Appendix F, Modeling

Attachment F.6 Oncorhynchus Bayesian Analysis Model

F.6.1 Model Overview

The Oncorhynchus Bayesian Analysis (OBAN) model uses statistical approaches to understand how a series of environmental driver variables (e.g., temperature and flow) that are under management control may affect winter-run Chinook salmon population dynamics. The model was developed by first determining which of a suite of parameters (e.g., water temperature, harvest, exports, striped bass abundance, and offshore upwelling) covaried with historical abundance data. The OBAN model incorporates uncertainty by estimating the influence of covariates on population abundance in a Bayesian estimation framework. The parameter values were estimated by fitting to winter-run escapement and juvenile counts from the 1967 to 2011 brood years. The set of covariates that provided the best model fit were then retained for the predictive model. The OBAN predictive model uses values of the covariates under climate or operational alternatives, which are produced primarily from CALSIM and SRWQM outputs, to predict patterns in winter-run Chinook salmon population dynamics. Furthermore, uncertainty in the predicted winter-run abundance is then incorporated into model output through Monte Carlo simulations (1,000 simulations per model run). The alternatives are compared to a baseline condition to provide inference on the relative performance of the alternatives to the baseline, which is a more robust approach for evaluating alternatives than absolute prediction (Fuller et al. 2008).

Specifically, the OBAN model:

- Accounts for mortality during all phases of the Chinook salmon life history, including environmental and anthropogenic factors;
- Evaluates covariates that may explain dynamic vital rates (e.g., thermal mortality reduces alevin survival rates in spawning reaches);
- Estimates model coefficients by fitting predictions of the population dynamics model to observed indices of abundance in a Bayesian framework

F.6.2 Model Development

F.6.2.1 OBAN Estimation Methods

The winter-run Chinook salmon OBAN model is composed of several life history stages:

- **Alevin –** incubation in the gravel below Keswick Dam
- **Fry –** rearing above Red Bluff Diversion Dam (RBDD)
- **Delta –** from RBDD to Chipps Island
- **Bay** – from Chipps Island to the Golden Gate
- **Gulf –** Gulf of Farrallones
- **Ocean 1 –** first year in the ocean, return to spawn as 2-year olds
- **Ocean 2 –** second year in the ocean, return to spawn as 3-year olds
- **Ocean 3 –** third and final year in the ocean, return to spawn as 4-year olds
- **Escapement –** composed of all spawners on the spawning ground

The winter-run Chinook salmon OBAN model has been developed from the conceptual life-cycle model of winter-run Chinook salmon, and uses a Bayesian statistical estimation algorithm to find a statistical "best fit" to empirical trends by matching model predictions to empirically observed juvenile and adult abundances. The model is capable of fitting any number of abundance data sources and estimating any number of coefficient values to find the best statistical prediction.

The transition between life history stages occurs with a Beverton-Holt recruitment function:

$$N_{j+1} = N_j \times \frac{p_j}{1 + \frac{p_j N_j}{K_j}}$$

where N_j is the abundance at stage j, p_j is the productivity in the absence of density dependence for stage j, K_j is the capacity at stage j. The two parameters of the Beverton-Holt transition equation are p_j and K_j , and they can be user defined constants, estimated parameters fixed across all years, or dynamic, i.e., $p_{j,t}$ and $K_{j,t}$ can be modeled as changing in each year t. Note that density dependence can be effectively removed from the formulation by setting K_j to a very large value.

In the case of dynamic productivity ($p_{j,t}$) and capacity ($K_{j,t}$), parameter values, the values of the productivities and capacities in a given year are modeled from a set of time-varying covariates. By using this formulation, the influence of anthropogenic and environmental factors on specific life history stages can be incorporated. Each productivity parameter can be influenced by independent covariates acting simultaneously on the life history stage to drive demographic rates.

The dynamic productivities used a logit transformation, which caused the productivities to remain between 0 and 1. This interval is the sample space for the survival for all stages from alevin to spawner.

$$\text{logit}(p_{j,t}) = \beta_{0,j} + \beta_{1,j}X_{1,t} + \beta_{2,j}X_{2,t} + \cdots + \beta_{5,j}X_{5,t}$$

The dynamic capacities used a natural log transformation, which caused the capacities to remain between 0 and infinity. This interval is the sample space for the abundance for all stages from alevin to spawner.

$$\ln(K_{j,t}) = \beta_{0,j} + \beta_{1,j}X_{1,t} + \beta_{2,j}X_{2,t} + \cdots + \beta_{5,j}X_{5,t}$$

The estimation of $p_{j,t}$ and $K_{j,t}$ involves estimating the b coefficients on the right hand sides of the equations. The $X_{1:5,t}$ are environmental covariates that represent water conditions such as temperature or flow, biotic factors such as predator abundance, food abundance, or anthropogenic factors such as water export levels or harvest rates. The model has the ability to estimate as few or as many of the parameters as desired, and covariates were used in the OBAN model based on their ability to explain historical patterns in winter-run escapement and juvenile abundance at Red Bluff Diversion Dam data.

F.6.2.1.1 Covariates

The following covariates were retained in the model and their coefficients were estimated:

- **STEMP:** July through September mean daily water temperature (degrees Fahrenheit) in the Sacramento River at Bend Bridge. This covariate affects survival of the egg to fry life history stage.
- **FLMIN:** August through November minimum monthly flow (cubic feet per second) in the Sacramento River at Bend Bridge (USGS Gauge 11377100 data). This covariate affects survival in the egg to fry life history stage.
- **EXPT:** Total water exports in the south Delta (CVP and SWP) during December through June, derived by taking average daily export rate (cubic feet per second), multiplying by the number of days in the month, and then summing over December-June (IEP Dayflow data). This covariate affects survival in the Delta life history stage.
- **YOLO:** Number of days during December through March with minimum flows of 100 cfs over the Fremont Weir, which is enough for positive flows onto the Yolo Bypass (December of the brood year and January – March of the year following) (Reclamation data). The 100 cfs minimum flow threshold was chosen to distinguish days with an actual inundation event from the rest of the days with year-round 100 cfs flows into the Bypass to maintain positive flows for adult fish passage under the via the preliminary proposal. Although this flow is much lower than the suggested flows needed for juveniles salmonids to gain survival benefits in the Yolo Bypass (~4,000 cfs, T. Sommer pers. comm.), the parameter used to fit the data is number of days of flooding, and not flow rate during flooding. This covariate affects survival in the Delta life history stage.

- **DCC:** Proportion of time that the Delta Cross Channel gates were open between December and March (December of the brood year and January – March of the year following) (US Bureau of Reclamation data). This covariate affects survival in the Delta life history stage.

- **UPW and FARA - ocean productivity indexes.** Nearshore ocean processes can have important consequences for Chinook salmon (Wells et al. 2007, Woodson et al. 2013), and here we use upwelling in a region south of the entrance to San Francisco Bay, *UPW* (Pacific Fisheries Environmental Laboratory (http://las.pfeg.noaa.gov/LAS/docs/upwell.nc.html) and the sea surface temperature in the Gulf of the Farallones, *FARA* (Gulf of Farallones sea surface temperature data – University of California San Diego (http://shorestation.ucsd.edu/active/indexactive.html#farallonstation)).

- **Harvest:** Ocean harvest of Ocean 2 and Ocean 3 individuals (Ocean 1 are assumed to be too small to be vulnerable to the fishery) is expressed as the proportion of the total Ocean 2 and Ocean 3 individuals available for harvest. The harvest rate index was constructed by using the California Department of Fish and Wildlife's ocean and recreational fishing regulations. Until 1987, there was little regulation of the Central Valley Chinook salmon fishery and estimates of the mortality rate on winter run Chinook salmon in the ocean fishery was approximately 0.7 of the mortality rate experienced by fall run Chinook salmon. The harvest rate of fall-run Chinook salmon is calculated annually as the Central Valley Index (CVI) by calculating the proportion of the fall-run that were captured in the fishery, relative to the number of fish that would have returned for spawning in the absence of fishing (i.e., harvested/(harvested + escaped)). In 1989, winter-run Chinook salmon were listed as threatened and the following year the ocean fishery regulations were shifted to open two weeks later (NMFS 1997). It was assumed that this had an effect on the winter-run Chinook salmon harvest mortality and reduced the impact to 0.5 of the CVI. In 1994, winter-run Chinook salmon were listed as endangered and, in 1997, a biological opinion was released by NMFS (1997) initiating a delayed opening of the ocean fishery from mid-March to mid-April and eventually to late April in 2001. Using coded wire tagged winter run from 1998 through 2000 cohorts, Grover et al. (2004) estimated ocean harvest rates of 0.22. The effect of the fishery is not the same for Ocean 2 and Ocean 3 stages, however. The rates described above were generated for the Ocean 2 stage. Ocean 2 and Ocean 3 fish are not captured at the same rate. Most winter-run Chinook salmon return to spawn as three-year olds (after the Ocean 2 phase); however, the Ocean 3 stages are more likely to be captured in the commercial fishery due to their larger size. Grover et al. (2004) found that the harvest related mortality of Ocean 3 winter-run Chinook was 2.5 to 3.7 times the rate of Ocean 2 aged fish. For OBAN, it is assumed that the harvest rates experienced by Ocean 3 stage winter-run Chinook salmon were 2.7 times the harvest rates experienced by Ocean 2 stage. In order to make sure that the harvest rate could not surpass 1, a logistic regression approach was used to incorporate the harvest rates.

