Appendix J, Spring Delta Outflow

Attachment J.1 Longfin Smelt Outflow

J.1.1 Model Overview

The potential effect of operations on Longfin Smelt abundance was investigated through development of a statistical modeling approach relating the Longfin Smelt Fall Midwater Trawl (FMWT) abundance index to: (1) Sacramento–San Joaquin Delta (Delta) outflow; (2) the FMWT abundance index two years earlier (as a representation of parental stock size), and; (3) ecological regime (i.e., 1967–1987, pre-*Potamocorbula amurensis* invasion; 1988–2002, post-*P. amurensis* invasion; and 2003–2022, Pelagic Organism Decline). The inclusion of the regime factor represents major ecological changepoints in the Bay-Delta (e.g., Nobriga and Rosenfield 2016; Sommer et al. 2007). Total Delta outflow (thousand acre-feet) was summed and examined as an explanatory covariate for two overlapping time periods: December through May, and March through May. Similar time periods have also been investigated in previous studies by Mount et al. (2013:66–69) and Nobriga and Rosenfield (2016). Bayesian methods were used to take into account model uncertainty (e.g., uncertainty in the time period over which Delta outflow is considered to be affecting Longfin Smelt abundance). Thereby integrating an important component of scientific uncertainty into the resulting model predictions for decision making.

J.1.2 Model Development

J.1.2.1 Methods

Twelve log-linear regression models were considered in the analysis. The models were fit to the FMWT index of Longfin Smelt abundance[1] (1967–2022) using a Bayesian approach implemented in the R statistical computing language (R Core Team 2023) via the *brms* package (Bürkner 2017). Three Markov Chain Monte Carlo chains were run for each model and flat priors were assumed for covariates. There was a 2,000-sample warm-up for each chain before 10,000 samples were retained as draws from the posterior (30,000 samples total drawn from the posterior). Bayesian values for the $\hat{R}$ statistic were less than 1.01 across estimated parameters, which indicated sampling converged on the posterior probability distributions for all models considered.

Preliminary model comparison was performed using leave-one-out cross validation (LOO; Vehtari et al. 2017). Measures of model predictive accuracy using LOO are asymptotically equal to the widely applicable information criteria (WAIC; Watanabe 2010), but in the case of finite data LOO has been shown to be more robust to influential observations like outliers (Vehtari et

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[1] Downloaded from: https://apps.wildlife.ca.gov/FMWT

al. 2017). The extent of model overlap in predictive accuracy was measured by the differences (and the standard errors of the differences) in expected log pointwise predictive densities, i.e., the differences in out-of-sample predictive accuracy between models. The preliminary model comparisons indicated there was a relatively high degree of similarity in terms of predictive ability between the top scoring individual models.

Therefore, rather than selecting a single model for inference, the posterior predictive probability distributions were combined as a weighted average across models. This process involved taking draws from the posterior of each single model in proportion to its model weight, with model weights for averaging posterior predictive distributions calculated using the *loo* package (Vehtari et al. 2020). For example, if a single model's weight was 25 percent of the total model set, then 2,500 draws from its posterior were added to the averaged posterior predictive distribution, which included 10,000 total draws taken across the posterior predictive distributions for all models. The statistical approach used to calculate the model weights for averaging the posterior predictive distributions across models is known as "stacking" (Yao et al. 2018).

Compared to more traditional model averaging approaches, stacking differs in terms of how model weights are assigned. Instead of calculating model weights based on the relative predictive ability for each individual model—where the best model for prediction would be given the highest weight—the model weights estimated through stacking minimize the LOO mean squared error of the resulting averaged posterior predictive distribution across models. In other words, stacking was used to estimate the optimal linear combination of model weights for averaging predictive distributions across the model set (Yao et al. 2018).

Hence, the model with the largest stacking weight does not necessarily have the highest predictive score compared to other models in the set. For example, the models in this case can be divided into two subsets: one subset includes a covariate for Delta outflow during December-May and the other model subset includes a covariate for March-May Delta outflow (Table J.1-1). Comparing the predictive ability of each individual model using LOO resulted in a model with December-May outflow (the model with the third highest stacking weight in Table J.1-1) having the highest individual predictive accuracy of any single model considered. In contrast, when the optimal linear combination of weighted model predictions was calculated, stacking resulted in a model with March–May Delta outflow having the highest single model weight (37 percent of the total stacking weight across the model set). Nevertheless, because stacking optimizes the linear combination of model weights for predictive accuracy, the next four models (~63 percent of the stacking weight) all include December–May Delta outflow instead of March–May Delta outflow. Therefore, in this case, even though the model with highest stacking weight included March–May Delta outflow, the averaged posterior predictive distribution was ultimately weighted more heavily with models that include December–May Delta outflow compared to models with March–May Delta outflow. Of the twelve models considered, the top five models by stacking weight accounted for >99.9 percent of the averaged posterior predictive distribution (Table J.1-1).

Predictions of the fall midwater trawl abundance index under the modeled CalSim 3 outflow scenarios (1922–2022) were generated using the model stacking approach described above to generate a weighted average Bayesian posterior predictive distribution across the set of models considered. Dropping subscripts denoting individual models for simplicity, the general form of the models can be written as:

$$Log_{10}[FMWT_{yr}] \sim N(\mu_{yr}, \sigma^2) \tag{1}$$

$$\mu_{yr} = \beta_{0,i} + \beta_1 Outflow_{yr,j} + \beta_2 Log_{10}\left[FMWT_{yr-2}\right] + \beta_3 Regime_i * Outflow_{yr,j} \tag{2}$$

where:

$Log_{10}[FMWT_{yr}]$ is the model predicted Log_{10} value of the fall midwater trawl index in water year yr;

μ_{yr} is the expected fall midwater trawl index in water year *yr* (the stacked posterior predictive distribution for μ_{yr} is shown as the dark grey ribbon in Figure J.1-1);

σ^2 is the residual variance parameter (the stacked posterior predictive distribution including the residual variance is shown as the light grey ribbon in Figure J.1-1);

$\beta_{0,i}$ represents the intercept parameter estimated for each regime: Pre-*Potamocorbula* (i = 1); *Potamocorbula* (i = 2); and POD (i = 3). For models without a regime covariate, a single intercept is estimated across all years instead, i.e., β_0 is substituted for $\beta_{0,i}$;

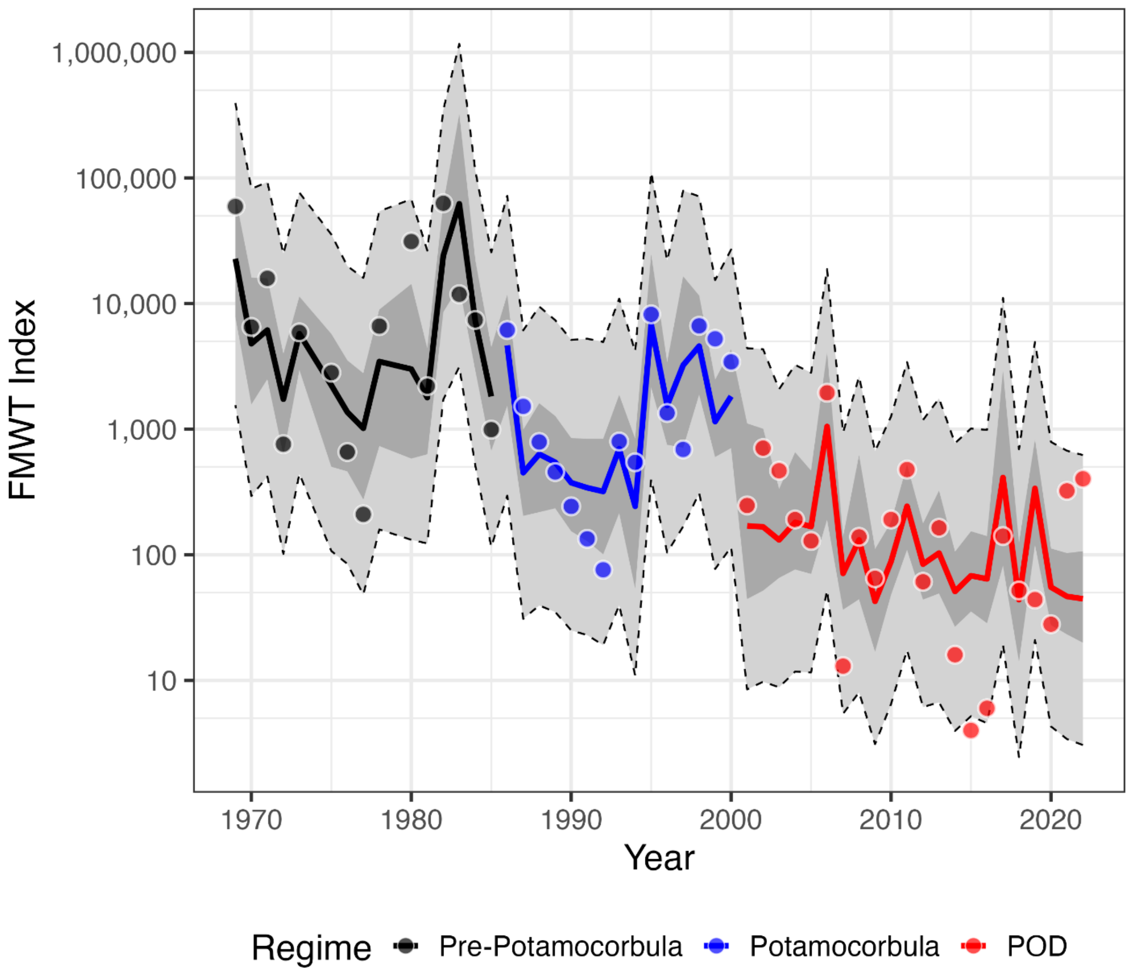
β_1 represents the slope parameter estimated for the relationship between the fall midwater trawl index and Delta outflow;

