compass

Action Specification and Evaluation Sheet

Outflow Augmentation / X2 management

1 Short Description and Hypothesized Bottleneck

This Action Specification Sheet addresses a range of possible actions to augment Delta outflow in the summer or fall for the purposes of improving environmental conditions for Delta Smelt, thereby increasing the fish's growth rate, survival, and recruitment.

The hypothesized effects are that augmenting outflow in the summer and/or fall through increasing reservoir releases and/or reducing exports will increase the quantity and quality of dynamic habitat conditions (the overlap of suitable salinity, turbidity, temperature and food conditions) and that Delta Smelt growth and survival will be higher with increased quantity and quality of dynamic habitat conditions in summer and fall. The related hypothesized bottleneck is that the area with suitable environmental conditions for Delta Smelt is frequently insufficient in the summer and fall thereby limiting Delta Smelt population growth rates.

The 2008 Biological Opinion for the Long-Term Operations of the Project (BiOp) included a Fall X2 management action for Delta Smelt intended to mitigate inadequate habitat conditions for Delta Smelt, requiring a 30-day average X2 target (location of the low-salinity zone in the upper San Francisco Estuary) in September and October at 74 km in Wet years and 81 km in Above Normal years. The 2019 Biological Assessment (BA), the 2019 BiOp, and 2020 Record Of Decision (ROD) modified the Fall X2 management action for Delta Smelt by adjusting the targeted X2 location to 80 km in September and October of Wet and Above Normal years (see Text Box 1).

Text Box 1. The 2019 BiOP articulates the following environmental and biological goals to benefit Delta Smelt:

> "In the summer and fall (June through October) of Below Normal, Above Normal, and Wet years, based on the Sacramento Valley Index, the environmental and biological goals are, to the extent practicable, the following:
>
> - Maintain low salinity habitat in Suisun Marsh and Grizzly Bay when water temperatures are suitable;
> - Manage the low salinity zone to overlap with turbid water and available food supplies; and
> - Establish contiguous low salinity habitat from Cache Slough Complex to the Suisun Marsh."
>
> The action will initially include modifying project operations to maintain a monthly average 2 ppt isohaline (X2[1]) at 80 km from the Golden Gate in Above Normal and Wet water years in September and October." (pg. 51)

The portfolios included in Round 1 of the SDM evaluation include the X2 management action in the 2020 ROD. Through an X2 sensitivity analysis on select portfolios, Round 1 SDM Evaluation seeks to understand the incremental effects of the timing, frequency, and intensity of a X2 management action on the status and trends in numbers of Delta Smelt and to other conservation objectives (see Section 0).

