Appendix 11F Smelt Analysis

Appendix 11F Smelt Analysis

11F.1 Introduction

This appendix describes quantitative methods and supplementary results used in the impact analyses of delta smelt and longfin smelt: the *Eurytemora affinis*–X2 analysis for smelt prey, the Delta outflow–longfin smelt abundance analysis (based on Nobriga and Rosenfield 2016), the X2–longfin smelt abundance index analysis, and tidal habitat restoration mitigation calculations for longfin smelt.

11F.2 *Eurytemora affinis*–X2 Analysis

This analysis followed Kimmerer's (2002) methods to conduct an analysis of the relationship between the smelt zooplankton prey *Eurytemora affinis* and spring (March–May) X2 for the period from 1980 to 2017, as described by Greenwood (2018). The main steps in preparing the data for analysis were as follows:

1. Historical zooplankton data were obtained from California Department of Fish and Wildlife (2018).
    a. Data were subset to only include surveys 3, 4, and 5 (March–May).
    b. Specific conductance was converted to salinity by applying Schemel's (2001) method, then only samples within the low salinity zone (salinity = 0.5–6) were selected.
    c. A constant of 10 was added to *E. affinis* adult catch per unit effort (number per cubic meter) in each sample, then the resulting value was $\log_{10}$-transformed.
    d. The $\log_{10}$-transformed values were averaged first by month, and then by year.
2. Historical X2 data were obtained from DAYFLOW (https://www.water.ca.gov/Programs/Environmental-Services/Compliance-Monitoring-And-Assessment/Dayflow-Data).
    a. For years prior to water year 1997 (which is the year DAYFLOW X2 values began to be provided), the DAYFLOW daily predictive equation for X2 was used, based on a starting value from Anke Mueller-Solger (see Greenwood 2018 for details).
    b. The mean March–May X2 was calculated for each year.

Similar to Kimmerer (2002), a generalized linear model (GLM) was used to regress mean annual $\log_{10}$-transformed *E. affinis* catch per unit effort against mean March–May X2, including a step change between 1987 and 1988 to reflect the *Potamocorbula amurensis* clam invasion and a step change between 2002 and 2003 to reflect the onset of the Pelagic Organism Decline (POD;

Thomson et al. 2010). The interaction of X2 and the step change was included in a full model, but the interaction was not statistically significant, so the model was rerun with only X2 and the step changes included. These analyses were conducted in SAS 9.4 software.[1] The statistical outputs indicate that there is little difference in the regression coefficients for the post-*Potamocorbula* and POD step changes, whereas both regression coefficients were significantly less than the coefficient for the pre-*Potamocorbula* period. Regression coefficients from the model were stored for prediction of *E. affinis* relative abundance for the No Action Alternative (NAA) and Alternative 1–3 scenarios.

The stored regression coefficients from the regression of historical *E. affinis* catch per unit effort vs. X2 and step changes were then applied to the NAA and Alternative 1–3 scenarios using PROC PLM in SAS 9.4 software. The basic regression model being applied was:

$$\log_{10}(\textit{E. affinis}\text{ catch per unit effort}) = 3.9404 - 0.0152\text{ (mean March–May X2)} - 0.7863$$

where 3.9404 is the intercept and -0.7863 is the coefficient for the POD step change (the POD step change being chosen because it represents the most recent time period). Predictions were back-transformed to the original measurement scale (catch per unit effort, number per cubic meter) for summary of results. X2 inputs for the analysis came from the DSM2 modeling of water years 1922–2003 for the NAA and Alternative 1–3 scenarios.

Results of the analysis are summarized in the main body of Chapter 11, *Aquatic Biological Resources*. Tables 11F-1 through 11F-5 provide supplemental information also discussed in the main body of Chapter 11.

Table 11F-1. *Eurytemora affinis*–X2 Analysis: Mean and 95% Prediction Limits, NAA.

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1922	154	21	850
1923	125	16	695
1924	64	4	392
1925	120	15	669
1926	111	13	620
1927	174	25	956
1928	129	17	714
1929	73	5	432
1930	106	12	596
1931	62	3	380
1932	102	11	575
1933	75	6	444

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Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1934	85	8	493
1935	135	18	744
1936	148	20	815
1937	134	18	740
1938	196	29	1,082
1939	70	5	420
1940	155	22	855
1941	191	28	1,056
1942	188	27	1,038
1943	164	23	905
1944	94	10	538
1945	118	15	659
1946	125	16	694
1947	87	8	501
1948	108	13	609
1949	96	10	543
1950	122	15	676
1951	149	20	821
1952	202	30	1,121
1953	151	21	830
1954	145	20	800
1955	84	8	486
1956	183	27	1,011
1957	113	14	630
1958	192	28	1,061
1959	107	12	599
1960	93	10	532
1961	94	10	536
1962	108	13	605
1963	157	22	862
1964	82	7	474
1965	160	22	880
1966	118	15	657
1967	203	30	1,121
1968	113	14	632
1969	201	30	1,112

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1970	140	19	771
1971	167	24	917
1972	100	11	567
1973	161	23	884
1974	180	26	990
1975	150	21	825
1976	63	4	387
1977	59	3	368
1978	176	25	970
1979	132	17	733
1980	162	23	891
1981	104	12	588
1982	194	28	1,070
1983	205	30	1,134
1984	147	20	812
1985	87	9	503
1986	145	20	800
1987	86	8	499
1988	84	8	488
1989	97	11	553
1990	72	5	427
1991	76	6	450
1992	88	9	505
1993	188	27	1,037
1994	74	6	438
1995	202	30	1,117
1996	186	27	1,029
1997	147	20	809
1998	201	30	1,110
1999	166	23	912
2000	143	19	789
2001	97	10	550
2002	122	15	680
2003	158	22	872

Table 11F-2. *Eurytemora affinis*–X2 Analysis: Mean and 95% Prediction Limits, Alternative 1A.