$Outflow_{yr,j}$ is the normalized[2] outflow level during water year *yr*, and *j* denotes the outflow level during either the December through May, or the March through May period;

β_2 represents the slope parameter estimated for the relationship between the expected fall midwater trawl index and the value of that index 2 years prior. For models without the parental stock covariate, $\beta_2 = 0$, and;

β_3 represents the interaction covariate (the difference in slopes) with respect to the estimated effect of outflow on the FMWT index of abundance during different regimes (The asterisk "*" sign represents an interaction term between Regime and Delta Outflow). For models without this interaction term, $\beta_3 = 0$.

[2] Normalized outflow values for each CalSim 3 scenario were calculated by subtracting the mean and dividing by the standard deviation of observed Delta outflow values (1967–2020).



Note: The circles represent the annual historical values of the fall midwater trawl abundance index. The solid lines connect the annual expected values from the stacked Bayesian posterior predictive distribution. Colors correspond to the three modeled regimes. The darker gray ribbon represents the averaged 95% probability interval for draws from the means (in log-space) of the posterior predictive distribution for the fall midwater trawl index value. The lighter gray ribbon with a dashed black outline represents the averaged 95% overall posterior predictive probability interval. The posterior predictive interval for the means has a smaller range than the overall posterior predictive interval because in addition to uncertainty in the estimated mean values, the overall posterior predictive distribution also incorporates uncertainty in the residual error of the model fits (Equations 1 and 2 below).

Figure J.1-1. Stacked Posterior Predictive Distributions for the Log-Linear Regressions of Longfin Smelt Fall Midwater Trawl Abundance Index as a Function of Delta Outflow (December–May), Ecological Regime (1967–1987, pre-*Potamocorbula amurensis* invasion; 1988–2002, post-*Potamocorbula* invasion [shown as *Potamocorbula*]; and 2003–2022, Pelagic Organism Decline [POD]), and Abundance Index 2 Years Earlier [Log10 FMWT(yr – 2)])

For those models that included the Log_{10} FMWT(yr – 2) parental stock size covariate (Table J.1-1), the starting parental stock size in 1922 and 1923 was set at a FMWT index value of 118.2, corresponding to the mean index value from 2013 through 2022. Given the starting values for the FMWT index (in the relevant models), the recursive nature of the regression formula was used to generate the expected FMWT index value in successive years from the posterior predictive distribution two years prior. For all models, predictions were conditional on the estimated relationship between the FMWT index and Delta outflow (in December–May, or March–May, depending on the model), and for those models that included a regime covariate, draws from the posterior predictive distributions were conditioned on estimates during the Pelagic Organism Decline regime.

As an example, starting in 1924, draws from the posterior predictive distribution for models including the parental stock size covariate were generated by first substituting the normalized 1924 December through May (or March through May) CalSim 3 outflow value for each alternative. Draws from the posterior distributions for the regression parameters and the starting value for $Log_{10}[FMWT_{1922}]$ were then used to generate the posterior predictive distribution for the fall midwater trawl index in 1924 (μ_{1924}). This value was then substituted into Equation 1, and the posterior distribution for the residual variance parameter was used to generate draws from the pointwise posterior predictive distributions for the fall midwater trawl index.[3] This process was iterated over each successive year, substituting the derived μ_{yr-2} values for $Log_{10}[FMWT_{yr-2}]$ to calculate μ_{yr}, and to generate the annual posterior predictive distributions for the fall midwater trawl index under each alternative. For models that did not include the parental stock size covariate, the posterior predictive distributions were generated based on the corresponding CalSim 3 outflow values for the monthly period corresponding to the individual model estimates, and likewise conditioned on covariate estimates during the POD regime for models that included a regime covariate (or the constant intercept parameter β_0, for models without the regime covariate). As noted above in the description of the model stacking approach, draws from the posterior predictive distribution for each model were sampled in proportion to the stacking model weights, to generate a weighted average posterior predictive distribution across the models considered. Summaries were then calculated by grouping the stacked annual posterior predictive distributions by water year type and calculating the means and credible intervals for each aggregated water year type posterior predictive distribution.

J.1.2.2 Assumptions/Uncertainty

Several additional models were also examined, in addition to those in Table J.1-1, but they were ultimately not included in this analysis due to poor model fits and what would have been additional computational cost without an expected difference in results (i.e., the poor model fits are indicative of poor model predictive accuracy, and hence tiny model weights). The additional models included a squared term on Delta outflow and their examination was motivated by the modeling results of Nobriga and Rosenfield (2016). Those authors assessed the relationship between Delta outflow and the ratio of age-0 to age-2 Longfin Smelt abundance in the two-life-stage versions of the models included in their analyses. They found support for non-linearity in this relationship (i.e., there was a peak in productivity at more intermediate outflow values),

[3] "~*N*" in Eqn. 1 denotes a normal (Gaussian) distribution.

which led to the inclusion of a second-order polynomial regression (i.e., a squared term) on Delta outflow (Nobriga and Rosenfield 2016:50). Given the approach taken here, which differs from the Nobriga and Rosenfield analysis in terms of: (1) the survey data used for Longfin Smelt abundance; (2) how Delta outflow values were included as covariates, and; (3) the overall time periods for available data included in the regression models, there was little to no support found for a second-order polynomial regression on Delta outflow. The aforementioned factors that differed between the two analyses are briefly described in the next paragraph for completeness; but, given the poor predictive ability of the second-order polynomial regressions under the current approach, that subset of models was ultimately not included because the preliminary results indicated the stacked model weights would be near zero. Hence the averaged posterior predictive distributions would not be expected to be sensitive to the exclusion of those models in this case, but their inclusion would have increased the computational time necessary to run and perform the averaging over a larger set of models.

As outlined above, there are several differences between these analyses and those of Nobriga and Rosenfield (2016) that might explain the discrepancy in terms of support (or lack thereof) found for dome shaped Longfin Smelt productivity as a function of Delta outflow. Firstly, Nobriga and Rosenfield (2016) found support for this relationship fitting models to catch data from the San Francisco Bay Study. In these analyses, on the other hand, the regression models have been fit to the FMWT index of abundance instead. Second, Nobriga and Rosenfield (2016) incorporated covariate values for Delta Outflow based on a principal component analysis (the first principal component values) of the *z*-scored monthly means from December to May. Here, the monthly total outflow (either from December to May, or March to May) were summed, resulting in a total outflow value during each time period each year, and the regression covariate values were calculated as the *z*-scores of the period-total outflow values taken across years. Third, in addition to examining indices of abundance from different surveys, the annual time periods that have been examined also differ. Nobriga and Rosenfield (2016) examined the relationship between annual indices of Longfin Smelt abundance-at-age and Delta outflow that were available from the Bay Study during 1980–2013. Whereas in these analyses this relationship was examined over a longer period, during 1967–2022, which includes >20 additional years in the comparison with Delta outflow.

