Tier 1 outcomes. Generally, those elements that are more uncertain (e.g., adult passage to the Shasta Crest) show more separation in the rates needed to achieve Tier 2 and Tier 3 outcomes relative to elements that are less uncertain and concentrated at high rates (e.g., Keswick Reservoir passage; Figure 15).

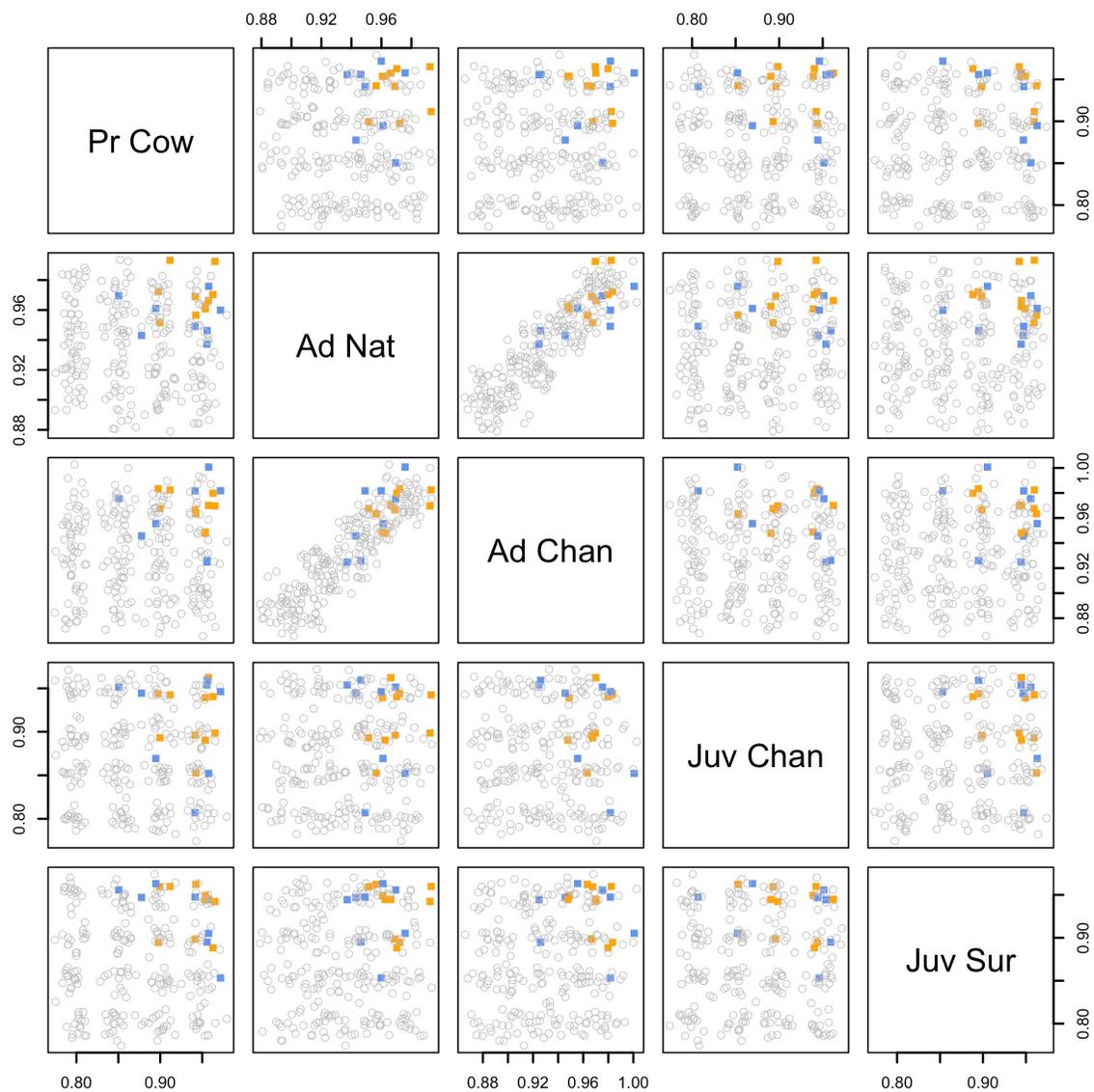
Similar patterns are apparent in the juvenile design elements under Alternative 3. For example, juvenile guidance is more uncertain than juvenile trucking rates (Figure 16).