2 Influence Diagrams

Figure 1. TWG Influence Diagram for IBMR, LCME, and Maunder & Deriso

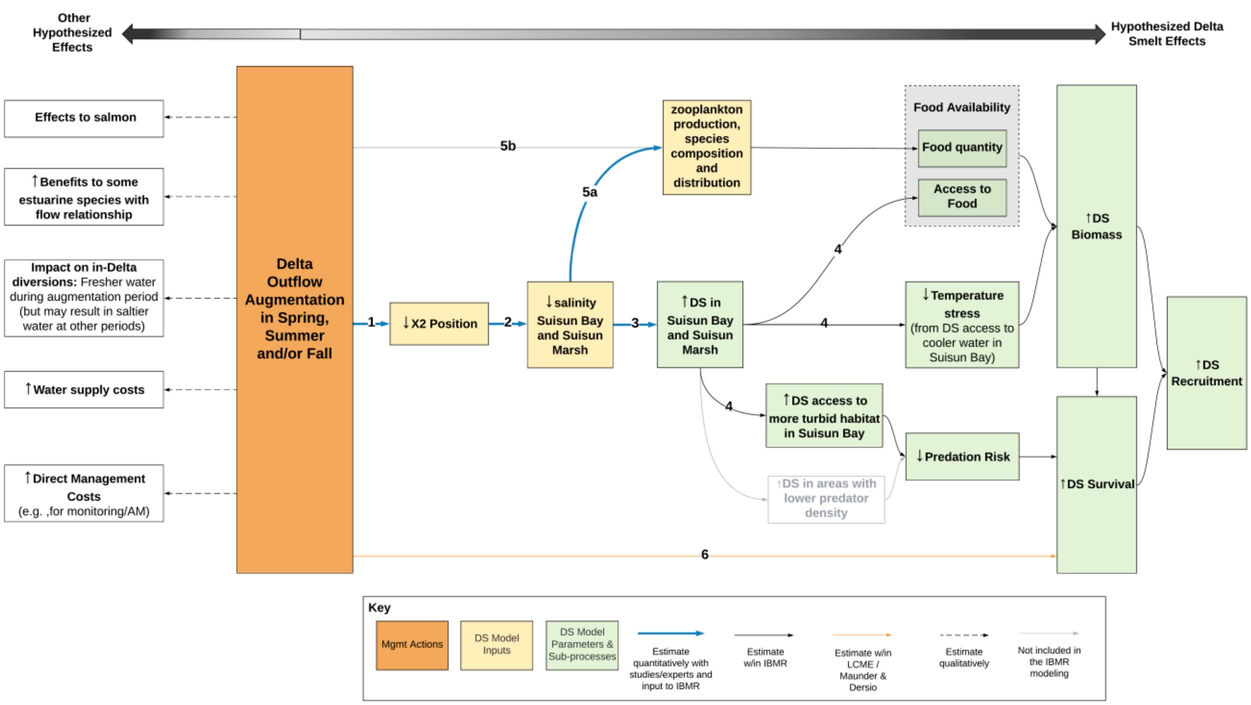
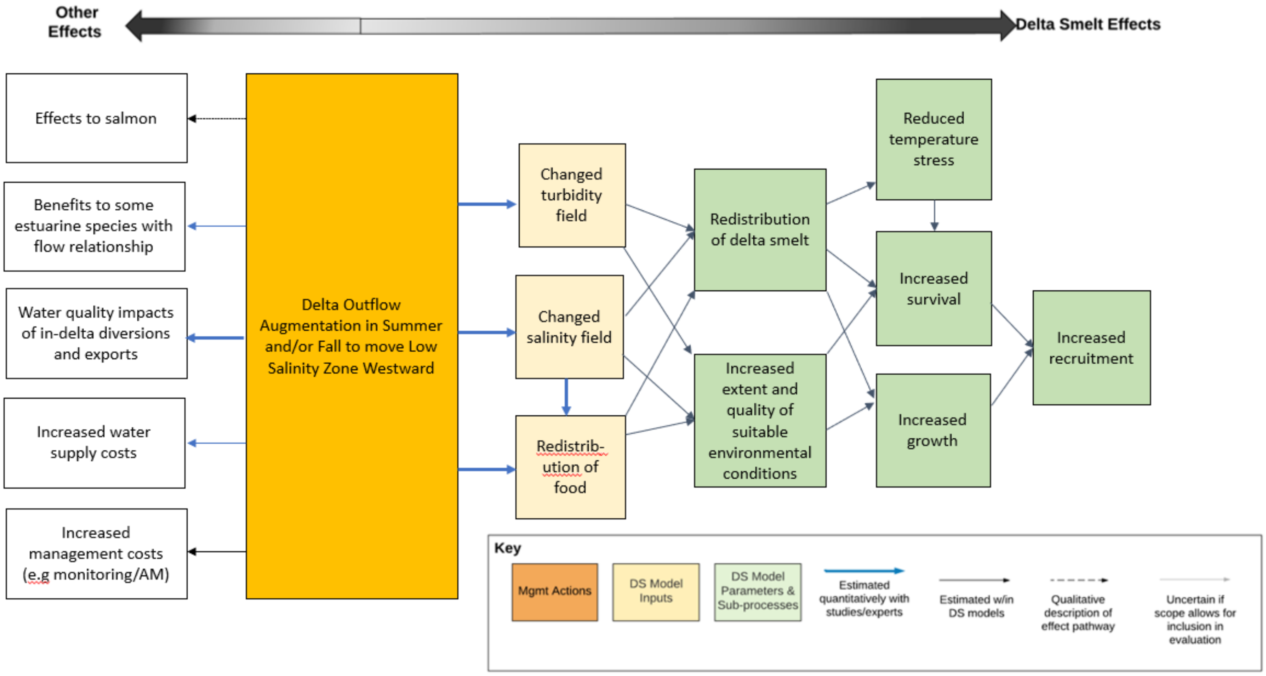


Figure 2. Alternative Influence Diagram suggested by S. Hamilton (which is also more consistent with Limiting Factors Model and Sub-models for flow-food and and Delta Smelt distribution)



3 Action Evaluation

3.1 Delta Smelt Effects

#1 - Estimating required outflow

To get an initial coarse estimate of the Delta Outflow required to carry out the X2 management actions, Compass worked with Ching-Fu Chang (Contra Costa Water District) to develop a coarse-level method of comparing the water cost associated with different X2 management scenarios. We used a combination of a steady-state outflow to X2 model (Monismith et al. 2002) with the G-model (Denton 1993). Specifically, equations (9) and (10) in Monismith et al. 2002.