J.1.2.3 Code and Data Repository

Analysis files and code for the Longfin Smelt Outflow analysis are available on ICF Sharepoint at Data and Code folder in the Appendix J. Spring Delta Outflow folder: J. SpringDeltaOutflow LFS Outflow

J.1.3 Results

[Key Take Aways Here]

Table J.1-1. The Optimal Linear Combination of Model Weights based on Stacking, which Minimizes the Mean Squared Error of the Leave-One-Out Cross Validation for the Resulting Model Averaged Posterior Predictive Distribution across the Twelve Log-Linear Regressions of Longfin Smelt Fall Midwater Trawl Abundance Index.

Log_{10}FMWT Linear Regression Model [a]	Stacking Weight
Mar–May + Regime + Log_{10} FMWT(yr – 2)	0.3661
Dec–May + Regime + Log_{10} FMWT(yr – 2)	0.2134
Dec–May + Regime + Dec–May*Regime	0.1636
Dec–May + Regime	0.1469
Dec–May + Log_{10} FMWT(yr – 2)	0.1099
Mar–May + Regime + Mar–May*Regime + Log_{10} FMWT(yr – 2)	<0.0001
Dec–May	<0.0001
Mar–May + Log_{10} FMWT(yr – 2)	<0.0001
Dec–May + Regime + Dec–May*Regime + Log_{10} FMWT(yr – 2)	<0.0001
Mar–May + Regime + Mar–May*Regime	<0.0001
Mar–May + Regime	<0.0001
Mar–May	<0.0001

Models are a Function of Delta Outflow (December–May or March–May), Ecological Regime (1967–1987, pre-Potamocorbula amurensis invasion; 1988–2002, post-P. amurensis invasion; and 2003–2022, Pelagic Organism Decline), and Abundance Index 2 Years Earlier (Log10 FMWT(yr – 2)).

[a] An asterisk "*" sign represents an interaction term between Regime and Delta Outflow.

Table J.1-2. Means of annual posterior predictive means for the FMWT index of Longfin Smelt abundance by water year type.

Water Year Type	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
Wet	2186.2	1626.5	725.6	701.5	713.9	716.3
Above Normal	592.7	423.6	215.8	208.8	215.0	221.8
Below Normal	216.0	170.2	104.8	103.0	105.6	109.1
Dry	196.3	151.2	95.9	94.7	96.4	99.2
Critical	130.7	107.3	76.4	77.8	77.8	79.1

Table J.1-3. Means of annual posterior predictive means for the FMWT index of Longfin Smelt abundance by water year type.

Water Year Type	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4
Wet	725.6	664.2 (-8%)	704.6 (-3%)	701.5 (-3%)	713.9 (-2%)	716.3 (-1%)	1015.7 (40%)	702.5 (-3%)
Above Normal	215.8	194.0 (-10%)	210.9 (-2%)	208.8 (-3%)	215.0 (0%)	221.8 (3%)	285.4 (32%)	210.1 (-3%)
Below Normal	104.8	96.1 (-8%)	103.8 (-1%)	103.0 (-2%)	105.6 (1%)	109.1 (4%)	129.0 (23%)	103.5 (-1%)
Dry	95.9	88.2 (-8%)	95.5 (0%)	94.7 (-1%)	96.4 (0%)	99.2 (3%)	116.8 (22%)	94.6 (-1%)
Critical	76.4	72.3 (-5%)	76.8 (0%)	77.8 (2%)	77.8 (2%)	79.1 (4%)	91.0 (19%)	76.3 (0%)

The percentage difference between scenarios and NAA is shown in the parentheses.

Table J.1-4. Means of annual posterior predictive distributions for the FMWT index of Longfin Smelt abundance.

