Appendix F, Modeling

Attachment F.2 CVPIA SIT Winter-run LCM

F.2.1 Model Overview

USFWS and Reclamation have been working to develop lifecycle models for use in structured decision making for CVPIA. Through a participatory process, the Science Integration Team (SIT) has developed a winter-run Chinook Salmon decision support model, or DSM. This model has been peer-reviewed and is publicly available. The participatory team's model proposals and meeting notes, background, documentation, and code for the model are available at: Resources - CVPIA Science Integration Team. Reclamation used the SIT DSM in the LTO lifecycle analyses.

F.2.2 Methods

F.2.2.1 Model Development

The CVPIA SIT DSM models were developed by the CVPIA Science Integration Team (SIT) as part of a Structured Decision-Making (SDM) process. The SIT is a collaborative team of stakeholders and scientists. The resulting decision support models (DSMs) are open source and publicly available (DSM R Packages - CVPIA Science Integration Team). An early version of the DSMs has been published in a peer-reviewed publication (Peterson and Duarte 2020). The models were parameterized and calibrated using a combination of empirical data, existing models, analysis of existing data, and expert opinion.

DSMs were created for fall-, winter-, and spring-run Chinook salmon to compare how habitat restoration actions might improve natural production of each run. The DSMs are stochastic or deterministic stage-based life cycle models (LCMs) that track the number of Chinook salmon across juvenile size classes and adult stages of natural and hatchery origin. The transitions between stages are estimated with survival, growth, and movement submodels. Model inputs include existing habitat areas, fish harvest rates, water diversions, flows, and temperatures. Original flow information was obtained from CalSim II outputs. Temperature data are primarily obtained from HEC-5Q outputs. Some areas for which HEC-5Q data were unavailable have temperatures modeled based on measured water temperatures, statistical models relating water temperature to air temperature, or matching of tributaries with similar hydrology and geomorphology. Habitat inputs are primarily based on previously published flow-habitat relationships. Where flow-habitat relationship information is not available, relationships were assumed to be similar to those of nearby, geomorphically similar watersheds (Available in Attachment O.2). All other inputs except for predator prevalence are obtained from previously published sources.
For the purposes of LTO analyses, Reclamation used the model structure from the peer-reviewed, published version of the DSMs, instead of more recent versions with updated model processes

and calibrations, based on recommendations from model developers and an emphasis on peer-reviewed model processes. The winter-run and spring-run DSMs were cloned by Reclamation staff from GitHub at the following URLs: https://github.com/CVPIA-OSC/winterRunDSM/tree/main and https://github.com/CVPIA-OSC/springRunDSM/tree/v1.0. These models required Reclamation to download the following data repositories from the FlowWest GitHub site: cvpiaHabitat (https://github.com/FlowWest/ cvpiaHabitat), cvpiaFlow (https://github.com/FlowWest/cvpiaFlow), cvpiaTemperature (https://github.com/FlowWest/cvpiaTemperature), and cvpiaData (https://github.com/FlowWest/ cvpiaData).

Reclamation updated the calculation of flow inputs to the DSM to use CalSim 3 data for alternatives of interest. CalSim 3 data was used in place of the original CalSim II data for the following reasons: 1) the original DSMs, as well as all subsequent versions, used CalSim II data and variable definitions because that was the most recent available version, 2) Reclamation has developed a new CalSim model, CalSim 3, for current application in LTO modeling and future modeling needs, and 3) base model structures, assumptions, and definitions differ between CalSim II and CalSim 3 (sometime substantially). A detailed description of this conversion is provided in Section F.2.2.3, *Assumptions / Uncertainty*.

Reclamation also identified two issues in the published versions of the SIT DSMs (i.e., those used in Peterson and Duarte 2020) that merited recalibration of core model parameters. First, values for total diversions in the Upper Sacramento, which influence expected rearing survival, were incorrectly calculated as proportional diversions. Second, when the model is run in the deterministic mode, size class-specific survival terms are incorrectly applied for fish rearing in migratory corridors (e.g., Upper-mid, Lower-mid, Lower Sacramento River); because deterministic model runs serve as the basis for model calibration, this issue was especially problematic for comparing old and new model outputs. Both of these concerns led Reclamation staff to recalibrate the winter-run DSM for application in LTO modeling efforts. Details on model recalibration are provided in Section F.2.2.3, *Assumptions / Uncertainty*.

F.2.2.2 Model Application

Reclamation ran the winter-run Chinook salmon DSM, both deterministically (i.e., no variability in parameters) and stochastically, to estimate demographic parameters, spawner abundances, and population trends for the period from 1980-1999 using updated flow and temperature inputs for each modeled alternative. The stochastic model was run for 100 iterations for each alternative, in which variability is simulated around select demographic parameters and abundances using random draws from statistical distributions. Stochastic model runs allow visualization of the implications of variability in life history parameters and processes on population demographic rates. Reclamation modified the model to output demographic parameters, in addition to previous reporting of juvenile and adult abundances; output demographic parameters hypothesized to be important to population trends included rearing survival in the Upper Sacramento River and smolt migratory survival through the Sacramento River and Delta. Reclamation only presents model outputs for demographic parameters that are sensitive to modified flow and temperature inputs. As noted in Section F.2.2.3, *Assumptions / Uncertainty*, Reclamation did not update habitat inputs due to the complexity and inconsistent documentation associated with updating these values; thus, differences in scenario results reflect differences in flow and temperature only.

F.2.2.3 Assumptions / Uncertainty

F.2.2.3.1 Assumptions related to model calibration and re-calibration

As noted above, Reclamation applied the same model structure described and implemented in Peterson and Duarte (2020), but with re-calibrated parameters that addressed corrections to faulty model functions and inputs. The methods and results of the re-calibration efforts are described below for completeness.

Re-calibration methods

Reclamation first modified the following functions to accurately apply rearing survival across age classes and watersheds: Delt.rearfunc() and rearfunc() (in the R scripts 'Delta juvenile growth n survival.R' and 'Survive and grow.R', respectively). Reclamation staff also generated accurate values for total diversions in the Upper Sacramento River using the original CalSim II input data and the R script 'Create new t.diver for calibration.R'. Finally, Reclamation also removed previous scalar adjustments to spawning and rearing habitat quantities for all watersheds.

Reclamation staff conducted recalibration using the GA package in R (v4.2.0). Reclamation used the same calibration model inputs used in the original calibration effort using the cvpiaCalibration package (FlowWest/cvpiaCalibration (github.com)), with two exceptions: staff used updated spawner abundance data from the Upper Sacramento River for brood years 1998-2017 and applied the updated total diversion values for the Upper Sacramento River watershed. Calibration model inputs were generated for 1998-2017 by constructing a synthetic time series of water years – see Peterson and Duarte (2020) for additional details. A total of 16 model parameters were estimated (Table F.2-1). Reclamation ran the calibration-version of the model for the simulated period 1998-2016 (i.e., 19 years of spawner abundance data). Estimated model fit was calculated as the sum of squared differences between observed and model-estimated spawner abundance data over the modeled time series; staff set the GA optimization to maximize the negative sum of squared differences.

Following exploratory rounds of calibrations with different optimization parameters and parameter constraints, Reclamation staff applied the following GA optimization parameters for the final calibration, drawing from recommendations from: Winter Run Calibration 2021 • winterRunDSM (cvpia-osc.github.io): popSize=100, maxiter=10000, run=50, pmutation=0.4. Staff used the original calibrated parameter values as starting values during optimization and set some informed constraints on possible values parameters. The adult en route survival parameter was bounded on the lower end at 0 to prevent unrealistically low survival values. Similarly, the last four parameters were bounded on the lower end at 0 based on expectations for the direction of covariate effects (e.g., survival should decrease with increased diversions). Staff bounded logit-transformed ocean survival to a maximum of -2 (i.e., experts would not reasonably expect total marine survival, from ocean entry to freshwater return as spawners, to exceed 12%). All other parameter values were constrained with a default of -3.5 and 3.5 because all were expressed as logit-transformed values. Recalibration efforts were informed in part by consultation with the researchers who conducted the original calibration efforts (J. Peterson and A. Duarte, personal communication).

To assess the robustness and reliability of calibration results, Reclamation conducted multiple rounds of calibration runs for each set of calibration parameters and compared both convergence model fit (i.e., the negative sum of squared differences) and parameter values among runs. The intent of this step is to investigate the possibility for local minima in optimization, evaluate whether parameter values were running up against constraints, and assess consistency in parameter estimates; ideally, most to all parameters should be generally similar among runs and should not be close to parameter constraints. If this assessment did not reveal obvious issues, Reclamation then used the parameter estimates from the calibration run with the best (highest) model fit as the final selected parameter values.

Reclamation also performed post-hoc tests for goodness of fit with the selected parameter values by generating model estimates of natural spawners for both the new and original parameter values and comparing these model estimates to historical estimates of spawner abundance used to calibrate the model.

Table F.2-1. Parameters recalibrated for the winter-run Chinook salmon SIT DSM.

Parameter ID	Description	Notes
1	Juvenile in-channel and floodplain rearing survival intercept	
2	Juvenile bypass rearing survival intercept	
3	Juvenile Delta rearing survival intercept	Might expect negative covariance with Parameter 16 (Delta diversions effect on rearing survival)
4	Juvenile San Joaquin migratory survival intercept	Not relevant to winter-run - expect no consistent values among runs
5	Juvenile Sacramento River migratory survival intercept (temperature model)	Expect parameters 5 and 6 to covary
6	Juvenile Sacramento River migratory survival intercept (discharge model)	Expect parameters 5 and 6 to covary
7	Juvenile Delta migratory survival intercept (flow model)	Expect parameters 7, 8 and 9 to covary
8	Juvenile Delta migratory survival intercept (temperature model)	Expect parameters 7, 8 and 9 to covary
9	Juvenile Delta migratory survival intercept (diversion model)	Expect parameters 7, 8 and 9 to covary
10	Juvenile ocean entry survival intercept	Expect this one to be < -2 (max of 0.12 overall marine survival)
11	Adult en route survival intercept	
12	Egg-to-fry survival intercept	
13	Effect of contact points on juvenile rearing survival	
14	Effect of proportion flow diverted on juvenile rearing/migratory survival	

Parameter ID	Description	Notes
15	Effect of total flow diverted on juvenile rearing/migratory survival	
16	Effect of Delta diversions on juvenile rearing survival	

Re-calibration results

Overview

The results are separated into sections by the optimization settings, parameter constraints, and length of data time series; most calibration runs were used to finalize calibration methods or validate selected parameter constraints. Based on these results and the criteria for calibration success, Reclamation staff selected the parameters from 'run 3' from the final set of calibration runs (i.e., long time series, standard marine survival constraint) as the new parameters for the winter-run DSM and for future use in comparing the effects of competing alternatives on the winter-run population.

Preliminary calibration results, short time series (1998-2010), no marine survival constraints

Before settling on the parameterization for the GA optimization discussed above, Reclamation conducted several rounds of exploratory calibration to identify potential issues. First, staff ran the calibration with all described parameter constraints except for marine survival (i.e., parameter 10, Table F.2-1). For marine survival intercept, staff applied the default constraints of -3.5 and 3.5. With these constraints, Reclamation ran three calibrations with a popSize=10 and two calibrations with a popSize=100. For these calibration runs, staff used a short time series of spawner abundances from 1998-2010. Reclamation obtained the following takeaways from these efforts:

- Model fit values varied widely among runs, both with a popSize=10 and a popSize=100; greater popSize values are expected to produce less variability and improved calibration performance (Figure F.2-1). Variability in observed model fit suggests optimization routines are finding numerous, different local minima.
- Calibrated parameter values varied widely among runs, both with a popSize=10 and a popSize=100 (Figure F.2-2).
- The parameter for juvenile ocean entry survival intercept (Parameter ID = 10) both varied widely and was estimated to have implausibly high values (Figure F.2-2). Recent estimates of marine survival, encompassing ocean entry as smolts to age-2, were 0.23 or lower for late-fall-run Chinook salmon (Michel 2019); these values suggest survival from ocean entry to spawning as age-3 or age-4 fish is even lower, as annual natural mortality rates for age-3 fish are assumed to be 0.2 in winter-run Chinook salmon cohort reconstructions and forecasts (O'Farrell et al. 2016). Given most winter-run Chinook salmon spawn at age-3, Reclamation staff expected the expected maximum marine survival to be in the ballpark of 0.184 (0.23 * 0.8) and average marine survival to be lower; these calculations do not account for any additional fishing mortality. With some runs, the marine survival parameter value was as high as 1.31, which translated to baseline marine survival of 0.79.

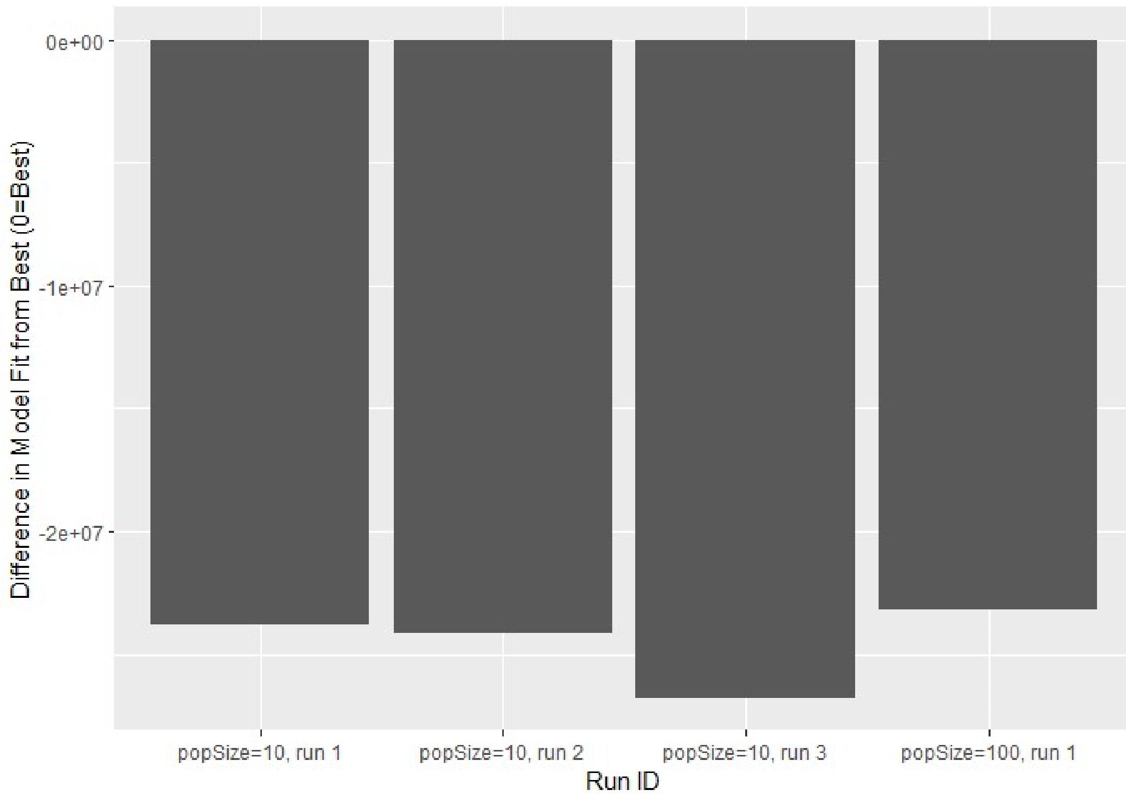

Figure F.2-1. Comparison of differences in model fit for all sub-optimal models from the best model. The best model was *popSize*=100, *run*=2 and had a model fit of -146618423, or -1.47e8.

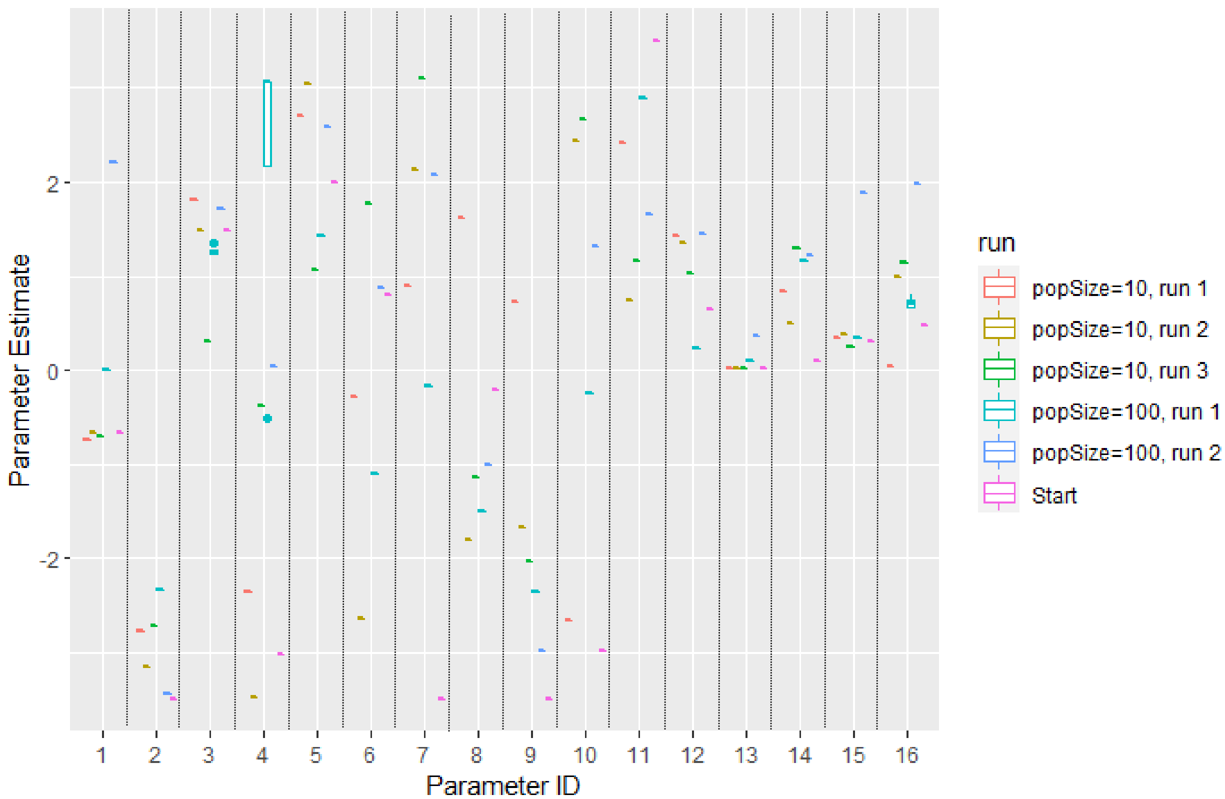

Figure F.2-2. Plot of parameter estimates for 5 exploratory runs without constraints on marine survival intercept and a short calibration time series, as well the starting values drawn from the parameter values from the original calibration. Ranges of parameter estimates for a given parameter and run indicate multiple parameter values produced the same measure of model fit.

Preliminary calibration results, short time series (1998-2010), marine survival constraints

Reclamation conducted another round of preliminary calibrations with the short time series of historical, or 'known', abundances after constraining marine survival to be less than 0.119 (logit-transformed value of -2); this value was based on a maximum observed marine survival to age-2 of 0.23 and expected natural mortality values for age-3 fish (see above text; O'Farrell et al. 2016; Michel 2019). With this new constraint, staff ran three calibrations with a popSize=100. These efforts resulted in the following observations:

- Although there was still variability in metrics of model fit among model runs, the total difference was an order of magnitude smaller than that observed without constraints on marine survival (Figure F.2-3)

- Staff observed reasonably consistent estimates for most parameters among the three calibration runs (Figure F.2-4). In particular, logit-transformed estimates of marine survival were broadly similar without running into upper or lower boundaries. Some parameters, notably parameter estimates for San Joaquin River migratory survival and juvenile Delta migratory survival (i.e., parameters 4, 7-9) were highly variable among runs; however, San Joaquin River survival is expected to have no effect on population dynamics for winter-run Chinook salmon, given the lack of spawning in the San Joaquin River or its tributaries, and the Delta survival parameters are expected to covary strongly because the three covariate hypotheses are equally weighted.
- Reclamation selected the parameters from 'run 2' and generated model estimates of spawner abundance to compare with 'known' spawners (Figure F.2-5). Although the newly calibrated parameter values provide better estimates of spawner abundance than the original values, the combination of the model structure and parameter values does not meaningfully account for observed variability in 'known' abundances.

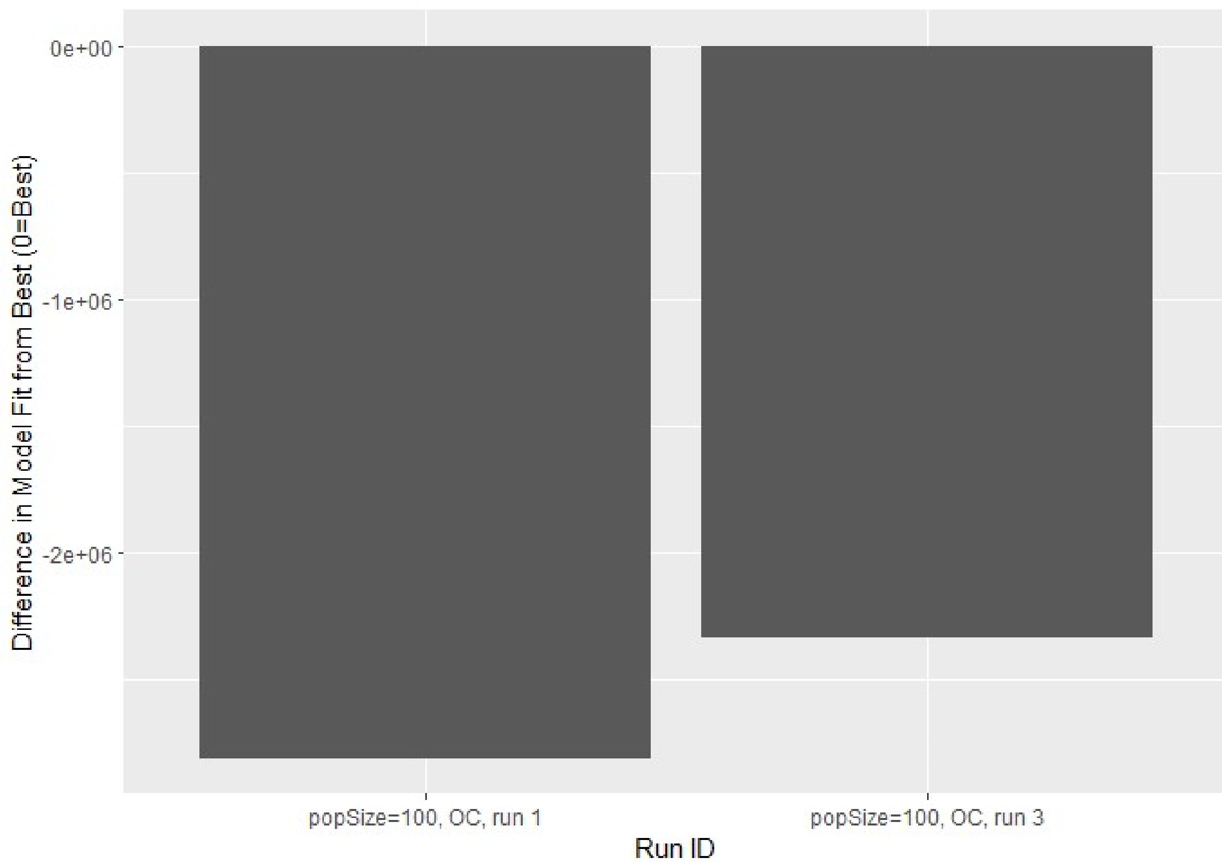

Figure F.2-3. Comparison of differences in model fit for all sub-optimal models from the best model. The best model was *popSize*=100, *OC*, *run*=2 and had a model fit of -171165739, or -1.71e8.

