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Technical Memorandum

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From: Noble Hendrix, QEDA Consulting
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Subject: Results of OBAN analysis of Sites Alternatives FEIR/S

Executive Summary

This technical memorandum describes results from running the winter-run Oncorhynchus Bayesian Analysis (OBAN) model for a baseline No Action Alternative (NAA) and four alternatives (Alt1A, Alt1B, Alt2, and Alt3) to evaluate the Sites project. The NAA and each alternative were defined by environmental driver variables that were input into the OBAN model. In addition, the OBAN analysis included the effects of diversions for the Sites project that were incorporated into a flow-survival relationship based on the non-linear survival function developed in Michel et al. (2021).

There was no difference in survival among the NAA and the alternatives due to the incorporation of Sites diversions into the Michel et al. (2021) flow-survival relationship. All alternatives had higher escapement abundance relative to the NAA over the 1922-2002 timeframe, but only Alt1B had higher abundance relative to the NAA over the period 1933-2002. The probability of quasi-extinction was higher in all alternatives relative to the NAA except Alt1B and Alt2, in which the probability was lower than the NAA. Egg to fry survival was also higher in Alt1B relative to the NAA, whereas all other alternatives had lower egg to fry survival compared to the NAA. Egg to fry survival is a function of temperature (mean daily water temperature in the Sacramento River at Bend Bridge) and flow (minimum monthly flow in the Sacramento River at Bend Bridge). Both Alt1B and Alt3 had higher median flow, whereas all alternatives except Alt3 had temperatures lower than the NAA on average. Delta survival was similar under the alternatives and the NAA, although Alt1B had the highest Delta survival of the alternatives.

OBAN Model Description

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 set of covariates that provided the best model fit were then retained for the predictive model. The OBAN model can be used to evaluate the effect of project operations on winter-run Chinook. The OBAN model uses values of the covariates under climate or operational alternatives, which are produced primarily from CALSIM and HEC-5Q 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.

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.

<u>Model Structure</u>
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 OBAN model has been developed from the conceptual life-cycle model of winter run, 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 β 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.

Covariates

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

STEMP: July through September mean daily water temperature (degrees Fahrenheit) in the Sacramento River at Bend Bridge. This covariate affects survival of the alevin 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 of the 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. Although this flow is much lower than the suggested flows needed for juvenile 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.

CURL: a wind stress curl index that is correlated with coastal productivity off California (Chelton 1982) (Pascals per meter) (Pacific Fisheries Environmental Laboratory, Pacific Grove data). Persistent longshore equatorward wind stress during spring and summer forces surface waters offshore via Eckman transport drawing nutrient-rich water to the euphotic zone to replace surface waters pushed offshore (Rykaczewski and Checkley 2008). Once nutrient-rich water reaches the euphotic zone, primary productivity increases. Positive effects of the CURL index on Chinook salmon growth and maturation have been observed (Wells et al. 2007). This covariate affects survival in the Gulf life history stage.

Harvest: Ocean harvest of Ocean 2 and Ocean 3 individuals (Ocean 1 are assumed to be too small to be vulnerable to the fishery) 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 ocean and recreational fishing regulations. Until 1987, there was little regulation of the Central Valley Chinook fishery and estimates of the mortality rate on winter run Chinook in the ocean fishery was approximately 0.7 of the mortality rate experienced by fall run Chinook. The harvest rate of fall-run Chinook is calculated annually as the Central Valley Index (CVI) by calculating the proportion of the fall run that were captured in the fishery (harvested/(harvested + escaped)). In 1989, winter-run 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 harvest mortality and reduced the impact to 0.5 of the CVI. In 1994, winter-run 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 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 winter run. For OBAN, it assumed that the harvest rates experienced by Ocean 3 stage winter run 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. 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 used 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.

Using the OBAN model for Evaluating Sites Project alternatives

In order to simulate winter-run Chinook salmon population dynamics under each of the alternatives, covariate data were required for each alternative. These covariates were produced for each alternative by using hydrological (CalSim) and water quality models (SRWQRM). In addition, DCC position does not differ between model scenarios during the period of winter-run presence in the Delta, as it is 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 used to estimate the OBAN model coefficients.

The OBAN model was modified to be able to run for the CalSim2 period of hydrologic outputs (1922 – 2003) 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 resample from the ocean productivity indices (CURL). The historical 1967 – 2014 CURL values were resampled with replacement in each iteration to provide variability in ocean productivity across the 1000 Monte Carlo simulations for each alternative.

To evaluate the role of Sites diversions on survival of winter-run Chinook, the flow-survival relationship that was developed in Michel et al. (2021) was incorporated into the juvenile survival in the Delta portion of the model (Figure 1). Their selected model uses a step function with three flow thresholds to capture the relationship between juvenile Chinook migration survival in the Sacramento River (from its confluence with Deer Creek to its confluence with the Feather River) and flow at Wilkins Slough gauge. Below a minimum flow threshold of 4,259 cfs, estimated survival is 0.03; between the minimum threshold and the historic mean flow of 10,712 cfs, estimated survival is 0.189; between the historic mean threshold and the high flow threshold of 22,872 cfs, estimated survival is 0.508; and estimated survival above the high flow threshold is 0.353. We modified the Michel et al. (2021) relationship in one important way; we retained the high survival level (0.508) for flows above 22,872 (red line in Figure 1). The objective of retaining this survival rate over those flows was to remove the possibility that survival benefits would be attained by reducing flow below the high threshold in the alternatives.

To obtain an annual survival adjustment factor using this model, we first used monthly averages of modeled flow at Wilkins Slough to calculate monthly estimates of survival. Since the flow model used the historic mean flow threshold as a monthly average flow target, we slightly adjusted this flow threshold in the flow-survival model to 10,690 cfs to remove any ambiguity about which survival estimate to apply to months with approximately 10,712 cfs average flow. These monthly survival estimates were then weighted according to an assumed fraction of the total annual population outmigrating in a given month (Table 1) to obtain an annual survival estimate.

Instead of applying the flow-survival values directly to the OBAN model, we applied a survival anomaly. The anomaly is the difference in survival in the alternative relative to the NAA baseline in the flow-survival relationship. For example, if flows in the NAA were 12,000 cfs at Wilkins, but the Alt3A flows in the same month were 9,000 cfs then the survival of the Alt3A was reduced by a value of approximately 0.3 (i.e., survival anomaly of -0.3) (Figure 1) to reflect the lower survival due to decreasing flows at Wilkins through Sites diversions in that month. Alternatively, if the flows in the NAA were 12,000 cfs and the flows in the same month were 11,000 cfs then the survival anomaly was zero for that month. Finally, months in which flows at Wilkins were higher under the alternative relative to the NAA could provide a positive survival anomaly if the alternative flow surpassed one of the flow thresholds (Figure 1).