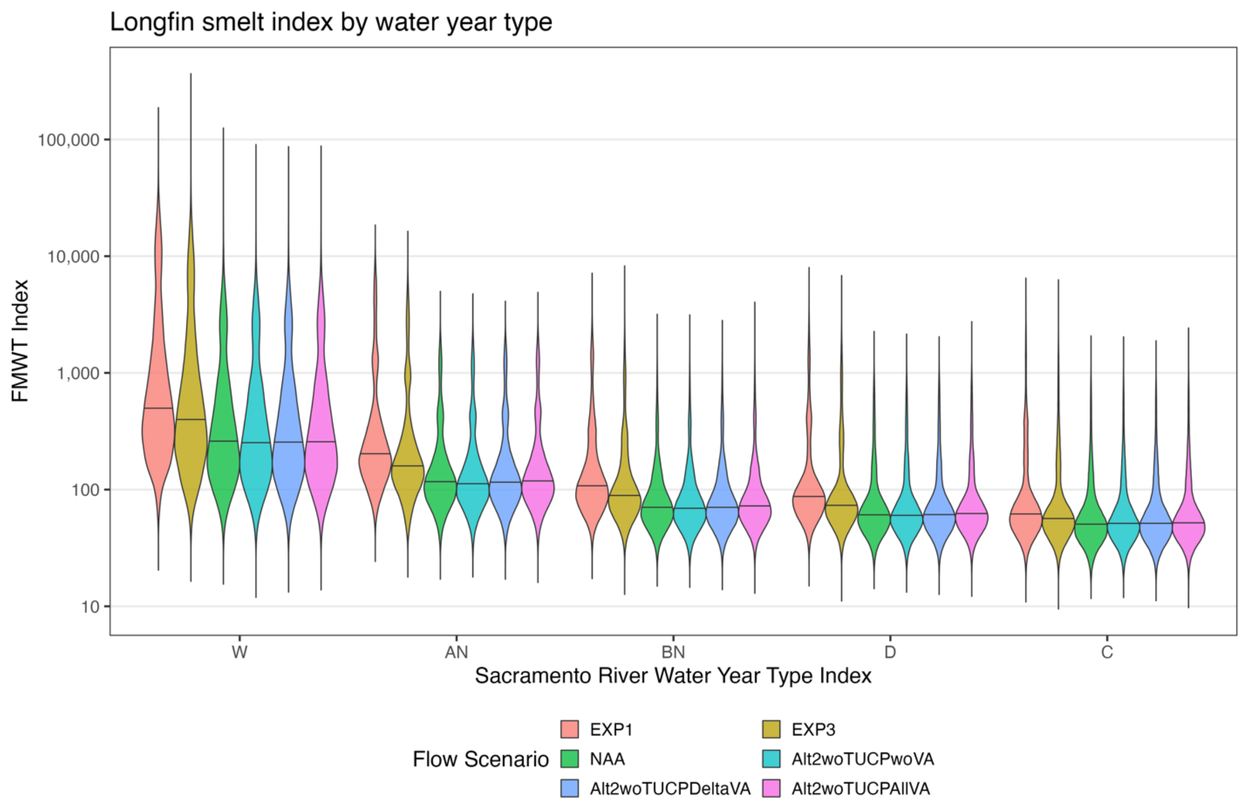
Water Year	WYT	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4	EXP1	EXP3
1922	AN	121.2	113.9 (-6%)	117.0 (-4%)	116.5 (-4%)	119.8 (-1%)	122.4 (1%)	142.4 (17%)	116.7 (-4%)	221.4 (83%)	158.2 (31%)
1923	BN	84.7	80.2 (-5%)	83.3 (-2%)	82.9 (-2%)	84.4 (0%)	86.2 (2%)	97.0 (15%)	81.8 (-3%)	126.9 (50%)	110.5 (31%)
1924	C	59.4	59.2 (0%)	59.4 (0%)	61.2 (3%)	61.5 (3%)	62.6 (5%)	64.6 (9%)	58.8 (-1%)	74.7 (26%)	70.0 (18%)
1925	D	84.4	80.2 (-5%)	85.4 (1%)	84.9 (1%)	86.1 (2%)	88.8 (5%)	99.8 (18%)	83.1 (-1%)	166.0 (97%)	108.7 (29%)
1926	D	69.3	65.9 (-5%)	69.7 (1%)	70.3 (1%)	70.4 (2%)	72.4 (4%)	74.4 (7%)	69.3 (0%)	101.1 (46%)	86.2 (24%)
1927	W	193.1	167.5 (-13%)	198.5 (3%)	196.5 (2%)	198.4 (3%)	205.4 (6%)	250.0 (29%)	194.3 (1%)	425.5 (120%)	291.7 (51%)
1928	AN	111.2	101.4 (-9%)	110.0 (-1%)	109.6 (-1%)	112.4 (1%)	117.2 (5%)	130.7 (18%)	111.0 (0%)	199.0 (79%)	168.0 (51%)
1929	C	70	67.0 (-4%)	72.1 (3%)	72.9 (4%)	72.3 (3%)	74.3 (6%)	85.3 (22%)	70.7 (1%)	119.3 (71%)	93.4 (33%)
1930	D	77.9	69.6 (-11%)	77.4 (-1%)	77.3 (-1%)	78.6 (1%)	81.4 (4%)	90.8 (16%)	78.5 (1%)	150.6 (93%)	108.2 (39%)
1931	C	54	53.5 (-1%)	54.2 (0%)	56.3 (4%)	55.7 (3%)	56.9 (6%)	59.6 (10%)	53.8 (0%)	70.0 (30%)	63.8 (18%)
1932	C	67.9	62.2 (-8%)	66.8 (-2%)	69.0 (2%)	69.2 (2%)	70.5 (4%)	79.9 (18%)	67.9 (0%)	137.4 (102%)	89.8 (32%)
1933	C	51.1	50.4 (-2%)	50.6 (-1%)	53.1 (4%)	52.6 (3%)	53.5 (5%)	53.9 (5%)	50.7 (-1%)	69.8 (37%)	61.4 (20%)
1934	C	55.4	54.2 (-2%)	55.3 (0%)	57.3 (3%)	57.3 (3%)	58.1 (5%)	60.7 (9%)	55.4 (0%)	89.0 (61%)	68.7 (24%)
1935	BN	80.4	74.4 (-7%)	80.6 (0%)	79.6 (-1%)	80.1 (0%)	81.9 (2%)	89.1 (11%)	80.3 (0%)	158.5 (97%)	104.8 (30%)
1936	BN	106	94.7 (-11%)	103.0 (-3%)	102.8 (-3%)	103.1 (-3%)	106.9 (1%)	110.4 (4%)	103.0 (-3%)	228.1 (115%)	158.1 (49%)
1937	BN	91.4	83.6 (-8%)	88.5 (-3%)	88.5 (-3%)	90.2 (-1%)	91.6 (0%)	102.3 (12%)	88.0 (-4%)	204.2 (124%)	136.2 (49%)
1938	W	794.6	749.8 (-6%)	762.0 (-4%)	763.0 (-4%)	773.2 (-3%)	765.2 (-4%)	1123.6 (41%)	762.1 (-4%)	2479.4 (212%)	1760.3 (122%)
1939	D	59.5	56.3 (-5%)	58.5 (-2%)	58.6 (-2%)	58.9 (-1%)	59.5 (0%)	66.0 (11%)	58.2 (-2%)	87.8 (48%)	76.8 (29%)
1940	AN	404.1	369.0 (-9%)	391.8 (-3%)	390.0 (-3%)	397.6 (-2%)	406.7 (1%)	528.9 (31%)	395.2 (-2%)	1478.4 (266%)	848.9 (110%)
1941	W	364.9	336.3 (-8%)	346.2 (-5%)	346.1 (-5%)	346.9 (-5%)	343.4 (-6%)	424.8 (16%)	350.3 (-4%)	967.2 (165%)	722.3 (98%)
1942	W	570.1	511.7 (-10%)	559.9 (-2%)	550.9 (-3%)	560.9 (-2%)	559.8 (-2%)	791.6 (39%)	555.7 (-3%)	2033.6 (257%)	1388.5 (144%)
1943	W	283.5	258.6 (-9%)	270.5 (-5%)	268.6 (-5%)	274.7 (-3%)	282.4 (0%)	385.1 (36%)	273.9 (-3%)	790.9 (179%)	616.5 (117%)
1944	D	138.1	126.2 (-9%)	135.8 (-2%)	136.3 (-1%)	139.0 (1%)	142.4 (3%)	171.3 (24%)	135.6 (-2%)	333.6 (142%)	247.8 (79%)
1945	D	126.3	112.3 (-11%)	122.8 (-3%)	122.4 (-3%)	125.9 (0%)	129.7 (3%)	162.3 (29%)	123.2 (-2%)	336.4 (166%)	247.7 (96%)
1946	BN	144.1	126.1 (-12%)	142.6 (-1%)	141.5 (-2%)	147.9 (3%)	152.0 (5%)	182.1 (26%)	140.8 (-2%)	334.6 (132%)	262.0 (82%)