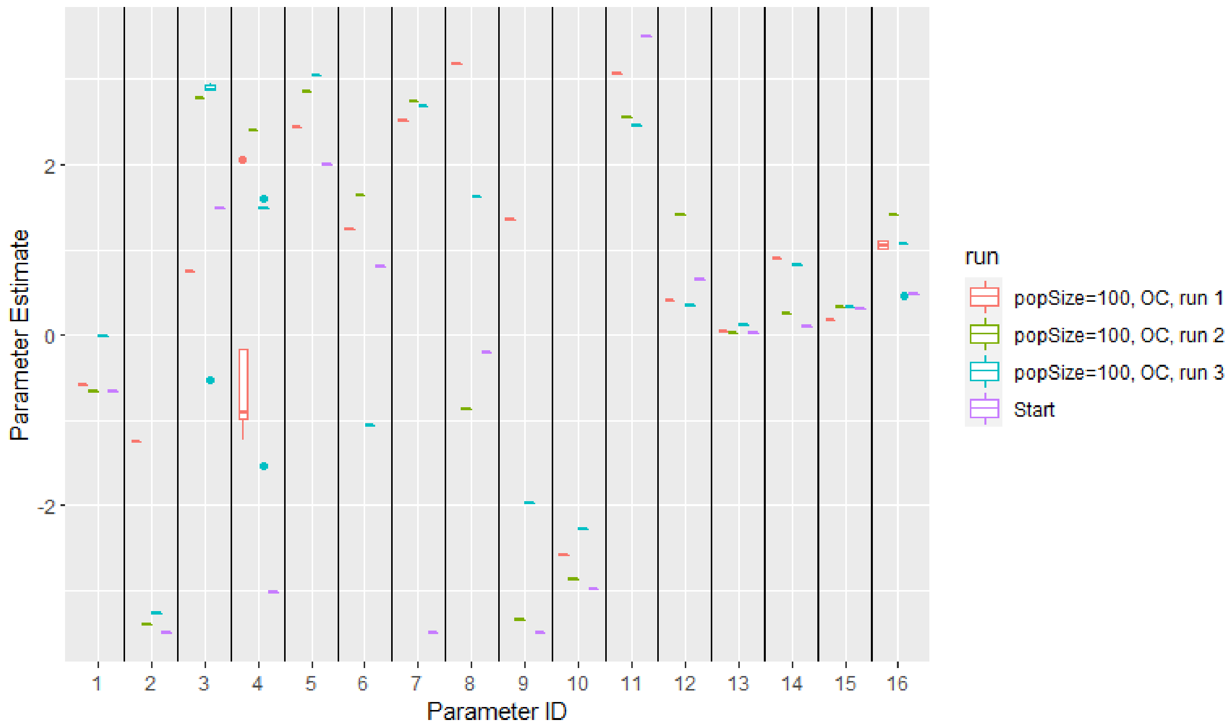

Figure F.2-4. Plot of parameter estimates for 3 calibration runs with constraints on marine survival intercept and the short calibration time series, as well the starting values drawn from the parameter values from the original calibration. Ranges of parameter estimates for a given parameter and run indicate multiple parameter values produced the same measure of model fit.

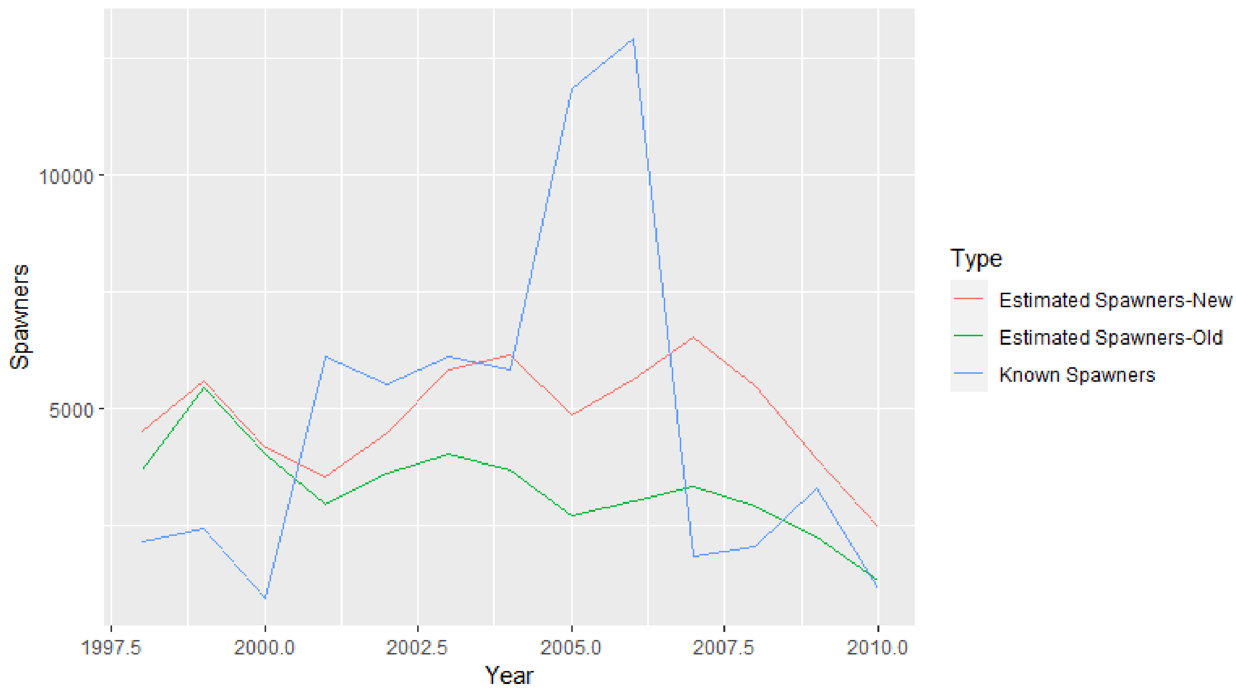

Figure F.2-5. Plot of estimated spawners, both with original and newly calibrated parameter estimates, and known spawner abundances with the short time series of calibration data and informed constraints on marine survival.

Final calibration results, long time series (1998-2016), marine survival constraints

Reclamation staff conducted a final round of three calibration runs with informed constraints on marine survival and the full time series of 'known' abundances. From this round of calibration runs, Reclamation obtained the following conclusions:

- Although there was still variability in metrics of model fit among model runs, the total difference was an order of magnitude smaller than that observed without constraints on marine survival and less than half that observed with the short calibration data time series (Figure F.2-6).
- Staff observed reasonably consistent estimates for most parameters among the three calibration runs (Figure F.2-7). Logit-transformed estimates of marine survival were again broadly similar without running into upper or lower boundaries. Some parameters, including parameter estimates for San Joaquin River migratory survival and juvenile Delta migratory survival (i.e., parameters 4, 7-9) continued to be highly variable among runs as expected.
- Finally, staff were assured that the specified upper bound for marine survival (logit-value = -2) was not overly restrictive in model fitting, as Reclamation performed three additional validation calibrations with a less restrictive upper bound (logit-value = -1, proportional marine survival = 0.27). None of the estimated marine survival terms exceeded the previous boundary (Figure F.2-8).

- Reclamation selected the parameters from ‘run 3’ as our best model (i.e., see Figure F.2-6, Figure F.2-7) and generated model estimates of spawner abundance to compare with ‘known’ spawners (Figure F.2-9, Figure F.2-10). The newly calibrated parameter values provide better estimates of spawner abundance than the original values, and the combination of model structure and newly calibrated parameter values do a reasonable job of approximating trends in ‘known’ spawners. The R^2 for known and newly model estimated abundances is 0.188.
- Based on these results and the criteria for calibration success, Reclamation selected the parameters from ‘run 3’ as the new parameters for the winter-run DSM and applied these values to compare the effects of competing alternatives on the winter-run population. The parameter values are presented in Table F.2-2.

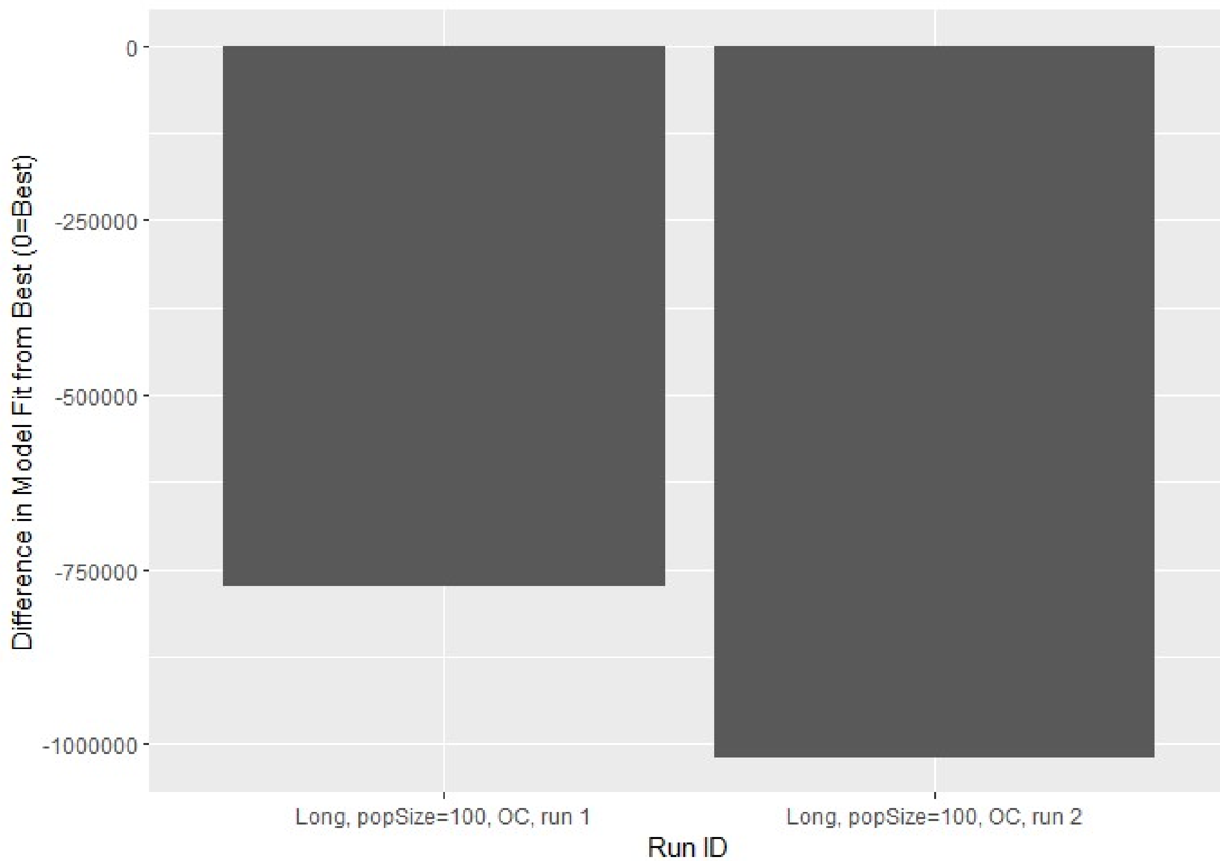

Figure F.2-6. Comparison of differences in model fit for all sub-optimal models from the best model. The best model was *Long, popSize*=100, *OC, run*=3 and had a model fit of -179222734, or -1.79e8.

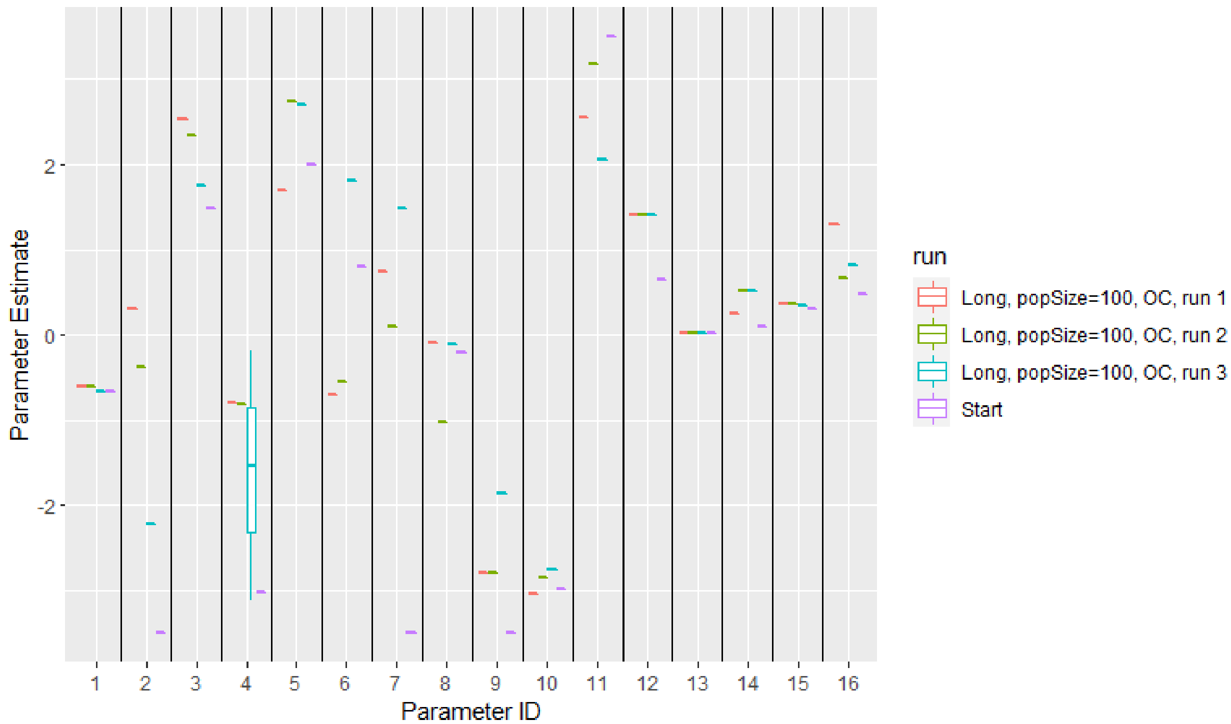

Figure F.2-7. Plot of parameter estimates for 3 calibration runs with constraints on marine survival intercept and the full calibration time series, as well the starting values drawn from the parameter values from the original calibration. Ranges of parameter estimates for a given parameter and run indicate multiple parameter values produced the same measure of model fit.

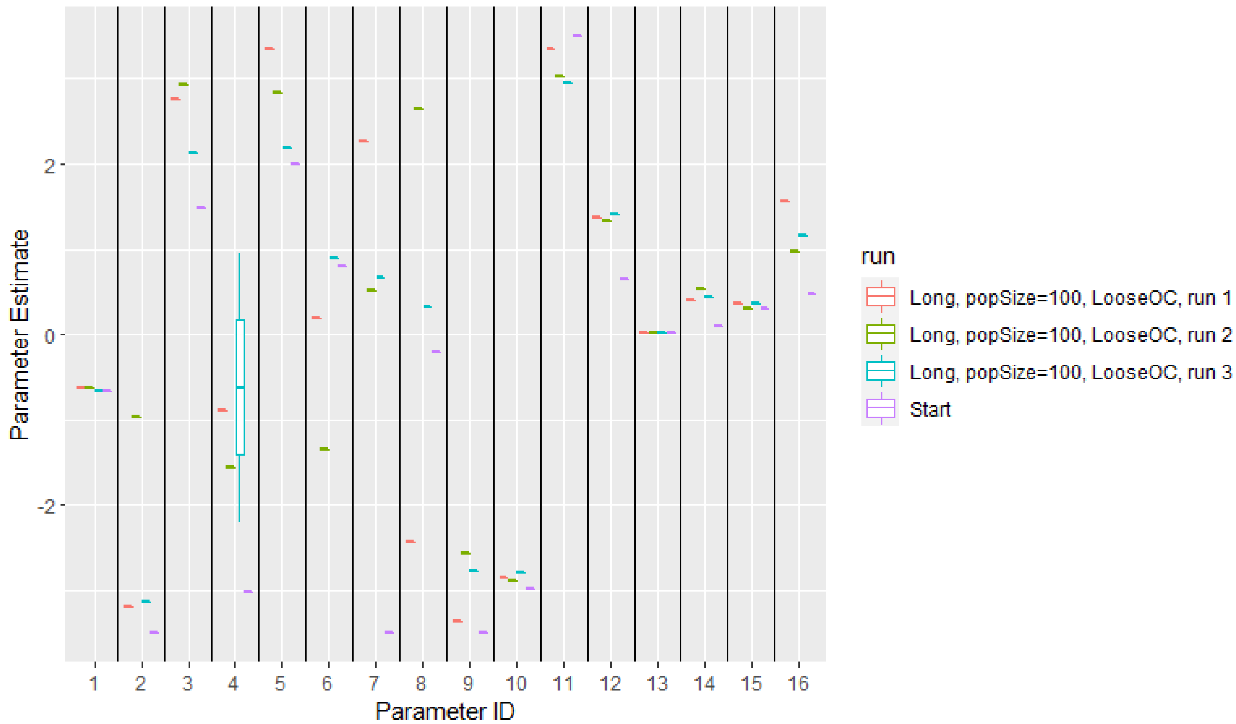

Figure F.2-8. Plot of parameter estimates for 3 calibration runs with looser constraints on marine survival intercept (logit-transformed upper boundary = -1) and the full calibration time series, as well as the starting values drawn from the parameter values from the original calibration. Ranges of parameter estimates for a given parameter and run indicate multiple parameter values produced the same measure of model fit.

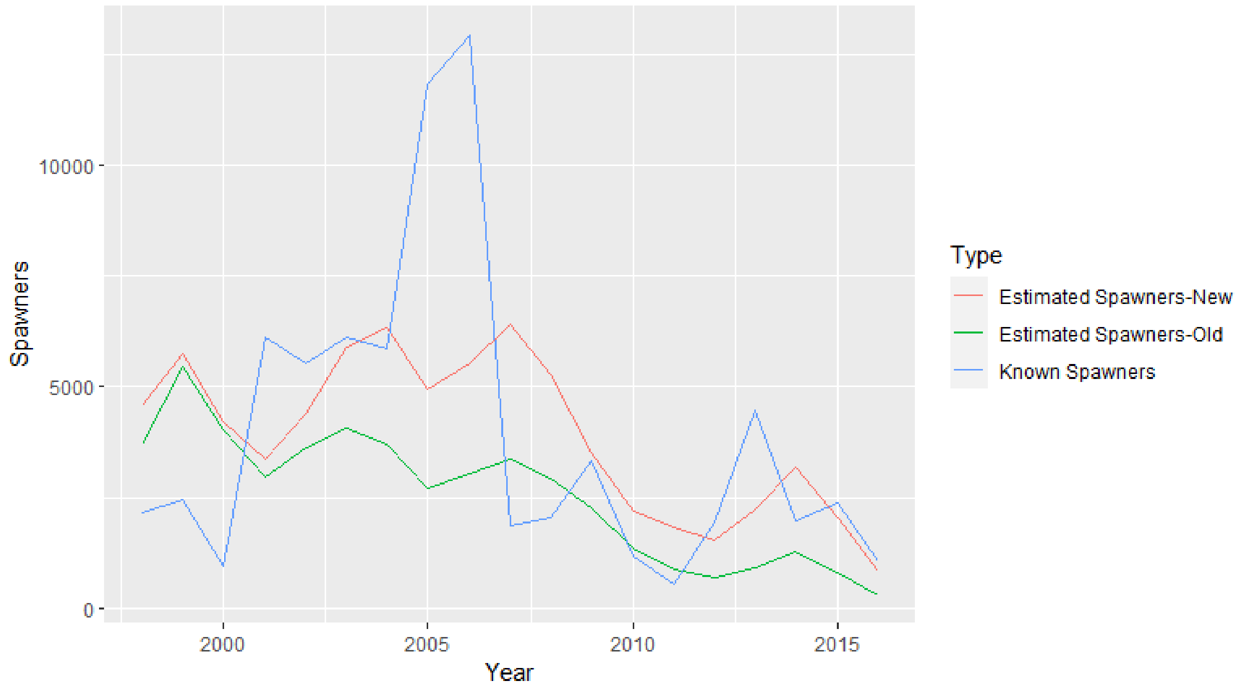

Figure F.2-9. Plot of estimated spawners, both with original and newly calibrated parameter estimates, and known spawner abundances with the full time series of calibration data and informed constraints on marine survival.

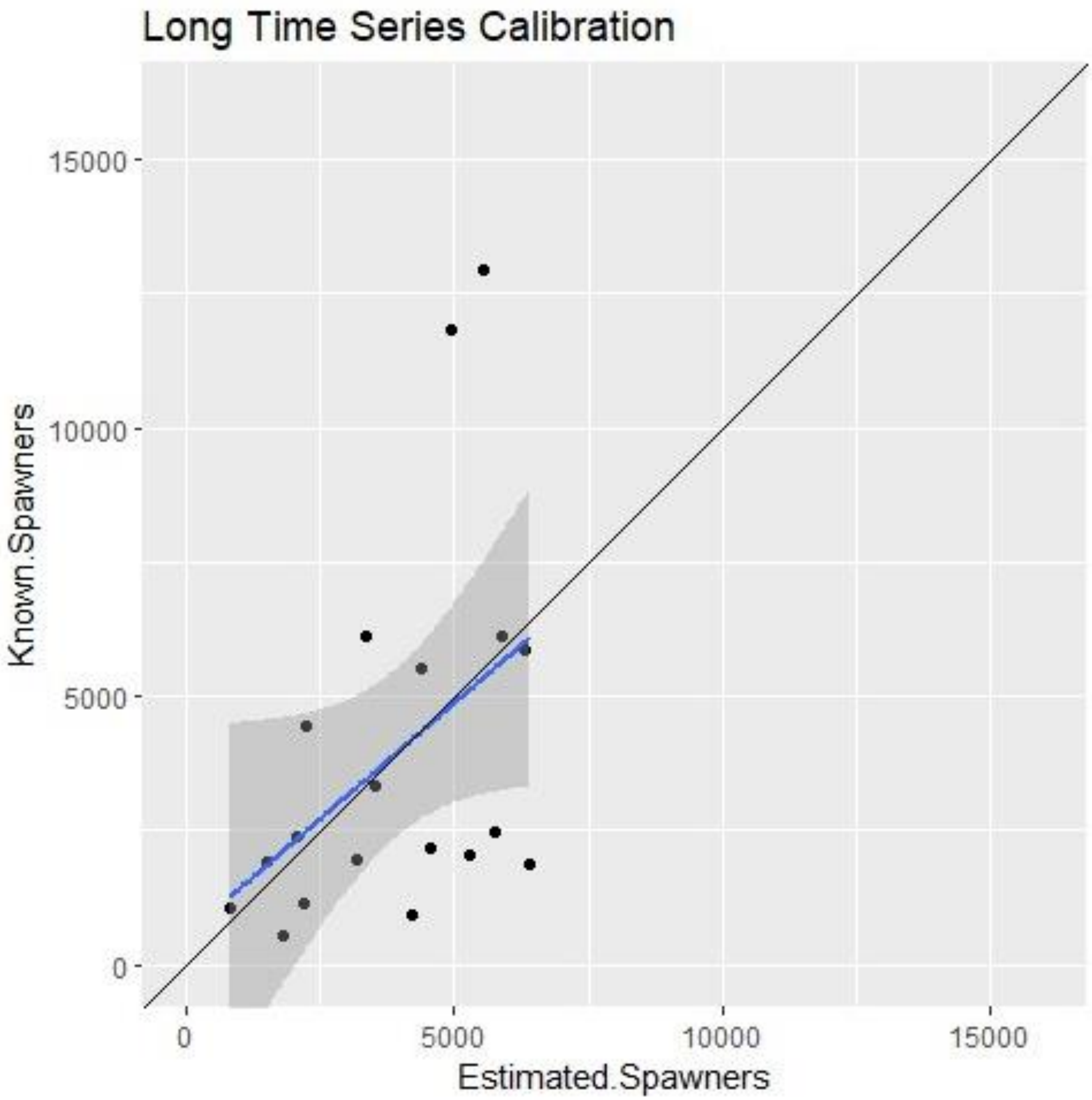

Figure F.2-10. Scatterplot of estimated spawners with the newly calibrated parameter estimates and known spawner abundances with the full time series of calibration data and informed constraints on marine survival. A 1:1 line (black) is provided for reference, in addition to the fit of a linear regression to the scatterplot points (blue).