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1922	152	21	837
1923	125	16	693
1924	65	4	393
1925	119	15	664
1926	109	13	613
1927	173	25	951
1928	127	16	706
1929	73	6	432
1930	105	12	592
1931	62	3	380
1932	100	11	568
1933	74	6	438
1934	84	8	486
1935	132	17	728
1936	146	20	807
1937	133	17	736
1938	195	29	1,080
1939	70	5	419
1940	155	22	853
1941	191	28	1,055
1942	188	27	1,037
1943	164	23	904
1944	93	10	533
1945	118	15	659
1946	125	16	692
1947	86	8	494
1948	105	12	593
1949	94	10	538
1950	120	15	667
1951	148	20	816
1952	202	30	1,120
1953	150	21	829
1954	144	20	795
1955	84	8	486

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1956	182	26	1,006
1957	111	13	623
1958	191	28	1,057
1959	106	12	598
1960	93	10	529
1961	93	10	531
1962	106	12	594
1963	155	22	856
1964	82	7	475
1965	158	22	869
1966	116	14	646
1967	202	30	1,119
1968	113	14	630
1969	201	30	1,111
1970	140	19	771
1971	166	24	915
1972	99	11	562
1973	160	23	883
1974	179	26	989
1975	149	20	823
1976	63	3	384
1977	59	3	368
1978	175	25	961
1979	131	17	723
1980	162	23	890
1981	103	12	579
1982	194	28	1,070
1983	205	30	1,134
1984	147	20	812
1985	87	8	501
1986	144	20	796
1987	85	8	493
1988	84	8	488
1989	97	10	550
1990	70	5	418
1991	76	6	446

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1992	86	8	499
1993	186	27	1,023
1994	73	6	432
1995	201	30	1,111
1996	186	27	1,025
1997	147	20	809
1998	200	30	1,109
1999	165	23	910
2000	143	19	788
2001	95	10	542
2002	123	15	681
2003	156	22	859

Table 11F-3. *Eurytemora affinis*–X2 Analysis: Mean and 95% Prediction Limits, Alternative 1B.

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1922	152	21	838
1923	125	16	693
1924	65	4	393
1925	119	15	664
1926	109	13	613
1927	172	25	946
1928	127	16	706
1929	73	6	432
1930	105	12	592
1931	62	3	380
1932	100	11	568
1933	74	6	438
1934	85	8	491
1935	132	17	728
1936	146	20	807
1937	133	17	736
1938	195	29	1,080
1939	70	5	418
1940	155	22	855

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1941	191	28	1,055
1942	188	27	1,037
1943	164	23	904
1944	93	10	533
1945	119	15	661
1946	125	16	692
1947	86	8	494
1948	106	12	594
1949	95	10	539
1950	120	15	667
1951	148	20	816
1952	202	30	1,120
1953	151	21	829
1954	144	20	795
1955	84	8	488
1956	182	26	1,006
1957	112	13	624
1958	192	28	1,059
1959	107	12	599
1960	93	10	529
1961	94	10	535
1962	106	12	595
1963	155	22	855
1964	82	7	475
1965	158	22	869
1966	116	14	646
1967	202	30	1,116
1968	113	14	631
1969	201	30	1,111
1970	140	19	772
1971	166	24	915
1972	99	11	562
1973	160	23	883
1974	179	26	989
1975	149	20	823
1976	63	3	385

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1977	60	3	369
1978	174	25	961
1979	131	17	723
1980	162	23	890
1981	103	12	581
1982	194	28	1,070
1983	205	30	1,134
1984	147	20	812
1985	87	8	500
1986	144	20	796
1987	85	8	492
1988	84	8	487
1989	97	10	550
1990	70	5	418
1991	75	6	445
1992	86	8	498
1993	186	27	1,024
1994	73	6	432
1995	201	30	1,111
1996	186	27	1,025
1997	147	20	809
1998	200	30	1,109
1999	165	23	910
2000	143	19	788
2001	95	10	540
2002	123	16	683
2003	156	22	860

Table 11F-4. *Eurytemora affinis*–X2 Analysis: Mean and 95% Prediction Limits, Alternative 2.

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1922	152	21	837
1923	125	16	693
1924	65	4	392
1925	119	15	664

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1926	109	13	613
1927	173	25	951
1928	127	16	706
1929	73	6	432
1930	105	12	592
1931	62	3	380
1932	100	11	568
1933	74	6	438
1934	85	8	491
1935	132	17	728
1936	147	20	808
1937	133	17	736
1938	195	29	1,080
1939	70	5	419
1940	155	22	853
1941	191	28	1,055
1942	188	27	1,037
1943	164	23	904
1944	93	10	533
1945	118	15	659
1946	125	16	692
1947	86	8	494
1948	105	12	593
1949	94	10	538
1950	119	15	665
1951	148	20	816
1952	202	30	1,120
1953	151	21	829
1954	144	20	795
1955	84	8	486
1956	182	26	1,006
1957	111	13	623
1958	191	28	1,057
1959	106	12	598
1960	93	10	529
1961	93	10	531

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1962	106	12	594
1963	155	22	855
1964	82	7	475
1965	158	22	869
1966	116	14	646
1967	202	30	1,119
1968	113	14	630
1969	201	30	1,111
1970	140	19	772
1971	166	24	915
1972	99	11	562
1973	160	23	883
1974	179	26	989
1975	149	20	823
1976	63	3	384
1977	60	3	369
1978	174	25	961
1979	131	17	723
1980	162	23	890
1981	103	12	581
1982	194	28	1,070
1983	205	30	1,134
1984	147	20	812
1985	87	8	501
1986	144	20	796
1987	85	8	493
1988	84	8	488
1989	97	10	551
1990	70	5	418
1991	76	6	446
1992	86	8	498
1993	186	27	1,023
1994	73	6	432
1995	201	30	1,111
1996	186	27	1,027
1997	147	20	809

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1998	200	30	1,109
1999	165	23	910
2000	143	19	788
2001	95	10	542
2002	123	15	681
2003	156	22	860

Table 11F-5. *Eurytemora affinis*–X2 Analysis: Mean and 95% Prediction Limits, Alternative 3.