  Harvest also occurs in the Sacramento River, and the best available published rates were used to characterize in-river harvest rates. Between 1967 and 1975, estimates of winter-run harvest in the recreational river fishery varied from 0.04 to 0.14 (Hallock and Fisher 1985). For OBAN, it was assumed that the in-river fishery harvest rates were 0.09 from

1975 to 1982, which was the average of the Hallock and Fisher (1985) estimates. NMFS (1997) published in-river harvest rates from 1983 to 1990 that varied between 0.013 and 0.087. For OBAN, it was assumed that the in-river harvest was constant at 0.05 from 1991 to 2007. The 0.05 river harvest rate was determined in combination with the 0.22 ocean harvest rate to equal the average harvest impact rate identified by Grover et al. (2004) for the 1998, 1999, and 2000 cohorts.

To conduct an effects analysis, the OBAN model requires that the physical covariates under each of the scenarios are standardized with the same values that were used in the OBAN calibration (Table F.6-1).

Table F.6-1. Measured physical freshwater covariates used in the calibration of the winter-run OBAN model (1967 – 2011). The mean and standard deviations are used to standardize the physical covariates in the effects analysis of alternative scenarios.

Covariate	Mean	Standard Deviation	Life Stage
STEMP (F)	56.23	1.66	Egg to fry
FLMIN (cfs)	6604	1477	Egg to fry
EXPT (cfs)	1.250×10^6	3.209×10^5	Delta
YOLO (days)	22.88	24.74	Delta
DCC	0.46	0.42	Delta

F.6.2.2 OBAN Effects Analysis: Incorporating Uncertainty and Assumptions

The OBAN effects analysis incorporates uncertainty in the predicted response of winter-run Chinook salmon to each of the hydrology and temperature covariates defined for each component. The estimation phase of the OBAN model generates samples from the posterior distribution of parameters that relate physical covariates to survival rates. Monte Carlo simulation is used to run the OBAN effects analysis phase for each of the 1000 samples to incorporate parameter uncertainty. In addition, variability in the population response to freshwater conditions are included by drawing 1000 samples from ocean productivity indices (described below). Finally, the OBAN model parameters were obtained from fitting to historical data. If the range of the physical drivers in the components is outside of this historical range, then the OBAN model will extrapolate the production of eggs and survival rates outside of this historical range using the equations described above.

To simulate winter-run Chinook salmon population dynamics under each of the components, covariate data were required for each component. These covariates were produced for each component by using hydrological (CalSim) and water quality models (SRWQRM). For EXPT, we used “C_DMC003”, “C_CAA003_SWP”, and “C_CAA003_CVP” nodes which are Jones Exports, Banks Export_SWP, and Banks Exports_CVP, respectively. For YOLO, we used daily Yolo Bypass flow consisting of “FRESPILL_xDV” nodes (with x being the number of day). We also provided HEC5Q outputs for TEMP and FLMIN. In addition, DCC position does not differ between components during the period of winter-run presence in the Delta, as it was assumed to be closed during winter-run presence. All covariates were normalized by subtracting the mean and dividing by the standard deviation of empirical data that were used in the estimation of the

OBAN model coefficients (values for standardization of freshwater covariates provided in Table F.6-1).

The OBAN model was modified to be able to run for the full CalSim 3 period of hydrologic outputs (1921 – 2023) by making two modifications to the 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 (Hendrix et al. 2014). The second modification was the need to create ocean productivity indices for the 1000 simulations of 98 years (1923 - 2020) by resampling the empirical data to create a single matrix of values for the *UPW* and a single matrix for the *FARA* productivity indices.

F.6.2.2.1 Model Inference and Performance Metrics

It is important to clarify how the modeling results can be used to inform decision-making for any model that seeks to assess the effects of management actions on fish (Rose et al. 2015). The OBAN model was developed as a decision support tool for use in scenario analysis, which is a useful approach for evaluating alternative management scenarios under uncertainty (Fuller et al. 2008). The model results are not accurate predictions of absolute abundance, but instead are predictions of directions of change in the populations. Furthermore, the modeling results are most robust when used in a comparative fashion for scenario analysis (Fuller et al. 2008), generally being compared to a baseline scenario. Because each iteration of the 1000 Monte Carlo simulation uses the same set of parameter values or "state of nature", the OBAN effects analysis generates the performance of each component across each state of nature. Performance metrics are calculated as the relative increase or decrease compared to the baseline for each state of nature. There are 1,000 values of the relative performance metrics that are summarized using point estimates (e.g., median) and ranges (e.g., 80% confidence interval) of the metrics.

- **Spawner abundance:** The spawner abundance and the difference in spawner abundance for each year and each iteration of the Monte Carlo simulation between component and the baseline (NAA). The median difference and 80% intervals were calculated across Monte Carlo iterations for each year.
- **Probability of quasi-extinction:** The proportion of 1000 Monte Carlo simulations in which the annual abundance is below a quasi-extinction threshold of 100 spawners. The difference in the probability of quasi-extinction is the difference in annual probability of quasi-extinction for the component and the baseline (NAA).
- **Egg to fry survival:** The egg to fry survival and the difference in egg to fry survival for each year and each iteration of the Monte Carlo simulation between component and the baseline (NAA). The median difference and 80% intervals were calculated across Monte Carlo iterations for each year.
- **Delta survival:** The delta survival and the difference in delta survival for each year and each iteration of the Monte Carlo simulation between component and the baseline (NAA). The median difference and 80% intervals were calculated across Monte Carlo iterations for each year.

F.6.2.3 Code and Data Repository

Input and output files are available upon request.

Code for the OBAN model has not been made publicly available.

F.6.3 Results

The mean values for the physical freshwater covariates in the alternatives indicated the following general patterns. Temperatures (STEMP) during the egg to fry survival stage ranged from 56.99F (Alternative 2 without TUCP without VA and Alternative 2 without TUCP All VA) to 57.23F (the No Action Alternative), and minimum flows at Bend Bridge ranged from 5469 cfs (the No Action Alternative) to 5607 (Alternative 2 With TUCP Without VA). Exports during the Delta survival stage ranged from 1.247×10^6 (Alternative 2 Without TUCP All VA) to 1.315×10^6 (Alternative 2 With TUCP Without VA), and Yolo access ranged from 60.59 days (Alternative 2 Without TUCP Delta VA) to 73.34 days (Alternative 2 Without TUCP All VA) (Table F.6-2).

It is also useful to evaluate the levels of the covariates under the alternatives relative to the historical values (e.g., Table F.6-1), which were used to calibrate the OBAN model. Under all of the alternatives, temperatures at Bend Bridge during spawning were higher, whereas the minimum flows at Bend Bridge were lower relative to the historical values. Exports were higher than the historical values in the NAA and Alternative 2 Without TUCP Without VA and Alternative 2 With TUCP Without VA whereas they were approximately equal to historical in the Alternative 2 Without TUCP Delta VA and Alternative 2 Without TUCP All VA.

Table F.6-2. Mean values for physical freshwater covariates.

Component	STEMP (F)	FLMIN (cfs)	EXPT (cfs)	YOLO (days)
NAA	57.23	5469	1.275×10^6	60.64
EXP1	70.11	2775	0	74.84
EXP3	58.01	4256	0	71.35
Alternative 2 Without TUCP Without VA	56.99	5574	1.312×10^6	60.84
Alternative 2 With TUCP Without VA	56.79	5607	1.315×10^6	60.81
Alternative 2 Without TUCP Delta VA	57.00	5569	1.249×10^6	60.59
Alternative 2 Without TUCP All VA	56.99	5557	1.247×10^6	73.34

F.6.3.1 Spawner Abundance

Median abundance dropped from an initial value of 10,000 in all components, and by year 15 of the 98-year model run all components had a median abundance of less than 1 fish (Figure F.6-1). The pattern in modeled abundances was similar for all components through the modeled time-series: after the initial crash, abundances were increasing over the 1940 – 1980 period, decreasing in the late 1990’s, increasing through the 2000’s, and decreasing at the end of the modeled time series (Figure F.6-1). After the first 15 years, component abundances ranked from lowest to highest were: NAA, Alternative 2 Without TUCP Without VA, Alternative 2 Without TUCP Delta VA, Alternative 2 Without TUCP All VA, Alternative 2 With TUCP Without VA (Figure F.6-1).

Differences in median abundance relative to the baseline NAA were greatest in the first 10 years of the time series and averaged from 47.5 (Alternative 2 With TUCP Without VA) to 55.9 (Alternative 2 Without TUCP Delta VA) (Figure F.6-2). Median differences between the components and the NAA for the following years of the timeseries were small, and they averaged from 0.60 (Alternative 2 Without TUCP Without VA) to 0.91 (Alternative 2 Without TUCP All VA). Uncertainty in the relative abundance of the components to the baseline indicated that the components were consistently higher than the NAA (i.e., 80% intervals did not include zero). The magnitude of the upper bound on the differences (90% quantile), did vary among components, however; the average ranged from 9.68 (Alternative 2 Without TUCP Without VA) to 30.6 (Alternative 2 Without TUCP All VA) over the period 1934 – 2020 (Figure F.6-3).