A steady-state model such as Monismith et al. (2002) will underestimate the outflow needed when X2 is being moved from a higher to a lower position. It will overestimate the outflow needed when X2 is being moved from a lower to a higher position. To correct for this, the G-model in (Denton 1993, equation 5) was be used. For a full description of methods, see the Section 5.

Figure 3. Excerpt from Monismith et al. (2002)

$X_2(t)$, and $X_2(t-1)$. Using a standard least squares nonlinear regression routine (the Matlab proprietary software function "nlinfit"), we found that with a value of $R^2 = 0.98$,

$$X_2(t) = 0.919X_2(t-1) + 13.57Q^{-0.141}. \quad (9)$$

Analogous to a simple RC filter, (9) models a linear system that has a time constant of (1/0.081) = 12 days. Thus, the fundamental response times of the estuary is comparable to the fortnight timescale of the spring–neap cycle, and, to first order, is independent of flow.

An alternative to (9) is one in which the coefficient multiplying $X_2(t-1)$ depends on flow (Denton 1993). Assuming a linear relationship between this coefficient and flow (i.e., the simplest model possible), we found that the response time varied between 7 days at the highest flows and 11.3 days at the lowest flows. However, this more complicated model did not improve the fit to observations nor did it reduce autocorrelation of the residuals. While it is intuitively appealing that the response time should depend on flow (see MacCready 1999), the present dataset does not allow us to unambiguously demonstrate the connection.

To deduce the steady-state response, we set $X_2(t) = X_2(t-1)$ and find that

$$X_2 = 167Q^{-0.141}. \quad (10)$$

#2a - Estimating changes in salinity

To estimate the changes to salinity in response to X2, Compass fit a model to historical salinity and X2 data, as well as other factors, and used it to predict subsequent changes in salinity when evaluating Delta Smelt outcomes under outflow/X2 management alternatives. Specifically, we built a global generalized linear regression model with a gamma distribution where mean year-month-subregion salinity (PSU) was the response variable influenced by month, $month^2$, X2 location, $X2^2$, subregion, and an X2 x subregion interaction effect. For a full description of methods and results, see the Compass Technical Memo (CRM 2022b). The model showed adequate fit to the data and explained 91.5% of the variation in salinity. Overall, salinity was low and did not vary with X2 for all subregions east of the Confluence. Salinity increased marginally with higher X2 in the Confluence and Suisun Marsh, and salinity increased more greatly with higher X2 in the Suisun Bay subregions. See Appendix 3 (Figure 11) for predicted salinity-X2 relationships with respect to observed values.

The location of the LSZ westward of 80 km leads to a notable increase in surface area of low-salinity waters compared to more confined channels upstream of the confluence (see MacWilliams and Bever, 2014). See Wiki page for documentation on the related hypotheses.

#2b - Estimating changes in turbidity

Compass estimated the relationship between turbidity and outflow using the same methods as the salinity-X2 modeling. We built a global generalized linear regression model with a gamma distribution where mean year-month-subregion turbidity (Secchi depth cm) was the response variable influenced by month, $month^2$, outflow (cfs), subregion, and an outflow x subregion interaction effect. The model showed adequate fit to the data (Appendix 3, Figure 12) but only explained 65.9% of the variation in turbidity. Overall, turbidity was variable across all subregions with respect to outflow, and this variability was particularly high when outflow was low. Turbidity marginally decreased with increased outflow for the Sacramento River, South Delta, and East Delta subregions, while the model predicted negligible effects on turbidity across the range of observed outflow values for all other subregions. See Appendix 3 (Figure 12) for predicted turbidity-outflow relationships with respect to observed values.

This model was not used in the IBMR for modeling outflow augmentation actions.

#3 - Estimating the redistribution of Delta Smelt

Multiple methods are available to estimate changes in Delta Smelt distribution with changes in salinity, turbidity, and other factors:

- Smith (2022) Delta Smelt Distribution Model
- The "X2 method" developed by Compass and a TWG distribution subgroup (Aug/Sep 2022 meetings)
- Hamilton (2022) Delta Smelt Distribution Model

The Smith distribution model predicts changes in Delta Smelt distribution across subregions in a given month as a function of salinity and temperature. Will developed a Dirichlet regression model, fit to trawl survey data covering the entire Delta Smelt range and life cycle. He assessed other covariates, including X2, Secchi depth, and prey density; however, models showed no effect of these other covariates. Despite months of analysis and investigation, even the best model showed some lack of fit to observed data. Still, the TWG discussed the model and results at the Dec 2021 TWG meeting, deemed the predictions coming from the model as reasonable and in agreement with other evidence to how fish are distributed, and supported the use of this model when evaluating actions. For a full description of methods and results, see Smith (2022).

