Appendix 11I Winter-Run Chinook Salmon Life Cycle Monitoring

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11I.1 Introduction

This appendix includes two memoranda describing the results of the IOS (Interactive Object-Oriented Simulation) and OBAN (Oncorhynchus Bayesian Analysis) winter-run Chinook salmon life cycle models (see Attachments 11I-1 and 11I-2). Methods and results are discussed in the IOS memorandum. Methods for the OBAN model are as described by ICF International (2016:5.D-513–5.D-526), except with modifications described in Attachment 11I-2. Additional discussion of the results is provided in Chapter 11, *Aquatic Biological Resources*.

11I.2 References Cited

ICF International. 2016. *Biological Assessment for the California WaterFix*. July. Sacramento, CA. Prepared for U.S. Department of the Interior, Bureau of Reclamation, Sacramento, CA. Available: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/docs/petitioners_exhibit/dwr/part2/dwr1142/App_5.D_Methods_update.pdf Accessed: April 15, 2021.

Attachment 11I-1 IOS Winter-Run Chinook Salmon Life Cycle Model

CRAMER FISH SCIENCES®
Oregon • California • Washington • Idaho • Alaska

13300 New Airport Rd. Suite 103
V: 530.240.6237
stevez@fishsciences.net

Memorandum
May, 15 2021
To: Steve Micko, Jacobs Engineering
From: Steven Zeug, Cramer Fish Sciences
Re: IOS plots updated and including Bend Bride flow modification

Proposed operational alternatives for the Sites Reservoir project were evaluated using the IOS winter run Chinook salmon life cycle model. This model combines data from field studies, long-term monitoring programs and laboratory studies in a simulation framework. IOS is composed of six primary life cycle components that can be affected by water temperature, river flow, or ocean productivity including 1) spawning (water temperature), 2) egg incubation (water temperature), 3) fry rearing (water temperature), 4) river migration (flow), 5) Delta passage (flow) and 6) ocean survival (ocean productivity). The model has been published in a peer reviewed journal (Zeug et al. 2012) and a description of the most recent version can be found in the appendix at the end of this document.

Here we provide five model outputs to evaluate four operational alternatives and a no-action alternative on winter run Chinook Salmon. One hundred iterations of the model were run for each alternative with parameters resampled for each iteration. The five outputs reported are 1) egg survival, 2) fry survival, 3) river survival, 4) Delta survival, and 5) female escapement. Below we describe differences among alternatives over the 82-year simulation period and among water year-types.

A bug in the DPM module was found and corrected in this latest run. Additionally, a modification was made to Bend Bridge flow to reflect the length of the Red Bluff to Verona reach of the river that would be affected by the Sites diversion. To evaluate this effect, the “River Survival” output from the original model results was subtracted from the same output including the Bend Bridge flow modification. Differences in “Delta Survival” are also provided to describe changes related to the bug fix. Differences in escapement between the two model runs are a composite of changes in the “River survival” and “Delta Survival” components.

Egg survival

In most years of the 82-year simulation period, median egg survival was high and similar among the 4 scenarios (Figure 1). The only substantial reductions in survival occurred during several Critical years in the late 1970s. In these Critical water years, the highest survival was observed for the ALT3 alternative and the lowest survival was observed for the No Action Alternative (NAA; Figure 2). Survival for ALT1A and ALT2 were similar lower than both Alt3 and Alt1B.

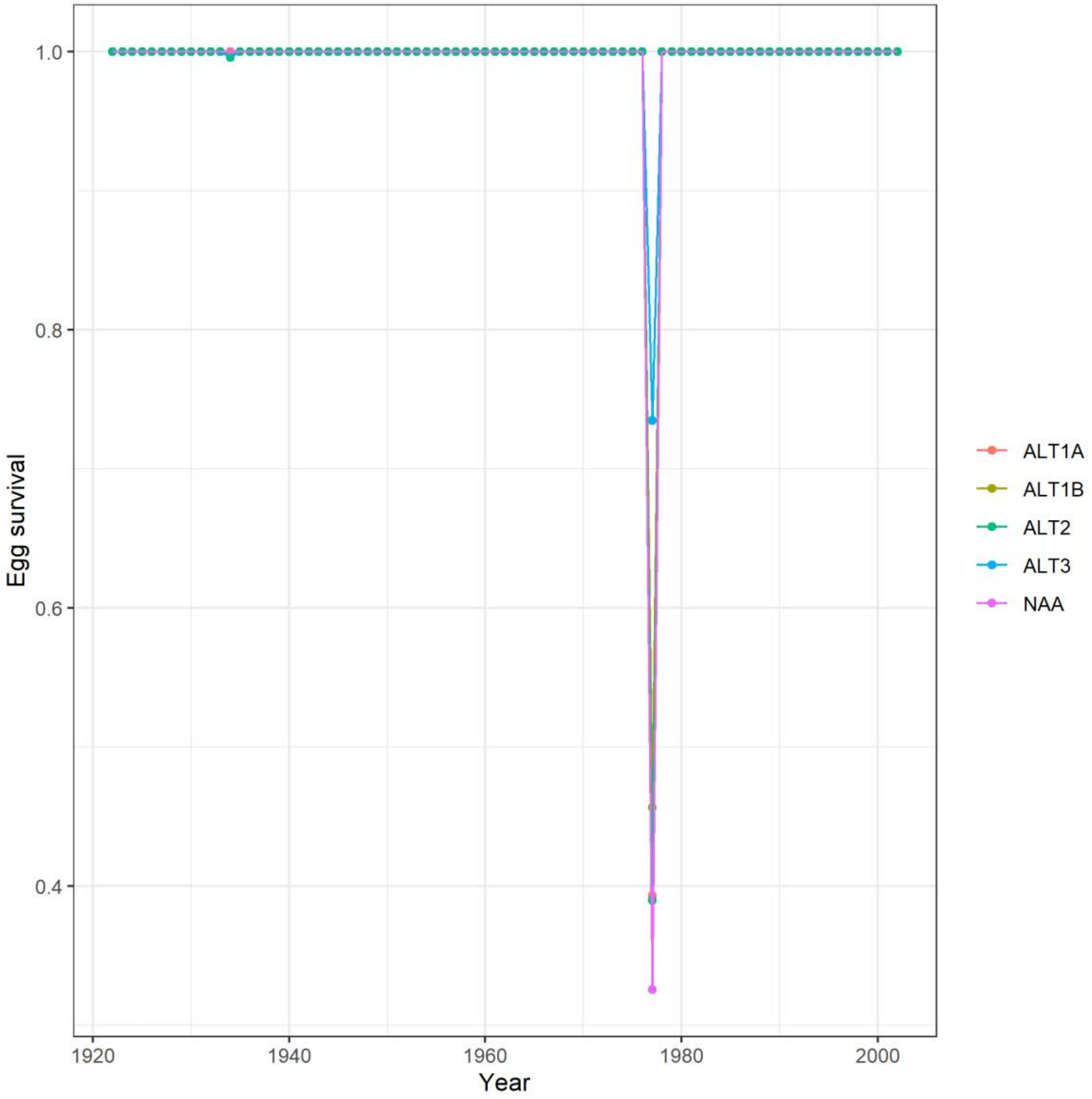


Figure 1. Median winter run Chinook Salmon egg survival over the 82-year simulation period.

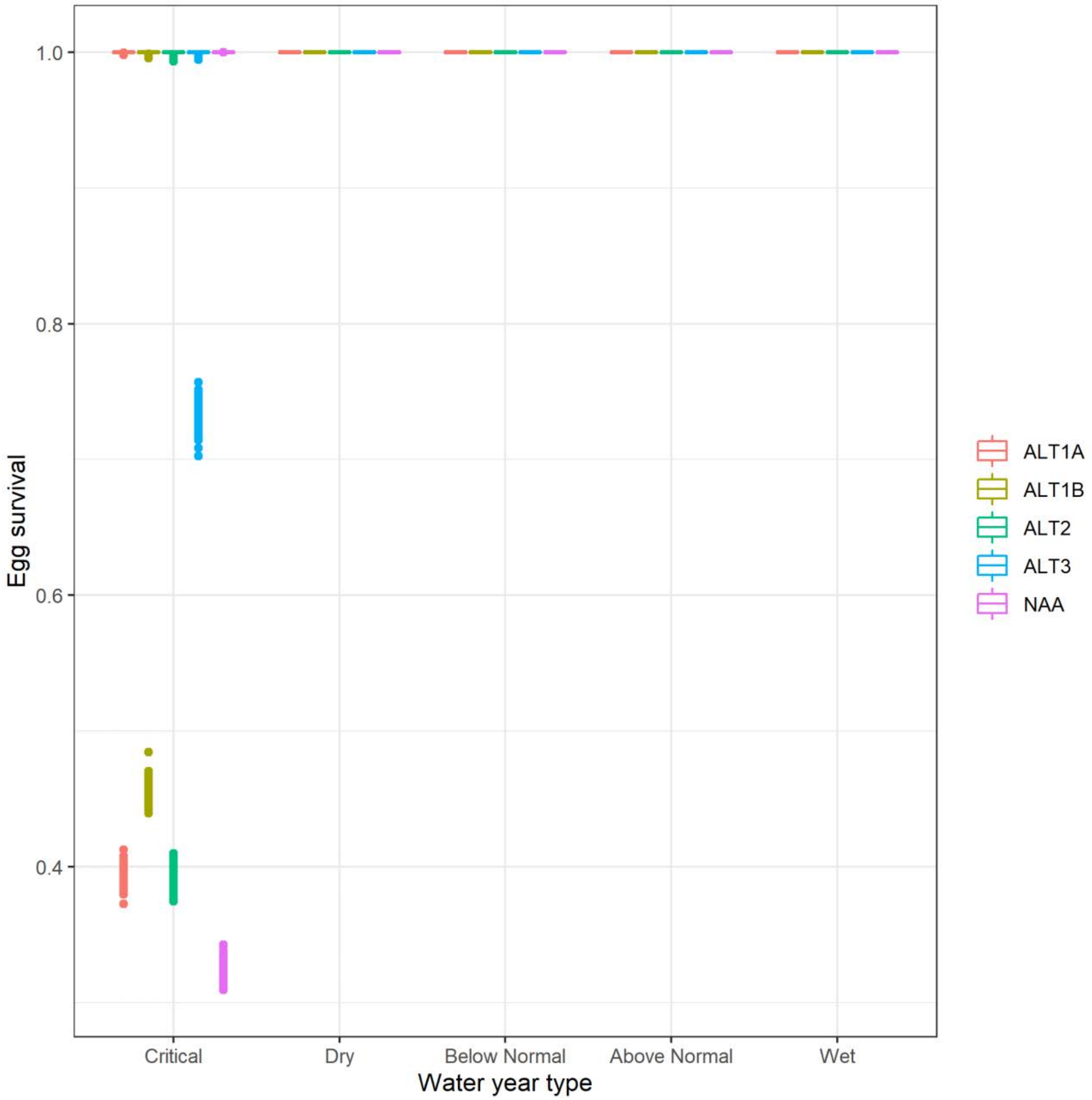


Figure 2. Box plots of egg survival by water year type for each of the alternatives evaluated. The results from all 100 iterations of each alternative are included in these plots. The box defines the interquartile range, the horizontal line is the median and the vertical lines define the largest value within 1.5 times the interquartile range. Individual points are those outside of that range.

Fry survival

Median fry survival over the 82-year period was almost always > 90% and similar among the four alternatives (Figure 3). Survival fell below 60% in only two years (Figure 3). Fry survival was most variable in Critical water year types and interquartile ranges did not overlap between Critical years and other water year types for any alternative (Figure 4). Among alternatives in these Critical water years, median survival was lowest for the NAA and highest for ALT1 A. However, interquartile ranges overlapped substantially among all alternatives (Figure 4). In the Critical years with the lowest fry survival, the lowest values were observed for the NAA and the highest for ALT3 (Figure 4).

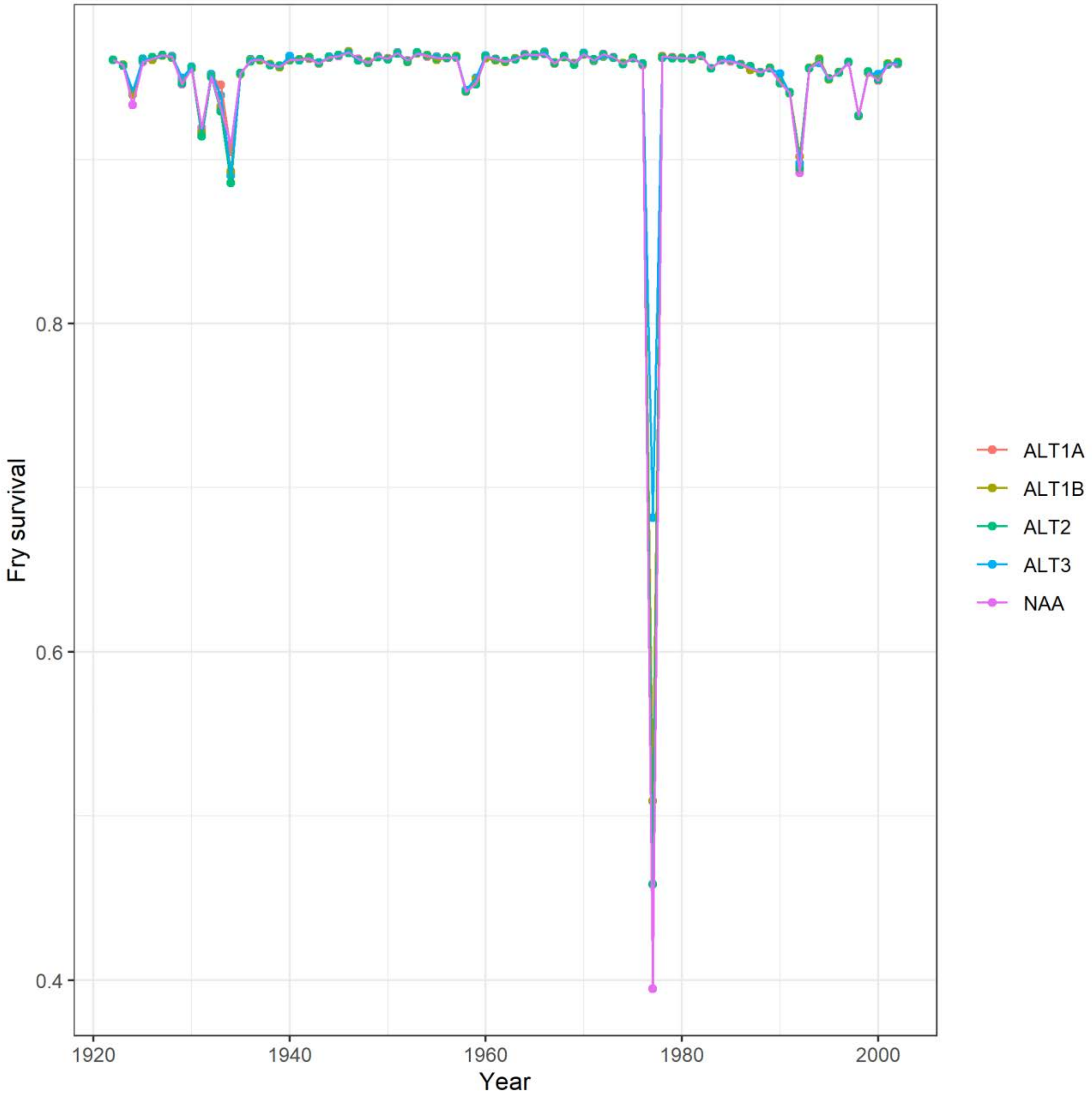


Figure 3. *Median winter run Chinook Salmon fry survival over the 82-year simulation period.*