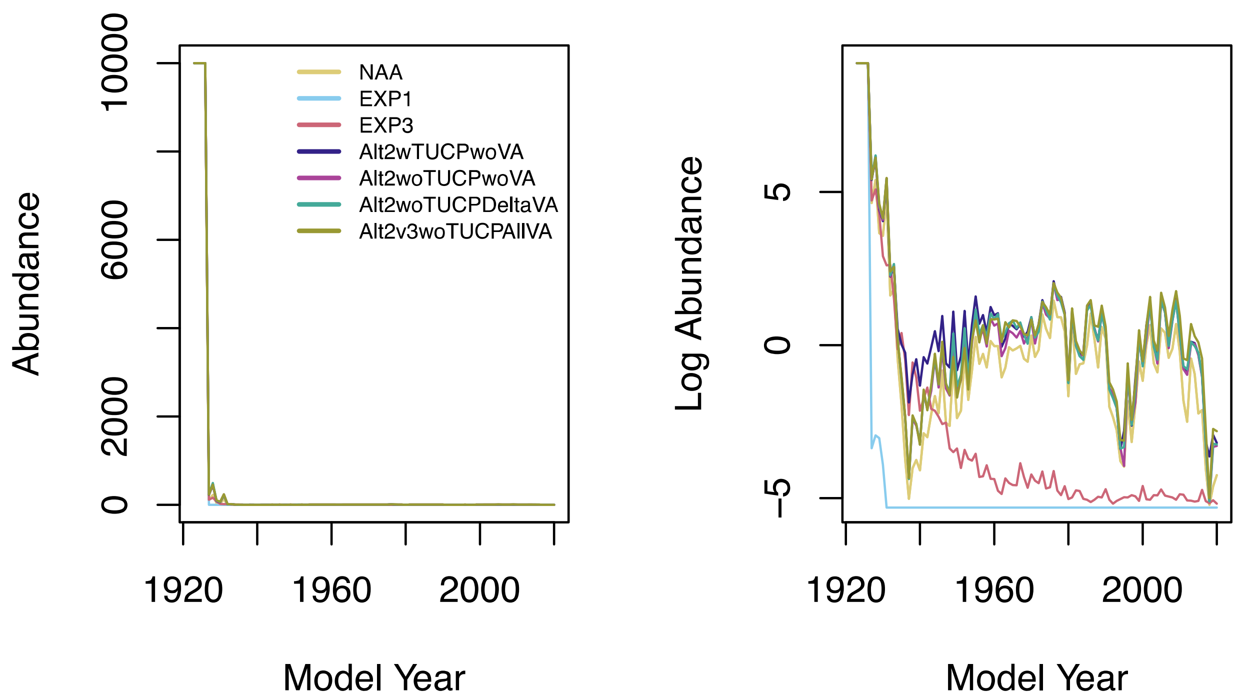

Figure F.6-1. Median spawner abundance (left) and log abundance (right) for model years 1923 - 2022.

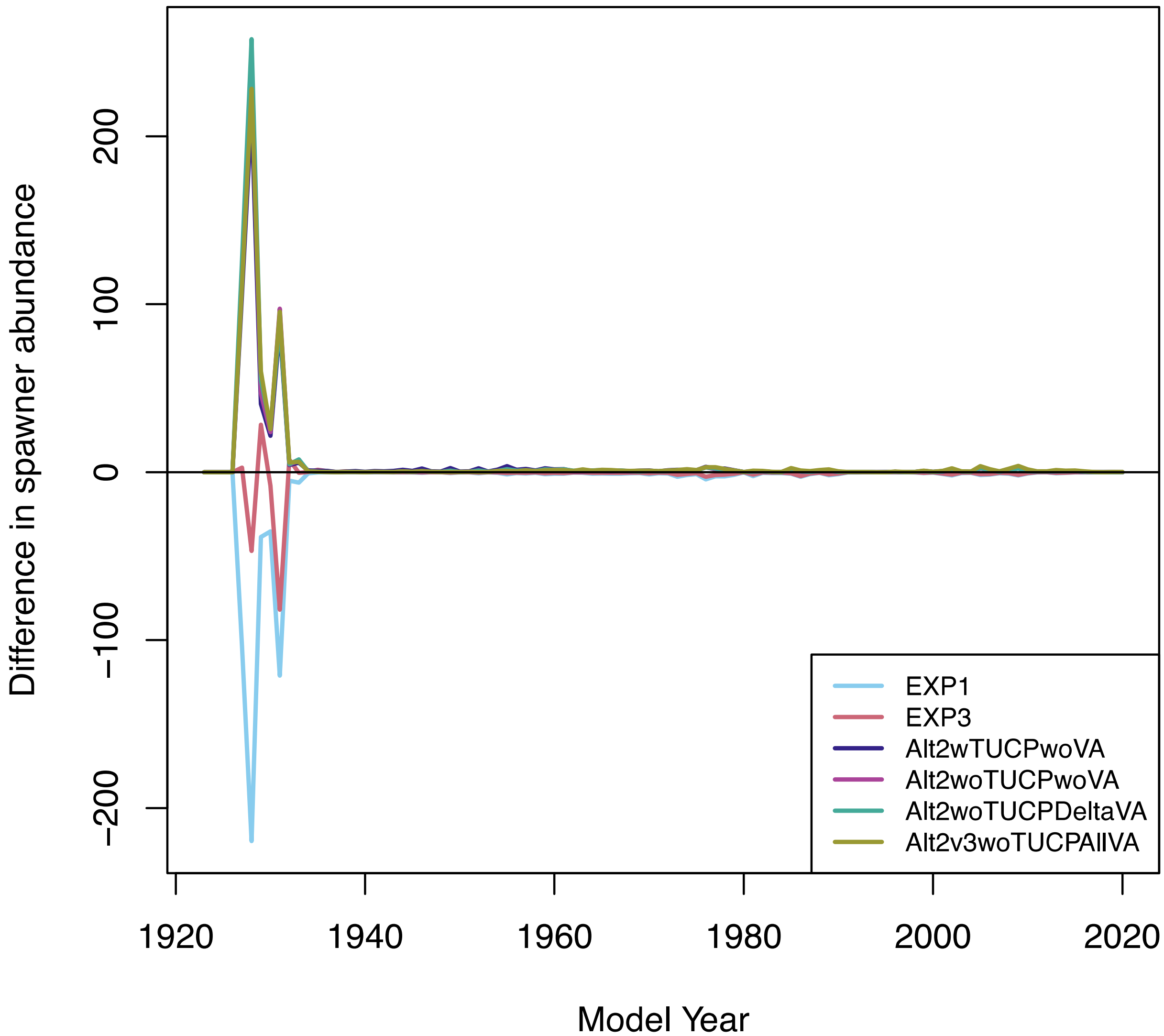

Figure F.6-2. Median difference (Component – NAA) in spawner abundance for model years 1923 - 2020. Positive values indicate higher abundances under components relative to the baseline (NAA).

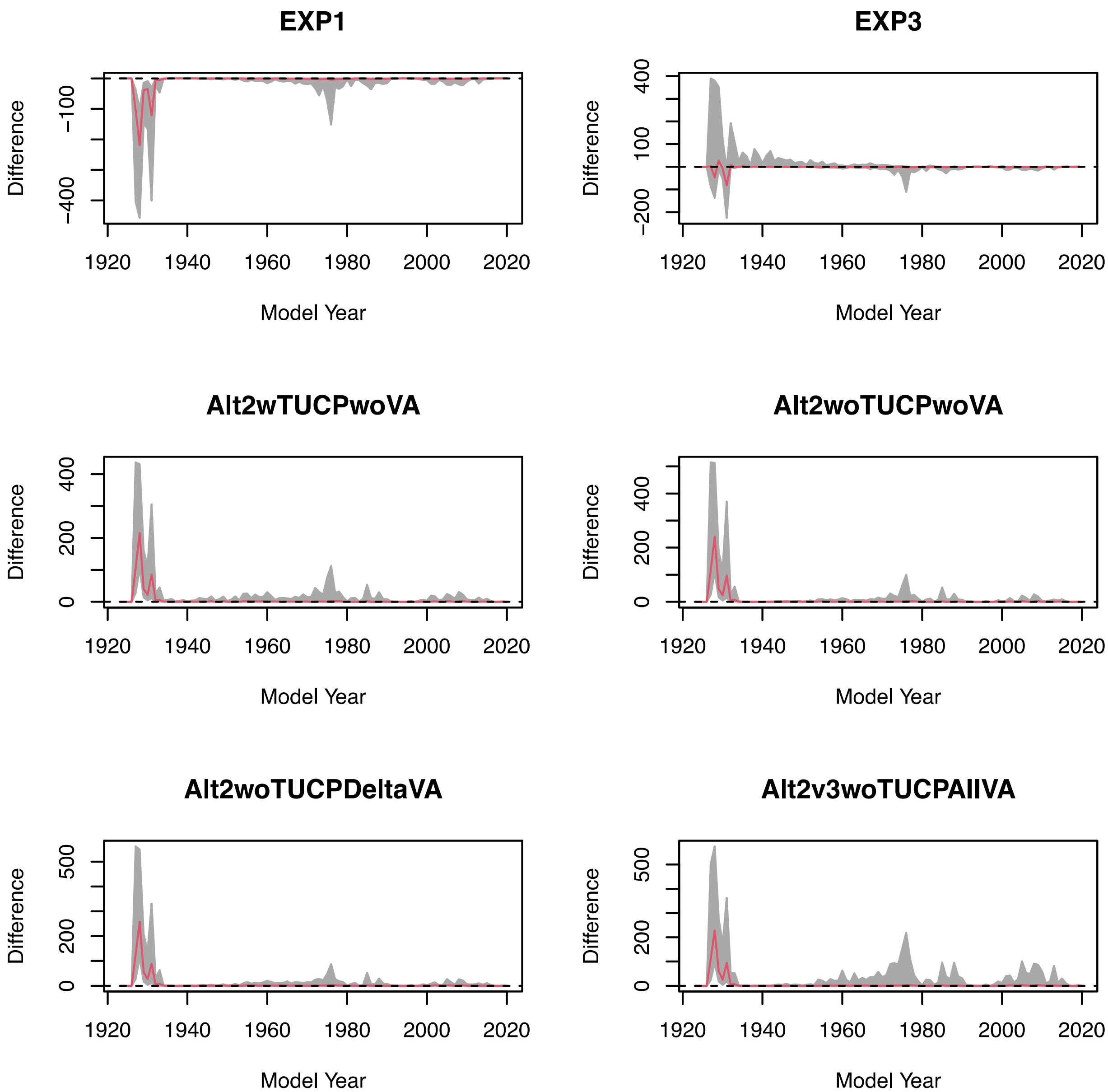

Figure F.6-3. Uncertainty in the difference in spawner abundance for model years 1923 – 2022. Positive values indicate higher abundances under components relative to the baseline (NAA). Median (red line) and 80% intervals (gray) across 1000 states of nature (Monte Carlo simulations) are presented. Please note difference in scale among the figures.