Table F.2-2. Original and new parameter values for the winter-run DSM.

Parameter ID	Description	Original Calibration Value	New Calibration Value
1	Juvenile in-channel and floodplain rearing survival intercept	-0.66	-0.67
2	Juvenile bypass rearing survival intercept	-3.5	-2.23
3	Juvenile Delta rearing survival intercept	1.49	1.76
4	Juvenile San Joaquin migratory survival intercept	-3.02	-1.53
5	Juvenile Sacramento River migratory survival intercept (temperature model)	2.0	2.70
6	Juvenile Sacramento River migratory survival intercept (discharge model)	0.80	1.80
7	Juvenile Delta migratory survival intercept (flow model)	-3.5	1.49
8	Juvenile Delta migratory survival intercept (temperature model)	-0.2	-0.11
9	Juvenile Delta migratory survival intercept (diversion model)	-3.5	-1.87
10	Juvenile ocean entry survival intercept	-2.98	-2.76
11	Adult en route survival intercept	3.5	2.06
12	Egg-to-fry survival intercept	0.65	1.41
13	Effect of contact points on juvenile rearing survival	0.02	0.02
14	Effect of proportion flow diverted on juvenile rearing/migratory survival	0.1	0.52
15	Effect of total flow diverted on juvenile rearing/migratory survival	0.3	0.35
16	Effect of Delta diversions on juvenile rearing survival	0.48	0.81

F.2.2.3.2 Assumptions related to model structure and parameterization

There are numerous additional model assumptions that bear mentioning. First, to seed the starting number of returning adults from the ocean (i.e., necessary to calculate numbers of returning spawners), the model is run for 5 preliminary years using a fixed number of spawners (2787 for winter-run) in each of those five years, as well as original CalSim II-based flow inputs for the first five years of the simulated time period. Additionally for winter-run, in each of the 20 tracked model years, a specified number of hatchery fish is added to the pool of spawners based on past CWT reports; this number is either 565 if the model is run deterministically or a randomly selected number based on the uniform distribution bounded by 355 and 755 if the model is run stochastically. Finally, for winter-run Chinook salmon only, the model assumes returning adults only spawn in the Upper Sacramento River, with no straying to other watersheds.

Additionally, some demographic rates are not constructed to vary as a function of changing flow and temperature inputs in this model version, despite potential expectations to the contrary; an incomplete list of examples is provided below:

- Timing of adult arrival to the spawning grounds and subsequent spawning
- Egg-to-fry survival
    - Egg-to-fry survival is estimated as a function of the annual proportion of natural-origin spawners for each watershed and constant watershed-specific effects of temperature and scour
    - Neither temperature nor scour effects are constructed to be responsive to model estimates of flow or temperature from CalSim or HEC-5Q models, respectively
- Juvenile growth rates

Finally, Reclamation staff note that that expected spawner abundances from model runs with and without stochasticity (i.e., stochastic and deterministic model runs) sometimes differ due to asymmetrical effects of adding variability. Specifically, stochasticity in model parameters (e.g., rearing survival) is implemented by drawing covariate effects from a statistical distribution (e.g., the effect of stranding is drawn from a Bernoulli distribution, in which the expected proportion of the population affected by stranding is the probability of stranding occurrence) and then obtaining parameter estimates by conducting inverse-logit transformations of these effect values. In isolation, drawing covariate effects from statistical distributions should produce variable but unbiased parameters relative the deterministic parameters. However, drawing covariate effects from statistical distributions and then applying non-linear transformations biases the expected values of the stochastic parameters relative to deterministic values, and can subsequently change expected spawner abundances. This phenomenon is documented in the R script, 'Proof of Biased Parameters with Stochasticity and Inverse-Logit Transformations.R'.

F.2.2.3.3 Assumptions related to construction of new flow inputs

Reclamation constructed new model inputs for flow using updated results from new CalSim 3 runs for each scenario. Using a combination of R annotation associated with the cvpiaData package, R scripts shared from the cvpiaFlow GitHub repository, and discussions with CalSim modelers, Reclamation generated all the model flow inputs using updated CalSim 3 results by pulling directly from the raw .dss output files. We note that updating flow inputs using CalSim 3 runs was markedly more complex than using CalSim II runs, as CalSim 3 operates under different assumptions and at a finer resolution than CalSim II.

The following flow variables used by the DSMs were updated with data from alternative-specific CalSim 3 runs:

- Monthly flows, variability in flow, and proportion of natal flow (relative to larger watersheds) for each of 31 watersheds in the Sacramento-San Joaquin River basin
- Monthly flows at Freeport, Vernalis, and Stockton
- Monthly total exports from the Central Valley Project and State Water Project

- Diverted flows in each of the 31 watersheds in the Sacramento-San-Joaquin River basin (expressed both as total diversions and diversions relative to total flow)
- Proportion of Sacramento River flow into the Sutter and Yolo Bypasses
- Indications for whether gates downstream of Sutter and Yolo Bypasses are overtopped
- Monthly operations of the Delta Cross Channel gates
- Inflow into the North and South Delta
- Diverted flows in the North and South Delta (expressed both as total diversions and diversions relative to inflow)

Reclamation conducted internal validation to ensure updates to flow inputs using new CalSim 3 runs did not result in unexpectedly large changes in flow values (i.e., resulting from user error). For each of the above inputs to the DSMs, staff visualized and compared input values among the original DSM inputs and those based on the LTO NAA alternative. Reclamation did not find any issues except where there was not 1:1 matching between CalSim II and CalSim 3 nodes. Input diagnostic plots are available for review in the cvpiaFlow folder in the shared Code and Data repository.

The following demographic parameters are expected to be influenced by the updated flow inputs based on CalSim 3 runs reflecting LTO alternatives:

- Adult straying rates among spawning tributaries (spring-run only)
- Adult en route survival
- Juvenile river rearing survival
- Juvenile movement as a function of pulse flows
- Juvenile river migratory survival
- Juvenile entrainment into the South Delta from the Sacramento River
- Juvenile routing and survival in the South Delta, following entrainment
- Juvenile routing and survival in the North Delta

Reclamation also changed the implementation of the flow input for the number of days the Delta Cross Channel is closed each month. In the published model, this input is based on prescribed operations from the 2009 NMFS BiOp, with no interannual variability. Reclamation currently has access to a CalSim 3 node that provides estimated gate operations for each month and year in the model time series, and therefore modified this variable in LTO analyses to use expected month- and year-specific operations from alternative-specific CalSim 3 runs.

There was another potential inconsistency between model documentation and model implementation that needed to be addressed while updating flow inputs. Model documentation, as interpreted by Reclamation, suggested multiple CalSim II diversion variables may be used when calculating proportion of Sacramento River flow diverted into the Sutter Bypass (D117, D124, D125, D126), but only one diversion term that only infrequently exceeds 0 cfs was used in the original R code that produced the final model input (D117). Due to uncertainty in the intent of this flow input (i.e., whether the higher or lower diversion flow should be used), staff retained the previously implemented diversion calculation. Therefore, differences in the neglected diversion terms among LTO alternatives will not translate to different model outcomes.

Reclamation staff again emphasize that updating flow inputs using CalSim 3 runs was markedly more complex than using CalSim II runs, as CalSim 3 operates under different assumptions and at a finer resolution than CalSim II. Extensive modifications and numerous judgment calls were required with these modifications, and the conversions were made in close consultation with the Bureau of Reclamation Bay-Delta Office's Modeling Division, which is partly responsible for developing and applying CalSim 3 (C. Koizumi, personal comm.). The conversions from CalSim II to CalSim 3 for all updated flow inputs to the v2019 SIT DSMs (i.e., Peterson and Duarte 2020) are summarized in the sections below, in which each section is a different data object, typically contained within the repositories cvpiaData (FlowWest/cvpiaData (github.com)) or cvpiaFlow (FlowWest/cvpiaFlow: Flow Data for use with CVPIA SIT DSM (github.com)). For additional details, refer to the R script 'DSS workflow_cvpiaFlow_clean_CalSim3.R', which generates modified data inputs to the SIT DSM from raw CalSim 3 outputs, or the supplemental Excel file 'CalSim Mapping Document_2.28.23.xlsx', which presents expected relationships between individual CalSim II and CalSim 3 variables, in the Code and Data repository. If inputs are not listed or described here, no change was required going from CalSim II to 3. Reclamation recommends future model users interested in running these models with new CalSim 3 runs carefully examine and revise, as necessary, the model documentation and annotation.

dlt_divers_tot: **Total diverted of delta inflow in cms from 1980-2000.**

The following is a comparison of CalSim II and CalSim 3 variables and calculations for total diversions in the North and South Delta. For example, variables proceeded by 'D' and 'C' typically indicate diversion- and flow-based terms, with proceeding numbers and letters reflecting different locations or processes.

- CalSim II:
  - North Delta: D403A + D403B + D403C + D403D + D404
  - South Delta: D418 + D419 + D412 + D410 + D413 + D409B + D416 + D408_OR + D408_VC
- CalSim 3:
  - North Delta: C_CSL004B + DD_SAC017_SACS
  - South Delta: D_OMR028_DMC000 + D_OMR027_CAA000 + DD_SJR026_SJRE + DD_SJR013_SJRW + DD_MOK004_MOK + DD_OMR027_OMR + D_RSL004_CCC004 + D_OMR021_ORP000 + D_VCT002_ORP000

- Important caveats or concerns:
    - There is a meaningful difference in how North Delta diversions are handled between CalSim II and 3. Replacing D404 with DD_SAC017_SACS adds ~200 TAF annually due to differences in assumptions regarding consumptive use.

***dlt_inflow:* Delta inflow in cms from 1980-2000.**

The following is a comparison of CalSim II and CalSim 3 variables and calculations for inflow to the North and South Delta.

- CalSim II:
    - North Delta: C400 + C157
    - South Delta: C401B + C504 + C508 + C644
- CalSim 3:
    - North Delta: C_SAC041 + C_CSL005
    - South Delta: C_SAC029B + D_SAC030_MOK014 + C_MOK022 + C_CLV004 + C_SJR056
- Important caveats or concerns:
    - None

The *dlt_inflow* and *dlt_divers_tot* objects are used in conjunction to calculate the *dlt_divers* object, which represents the proportion of Delta diversions relative to inflow.

***flows_cfs:* Average monthly flows in all 31 modeled watersheds from 1980-2000**

- CalSim II:
    - Upper Sacramento River: C104
    - Antelope Creek: C11307
    - Battle Creek: C10803
    - Bear Creek: C11001
    - Big Chico Creek: C11501
    - Butte Creek: C217A
    - Clear Creek: C3
    - Cottonwood Creek: C10802
    - Cow Creek: C10801
    - Deer Creek: C11309
    - Elder Creek: C11303

    - Mill Creek: C11308
    - Paynes Creek: C11001
    - Stony Creek: C142A
    - Thomes Creek: C11304
    - Upper-mid Sacramento River: C115
    - Bear River: C285
    - Feather River: C203
    - Yuba River: C230
    - Lower-mid Sacramento River: C134*35.6/58 + C160*22.4/58
    - American River: C9
    - Lower Sacramento River: C166
    - Calaveras River: C92
    - Cosumnes River: C501
    - Mokelumne River: *NA*
    - Merced River: C561
    - Stanislaus River: C520
    - Tuolumne River: C540
    - San Joaquin River: C630
- CalSim 3:
    - Upper Sacramento River: C_SAC273
    - Antelope Creek: C_ANT010
    - Battle Creek: C_BTL006
    - Bear Creek: C_BCN005
    - Big Chico Creek: C_BCC004
    - Butte Creek: C_BTC012
    - Clear Creek: C_CLR009
    - Cottonwood Creek: C_CWD003
    - Cow Creek: C_COW003

  - Deer Creek: C_DRC005
  - Elder Creek: C_ELD005
  - Mill Creek: C_MLC004
  - Paynes Creek: C_PYN001
  - Stony Creek: C_STN004
  - Thomes Creek: C_THM005
  - Upper-mid Sacramento River: C_SAC193
  - Bear River: C_CMPFW
  - Feather River: C_FTR059
  - Yuba River: C_YUB002
  - Lower-mid Sacramento River: C_SAC093*35.6/58 + C_SAC048*22.4/58
  - American River: C_NTOMA
  - Lower Sacramento River: C_SAC063
  - Calaveras River: C_NHGAN
  - Cosumnes River: C_CSM005
  - Mokelumne River: C_CMCHE
  - Merced River: C_MCD050
  - Stanislaus River: C_STS059
  - Tuolumne River: C_TUO054
  - San Joaquin River: C_SJR081
- Important caveats or concerns:
  - In CalSim II, the same variable (C11001) previously included both Bear Creek and Paynes Creek. In Calsim 3, the two watersheds have unique flow values.
  - CalSim 3 includes flow values for the Mokelumne River.
  - For several tributaries near the Upper Sacramento River (e.g., Deer Creek, Thomes Creek, Antelope Creek, Mill Creek, Big Chico Creek, Cow Creek, Cottonwood Creek, Battle Creek), there are new Surface Runoff terms included in CalSim 3 that are not present in CalSim II and could influence flow values.

The *flows_cfs* object is used to calculate both the expected intra-annual variability in flow, or *prop.pulse* (i.e., as a proxy for pulse flow effects), and the flow signal for returning adults as a determinant of straying rates, or *returnQ*.

upsac_flow: **Flow at Bend Bridge in cms from 1980-2000.**

- CalSim II:
    - C109
- CalSim 3:
    - C_SAC257
- Important caveats or concerns:
    - None

freeportQcms: **Inflow at Freeport in cms from 1980-2000.**

- CalSim II:
    - C400
- CalSim 3:
    - C_SAC041
- Important caveats or concerns:
    - None

Q_vern: **Flow in cms at Vernalis from 1980-1999.**

- CalSim II:
    - C639
- CalSim 3:
    - C_SJR070
- Important caveats or concerns:
    - None

Q_stck: **Flow in cms at Stockton from 1980-1999.**

- CalSim II:
    - C417A
- CalSim 3:
    - C_SJR053A
- Important caveats or concerns:
    - None

CVP_exp: **Total exports for CVP in cms.**

- CalSim II:
  - DEL_CVP_TOTAL
- CalSim 3:
  - DEL_CVP_TOTAL_N + DEL_CVP_TOTAL_s
- Important caveats or concerns:
  - Recommend replacing previous variables from both CalSim II and CalSim 3 with D418 (CalSim II) and D_OMR028_DMC000 (CalSim 3) to reflect realized diversions from the Jones pumping facility (C. Koizumi, personal comm.).

SWP_exp: **Total exports for SWP in cms.**

- CalSim II:
  - DEL_SWP_TOTAL
- CalSim 3:
  - DEL_SWP_PMI + DEL_SWP_PAG + DEL_SWP_PIN
- Important caveats or concerns:
  - Recommend replacing previous variables from both CalSim II and CalSim 3 with D419 (CalSim II) and D_OMR027_CAA000 (CalSim 3) to reflect realized diversions from the Banks pumping facility (C. Koizumi, personal comm.).

prop_diversion: **Proportion of flow diverted for each watershed every month of every year in the simulation (1980-200).**

- CalSim II:
  - Upper Sacramento River: D104 / C104
  - Antelope Creek: (C11307 / (C11307 + C11308 + C11309) * D11305) / C11307
  - Battle Creek: *NA*
  - Bear Creek: *NA*
  - Big Chico Creek: *NA*
  - Butte Creek: (C217B + D217) / (C217B + D217 + C217A)
  - Clear Creek: *NA*
  - Cottonwood Creek: *NA*
  - Cow Creek: *NA*
  - Deer Creek: (C11309 / (C11307 + C11308 + C11309) * D11305) / C11309

- Elder Creek: (C11303 / (C11303 + C11304) * D11301) / C11303
- Mill Creek: (C11308 / (C11307 + C11308 + C11309) * D11305) / C11308
- Paynes Creek: *NA*
- Stony Creek: D17301 / C41
- Thomes Creek: (C11304 / (C11303 + C11304) * D11301) / C11304
- Upper-mid Sacramento River: (D109 + D112 + D113A + D113B + D114 + D118 + D122A + D122B + D123 + D124A + D128_WTS + D128) / C110
- Bear River: D285 / (C285 + D285)
- Feather River: (D201 + D202 + D7A + D7B) / C6
- Yuba River: D230 / (C230 + D230)
- Lower-mid Sacramento River: (D129A + D134 + D162 + D165) / C128
- American River: D302 / C9
- Lower Sacramento River: (D167 + D168 + D168A_WTS) / C166
- Calaveras River: (D506A + D506B + D506C + D507) / C92
- Cosumnes River: *NA*
- Mokelumne River: *NA*
- Merced River: (D562 + D566) / C561
- Stanislaus River: D528 / C520
- Tuolumne River: D545 / C540
- San Joaquin River: (D637 + D630B + D630A + D620B) / (D637 + D630B + D630A + D620B + C637)

- CalSim 3:
    - Upper Sacramento River: (D_SAC296_WTPFTH + D_SAC296_02_SA + D_SAC294_WTPBLV + D_SAC294_03_PA + D_SAC289_03_PA + D_SAC281_02_NA + D_SAC273_03_NA) / C_SAC273
    - Antelope Creek: D_ANT010_05_NA / C_ANT010
    - Battle Creek: *NA*
    - Bear Creek: *NA*
    - Big Chico Creek: *NA*

- Butte Creek: (D_BTC045_ESL008 + D_BTC043_10_NA + D_BTC036_10_NA + DBTC012_09_SA2 + D_BTC012_CRK005) / (D_BTC045_ESL008 + D_BTC043_10_NA + D_BTC036_10_NA + DBTC012_09_SA2 + D_BTC012_CRK005 + C_BTC012)
- Clear Creek: *NA*
- Cottonwood Creek: *NA*
- Cow Creek: *NA*
- Deer Creek: (D_DRC010_05_NA + D_DRC005_05_NA) / C_DRC005
- Elder Creek: D_ELD012_04_NA / C_ELD005
- Mill Creek: D_MLC006_05_NA / C_MLC004
- Paynes Creek: *NA*
- Stony Creek: D_STN021_06_PA / C_STN026
- Thomes Creek: D_THM012_04_NA / C_THM005
- Upper-mid Sacramento River: (D_SAC240_TCC001 + D_SAC240_05_NA + D_SAC224_04_NA + D_SAC196_MTC000 + D_SAC185_08N_NA + D_SAC185_09_NA + D_SAC178_08N_SA1 + D_SAC162_09_SA2 + D_SAC159_08S_SA1 + D_SAC159_08N_SA1 + D_SAC146_08S_NA1 + D_SAC136_18_NA + D_SAC136_18_SA + D_SAC129_08S_NA2 + D_SAC122_19_SA) / C_SAC247
- Bear River: D_BRR017_23_NA / C_CMPFW
- Feather River: (D_THRMF_12_NU1 + D_THRMF_11_NU1 + D_THRMA_WEC000 + D_THRMA_RVC000 + D_THRMA_JBC000) / C_OROVL
- Yuba River: D_YUB011_15S_NA2 / (D_YUB011_15S_NA2 + C_YUB002)
- Lower-mid Sacramento River: (D_SAC121_08S_SA3 + D_SAC115_19_SA + D_SAC109_08S_SA3 + D_SAC109_19_SA + D_SAC099_19_SA + D_SAC091_19_SA + D_SAC083_21_SA + D_SAC082_22_SA1 + D_SAC081_21_NA + D_SAC078_22_SA1 + D_SAC075_22_NA + D_SAC074_21_SA + D_SAC065_WTPBTB) / C_SAC120
- American River: D_AMR007_WTPFBN / C_NTOMA
- Lower Sacramento River: (D_SAC050_FPT013 + D_SAC062_WTPSAC) / C_SAC120
- Calaveras River: (D_LJC022_60S_PA1 + D_CLV037_CACWD + D_CLV026_60S_PA1 + D_CLV026_WTPWDH) / C_NHGAN
- Cosumnes River: *NA*

- Mokelumne River: (D_MOK050_60N_NA3 + D_MOK050_60N_NA5 + D_MOK039_60N_NA5 + D_MOK035_60N_NA4 + D_MOK035_60N_NU1 + D_MOK035_WTPDWS + D_MOK033_60N_NA5) / C_CMCHE
- Merced River: (D_MC042_63_NA2 + D_MCD021_63_NA4) / C_MCD050
- Stanislaus River: (D_STS030_61_NA4 + D_STS004_61_NA6) / C_STS059
- Tuolumne River: (D_TUO047_61_NA3 + D_TUO047_62_NA4 + D_TUO015_61_NA3 + D_TUO015_62_NA4) / C_TUO054
- San Joaquin River: (D_SJR062_50_PA1 + D_SJR090_71_NA2 + D_SJR081_61_NA5 + D_SJR116_72_NA1) / (D_SJR062_50_PA1 + D_SJR090_71_NA2 + D_SJR081_61_NA5 + D_SJR116_72_NA1 + C_SJR072)

- Important caveats or concerns:
    - Watersheds with *NA* are assumed to have no diversions.
    - Some of the diversion terms in CalSim II corresponded to 'Depletion' terms that have no direct analogue in Calsim 3 (i.e., Calsim 3 uses 'Closure-Terms' that aggregate both accretion and depletion influences). These flow variables are therefore not accounted for in the CalSim 3 conversion.
    - In CalSim II, diversions for Antelope Creek, Deer Creek, Elder Creek, Mill Creek, and Thomes Creek were calculated by partitioning aggregate, multi-watershed diversion terms based on watershed-specific flows. Some of these aggregate diversion terms also encompassed diversions from the Sacramento River. This partitioning is not necessary in CalSim 3 due to finer resolution in diversion terms.
    - CalSim 3 includes flow and diversion values for the Mokelumne River.
    - Reclamation used CalSim II diversion variables for the 4 watershed regions along the Sacramento River to identify functional splits among regions, and then identified CalSim 3 diversion terms for each region based on these splits.

The numerator for each watershed was used to calculate the total diversions for each watershed every month of every year, or *total_diversion*.

bypass_prop_Q: **Proportion of Lower Sacramento River flow at each bypass weir.**

- CalSim II:
    - Sutter Bypass: D117 / C116
    - Yolo Bypass: D160 / (D160 + C160)

- CalSim 3:
    - Sutter Bypass: (SP_SAC193_BTC003 + SP_SAC188_BTC003 + SP_SAC178_BTC003) / C_SAC195
    - Yolo Bypass: SP_SAC083_YBP037 / (SP_SAC083_YBP037 + C_SAC048)
- Notes:
    - A potentially better characterization of proportional flow diverted into the Sutter Bypass, and the characterization that is used in more recent versions of the SIT DSMs (e.g., v2021, v2023) is expressed in CalSim II and CalSim 3 as the following:
        - CalSim II: (D117 + D124 + D125 + D126) / C116
        - CalSim 3: (SP_SAC193_BTC003 + SP_SAC188_BTC003 + SP_SAC178_BTC003 + SP_SAC159_BTC003 + SP_SAC148_BTC003 + SP_SAC122_SBP021) / C_SAC195
    - The conversion of C116 to C_SAC195 in CalSim 3 represents the best judgment of the Modeling Division.

bypass_over: **Binary (yes/no) monthly record of the bypasses over topped**

- CalSim II:
    - Sutter Bypass: TRUE if (D117 + D124 + D125 + D126 + C137) >= 100
    - Yolo Bypass: TRUE if (D160 + C157) >= 100
- CalSim 3:
    - Sutter Bypass: TRUE if (SP_SAC193_BTC003 + SP_SAC188_BTC003 + SP_SAC178_BTC003 + SP_SAC159_BTC003 + SP_SAC148_BTC003 + SP_SAC122_SBP021 + C_SSL001) >= 100
    - Yolo Bypass: TRUE if (SP_SAC083_YBP037 + C_CSL005) >= 100
- Notes:
    - The conversion of C137 in CalSim II to a CalSim 3 equivalent is problematic, as CalSim 3 changes the number and nature of connections among the Sacramento River, Sutter Bypass, Feather River, and Butte Creek. In fact, the best proposed replacement variable (C_SSL001) results in constant overtopping of Sutter Bypass in the model with the current flow threshold of 100 cfs.
        - Modeling also questions why C137 is included in the flow threshold in the first place, as the diversions terms should be sufficient by themselves.