The "X2 method" is a straightforward approach that predicts the distribution of Delta Smelt across subregions for a given month, given a new X2 location specified in a management scenario, by using mean historical distributions of Delta Smelt observed under the same X2 location. The X2 method only predicts changes in distribution for X2 actions and cannot be applied for actions that change other factors (e.g., turbidity, salinity) but not X2. For a full description of methods, see the Compass Technical Memo (CRM 2022a). Note that a recent study by Hendrix et al (2023) suggested that salinity was a better predictor for delta smelt distribution than X2 (see discussion below).

The Hamilton distribution model predicts Delta Smelt distribution using a Dirichlet regression model, where distribution is influenced by food, outflow, prior distribution, temperature, turbidity, salinity, and OMR flows (see Hamilton 2022).

Comparison to recent distribution study – Outside of this SDM process, a recent study (supported by CSAMP's Delta Smelt Scoping Team) generated and evaluated several hypotheses relating abiotic and biotic variables to Delta Smelt occupancy across subregions (Hendrix et al. 2023). The highest-supported model suggested occupancy was influenced by subregion salinity and temperature. These findings generally agreed with the Smith distribution model; however, the Hendrix et al. model predicted greater strength of the relationship (determined by the salinity coefficients and their uncertainties), relative to the Smith model. The Hendrix et al. model predicted occupancy was high at salinity values at or below 5.6 PSS and declined as salinity increased above that value. Several of the top models also supported that turbidity had some influence on detection of Delta Smelt (or local occupancy that could not be estimated with available data). The study concludes that these results indicate salinity is a better predictor of occupancy than X2 (as well as other variables tested but not included in the best model). The authors acknowledge the link between X2 and salinity and that shifting X2 would change salinity in western subregions. Analyses in this SDM process also supported strong relationships between X2 and subregion-specific salinities (see Appendix 2, Figure 11).

In this SDM process, the TWG had been evaluating multiple actions and portfolios that change X2 and/or salinity using both the Smith model and X2 method prior to the Hendrix et al. paper's publishing. The

TWG supported continuing to evaluate and discuss predicted outcomes using the X2 method, given the co-relationships between X2, salinity, and distribution that most of the analyses to date support. A fruitful area of future work may be to use the Hendrix et al. model to predict distributions, given the effects of management actions, that would then be used as inputs into Delta Smelt population models. This approach would require obtaining the source data and estimated coefficients from the best model in Hendrix et al. (2022), estimating the change in salinity of a given management action for each subregion, and converting between the spatial subregions used in this process (12 subregions in the IBMR, 10 subregions in the Limiting Factors model) and the Hendrix et al. model (15 subregions).

#4 – Estimating the effect of a change in distribution of Delta Smelt to Delta Smelt growth and survival

Each subregion in the IBMR is characterized by its turbidity, temperature, and zooplankton conditions from 1995 to 2014. These conditions affect Delta Smelt growth and survival. For a visualization of this effect, see Compass/TWG (2021) - the Dynamic Habitat Analysis Tool.

The Limiting Factor model (2022) can also be used to estimate this effect.

To assess the effect of the action, input to models will include the estimated changes in temperature, turbidity, salinity, zooplankton distribution and density, and Delta Smelt distribution as a result of the action.

#5a - Estimating changes in zooplankton composition and density with changes in salinity

Sam Bashevkin (State Water Board) developed salinity-zooplankton models for the Suisun Bay and Marsh area for the Delta Coordination Group (DCG), which is the group working on the Delta Smelt Summer-Fall Habitat Action. For the IBMR, effects of flow on subregion- and taxa-specific zooplankton density were estimated with the Bashevkin salinity-food model, fit to historical data (CRM 2022c). All model code, performance information, and results are available on GitHub here. The generalized additive model predicts density of each taxon for a given month and subregion as a function of salinity, the interaction between salinity and day of year, and random effects for year and location.

A similar version of this model was recently published (Bashevkin et al. 2023). This model predicts changes in zooplankton for the Confluence and Suisun Marsh and Bay. It does not capture the effect of flows on zooplankton Delta subregions. This modeling decision was made since the model focuses on effects of subregion-specific salinity (not Delta-wide flow) and previous analysis showed no substantial changes in salinity in Delta subregions across a range of X2/outflow conditions (CRM 2022b). The model's structure does not capture the potential mechanism of downstream transport of zooplankton from flow.

#5b - Estimating changes in the distribution and density of zooplankton with changes in flow

Flows influence the distribution of zooplankton throughout the estuary. For the Limiting Factors model, effects of flow on food were estimated from the Hamilton flow-food submodel that predicts subregion-specific food density as a function of water temperature, flow, salinity, upstream abundance of copepods, and prior abundance of copepods (Hamilton et al. 2020, Hamilton 2022). Unlike the Bashevkin model, this model predicts changes in zooplankton across all subregions (including in the Delta) and accounts for downstream transport of zooplankton with flow.