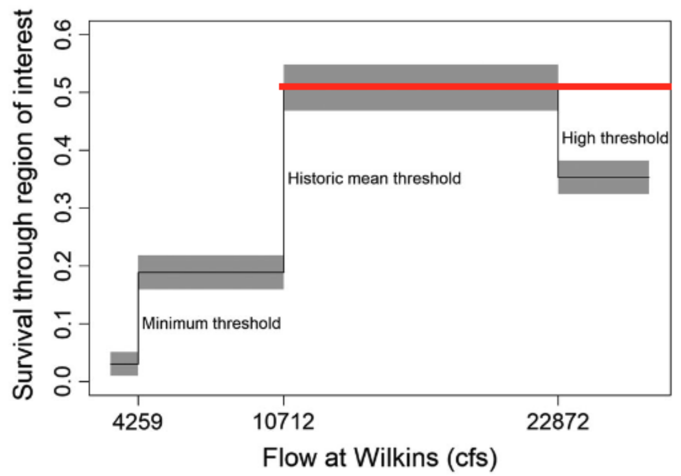

Fig. 6. Thresholds of predicted survival as a function of flow at Wilkins Slough. Predictions are based on the model averaged parameters from the most parsimonious triple threshold models, with mean thresholds at 4259, 10,712, and 22,872 cfs, with 95% confidence intervals (gray fill).

Figure 1. Michel et al. (2021) figure 6 indicating the non-linear relationship between flow at Wilkins Slough and survival with red line showing modification for implementation in the OBAN model.

Table 1. Monthly weights applied to the monthly survival anomalies to reflect Sites diversions.

Month	Weight
January	0.27
February	0.365
March	0.365

In general, the flow at Wilkins was similar between the NAA and alternatives thus the survival anomalies were zero (Figure 2).

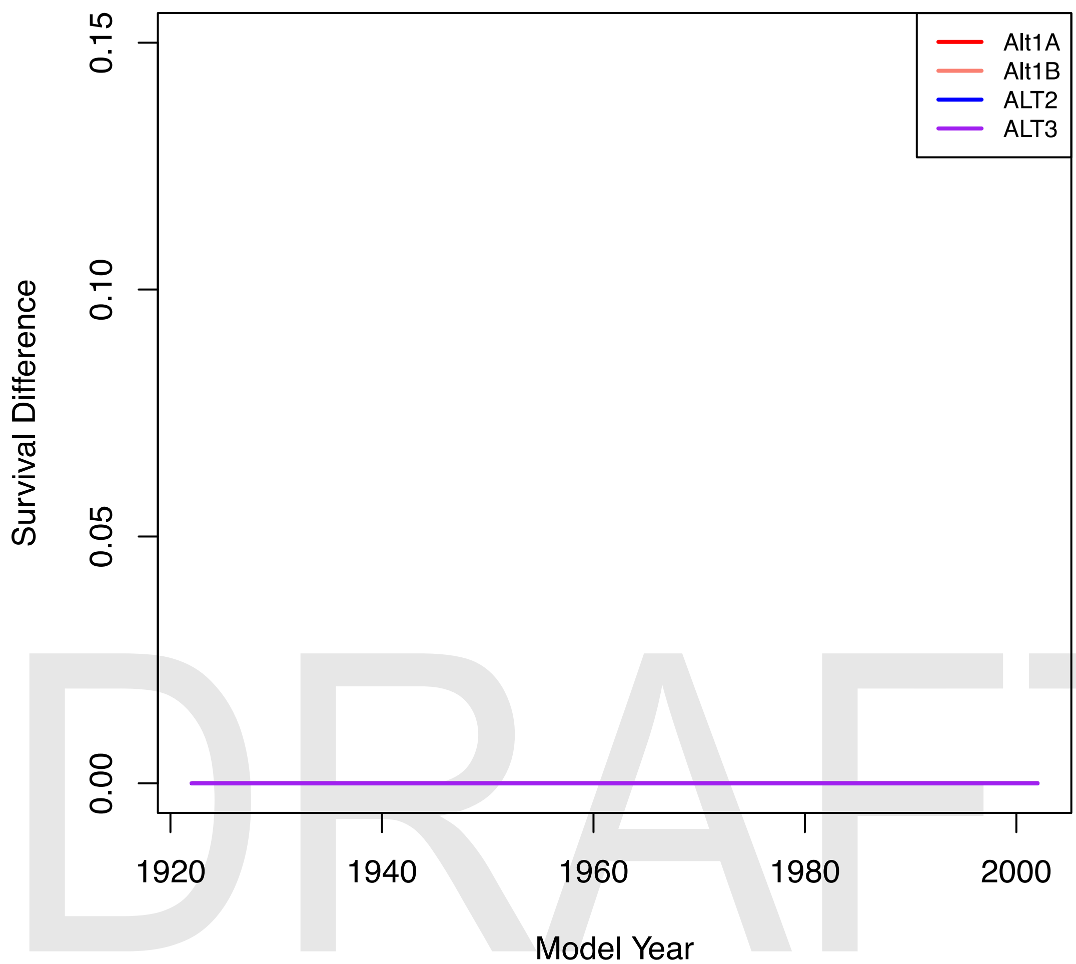

Figure 2. Annual survival differences applied in the Delta life stage to reflect Sites effect on flows at Wilkins Slough.

OBAN Model Results

Median abundance was the highest under Alt 1B relative to the no action alternative (NAA) and to the other alternatives (Figure 3). The greatest differences in spawner abundances between the alternatives and the NAA occurred in the early model years, which may reflect differences in the production during the initialization of the model. Including the first 10 years, Alt3 had the highest median abundance of the alternatives. When the period of evaluation for the abundances was truncated to 1933 – 2002 to allow comparisons between alternatives and the NAA to occur during more representative conditions, median abundance was higher under Alt 1B. Furthermore, over the 1933 – 2002 timeframe the only alternative with higher abundance on average than the NAA was Alt 1B (Figure 3).