F.6.3.2 Probability of quasi-extinction

The probability of quasi-extinction was high (>0.9) for all components, and the average probability of quasi-extinction was > 0.95 across all components after year 10 of the time series (Figure F.6-4). The components were ranked from lowest to highest probability of quasi-extinction as: Alternative 2 Without TUCP All VA, Alternative 2 With TUCP Without VA, Alternative 2 Without TUCP Delta VA, Alternative 2 Without TUCP Without VA, and NAA (Figure F.6-4).

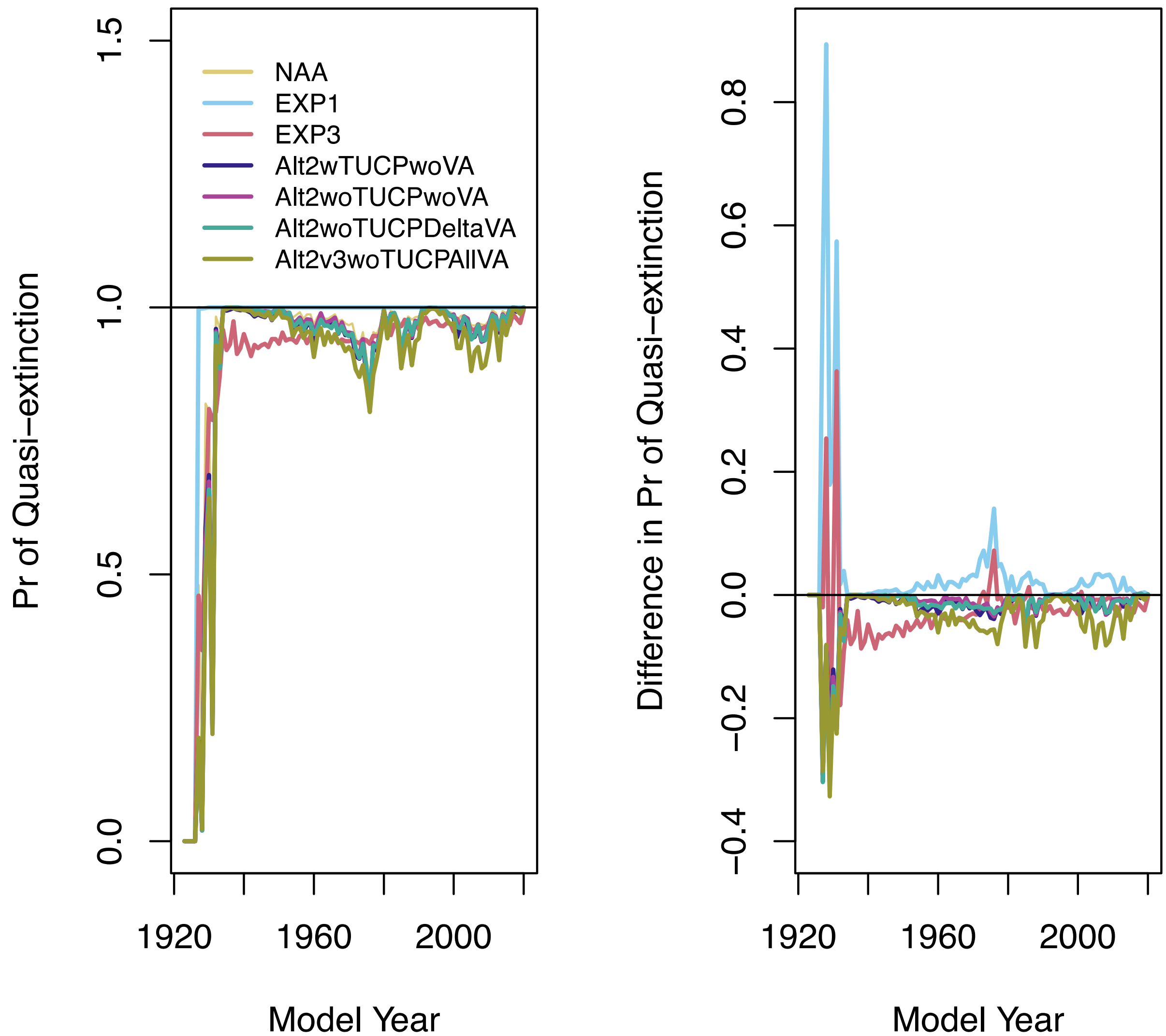

Figure F.6-4. Probability of quasi-extinction, which is defined as spawner abundance < 100 (left). Difference in the probability of quasi-extinction (right); negative values indicate lower probability of quasi-extinction under the components relative to the baseline (NAA).

F.6.3.3 Egg to fry survival

Annual patterns in median egg to fry survival were similar across the components (Figure F.6-5). When averaged over the time series, median egg to fry survival ranged from 0.137 (NAA) to 0.165 (Alternative 2 With TUCP Without VA). The components were ordered from lowest to highest median egg to fry survival as: NAA, Alternative 2 Without TUCP All VA, Alternative 2 Without TUCP Delta VA, Alternative 2 Without TUCP Without VA, Alternative 2 With TUCP Without VA (Figure F.6-5).

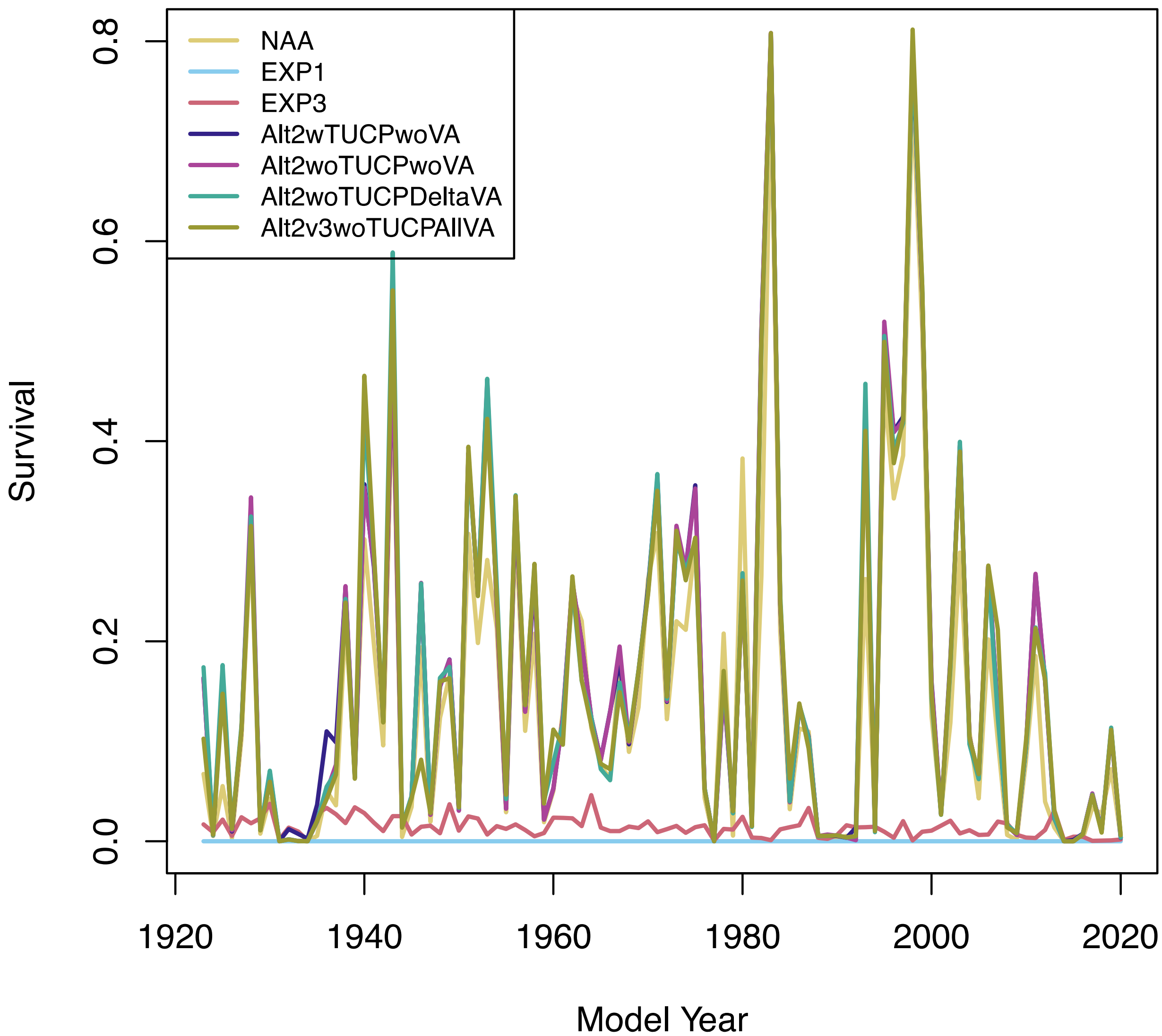

Figure F.6-5. Median survival of the egg to fry stage which includes thermal mortality and Bend Bridge flow effects.