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1922	152	21	838
1923	125	16	693
1924	65	4	393
1925	119	15	664
1926	109	13	614
1927	172	25	948
1928	127	16	706
1929	73	6	433
1930	105	12	592
1931	62	3	380
1932	101	11	568
1933	74	6	438
1934	84	8	486
1935	132	17	728
1936	146	20	807
1937	133	17	737
1938	195	29	1,080
1939	69	5	415
1940	155	22	856
1941	191	28	1,057
1942	188	27	1,037
1943	164	23	904
1944	93	10	533
1945	116	14	647
1946	125	16	692

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1947	87	8	499
1948	107	12	599
1949	95	10	541
1950	120	15	666
1951	148	20	815
1952	202	30	1,120
1953	151	21	829
1954	144	20	795
1955	86	8	496
1956	182	26	1,006
1957	112	13	624
1958	192	28	1,061
1959	106	12	598
1960	93	10	530
1961	93	10	532
1962	105	12	593
1963	155	22	855
1964	81	7	473
1965	158	22	869
1966	116	14	646
1967	201	30	1,115
1968	113	14	630
1969	201	30	1,113
1970	140	19	772
1971	166	24	915
1972	99	11	561
1973	160	22	882
1974	179	26	989
1975	149	20	822
1976	63	3	384
1977	59	3	366
1978	175	25	962
1979	131	17	724
1980	162	23	890
1981	103	12	581
1982	194	28	1,070

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1983	205	30	1,134
1984	147	20	812
1985	87	8	500
1986	145	20	802
1987	85	8	492
1988	84	8	488
1989	98	11	556
1990	70	5	418
1991	75	6	443
1992	87	8	501
1993	186	27	1,024
1994	73	6	432
1995	201	30	1,111
1996	186	27	1,025
1997	147	20	809
1998	200	30	1,109
1999	165	23	910
2000	143	19	788
2001	95	10	540
2002	123	16	684
2003	156	22	860

11F.3 Delta Outflow–Longfin Smelt Abundance Analysis (Based on Nobriga and Rosenfield 2016)

Nobriga and Rosenfield (2016) examined various formulations of a Ricker (1954) stock-recruitment model to simulate fall midwater trawl indices through time. They found that December–May Delta outflow had a positive association with recruits per spawner and that juvenile recruitment from age 0 to age 2 was density dependent (lower survival with greater numbers of juveniles) but cautioned that the density dependence in the model may be too strong.[2] As described by California Department of Water Resources (2020:4-178), it should also be noted that analyses relying on surveys such as the fall midwater trawl index do not fully encompass the range of longfin smelt and do not reflect potential changes in catchability over time because of factors such as increased water clarity and gear avoidance (Latour 2016) that are the subject of ongoing investigations. Nonetheless, the model represents the best available option for assessing potential impacts of Alternatives 1–3.

11F.3.1. Reproduction of Nobriga and Rosenfield (2016) Model

This analysis reproduced the methods described in Nobriga and Rosenfield (2016) for calculation of the two-life-stage model referred to as the “2abc” model, which includes the embedded hypotheses that understanding the trend in age-0 LFS relative abundance requires explicit modeling of spawning and recruit relative abundance, that the production of age-0 fish is density dependent, and that juvenile survival from age 0 to age 2 has changed over time. For purposes of this effects analysis, the “2abc” model was selected because its median predictions visually fit recent years of empirical data better than the other model evaluated.

Model input data used to reproduce the “2abc” model were as provided in Table 2 of Nobriga and Rosenfield (2016). The input data are provided in Appendix A of Greenwood and Phillis (2018). The analyses were run in R software (R Core Team 2016).

Graphical comparison of the reproduction of the “2abc” model to the original Nobriga and Rosenfield (2016) “2abc” model (Figure 11F-1 and Figure 11F-2) suggests that the reproduced model was a reasonable approximation of the original model (i.e., the reproduction of the method was reasonably successful). It should be noted that the original “2abc” model 95% confidence intervals are wider than the reproduction utilized in this analysis. However, the model coefficients and standard errors are identical between the original and reproduced models. Therefore, the reproduced “2abc” model utilized in this analysis is considered appropriate, and the differences in 95% confidence intervals among the original and reproduced models do not affect the comparison of the scenarios discussed below.