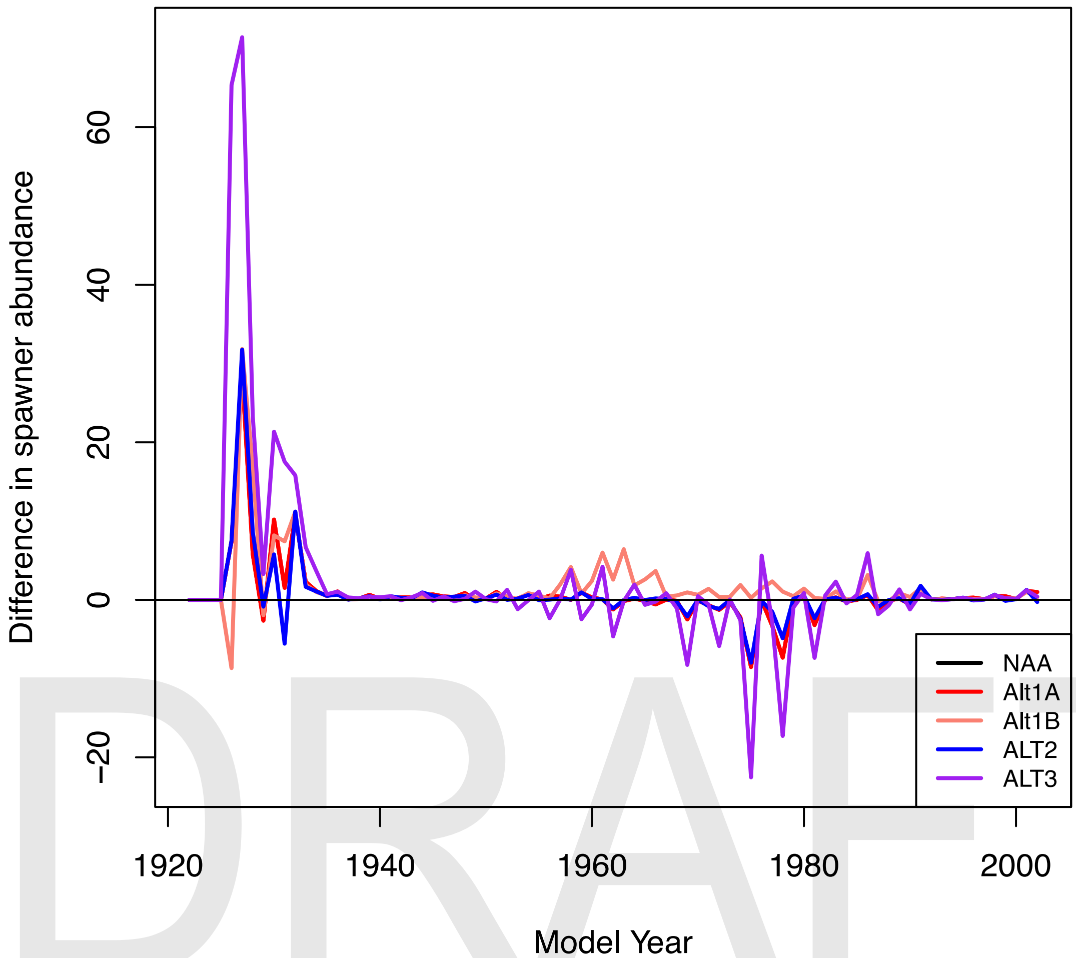

Figure 3. Difference (Alternative – NAA) in median spawner abundance for model years 1922 – 2002. Positive values indicate higher abundances under alternatives relative to the baseline no action alternative (NAA).

For much of the modeled time series, abundances were variable among the alternatives and the NAA except for the 1940's and 1990's 2002 (Figure 3). Uncertainty in the abundances followed these general patterns in which the spawner abundances in the alternatives and the NAA were consistently equivalent (Figure 4). The periods in which there was little difference between the NAA and the alternatives (Figure 3) and low variability in the difference between the NAA and the alternatives (Figure 4) were years of low abundance in both the alternatives and the NAA.