F.2.2.3.4 Assumptions related to construction of new temperature inputs

Reclamation generated new monthly temperature inputs using alternative-specific HEC-5Q model results, which in turn used alternative-specific CalSim 3 model results, for the following watersheds: Upper Sacramento River, Clear Creek, Cottonwood Creek. Temperature updates were restricted to these watersheds based the limited spatial coverage of HEC-5Q modeling to watersheds utilized by winter-run and spring-run Chinook salmon for spawning and rearing. Reclamation also observed that model documentation for the original HEC-5Q variables used in the Upper Sacramento River temperature inputs was inconsistent with their actual application in the published DSMs: specifically, temperature inputs for both Cottonwood Creek and the Upper Sacramento were reportedly derived from the same HEC-5Q variable, but actual inputs differed between watersheds without clear explanation. In light of this uncertainty, Reclamation used the average of monthly temperatures from the HEC-5Q variables corresponding to the Sacramento River just below Keswick Dam (BLW KESWICK) and at Red Bluff Diversion Dam (RED BLUFF DAM) to characterize expected temperature conditions in the Upper Sacramento River, the temperatures at the IGO node to characterize temperatures in Clear Creek, and temperatures at the COTTONWOOD CR node to characterize temperatures in Cottonwood Creek.

The following temperature inputs were updated with this modification:

- Monthly average temperature for the Upper Sacramento River, Clear Creek, and Cottonwood Creek
- Monthly degree day accumulation (i.e., the sum of daily average temperatures for each month) for the Upper Sacramento River, Clear Creek, and Cottonwood Creek

Reclamation conducted internal validation to ensure updates to temperature inputs using new HEC-5Q runs did not result in unexpectedly large changes in values (i.e., resulting from user error). For each of the above inputs to the DSMs, staff visualized and compared input values among the original DSM inputs and those based on the LTO NAA alternative. Reclamation observed generally similar ranges in temperature input values for the Upper Sacramento River and Clear Creek, albeit with lower extremes observed for the LTO NAA alternative relative to original DSM inputs, but a much more muted range of temperature values for the LTO NAA alternative in Cottonwood Creek. Input diagnostic plots are available for upon request.

The following demographic parameters are expected to be influenced by the updated temperature inputs:

- In-channel and floodplain juvenile rearing survival in the Upper Sacramento River
- Adult pre-spawn survival during holding in the Upper Sacramento River

F.2.2.3.5 Assumptions related to construction of new habitat inputs

Model habitat inputs for the Peterson and Duarte (2020) version of the DSMs were based on a combination of expert judgment and flow to habitat relationships specific to both watershed and run type. Due to the considerable complexity associated in updating these values using new CalSim runs, Reclamation left the base habitat inputs unchanged from the published version of the DSMs. However, Reclamation reset a vector of habitat modifiers (i.e., values used to adjust expected habitat quantities via multiplication) to values of one during recalibration of the DSM, such that habitat quantities were equal to those values based on expert judgment and flow alone. Original calibration efforts for the Peterson and Duarte (2020) models used calibration to obtain both parameter values and new habitat modifiers, but Reclamation staff achieved sufficient model fit without needing to secondarily modify habitat quantities.

F.2.2.3.6 Assumptions related to selection of habitat restoration strategies

Model users must select a habitat restoration scenario when running the SIT DSMs, including no action (i.e., availability of spawning and rearing habitat will decrease over time without intervention) or some form habitat restoration (i.e., select watersheds are prioritized for additions of spawning and/or rearing habitat). Reclamation staff ran all DSM models with the no action habitat restoration scenario to avoid any possible interactions between flow, temperature, and habitat differences.

F.2.2.4 Code and Data Repository

All R scripts and model inputs necessary to re-calibrate and run the model, with the exception of the raw CalSim 3 .dss files (due to file size concerns), are available on upon request.

F.2.3 Results

The EIS results include comparisons among the No Action Alternative (NAA) and all other management alternatives (Alt1 – Alt4), including the Proposed Action (PA, or Alt2). The BA results include results for the NAA, the EXP1 and EXP3 baseline alternatives, and the PA.

F.2.3.1 BA

Results for the BA are summarized in Table F.2-3 through Table F.2-6 and Figure F.2-11 through Figure F.2-22.

Predicted total and natural-origin-only spawner abundances in the Upper Sacramento River for deterministic model runs generally peaked in 1986, decreased steadily until 1994, and then generally increased steadily through 1999 (Table F.2-3, Table F.2-4; Figure F.2-11). The range of natural-origin-only spawner abundances across alternatives at the end of the time series was narrow, ranging from a low of 5461 (Alt2woTUCPDeltaVA) to a high of 5,558 (NAA); over the entire time series predicted natural-origin-spawner abundances ranged from 1,571 (Alt2woTUCPwoVA) to 14,738 (Alt2woTUCPAllVA; Table F.2-4). Predicted natural-origin-only spawner abundances varied more widely across stochastic model runs, from a low of approximately 0 to a high of approximately 30,000 spawners (Figure F.2-12).

For deterministic model runs, population change over time, defined by mean (i.e., geometric) lambda values (N_t/N_{t+1}), over the entire 1980-1999 time series ranged from only 0.979 to 0.980, and terminal lambda values ($N_{t=19}/N_{t=1}$) ranged from 0.668 (Alt2woTUCP with either DeltaVa or AllVA) to 0.679 (NAA); these values indicated that predicted spawner abundances declined over the course of the time series (Table F.2-5, Table F.2-6). Annual lambda values from deterministic model runs ranged from approximately 0.5 to 1.55, excluding baseline runs; both occurred for Alt2woTUCPwoVA (Figure F.2-13). Wet water years had the highest mean annual lambdas (>1.1 for all Alternatives) and Dry water years also had a mean annual lambda greater than 1, indicating that the population grew in Wet or Dry years (Table F.2-5). Mean lambdas were less than 1 in Critical and Above normal water years, indicating that populations declined. Across stochastic model runs, mean lambda values over individual stochastic iterations ranged from approximately 0.925 to 1.025 (Figure F.2-14) and Critical water years had a lower mean lambda value than other water year types (Figure F.2-15). Terminal lambda values ranged from approximately 0.2 to 1.75 (Figure F.2-16), suggesting some model runs resulted in expected population growth over the time series.

Population trends may be explained by differences in life stage-specific demographic parameters. It is worth emphasizing again that the egg-to-fry survival life stage transition in the DSM is not sensitive to alternative-dependent flow or temperature values, and thus will be constant across alternatives. Across deterministic runs, monthly rearing survival for small juveniles (i.e., <42 mm) in the Upper Sacramento River varied from a low of approximately 0.01 to a high of approximately 0.2; rearing survival also varied across months, peaking in November and December (Figure F.2-17). Model-estimated migratory survival for very large fish (i.e., smolt size, >110 mm) in the Upper-mid, Lower-mid, and Lower Sacramento River was very close to 1, with slight variations across months and water year types (WYTs) (Figure F.2-18 through Figure F.2-20). In the Upper-mid and Lower-mid Sacramento River, expected survival was consistently lower in May than other migratory months; no such patterns were observed in the Lower Sacramento River. Migratory survival for very large fish also varied across months and WYT in the North and South Delta (Figure F.2-21, Figure F.2-22). Migratory survival often increased moving from a Critical to Dry to Above Normal to Wet WYT. Expected migratory survival was greatest in February and March (0.847-0.860, multiple alternatives) and lowest in September, October, and May (0.809 – 0.848). With migratory survival in the mainstem Sacramento River high across the alternatives, rearing survival and migratory survival in the Delta likely act as drivers of lambda, creating a negative feedback loop with winter-run spawner abundance.

F.2.3.1.1 Population abundance, trends

Table F.2-3. Predicted annual total winter-run spawner abundance in the Upper Sacramento River, including both natural- and hatchery-origin fish, from deterministic model runs.

Year	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP wo VA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
1980	8762	8762	8762	8762	8762	8762	8762
1981	9376	9376	9376	9376	9376	9376	9376
1982	6456	8235	8156	8147	8146	8177	8215
1983	2542	8632	8371	8367	8366	8375	8523
1984	2022	11570	11391	11411	11410	11339	11540
1985	3374	13951	14384	14403	14402	14350	14526
1986	3069	14195	14884	14931	14929	14915	15125
1987	1454	13383	13350	13454	13451	13381	13708
1988	585	13647	13113	13232	13230	13118	13558
1989	483	12730	12314	12336	12336	12284	12627
1990	427	9123	8234	8141	8140	8114	8325
1991	392	8116	6230	6201	6196	6154	6484
1992	391	8057	6089	6160	6169	6140	6504
1993	390	5103	4015	4161	4148	4155	4288
1994	389	3178	2777	2754	2021	2231	2243
1995	391	3975	3657	3338	1962	2297	2352
1996	392	4535	4052	3856	3066	3220	3295
1997	394	4119	3735	3700	3390	3421	3474
1998	403	4793	4698	4661	4395	4413	4436
1999	421	5855	5946	5941	5859	5848	5853

Table F.2-4. Predicted annual natural-origin winter-run spawner abundance in the Upper Sacramento River from deterministic model runs.

Year	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
1980	8374	8374	8374	8374	8374	8374	8374
1981	8989	8989	8989	8989	8989	8989	8989
1982	6069	7847	7769	7760	7759	7790	7827
1983	2155	8245	7984	7980	7978	7987	8136

Year	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
1984	1634	11183	11004	11024	11022	10951	11152
1985	2987	13563	13997	14016	14014	13962	14138
1986	2682	13808	14497	14544	14542	14528	14738
1987	1066	12995	12962	13066	13064	12993	13321
1988	198	13259	12726	12845	12843	12731	13171
1989	96	12343	11927	11949	11948	11897	12240
1990	40	8735	7847	7754	7752	7727	7938
1991	5	7729	5842	5814	5809	5766	6097
1992	4	7670	5702	5773	5782	5753	6117
1993	3	4716	3627	3774	3761	3768	3901
1994	2	2791	2390	2367	1634	1844	1856
1995	3	3588	3270	2951	1575	1909	1965
1996	5	4148	3665	3469	2679	2833	2908
1997	7	3732	3348	3313	3002	3033	3087
1998	16	4405	4311	4273	4008	4026	4049
1999	33	5467	5558	5554	5471	5461	5466

Table F.2-5. Predicted mean lambda (N_{t+1}/N_t) for total winter-run spawner abundance in the Upper Sacramento River, including both natural- and hatchery-origin fish, from deterministic model runs.

WYT	EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
C	0.840	0.848	0.815	0.812	0.778	0.787	0.791
D	1.010	1.038	1.042	1.041	1.041	1.042	1.042
AN	0.998	0.633	0.659	0.676	0.672	0.677	0.659
W	0.874	1.108	1.129	1.129	1.174	1.155	1.157
All	0.852	0.979	0.980	0.980	0.979	0.979	0.979

Table F.2-6. Predicted terminal lambda ($N_{t=19}/N_{t=1}$) for total winter-run spawner abundance in the Upper Sacramento River, including both natural- and hatchery-origin fish, from deterministic model runs.

EXP1	EXP3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
0.048	0.668	0.679	0.678	0.669	0.668	0.668

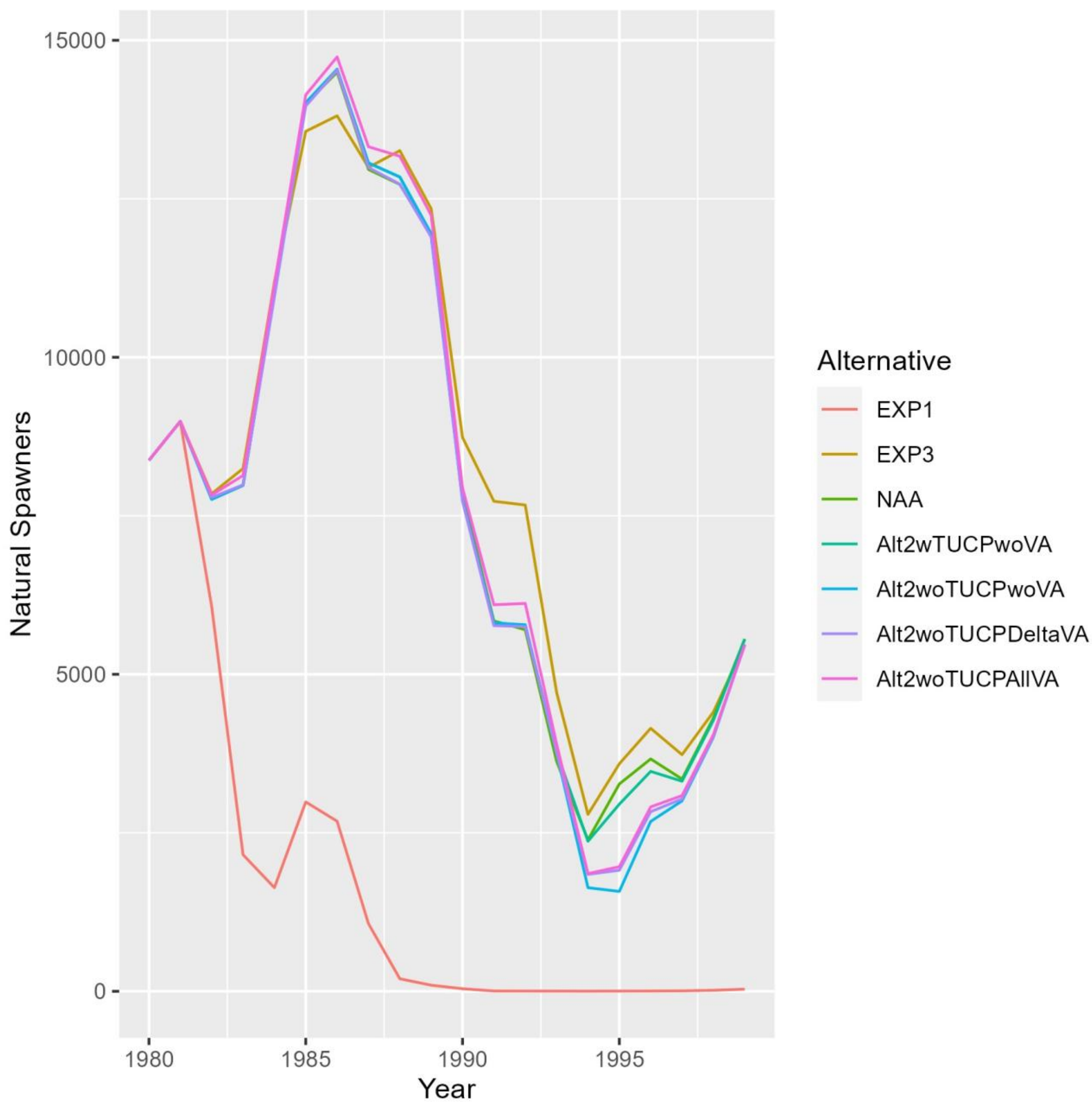

Figure F.2-11. Expected annual abundances of natural-origin winter-run Chinook salmon spawners in the Upper Sacramento River from deterministic model runs.

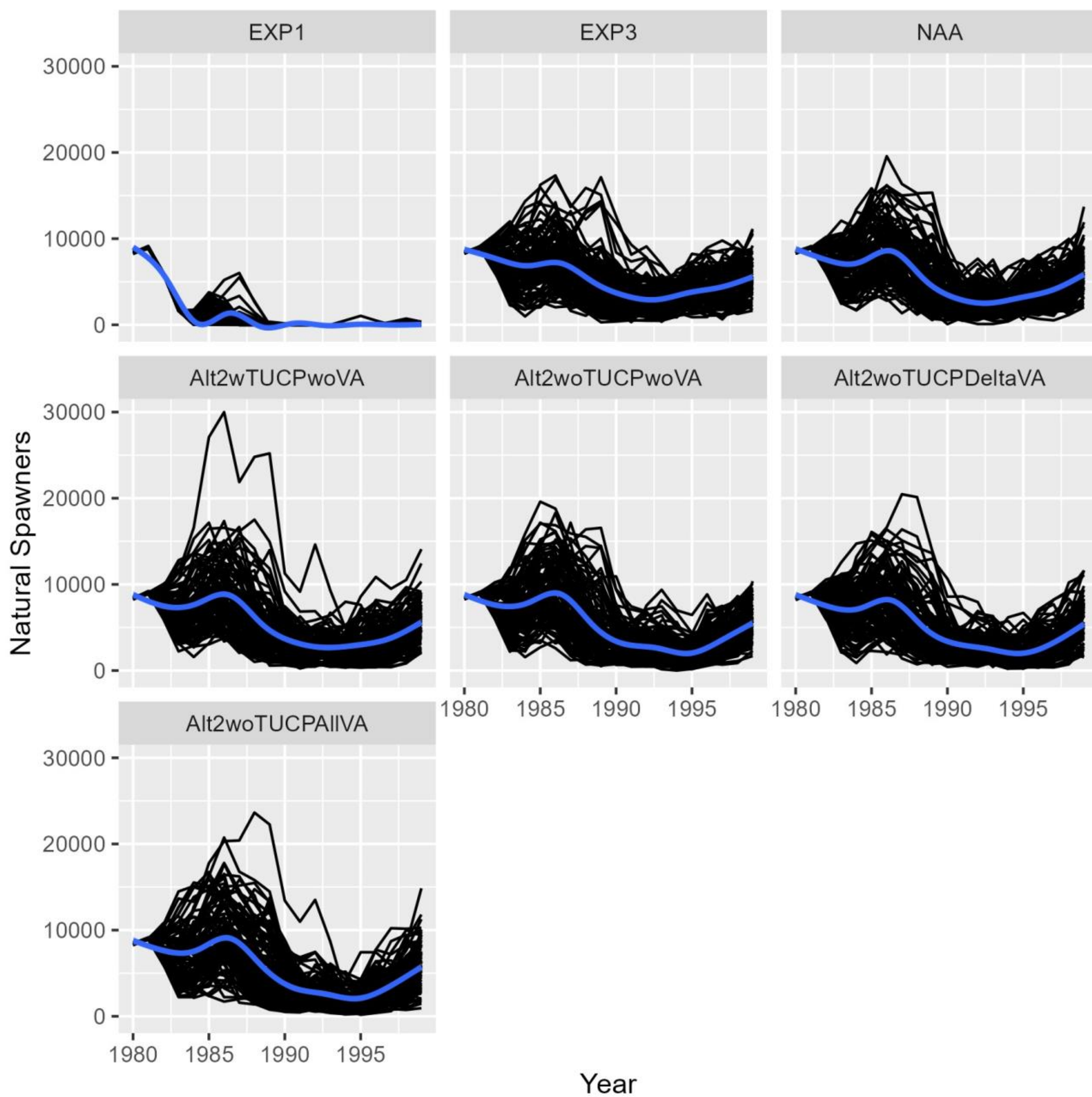

Figure F.2-12. Expected annual abundances of natural-origin winter-run Chinook salmon spawners in the Upper Sacramento River from stochastic model runs. Black lines represent iteration-specific abundances over time and the blue line represents an expected trend obtained by 'gam' smoothing in ggplot2.

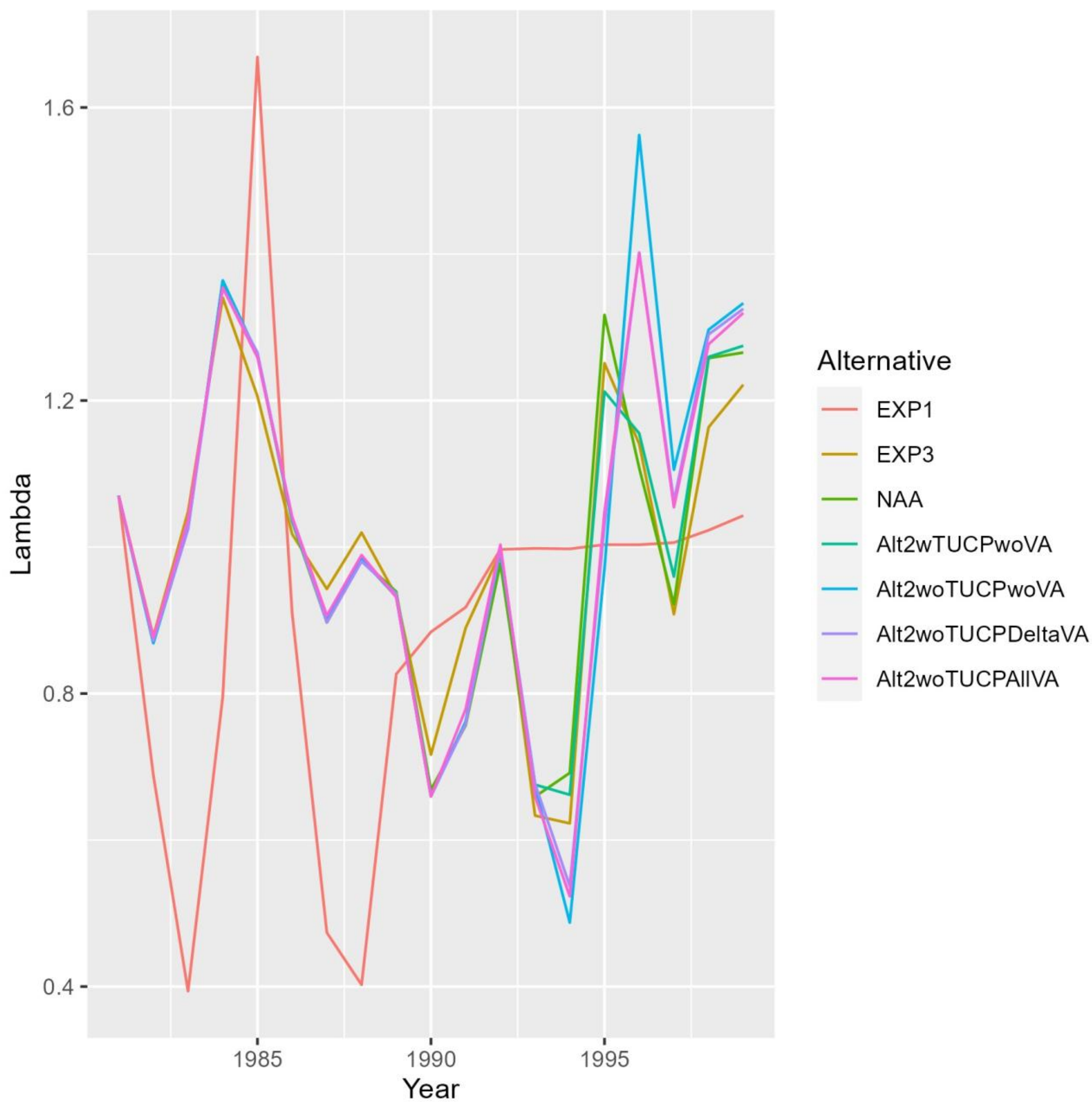

Figure F.2-13. Predicted annual lambda values (N_{t+1}/N_t) for total winter-run spawner abundance in the Upper Sacramento River, including both natural- and hatchery-origin fish, from deterministic model runs.