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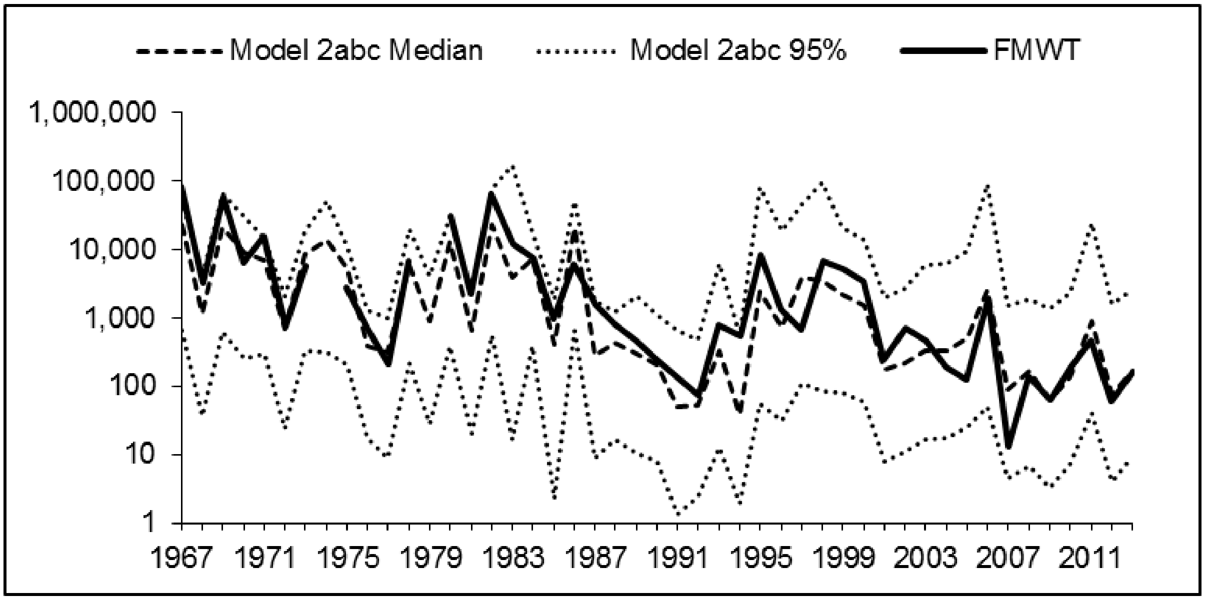
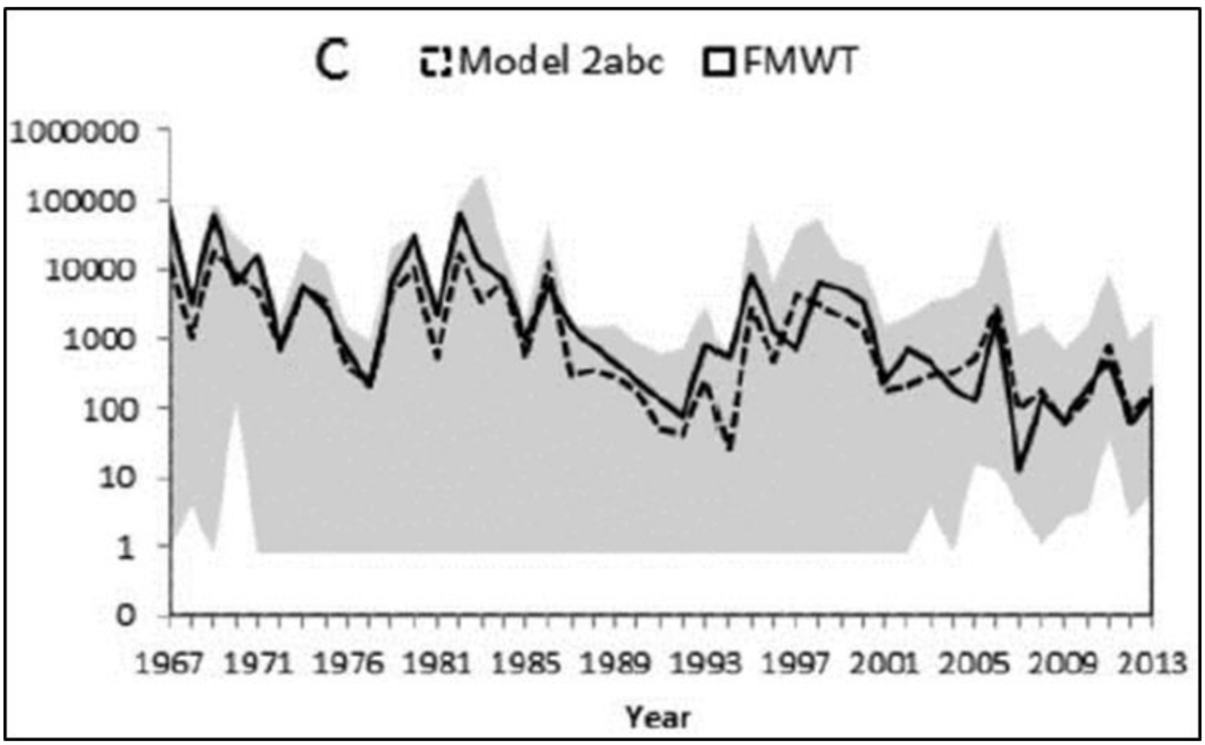
[2] Comments on the draft Environmental Impact Report for Long-Term Operation of the California State Water Project suggested that a form of stock-recruitment function other than the Ricker method used by Nobriga and Rosenfield (2016) would be appropriate for exploration, such as the Beverton-Holt method (California Department of Water Resources 2020:4-178). The Beverton-Holt method was explored for the FEIR but was found to be a poorer fit to the empirical data than the Ricker method, so the Ricker method consistent with Nobriga and Rosenfield (2016) was retained (California Department of Water Resources 2020:4-178). For the present impact analysis of Alternatives 1–3 compared to NAA, the Ricker method was also retained, consistent with California Department of Water Resources (2020) and Nobriga and Rosenfield (2016).



Source: California Department of Water Resources (2020:E-86).
FMWT = fall midwater trawl.

Figure 11F-1. Reproduction of Nobriga and Rosenfield (2016) 2abc Model Predictions Compared to Historical Fall Midwater Trawl Survey Longfin Smelt Abundance Index.



Source: California Department of Water Resources (2020:E-86).
Grey shading indicates 95% interval.
FMWT = fall midwater trawl.

Figure 11F-2. Original (Figure 6c of Nobriga and Rosenfield 2016) 2abc Model Predictions Compared to Historical Fall Midwater Trawl Survey Longfin Smelt Abundance Index.

11F.3.2. Calculation of Delta Outflow Model Inputs for Scenario Comparison

To obtain the required first principal component (PC1) model inputs for comparison of the NAA and Alternative 1–3 scenarios, it was first necessary to reproduce the principal components analysis (PCA). Following Nobriga and Rosenfield (2016), historical daily Delta outflow data were acquired from the DAYFLOW database.[3] Flow data were averaged for December to May by month and year and the Principal Component Analysis was conducted using the 'PCA' function in the R package FactoMineR (Le et al. 2008) on water years 1956–2013. The resulting PC1 outputs were very similar to the original values computed by Nobriga and Rosenfield (2016), suggesting that the reported method had been successfully reproduced.[4] The 'predict PCA' function was then used to predict PC1 values for the NAA and Alternative 1–3 scenarios for water years 1922–2003 based on the CalSim modeling of the scenarios, on the same projection as the PCA. The resulting PC1 values were used as the input for the model simulation of the flow scenarios described in the next section.

11F.3.3. Model Simulation to Compare Scenarios

Model simulation to compare the NAA and Alternative 1–3 scenarios used the PC1 flow inputs. To produce a simulation for the 1922–2003 time series, and consistent with Nobriga and Rosenfield (2016), the model was initiated with 2 years (i.e., years 1922 and 1923) of Fall Mid-water Trawl (FMWT) indices equal to 798, which represents the median observed FMWT index from 1967 to 2013. The simulation was conducted for two juvenile survival functions:

- 'good', which used the pre-1991 relatively high survival for simulation over the full 1922–2003 time series;
- 'poor', which used the post-1991 relatively low survival for simulation over the full 1922–2003 simulation time series.

Following Nobriga and Rosenfield (2016), 1,000 stochastic simulations were conducted in which random draws were made based on the mean and standard error of the model parameters. Consistent with Nobriga and Rosenfield (2016), the variability among the estimates was examined using the 95% intervals. Violin plots were used to illustrate the distribution of simulated FMWT indices. Results of the analysis are summarized in the main body of Chapter 11, *Aquatic Biological Resources*.