Patterns in egg to fry survival across water year types were similar with the highest survivals occurring in Wet and Above Normal years compared to other water year types (Figure F.6-6). Wet year average egg to fry survivals ranged from 0.267 (NAA) to 0.312 (Alternative 2 Without TUCP Without VA), whereas Above Normal year survivals ranged from to 0.254 (NAA) to 0.306 (Alternative 2 Without TUCP Delta VA). Survival ranged from 0.067 (NAA) to 0.104 (Alternative 2 With TUCP Without VA) in Below Normal years, from 0.055 (NAA) to 0.068 (Alternative 2 Without TUCP Delta VA) in Dry years, and 0.006 (NAA) to 0.009 (Alternative 2 With TUCP Without VA) in Critical years (Figure F.6-6).

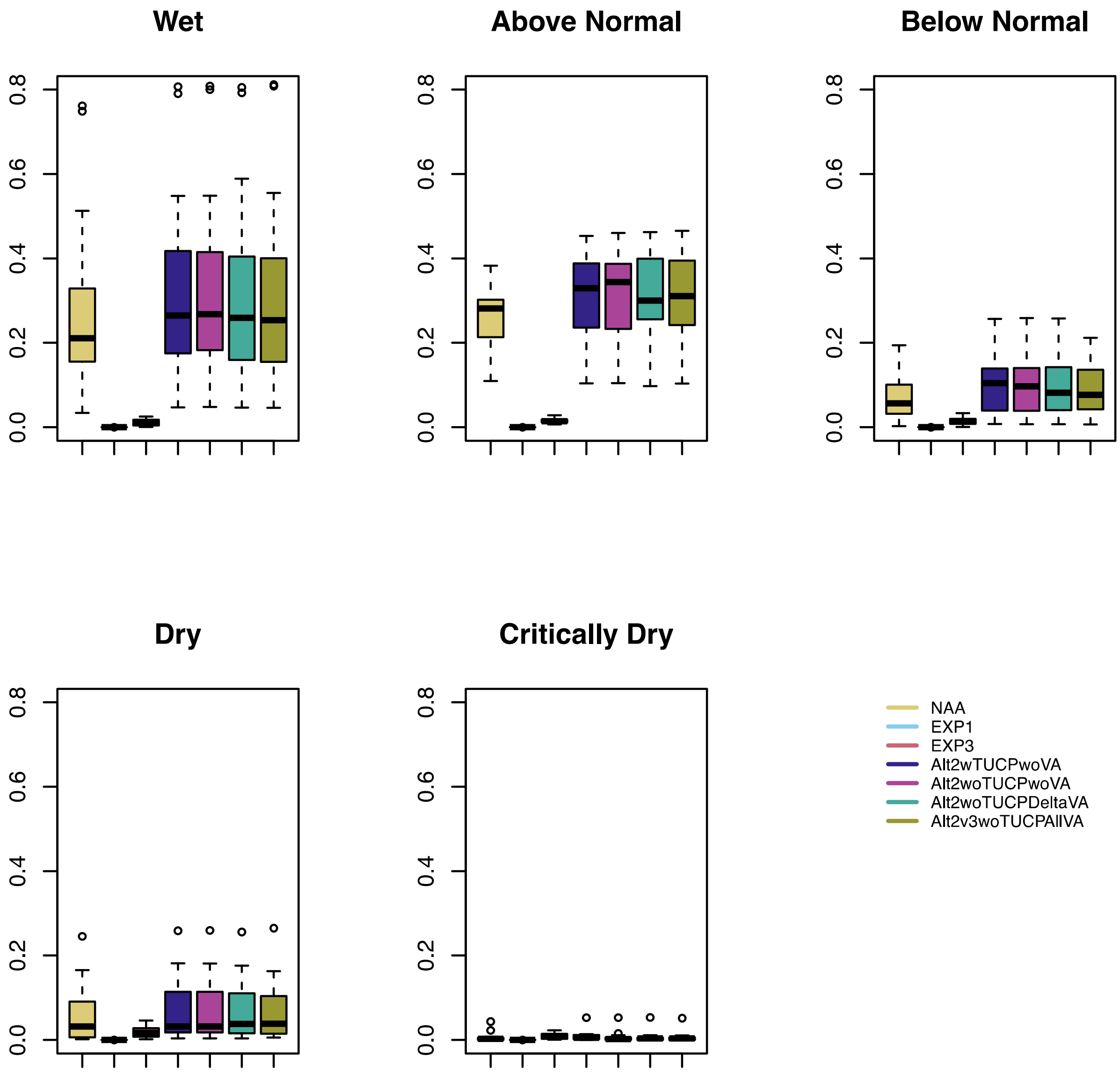

Figure F.6-6. Median survival in the egg to fry stage categorized by water year type.

When compared to the NAA, the median egg to fry survival of Alternative 2 components varied over the modeled time series (Figure F.6-7). Median differences between the Alternative 2 components and NAA were all positive and ranged from 0.023 (Alternative 2 Without TUCP All VA) to 0.0266 (Alternative 2 With TUCP Without VA) when averaged over the timeseries. The median differences were ranked from the smallest difference to the largest difference from the NAA as: Alternative 2 Without TUCP All VA, Alternative 2 Without TUCP Delta VA, Alternative 2 Without TUCP Without VA, Alternative 2 With TUCP Without VA.

Uncertainty in the egg to fry survival difference between NAA and Alternative 2 components was variable among components (Figure F.6-8). The number of years in which the 80% intervals were below zero indicates when the Alternative 2 component survival was consistently less than the NAA. The number of years in which the 80% intervals were below zero ranged from 12 (Alternative 2 With TUCP Without VA) to 17 (Alternative 2 without TUCP All VA) (Figure F.6-8).

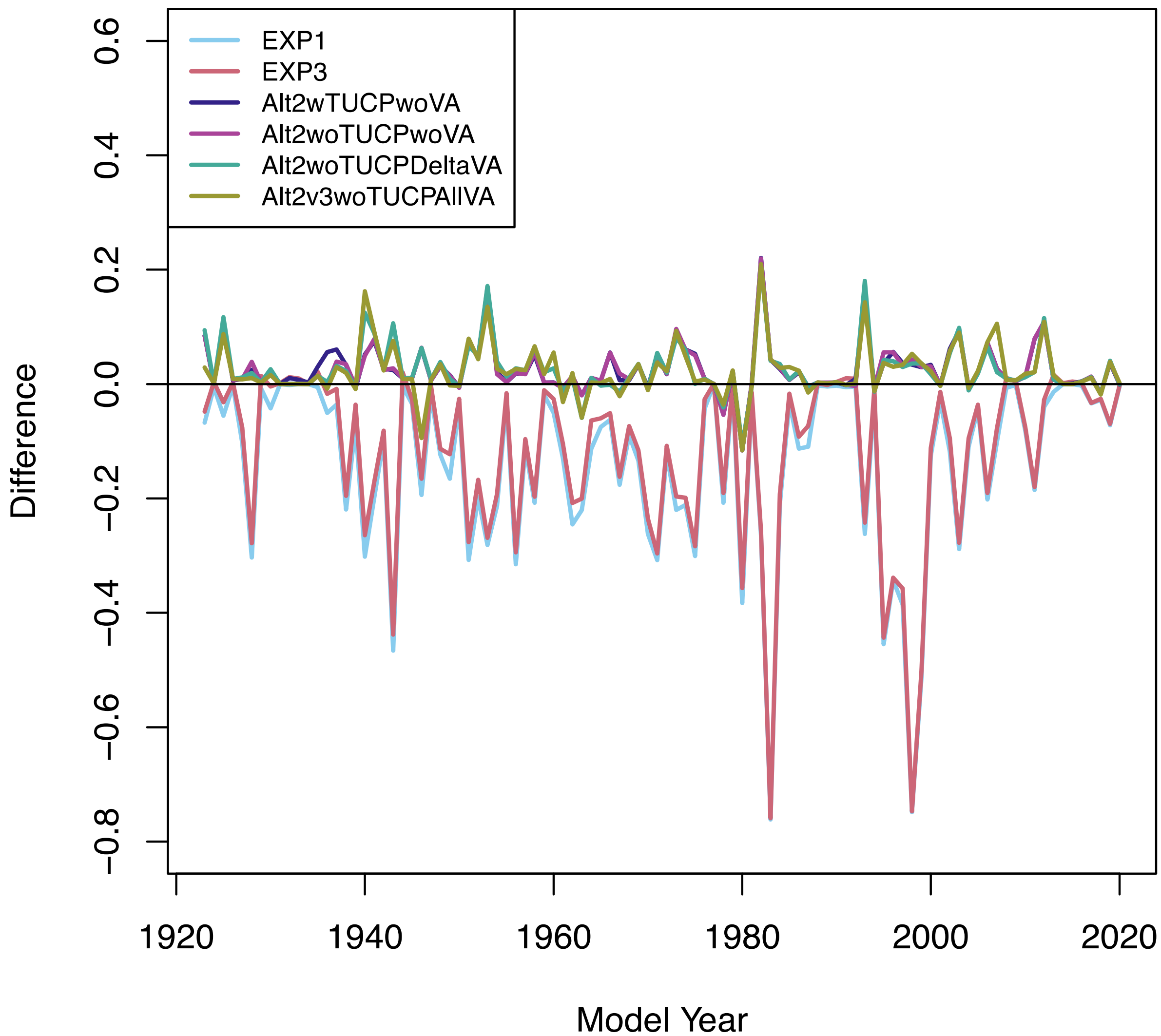

Figure F.6-7. Median difference between components and the NAA in survival of the egg to fry stage.