Figure 13
Triangular Probability Distributions for the Four Engineering Elements Associated with Adult Collection Under Alternative 3



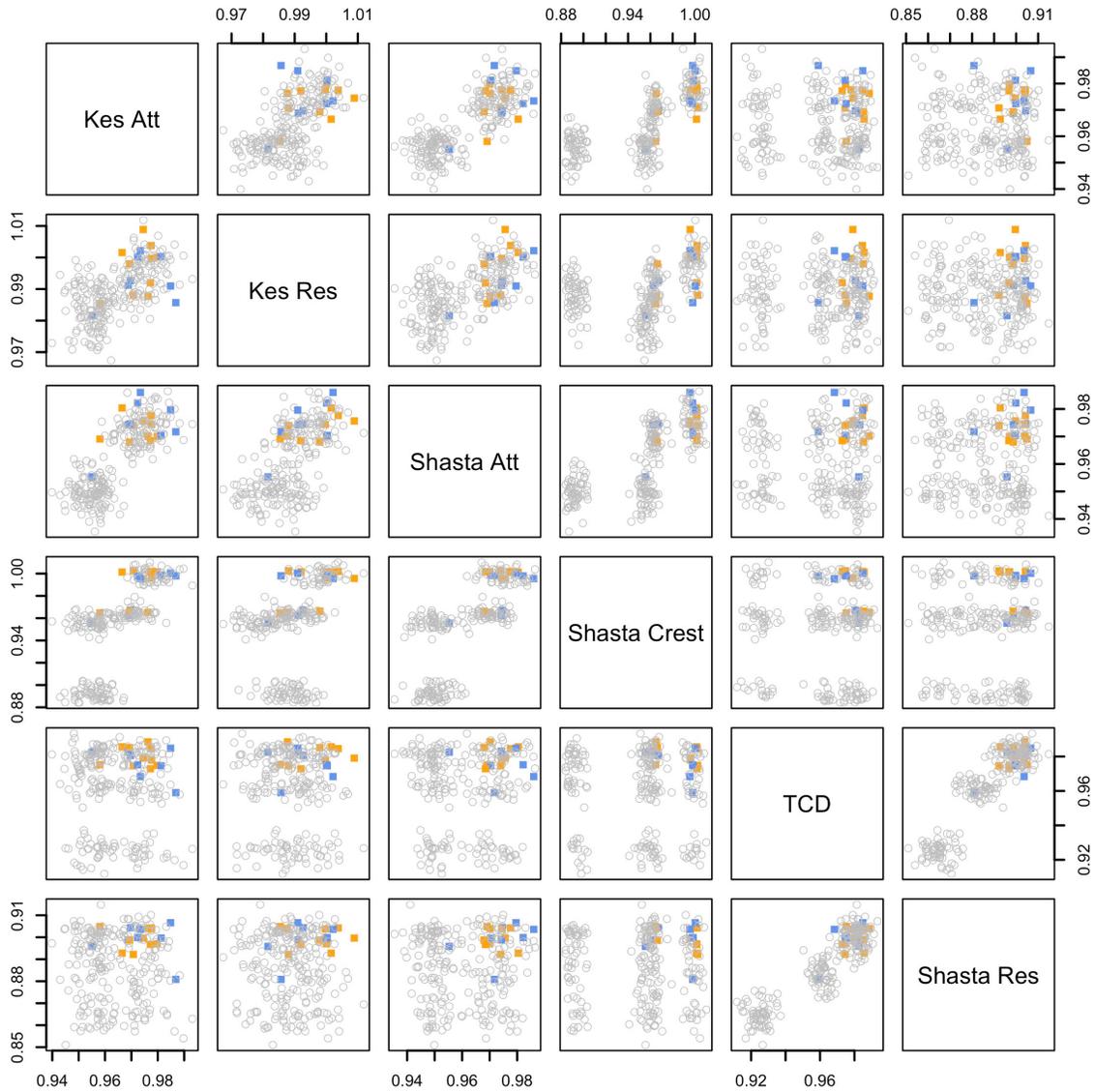
Notes: Triangular probability distributions defined by low, mid, and high levels for each of the four engineering elements (Keswick attraction, Keswick Reservoir passage, Shasta attraction, and Shasta ladder passage) associated with adult collection under Alternative 3 (dashed lines). For a total adult collection rate of 0.85, the most likely level of each engineering element that equals the overall collection rate (colored rugs on the x-axis).