We briefly summarize the findings of Hamilton et al. 2020 below:

- Historical data in that analysis showed lower levels of zooplankton in Suisun Bay than further upstream in most months other than May-July.
- When comparing zooplankton density in high flow (Wet and Above Normal water years) vs. low flow (other water year types), some sites in the Lower Rivers, Confluence, and Suisun Marsh and Bay historically had similar densities in high and low flow years in most months while some sites

tended to have higher zooplankton density in high flow years in May-Aug (see Hamilton et al. [2020], Figure 2).

- Fitted models estimated mostly non-linear or marginally positive relationships between zooplankton and flow in the sites mentioned above in May through Sep (see Hamilton et al. [2020], Figure 3).
- Lastly, the analysis predicted similar or slightly reduced zooplankton density at most of those sites with a 4500 cfs increase in Sacramento River flows in Sep/Oct and predicted similar or slightly increased zooplankton density at most of those sites with a 1000 cfs increase in Sacramento and San Joaquin River flows in Apr/May (see Hamilton et al. [2020], Figures 4 and 5).

Additionally, a recent study by Lee et al. (2023) evaluated effects of flow augmentation in the fall on taxa-specific changes in zooplankton. Comparing fall zooplankton in 2 flow augmented years (when X2 was ~75/76) vs. 2 non-augmented years (when X2 was 83/87), they found (a) higher total zooplankton abundance in Suisun Bay in augmented years, while total abundance in other regions (Cache Slough Complex, Deep Water Ship Channel, Lower Sacramento, and Suisun Marsh) was not significantly different between flow augmented and non-augmented years and (b) responses were taxa-specific: lower salinity from augmented years in Suisun Marsh and Bay was associated with higher abundance of *Pseudodiaptomus forbesi*, a preferred prey of Delta Smelt; other species (*Acartiella sinensis* and *Tortanus dextrilobatus*) were less abundant. The authors conclude that fall flow augmentations that lower X2 can increase foraging habitat and prey availability for Delta Smelt in Suisun Bay.

#6 – Estimating the effect of a change in X2 position to change in Delta Smelt survival

The USFWS Life Cycle Model and Maunder & Deriso (2011) model predicts changes in Delta Smelt survival with changes of outflow/X2 position.

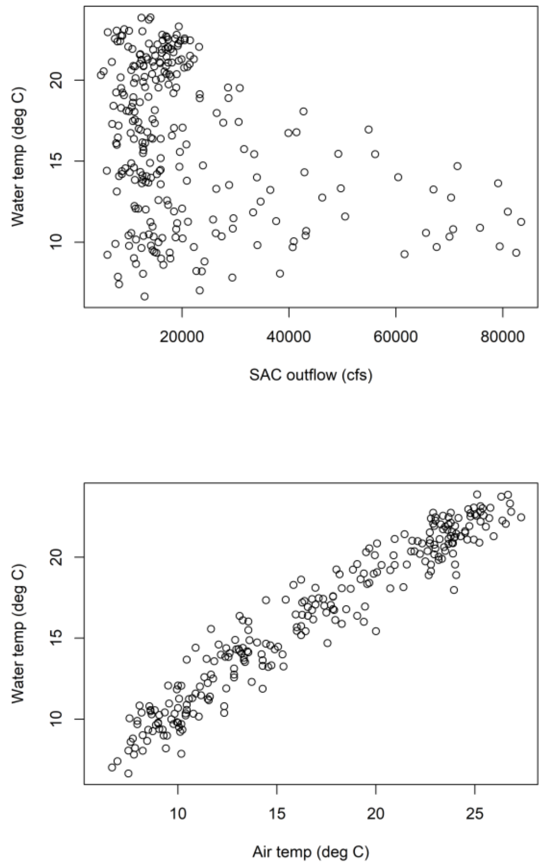
#7 – Exploring the effect of a change in X2 position/outflow to change in temperature

There was interest in the TWG to investigate the ability of flow actions to decrease water temperature, especially in the Upper Sacramento and Yolo Bypass/Cache Slough subregions. Compass worked with Lauren Damon (CDFW) to explore relationships between historical X2/outflow and water temperature data. We extracted three datasets for this analysis: (1) daily Sacramento flow data obtained from the Dayflow dataset (available on https://data.cnra.ca.gov/dataset/dayflow), (2) daily water temperature data from the Rio Visto station (RIV) available from CDEC (https://cdec.water.ca.gov/dynamicapp/wsSensorData), and (3) daily air temperature data from a nearby NOAA weather station (Vacaville: https://www.weather.gov/wrh/Climate?wfo=sto). We accounted for temporal autocorrelation in all datasets by selecting data from the 15th day of each month.