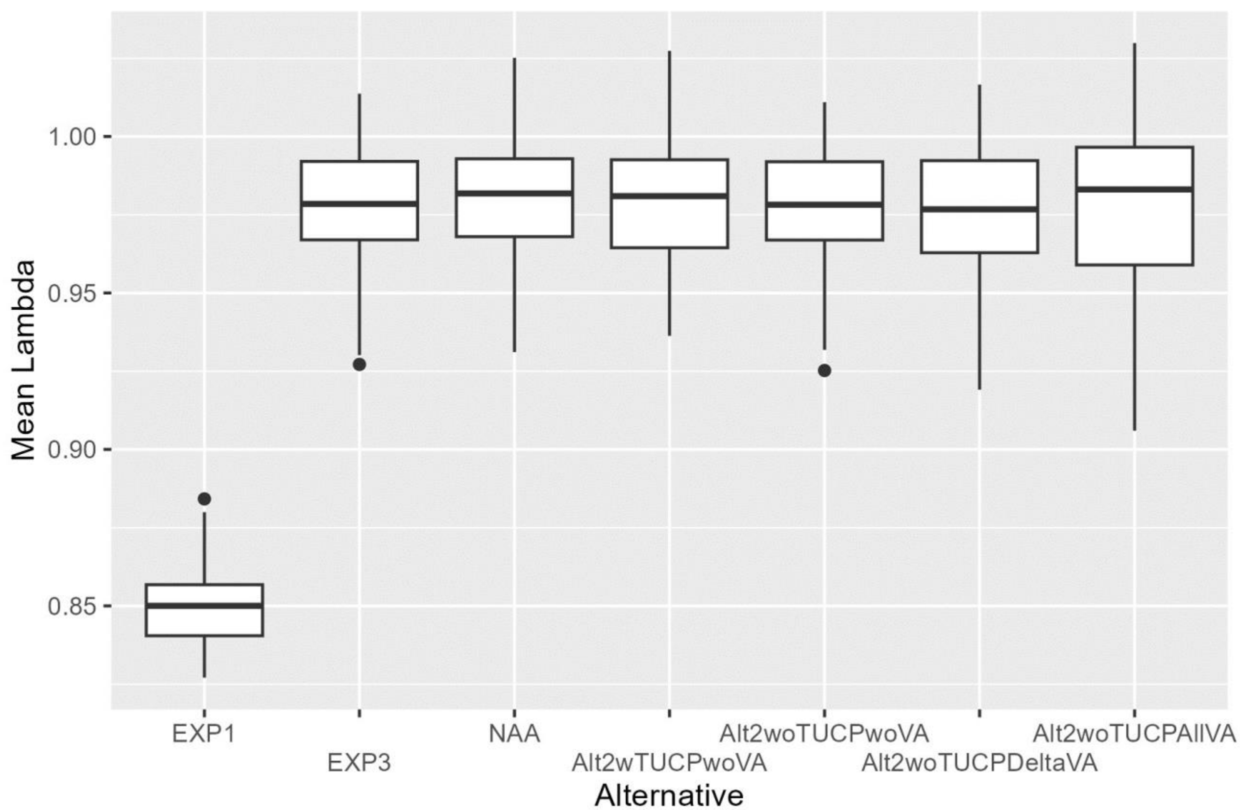

Figure F.2-14. Predicted mean lambda values (N_{t+1}/N_t) for total winter-run spawner abundance in the Upper Sacramento River, including both natural- and hatchery-origin fish, across 100 stochastic model iterations.

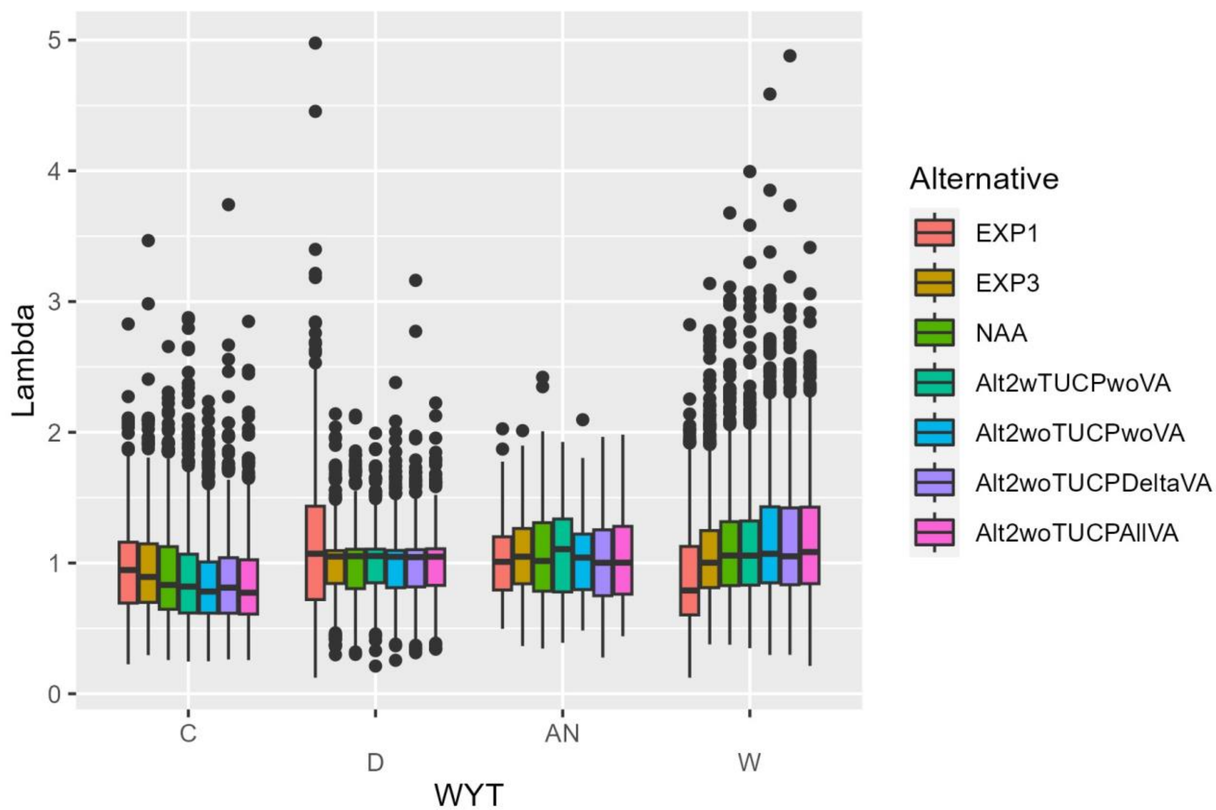

Figure F.2-15. Predicted lambda values for each water year type (N_{t+1}/N_t) for total winter-run spawner abundance in the Upper Sacramento River, including both natural- and hatchery-origin fish, across 100 stochastic model iterations.

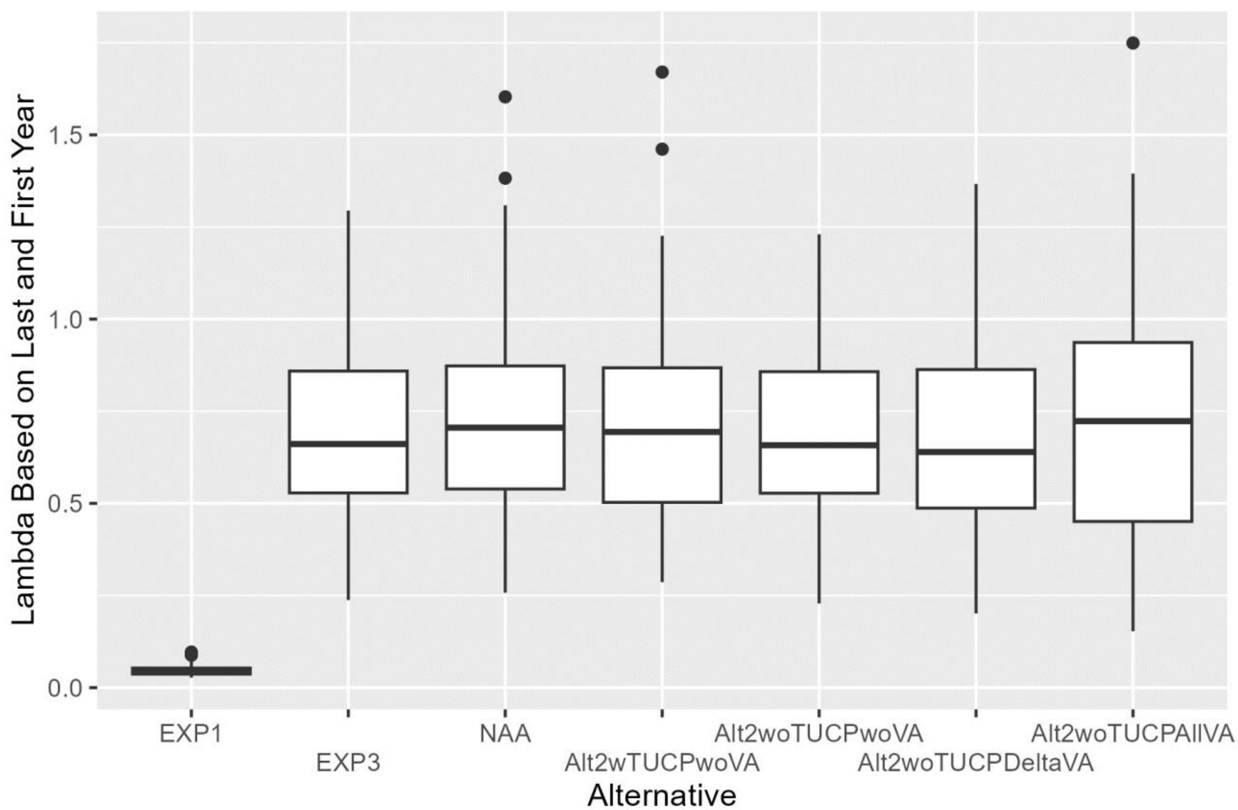

Figure F.2-16. Predicted terminal lambda values ($N_{t=19}/N_{t=1}$) for total winter-run spawner abundance in the Upper Sacramento River, including both natural- and hatchery-origin fish, across 100 stochastic model iterations.

F.2.3.1.2 Life stage-specific demographic parameters

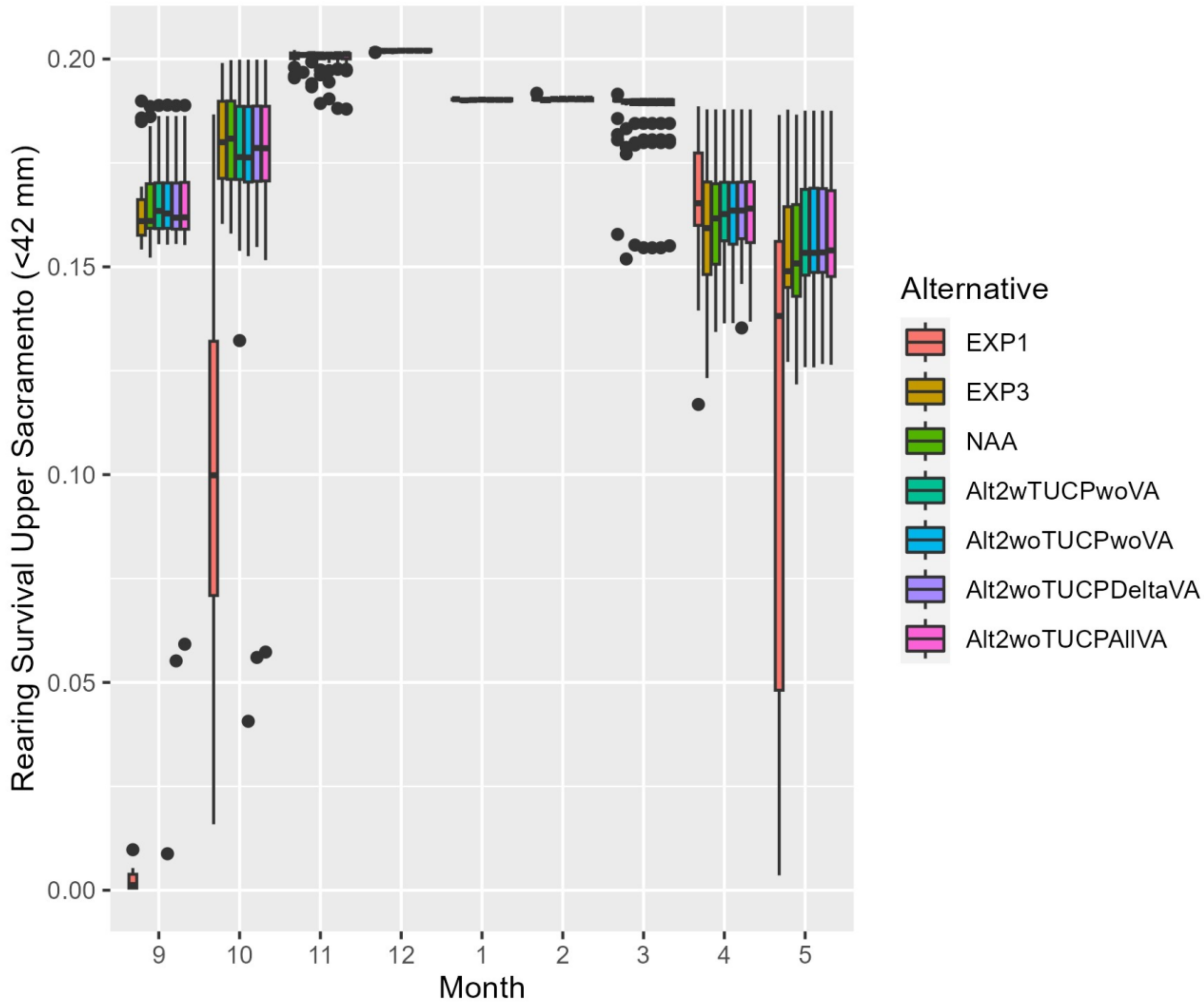

Figure F.2-17. Predicted small juvenile rearing survival for winter-run Chinook salmon in the Upper Sacramento River from deterministic model runs across the 20 year timeseries.

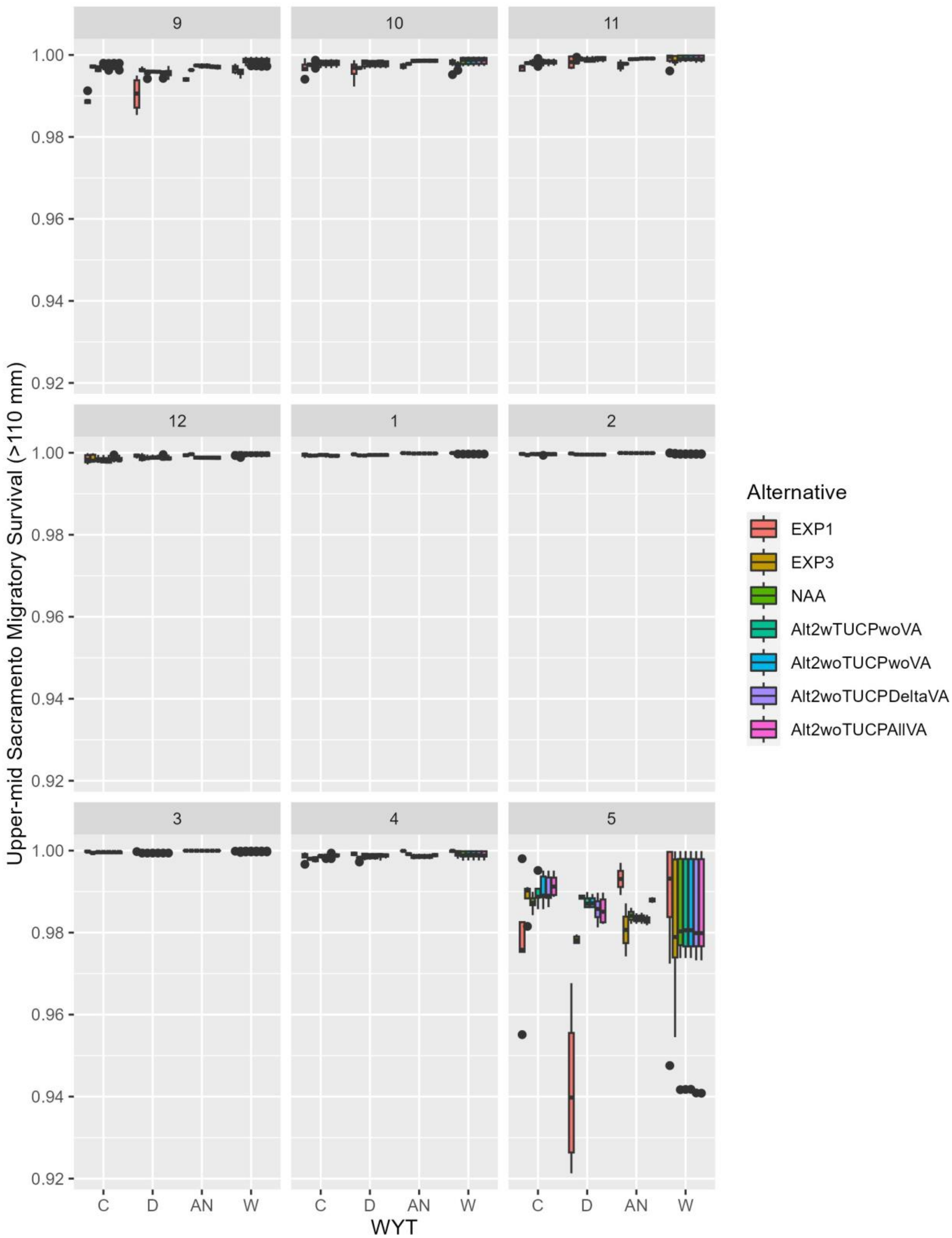

Figure F.2-18. Predicted smolt migratory survival for winter-run Chinook salmon in the Upper-mid Sacramento River from deterministic model runs across the 20 year timeseries, faceted by month.

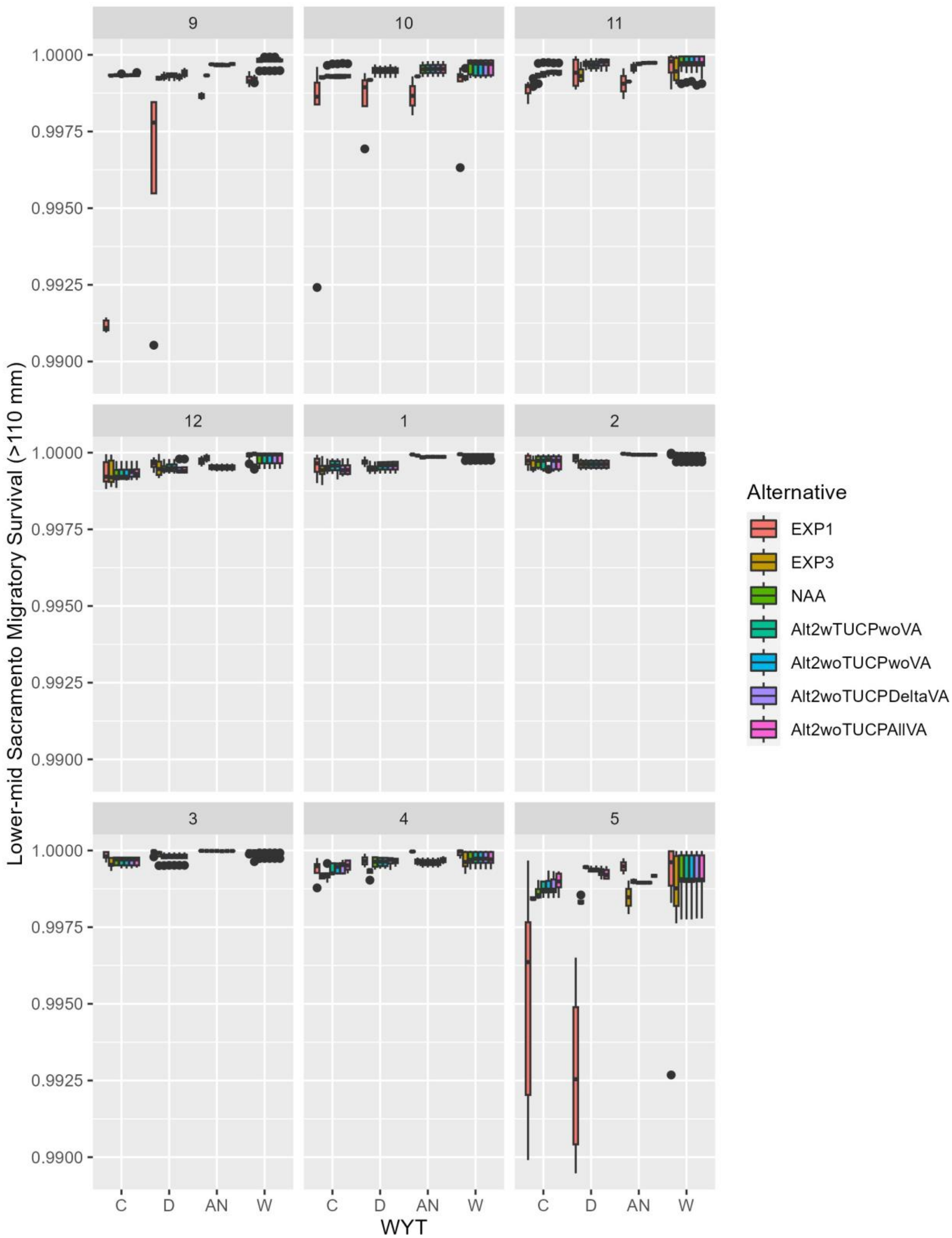

Figure F.2-19. Predicted smolt migratory survival for winter-run Chinook salmon in the Lower-mid Sacramento River from deterministic model runs across the 20 year timeseries, faceted by month.

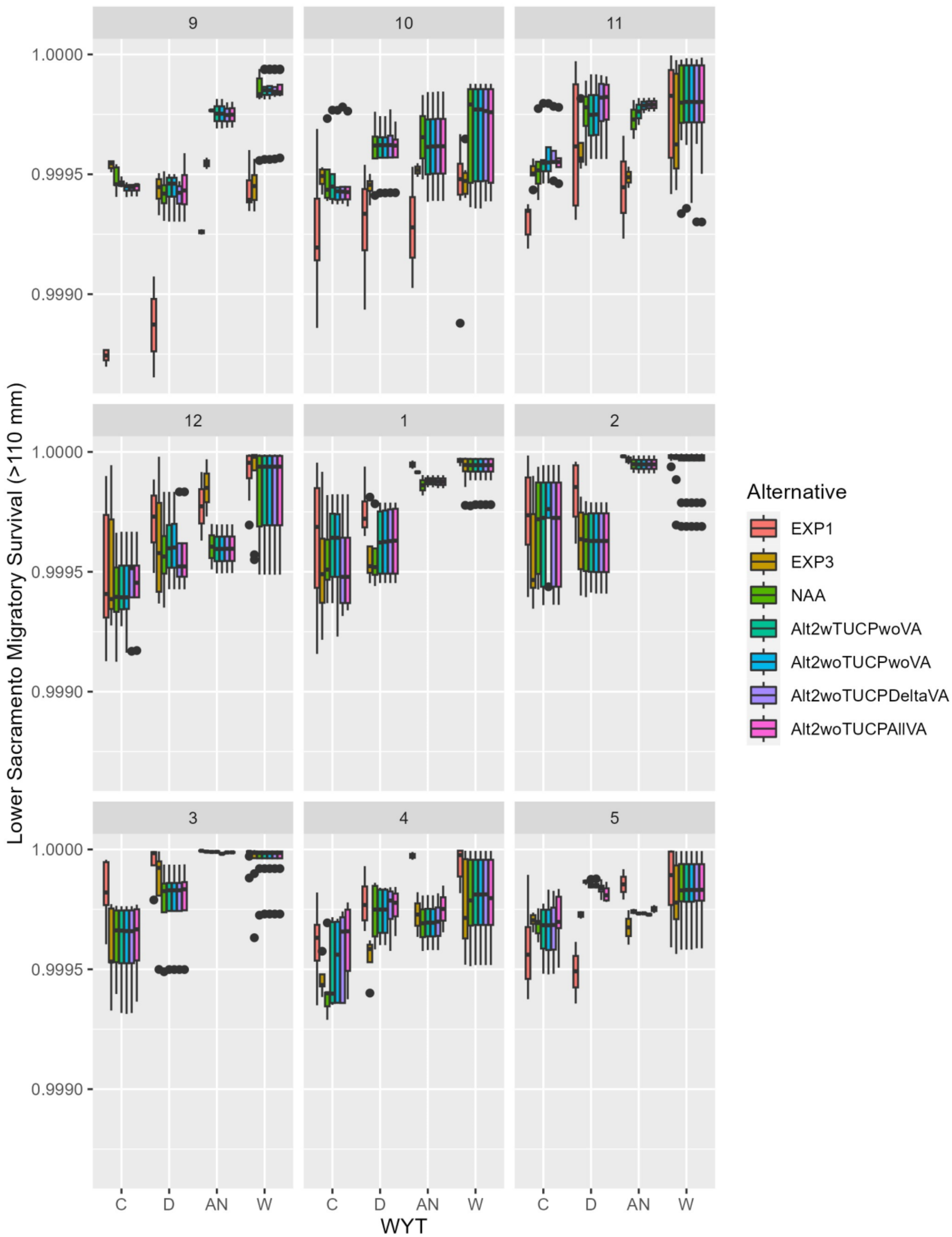

Figure F.2-20. Predicted smolt migratory survival for winter-run Chinook salmon in the Lower Sacramento River from deterministic model runs across the 20 year timeseries, faceted by month.