11F.4 X2–Longfin Smelt Abundance Index Analysis

The method is the same as that used recently by California Department of Water Resources (2020). The methods described herein are the same as those used in that application; the methods description below was adapted from California Department of Water Resources (2020:E2-1).

[3] https://www.water.ca.gov/Programs/Environmental-Services/Compliance-Monitoring-And-Assessment/Dayflow-Data

[4] The small differences may have arisen because of varying PCA algorithms in different statistical software packages, for example.

The analysis essentially updated previously described X2-abundance index regressions (Kimmerer et al. 2009, Mount et al. 2013) by adding additional years of data. Updating the analysis allowed full accounting of sources of error in the predictions, allowing calculation of prediction intervals from estimates of X2, as recommended by Simenstad et al. (2016), for the NAA and Alternative 1–3 scenarios.

Longfin smelt fall-mid-water trawl index data were obtained (http://www.dfg.ca.gov/delta/data/fmwt/indices.asp?view=single), including indices for 1967–2014 (excluding 1974 and 1979, when there was no sampling). For each index year, mean X2 during January–June was calculated based on X2 from the DAYFLOW database (https://data.cnra.ca.gov/dataset/dayflow), in addition to calculated X2 for earlier years.[5]

Similar to Mount et al. (2013), GLMs were run, predicting longfin smelt fall midwater trawl relative abundance index as a function of X2 and step changes in 1987/1988 and 2002/2003:

$$\mathrm{Log}_{10}(\mathrm{FMWT\ index}_y) = a + b\cdot(\mathrm{mean\ X2}_y) + c\cdot\mathrm{period}_y$$

Where *y* indicates year, *a* is the intercept, *b* is the coefficient applied to the mean Delta outflow, and *c* takes one of three values for period: 0 for the pre-*Potamocorbula* period (1967–1987), and values to be estimated for post-*Potamocorbula* (1988–2002) and Pelagic Organism Decline (POD; 2003–2014) periods.

Regarding the months used for mean X2, Mount et al. (2013:67) noted the following:

> *The months selected in the original analysis [by Jassby et al. 1995] were based on the assumption that the (unknown) X2 mechanism operated during early life history of Longfin Smelt, which smelt experts linked to this period. Autocorrelation in the X2 values through months means that statistical analysis provides little guidance for improving the selection of months. A better understanding of the mechanism(s) underlying the relationship would probably allow this period to be narrowed and focused, but for now there is little basis for selecting a narrower period for averaging X2.*

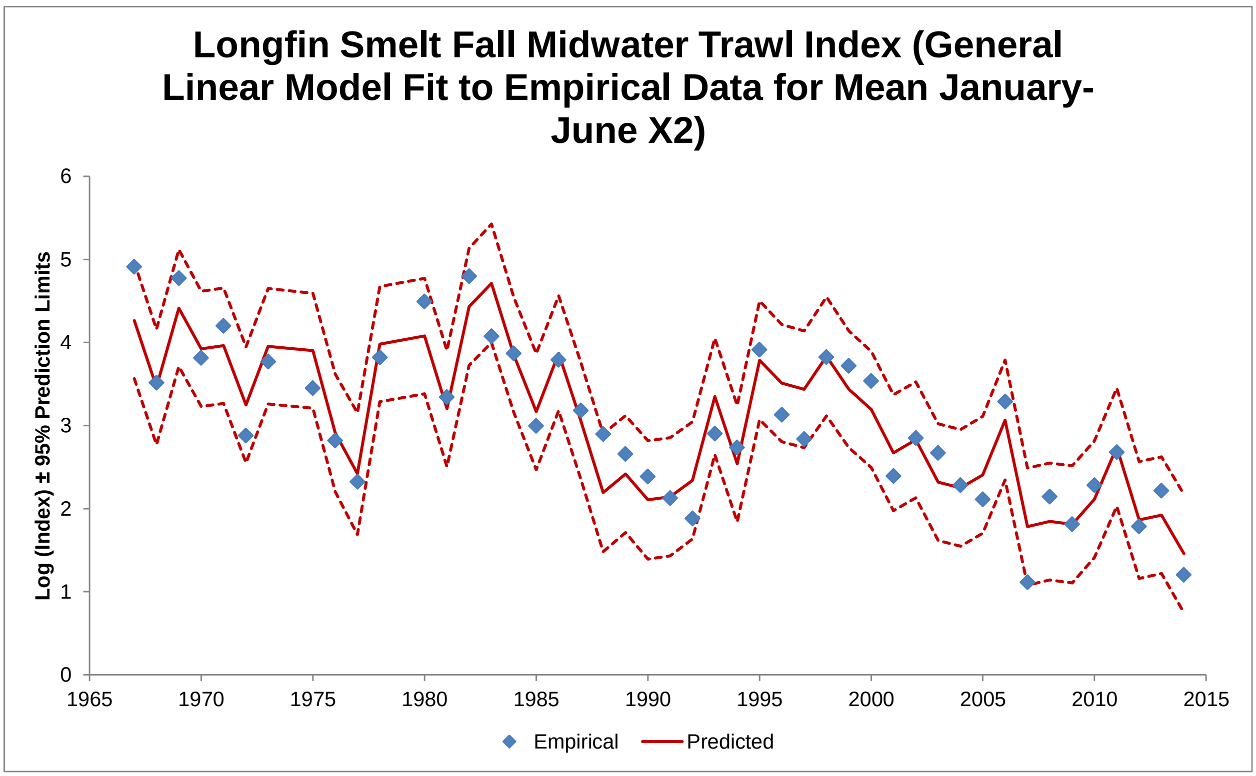
Mount et al. (2013) compared the fit of X2 averaging periods for January–June (i.e., the original period used by Jassby et al. 1995, also used by Kimmerer et al. 2009) and March–May; they selected the former because the fit to the empirical data was slightly superior. In the present analysis, both the January–June and March–May averaging periods were compared for their adequacy of fit, using standard criteria (Akaike's Information Criterion adjusted for small sample sizes, AIC_c; and variation explained, r^2). This showed that the January–June X2 averaging period was better supported in terms of explaining variability in the FWMT index (Table 11F-6; Figure 11F-3), so this averaging period was used in the subsequent comparison of the NAA and Alternative 1–3 scenarios based on DSM2 outputs of X2.