We built a global generalized linear regression model with a gaussian distribution where year-month water temperature at Rio Vista was the response variable influenced by Sacramento outflow, air temperature, and an outflow x air temperature interaction effect. We fit the model to a final dataset between January 1995 and December 2014 (n = 2880) to align with the modeling timeframe of the IBMR. We performed AIC_c-based model selection for a specific set of candidate models including the global model and simpler models where predictor effects were dropped (Burnham and Anderson 2002).

The global model outperformed all others and explained 94% of variation in water temperature. However, the model with only air temperature explained 93% of the variation in water temperature. This suggests water temperature is minimally influenced by Sacramento flow, relative to air temperature (see Figure 4). We also used the model to predict that water temperature would only decrease by < 0.1 deg C in Winter/Spring months (Jan-Apr) with an additional 100 TAF of Sacramento outflow and assuming no change in air temperature. Because the actions of interest could only modify flows and not air temperature, further use of this model to capture effects of flow on water temperature were not pursued in this SDM process.

Figure 4. Daily water temperatures (deg C) at Rio Vista compared to Sacramento outflow (cfs: upper panel) and air temperature (deg C: lower panel) between 1995 and 2014.



4 Outflow/X2 Sensitivity Analysis & Delta Smelt Results

The Technical Working Group has taken an iterative approach to doing outflow/X2 sensitivity analysis using the Delta Smelt population models. This section summarizes the progression and results of this modeling.

4.1 Action Model Run Descriptions

Model runs #6.1 to #6.11 (DS Distribution focus; W, AN & BN water years): The purpose of these model runs is to test the sensitivity of Delta Smelt population growth to variations in fall and summer X2 in Wet (W), Above Normal (AN) and Below Normal (BN) years and different models for how X2 influenced Delta Smelt distribution. Two distribution models were applied – the Smith Distribution model and the "X2 method" developed by Compass and a TWG sub-group (CRM 2022a). A TWG Sub-group reviewed the two distribution models and decided to move forward with the "X2 method" for future model runs. These model runs do not include an effect between changes in flow/salinity and zooplankton.

Model runs #6.12 to #6.23 (Flow/Salinity-Food focus; W, AN & BN water years): The purpose of these model runs is to test the sensitivity of Delta Smelt population growth to variations in fall and summer X2 in W, AN and BN years and different models for how changes in flow or salinity influence zooplankton. About half of the runs use a model developed by Sam Bashevkin that predicts taxa-specific changes to food, given changes to salinity (CRM 2022b,c). Separate model runs used the lower and upper 95% credible intervals from the Bashevkin model to capture uncertainty around changes to food. These runs use the "X2 method" for Delta Smelt distribution. The other half of the runs are placeholders for applying the Hamilton flow-food model (these model runs have not been completed).

Model runs #6.24 to #6.33 (W & AN water years, X2 method, Bashevkin food model): These model runs use the same summer and fall X2 targets as the previous runs, but only vary X2 values in W and AN years. These runs use the median prediction for zooplankton from the Bashevkin model and the X2 method for Delta Smelt distribution.

All of the above model runs were run with the IBMR and a subset was run with the other three Delta Smelt models. Throughout all of the above runs, X2 targets were varied in the summer or fall for five location targets as presented in the table below:

	Summer		Fall		
Location target	Jul	Aug	Sep	Oct	Rationale for values
Low bookend	59	66	68	72	Minimum values observed in Jul-Oct, W/AN/BN years, 95-14
Increment 1	65	71	74	76	Mid-point between increment 2 and low bookend
Increment 2	70	75	80*	80*	Summer: mid-point between high and low bookend Fall: 2020 ITP/BiOp X2 values
Increment 3	75	80	83	84	Mid-point between increment 2 and high bookend
High bookend	80	84	87	88	Maximum values observed in Jul-Oct, W/AN/BN years, 95-14

*Increment 2 for Fall is the same as the X2 values in the base portfolios, so these do not require additional model runs.

The IBMR and LCME models use 1995 to 2014 as baseline years. Using the Sacramento Valley Water Index reference, there are eight Wet years, one Above Normal year, and 4 Below Normal water years across 1995-2014. Changing X2 in W, AN, and BN years results in changing X2 in 13 out of 20 of the modeled years; changing X2 in W and AN years changed X2 in 9 out of 20 modeled years. Note that for 'action' sensitivity model runs, X2 locations were changed to the new target in the model run for all years specified (e.g., all W and AN years), even if historical X2 conditions were lower than the target. See Appendix 1 (Table 6) for historical X2 locations.