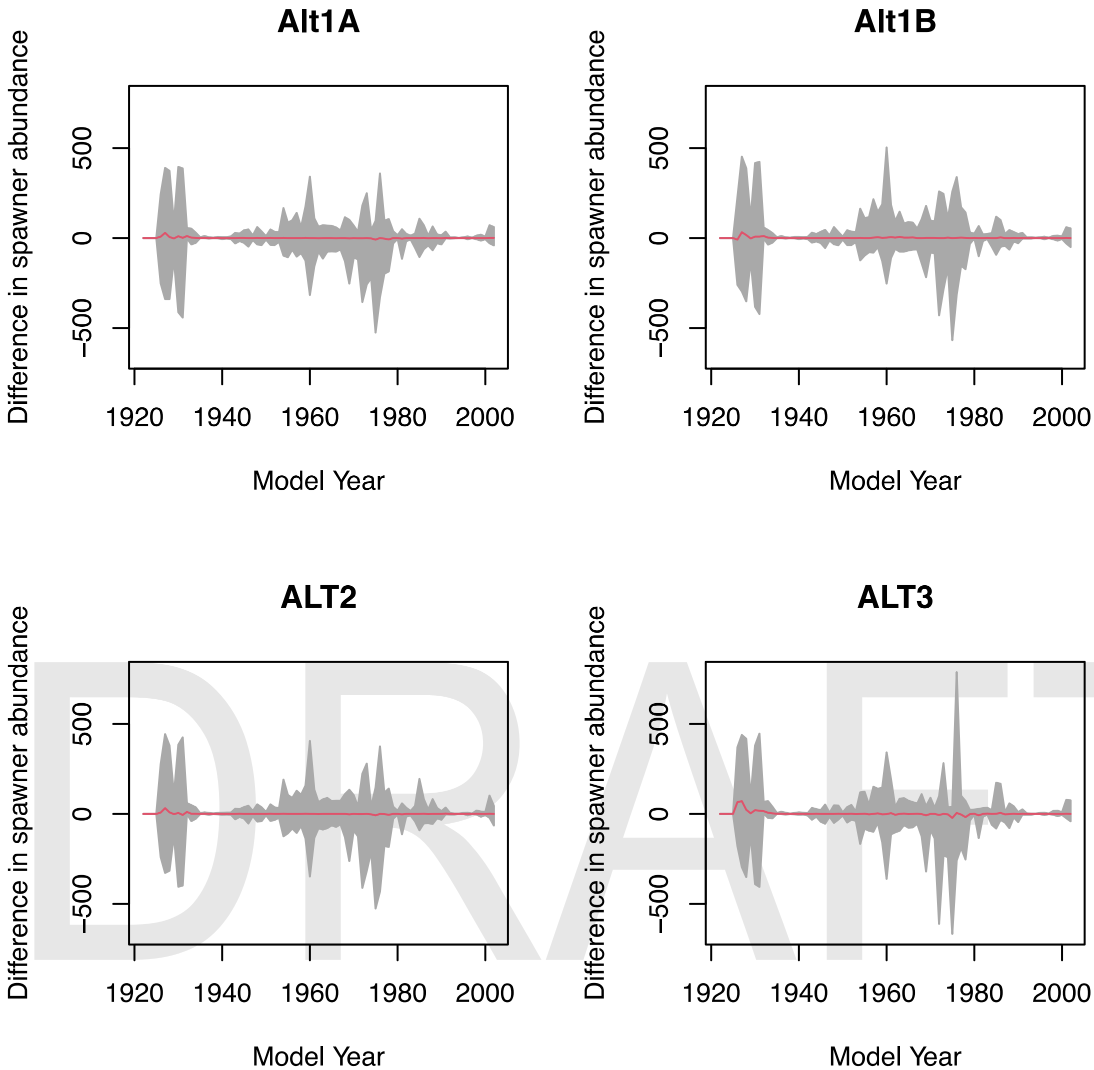

Figure 4. Difference (Alt - NAA) in spawner abundance for model years 1922 – 2002. Positive values indicate higher abundances under alternatives relative to the no action alternative (NAA). Median (red line) and 80% intervals (gray) across 1000 Monte Carlo simulations are presented.

The probability of quasi-extinction (probability that spawner abundance < 100) followed these same general temporal patterns (Figure 5). Periods in which there was little difference between the NAA and the alternatives were periods in which the probability of quasi-extinction was high (Figure 5). Temporal patterns in quasi-extinction were similar among alternatives and the NAA (Figure 5 left). Performance of the alternatives relative to the NAA indicated that Alt1B and Alt2 had lower probabilities of quasi-extinction than the NAA, whereas all other alternatives had higher probabilities (Figure 5, right).

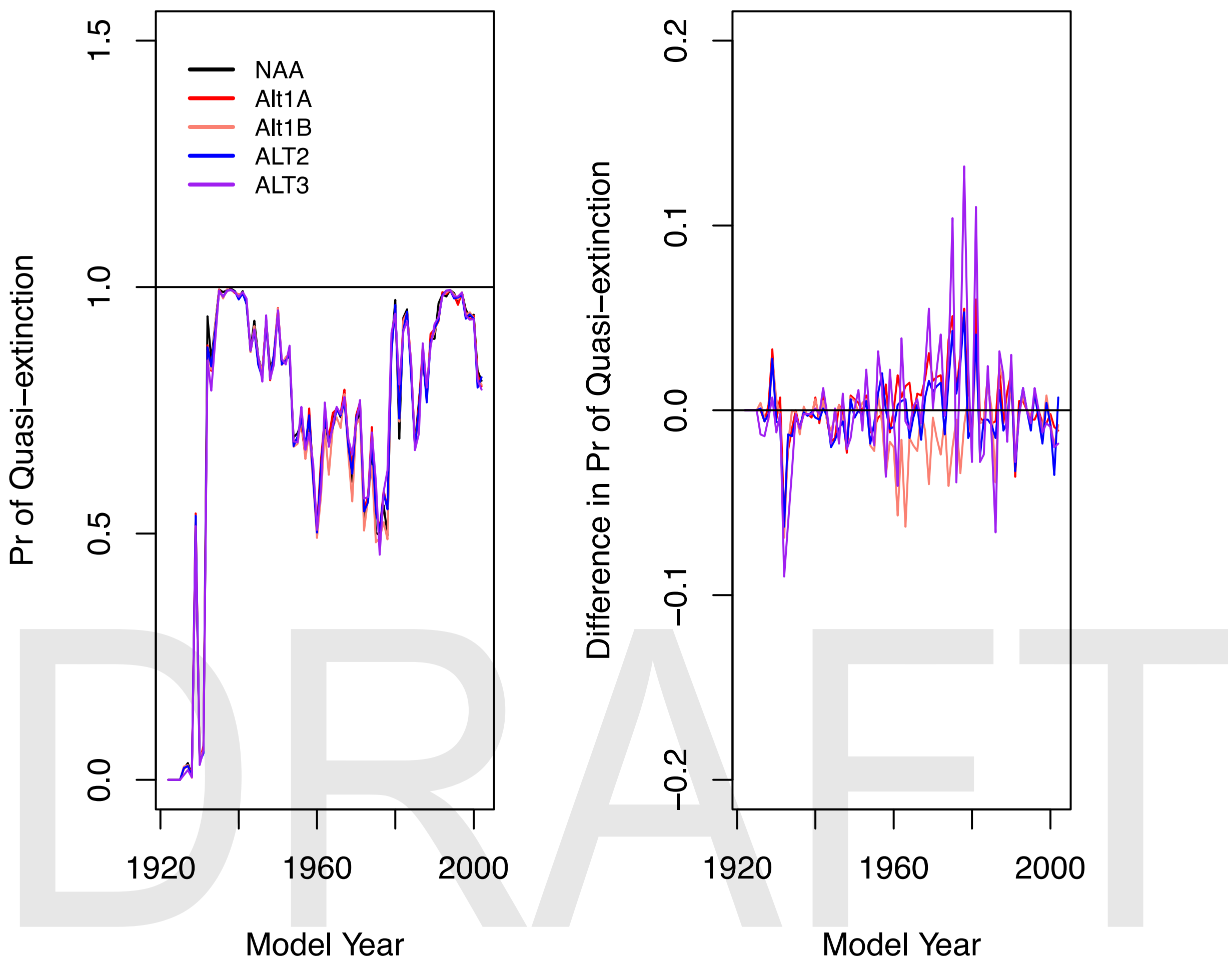

Figure 5. Probability of quasi-extinction (spawner abundance < 100) showing the no action alternative (NAA) (black) and alternatives (left). Difference (Alt – NAA) in the probability of quasi-extinction (right); thus, negative values indicate lower probability of quasi-extinction.

The survival rates in the egg through fry stage provided an indicator of how the Sites project affected the early winter-run life history stages. The differences in survival rates of the alternatives relative to the NAA were calculated to identify the model years in which those differences were occurring. Average egg through fry survival was higher only in Alt 1B relative to the NAA, whereas all other alternatives had lower egg through fry survival than the NAA (Figure 6). Variability in the difference in egg to fry survival (i.e., greater differences above and below the NAA) was the greatest in Alt3 relative to the other alternatives (Figure 6 and 7).