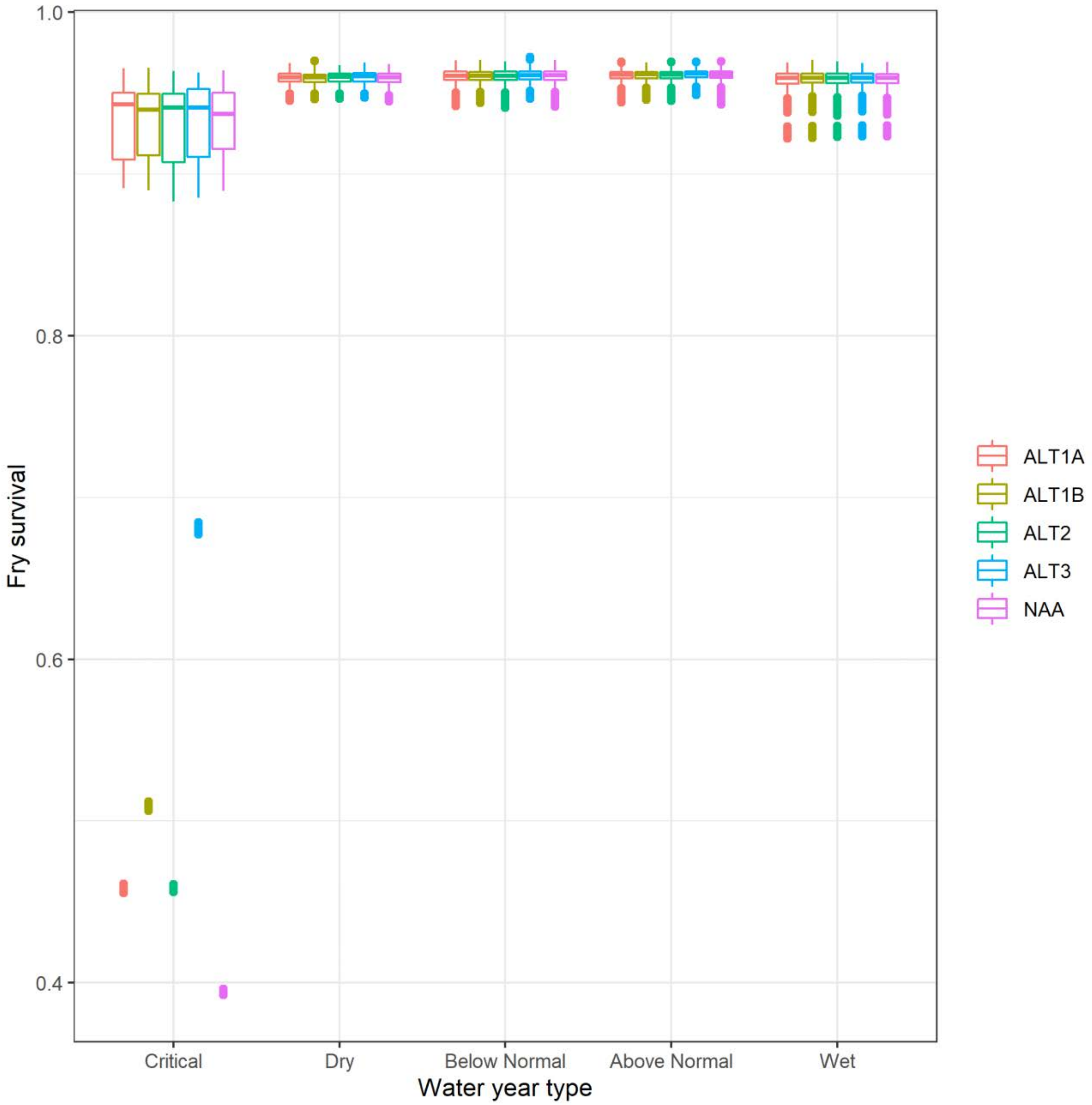


Figure 4. *Box plots of fry survival by water year type for each of the alternatives evaluated. The results from all 100 iterations of each alternative are included in these plots. The box defines the interquartile range, the horizontal line is the median and the vertical lines define the largest value within 1.5 times the interquartile range. Individual points are those outside of that range.*

River migration survival

Survival of juvenile winter run Chinook Salmon during river migration never fell below 20% or exceeded 37.5% for any alternative across all simulation years (Figure 5). There were only minor differences among scenarios in each year. Survival in NAA was greater than any of the other alternatives and this trend attenuated in drier year types. Interquartile ranges overlapped substantially among scenarios, but values were shifted slightly higher for the NAA; primarily in Wet, Above Normal and Below Normal year-types (Figure 6).

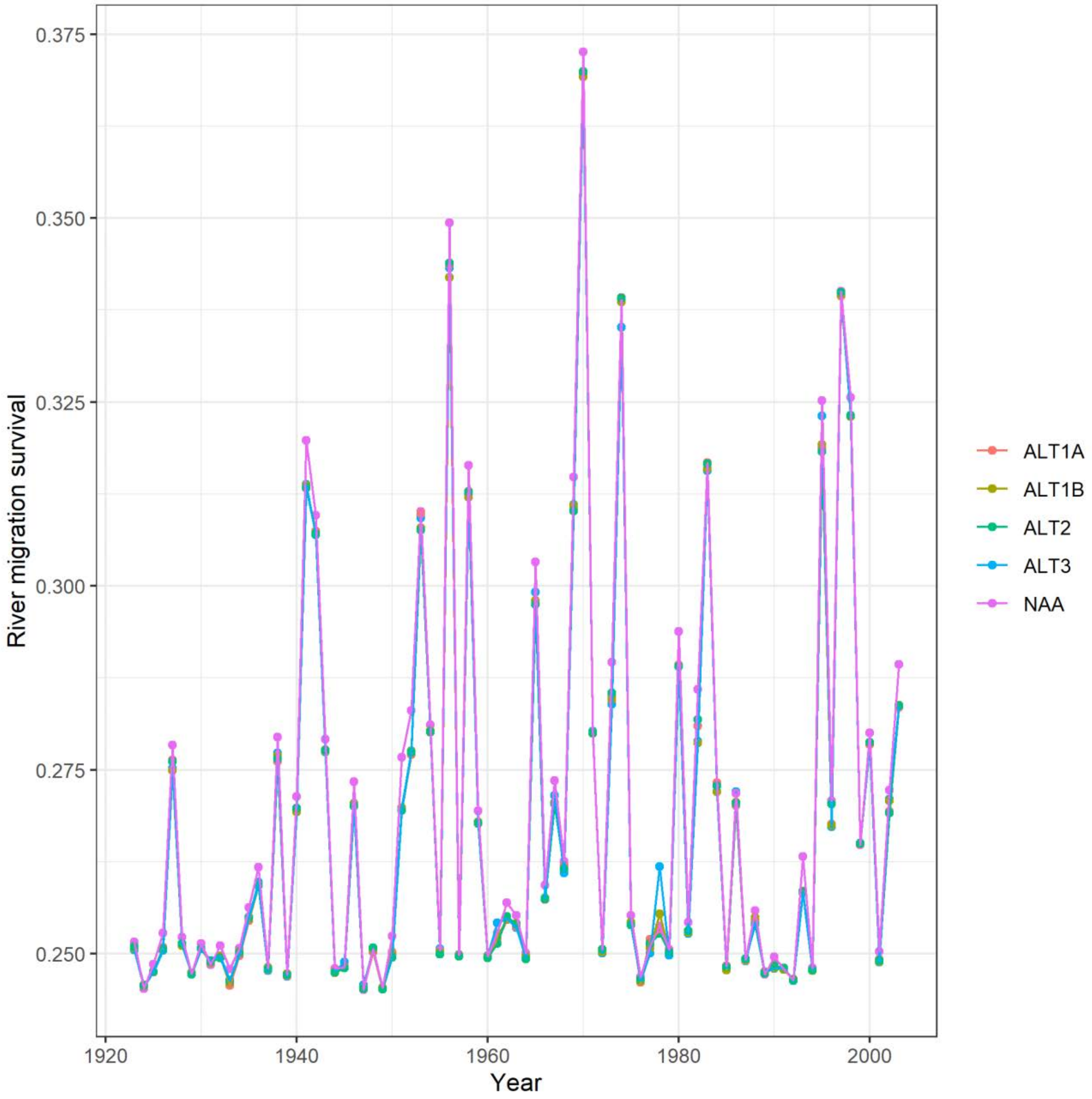


Figure 5. Median winter run Chinook Salmon river migration survival (Red Bluff to Fremont Weir) over the 82-year simulation period.

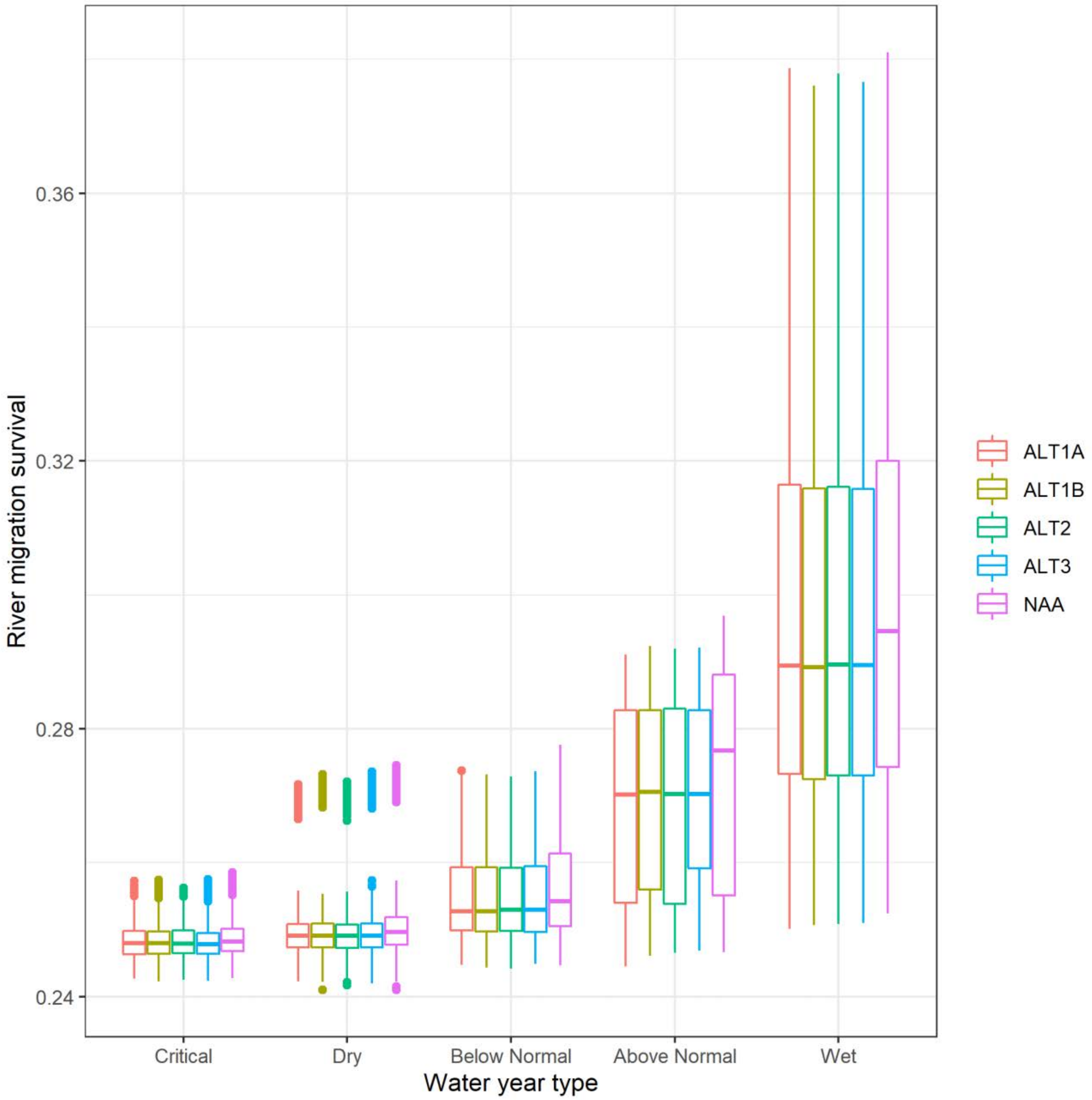


Figure 6. *Box plots of river migration survival by water year type for each of the alternatives evaluated. The results from all 100 iterations of each alternative are included in these plots. The box defines the interquartile range, the horizontal line is the median and the vertical lines define the largest value within 1.5 times the interquartile range. Individual points are those outside of that range.*