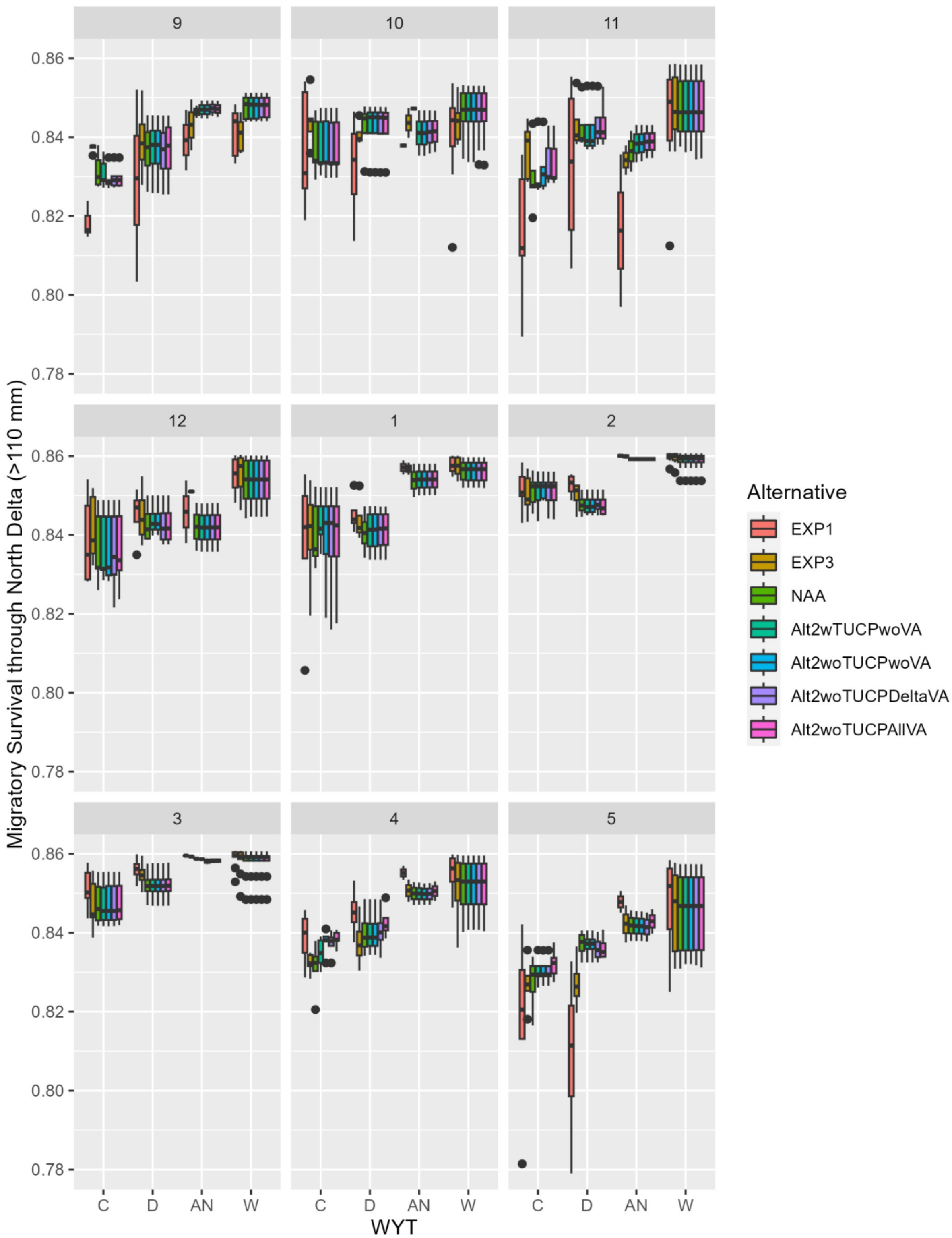

Figure F.2-21. Predicted smolt migratory survival for winter-run Chinook salmon in the North Delta from deterministic model runs across the 20 year timeseries, faceted by month.

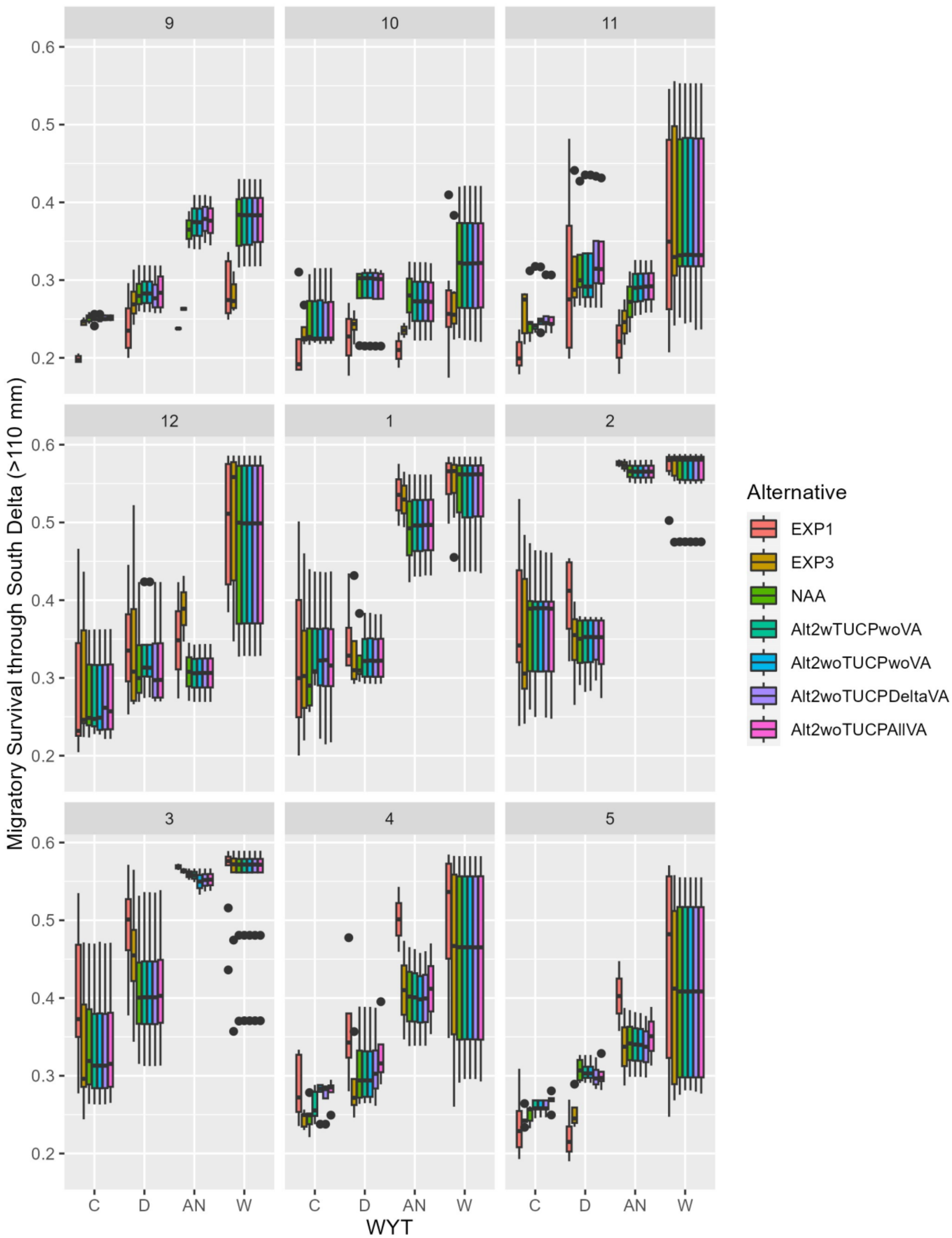

Figure F.2-22. Predicted smolt migratory survival for winter-run Chinook salmon in the South Delta from deterministic model runs across the 20 year timeseries, faceted by month.

F.2.3.2 EIS

Results for the EIS are summarized in Table F.2-7 through Table F.2-10 and Figure F.2-23 through Figure F.2-35.

Predicted total and natural-origin-only spawner abundances in the Upper Sacramento River for deterministic model runs generally peaked in 1986, decreased steadily until 1994, and then generally increased steadily through 1999 (Table F.2-7, Table F.2-8; Figure F.2-23). The range of natural-origin-only spawner abundances across alternatives at the end of the time series was narrow, ranging from a low of 5,461 (Alt2woTUCPDeltaVA) to a high of 5,606 (Alt3); over the entire time series predicted natural-origin-spawner abundances ranged from 1,575 (Alt2woTUCPwoVA) to 14,738 (Alt2woTUCPAllVA; Table F.2-8). The alternative Alt1 generally resulted in reduced spawner abundances relative to NAA over the modeled time series (i.e., -16.7 to 1.2% differences relative to NAA) (Figure F.2-24). The four components of Alt2, in addition to Alt4, generally resulted in small increases in spawner abundance for the years 1980-1993 (i.e., -1.5% to 7.6% differences relative to NAA) but decreases in spawner abundance for 1994-1999 (i.e., -51.8% to 0.4% differences). Alt3 resulted in small decreases in spawner abundance for the years (1980-1996 (i.e., -12.4% to -0.1% differences) and increases in spawner abundance for 1997-1999 (i.e., 0.9% to 3.1% differences). The Alt2wTUCPwoVA components resulted in less dramatic decreases in abundance, relative to NAA, for 1994-1999 (i.e., -9.8 to -0.1% differences) than the remaining Alt2 components (-51.8 to -1.6% differences). Predicted natural-origin-only spawner abundances varied more widely across stochastic model runs, from a low of approximately 0 to a high of approximately 30,000 spawners (Figure F.2-25).

For deterministic model runs, population change over time, defined by mean (i.e., geometric) lambda values (N_t/N_{t+1}), over the entire 1980-1999 time series ranged from only 0.979 to 0.980, and terminal lambda values ($N_{t=19}/N_{t=1}$) ranged from 0.668 (Alt2woTUCP with either DeltaVa or AllVA) to 0.684 (Alt3); these values indicated that predicted spawner abundances declined over the course of the time series (Table F.2-9, Table F.2-10). Mean lambda values across all WYs either did not change relative to NAA or declined slightly for all alternatives (i.e., -0.1% to 0.0% difference; Table F.2-9). All alternatives but Alt2wTUCPwoVA (i.e., 0.1% difference relative to NAA) and Alt3 (i.e., 0.8% difference) resulted in a decrease in terminal lambda relative to NAA (i.e., 1.6% to -0.1% difference for all other alternatives; Table F.2-10).

Annual lambda values from deterministic model runs ranged from approximately 0.5 to 1.55 (Figure F.2-26). Wet water years had the highest mean annual lambdas (>1.1 for all Alternatives) and Dry water years also had a mean annual lambda greater than 1, indicating that the population grew in Wet or Dry years (Table F.2-9). Mean lambdas were less than 1 in Critical and Above normal water years, indicating that populations declined. Reclamation staff emphasize that analyzing population growth rate by WYT in this manner does not account for the effects of spawning abundances and environmental conditions during spawning and rearing in previous years, which is an important consideration for the multi-year life histories of Chinook Salmon. Across stochastic model runs, mean lambda values over individual stochastic iterations ranged from approximately 0.925 to 1.025 (Figure F.2-27) and Critical water years had a lower mean lambda value than other water year types (Figure F.2-28). Terminal lambda values ranged from approximately 0.2 to 1.75 (Figure F.2-29), suggesting some model runs resulted in expected population growth over the time series.

Population trends may be explained by differences in life stage-specific demographic parameters. It is worth emphasizing again that the egg-to-fry survival life stage transition in the DSM is not sensitive to alternative-dependent flow or temperature values, and thus will be constant across alternatives. Across deterministic runs, monthly rearing survival for small juveniles (i.e., <42 mm) in the Upper Sacramento River varied from a low of approximately 0.01 to a high of approximately 0.2; rearing survival also varied across months, peaking in November and December (Figure F.2-30). Model-estimated migratory survival for very large fish (i.e., smolt size, >110 mm) in the Upper-mid, Lower-mid, and Lower Sacramento River was very close to 1, with slight variations across months and water year types (WYTs) (Figure F.2-31 through Figure F.2-33). In the Upper-mid and Lower-mid Sacramento River, expected survival was consistently lower in May than other migratory months; no such patterns were observed in the Lower Sacramento River. Migratory survival for very large fish also varied across months and WYT in the North and South Delta (Figure F.2-34, Figure F.2-35). Migratory survival often increased moving from a Critical to Dry to Above Normal to Wet WYT. Expected migratory survival in the North Delta was greatest in February and March and lowest in September, October, and May. Expected migratory survival in the South Delta was greatest in Wet and Above Normal Years in February and March and lowest in Critical Years in September, November, April, and May. With migratory survival in the mainstem Sacramento River high across the alternatives, rearing survival and migratory survival in the Delta likely act as drivers of lambda, creating a negative feedback loop with winter-run spawner abundance.

F.2.3.2.1 Population abundance, trends

Table F.2-7. Predicted annual total winter-run spawner abundance in the Upper Sacramento River, including both natural- and hatchery-origin fish, from deterministic model runs. Parentheses indicate percent difference from NAA (negative values indicate a decrease in annual spawner abundance).

Year	NAA	Alt1	Alt2 wTUCP woVA	Alt2 woTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA	Alt3	Alt4
1980	8762	8762 (0.0)	8762 (0)	8762 (0)	8762 (0)	8762 (0)	8762 (0)	8762 (0)
1981	9376	9376 (0.0)	9376 (0)	9376 (0)	9376 (0)	9376 (0)	9376 (0)	9376 (0)
1982	8156	8035 (-1.5)	8147 (-0.1)	8144 (-0.1)	8177 (0.3)	8214 (0.7)	8151 (-0.1)	8098 (-0.7)
1983	8371	8143 (-2.7)	8374 (0)	8367 (0)	8368 (0)	8518 (1.8)	8345 (-0.3)	8306 (-0.8)
1984	11391	11246 (-1.3)	11423 (0.3)	11416 (0.2)	11325 (-0.6)	11532 (1.2)	11338 (-0.5)	11407 (0.1)
1985	14384	14178 (-1.4)	14410 (0.2)	14402 (0.1)	14340 (-0.3)	14519 (0.9)	14331 (-0.4)	14348 (-0.3)
1986	14884	14491 (-2.6)	14940 (0.4)	14930 (0.3)	14906 (0.1)	15117 (1.6)	14790 (-0.6)	14644 (-1.6)
1987	13350	12817 (-4.0)	13537 (1.4)	13527 (1.3)	13436 (0.6)	13707 (2.7)	13128 (-1.7)	13032 (-2.4)
1988	13113	12260 (-6.5)	13393 (2.1)	13382 (2.1)	13241 (1)	13566 (3.5)	12744 (-2.8)	12780 (-2.5)
1989	12314	11354 (-7.8)	12434 (1)	12424 (0.9)	12340 (0.2)	12633 (2.6)	11928 (-3.1)	11896 (-3.4)
1990	8234	7513 (-8.8)	8166 (-0.8)	8158 (-0.9)	8153 (-1)	8285 (0.6)	7982 (-3.1)	7924 (-3.8)

Year	NAA	Alt1	Alt2 wTUCP woVA	Alt2 woTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA	Alt3	Alt4
1991	6230	5382 (-13.6)	6257 (0.4)	6245 (0.2)	6270 (0.6)	6397 (2.7)	5971 (-4.2)	5942 (-4.6)
1992	6089	5170 (-15.1)	6237 (2.4)	6251 (2.7)	6224 (2.2)	6444 (5.8)	5812 (-4.5)	5778 (-5.1)
1993	4015	3564 (-11.2)	4183 (4.2)	4257 (6)	4154 (3.5)	4144 (3.2)	3971 (-1.1)	3988 (-0.7)
1994	2777	2431 (-12.5)	2524 (-9.1)	2823 (1.7)	2514 (-9.5)	1878 (-32.4)	2673 (-3.7)	2861 (3)
1995	3657	3110 (-15.0)	2915 (-20.3)	3387 (-7.4)	2885 (-21.1)	2001 (-45.3)	3252 (-11.1)	3649 (-0.2)
1996	4052	3704 (-8.6)	3621 (-10.6)	3899 (-3.8)	3593 (-11.3)	3110 (-23.2)	3782 (-6.7)	4128 (1.9)
1997	3735	3663 (-1.9)	3635 (-2.7)	3747 (0.3)	3619 (-3.1)	3311 (-11.4)	3775 (1.1)	3845 (2.9)
1998	4698	4752 (1.2)	4628 (-1.5)	4693 (-0.1)	4584 (-2.4)	4319 (-8.1)	4831 (2.8)	4724 (0.6)
1999	5946	5870 (-1.3)	5941 (-0.1)	5950 (0.1)	5902 (-0.7)	5829 (-2)	5994 (0.8)	5920 (-0.4)

Table F.2-8. Predicted annual natural-origin winter-run spawner abundance in the Upper Sacramento River from deterministic model runs. Parentheses indicate percent difference from NAA (negative values indicate a decrease in annual spawner abundance).

Year	NAA	Alt1	Alt2 wTUCP woVA	Alt2 woTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA	Alt3	Alt4
1980	8374	8374 (0.0)	8374 (0)	8374 (0)	8374 (0)	8374 (0)	8374 (0)	8374 (0)
1981	8989	8989 (0.0)	8989 (0)	8989 (0)	8989 (0)	8989 (0)	8989 (0)	8989 (0)
1982	7769	7648 (-1.6)	7760 (-0.1)	7757 (-0.2)	7790 (0.3)	7826 (0.7)	7764 (-0.1)	7711 (-0.7)
1983	7984	7756 (-2.9)	7987 (0)	7979 (-0.1)	7981 (0)	8131 (1.8)	7958 (-0.3)	7919 (-0.8)
1984	11004	10859 (-1.3)	11036 (0.3)	11029 (0.2)	10937 (-0.6)	11145 (1.3)	10951 (-0.5)	11020 (0.1)
1985	13997	13790 (-1.5)	14023 (0.2)	14015 (0.1)	13952 (-0.3)	14131 (1)	13943 (-0.4)	13961 (-0.3)
1986	14497	14104 (-2.7)	14553 (0.4)	14543 (0.3)	14519 (0.2)	14730 (1.6)	14403 (-0.6)	14257 (-1.7)
1987	12962	12430 (-4.1)	13150 (1.5)	13140 (1.4)	13049 (0.7)	13320 (2.8)	12740 (-1.7)	12644 (-2.5)
1988	12726	11873 (-6.7)	13006 (2.2)	12995 (2.1)	12854 (1)	13179 (3.6)	12357 (-2.9)	12393 (-2.6)
1989	11927	10967 (-8.1)	12047 (1)	12036 (0.9)	11953 (0.2)	12246 (2.7)	11541 (-3.2)	11509 (-3.5)
1990	7847	7125 (-9.2)	7779 (-0.9)	7770 (-1)	7766 (-1)	7898 (0.6)	7595 (-3.2)	7537 (-4)
1991	5842	4995 (-14.5)	5870 (0.5)	5857 (0.3)	5882 (0.7)	6010 (2.9)	5583 (-4.4)	5555 (-4.9)
1992	5702	4783 (-16.1)	5849 (2.6)	5864 (2.8)	5837 (2.4)	6057 (6.2)	5425 (-4.9)	5391 (-5.5)
1993	3627	3177 (-12.4)	3796 (4.7)	3869 (6.7)	3767 (3.9)	3756 (3.6)	3583 (-1.2)	3601 (-0.7)
1994	2390	2044 (-14.5)	2137 (-10.6)	2435 (1.9)	2126 (-11)	1490 (-37.7)	2286 (-4.4)	2474 (3.5)
1995	3270	2723 (-16.7)	2528 (-22.7)	3000 (-8.3)	2498 (-23.6)	1613 (-50.7)	2865 (-12.4)	3262 (-0.2)

Year	NAA	Alt1	Alt2 wTUCP woVA	Alt2 woTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA	Alt3	Alt4
1996	3665	3316 (-9.5)	3233 (-11.8)	3512 (-4.2)	3205 (-12.6)	2723 (-25.7)	3395 (-7.4)	3741 (2.1)
1997	3348	3276 (-2.2)	3247 (-3)	3360 (0.4)	3231 (-3.5)	2924 (-12.7)	3387 (1.2)	3457 (3.3)
1998	4311	4364 (1.2)	4241 (-1.6)	4306 (-0.1)	4197 (-2.6)	3932 (-8.8)	4444 (3.1)	4337 (0.6)
1999	5558	5482 (-1.4)	5553 (-0.1)	5563 (0.1)	5515 (-0.8)	5441 (-2.1)	5606 (0.9)	5532 (-0.5)

Table F.2-9. Predicted mean lambda (N_{t+1}/N_t) for total winter-run spawner abundance in the Upper Sacramento River, including both natural- and hatchery-origin fish, from deterministic model runs. Parentheses indicate percent difference from NAA (negative values indicate a decrease in annual spawner abundance).

WYT	NAA	Alt1	Alt2 wTUCP woVA	Alt2 woTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA	Alt3	Alt4
C	0.815	0.795 (-2.4)	0.802 (-1.6)	0.815 (0)	0.803 (-1.5)	0.776 (-4.8)	0.807 (-1)	0.817 (0.2)
D	1.042	1.035 (-0.7)	1.042 (0)	1.042 (0)	1.042 (0)	1.042 (0)	1.039 (-0.3)	1.037 (-0.5)
AN	0.659	0.689 (4.5)	0.671 (1.8)	0.681 (3.3)	0.667 (1.2)	0.643 (-2.4)	0.683 (3.6)	0.69 (4.7)
W	1.129	1.141 (1.0)	1.139 (0.9)	1.126 (-0.3)	1.138 (0.8)	1.183 (4.8)	1.131 (0.2)	1.123 (-0.5)
All	0.980	0.979 (-0.1)	0.98 (0)	0.98 (0)	0.979 (-0.1)	0.979 (-0.1)	0.98 (0)	0.98 (0)

Table F.2-10. Predicted terminal lambda ($N_{t=19}/N_{t=1}$) for total winter-run spawner abundance in the Upper Sacramento River, including both natural- and hatchery-origin fish, from deterministic model runs. Parentheses indicate percent difference from NAA (negative values indicate a decrease in annual spawner abundance).