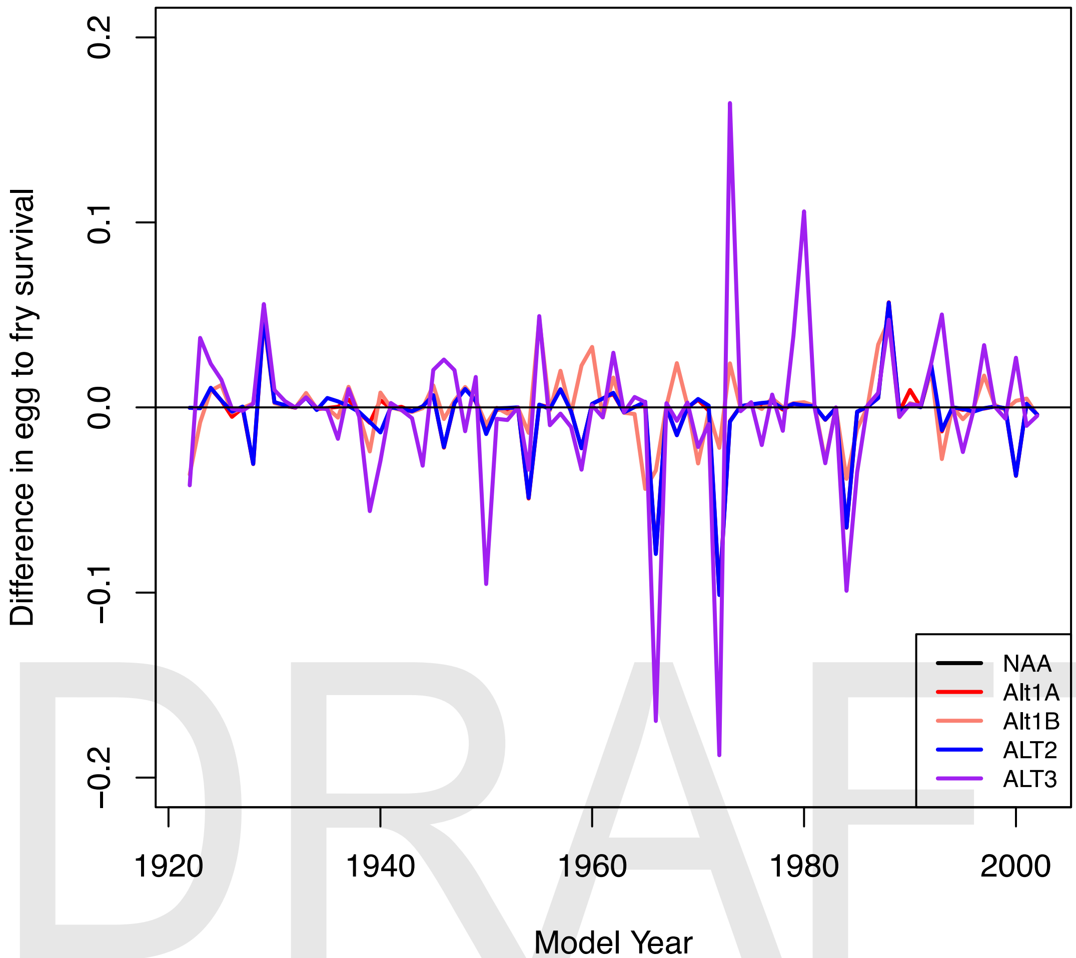

Figure 6. Median difference (Alt – NAA) in survival of the egg through fry stages which includes thermal mortality and Bend Bridge flow effects.

The relative survival of egg through fry in the alternatives varied in their temporal patterns (Figure 6, Figure 7). In most years, the survival of the alternatives and NAA were similar, with a few years having large positive or negative differences, particularly in Alt 3 (Figure 6). The number of years with positive and negative median survival differences provided insight into the different levels of performance of the alternatives. Alt1A had one year with survival differences > 0.05 (i.e., positive effects) and three years with survival differences < -0.05 (i.e., negative effects). For Alt1B there were zero positive and zero negative; Alt2 had one positive and three negative; and Alt3 had four positive and five negative.