Delta passage survival

Delta passage survival ranged between ~ 15% and 40%. Median Delta passage survival values over the simulation period were similar among all scenarios in individual years (Figure 7). Within water year-types, the interquartile ranges overlapped substantially for most scenarios although there was a slight shift toward higher survival for NAA is some year types. The median value for ALT3 was higher than all other alternatives in Above Normal years and lower in Below Normal years (Figure 8)

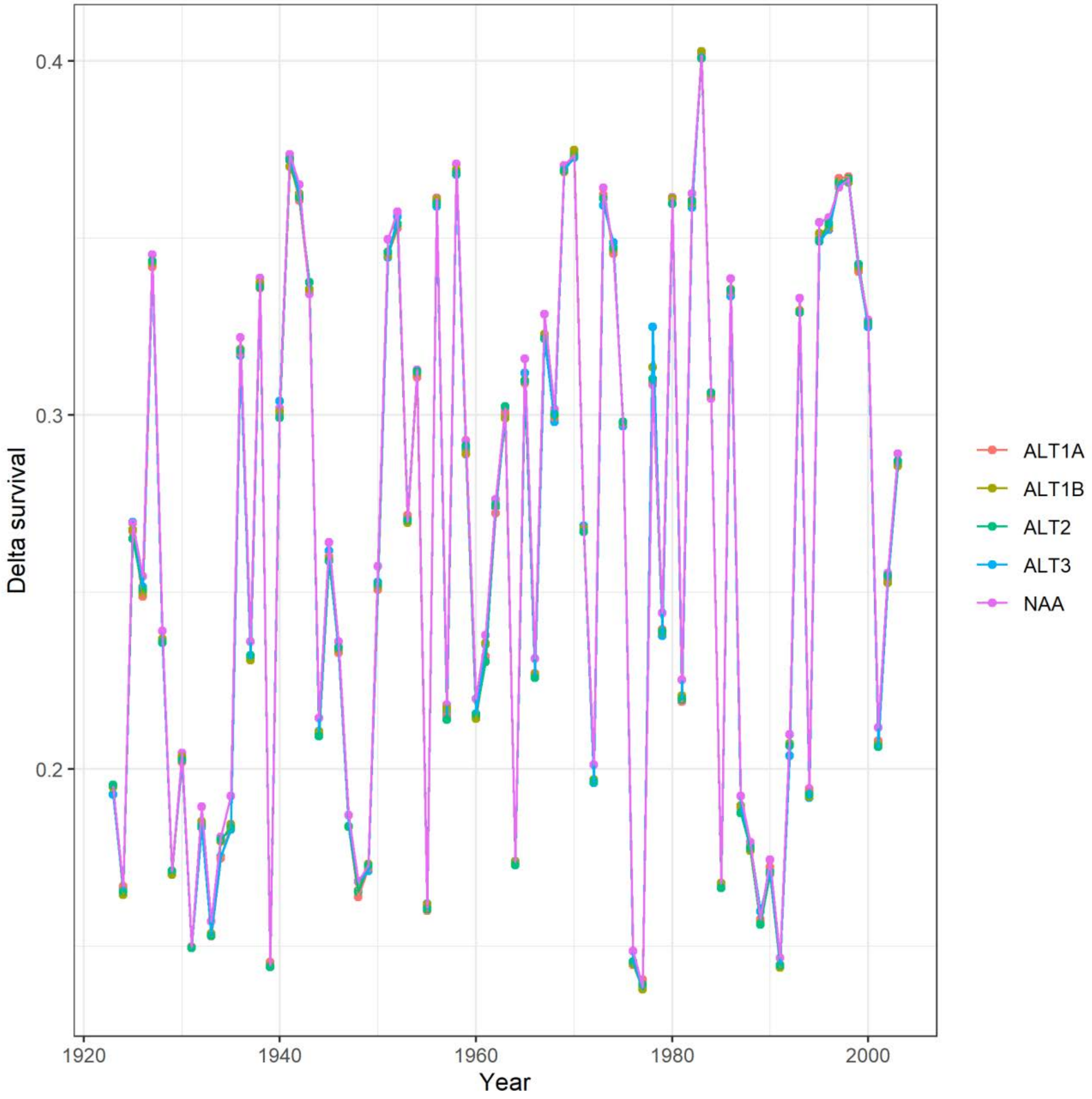


Figure 7. *Median winter run Chinook Salmon Delta passage survival (Fremont Weir to Chipps Island) over the 82-year simulation period.*

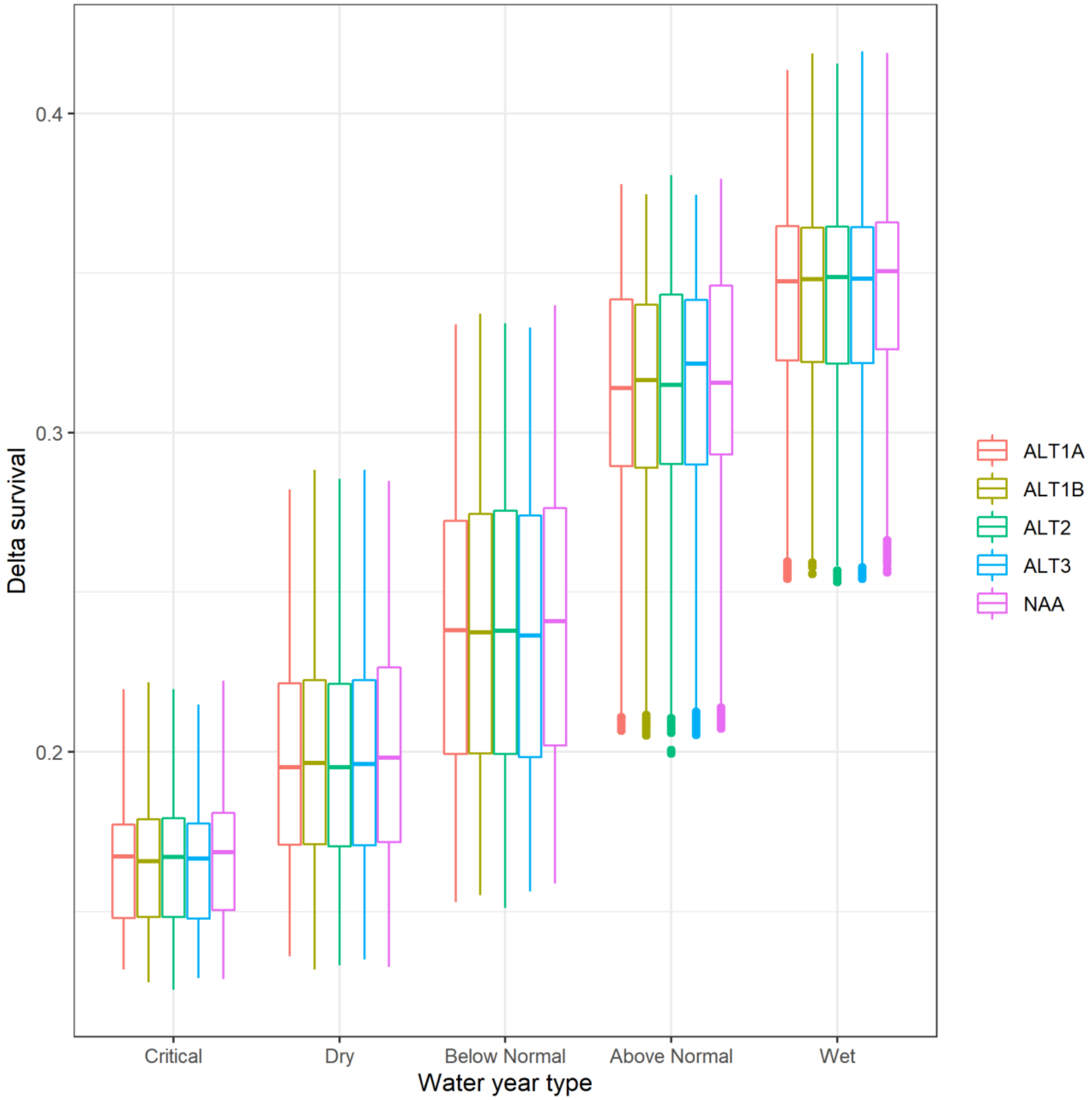


Figure 8. *Box plots of Delta passage survival by water year type for each of the alternatives evaluated. The results from all 100 iterations of each alternative are included in these plots. The box defines the interquartile range, the horizontal line is the median and the vertical lines define the largest value within 1.5 times the interquartile range. Individual points are those outside of that range.*

Female escapement

Female escapement integrates all effects from the operational alternatives into a population-level effect. Median values of female escapement were more variable than other outputs among the alternatives in individual years throughout the 82-year simulation period (Figure 9). The alternative with higher median escapement in each year was also variable. (Figure 9). Among the different water year-types, there was substantial overlap in the interquartile range of female escapement values (Figure 10). However, female escapement was shifted higher for ALT3 in Critical and Dry year-types (Figure 10).

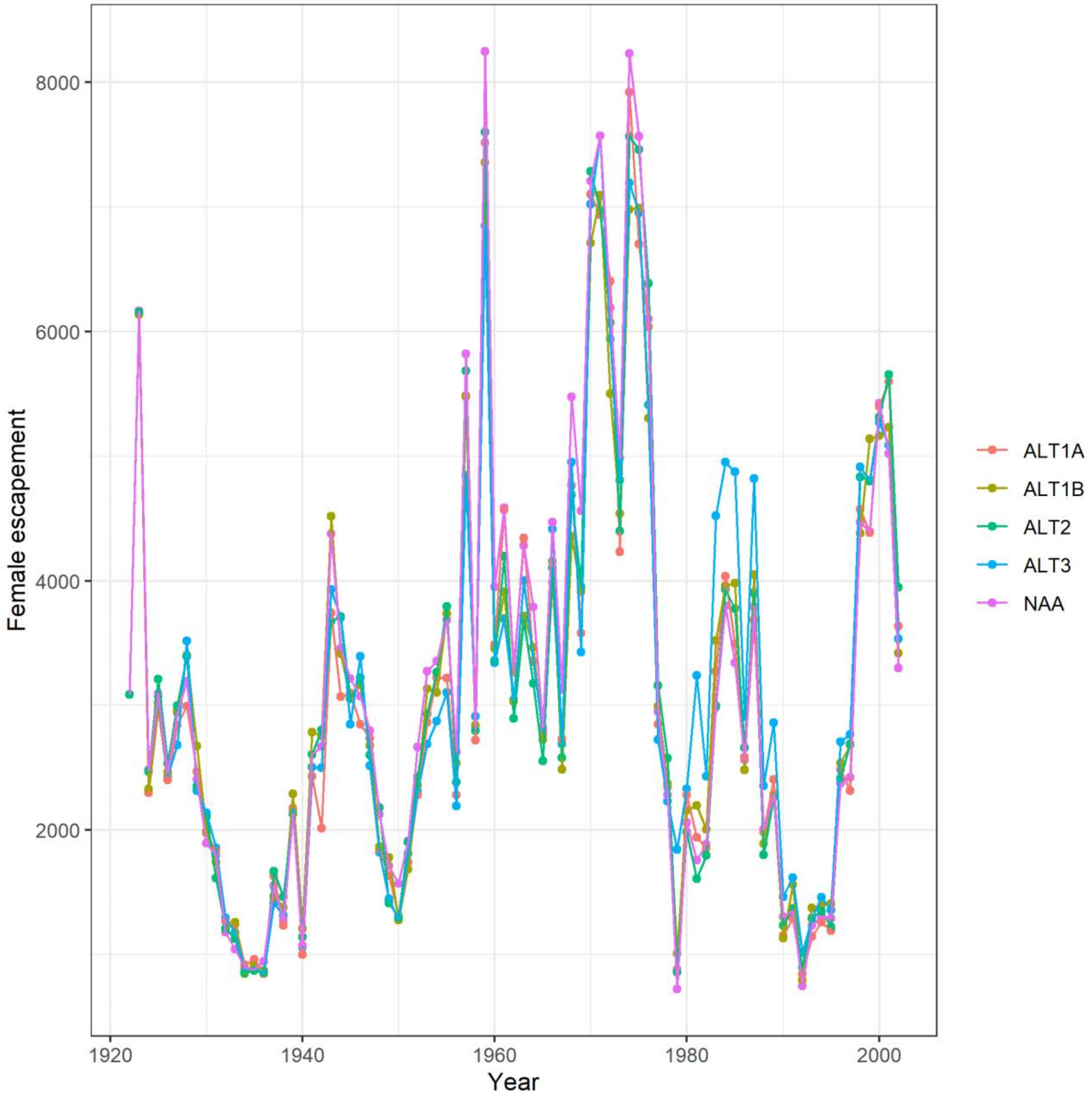


Figure 9. Median female escapement over the 82-year simulation period.