Water Year	WYT	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4	EXP1	EXP3
1947	D	73.4	69.7 (-5%)	73.5 (0%)	72.3 (-1%)	72.8 (-1%)	75.2 (2%)	87.6 (19%)	72.6 (-1%)	138.2 (88%)	110.1 (50%)
1948	D	89.4	85.7 (-4%)	91.5 (2%)	90.6 (1%)	93.2 (4%)	95.2 (6%)	107.8 (21%)	88.9 (-1%)	199.5 (123%)	143.8 (61%)
1949	D	74.4	69.8 (-6%)	74.8 (0%)	73.2 (-2%)	74.0 (-1%)	77.0 (3%)	80.2 (8%)	73.4 (-1%)	124.1 (67%)	102.9 (38%)
1950	D	80.7	74.6 (-7%)	80.6 (0%)	80.8 (0%)	82.6 (2%)	84.9 (5%)	91.1 (13%)	79.3 (-2%)	163.5 (103%)	114.3 (42%)
1951	AN	172	156.4 (-9%)	169.6 (-1%)	168.3 (-2%)	174.0 (1%)	175.8 (2%)	200.0 (16%)	167.0 (-3%)	349.3 (103%)	297.8 (73%)
1952	W	331.7	296.4 (-11%)	319.6 (-4%)	319.7 (-4%)	321.9 (-3%)	322.3 (-3%)	421.0 (27%)	317.1 (-4%)	966.9 (192%)	653.5 (97%)
1953	AN	142.9	128.5 (-10%)	139.5 (-2%)	139.0 (-3%)	144.8 (1%)	148.6 (4%)	177.8 (24%)	139.3 (-3%)	302.5 (112%)	245.1 (72%)
1954	AN	149.9	128.3 (-14%)	145.6 (-3%)	145.0 (-3%)	148.7 (-1%)	154.1 (3%)	203.0 (35%)	144.6 (-4%)	366.9 (145%)	270.3 (80%)
1955	D	76.5	70.9 (-7%)	75.5 (-1%)	75.2 (-2%)	77.1 (1%)	78.8 (3%)	96.6 (26%)	76.0 (-1%)	135.2 (77%)	114.8 (50%)
1956	W	522.6	464.0 (-11%)	509.1 (-3%)	509.4 (-3%)	522.1 (0%)	529.7 (1%)	727.4 (39%)	503.8 (-4%)	1895.4 (263%)	1254.1 (140%)
1957	BN	80.1	73.5 (-8%)	78.9 (-1%)	78.6 (-2%)	80.8 (1%)	83.7 (4%)	100.1 (25%)	78.5 (-2%)	146.6 (83%)	122.7 (53%)
1958	W	1085	911.6 (-16%)	1040.7 (-4%)	1036.3 (-4%)	1054.9 (-3%)	1065.5 (-2%)	1613.1 (49%)	1041.1 (-4%)	3824.4 (252%)	2821.6 (160%)
1959	BN	74.8	70.0 (-6%)	73.1 (-2%)	72.6 (-3%)	75.1 (0%)	76.4 (2%)	90.7 (21%)	73.2 (-2%)	118.2 (58%)	109.5 (46%)
1960	D	188.6	172.5 (-9%)	192.0 (2%)	184.0 (-2%)	188.8 (0%)	194.9 (3%)	262.0 (39%)	186.5 (-1%)	531.4 (182%)	371.9 (97%)
1961	D	63.2	57.8 (-9%)	62.7 (-1%)	62.4 (-1%)	63.3 (0%)	64.1 (2%)	70.8 (12%)	62.4 (-1%)	99.0 (57%)	83.4 (32%)
1962	D	118.9	109.2 (-8%)	118.7 (0%)	116.9 (-2%)	118.4 (0%)	124.2 (4%)	156.8 (32%)	116.7 (-2%)	287.0 (141%)	205.1 (73%)
1963	W	147.3	128.5 (-13%)	145.3 (-1%)	144.6 (-2%)	146.9 (0%)	150.1 (2%)	173.8 (18%)	144.5 (-2%)	268.8 (82%)	219.8 (49%)
1964	D	71	67.6 (-5%)	70.9 (0%)	70.1 (-1%)	70.6 (-1%)	72.3 (2%)	88.0 (24%)	70.6 (-1%)	118.8 (67%)	105.5 (48%)
1965	W	238.2	205.1 (-14%)	236.0 (-1%)	232.3 (-3%)	236.5 (-1%)	243.6 (2%)	321.3 (35%)	232.2 (-3%)	611.4 (157%)	420.1 (76%)
1966	BN	72.5	66.1 (-9%)	71.7 (-1%)	71.2 (-2%)	72.3 (0%)	74.6 (3%)	89.7 (24%)	71.6 (-1%)	119.6 (65%)	108.2 (49%)
1967	W	279.5	234.8 (-16%)	273.5 (-2%)	270.1 (-3%)	277.8 (-1%)	288.2 (3%)	392.5 (40%)	271.5 (-3%)	858.8 (207%)	599.7 (115%)
1968	BN	79.2	73.6 (-7%)	79.5 (0%)	78.5 (-1%)	80.0 (1%)	82.5 (4%)	93.5 (18%)	78.5 (-1%)	124.4 (57%)	116.0 (46%)
1969	W	719.9	640.2 (-11%)	735.9 (2%)	725.1 (1%)	721.8 (0%)	731.1 (2%)	1091.5 (52%)	709.8 (-1%)	2848.3 (296%)	1885.7 (162%)
1970	W	288.5	280.2 (-3%)	282.5 (-2%)	281.6 (-2%)	286.9 (-1%)	288.3 (0%)	381.6 (32%)	281.0 (-3%)	539.6 (87%)	527.2 (83%)
1971	W	301.7	263.9 (-13%)	304.5 (1%)	301.6 (0%)	298.6 (-1%)	301.5 (0%)	460.4 (53%)	298.5 (-1%)	1018.5 (238%)	694.5 (130%)
1972	BN	97.4	87.1 (-11%)	96.3 (-1%)	96.2 (-1%)	97.9 (1%)	100.7 (3%)	128.9 (32%)	96.5 (-1%)	180.6 (85%)	162.4 (67%)
1973	AN	303.5	259.6 (-14%)	300.8 (-1%)	295.0 (-3%)	305.3 (1%)	318.9 (5%)	436.0 (44%)	297.0 (-2%)	856.3 (182%)	639.1 (111%)

Water Year	WYT	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4	EXP1	EXP3
1974	W	476.1	412.3 (-13%)	466.7 (-2%)	464.6 (-2%)	469.8 (-1%)	469.4 (-1%)	623.7 (31%)	465.4 (-2%)	988.9 (108%)	892.0 (87%)
1975	AN	223	189.3 (-15%)	216.4 (-3%)	213.9 (-4%)	224.3 (1%)	233.0 (4%)	313.0 (40%)	213.2 (-4%)	600.9 (169%)	466.9 (109%)
1976	C	97.3	90.9 (-7%)	96.5 (-1%)	96.4 (-1%)	96.3 (-1%)	98.6 (1%)	119.6 (23%)	96.9 (0%)	154.4 (59%)	155.3 (60%)
1977	C	76.1	73.4 (-4%)	77.6 (2%)	77.8 (2%)	78.2 (3%)	79.6 (5%)	89.5 (18%)	76.4 (0%)	110.3 (45%)	104.4 (37%)
1978	AN	182	167.2 (-8%)	182.8 (0%)	178.3 (-2%)	184.9 (2%)	189.4 (4%)	259.7 (43%)	179.3 (-1%)	569.3 (213%)	329.6 (81%)
1979	D	81.1	74.2 (-9%)	79.8 (-2%)	79.8 (-2%)	81.4 (0%)	83.7 (3%)	95.4 (18%)	78.6 (-3%)	156.0 (92%)	128.6 (58%)
1980	AN	316.5	295.4 (-7%)	308.3 (-3%)	303.8 (-4%)	316.7 (0%)	331.2 (5%)	415.2 (31%)	301.3 (-5%)	946.4 (199%)	666.4 (111%)
1981	D	66.8	62.4 (-7%)	66.5 (0%)	65.9 (-1%)	68.2 (2%)	68.7 (3%)	77.2 (16%)	65.6 (-2%)	113.8 (70%)	95.9 (44%)
1982	W	1151	1015.8 (-12%)	1099.6 (-4%)	1096.4 (-5%)	1110.1 (-4%)	1145.7 (0%)	1599.6 (39%)	1109.0 (-4%)	3937.1 (242%)	3016.6 (162%)
1983	W	3476.1	3336.9 (-4%)	3375.0 (-3%)	3399.6 (-2%)	3507.9 (1%)	3456.5 (-1%)	4489.4 (29%)	3372.6 (-3%)	7315.3 (110%)	6540.0 (88%)
1984	W	676.6	593.1 (-12%)	661.0 (-2%)	637.3 (-6%)	652.6 (-4%)	665.9 (-2%)	962.2 (42%)	641.3 (-5%)	1969.9 (191%)	1640.3 (142%)
1985	BN	229.3	212.9 (-7%)	226.7 (-1%)	226.4 (-1%)	231.3 (1%)	238.6 (4%)	288.1 (26%)	225.4 (-2%)	432.7 (89%)	407.5 (78%)
1986	W	939.5	822.2 (-12%)	914.3 (-3%)	900.7 (-4%)	905.9 (-4%)	920.5 (-2%)	1494.5 (59%)	908.8 (-3%)	3519.7 (275%)	2654.4 (183%)
1987	D	100.3	93.5 (-7%)	102.2 (2%)	102.2 (2%)	101.6 (1%)	104.9 (5%)	113.0 (13%)	99.8 (-1%)	159.4 (59%)	143.1 (43%)
1988	C	168.9	143.8 (-15%)	169.7 (0%)	167.6 (-1%)	166.5 (-1%)	170.3 (1%)	229.0 (36%)	167.2 (-1%)	396.9 (135%)	296.5 (76%)
1989	D	86.9	82.1 (-6%)	87.5 (1%)	87.2 (0%)	88.2 (2%)	90.2 (4%)	97.9 (13%)	86.5 (0%)	163.0 (88%)	126.4 (45%)
1990	C	79.1	74.3 (-6%)	80.4 (2%)	80.2 (1%)	79.6 (1%)	81.6 (3%)	95.0 (20%)	80.9 (2%)	131.2 (66%)	107.3 (36%)
1991	C	66.6	65.4 (-2%)	66.6 (0%)	68.5 (3%)	66.7 (0%)	67.5 (1%)	72.5 (9%)	66.0 (-1%)	99.4 (49%)	80.6 (21%)
1992	C	66.9	64.4 (-4%)	68.7 (3%)	69.2 (4%)	69.5 (4%)	70.2 (5%)	74.5 (11%)	68.2 (2%)	102.0 (53%)	83.3 (25%)
1993	AN	148	124.0 (-16%)	140.7 (-5%)	130.3 (-12%)	135.1 (-9%)	137.1 (-7%)	183.4 (24%)	141.0 (-5%)	366.8 (148%)	224.9 (52%)
1994	C	57.1	55.2 (-3%)	57.4 (1%)	57.2 (0%)	58.0 (2%)	58.8 (3%)	62.3 (9%)	57.4 (1%)	76.2 (34%)	72.5 (27%)
1995	W	908.8	822.6 (-9%)	887.8 (-2%)	865.6 (-5%)	877.7 (-3%)	885.7 (-3%)	1220.0 (34%)	880.8 (-3%)	3207.1 (253%)	1785.3 (96%)
1996	W	220.8	215.8 (-2%)	209.8 (-5%)	209.6 (-5%)	212.0 (-4%)	212.3 (-4%)	275.8 (25%)	209.9 (-5%)	444.3 (101%)	370.1 (68%)
1997	W	1238.4	1133.0 (-9%)	1162.7 (-6%)	1161.2 (-6%)	1170.0 (-6%)	1170.4 (-5%)	1701.7 (37%)	1171.1 (-5%)	4213.5 (240%)	3145.6 (154%)
1998	W	1026	1089.7 (6%)	981.7 (-4%)	1002.8 (-2%)	1022.2 (0%)	1013.9 (-1%)	1339.3 (31%)	1002.8 (-2%)	3211.5 (213%)	2402.7 (134%)
1999	W	586	519.6 (-11%)	544.4 (-7%)	543.6 (-7%)	547.2 (-7%)	556.5 (-5%)	856.0 (46%)	559.1 (-5%)	1729.0 (195%)	1363.0 (133%)
2000	AN	428.9	403.6 (-6%)	415.3 (-3%)	422.1 (-2%)	427.5 (0%)	438.1 (2%)	590.0 (38%)	421.2 (-2%)	1316.6 (207%)	1041.4 (143%)