Figure 14
Mapping of 256 combinations of the Design Elements Related to All Four Reintroduction Rates Under Alternative 1



Notes: Gray circles indicate Tier 1 combinations, blue squares indicate Tier 2 combinations, and orange squares indicate Tier 3 combinations. Combinations have been jittered to facilitate the visualization. Pr Cow is the proportion of adults that turn into Cow Creek; Ad Nat is the proportion of adults that survive the natural channel; Ad Chan is the proportion of adults that make it through the constructed channel and into the Winnemem Waywaket; Juv Chan is the proportion of fish that are guided into the constructed channel; and Juv Sur is the proportion of juveniles that survive the constructed and natural channel and make it to the Nontipom Waywaket.

Figure 15
Mapping of 256 Combinations of the Design Elements Related to the Adult Reintroduction Rates Under Alternative 3



Notes: Gray circles indicate Tier 1 combinations, blue squares indicate Tier 2 combinations, and the orange squares indicate Tier 3 combinations. Combinations at design points related to reintroduction rates of (0.80, 0.85, 0.90, and 0.95) have been jittered to facilitate the visualization. Kes Att is the percent of adults that make it through the Keswick fish ladder; Kes Res is the percent of adults that travel through Keswick Reservoir; Shasta Att is the percentage of adults that go into the guidance structure; Shasta Crest is the percent of adults that make it to Shasta Dam crest; TCD is the percent that make it through the temperature control structure; and Shasta Res is the percentage of fish that make it through Shasta Reservoir.

Figure 16
Mapping of 256 Combinations of the Design Elements Related to the Juvenile
Reintroduction Rates Under Alternative 3



Notes: Gray circles indicate Tier 1 combinations, blue squares indicate Tier 2 combinations, and the orange squares indicate Tier 3 combinations. Combinations at design points related to reintroduction rates of (0.80, 0.85, 0.90, and 0.95) have been jittered to facilitate the visualization. Juv Guide is the percent of juveniles that make it through the collection facility on the Winnemem Waywaket; Juv Truck is the percent that survive trucking to Shasta Dam; Juv Sort is the percent that survive the sorting facility; Juv Kes is the percent that survive to Keswick Dam; and Juv Out is the percent that survive the surface flow outlet.

4 Summary, Caveats, and Potential Additional Evaluations

4.1 Phase 1

One of the benefits to Chinook Salmon of the Winnemem Waywaket ecosystem is the consistently cool water temperatures during the summer. These environmental conditions can reduce the thermal mortality that eggs deposited by Chinook Salmon in the reach below Keswick Dam experience during summer and fall in many years. We can evaluate the advantages of spawning in the Winnemem Waywaket relative to spawning below Keswick Dam by evaluating the TDM in each of those locations.

A reintroduction scenario in which winter-run Chinook Salmon were allowed to access the Winnemem Waywaket with passage and survival and passage rates of 0.8 would lead to a spawner abundance that was approximately equivalent to the historical spawner average (1995 to 2020). Greater levels of passage and survival would lead to increases in the average abundance over baseline average abundance.