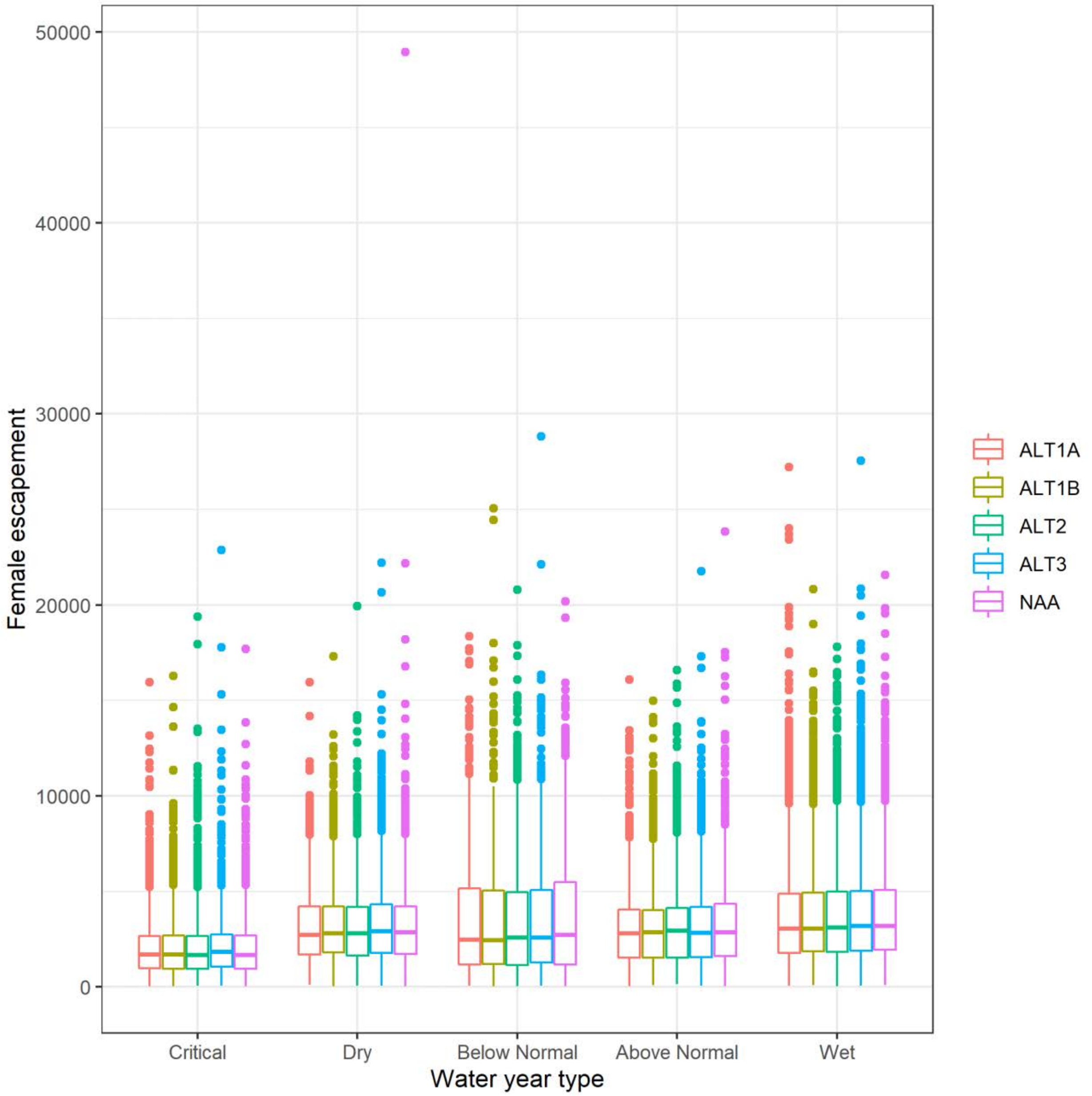


Figure 10. *Box plots of female escapement by water year type for each of the alternatives evaluated. The results from all 100 iterations of each alternative are included in these plots. The box defines the interquartile range, the horizontal line is the median and the vertical lines define the largest value within 1.5 times the interquartile range. Individual points are those outside of that range.*

Effect of modified Bend Bridge flow

To examine how the diversion location within the Red Bluff to Verona reach influences River Migration Survival, Cramer was provided with a modified Bend Bridge flow and IOS was run again. The diffence in mean “River Survival” output between the runs that used unmodified Bend Bridge flow (V1) and the output using the modified Bend Bridge flow (V2) was calculated for each alternative. Table 1 below lists the differnce in mean values (V1-V2) for each model output. Positive values indicate greater survival in results using unmodified Bend Bridge flow. There was no differnce in the mean values of river survival (values averaged across the 82 year period). However, differences in individual years occurred and were reflected in escapement values since differences in individual years propagate through time. These differences were minor relative to the escapement values displayed above. However, patterns were apparent among alternatives. For ALT1A, higher mean escapement occurred when unmodified flows were used except in Critical water years. Under ALT2, escapement for all year types was greater with modified Bend Bridge whereas under ALT3 escapement was always lower with modified Bend Bridge flow. The water year type with higher mean escapement was variable under ALT1B.

WYT	Scenario	Egg_S	Fry_S	Escapement	River_S	Delta_S
Above Normal	ALT1A	0.000	0.000	87.667	0.000	0.000
Below Normal	ALT1A	0.000	0.000	78.360	0.000	0.000
Critical	ALT1A	0.000	0.000	-25.243	0.000	0.000
Dry	ALT1A	0.000	0.000	94.269	0.000	0.000
Wet	ALT1A	0.000	0.000	94.938	0.000	0.000
Above Normal	ALT1B	0.000	0.000	70.465	0.000	0.000
Below Normal	ALT1B	0.000	0.000	-5.817	0.000	0.000
Critical	ALT1B	0.000	0.000	96.622	0.000	0.001
Dry	ALT1B	0.000	0.000	-48.283	0.000	0.000
Wet	ALT1B	0.000	0.000	13.393	0.000	0.000
Above Normal	ALT2	0.000	0.000	-16.218	0.000	0.000
Below Normal	ALT2	0.000	0.000	-45.699	0.000	0.000
Critical	ALT2	0.000	0.000	-0.867	0.000	0.000
Dry	ALT2	0.000	0.000	-37.113	0.000	0.001
Wet	ALT2	0.000	0.000	-15.663	0.000	0.000
Above Normal	ALT3	0.000	0.000	55.815	0.000	0.000
Below Normal	ALT3	0.000	0.000	44.601	0.000	0.000
Critical	ALT3	0.000	0.000	6.658	0.000	0.000
Dry	ALT3	0.000	0.000	74.564	0.000	0.000
Wet	ALT3	0.000	0.000	28.103	0.000	0.000

Appendix

Interactive Object-Oriented Simulation (IOS) Model (Winter-Run Chinook Salmon)

Model Structure

The IOS Model is composed of six model stages defined by a specific spatiotemporal context and are arranged sequentially to account for the entire life cycle of winter-run Chinook salmon, from eggs to returning spawners (Figure 1). In sequential order, the IOS Model stages are listed below.

1. *Spawning*, which models the number and temporal distribution of eggs deposited in the gravel at the spawning grounds in the upper Sacramento River between Red Bluff Diversion Dam and Keswick Dam as a function of water Temperatures in April and May.
2. *Early Development*, which models the effect of temperature on maturation timing and mortality of eggs incubating in the gravel.
3. *Fry Rearing*, which models the relationship between temperature and mortality of fry during the river rearing period in the upper Sacramento River between Red Bluff Diversion Dam and Keswick Dam.
4. *River Migration*, which estimates mortality of migrating smolts in the Sacramento River between Red Bluff and the Delta as a function of river flow.
5. *Delta Passage*, which models the effect of flow, routing, and exports on the survival of smolts migrating through the Delta to San Francisco Bay.
6. *Ocean Survival*, which estimates the effect of natural mortality, ocean harvest, and ocean conditions to predict survival and spawning returns by age.

A detailed description of each model stage follows.

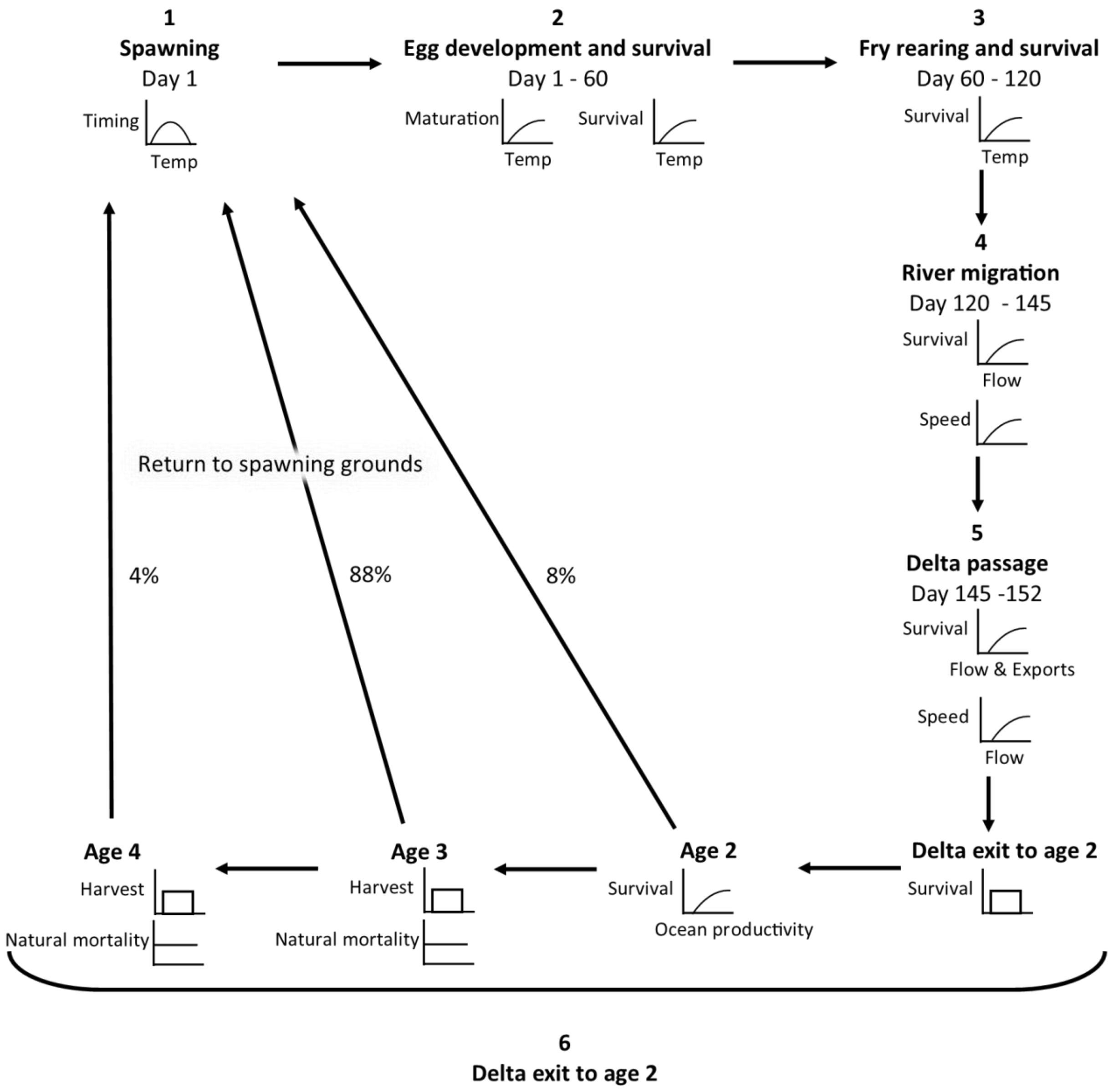


Figure 1. Conceptual Diagram of the IOS Model Stages and Environmental Influences on Survival and Development of Winter-Run Chinook Salmon at Each Stage.

Spawning

For the first four simulation years of the 82-year CALSIM simulation period, the model is seeded with 5,000 spawners, of which 3,087.5 are female based on the wild male to female ratio of spawners. In each subsequent simulation year, the number of female spawners is determined by the model's probabilistic simulation of survival to this life stage. To ensure that developing fish experience the correct environmental conditions during each year, spawn timing is a function of water tempertures in April and May as described by the function of Jennigs and

Hendrix (2020). Eggs deposited on a particular date are treated as cohorts that experience temperature on a daily time step during the early development stage. The daily number of female spawners is calculated by multiplying the predicted daily proportion of spawners by the total Jolly-Seber estimate of female spawners (Poytress and Carillo 2010).

(Equation 1) $S_d = P_d S_{JS}$

where, S_d is the daily number of female spawners, P_d is the daily proportion of total spawners and S_{JS} is the total Jolly-Seber estimate of female spawners.

To account for the time difference between egg deposition and carcass observations, the date of egg deposition is assumed to be 14 days prior to carcass observations (Niemela pers. comm.).

To obtain estimates of juvenile production, a Ricker stock-recruitment curve (Ricker 1975) was fit between the winter run Juvenile Production Index (JPI) each year (estimated by rotary screw–trap sampling at Red Bluff Diversion Dam) and the number of female spawners (from USFWS carcass surveys) for years 1996–1999 and 2002–2017:

(Equation 2) $R = \alpha S e^{-\beta S} + \varepsilon$

where α is a parameter that describes recruitment rate, and β is a parameter that measures the level of density dependence.

The density-dependent parameter (β) did not differ significantly from 0 (t = 1.662, p = 0.114)), indicating that the relationships between emergent fry and female spawners was linear (density-independent). Therefore, β was removed from the equation and a linear version of the stock-recruitment relationship was estimated. The number of female spawners explained 90% of the variation in fry production ($F_{1,19} = 173$, $p<0.001$) in the data, so the value of α was taken from the regression:

(Equation 3) $R = 1027 * S$

In the IOS Model, this linear relationship is used to predict values for mean fry production along with the confidence intervals for the predicted values. These values are then used to define a normal probability distribution, which is randomly sampled to determine the annual fry production. Although the Ricker model accounts for mortality during egg incubation, additional mortality was imposed at temperatures higher than those experinced during the years used to construct the Ricker model.

Early Development

Data from three laboratory studies were used to estimate the relationship between temperature, egg mortality, and development time (Murray and McPhail 1988; Beacham and Murray 1989; U.S. Fish and Wildlife Service 1999). Using data from these experiments, a relationship was constructed between maturation time and water temperature. First *maturation time* (days) was converted to a *daily maturation rate* (1/day):

(Equation 4) $\text{daily maturation rate} = \text{maturation time}^{-1}$

A significant linear relationship between maturation rate and water temperature was detected using linear regression. Daily water temperature explained 99% of the variation in *daily maturation rate* (F =2188; df =1,15; p<0.001):

(Equation 5) $$\text{daily maturation rate} = 0.00058 \cdot \text{Temp} - 0.018$$

In the IOS Model, the daily mean maturation rate of the incubating eggs is predicted from daily water temperatures using a linear function; the predicted mean maturation rate, along with the confidence intervals of the predicted values, is used to define a normal probability distribution, which then is randomly sampled to determine the daily maturation rate. A cohort of eggs accumulates a percentage of total maturation each day from the above equation until 100% maturation is reached.