[5] DAYFLOW provides X2 estimates from water year 1997 onwards, so the DAYFLOW equation (X2(t) = 10.16 + 0.945*X2(t-1) – 1.487log(QOUT(t))) was used to provide X2 for earlier years, based on a starting unpublished estimate of X2 (Mueller-Solger 2012 as cited by Greenwood [2018: 3]).

Table 11F-6. Parameter Coefficients for General Linear Models Explaining Longfin Smelt Fall Midwater Trawl Index as a Function of Mean January–June and March–May X2 and Step Changes in 1987/1988 (*Potamocorbula* Invasion) and 2002/2003 (Pelagic Organism Decline).

Parameter	January–June Estimate	January–June Standard Error	January–June *P*	March–May Estimate	March–May Standard Error	March–May *P*
a (Intercept)	7.3059	0.3299	< 0.0001	6.8100	0.3224	< 0.0001
b (X2)	-0.0542	0.0049	< 0.0001	-0.0475	0.0047	< 0.0001
c (Period: Post-*Potamocorbula*)	-0.5704	0.1174	< 0.0001	-0.6368	0.1271	< 0.0001
c (Period: POD)	-1.4067	0.1244	< 0.0001	-1.4581	0.1351	< 0.0001
Fit	-	-	-	-	-	-
AIC_c[1]	-47.4904	-47.4904	-47.4904	-39.5492	-39.5492	-39.5492
r^2	0.8666	0.8666	0.8666	0.8414	0.8414	0.8414

Note:
[1] The difference of ~8 AIC_c units between the two GLMs indicates that the January–June mean X2 GLM is better supported in terms of explaining the patterns in the data (Burnham et al. 2011).



Source: California Department of Water Resources 2020:E2-3.

Figure 11F-3. Fit to Empirical Data of General Linear Model Predicting Longfin Smelt Fall Midwater Trawl Relative Abundance Index as a Function of Mean January–June X2 and Step Changes for *Potamocorbula* and Pelagic Organism Decline.

For the comparison of the NAA and Alternative 1–3 scenarios, mean January–June X2 was calculated for each year of the 1922–2003 simulation based on DSM2 X2 outputs. The X2-abundance index GLM calculated as above was used to estimate abundance index for the scenarios, based on the POD period coefficient in addition to the intercept and X2 slope terms. The basic equation used was (see also Table 11F-6):

$$\log_{10}(\text{Longfin Smelt FMWT index}) = 7.3059 - 0.0542*(\text{January–June X2}) - 1.4067$$

The log-transformed abundance indices were back-transformed to a linear scale for comparison of scenarios. In order to illustrate the variability in predictions from the X2-abundance index GLM, annual estimates were made for the mean and upper and lower 95% prediction limits of the abundance indices, as recommended by Simenstad et al. (2016). Statistical analyses were conducted with PROC GLM and PROC PLM in SAS/STAT software, Version 9.4 of the SAS System for Windows.[6]

Results of the analysis are summarized in the main body of Chapter 11, *Aquatic Biological Resources*. Tables 11F-7 through 11F-11 provide supplemental information also discussed in the main body of Chapter 11.

Table 11F-7. X2–Longfin Smelt Abundance Index Analysis: Mean and 95% Prediction Limits, NAA.

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1922	351	61	1,824
1923	171	26	902
1924	12	-6	102
1925	148	21	787
1926	111	14	598
1927	526	94	2,742
1928	189	29	993
1929	21	-4	151
1930	94	11	516
1931	9	-6	90
1932	82	8	453
1933	25	-3	169
1934	42	0	254
1935	219	35	1,145
1936	303	52	1,577

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Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1937	215	34	1,124
1938	795	145	4,178
1939	18	-5	135
1940	359	62	1,865
1941	733	133	3,843
1942	692	126	3,623
1943	437	77	2,274
1944	62	4	353
1945	140	20	745
1946	170	26	898
1947	45	1	270
1948	103	12	558
1949	65	5	367
1950	153	22	814
1951	312	53	1,622
1952	892	163	4,698
1953	323	56	1,680
1954	284	48	1,482
1955	39	0	240
1956	635	115	3,321
1957	117	15	631
1958	744	135	3,904
1959	96	11	527
1960	59	4	340
1961	61	4	349
1962	100	12	545
1963	370	65	1,922
1964	35	-1	219
1965	397	70	2,064
1966	138	19	735
1967	893	163	4,706
1968	119	16	639
1969	868	158	4,570
1970	249	41	1,302
1971	456	81	2,372
1972	77	7	432

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1973	402	71	2,090
1974	591	107	3,085
1975	317	54	1,649
1976	11	-6	97
1977	7	-7	78
1978	553	99	2,884
1979	207	33	1,086
1980	414	73	2,155
1981	90	10	492
1982	765	139	4,017
1983	927	169	4,890
1984	300	51	1,561
1985	46	1	275
1986	284	48	1,482
1987	44	1	266
1988	40	0	244
1989	69	6	391
1990	20	-4	145
1991	27	-3	178
1992	47	1	279
1993	689	125	3,609
1994	23	-4	160
1995	882	161	4,645
1996	672	122	3,516
1997	296	50	1,542
1998	864	158	4,548
1999	448	80	2,334
2000	271	45	1,411
2001	68	5	384
2002	158	23	835
2003	384	67	1,999

Table 11F-8. X2–Longfin Smelt Abundance Index Analysis: Mean and 95% Prediction Limits, Alternative 1A.