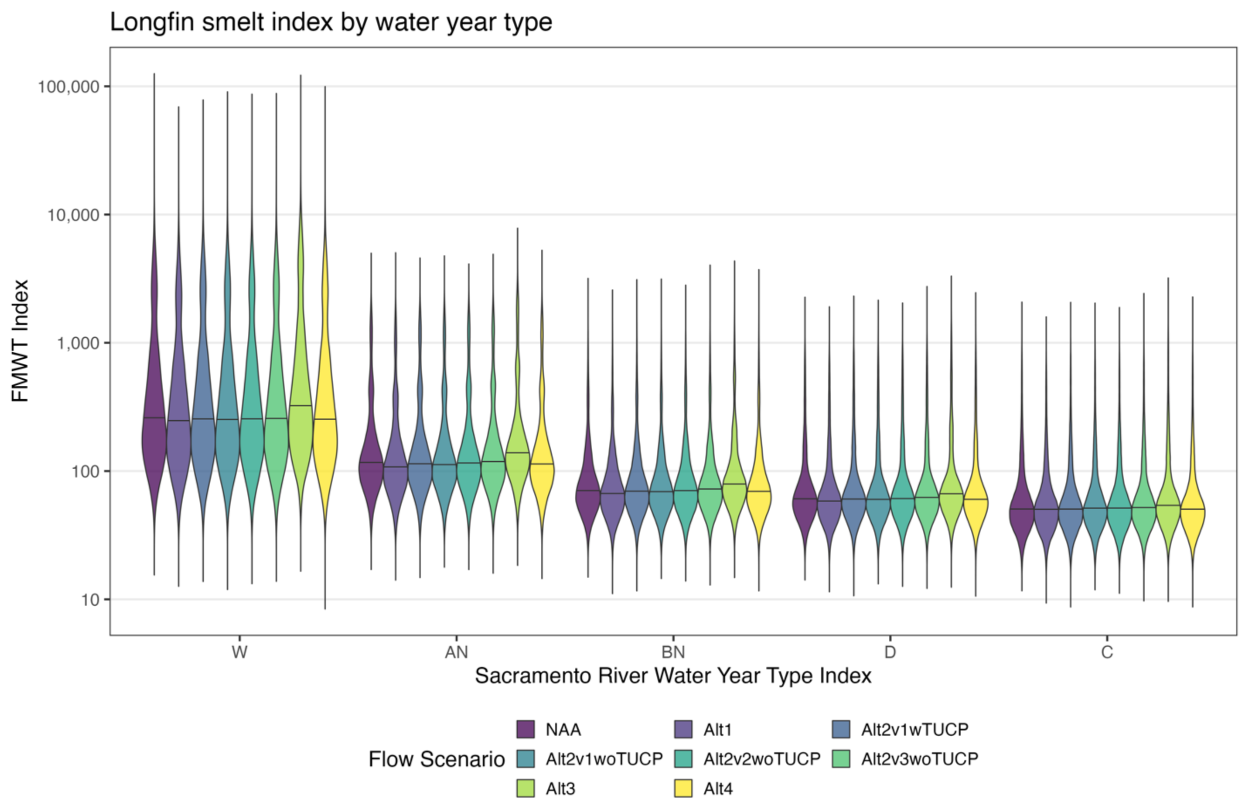
Water Year	WYT	NAA	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4	EXP1	EXP3
2001	D	145.3	129.0 (-11%)	141.2 (-3%)	140.3 (-3%)	143.0 (-2%)	146.8 (1%)	178.9 (23%)	141.7 (-2%)	299.1 (106%)	249.4 (72%)
2002	BN	161.2	151.1 (-6%)	159.8 (-1%)	159.9 (-1%)	163.6 (2%)	173.1 (7%)	219.2 (36%)	162.2 (1%)	407.4 (153%)	310.8 (93%)
2003	AN	154.5	132.9 (-14%)	152.3 (-1%)	149.8 (-3%)	153.3 (-1%)	158.3 (2%)	198.6 (29%)	152.6 (-1%)	360.7 (134%)	268.8 (74%)
2004	AN	164.1	146.0 (-11%)	162.0 (-1%)	161.1 (-2%)	165.1 (1%)	174.3 (6%)	217.0 (32%)	162.7 (-1%)	363.7 (122%)	305.4 (86%)
2005	BN	147.2	129.2 (-12%)	145.2 (-1%)	143.4 (-3%)	148.4 (1%)	153.2 (4%)	194.6 (32%)	146.6 (0%)	433.7 (195%)	298.5 (103%)
2006	W	1352.3	1250.2 (-8%)	1316.3 (-3%)	1319.7 (-2%)	1371.1 (1%)	1388.0 (3%)	2041.8 (51%)	1333.0 (-1%)	3912.4 (189%)	3117.8 (131%)
2007	BN	79.3	72.4 (-9%)	78.5 (-1%)	77.3 (-3%)	80.1 (1%)	81.7 (3%)	98.0 (23%)	78.6 (-1%)	150.3 (89%)	125.3 (58%)
2008	D	190.4	168.1 (-12%)	188.0 (-1%)	185.7 (-2%)	190.5 (0%)	197.3 (4%)	253.6 (33%)	187.1 (-2%)	417.5 (119%)	308.4 (62%)
2009	D	70.3	64.7 (-8%)	69.7 (-1%)	68.8 (-2%)	71.3 (1%)	74.2 (6%)	79.5 (13%)	69.3 (-1%)	134.1 (91%)	97.3 (38%)
2010	BN	118.5	105.5 (-11%)	119.6 (1%)	118.0 (0%)	122.6 (3%)	128.3 (8%)	155.6 (31%)	117.3 (-1%)	271.4 (129%)	196.2 (66%)
2011	W	289.7	263.6 (-9%)	278.0 (-4%)	277.0 (-4%)	280.0 (-3%)	283.0 (-2%)	394.8 (36%)	276.0 (-5%)	687.3 (137%)	536.4 (85%)
2012	BN	79.6	76.4 (-4%)	80.4 (1%)	79.0 (-1%)	81.1 (2%)	83.9 (5%)	98.8 (24%)	79.0 (-1%)	142.5 (79%)	117.8 (48%)
2013	D	108.8	97.5 (-10%)	107.1 (-2%)	107.3 (-1%)	108.3 (0%)	111.5 (3%)	132.7 (22%)	106.5 (-2%)	204.2 (88%)	170.9 (57%)
2014	C	58.5	57.0 (-3%)	58.6 (0%)	58.8 (0%)	59.6 (2%)	59.5 (2%)	64.0 (9%)	58.0 (-1%)	80.8 (38%)	71.1 (21%)
2015	C	69.8	68.6 (-2%)	69.8 (0%)	72.7 (4%)	73.3 (5%)	73.5 (5%)	81.7 (17%)	69.2 (-1%)	116.9 (67%)	95.1 (36%)
2016	BN	83.9	78.3 (-7%)	83.5 (-1%)	81.6 (-3%)	83.1 (-1%)	87.6 (4%)	95.6 (14%)	84.0 (0%)	171.2 (104%)	105.7 (26%)
2017	W	1169.2	1077.1 (-8%)	1155.3 (-1%)	1139.6 (-3%)	1141.0 (-2%)	1123.8 (-4%)	1762.8 (51%)	1134.4 (-3%)	3890.3 (233%)	2596.0 (122%)
2018	BN	77.1	74.6 (-3%)	76.3 (-1%)	76.4 (-1%)	77.8 (1%)	80.8 (5%)	87.7 (14%)	77.2 (0%)	137.5 (78%)	111.1 (44%)
2019	W	684.8	596.1 (-13%)	693.1 (1%)	680.0 (-1%)	699.5 (2%)	689.7 (1%)	1120.3 (64%)	669.8 (-2%)	2657.9 (288%)	1626.7 (138%)
2020	D	60.5	57.8 (-5%)	59.6 (-2%)	59.6 (-1%)	60.6 (0%)	61.8 (2%)	69.4 (15%)	60.3 (0%)	91.7 (52%)	81.5 (35%)
2021	C	124.6	117.2 (-6%)	124.8 (0%)	125.9 (1%)	128.2 (3%)	130.6 (5%)	164.2 (32%)	123.6 (-1%)	262.0 (110%)	203.7 (63%)