Data from experimental work (U.S. Fish and Wildlife Service 1999) was used to parameterize the relationship between temperature and mortality of developing winter-run Chinook salmon eggs. Predicted proportional mortality over the entire incubation period was converted to a daily mortality rate to apply these temperature effects in the IOS Model. This conversion was used to calculate daily mortality using the methods described by Bartholow and Heasley (2006):

(Equation 6) $$\text{mortality} = 1-(1-\text{total mortality})^{(1/\text{development time})}$$

where *total mortality* is the predicted mortality over the entire incubation period observed for a particular water temperature and *development time* was the time to develop from fertilization to emergence.

Limited sample size in the USFWS study (1999) did not allow a statistically valid test for effects of temperature on mortality (e.g., a general additive model) to be performed. However, the following exponential relationship was fitted between observed *daily mortality* and observed water temperatures (U.S. Fish and Wildlife Service 1999) to provide the required values for the IOS Model:

(Equation 7) $$\text{daily mortality} = 1.38 \cdot 10^{-15} e^{(0.503 \cdot \text{Temp})}$$

Equation 7 yields the following graphic (2), which indicates that proportional daily egg mortality increases rapidly with only small changes in water temperature. For example, within the predominant water temperature range found in model scenarios (55°F to 60°F), proportional daily mortality increases over ten-fold (~0.001 at 55°F to ~0.018 at 60°F).

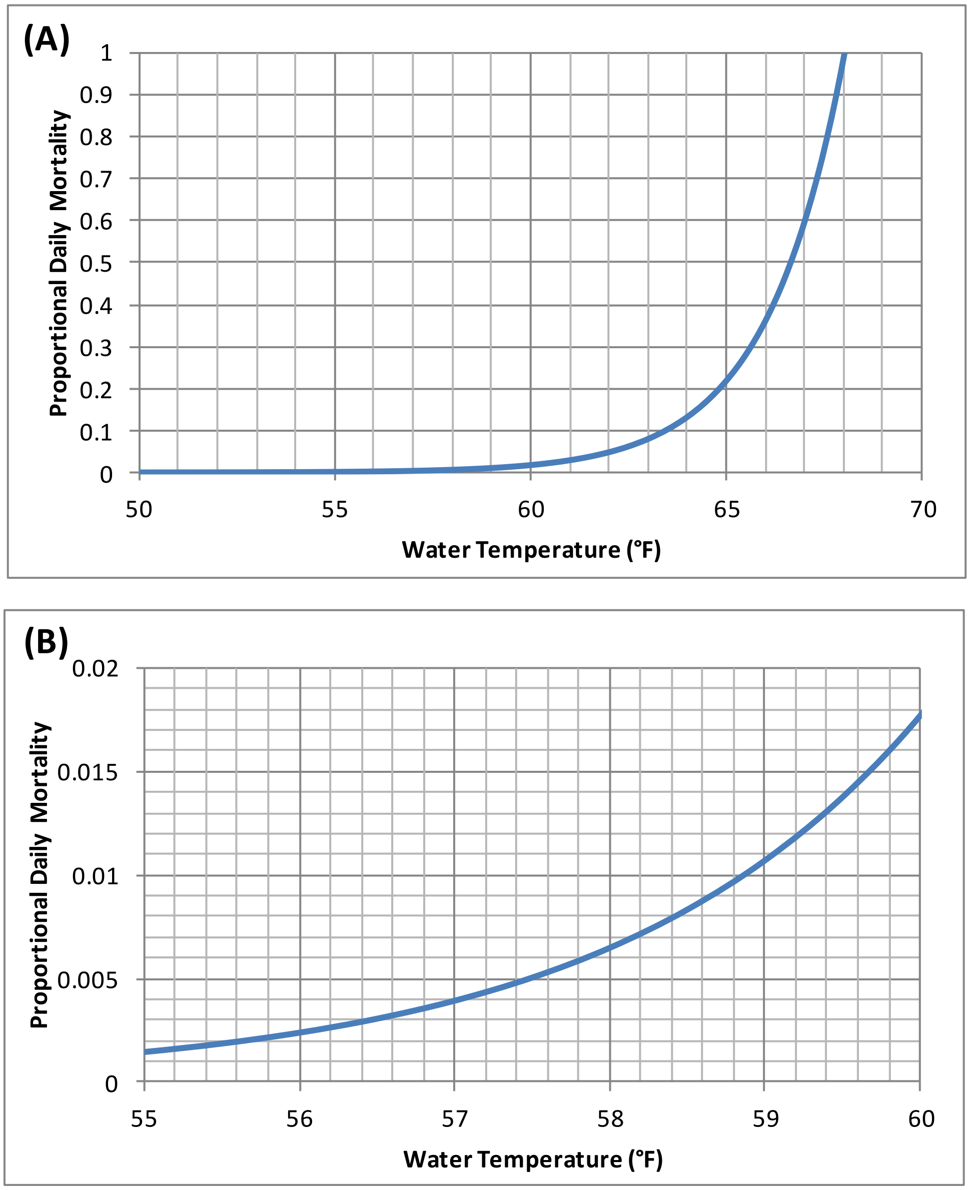


Figure 2. Relationship between Proportional Daily Mortality of Winter-Run Chinook Salmon Eggs and Water Temperature (Equation 7) for (A) the Entire Temperature Range, and (B) the Predominant Range Found in Model Scenarios

In the IOS Model, mean daily mortality rates of the incubating eggs are predicted from weighted mean daily water temperature at Keswick Dam and Balls Ferry where temperatures are weighted by a 10 year average distribution of winter run redds between these two locations. The predicted mean mortality rate, along with the confidence intervals of the predicted values, is used to define a normal probability distribution, which then is randomly sampled to determine the daily egg mortality rate.

Fry Rearing

Data from USFWS (1999) was used to model fry mortality during rearing as a function of water temperature. Again, because of a limited sample size from the study by USFWS, statistical analyses to test for the effects of water temperature on rearing mortality could not be run. However, to acquire predicted values for the model, the following exponential relationship was fitted between observed daily mortality and observed water temperatures (U.S. Fish and Wildlife Service 1999):

(Equation 8) $daily\ mortality = 3.92*10-12e\ (0.349*Temp)$

Equation 8 yields the following graphic (Figure 3), which indicates that proportional daily fry mortality increases rapidly with only small changes in water temperature. For example, within the predominant water temperature range found in model scenarios (55°F to 60°F), proportional daily mortality increases over five-fold (~0.001 at 55°F to ~0.005 at 60°F). This indicates that, although fry mortality is highly sensitive to changes in water temperature, this sensitivity is not as great as that of egg mortality within the predominant range observed in the model scenarios in focus.

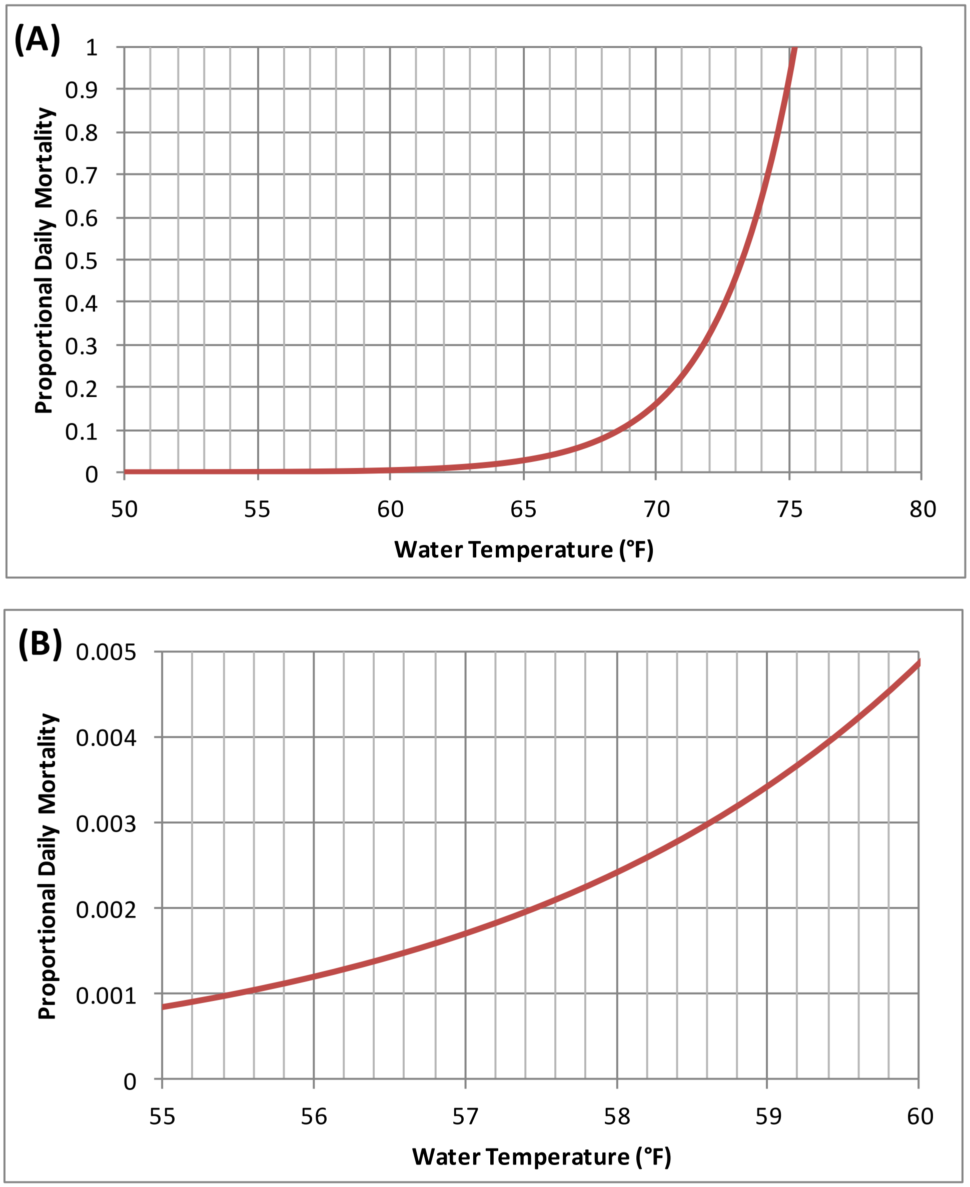


Figure 3. Relationship between Proportional Daily Mortality of Winter-Run Chinook Salmon Fry and Water Temperature (Equation 8) for (A) the Entire Temperature Range, and (B) the Predominant Range Found in Model Scenarios

Each day the mean proportional mortality of the rearing fish is predicted from the daily water temperature using the above exponential relationship; the predicted mean mortality, along with the confidence intervals of the predicted values, is used to define a normal probability distribution, which then is randomly sampled to determine the daily mortality of the rearing fish. Temperature mortality is applied to rearing fry for 60 days, which is the approximate time required for fry to transition into smolts (U.S. Fish and Wildlife Service 1999) and enter the *River Migration* stage. All fish migrating through the Delta are assumed to be smolts.

River Migration

Survival of smolts between Red Bluff Diversion Dam and Fremont Weir is estimated as a function of flow at Bend Bridge (Figure 4). The flow-survival relationship in this reach was modeld using 7 years of releases of winter run smolts from Livingston Stone hatchery that were implanted with JSATS transmitters (total of 2912 tagged fish detected at Red Bluff). Mortality in this stage is applied on the day fish pass Red Bluff with the specific value estimated based on flow at Bend Bridge. Smolts are delayed from entering the next model stage to account for travel time. Mean travel time (20 days) is used along with the standard error (3.6 days) to define a normal probability distribution, which is randomly sampled to provide estimates of the total travel time of migrating smolts.