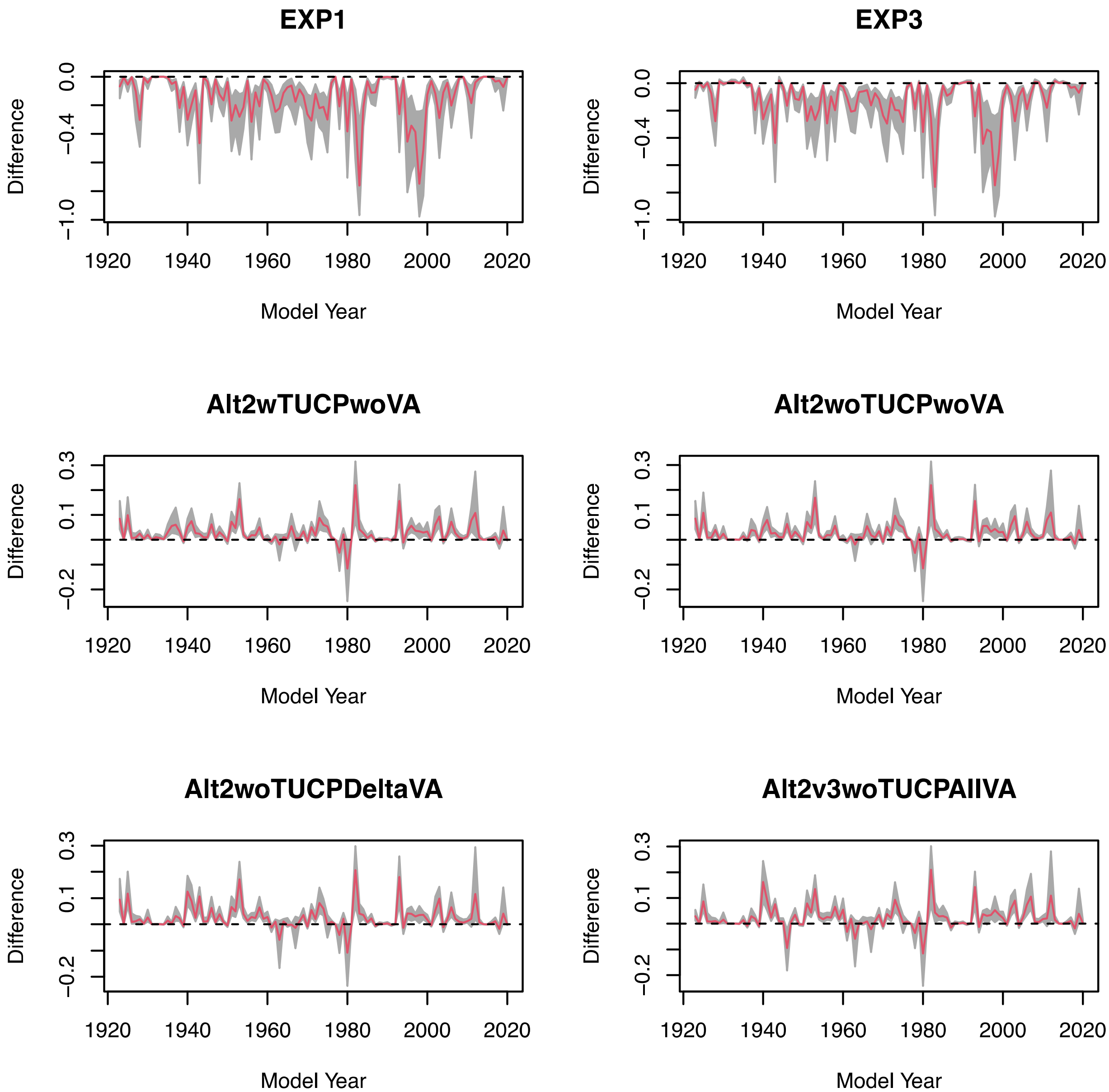

Figure F.6-8. Uncertainty in the difference between components and NAA in egg to fry survival. Positive values indicate higher survival under components relative to the baseline (NAA). Median (red line) and 80% intervals (gray) across 1000 states of nature (Monte Carlo simulations) are presented.

F.6.3.4 Delta survival

Annual patterns in median delta survival were similar across the NAA and Alternative 2 components (Figure F.6-9). When averaged over the time series, median delta survival ranged from 8.67 x 10^{-3} (Alternative 2 with TUCP Without VA) to 8.86 x 10^{-3} (Alternative 2 Without TUCP All VA). The components were ordered from lowest to highest median delta survival as: Alternative 2 With TUCP Without VA, Alternative 2 Without TUCP Without VA, NAA, Alternative 2 Without TUCP Delta VA, Alternative 2 Without TUCP All VA (Figure F.6-9).

Delta survivals were similar across water year types, but increased slightly from Wet year types to Critically Dry (Figure F.6-10). Patterns within water year types were similar across components, with the exception of reduced variation in Below Normal water years (Figure F.6-10). Wet year average delta survivals ranged from 8.59 x 10^{-3} (Alternative 2 With TUCP Without VA) to 8.80 x 10^{-3} (Alternative 2 Without TUCP All VA and Alternative 2 Without TUCP Delta VA); Above Normal year survivals ranged from 8.41 x 10^{-3} (Alternative 2 With TUCP Without VA) to 8.61 x 10^{-3} (Alternative 2 Without TUCP All VA); Below Normal year survivals ranged from 8.71 x 10^{-3} (Alternative 2 With TUCP Without VA) to 8.89 x 10^{-3} (Alternative 2 Without TUCP All VA); Dry year survivals ranged from 8.75 x 10^{-3} (Alternative 2 With TUCP Without VA) to 8.95 x 10^{-3} (Alternative 2 Without TUCP Delta VA); and Critically Dry year survivals ranged from 8.87 x 10^{-3} (Alternative 2 With TUCP Without VA) to 9.04 x 10^{-3} (Alternative 2 Without TUCP All VA). The rankings from lowest to highest median delta survival was consistent across water year types (except Dry) and were: Alternative 2 With TUCP Without VA, Alternative 2 Without TUCP Without VA, NAA, Alternative 2 Without TUCP Delta VA, Alternative 2 Without TUCP All VA. In the Dry water year type, the highest median survival was Alternative 2 Without TUCP Delta VA and the next highest was Alternative 2 Without TUCP Delta VA.

When compared to the NAA, annual patterns in delta survival under the components of Alternative 2 varied (Figure F.6-7). There were two general patterns relative to the NAA: Alternative 2 With TUCP Without VA and Alternative 2 Without TUCP Without VA both had negative median differences (i.e., less than the NAA), whereas Alternative 2 Without TUCP Delta VA and Alternative 2 Without TUCP All VA had positive median differences (i.e., greater than the NAA). Averaged across the time series, differences ranged from -6.33 x 10^{-5} (Alternative 2 Without TUCP Without VA) to 7.69 x 10^{-5} (Alternative 2 Without TUCP All VA) and were ranked from the lowest survival relative to the NAA to the highest survival relative to the NAA as: Alternative 2 With TUCP Without VA, Alternative 2 Without TUCP Without VA, Alternative 2 Without TUCP Delta VA, Alternative 2 Without TUCP All VA. Finally, the patterns in variation for differences between components of Alternative 2 and the NAA all included zero in all 98 years of the modeled timeseries (Figure F.6-12), indicating that there was no difference between the NAA delta survival and the four components of Alternative 2 when incorporating uncertainty in the states of nature (Figure F.6-12).