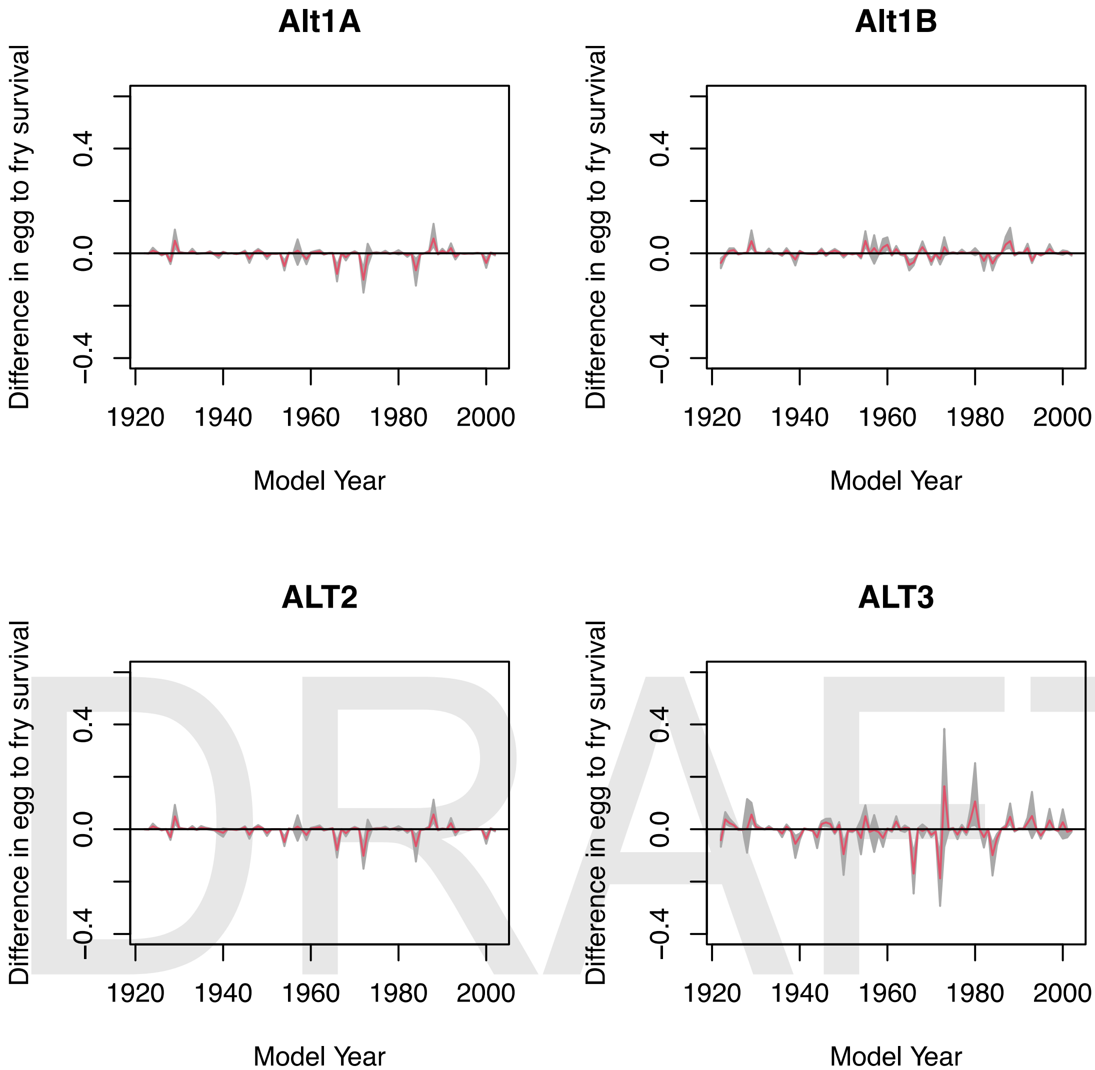

Figure 7. Difference (ALT – NAA) in survival of the egg through fry stages which includes thermal mortality and Bend Bridge flow effects. Median (red line) and 80% intervals (gray) across 1000 Monte Carlo simulations are presented.

In the Delta, survivals under the alternatives were slightly greater than the NAA on average (Figure 8). Over the time series, there was generally little difference between the alternatives and the NAA. The observed anomalies under Alt1B and Alt3 (Figure 8) were less than a 5% difference relative to the mean Delta survival in the NAA. Uncertainty in the estimates followed similar patterns to the median Delta survivals (Figure 9).

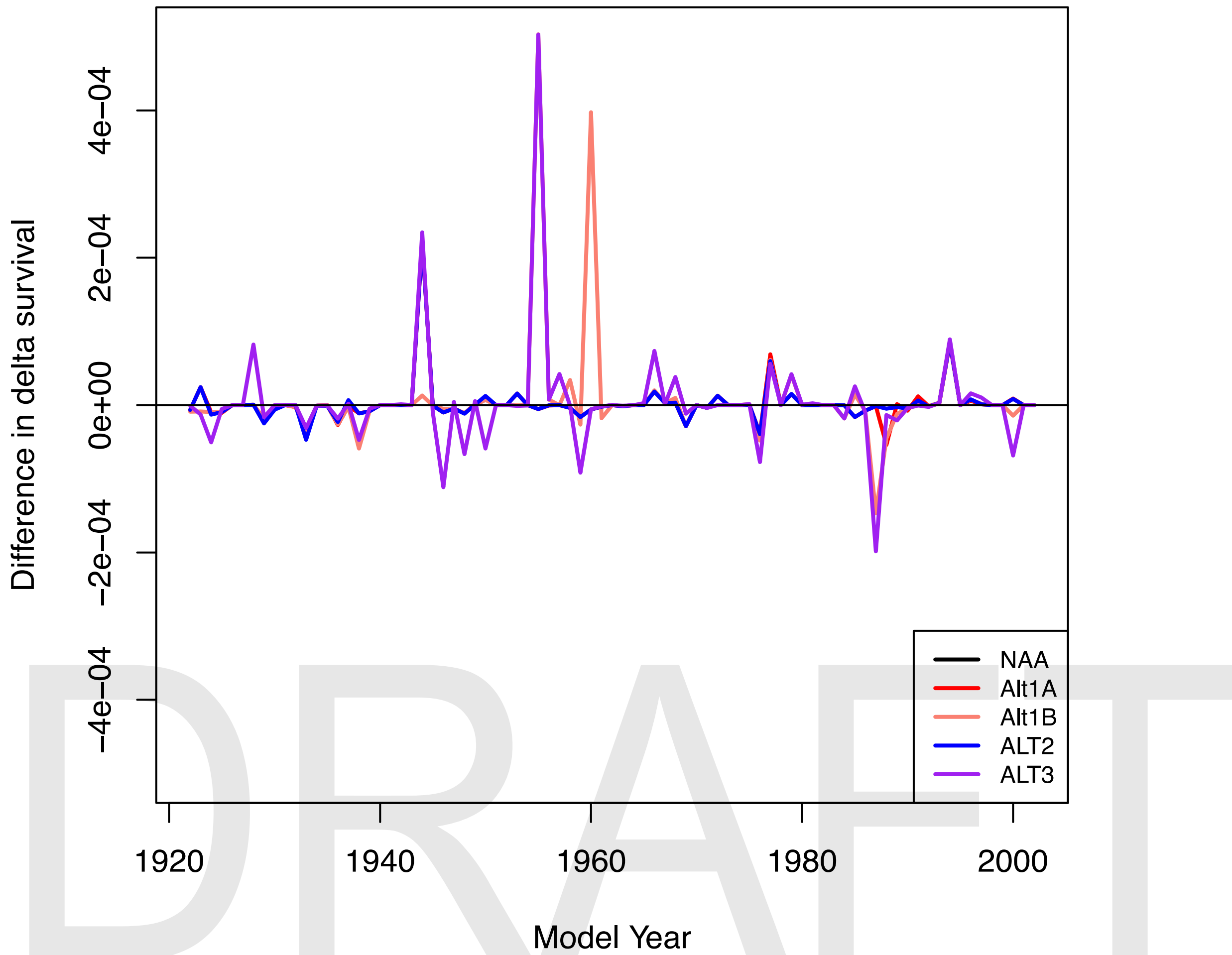

Figure 8. Median difference (Alt – NAA) in survival of the delta stage which includes access to Yolo bypass and export effects.