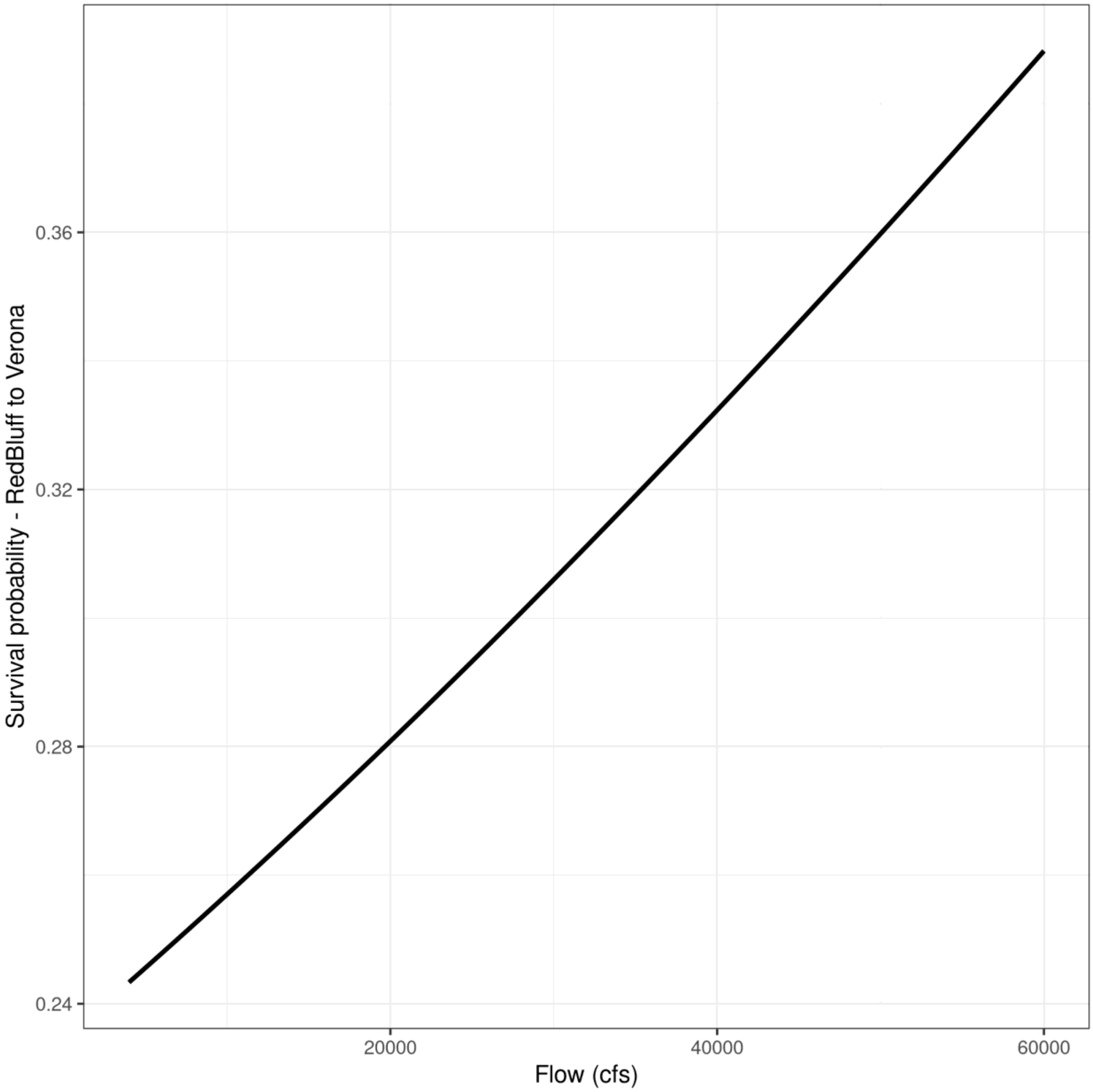
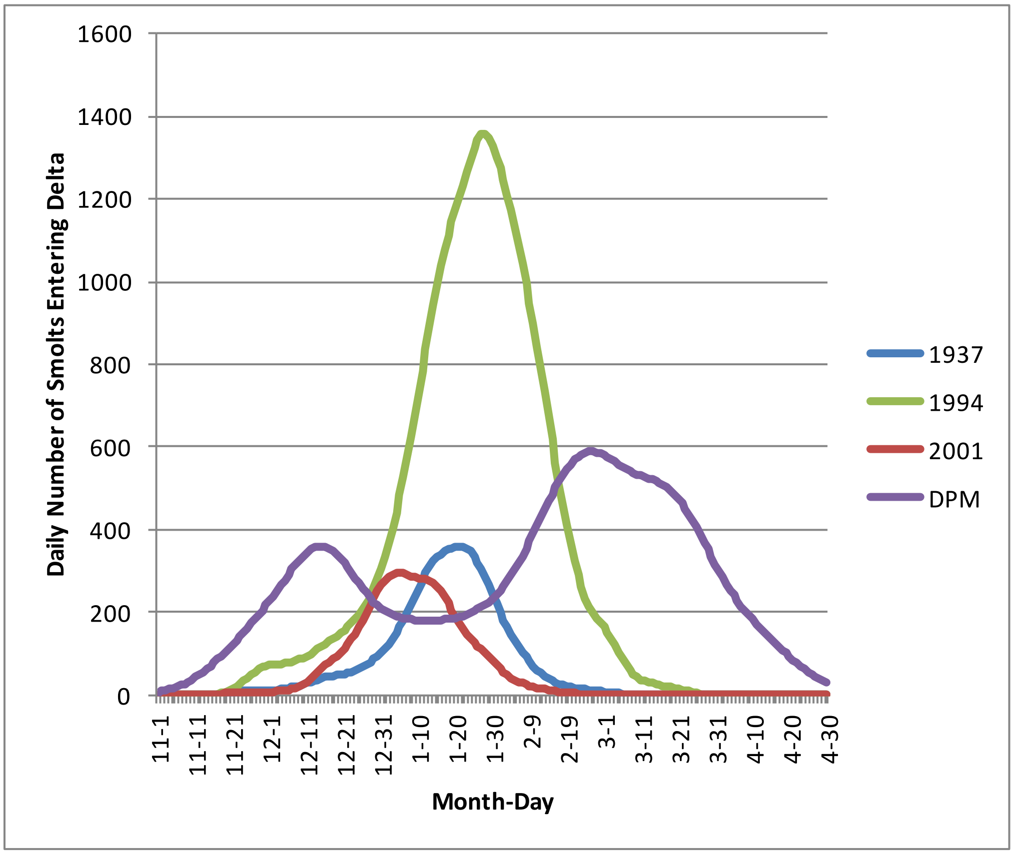


Figure 4. Relationship between flow at Bend Bridge and the probability of winter run smolt survival between Red Bluff and the first Delta Passage reach at Verona. This relationship includes smolts that entered the Yolo Bypass and those that remained in the Sacramento River.

Delta Passage

Winter-run Chinook salmon passage through the Delta within IOS is modeled with the DPM, which is described fully in a separate docuemnt. Note that there is one difference between the implementation of the DPM in IOS and the standalone DPM. The timing of winter-run entry into the Delta is a function of upstream fry/egg rearing and river migration so timing changes annually, in contrast to the fixed nature of Delta entry for the standalone DPM. Also, the IOS entry distribution is a unimodal term that tends to peak between the bimodal peaks of the standalone DPM entry distribution (Figure 5). As each cohort of smolts exits the final reaches of the Delta (Sac4 and the interior Delta), the cohorts accumulate until all cohorts from that year have exited the Delta. After all cohorts have arrived, they all enter the *Ocean Survival* model as a single cohort and the model begins applying mortality on an annual time step.



DPM: purple line, fixed bimodal distribution.
IOS in 1937: blue line, an average peak of January 21.
IOS in 1994: green line, a late peak of January 28.
IOS in 2001: red line, an early peak of January 4.
IOS data are from scenario ALT9_LLT of the BDCP EIR/EIS.

Figure 5. Winter-Run Chinook Salmon Smolt Delta Entry Distributions Assumed under the Delta Passage Model Compared with Entry Distributions for IOS in 1937, 1994, and 2001

Ocean Survival

As described by Zeug et al. (2012), this model stage uses a set of equations for smolt-to-age-2 mortality, winter mortality, ocean harvest, and spawning returns to predict yearly survival and escapement numbers (i.e., individuals exiting the ocean to spawn). Certain values during the ocean survival life stage were fixed constant among model scenarios. Ocean survival model-stage elements are listed in Table 1 and discussed below.

Table 1. Functions and Environmental Variables Used in the Ocean Survival Stage of the IOS Model

Model Element	Environmental Variable	Value
Smolt-age 2 mortality	None	Uniform random variable between 94% and 98%
Age 2 ocean survival	Wells' Index of Ocean productivity	Equation 13
Age 3 ocean survival	None	Equation 14
Age 4 ocean survival	None	Equation 15
Age 3 harvest	None	Fixed at 17.5%
Age 4 harvest	None	Fixed at 45%

Relying on ocean harvest, mortality, and returning spawner data from Grover et al. (2004), a uniformly distributed random variable between 94% and 98% mortality was applied for winter-run Chinook salmon from ocean entry to age 2 and functional relationships were developed to predict ocean survival and returning spawners for age 2 (8%), age 3 (88%), and age 4 (4%), assuming that 100% of individuals that survive to age 4 return for spawning. In the IOS Model, ocean survival to age 2 is given by:

(Equation 13) $$A_2 = A_i(1\text{-}M_2)(1\text{-}M_w)(1\text{-}H_2)(1\text{-}S_{r2})*W$$

Survival to age 3 is given by:

(Equation 14) $$A_3 = A_2(1\text{-}M_w)(1\text{-}H3)(1\text{-}S_{r3})$$

And survival to age 4 is given by:

(Equation 15) $$A_4 = A_3(1\text{-}M_w)(1\text{-}H_4)$$

where A_i is initial abundance at ocean entry (from the DPM stage), $A_{2,3,4}$ are abundances at ages 2–4, $H_{2,3,4}$ are harvest percentages at ages 3–4 represented by uniform distributions bounded by historical harvest levels, M_2 is smolt-to-age-2 mortality, M_w is winter mortality for ages 2–4, and $S_{r2,r3}$ are returning spawner percentages at age 2 and age 3.

Harvest mortality is represented by a uniform distribution that is bounded by historical levels of harvest. Age 2 survival is multiplied by a scalar W that corresponds to the value of Wells Index of ocean productivity. This metric was shown to significantly influence over-winter survival of age 2 fish (Wells et al. 2007). The value of Wells Index is a normally distributed random variable that is resampled each year of the simulation. In the analysis, the following values from Grover et al. (2004) were used: $H_2 = 0\%$, $H_3 = 0\text{-}39\%$, $H_4 = 0\text{-}74\%$, $M_2 = 94\text{-}98\%$, $M_w = 20\%$, $S_{r2} = 8\%$, and $S_{r3} = 96\%$.

Adult fish designated for return to the spawning grounds are assumed to be 65% female and are assigned a pre-spawn mortality of 5% to determine the final number of female returning spawners (Snider et al. 2001).

Time Step

The IOS Model operates on a daily time step, advancing the age of each cohort/life stage and thus tracking their numerical fate throughout the different stages of the life cycle. Some variables (e.g., annual mortality estimates) are randomly sampled from a distribution of values and are applied once per year. Although a daily time step is implemented for the Delta Passage component of IOS, flow inputs that rely on CALSIM outputs (i.e., all flows except flows at Fremont Weir) are based on monthly modeling and are assumed to be constant within a particular month. In addition, for the ocean phase of the life cycle, the model operates on an annual time step by applying annual survival estimates to each ocean cohort.

Model Inputs

Delta flows and export flow into SWP and CVP pumping plants were modeled using monthly flow output from CALSIM II, with the monthly average flow in a particular month being applied to all days within that month, as described above. A separate set of flow inputs was developed for each of the BDCP scenarios, based on the CALSIM II flow predictions for each scenario across the entire 1922 to 2002 prediction record. Flows into the Yolo Bypass over Fremont Weir were based on disaggregated monthly CALSIM II data based on historical patterns of variability. Temperature data for the Sacramento River was obtained from the SRWQM developed by the Bureau of Reclamation (Reclamation). The nodes in the CALSIM II and SRWQM models that were used to provide flow and temperature data for specific reaches in the Sacramento River and Delta are shown in Table 2.

Table 2. IOS Reaches and Associated Channels from CALSIM II and SRWQM Models

IOS Reach	CALSIM Channel	SRWQM
Spawning-Rearing Reach	–	Weighted average of Keswick and Balls Ferry temperatures based on spawning distribution
River Migration	Bend Bridge	
Sac1	Rsac155	–
Sac2	Sac_ds_stmbsl	–
Sac3	Rsac123	–
Sac4	Rsac101	–
SS	Sutr_sl+stmbt_sl	–
Geo/DCC	Dcc+georg_sl	–
Interior Delta	Total_exports	–

Model Outputs

Four model outputs are used to determine differences among model scenarios.

1. Egg survival: The Sacramento River between Keswick Dam and the Red Bluff Diversion Dam provides egg incubation habitat for winter-run Chinook salmon. Water temperature has a large effect on the survival of Chinook salmon during the egg incubation period by

controlling mortality as well as development rate. Temperatures in this reach are partially controlled by releases of cold water from Shasta Reservoir and ambient weather conditions.

2. Fry survival: The Sacramento River between Keswick Dam and Red Bluff Diversion Dam provides rearing habitat for juvenile winter-run Chinook salmon. Water temperature can have a large effect on the survival of Chinook salmon during the fry rearing stage by controlling mortality and development rate. Temperatures in this reach are partially controlled by releases of cold water from Shasta Reservoir and ambient weather conditions.
3. River migration survival: The Sacramento River between Red Bluff Diversion Dam and Fremont Weir is a migration route for juvenile winter-run Chinook salmon. Flow magnitude at the Bend Bridge station influences survival and travel time in this reach. Flows at Bend Bridge are partially controlled by releases from Shasta and Keswick Reservoirs.
4. Through-Delta survival: The Delta between the Fremont Weir on the Sacramento River and Chipps Island is a migration route for juvenile winter-run Chinook salmon. Flow magnitude in different reaches of the Delta influences survival and travel time and entrainment into alternative migration routes with different survival probabilities.
5. Escapement: Each year of the IOS Model simulation, escapement is calculated as the combined number of 2-, 3-, and 4-year-old fish that leave the ocean and migrate back into the Sacramento River to spawn between Keswick Dam and the Red Bluff Diversion Dam. These numbers are influenced by the combination of all previous life stages and the functional relationships between environmental variables and survival rates.

Model Limitations and Assumptions

The following model limitations and assumptions should be recognized when interpreting results.

1. Other important ecological relationships likely exist but quantitative relationships are not available for integration into IOS (e.g., the interaction among flow, turbidity, and predation). To the extent that these unrepresented relationships are important and alter IOS outcomes, each alternative considered is assumed to be affected in the same way.
6. For relationships that are represented in IOS, operational alternatives considered are not assumed to alter those underlying functional relationships.
7. There is a specific range of environmental conditions (temperature, flow, exports, and ocean productivity) under which functional relationships were derived. These functional relationships are assumed to hold true for the environmental conditions in the scenarios considered.
8. Differential growth because of different environmental conditions (e.g., river temperature) and subsequent potential differences in survival and other factors are not directly included in the model. Differences in survival related to growth are indirectly included to an unknown extent in flow-survival, temperature-survival, and ocean productivity-survival relationships.

9. Juvenile winter-run Chinook salmon migrating through the Delta all are assumed to be smolts that are not rearing in the Delta.

Model Sensitivity and Influence of Environmental Variables

Zeug et al. (2012) examined the sensitivity of the previous IOS model estimates of escapement to its input parameter values, input parameters being the functional relationships between environmental inputs and biological outputs. Although revisions have been undertaken to IOS since that time, particularly the river survival function, the main points from their analysis are still likely to be valid.