NAA	Alt1	Alt2 wTUCP woVA	Alt2 woTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA	Alt3	Alt4
0.679	0.67 (-1.3)	0.678 (-0.1)	0.679 (0)	0.674 (-0.7)	0.665 (-2.1)	0.684 (0.7)	0.676 (-0.4)

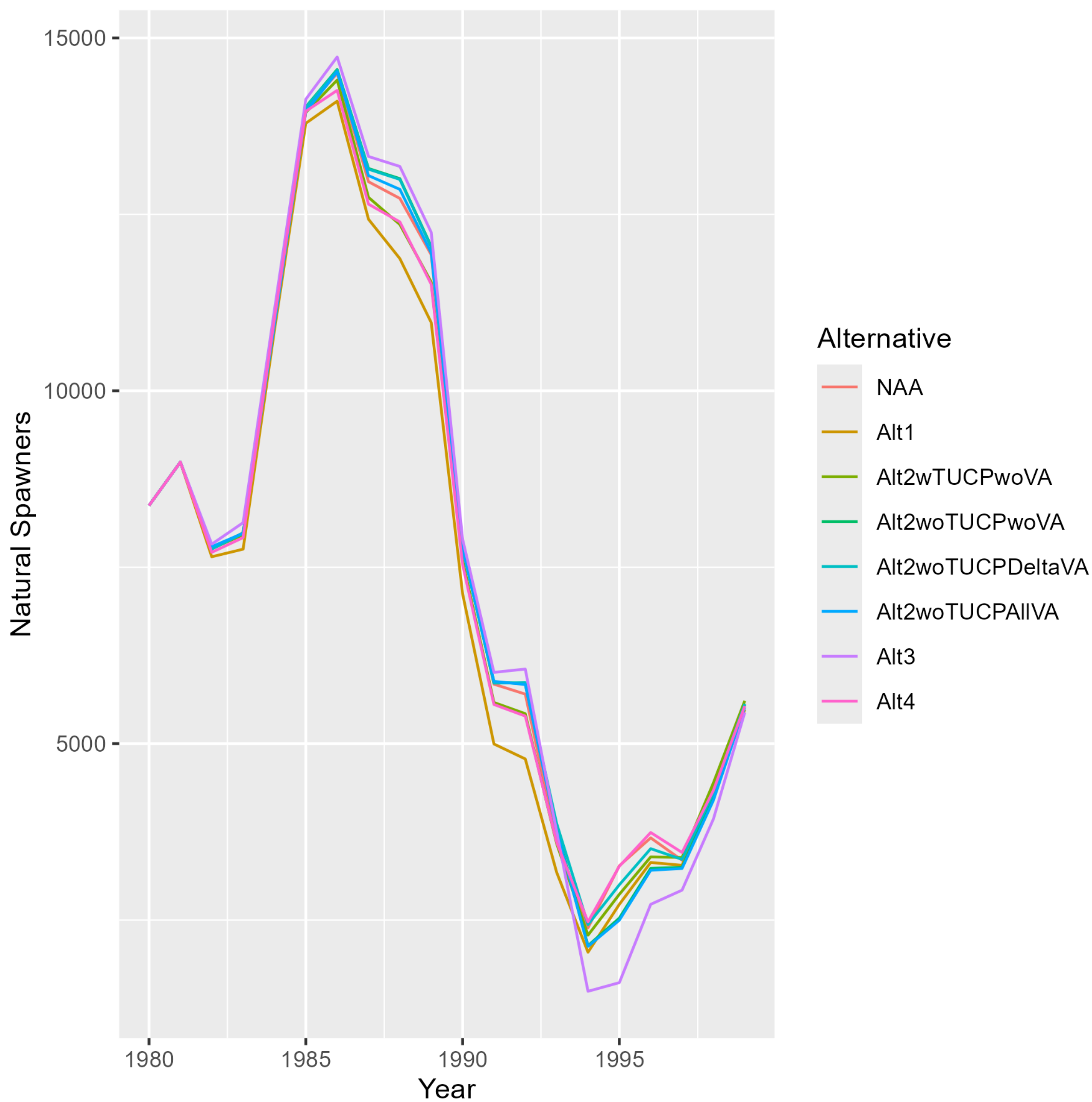

Figure F.2-23. Expected annual abundances of natural-origin winter-run Chinook salmon spawners in the Upper Sacramento River from deterministic model runs.

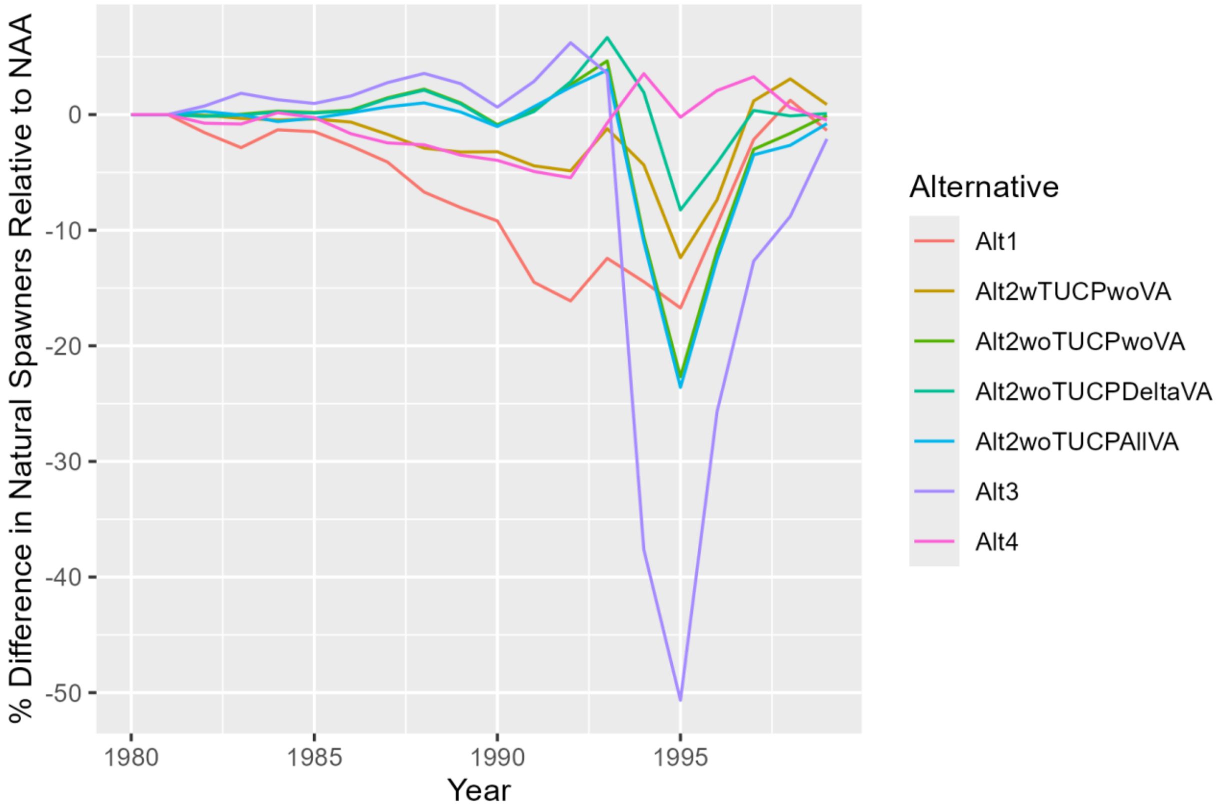

Figure F.2-24. Expected percent differences in annual abundances of natural-origin winter-run Chinook salmon spawners in the Upper Sacramento River from deterministic model runs.

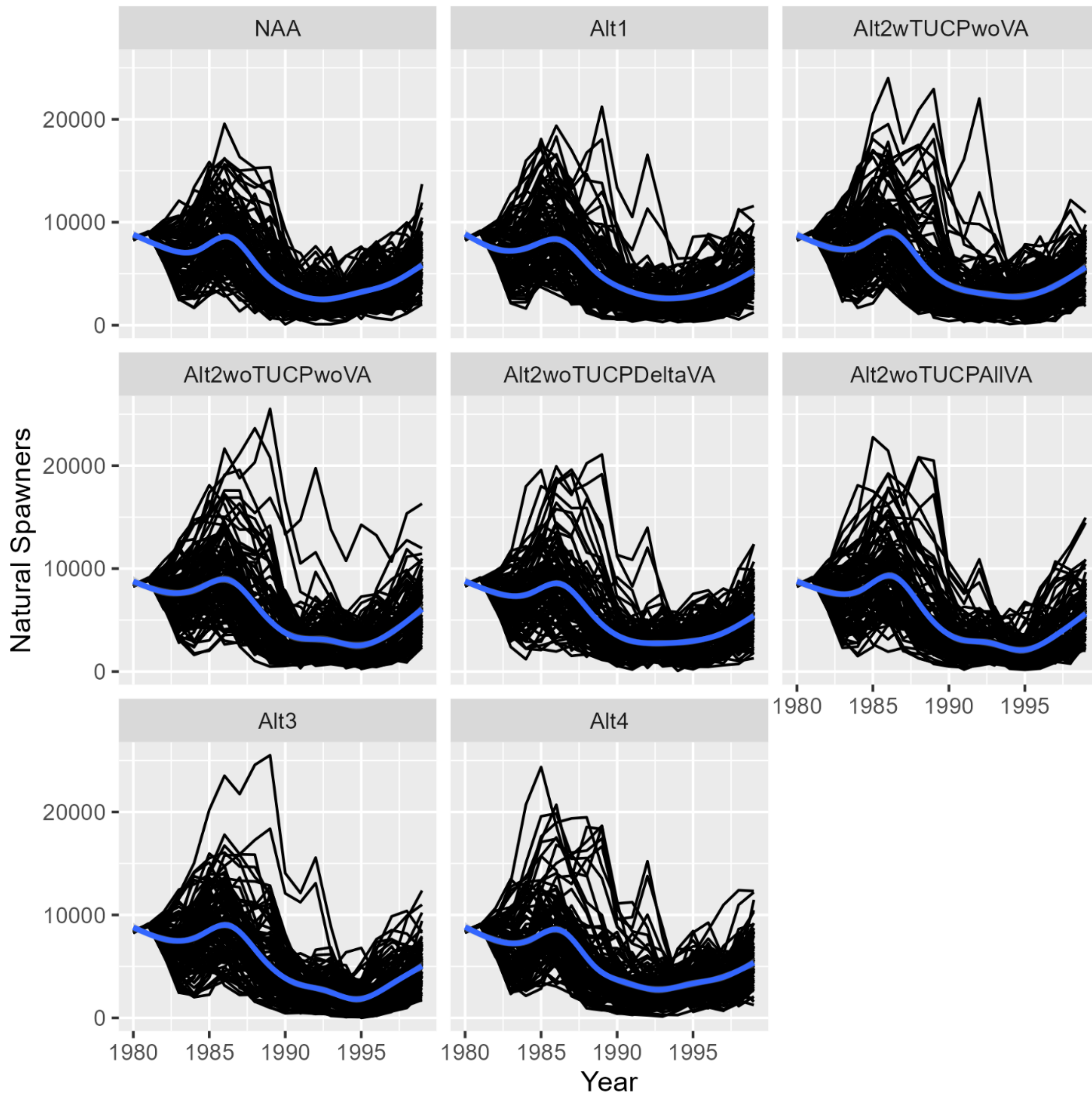

Figure F.2-25. Expected annual abundances of natural-origin winter-run Chinook salmon spawners in the Upper Sacramento River from stochastic model runs. Black lines represent iteration-specific abundances over time and the blue line represents an expected trend obtained by 'gam' smoothing in ggplot2.

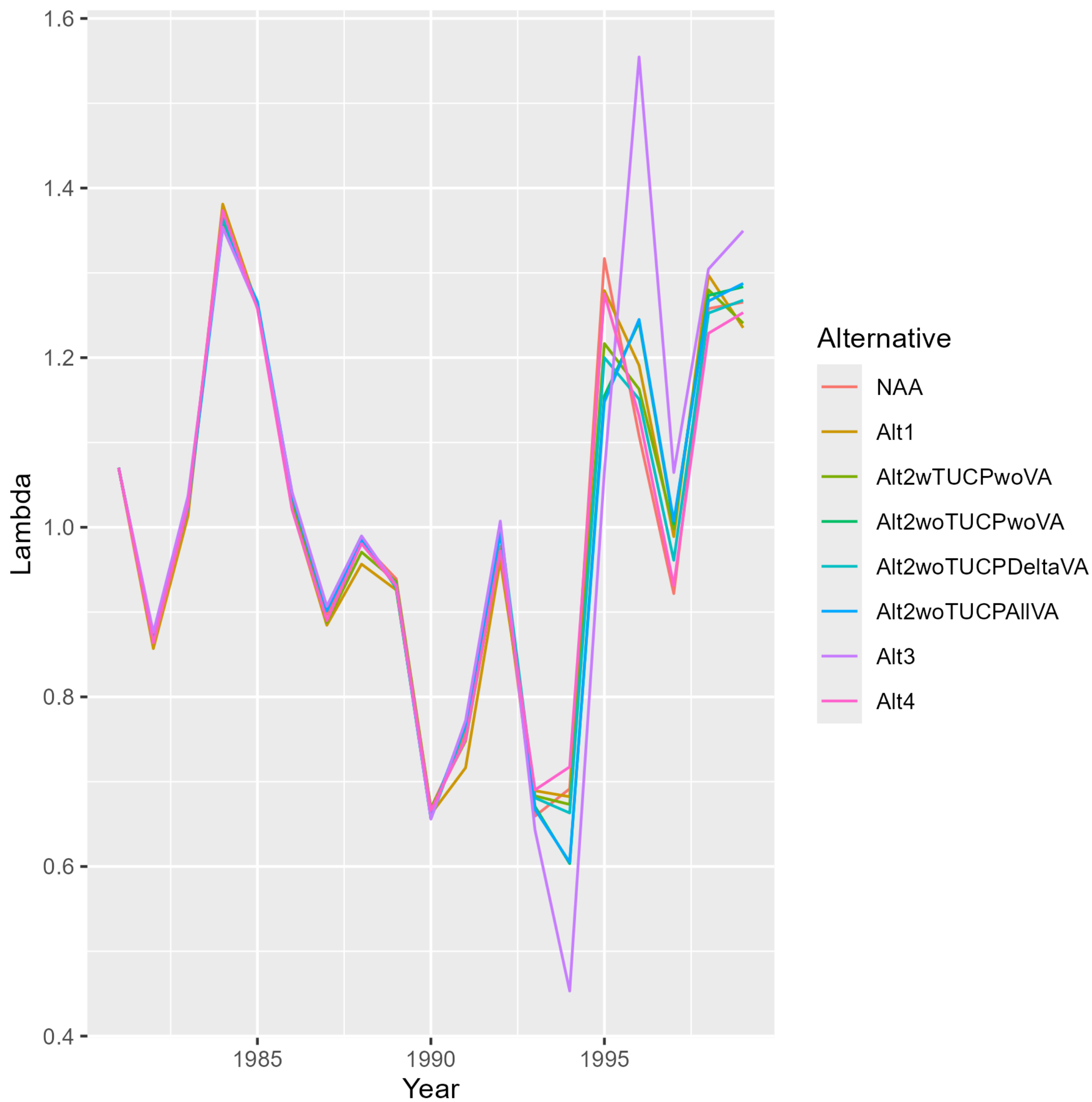

Figure F.2-26. Predicted annual lambda values (N_{t+1}/N_t) for total winter-run spawner abundance in the Upper Sacramento River, including both natural- and hatchery-origin fish, from deterministic model runs.

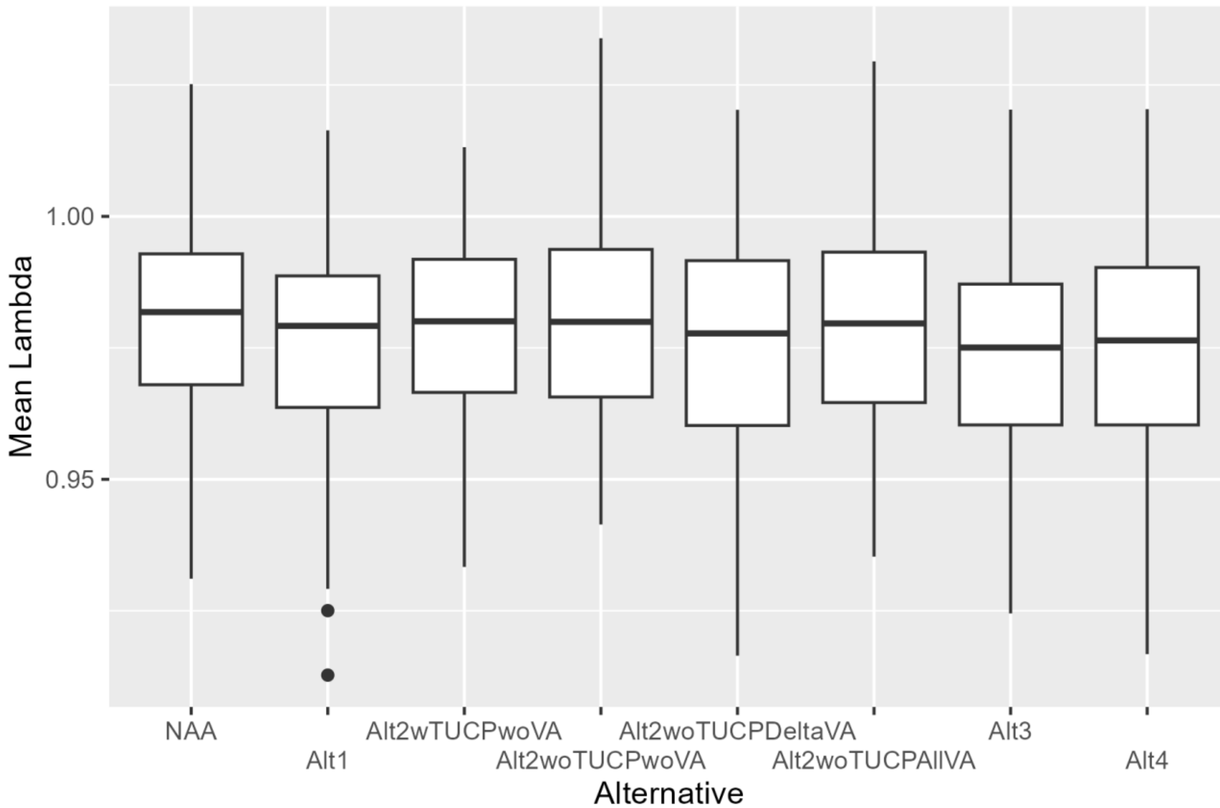

Figure F.2-27. Predicted mean lambda values (N_{t+1}/N_t) for total winter-run spawner abundance in the Upper Sacramento River, including both natural- and hatchery-origin fish, across stochastic model iterations.

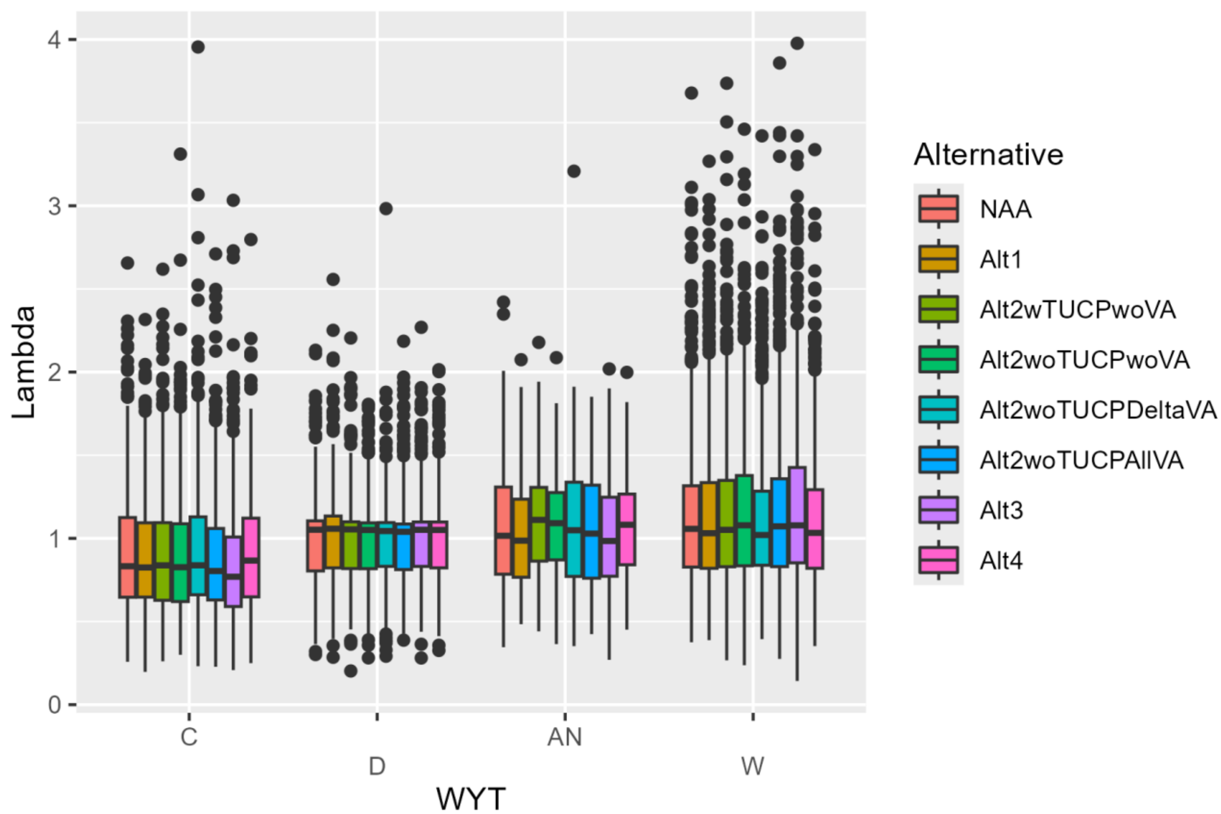

Figure F.2-28. Predicted lambda values for each water year type (N_{t+1}/N_t) for total winter-run spawner abundance in the Upper Sacramento River, including both natural- and hatchery-origin fish, across 100 stochastic model iterations.

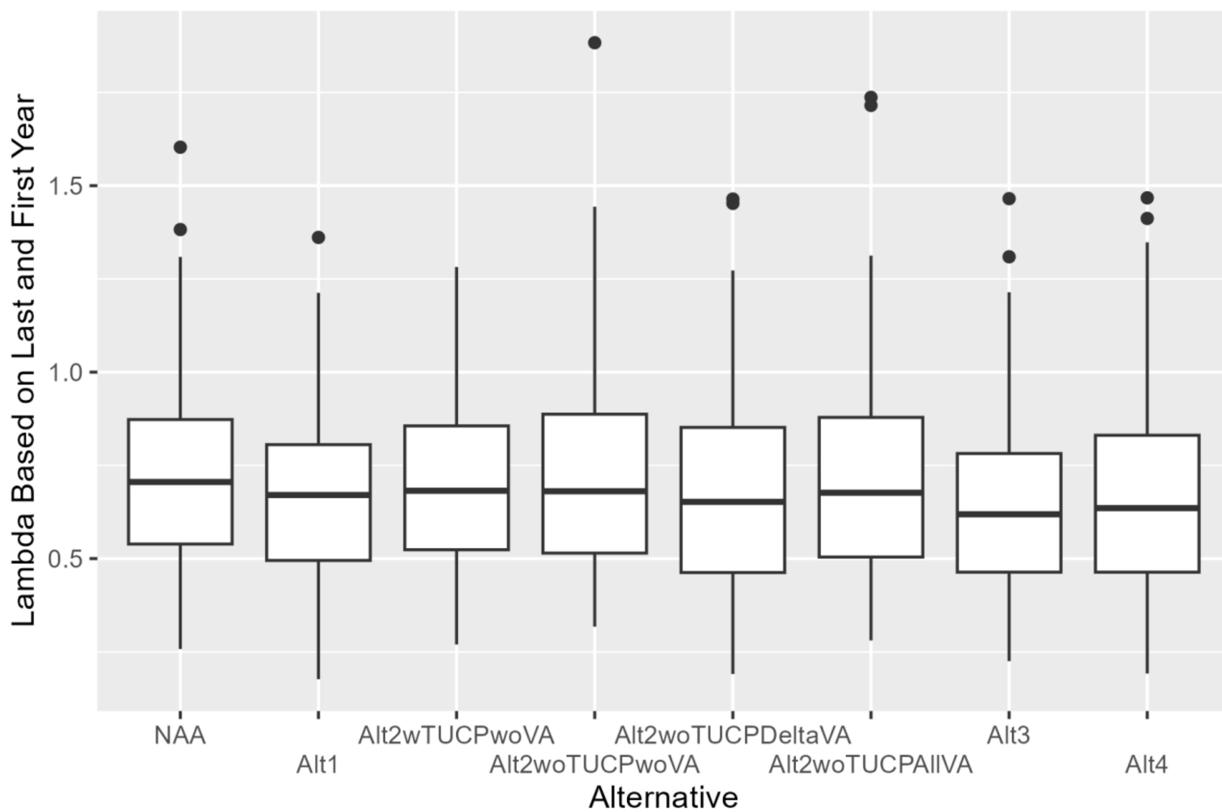

Figure F.2-29. Predicted terminal lambda values ($N_{t=19}/N_{t=1}$) for total winter-run spawner abundance in the Upper Sacramento River, including both natural- and hatchery-origin fish, across stochastic model iterations.