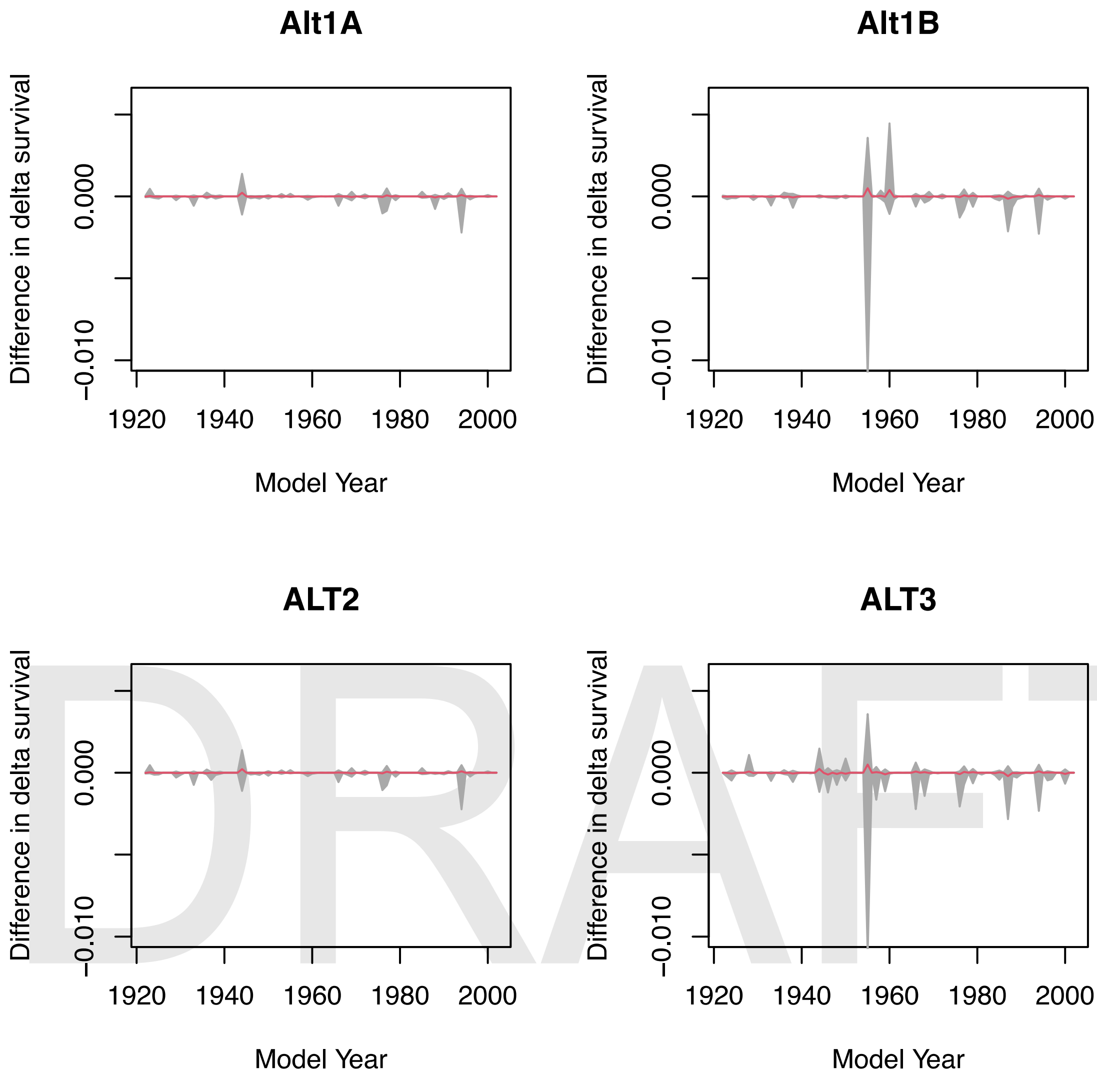

Figure 9. Difference (Alt – NAA) in survival of the delta stage which includes access to Yolo bypass and export effects. Median (red line) and 80% intervals (gray) across 1000 Monte Carlo simulations are presented.

Evaluation of Physical Data Affecting Performance

The two physical drivers that affect the egg through fry survival in the OBAN model are the temperatures at Bend Bridge during egg incubation and the minimum flow at Bend Bridge during fry rearing and outmigration (Figure 10 and 11). Mean temperatures were lower in all alternatives except Alt3 relative to the NAA, with Alt1B providing lowest temperature on average. These differences were driven by a few years, however, and median temperature was less than the NAA only under Alt2.

Differences in minimum flow between the alternatives and the NAA indicated higher minimum flows at Bend Bridge relative to the NAA on average across all alternatives (Figure 11). Median minimum flows were approximately equivalent between the NAA and the alternatives, with Alt1B and Alt3 providing median flows higher than the NAA, whereas Alt1A and Alt2 had median flows less than the NAA (Figure 11).