Zeug et al. (2012) found that escapement of different age classes was sensitive to different input parameters(Table 5). Escapement of age-2 fish (which compose 8% of the total returning fish in a given cohort) was most sensitive to smolt-to-age-2-survival and water year when considering either independent or interactive effects of these parameters, and there was also sensitivity to river migration survival when considering interactive effects of this parameter with other parameters. Escapement of age-3 fish (which compose 88% of the total returning fish in a given cohort) was sensitive to several input parameters when considering the independent effects of these parameters but was sensitive to through-Delta survival alone when considering first-order interactions between parameters. Escapement of age-4 fish (which compose 4% of the total returning fish in a given cohort) was sensitive to nearly all input parameters when considering the independent effects of these parameters, but was not sensitive to any of the parameters when considering first-order interactions between parameters (Zeug et al. 2012).

Zeug et al. (2012) also explored how uncertainty in model parameter estimates influences model output by increasing by 10–50% the variation around the mean of selected parameters that could be addressed by management actions (egg survival, fry-to-smolt survival, river migration survival, Delta survival, age-3 harvest, and age-4 harvest). They found that model output was robust to parameter uncertainty and that age-3 and age-4 harvest had the greatest coefficients of variation as a result of the uniform distribution of these parameters. Zeug et al. (2012) noted that there are limitations in the data used to inform certain parameters in the model that may be ecologically relevant but that are not sensitive in the current IOS configuration: river survival is a good example because it is based on a three-year field study of relatively low-flow conditions that does not cover the range of potential conditions that may be experienced by downstream-migrating juvenile Chinook salmon.

To understand the influence of environmental parameter inputs on escapement estimates from IOS, Zeug et al. (2012) performed three sets of simulations of a baseline condition and either a 10% increase or a 10% decrease in river flow, exports, water temperature (on the Sacramento River at Bend Bridge; see above), and ocean productivity (i.e., Wells Index; see above). They found that only 10% changes in temperature produced a statistically significant change in escapement; a 10% increase in temperature produced a far greater reduction in escapement (>95%) than a 10% decrease in temperature gave an increase in escapement (>10%). Zeug et al. (2012) suggested that the lack of significant changes in escapement with 10% changes of flow, exports, and ocean productivity may reflect the fact that these variables' relationships within the model were based on observational studies with large error estimates associated with the responses. In contrast, temperature functions were parameterized with data from controlled experiments with small error estimates. Also, Zeug et al. (2012) noted that water temperatures within the winter-run Chinook salmon spawning and rearing area are close to the upper tolerance limit for the species; therefore, even small changes have the potential to significantly affect the population.

Table 5. Sobol' Sensitivity Indices (Standard Deviation in Parentheses) for Each Age Class of Returning Spawners Based on 1,000 Monte Carlo Iterations, Conducted to Test Sensitivity of IOS Input Parameters by Zeug et al. (2012)

Input Parameter	Age 2		Age 3		Age 4	
	Main Index (Effect Independent of Other Input Parameters)	Total Index (Effect Accounting for First-Order Interactions with Other Input Parameters)	Main Index (Effect Independent of Other Input Parameters)	Total Index (Effect Accounting for First-Order Interactions with Other Input Parameters)	Main Index (Effect Independent of Other Input Parameters)	Total Index (Effect Accounting for First-Order Interactions with Other Input Parameters)
Water year	0.300[a] (0.083)	0.306[a] (0.079)	0.181[a] (0.091)	0.150 (0.091)	0.073 (0.067)	0.012 (0.065)
Egg survival	0.030 (0.016)	-0.006 (0.016)	0.222[a] (0.081)	-0.021 (0.081)	0.102[a] (0.044)	-0.072 (0.044)
Fry-to-smolt survival	0.039 (0.020)	-0.009 (0.020)	0.166 (0.090)	0.091 (0.092)	0.079a (0.017)	-0.071 (0.017)
River migration survival	0.007 (0.034)	0.135a (0.034)	0.164 (0.084)	0.062 (0.085)	0.079 (0.018)	-0.07 (0.018)
Delta survival	0.010[a] (0.002)	-0.009 (0.002)	0.404[a] (0.180)	0.643[a] (0.177)	0.313[a] (0.134)	-0.009 (0.132)
Smolt to age 2 survival	0.734[a] (0.118)	0.454[a] (0.113)	0.015 (0.016)	-0.006 (0.016)	0.057a (0.017)	-0.052 (0.017)
Ocean productivity	0.003 (0.009)	0.009 (0.009)	0.034[a] (0.015)	-0.034 (0.015)	0.061[a] (0.030)	-0.048 (0.029)
Age 3 harvest	N/A	N/A	0.029[a] (0.001)	-0.028 (0.001)	1.48[a] (0.306)	0.188 (0.293)
Age 4 harvest	N/A	N/A	N/A	N/A	0.055a (0.003)	-0.054 (0.003)

Source: Zeug et al. 2012.

[a] Index value was statistically significant at α=0.05.

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Personal Communications

Niemela, Kevin pers. comm.

Attachment 11I-2 OBAN Winter-Run Chinook Salmon Life Cycle Model

QEDA Consulting LLC
4007 Densmore Ave N
Seattle, WA 98103
206.300.5595
NOBLEHENDRIX@GMAIL.COM

QEDα

TECHNICAL MEMORANDUM

To: Steve Micko, Jacobs
From: Noble Hendrix, QEDA Consulting
Date: February 26, 2021
Subject: Draft results of OBAN analysis of Sites Alternatives NAA_011221 ALT1A_011221 ALT1B_011221 ALT2_011221 ALT3_020121

This technical memorandum describes preliminary results from running the OBAN model for a baseline alternative (NAA_011221) and several Sites proposed action alternatives (ALT1A_011221, ALT1B_011221, ALT2_011221, and ALT3_020121).

Model Details:

The OBAN model was modified to be able to run for the full CalSim period of hydrologic outputs. Two modifications were made to the OBAN model. The first was the inclusion of a harvest control rule for calculating harvest rates as a function of spawning abundance. The harvest control rule is consistent with the rule used in the NMFS winter-run life cycle model (WRLCM) and has a maximum harvest rate of 0.2 when the three-year geometric average is greater than 3500 spawners. The second modification was the need to resample from the ocean productivity indices in each Monte Carlo iteration of the model. The historical 1967 – 2014 ocean productivity indices were resampled in each iteration with replacement to provide variability in ocean productivity across Monte Carlo simulations.

Model Results:

The alternatives tended to have slightly higher median abundances relative to the NAA (Figure 1). The patterns in relative abundance were different among alternatives during the 1922 – 1930’s, but during the 1940’s and 1990’s there was little difference in median abundance of the alternatives relative to the NAA_011221 (Figure 1). After the 1940’s, patterns in the relative median abundance were similar under alternatives ALT1A_011221 and ALT2_011221. In contrast, patterns in relative median abundance were different under ALT1B_011221 and under ALT3_020121 relative to both the NAA and to the other alternatives (Figure 1). Furthermore, the annual variability in the median was higher under ALT3_020121 relative to the other alternatives (Figure 1). Variability across Monte Carlo simulations in the difference in abundance was substantial (gray area in Figure 2) for all alternatives. Periods with low variability coincided with overall low abundance in the model runs across all alternatives and the NAA, which occurred during the 1940’s and 1990’s (Figure 1, Figure 2).

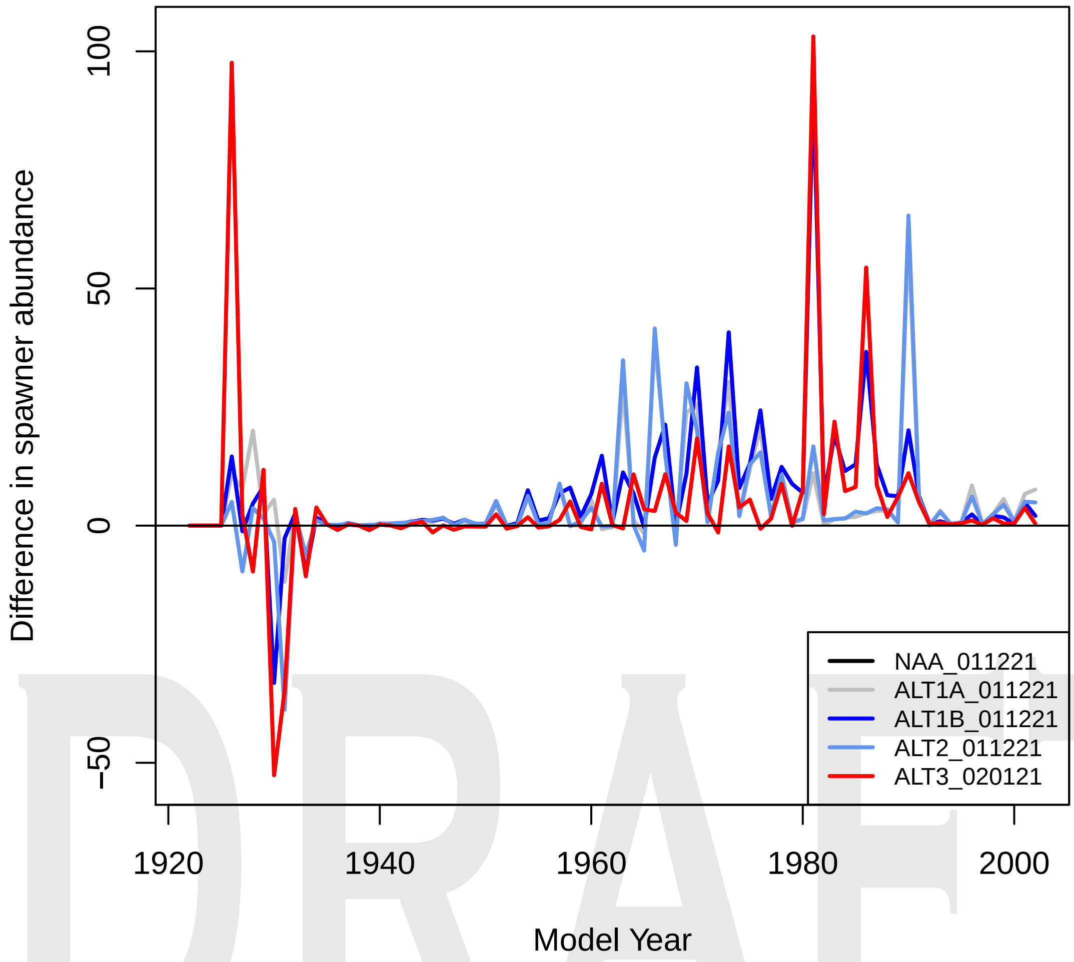

Figure 1. Difference (ALT – NAA) in spawner abundance for model years 1922 – 2002. Positive values indicate higher abundances under alternatives relative to NAA.

The probability of quasi-extinction (probability that spawner abundance < 100) showed similar temporal patterns for the NAA and for each of the alternatives (Figure 3 left). The probability of quasi-extinction was generally lower for alternatives compared to the NAA, particularly after the 1960's in the time series (Figure 3 right). Alternative ALT1B_011221 appeared to provide lower probability of extinction relative to the other alternatives during the 1990's, but ALT3_020121 had lower probabilities of quasi-extinction during the 1980's (Figure 3 right).

The difference in survival rates in the egg through fry stage and in the delta stage was calculated to understand which alternatives differed from the NAA_011221, how the alternatives differed from each other, and the model years in which those differences were occurring. The survival differences in the egg through fry stage generally indicated periods of improvement in survival under the alternatives ALT1A_011221, ALT1B_011221, and ALT2_011221 relative to the NAA (Figure 4). The patterns in egg to fry survival were slightly different under ALT3_020121, in which survivals were also generally higher under ALT3_020121 relative to NAA except for a couple years, namely 1940 and 1973 (Figure 4). Patterns in survival relative to the NAA were similar in the alternatives ALT1A_011221 and ALT2_011221, which is the likely reason for similar results under these two alternatives in the spawner abundance and probability of extinction. In contrast, the patterns in relative egg to fry survival were unique to ALT1B_011221 and ALT3_020121. Finally, in the delta survival comparison, there was little difference in the survivals under the alternatives relative to the NAA__011221 (Figure 5).