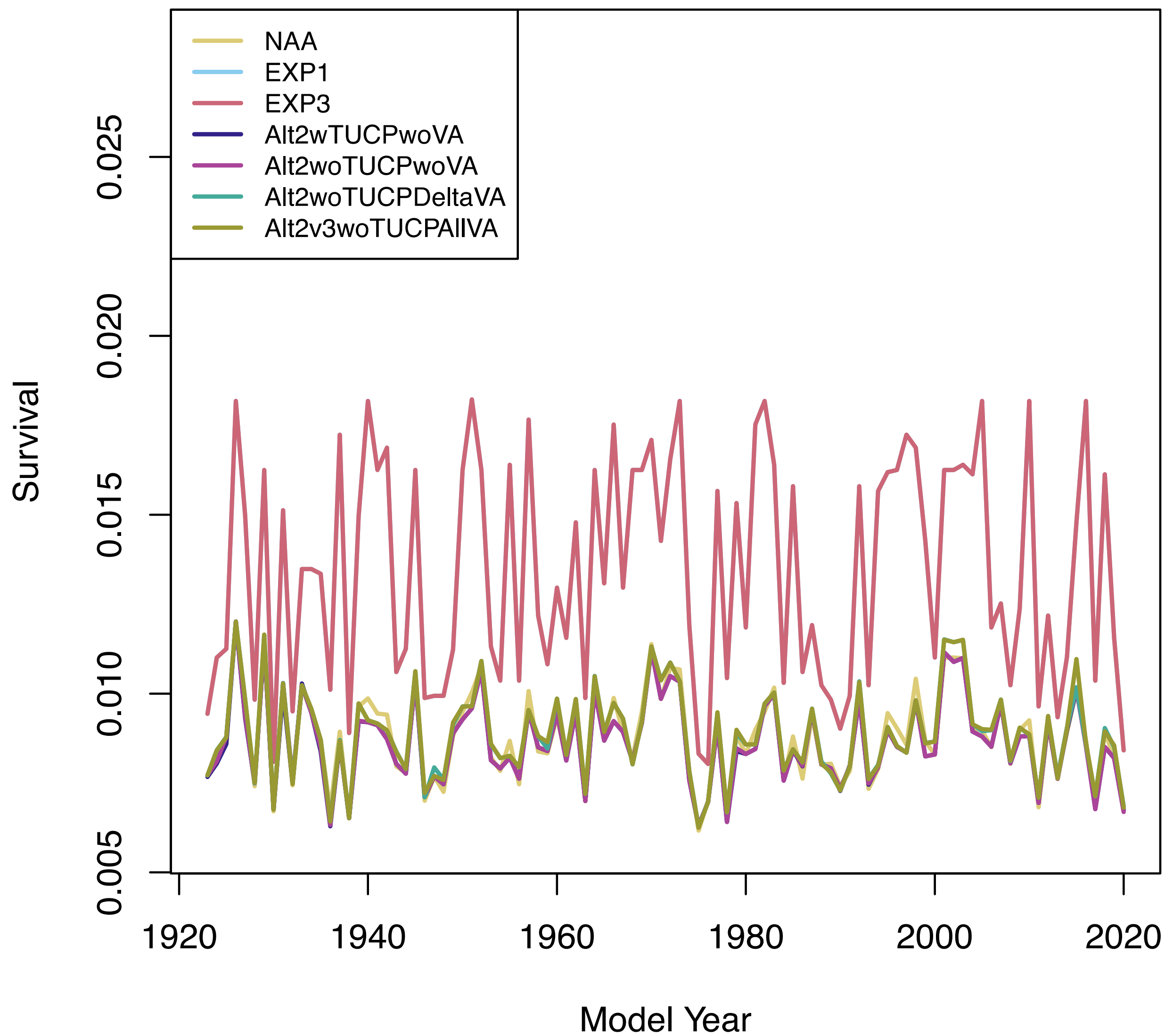

Figure F.6-9. Median survival in the Delta stage which includes Exports and access to Yolo bypass.

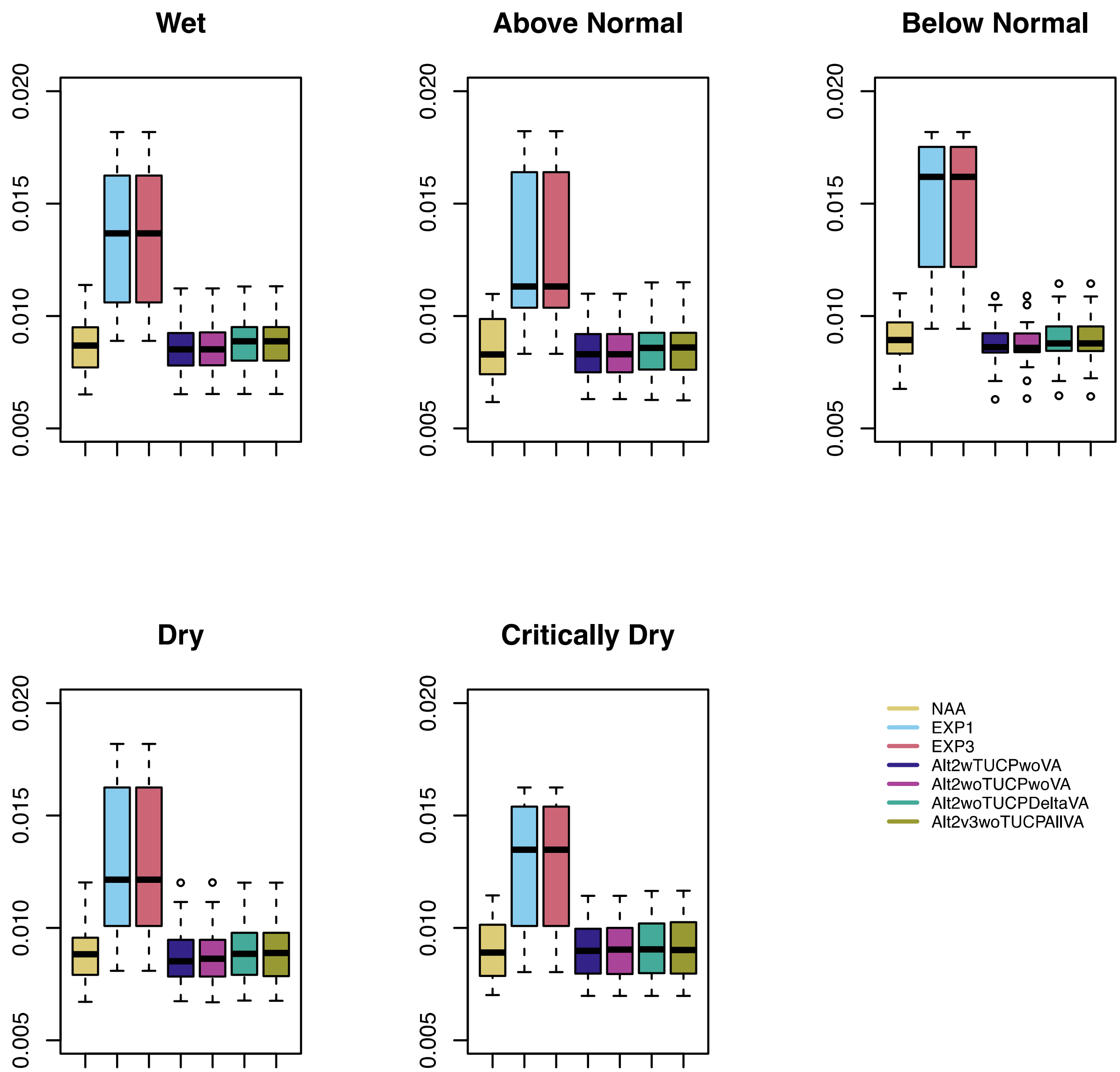

Figure F.6-10. Median survival in the delta stage categorized by water year type.

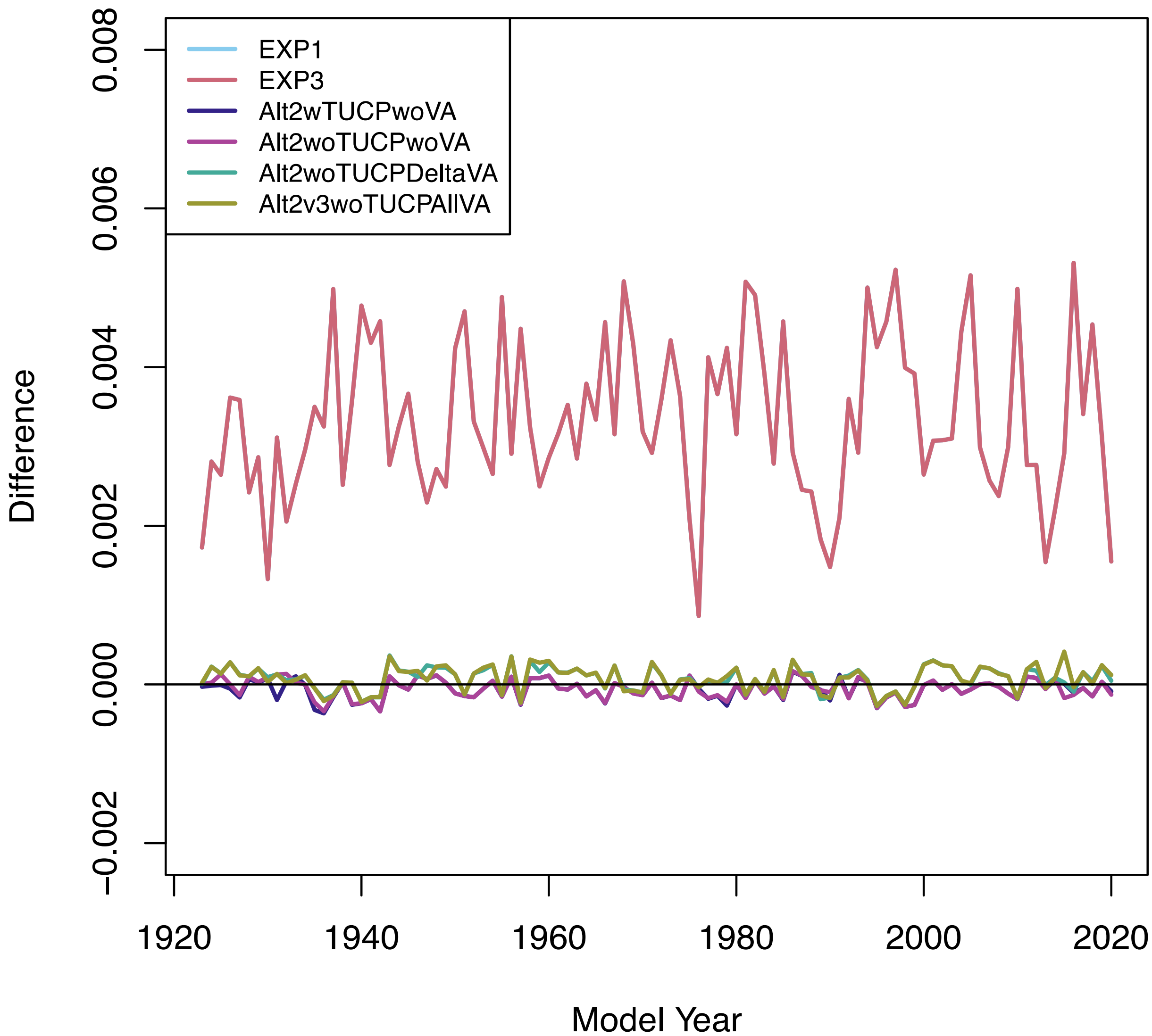

Figure F.6-11. Median difference in survival of the delta stage. Note that EXP1 follows the same trend as EXP3 and is hidden by that line.