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1922	333	57	1,732
1923	169	25	892
1924	12	-6	103
1925	144	21	765
1926	105	13	572
1927	516	92	2,688
1928	181	28	955
1929	21	-4	152
1930	92	10	505
1931	9	-6	90
1932	78	7	432
1933	23	-4	160
1934	39	0	240
1935	202	32	1,060
1936	293	50	1,525
1937	211	34	1,106
1938	789	144	4,143
1939	18	-5	135
1940	355	62	1,848
1941	731	133	3,834
1942	690	125	3,615
1943	435	77	2,262
1944	59	4	341
1945	140	20	746
1946	168	25	888
1947	42	0	256
1948	93	10	508
1949	62	4	354
1950	146	21	776
1951	305	52	1,586
1952	891	162	4,693
1953	322	55	1,676
1954	278	47	1,449
1955	39	0	241

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1956	624	113	3,262
1957	113	14	608
1958	736	134	3,860
1959	96	11	523
1960	58	3	333
1961	59	4	337
1962	93	10	511
1963	359	63	1,870
1964	35	-1	220
1965	379	66	1,972
1966	129	18	692
1967	886	162	4,669
1968	118	15	633
1969	866	158	4,558
1970	250	41	1,303
1971	453	80	2,357
1972	75	7	417
1973	401	71	2,087
1974	588	106	3,072
1975	313	54	1,632
1976	10	-6	94
1977	7	-7	78
1978	536	96	2,792
1979	197	31	1,035
1980	412	73	2,141
1981	84	9	463
1982	765	139	4,014
1983	927	169	4,890
1984	299	51	1,558
1985	45	1	271
1986	279	47	1,455
1987	42	0	254
1988	40	0	244
1989	68	5	385
1990	18	-5	133
1991	25	-3	172

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1992	44	1	265
1993	660	120	3,454
1994	21	-4	152
1995	866	158	4,561
1996	663	120	3,470
1997	295	50	1,536
1998	861	157	4,534
1999	445	79	2,316
2000	269	45	1,403
2001	64	5	364
2002	159	23	839
2003	365	64	1,897

Table 11F-9. X2–Longfin Smelt Abundance Index Analysis: Mean and 95% Prediction Limits, Alternative 1B.

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1922	334	58	1,740
1923	169	25	892
1924	12	-6	103
1925	144	21	765
1926	106	13	573
1927	507	91	2,643
1928	181	28	954
1929	21	-4	152
1930	92	10	505
1931	9	-6	90
1932	78	7	432
1933	23	-4	160
1934	41	0	250
1935	202	32	1,061
1936	293	50	1,525
1937	211	34	1,106
1938	789	144	4,143
1939	18	-5	133
1940	359	63	1,867

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1941	731	133	3,835
1942	691	125	3,616
1943	435	77	2,262
1944	59	4	341
1945	141	20	752
1946	168	25	888
1947	43	0	257
1948	93	10	509
1949	62	4	356
1950	146	21	776
1951	304	52	1,585
1952	891	162	4,693
1953	322	55	1,676
1954	278	47	1,447
1955	40	0	245
1956	624	113	3,262
1957	113	14	611
1958	740	135	3,879
1959	96	11	525
1960	58	3	332
1961	60	4	346
1962	94	11	513
1963	359	63	1,868
1964	35	-1	220
1965	379	66	1,972
1966	129	18	692
1967	880	161	4,637
1968	118	15	637
1969	866	158	4,562
1970	250	41	1,303
1971	453	81	2,358
1972	74	7	415
1973	401	71	2,088
1974	588	106	3,072
1975	313	54	1,632
1976	10	-6	94

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1977	7	-7	79
1978	534	96	2,785
1979	197	31	1,035
1980	412	73	2,142
1981	85	9	471
1982	765	139	4,014
1983	927	169	4,890
1984	299	51	1,558
1985	45	1	269
1986	279	47	1,457
1987	42	0	252
1988	40	0	243
1989	68	5	383
1990	18	-5	133
1991	25	-3	171
1992	44	1	265
1993	663	120	3,467
1994	21	-4	152
1995	867	158	4,563
1996	664	120	3,475
1997	295	50	1,536
1998	861	157	4,534
1999	445	79	2,316
2000	269	45	1,403
2001	63	4	359
2002	160	24	846
2003	366	64	1,903

Table 11F-10. X2–Longfin Smelt Abundance Index Analysis: Mean and 95% Prediction Limits, Alternative 2.

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1922	333	57	1,732
1923	169	25	892
1924	12	-6	103
1925	144	21	766

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1926	106	13	572
1927	516	93	2,689
1928	181	28	955
1929	21	-4	152
1930	92	10	505
1931	9	-6	90
1932	78	7	432
1933	23	-4	160
1934	41	0	250
1935	202	32	1,060
1936	294	50	1,530
1937	211	34	1,106
1938	789	144	4,143
1939	18	-5	135
1940	355	62	1,848
1941	731	133	3,835
1942	691	125	3,616
1943	435	77	2,262
1944	59	4	341
1945	140	20	746
1946	168	25	888
1947	42	0	256
1948	93	10	508
1949	62	4	354
1950	145	21	769
1951	305	52	1,586
1952	891	163	4,693
1953	322	55	1,676
1954	278	47	1,449
1955	39	0	241
1956	624	113	3,262
1957	113	14	608
1958	736	134	3,860
1959	96	11	523
1960	58	3	333
1961	59	4	337

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1962	93	10	510
1963	359	63	1,868
1964	35	-1	220
1965	379	66	1,972
1966	129	18	692
1967	886	162	4,669
1968	118	15	633
1969	866	158	4,558
1970	250	41	1,303
1971	453	81	2,358
1972	75	7	417
1973	401	71	2,087
1974	588	106	3,072
1975	313	54	1,632
1976	10	-6	94
1977	7	-7	79
1978	534	96	2,786
1979	197	31	1,035
1980	412	73	2,142
1981	85	9	471
1982	765	139	4,014
1983	927	169	4,890
1984	299	51	1,558
1985	45	1	271
1986	279	47	1,455
1987	42	0	254
1988	40	0	244
1989	68	6	386
1990	18	-5	133
1991	25	-3	172
1992	44	1	265
1993	660	120	3,454
1994	21	-4	152
1995	866	158	4,562
1996	667	121	3,492
1997	295	50	1,536

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1998	861	157	4,535
1999	445	79	2,316
2000	269	45	1,403
2001	64	5	365
2002	158	23	839
2003	366	64	1,902

Table 11F-11. X2–Longfin Smelt Abundance Index Analysis: Mean and 95% Prediction Limits, Alternative 3.