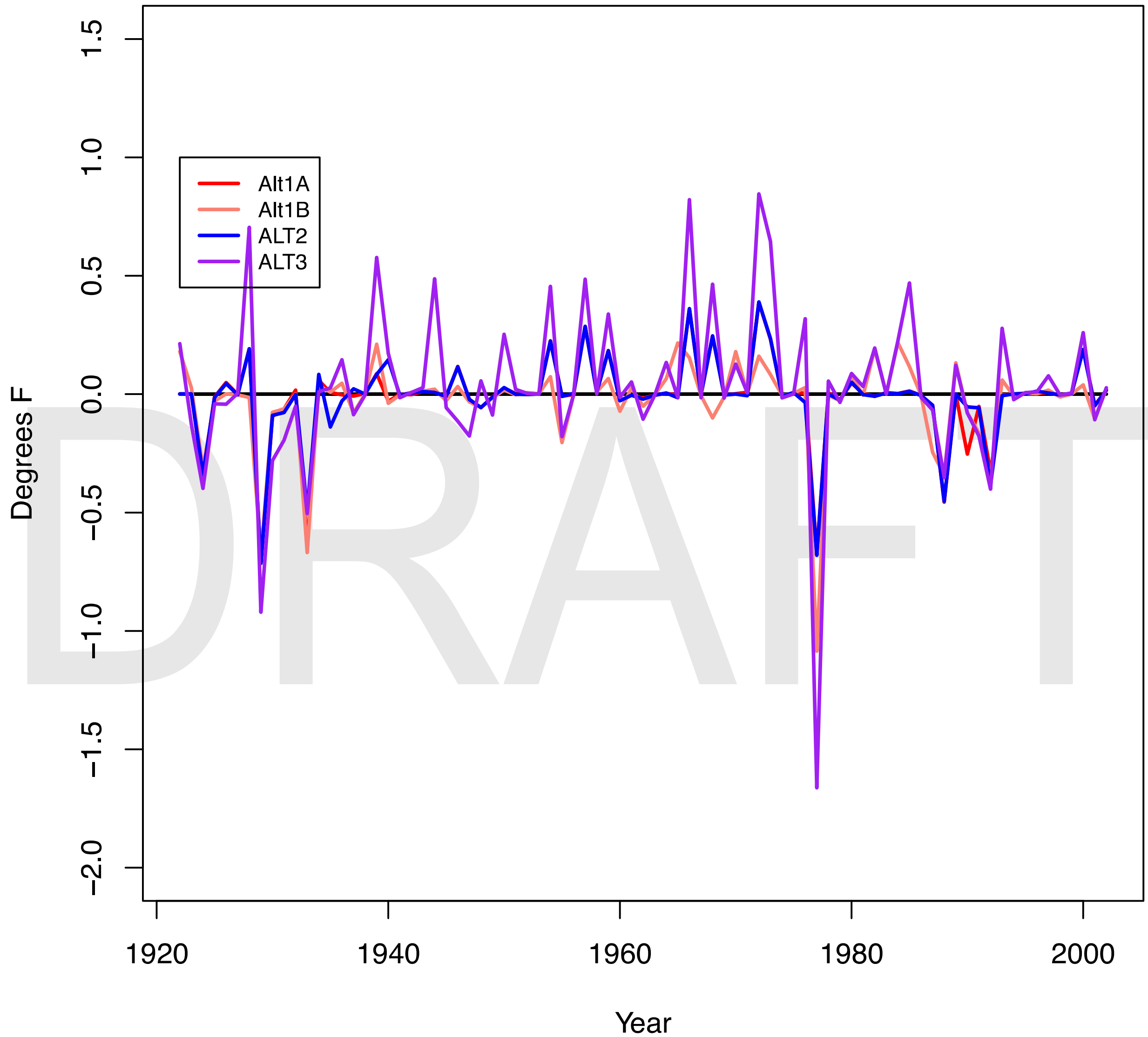

Figure 10. Difference (Alt – NAA) in the TEMP covariate, temperature in the Sacramento River at Bend Bridge (degrees F), between the No Action Alternative (NAA) and the alternatives.

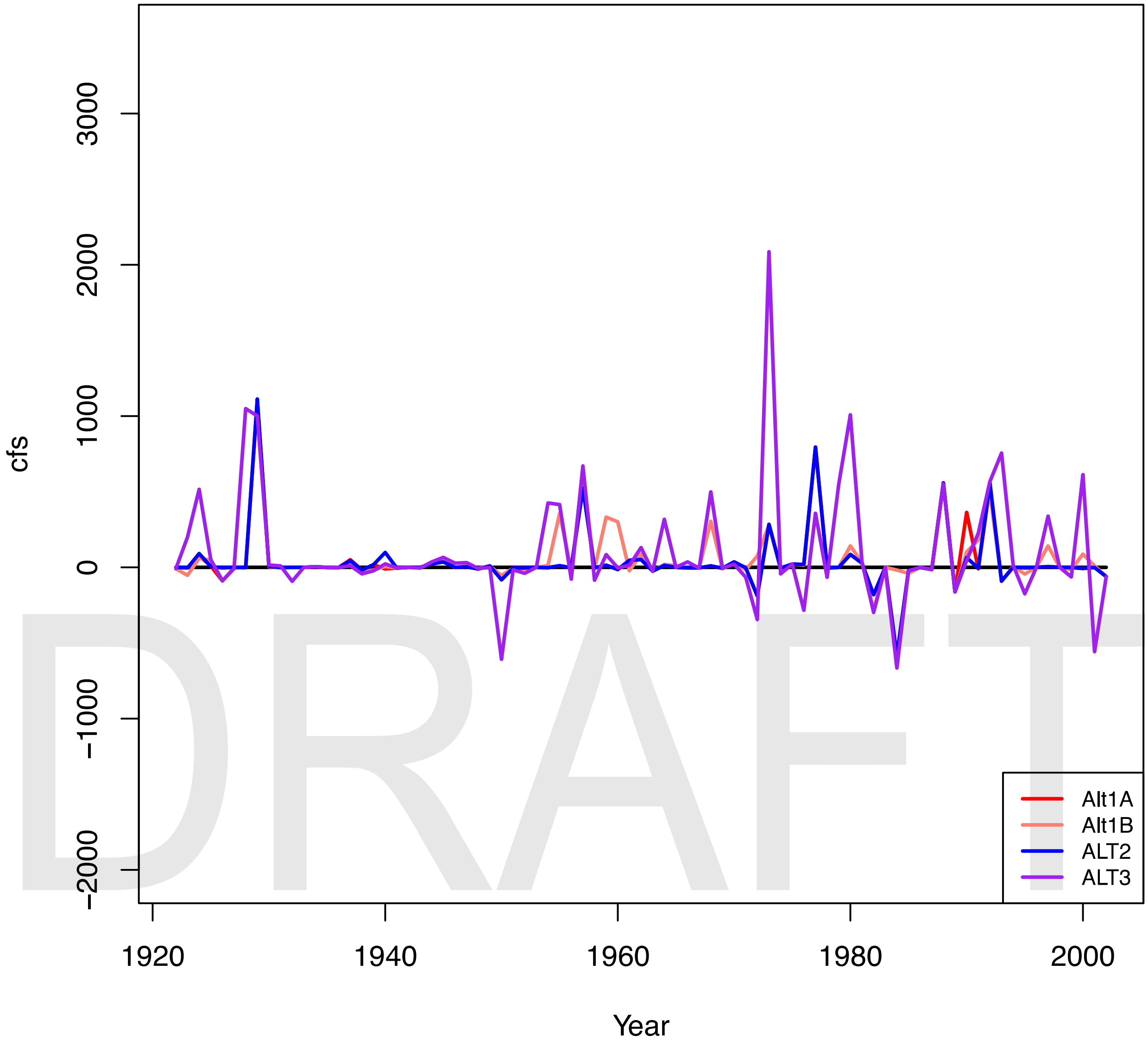

Figure 11. Difference (Alt – NAA) in the FLMIN covariate, minimum flow at Bend Bridge (cubic feet per second, cfs), between the No Action Alternative (NAA) and the alternatives.

Due to small differences in the Delta survivals among the NAA and the alternatives, no physical drivers were further evaluated for the Delta.

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