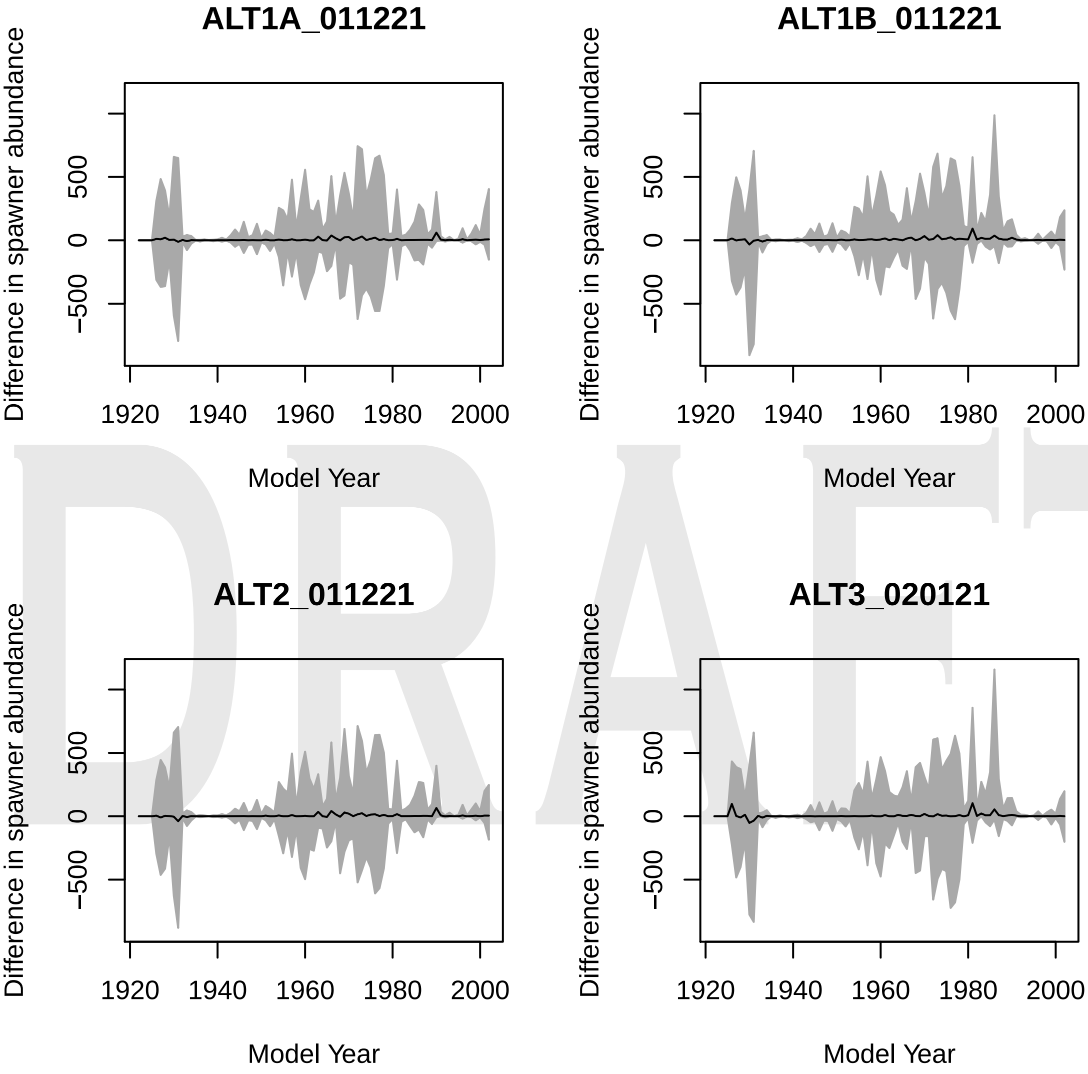

Figure 2. Difference (ALT – NAA) in spawner abundance for model years 1922 – 2002. Positive values indicate higher abundances under alternatives relative to NAA. Median (line) and 80% intervals (gray) across 1000 Monte Carlo simulations are presented.

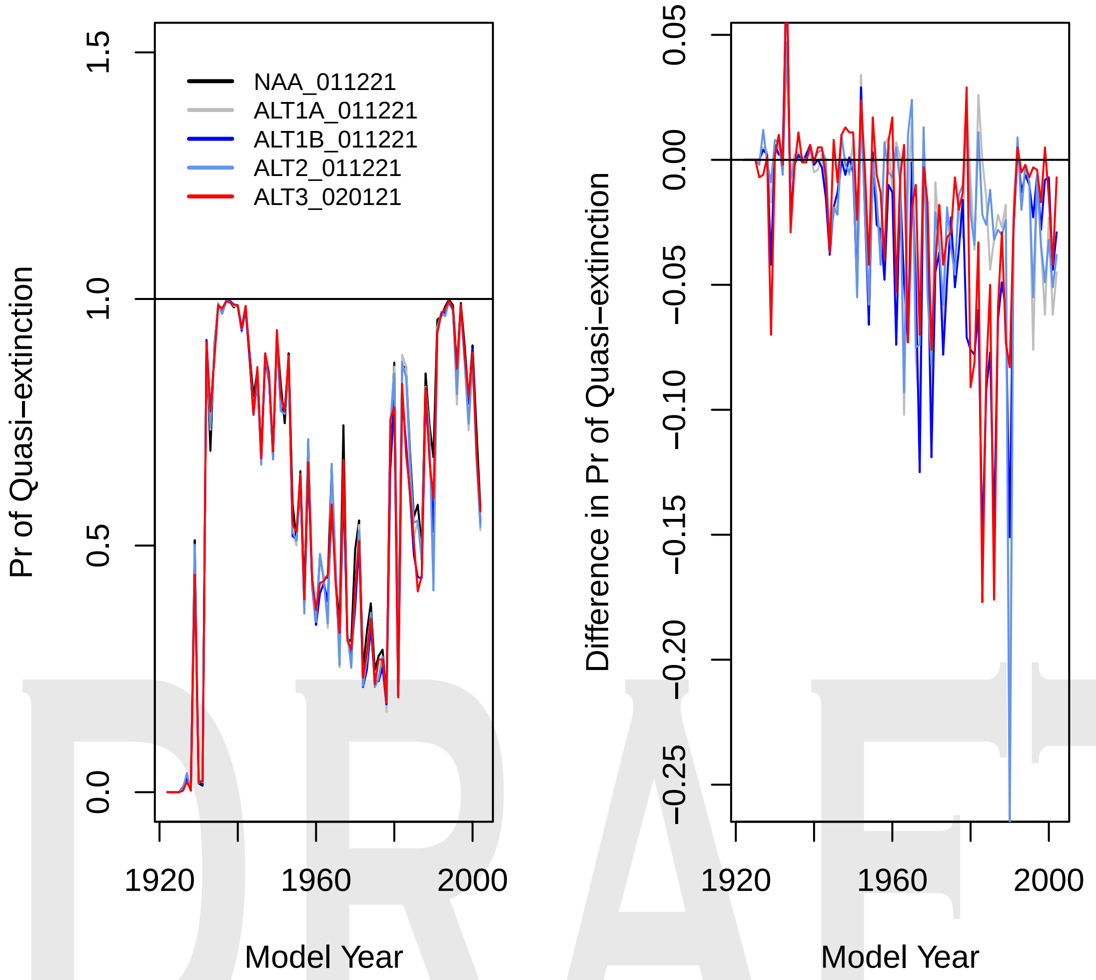

Figure 3. Probability of quasi-extinction (spawner abundance < 100) showing the NAA (black) and alternatives (left). Difference (ALT – NAA) in the probability of quasi-extinction (right), where negative values indicate lower probability of quasi-extinction.

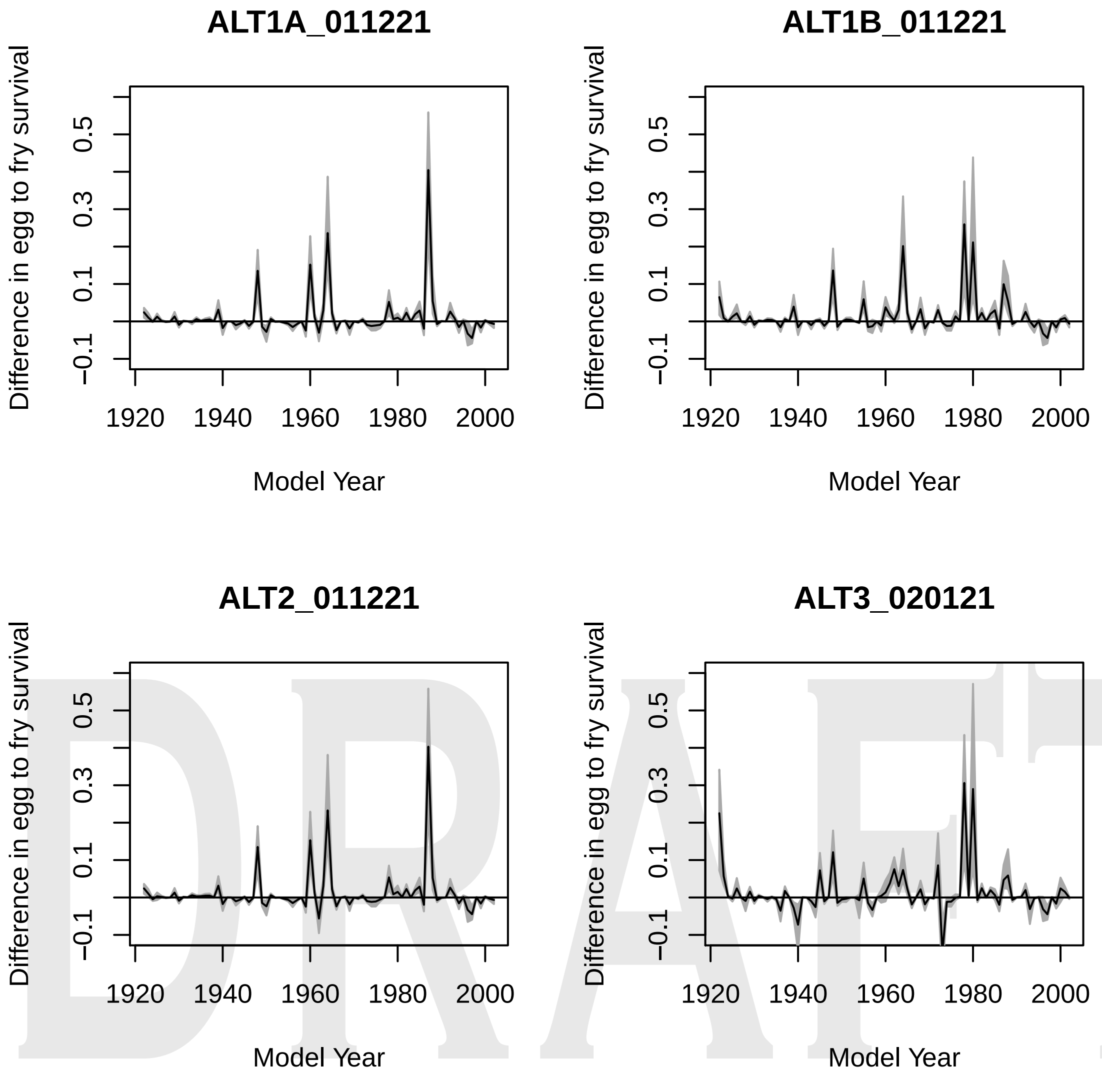

Figure 4. Difference (ALT – NAA) in survival of the egg through fry stages which includes thermal mortality and Bend Bridge flow effects. Median (line) and 80% intervals (gray) across 1000 Monte Carlo simulations are presented.

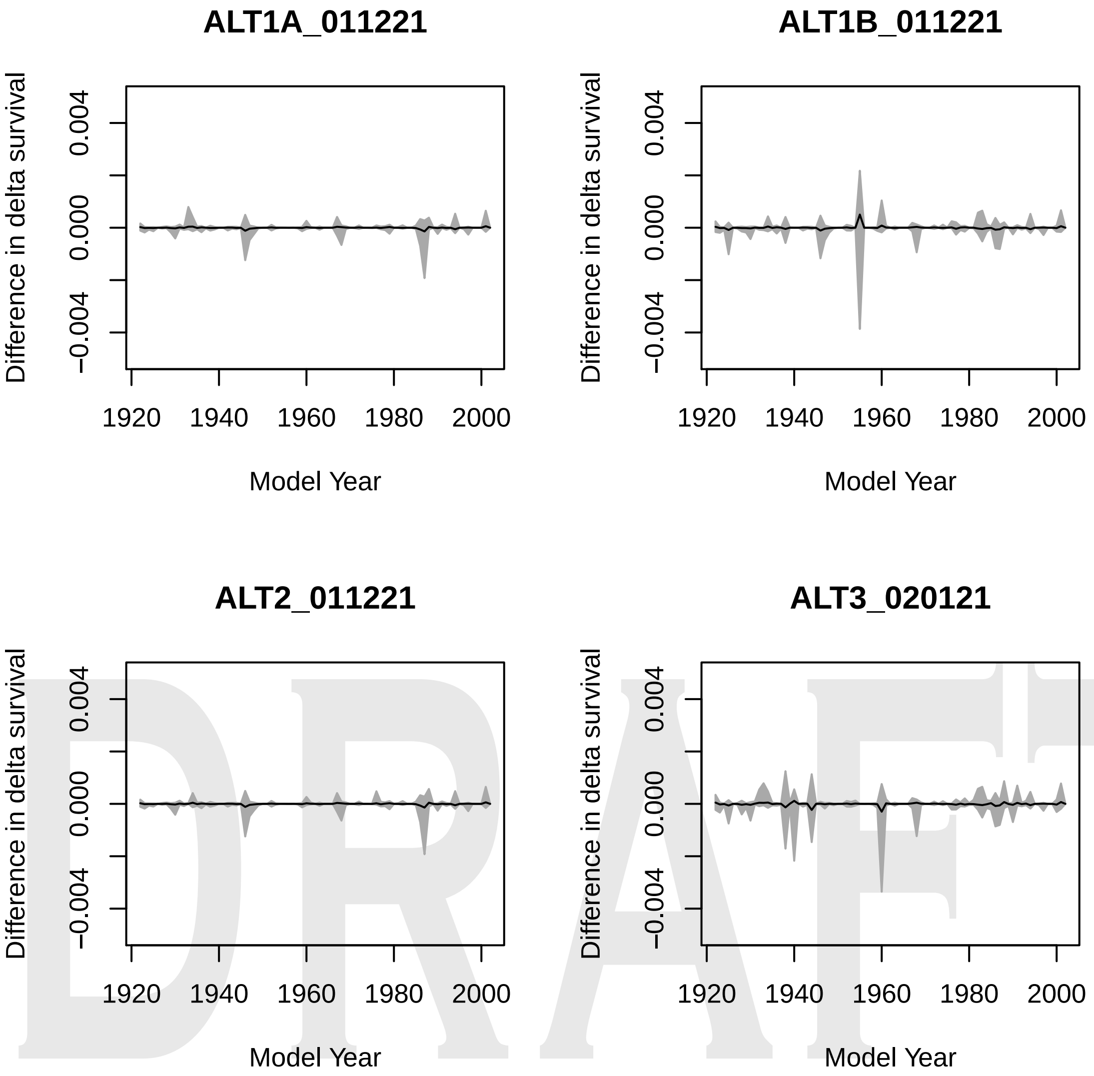

Figure 5. Difference (ALT – NAA) in survival of the delta stage which includes access to Yolo bypass and export effects. Median (line) and 80% intervals (gray) across 1000 Monte Carlo simulations are presented.