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1922	334	58	1,740
1923	169	25	892
1924	12	-6	103
1925	144	21	764
1926	106	13	575
1927	510	91	2,658
1928	181	28	954
1929	22	-4	153
1930	92	10	504
1931	9	-6	90
1932	78	7	434
1933	23	-4	160
1934	39	0	240
1935	202	32	1,061
1936	293	50	1,526
1937	212	34	1,109
1938	789	144	4,143
1939	17	-5	129
1940	360	63	1,872
1941	734	133	3,849
1942	691	125	3,617
1943	435	77	2,263
1944	59	4	341
1945	131	18	698
1946	168	25	888

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1947	44	1	267
1948	96	11	525
1949	64	5	362
1950	145	21	772
1951	304	52	1,583
1952	891	162	4,692
1953	322	55	1,677
1954	277	47	1,446
1955	43	0	261
1956	624	113	3,262
1957	113	14	611
1958	743	135	3,899
1959	96	11	523
1960	58	3	334
1961	59	4	340
1962	93	10	508
1963	359	63	1,868
1964	35	-1	217
1965	379	66	1,972
1966	129	18	692
1967	875	160	4,611
1968	118	15	633
1969	871	159	4,584
1970	250	41	1,303
1971	453	81	2,359
1972	74	7	414
1973	400	70	2,079
1974	589	106	3,073
1975	313	54	1,630
1976	10	-6	94
1977	6	-7	76
1978	537	96	2,799
1979	198	31	1,039
1980	412	73	2,143
1981	86	9	472
1982	765	139	4,015

Year	Mean Estimate	Lower 95% Prediction Limit	Upper 95% Prediction Limit
1983	927	169	4,890
1984	299	51	1,558
1985	45	1	269
1986	286	48	1,492
1987	41	0	252
1988	40	0	244
1989	71	6	400
1990	18	-5	133
1991	25	-3	168
1992	45	1	270
1993	661	120	3,459
1994	21	-4	152
1995	867	158	4,564
1996	664	120	3,475
1997	295	50	1,536
1998	861	157	4,534
1999	445	79	2,316
2000	269	45	1,403
2001	63	4	359
2002	160	24	849
2003	366	64	1,903

11F.5 Tidal Habitat Restoration Mitigation Calculations for Longfin Smelt

Tidal habitat restoration mitigation for longfin smelt was calculated based on the same method recently applied by California Department of Water Resources (2019:5-5). The method applied is that of Kratville (2010), who combined statistical relationships between export:inflow (E:I) ratio and proportion of particles entrained from various particle injection locations included in DSM2-PTM runs by Kimmerer and Nobriga (2008) with areas of habitat represented by groups of particle injection locations. The logistic equations for these particle injection locations that were applied in the analysis to mean CalSim-modeled E:I during February–June were as follows (Nobriga pers. comm.; see Kratville 2010 for further explanation of station codes):

- Antioch: Proportional entrainment = $1-(1/(1+ 0.00271028300855596*e^{6.84578776491213*E:I}))$
- Bacon Island: Proportional entrainment = $1-(1/(1+ 0.00360067831643248*e^{48.0279532945984*E:I}))$

- Collinsville: Proportional entrainment = 1-(1/(1+ $0.00122681735447479*e^{7.34600447344753*E:I}$))
- Franks Tract East: Proportional entrainment = 1-(1/(1+ $0.0882721350895259*e^{6.51283857598075*E:I}$))
- Franks West: Proportional entrainment = 1-(1/(1+ $0.0321221161869743*e^{5.5544157874989*E:I}$))
- Georgiana Slough: Proportional entrainment = 1-(1/(1+ $0.0556193254426028*e^{7.53188118299606*E:I}$))
- Hood: Proportional entrainment = 1-(1/(1+ $0.0370940945312037*e^{6.00721899458561*E:I}$))
- Medford Island: Proportional entrainment = 1-(1/(1+ $0.00592509281258315*e^{34.8002358833536*E:I}$))
- Mossdale: Proportional entrainment = 1-(1/(1+ $0.111111111111111*e^{26.6493233888825*E:I}$))
- North Fork Mokelumne: Proportional entrainment = 1-(1/(1+ $0.0610234435346189*e^{7.28620279196804*E:I}$))
- Potato Slough: Proportional entrainment = 1-(1/(1+ $0.0163841512024925*e^{23.708308398635*E:I}$))
- Rio Vista: Proportional entrainment = 1-(1/(1+ $0.0076755045686138*e^{6.69498358561645*E:I}$))
- Ryde: Proportional entrainment = 1-(1/(1+ $0.0117017438595754*e^{6.7207341005591*E:I}$))
- South Fork Mokelumne: Proportional entrainment = 1-(1/(1+ $0.0389615268878375*e^{14.4737516748024*E:I}$))
- Stockton: Proportional entrainment = 1-(1/(1+ $0.00840706847099802*e^{32.6988703978096*E:I}$))
- Three Mile Slough: Proportional entrainment = 1-(1/(1+ $0.0157935505682666*e^{6.10724605041376*E:I}$))
- Twitchell Island: Proportional entrainment = 1-(1/(1+ $0.0342441647821108*e^{6.37831755748149*E:I}$))
- Vernalis: Proportional entrainment = 1-(1/(1+ $0.111111111111111*e^{27.3073879175582*E:I}$))
- Victoria Canal: Proportional entrainment = 1-(1/(1+ $0.00000001283874368*e^{219.722457733622*E:I}$))

The mean estimate of particle proportional entrainment from application of these equations was calculated for four geographic zones, with this mean estimate of particle entrainment then being multiplied by the area of each zone:

- Lower Sacramento (Antioch, Collinsville, Rio Vista, Ryde, Three Mile Slough): 19,140.69 acres
- Hood and West Dela San Joaquin (Hood, Twitchell Island): 6,080.929 acres
- Georgiana Slough/North Fork Mokelumne (Georgiana Slough, North Fork Mokelumne): 2,704.28 acres

- San Joaquin (Bacon Island, Franks Tract East, Franks Tract West, Medford Island, Mossdale, Potato Slough, South Fork Mokelumne, Stockton, Vernalis, Victoria Canal): 21,124.31 acres

The overall area of effect for each scenario was calculated as 10% of the area of the above calculations, consistent with calculations for the mitigation requirements used by California Department of Fish and Game (2009) and California Department of Water Resources (2019). Results of the mitigation calculations for the number of acres that Alternatives 1–3 were in excess of NAA are provided in the main body of Chapter 11, *Aquatic Biological Resources*.

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