There are caveats to the Phase 1 analysis that are worth identifying, as follows:

- It was assumed that the TDM levels in the Winnemem Waywaket were constant across all years, with a value of 0.05 in August only. If the TDM values in the Winnemem Waywaket are higher than assumed, greater levels of survival and passage rates would be required to match the historical spawner averages.
- The results of this analysis are dependent on the TDM from 1995 to 2020 that defined the baseline scenario. A different set of hydrologic and thermal conditions could result in different levels of survival and passage rates to match the baseline average abundance.

4.2 Phase 2

Development of the WRLCM with reintroduction allows a more accurate depiction of the reintroduction dynamics by explicitly incorporating the reintroduction rates of adult attraction, adult survival, juvenile guidance/collection, and juvenile survival.

Running the WRLCM with reintroduction over a set of hydrological conditions from 1970 to 2020 can provide some insight into what levels of reintroduction rates would lead to population responses that are desirable under reintroduction, namely increases in population abundance (Tier 2) and the potential for sustainability under an ocean fishery (Tier 3).

When all reintroduction rates were greater than 0.92, most of the model runs resulted in the potential for sustainability under harvest, whereas when all rates were in the 0.9 to 0.92 range, higher population abundances could be achieved under the reintroduction relative to the baseline.

The Alternative 1 and 3 design elements can be mapped to reintroduction rates. Using an optimization algorithm, the design levels can be identified for a given reintroduction rate, and the levels of the design elements can be associated with a specific Tier level. Under this approach, targets can be identified for each of the design elements to reach a specific set of Tier outcomes.

As in Phase 1, there are caveats to the Phase 2 analysis that are worth identifying, as follows:

- The same caveats from Phase 1 apply in Phase 2, and in particular, the conditions from 1970 to 2020 set the conditions for the baseline abundance.
- Multiple assumptions that were made in order to model the Winnemem Waywaket population are identified in the methods section.
- Other criteria and metrics could be used that would lead to different sets of reintroduction rates being identified.

4.3 Potential Additional Evaluations

In this technical memorandum, we evaluated multiple sets of reintroduction rates using historical hydrologic and temperature conditions from 1970 to 2020. Given the likelihood of climate change causing warmer conditions in California, a more robust set of hydrologic conditions could be evaluated as an extension of this work. This would be implemented by running the reintroduction under multiple hydrologic scenarios, either through resampling of the 1970 to 2020 conditions or through the use of future climate projections and water planning models that can incorporate those climate scenarios, such as CalSim3.

Other possible evaluations using the WRLCM that could be done in the future include running the model on the alternatives as they are modified or changed to meet the objectives of a successful reintroduction program.

5 References

- Anchor QEA and HDR (HDR Engineering, Inc.), 2026. *Alternatives Formulation and Evaluation Report. Feasibility Study of Salmon Passage at Shasta and Keswick Dams*. January 2026.
- Carlson, S.M. and W.H. Satterthwaite, 2011. "Weakened Portfolio Effect in a collapsed Salmon Population Complex." *Canadian Journal of Fisheries and Aquatic Sciences* 68(9):1579–1589.
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- O'Farrell, M.R., W.H. and Satterthwaite, 2015. "Inferred Historical Fishing Mortality Rates for an Endangered Population of Chinook Salmon (*Oncorhynchus tshawytscha*)." *Fishery Bulletin* 113:341–351. doi: 10.7755/FB.113.3.9.