4.2 Action Model Run Results

The table below compares IBMR results for the different distribution models used with the low/high bookend X2 locations for summer and fall. Prior to the sensitivity analysis, an earlier version of the LCME (LCMG: Polansky et al. 2021, see Appendix C, Table C.2, Figure C.1) found substantial evidence for the effect of summer outflow on survival (in Jun-Aug), but the effect of fall outflow on survival was not significantly different than 0. The set of best-supported covariates (including an effect of summer – but not fall – outflow) was used in the LCME (Smith 2021a,b, Smith et al. 2021). However, Smith 2021a states, "…summer outflow and fall X2 are highly correlated. The highest summer outflow years are the lowest fall X2 years, and vice versa." Still, the low evidence found with the LCMG between fall outflow and survival resulted in 0% change in population growth rate for any model run that varied fall X2 in the absence of other changes.

X2 Scenario Name (X2 targets for W, AN, and BN years)	**% change in average lambda from baseline (1995-2014)**		
	IBMR - No food, Smith method distribution	**IBMR - No food, X2 method distribution**	**LCME – No food, no distribution**
X2 summer low (59/66 km)	-1%	-1%	33%
X2 summer high (80/84 km)	-1%	-4%	-16%
X2 fall low (68/72 km)	0%	3%	0%
X2 fall high (87/88 km)	0%	0%	0%
Model Run Reference #s	6.8-6.10	6.1, 6.2, 6.3, 6.7	6.1, 6.2, 6.3, 6.7

Footnotes: (1) Results are % change from baseline, and average predicted lambda under baseline conditions differs for the IBMR and LCME. (2) X2 was set to month-specific targets in all W, AN, and BN water year types (13 of 20 model years; defined by the Sacramento Valley Water Index), regardless of whether historical X2 locations were above or below target. (3) For the LCME, low evidence found with the LCMG (on which the LCME was based) between fall outflow and survival resulted in 0% change in population growth rate for any model run that varied fall X2 in the absence of other changes.

The table below compares IBMR and LCME results across the summer and fall X2 high and low bookend scenarios applied in W, AN and BN water years. IBMR model runs vary in their treatment of how X2 influences zooplankton (no food effect or the "Sal-food" effect using the Bashevkin model to predict taxa-specific food changes from changes in salinity). All IBMR runs in this table apply the X2 method for Delta Smelt distribution. Compared to runs with no food effect, including an effect between flow and food in the IBMR yielded larger population changes across the low/high bookends for summer and fall X2. Including the food effect in summer runs resulted in the IBMR predictions to be more similar to the LCME. The IBMR showed a difference in the range of population changes between low and high X2 in fall (range = 3% no food effect; 13% low food effect; 15% high food effect). Differences in the range of population changes between low and high X2 in summer were larger for both the IBMR (range = 5%, 31%, 32%) and LCME (range = 49%).

X2 Scenario Name (X2 targets for W, AN, and BN years)	**% change in average lambda from baseline (1995-2014)**			
	IBMR - No food effect	**IBMR - Sal-food low**	**IBMR - Sal-food high**	**LCME**
X2 summer low (59/66 km)	-1%	14%	27%	33%
X2 summer high (80/84 km)	-4%	-17%	-5%	-16%
X2 fall low (68/72 km)	3%	7%	17%	0%
X2 fall high (87/88 km)	0%	-6%	2%	0%
Model Run Reference #s	6.3, 6.7, 6.1, 6.2	6.12, 6.15, 6.18, 6.21	6.13, 6.16, 6.19, 6.22	6.3, 6.7, 6.1, 6.2

Footnotes: (1) Results are % change from baseline, and average predicted lambda under baseline conditions differs for the IBMR and LCME. (2) X2 was set to month-specific targets in all W, AN, and BN water year types (13 of 20 model years; defined by the Sacramento Valley Water Index), regardless of whether historical X2 locations were above or below target. (3) For the LCME, low evidence found with the LCMG (on which the

LCME was based) between fall outflow and survival resulted in 0% change in population growth rate for any model run that varied fall X2 in the absence of other changes.

The table below compares IBMR and LCME results across five levels of X2 targets in summer or fall for W and AN years. All IBMR runs in this table apply the median prediction for zooplankton from the Bashevkin model and the X2 method for Delta Smelt distribution. The difference in the range of population changes between low and high X2 in fall was 10% and 0% for the IBMR and LCME, respectively. The range in population changes between low and high X2 in the summer was 23% and 30% for the IBMR and LCME, respectively. Comparing results from the previous table (where X2 management was simulated for W, AN, and BN years) and this table (W and AN years), population growth increases with more years of X2 being low in summer and/or fall; population growth decreases with more years of X2 being high in summer and/or fall.