The percentage difference between scenarios and NAA is shown in the parentheses.
WYT = Water Year Type; W = Wet; AN = Above Normal; BN = Below Normal; D = Dry; C = Critical; NAA = No Action Alternative.



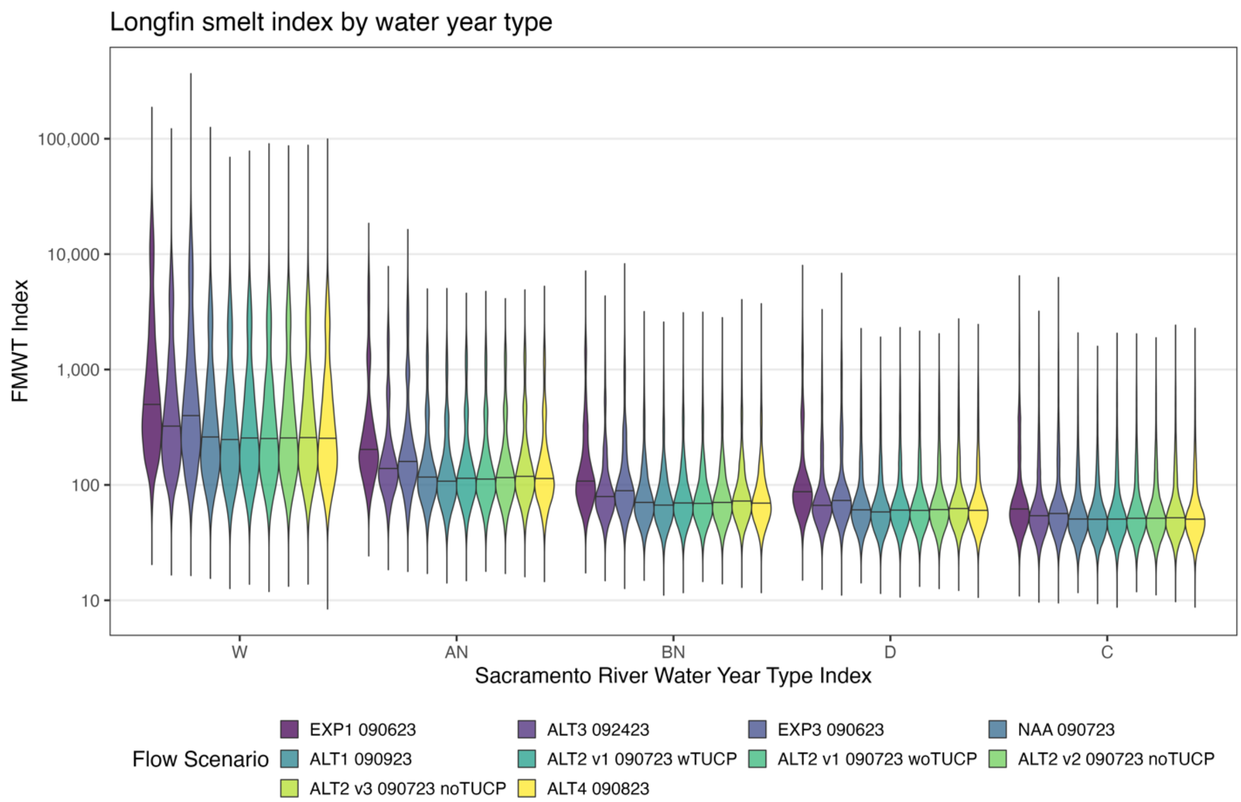
The horizontal line in the distribution for each scenario represents the median predicted value.

Figure J.1-2. Posterior predictive distributions for the FMWT index of Longfin Smelt abundance are shown aggregated by water year type for each scenario.



The horizontal line in the distribution for each scenario represents the median predicted value.

Figure J.1-3. Posterior predictive distributions for the FMWT index of Longfin Smelt abundance are shown aggregated by water year type for each scenario.



The horizontal line in the distribution for each scenario represents the median predicted value.

Figure J.1-4. Posterior predictive distributions for the FMWT index of Longfin Smelt abundance are shown aggregated by water year type for each scenario.