Attachment 1

Winnemem Waywaket Capacity Estimates

Winnemem Waywaket Capacity Estimates

Life Stage	Input Parameter Description	Metric	Sensitivity	Notes
Adults	Estimated Spawner Capacity (number of females)	Number of females (Reclamation 2014): Low: 402 Medium: 4,155 High: 4,861	NA	<p>From Reclamation (2014):</p> <ul style="list-style-type: none"> Upper reach (McCloud Dam, RM 23.2, to AhDiNa Campground, RM 19.8); middle reach (AhDiNa Campground, RM 19.8, to Yet Atwam Creek, RM 9.5; lower reach, Yet Atwam Creek, RM 9.5, to Nawtawaket Creek, RM 0) Chatterdown Creek is at RM 4 in the lower reach (about half way up the lower reach) that only had a video survey. This area is in the lower reach (RM 0 to RM 9.5), which did not have a metric for the substrate, so no reliable condition score was provided; areas above lower reach show fair to good spawning habitat condition ratings based on the video survey. The field survey derived estimate of spawning area was over 7 times the estimate derived using the video survey and the field survey did not have an estimate for the lower reach because no field verification surveys could be completed. The available long-term temperature records and PG&E's recent water temperature modeling information suggest that suitable thermal conditions (i.e., < or = 56°F (13.3°C) daily average temperature) for the entire duration of winter-run Chinook Salmon egg incubation season (late April through September), under most water year types, occurs upstream of RM 15 between Claiborne Creek (RM 12) to Ladybug Creek (RM 18) to McCloud Dam.
Juveniles	Amount of rearing habitat (not limited so no need to characterize)	See notes column	NA	<p>Neither Reclamation (2014) nor FitzGerald et. al. (2024) have an estimate of rearing capacity that we can use here. Reclamation (2014) indicated that "the Chinook salmon rearing life stage habitat condition scores were fair-to-good, with little spatial variation in the upper and middle study reaches, for both aerial video- and field-derived habitat inventories. Cover attribute scores were the lowest rated component, which influenced the overall rearing habitat condition scores for each study reach. As for the upper Nomtipom Waywaket, the cover attribute scores are highly dependent on the amounts and diversity of LWD for pool formation and physical cover, which are limited in the McCloud River and may not be as important in the large river tributaries because of the bedrock-controlled channel and pool forming structures. Substrate and habitat attribute scores were fair-to-good from both the aerial video- and field-derived habitat inventories," and "physical rearing habitat conditions, including water temperatures through the summer months, are fair-to-good for Chinook salmon in the McCloud River from McCloud Dam downstream through the middle study reach to at least Yet Atwam Creek. While the rearing habitat condition assessment of the lower study reach using aerial video interpretation will ultimately need to be verified through ground-level field surveys of representative sites, the thermal conditions throughout the summer remain within the suitable range for juvenile Chinook salmon growth and survival, not exceeding an MMWAT of 66.0°F (19.0°C), all the way downstream to Shasta Lake."</p>

Notes:

FitzGerald, A.M., L.R. Harrison, and D.A. Boughton, 2024. *Evaluating Reintroduction Potential in Spring-Fed Mountain Streams for the Endangered Sacramento River Winter-Run Chinook Salmon*. Report to NOAA WCR FERC Branch. October 9, 2024.

Reclamation, 2014. *Habitat Assessment Final Report*. Shasta Dam Fish Passage Evaluation. U.S. Department of the Interior. Mid-Pacific Region, Bureau of Reclamation. August 2014.

PG&E: Pacific Gas and Electric Company

NA: not applicable

Reclamation: U.S. Bureau of Reclamation

RM: river mile

Attachment 2

Description of Alternative Attraction and Collection Rates

Alternative 1: Volitional Passage up Cow, Little Cow, Dry Creeks and into a Constructed Channel to the Winnemem Waywaket

Life Stage	Input Parameter Description	Metric	Sensitivity Runs	Notes
Adults	% into mouth of Cow Creek that remain	50%	+48/-40%	Assumes fish turn into Cow Creek and do not leave.
Adults	% from mouth of Cow Creek to top of natural channel	85%	+13/-10%	--
Adults	% through Constructed Channel and into the McCloud River	75%	+23/-20%	Assumes fish leaving Dry Creek and arriving in the Winnemem Waywaket habitat reach.
Juveniles	% through Guidance Structure and into Constructed Channel	81%	+17% /-24%	% of fish that arrive at the guidance structure and get into the constructed channel. From Yuba juvenile collection study, Alternative 2.
Juveniles	% through Constructed Channel and into the Nontipom Waywaket	60%	+38/-35%	Assumes there will be a level of predation that is unknown. 48 miles of constructed channel and natural channel at 2 to 4 ft/s = approximately 7 to 10 days of travel.