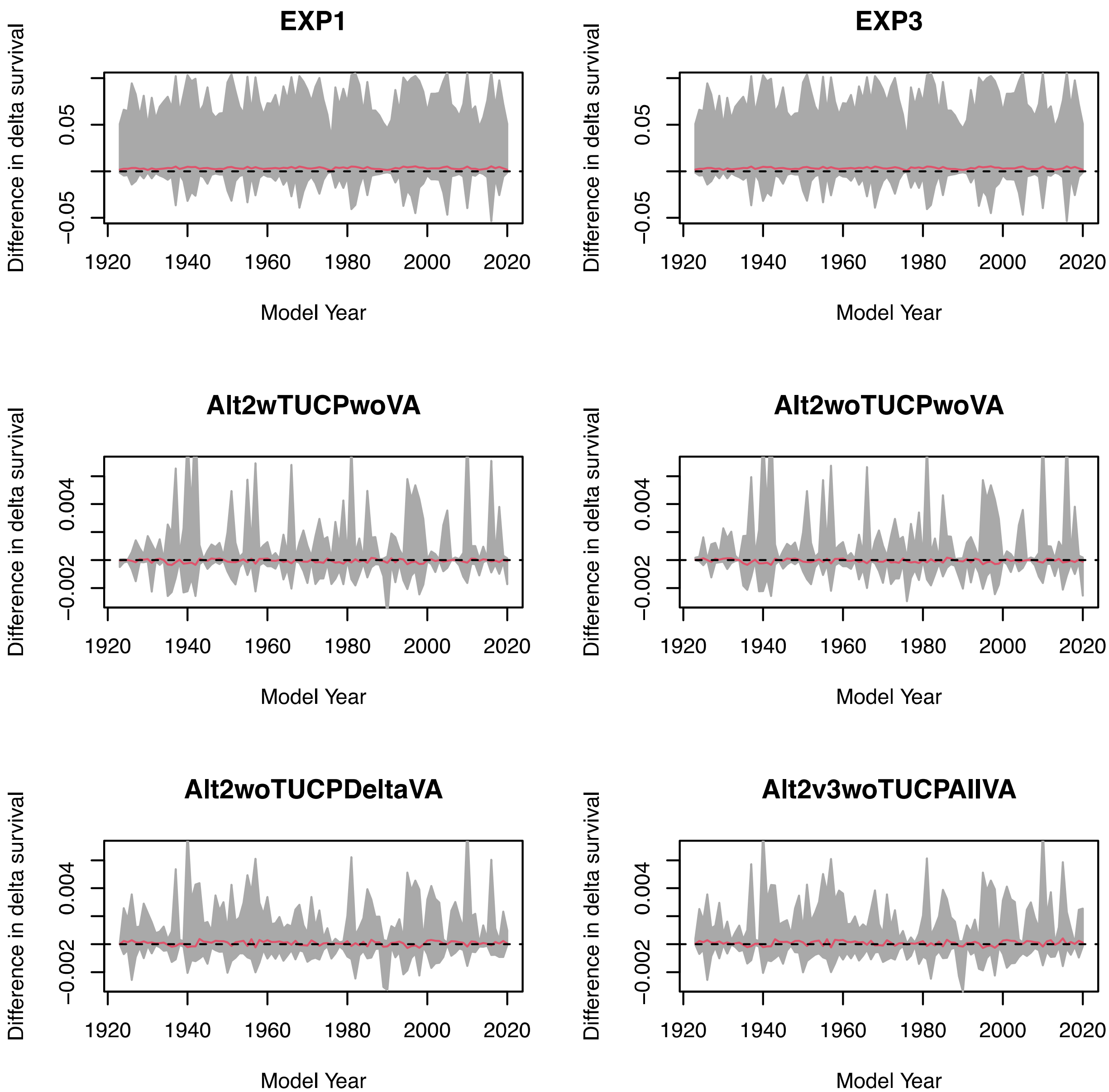

Figure F.6-12. Uncertainty in the difference between components and NAA in delta survival. Positive values indicate higher survival under components relative to the baseline (NAA). Median (red line) and 80% intervals (gray) across 1000 states of nature (Monte Carlo simulations) are presented. Please note the difference in scale in the top two figures (EXP1 and EXP3).

F.6.4 Summary

Under all Alternative 2 components and the NAA, median abundances dropped to below the quasi-extinction threshold within 10 years and to a value of less than 1.0 within 14 years. Median abundance was less than 9.0 for the remainder of the time series across all Alternative 2 components and the NAA. The pattern in abundance across components was due to low levels of egg to fry survival and delta survival throughout the model. In all components the median egg to fry survival was less than the median historical estimated egg to fry survival (median = 0.212, 95% Credible Interval (0.083, 0.501)) and the median delta survival (median = 1.23×10^{-2}, 95% Credible Interval 5.60×10^{-3}, 3.39×10^{-2})) . The historical estimated survival rates were estimated from escapements in 1967 – 2011, which was a period of winter-run Chinook population decline. Thus, median survival rates that are below the historical values would result in modeled abundance declines over the 98-year time series. Furthermore, during the early portion of the modeled time series, the hydrology included four critical dry years in succession (1931 – 1934). Median egg to fry survival under all components was less than 0.01 in these years (Figure F.6-6) causing sharp declines in the modeled populations in all components (Figure F.6-1).

The relative abundance levels for each of the Alternative 2 components and the NAA indicated that Alternative 2 With TUCP Without VA had higher median abundance than the other Alternative 2 components and the NAA after year 10 of the modeled timeseries. Still, all Alternative 2 components had higher median abundance relative to the NAA, and all Alternative 2 components were consistently greater than the NAA (i.e., had 80% intervals that were greater than the NAA for all modeled years after year 10).

The performance of the component Alternative 2 With TUCP Without VA was due to survival of juvenile winter-run in the egg to fry stage that was higher, but similar to the other Alternative 2 components (Figure F.6-4). Further, the egg to fry survival was generally the highest among the components during the Below Normal, Dry, and Critically Dry water year types (Figure F.6-6). The egg to fry survival is a function of temperatures and minimum flows at Bend Bridge. The temperatures were similar among all Alternative 2 components, but slightly lower under Alternative 2 With TUCP Without VA. The flows were also similar under all Alternative 2 components, but they were higher under Alternative 2 With TUCP Without VA (Table F.6-2). The lower temperatures and higher Bend Bridge minimum flows lead to similar but slightly higher survival in the Alternative 2 With TUCP Without VA relative to the other Alternative 2 components (Table F.6-2).

The survival in the delta stage was the highest under PA Without TUCP All VA relative to the other Alternative 2 components and the NAA, which improved the performance over the other components (Figure F.6-9, Figure F.6-11). The Alternative 2 Without TUCP All VA component had lower exports and higher days of flooding in the Yolo bypass (Table F.6-2), both of which increased the delta survival relative to the baseline and other Alternative 2 components. Variability among components in the delta survival had less of an effect on abundance than the egg to fry survival, however.

F.6.5 References

Fuller, M.M., Gross, L.J., Duke-Sylvester, S.M. and Palmer, M., 2008. Testing the robustness of management decisions to uncertainty: Everglades restoration scenarios. *Ecological Applications*, 18(3): 711-723.

Grover, A., A. Lowe, P. Ward, J. Smith, M. Mohr, D. Viele, and C. Tracy. 2004. *Recommendations for developing fishery management plan conservation objectives for Sacramento River winter Chinook and Sacramento River spring Chinook.* Interagency Workgroup Progress Report. February 2004.

Hallock, R. J., & F.W. Fisher. 1985. *Status of winter-run chinook salmon,* Oncorhynchus tshawytscha*, in the Sacramento River.* State of California, Department of Fish and Game, Anadromous Fisheries Branch.

Hendrix, N., Criss, A., Danner, E., Greene, C.M., Imaki, H., Pike, A., and Lindley, S.T. 2014. *Life cycle modeling framework for Sacramento River Winter run Chinook salmon*, NOAA Technical Memorandum 530, National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, Ca.

NMFS. 1997. *Proposed Recovery Plan for the Sacramento River Winter-Run Chinook Salmon.* Long Beach, CA: National Marine Fisheries Service, Southwest Region.

Rose, K.A., Sable, S., DeAngelis, D.L., Yurek, S., Trexler, J.C., Graf, W. and Reed, D.J., 2015. Proposed best modeling practices for assessing the effects of ecosystem restoration on fish. *Ecological Modelling*, 300:12-29.

Wells, B. K., Grimes, C. B. and Waldvogel, J. B. 2007. Quantifying the effects of wind, up-welling, curl, sea surface temperature and sea level height on growth and maturation of a California Chinook salmon (*Oncorhynchus tshawytscha*) population. *Fisheries Oceanography* 16(4): 363–382.

Woodson, L. E., Wells, B. K., Weber, P. K., MacFarlane, R. B., Whitman, G. E. and Johnson, R. C. 2013.Size, growth and origin-dependent mortality of juvenile Chinook salmon *Oncorhynchus tshawytscha* during early ocean residence. *Marine Ecology Progress Series* 487: 163–175.