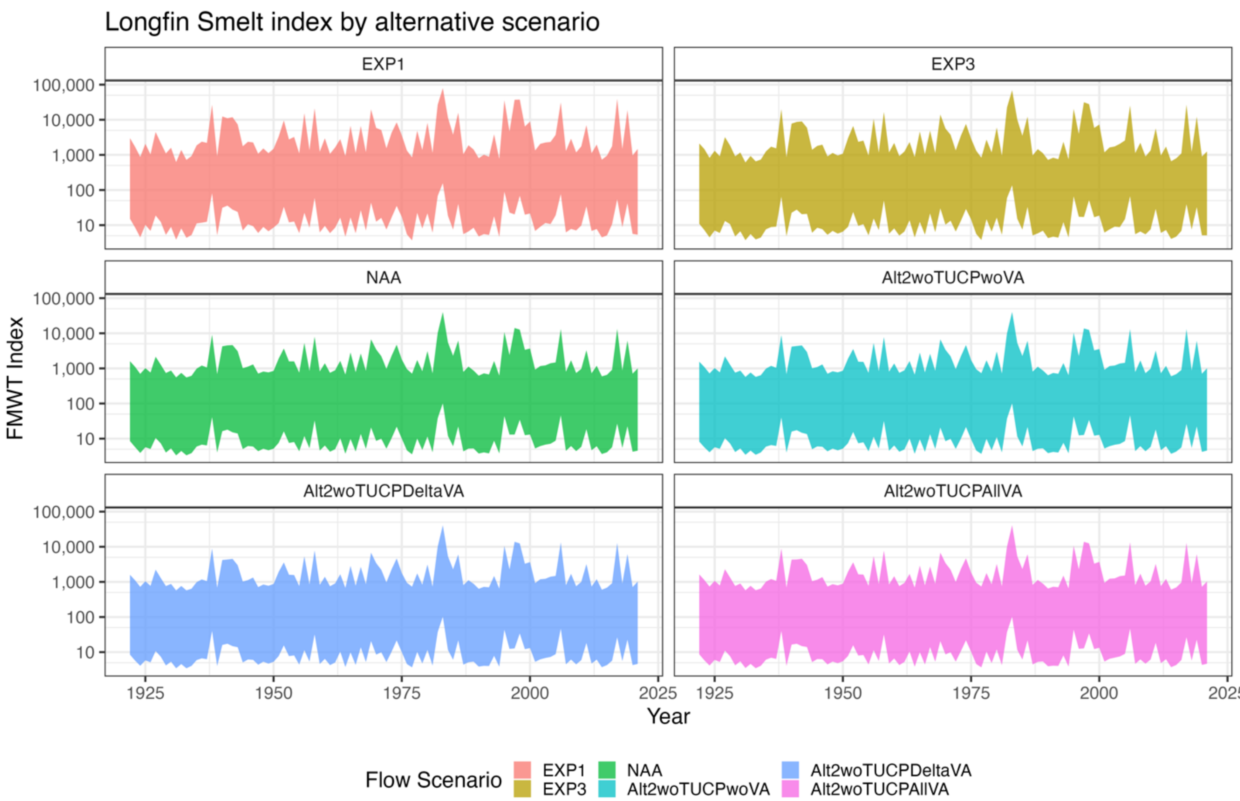
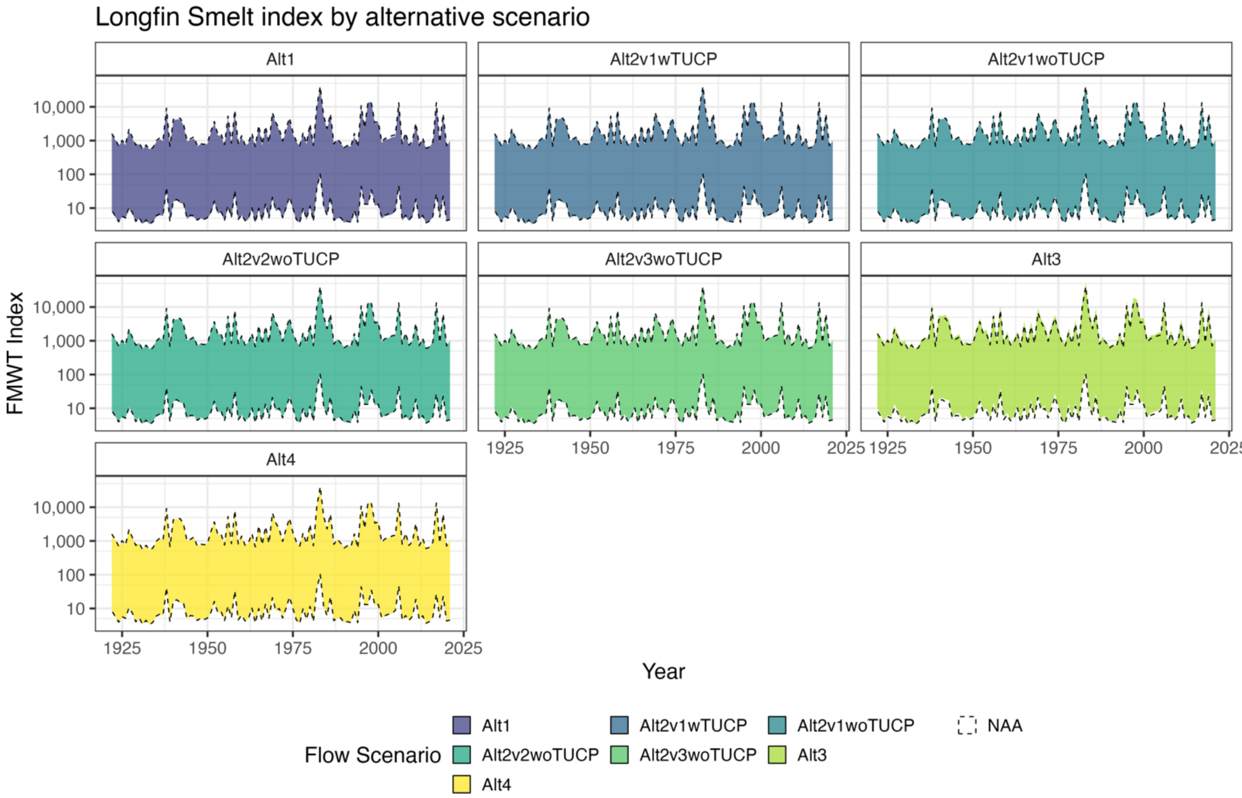


Fig J.1-5. The 95th Bayesian credible intervals for the posterior predictive distributions are shown, based on the parental stock model and the 100 year time series of CalSim 3 Delta Outflow values for each scenario.



The credible intervals for the NAA scenario are overlaid as the dashed black lines for comparison with the alternatives.

Fig J.1-6. The 95th Bayesian credible intervals for the posterior predictive distributions are shown, based on the parental stock model and the 100 year time series of CalSim 3 Delta Outflow values for each scenario.

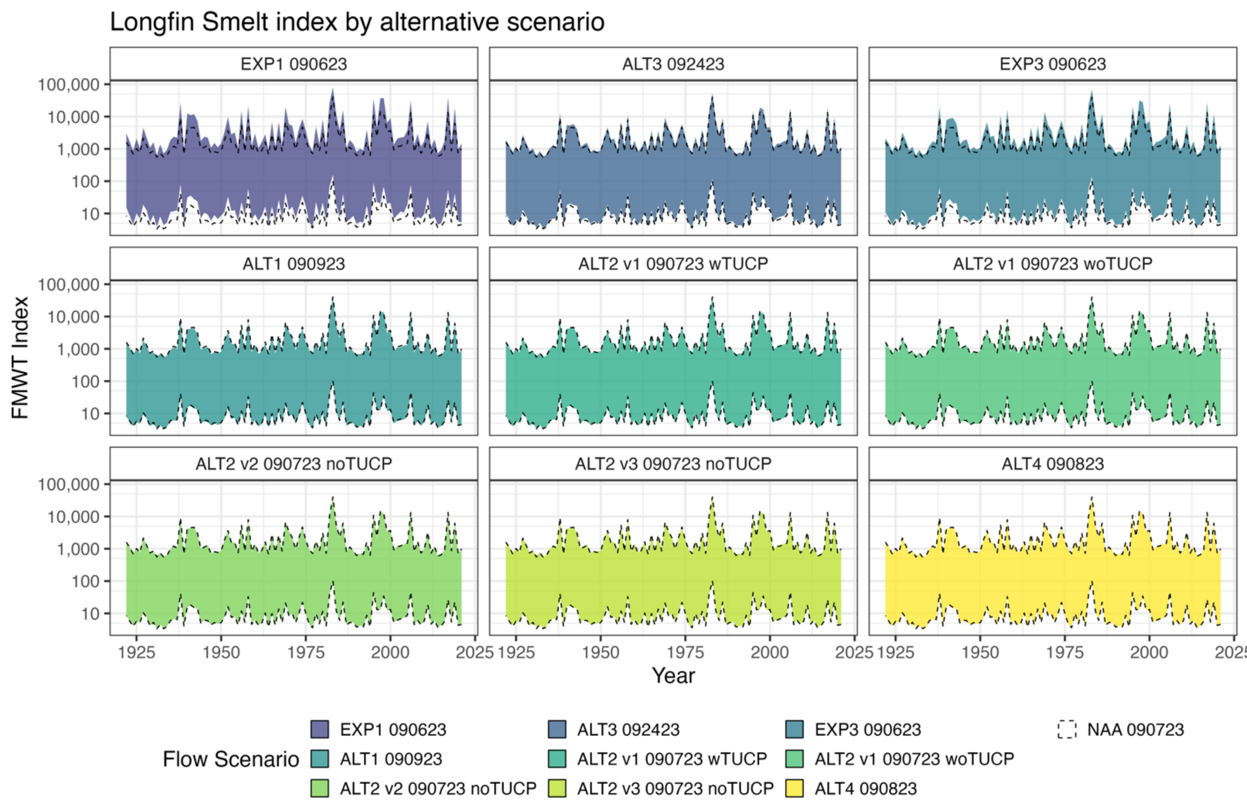


Figure J.1-7. The 95th Bayesian credible intervals for the posterior predictive distributions are shown using the recursive parental stock model to project the predicted abundance forward through time given the 100 year time series of CalSim 3 Delta Outflow values for each scenario.

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