Note:

Note that this volitional passage is a technology that has never been applied before, so it is untested, and the metrics listed in this table are based on best professional judgement. As reintroduction progresses in the future these input parameters will need to be tested through experimental studies.

ft/s: foot per second

Alternative 3: Fish Ladders at Keswick and Shasta Dams

Life Stage	Input Parameter Description	Metric	Sensitivity Runs	Notes
Adults	% of fish that make it to Keswick Dam and through the fish ladder to Keswick Reservoir	95%	+3% /-5%	-# adult fish from above Shasta Dam coming back and going past spawning reach and to the dam and through the fish ladder to Keswick Reservoir; assume fish produced from above Shasta Dam and are trying to get as far upstream as possible.
Adults	% through Keswick Reservoir	98%	+/- 2%	
Adults	% into Guidance Structure to fish ladder	95%	+3% /-5%	BPJ
Adults	% through ladder at Shasta Dam to the Crest	85%	+/-15%	BPJ
Adults	% through the temperature-controlled acclimation and release structure	95%	+3% /-25%	This is fish going through the structure and surviving; untested technology.
Adults	% through Shasta Reservoir	80%	+18/-10%	Assume some fish will be lost to the Pit River (will also have Winnemem Waywaket water coming down the river).
Juveniles	% through Collection Facility on McCloud	81%	+17% /-24%	% of fish that arrive at the guidance structure and are collected. From Yuba juvenile collection study, Alternative 2.
Juveniles	% survive trucking to Shasta	98%	+2%/-8%	Assume conditioned water and high-quality transport conditions; the -8% includes the assumption of some level of delayed mortality.
Juveniles	% survive sorting facility	99%	+1%/-2%	Placed into recovery pools; some % of the fish will be sampled and released into a bypass tunnel into river.
Juveniles	% to Keswick Dam	90%	+8%/-10%	Predator mortality.
Juveniles	% through surface flow outlet	98%	+1%/-8%	Based on Wanapum Dam surface flow outlet.

Note:

BPJ: best professional judgement

Trap and Haul

Life Stage	Input Parameter Description	Metric	Sensitivity Runs	Notes
Adults	% through the fish ladder	95%	+3% /-5%	-# adult fish from above Shasta Dam coming back and going past spawning reach and to the dam and through the fish ladder to Keswick Reservoir; assume fish produced from above Shasta Dam and are trying to get as far upstream as possible.
Adults	% through Keswick Reservoir	98%	+/- 2%	Capture in the narrative what might occur with the below Keswick population (i.e., some may go into ladder, etc.), but this analysis is focused on natural origin fish from Winnemem Waywaket.
Adults	% into Guidance Structure	95%	+3% /-5%	BPJ
Adults	% through ladder at Shasta Dam	85%	+/-15%	BPJ
Adults	% through sorting facility	98%	+/-1%	
Adults	% survive trucking	98%	+/-1%	
Juveniles	% through Collection Facility on McCloud	81%	+8% /-24%	% of fish that arrive at the guidance structure and are collected. From Yuba juvenile collection study, Alternative 2.
Juveniles	% survive trucking to Shasta	98%	+2%/-8%	Assume conditioned water and high quality transport conditions; the -8% includes the assumption of some level of delayed mortality.
Juveniles	% survive sorting facility	99%	+1%/-2%	Placed into recovery pools; some % of the fish will be sampled and released into a bypass tunnel into river.
Juveniles	% to Keswick Dam	90%	+8%/-10%	Predator mortality.
Juveniles	% through surface flow outlet	98%	+1%/-8%	Based on Wanapum Dam surface flow outlet.

Note:

BPJ: best professional judgement