F.2.3.2.2 Life stage-specific demographic parameters

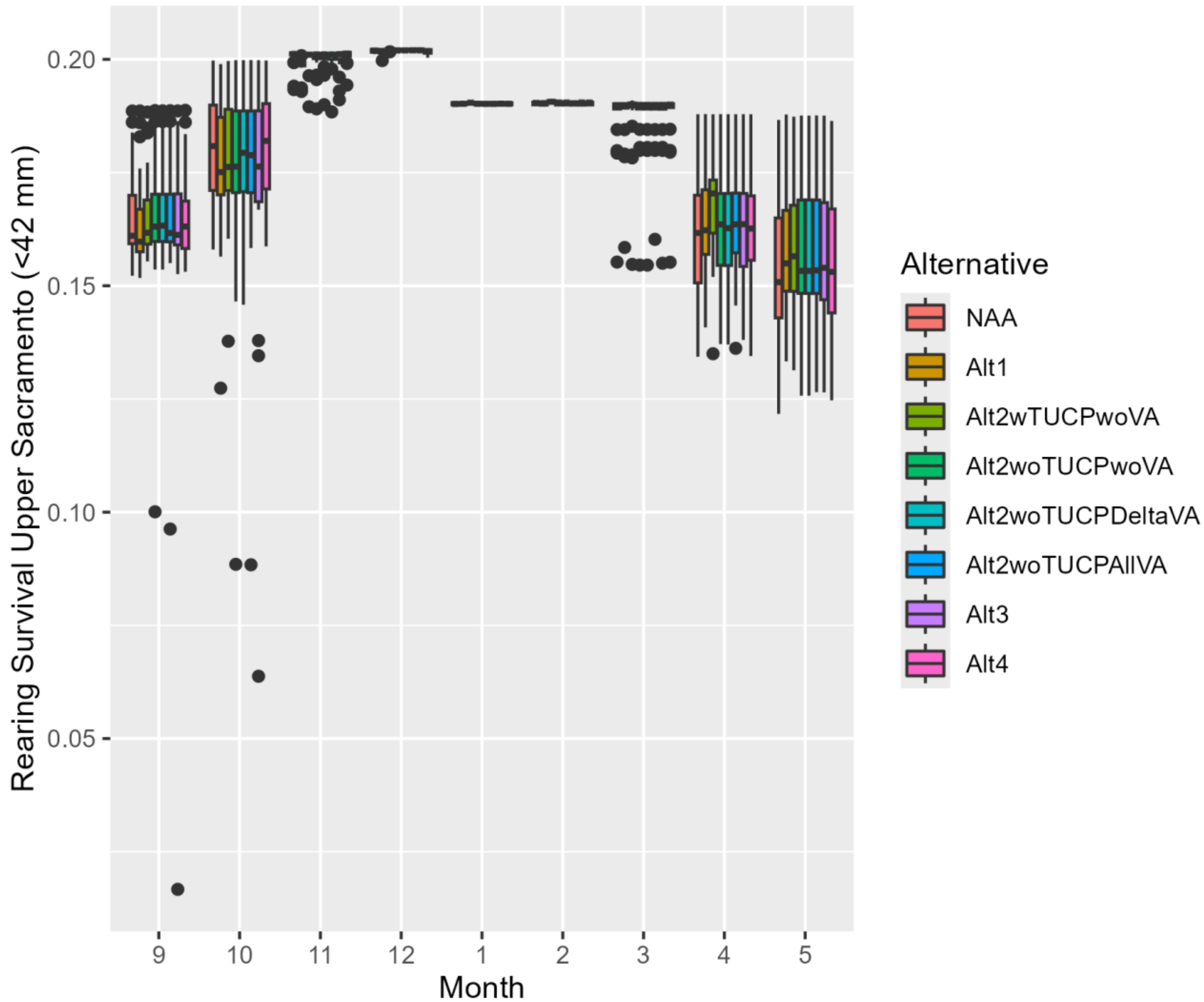

Figure F.2-30. Predicted small juvenile rearing survival for winter-run Chinook salmon in the Upper Sacramento River from deterministic model runs.

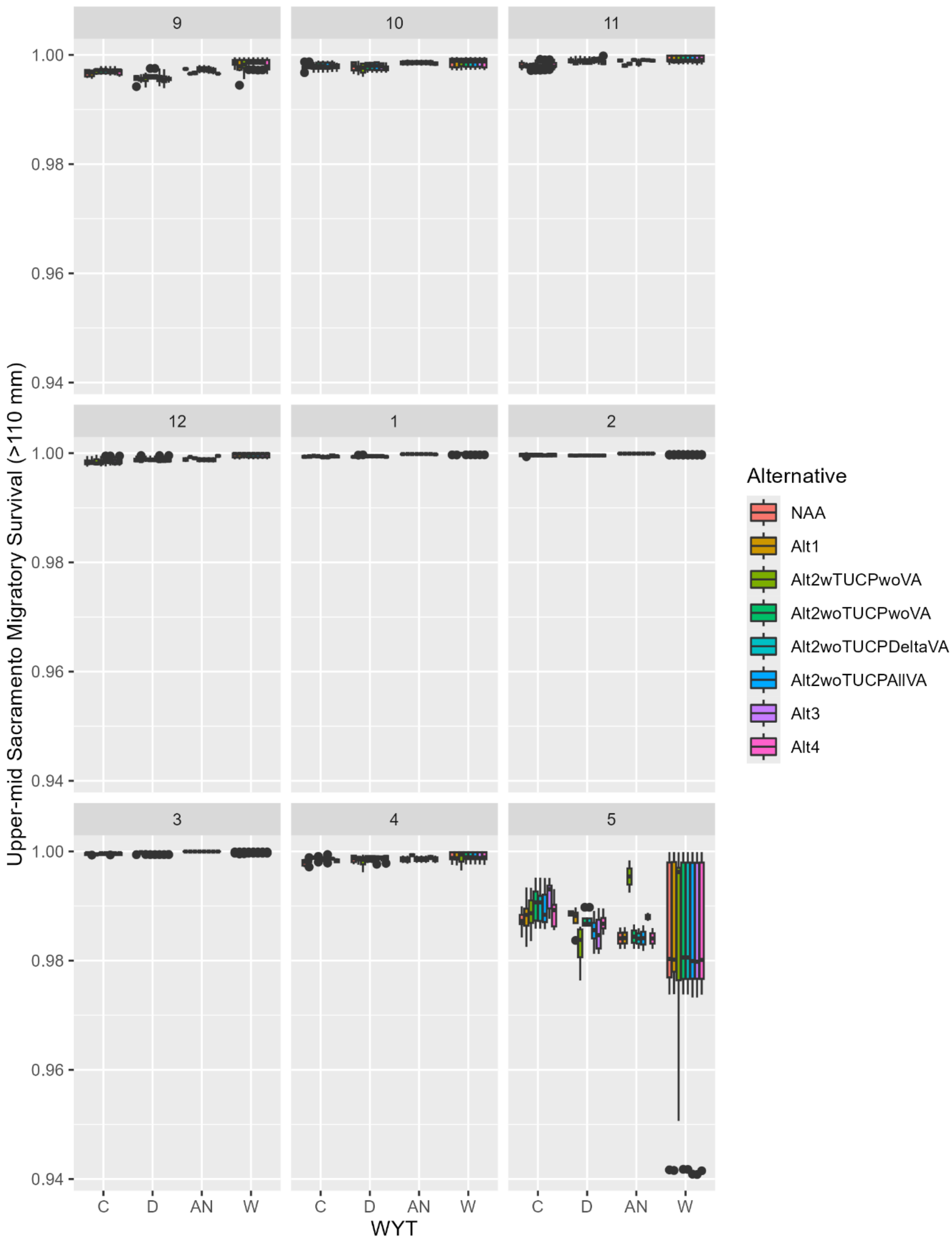

Figure F.2-31. Predicted smolt migratory survival for winter-run Chinook salmon in the Upper-mid Sacramento River from deterministic model runs, faceted by month.

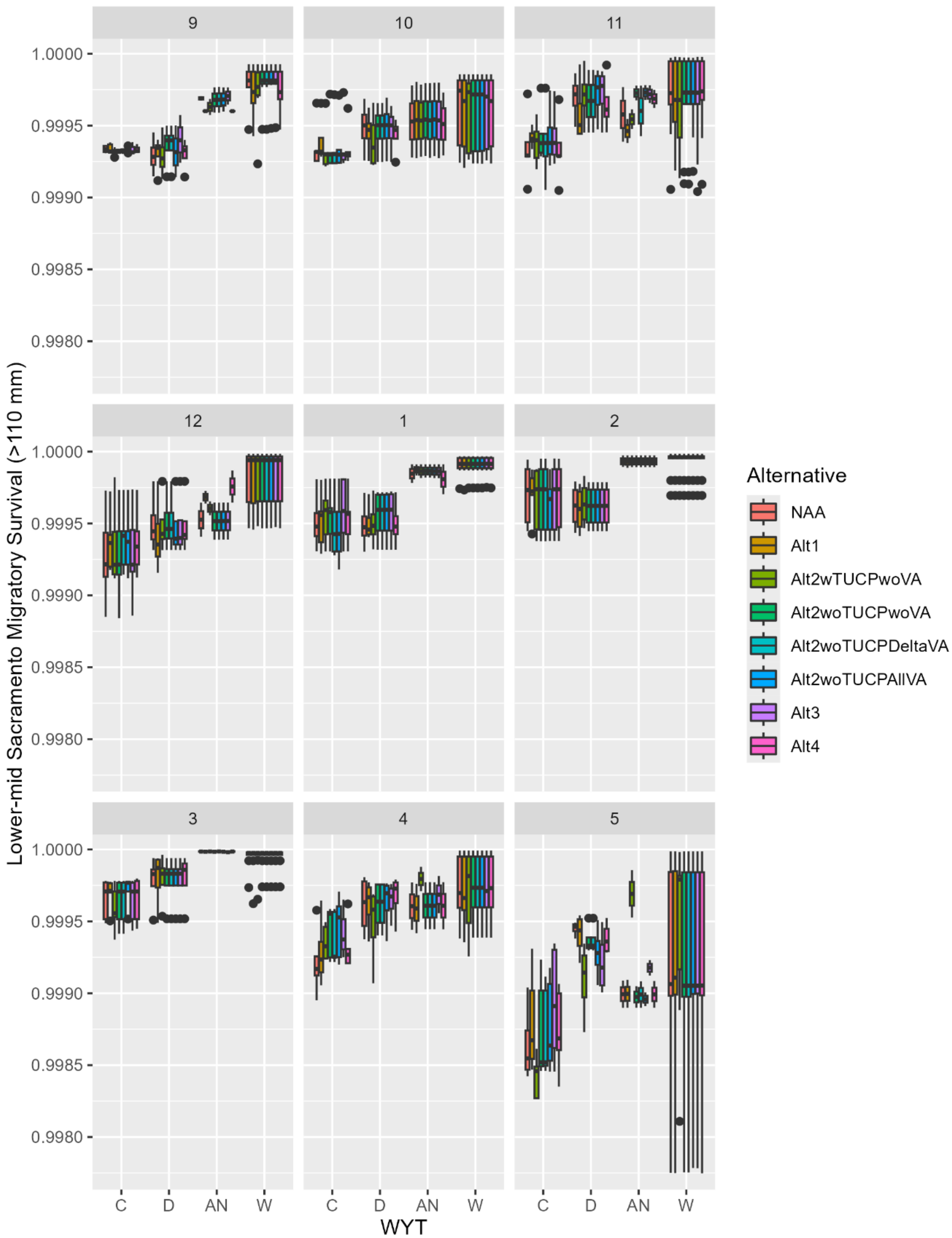

Figure F.2-32. Predicted smolt migratory survival for winter-run Chinook salmon in the Lower-mid Sacramento River from deterministic model runs, faceted by month.

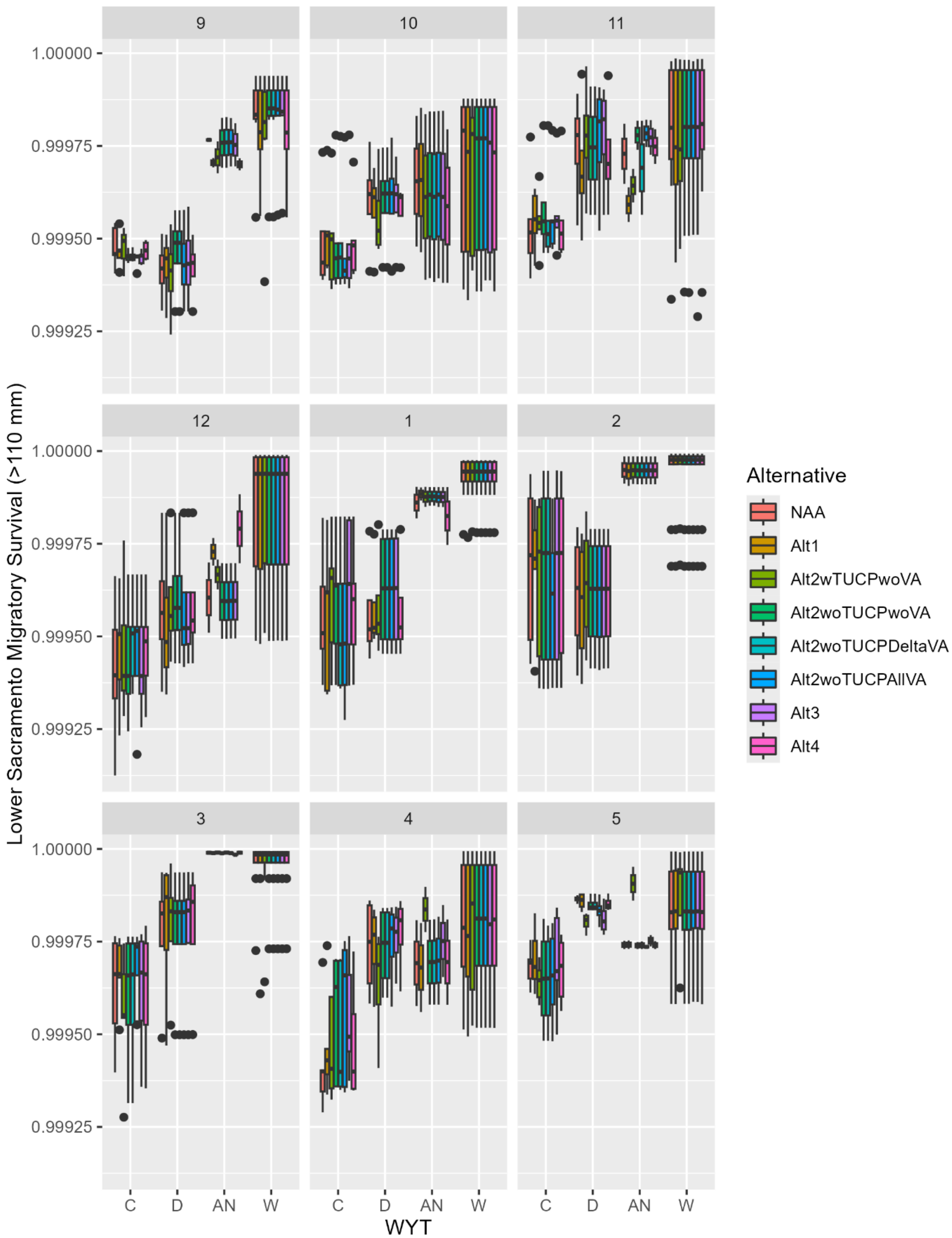

Figure F.2-33. Predicted smolt migratory survival for winter-run Chinook salmon in the Lower Sacramento River from deterministic model runs, faceted by month.

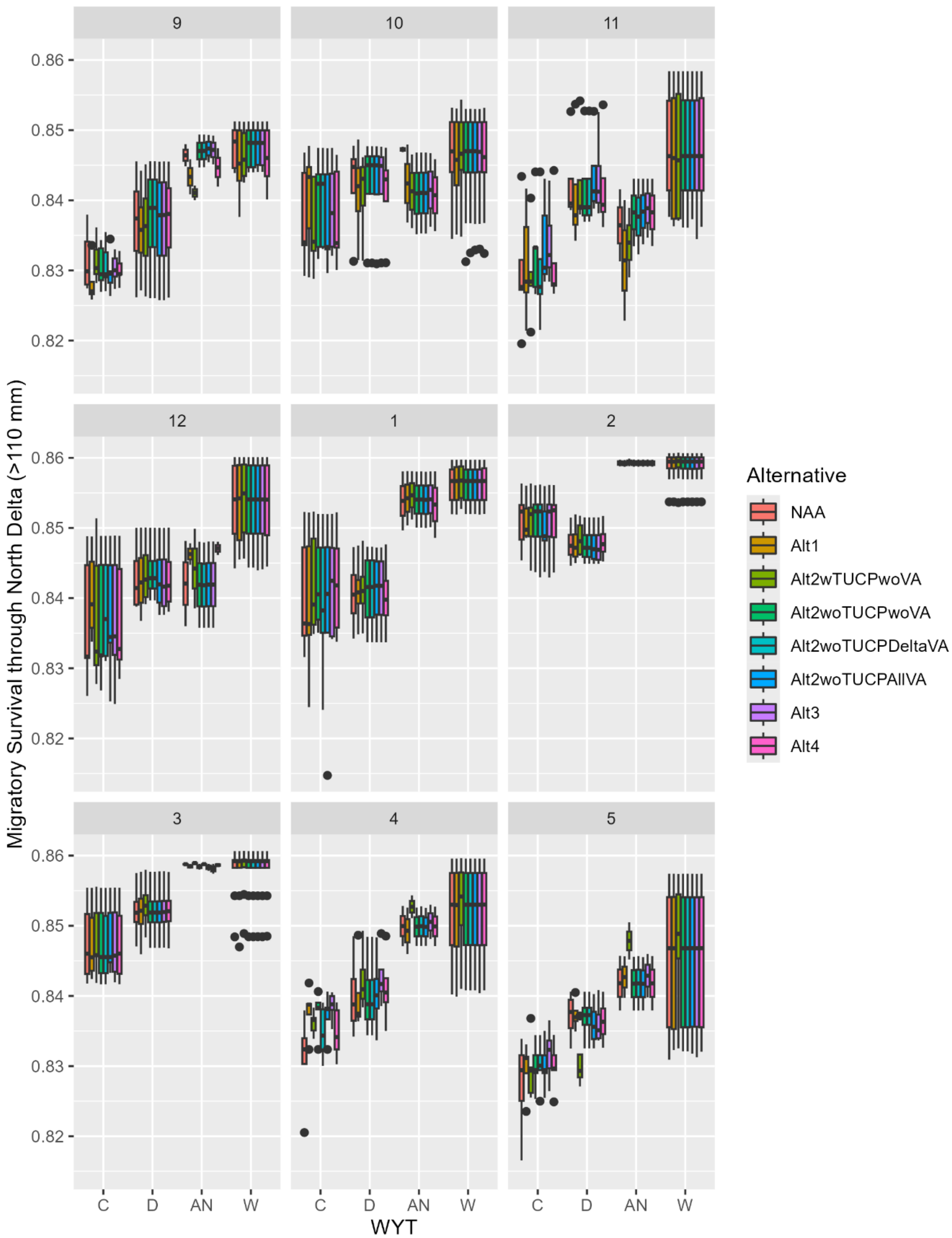

Figure F.2-34. Predicted smolt migratory survival for winter-run Chinook salmon in the North Delta from deterministic model runs, faceted by month.

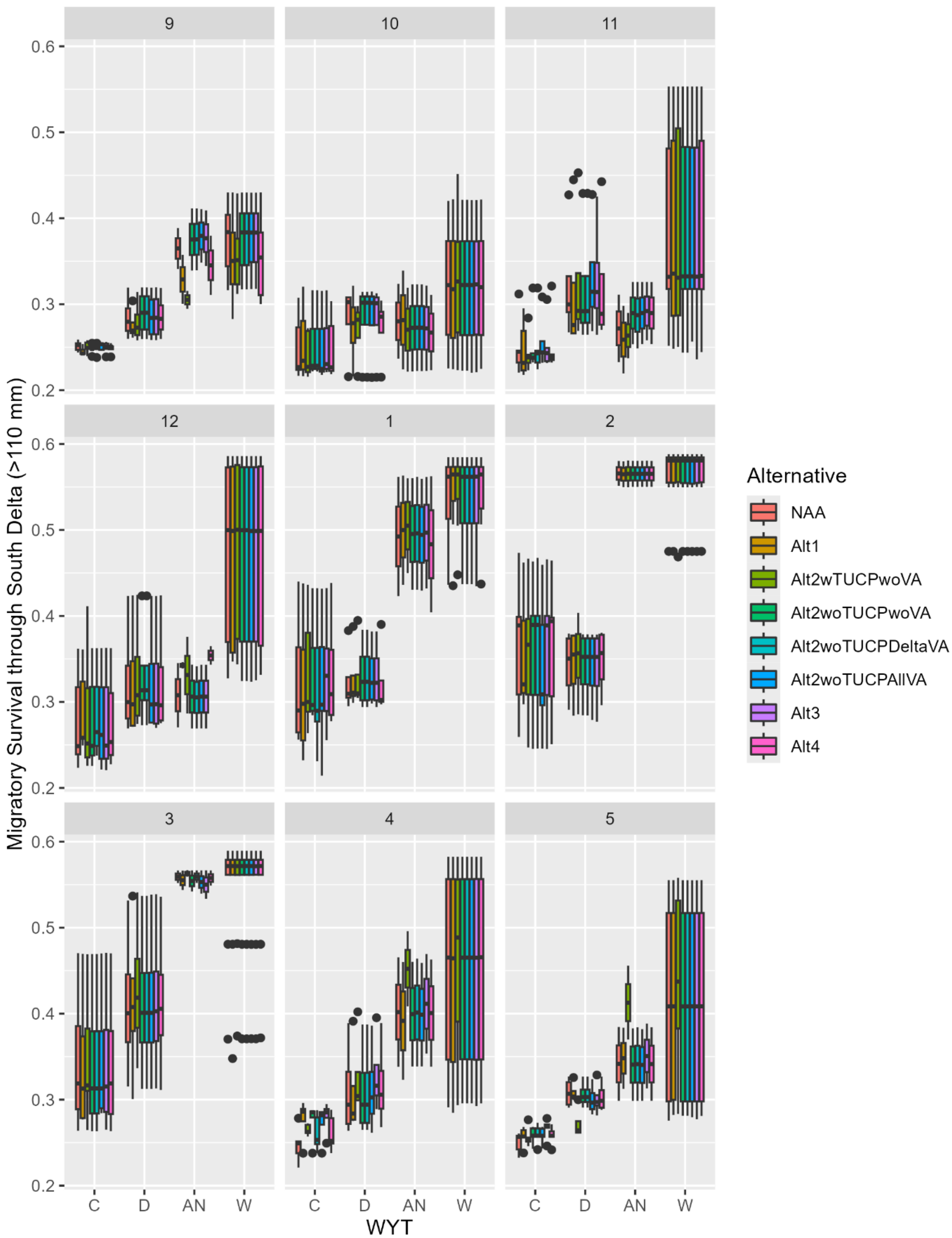

Figure F.2-35. Predicted smolt migratory survival for winter-run Chinook salmon in the South Delta from deterministic model runs, faceted by month.

F.2.4 References

Michel, C.J. 2019. Decoupling outmigration from marine survival indicates outsized influence of streamflow on cohort success for California's Chinook salmon populations. *Canadian Journal of Fisheries and Aquatic Sciences* 76: 1398-1410.

National Marine Fisheries Service. 2019. *Biological Opinion on Long-Term Operation of the Central Valley Project and the State Water Project.* National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce. WCRO-2016-00069

O'Farrell, M., Hendrix, N., and Mohr, M. 2016. *An Evaluation of preseason abundance forecasts for Sacramento River winter Chinook salmon.* Agenda Item D.2., Attachment 1.

Peterson, J.T., and Duarte, A. 2020. Decision analysis for greater insights into the development and evaluation of Chinook salmon restoration strategies in California's Central Valley. *Restoration Ecology* 28(6): 1596-1609.

This page intentionally left blank.