	% change in average lambda from baseline (1995-2014)		
X2 Scenario Name	**Location targets in W and AN years (Summer = Jul/Aug; Fall = Sep/Oct)**	**IBMR**	**LCME**
X2 summer low	59 / 66	11%	17%
X2 summer, inc 1	65 / 71	8%	11%
X2 summer, inc 2	70 / 75	3%	4%
X2 summer, inc 3	75 / 80	-4%	-4%
X2 summer high	80 / 84	-12%	-13%
X2 fall low	68 / 72	6%	0%
X2 fall, inc 1	74 / 76	4%	0%
X2 fall, inc 2	80 / 80	-3%	0%
X2 fall, inc 3	83 / 84	-5%	0%
X2 fall high	87 / 88	-4%	0%
Model Run Reference #s		6.24-6.33	6.24-6.33

Footnotes: (1) Results are % change from baseline, and average predicted lambda under baseline conditions differs for the IBMR and LCME. (2) X2 was set to month-specific targets in all W and AN water year types (9 of 20 model years; defined by the Sacramento Valley Water Index), regardless of whether historical X2 locations were above or below target. (3) For the LCME, low evidence found with the LCMG (on which the LCME was based) between fall outflow and survival resulted in 0% change in population growth rate for any model run that varied fall X2 in the absence of other changes.

4.3 Portfolio Model Run Descriptions

Early exploratory model results showed potential for interactive effects between flow and other action types, so the TWG designed certain portfolios to further test the sensitivity of Delta Smelt population outcomes to varying X2 alongside other actions. Portfolios used in these sensitivity runs are described below. Note that unlike in the 'action' sensitivity model runs, portfolio model runs only reduced X2 in months where the historical X2 location was higher than the target; if the historical X2 location was lower than the monthly target, the historical location was used in the model run (no change). See the tables in Appendix 1 for specific X2 inputs for each portfolio run.

Portfolio 3c runs (#3c1 to #3c8): The purpose of these model runs is to test Delta Smelt population responses to variations in fall and summer X2 in W and AN years, alongside a large-scale food action (~9,000 ac of tidal wetland restoration) consistent across all runs. Runs #3c1-4 assumed the "low bookend" effect of tidal wetland restoration on food while runs #3c5-8 assumed the "high bookend" effect.

- **3c1, 3c5:** Summer X2 (65/70km) (Action model run #6.25), historical fall X2 (< 88km)
- **3c2, 3c6:** Summer X2 (65/70km) (#6.25), current fall X2 of 80km (#6.31)
- **3c3, 3c7:** Summer X2 (70/75km) (#6.26), historical fall X2 (< 88km)
- **3c4, 3c8:** Summer X2 (70/75km) (#6.26), current fall X2 of 80km (#6.31)

Portfolio 2a runs (#2a1 and #2a2): The purpose of these model runs is to test Delta Smelt population responses to strategically increasing flows in condition-specific months between Jan-Oct across all water year types alongside actions included in the Reference Portfolio 1b (current management approximation, including OMR management, Suisun Marsh Salinity Control Gates, and North Delta Food Subsidies). Starting each year in January, portfolio runs simulated deploying flow actions in months when historical flows go below minimum thresholds (see table below), assuming there is still water left in the annual budget. The portfolio was tested under two annual water budgets:

- **2a1:** No annual water budget (flows necessary to meet minimum thresholds year-round)
- **2a2:** Annual water budget of 700 TAF

Seasonal thresholds/triggers for Portfolio 2a

Season	Flow trigger	Action
Winter (Jan)	If the natural first flush either did not occur, was small, or was late	Engineered First Flush (Action #11.2)
Spring (Mar-May)	Monthly average flows < 25,000 cfs in W or AN yrs; <11,700 cfs in BN, D, and C	Additional releases from water block to achieve flow targets in trigger
Summer (Jun)	Monthly average flows < 12,400 cfs in W yrs; < 11,400 cfs in AN or BN years; < D-1641 for D and C yrs	Additional releases from water block to achieve flow targets in trigger
Summer (Jul-Aug)	Monthly average flows < 7,500 cfs in W, AN, or BN yrs; < D-1641 for D and C yrs	Additional releases from water block to achieve flow targets in trigger
Fall (Sep-Oct)	X2 > 80 km	Implement current Fall X2 mgmt targeting 80 km (Action #6.31, modified)

4.4 Portfolio Model Run Results

The table below compares IBMR and LCME results across versions of Portfolios 2a and 3c that varied outflow/X2 management while keeping all other actions within the portfolio unchanged between runs. All IBMR runs in this table apply the median prediction for zooplankton from the Bashevkin model and the X2 method for Delta Smelt distribution. Preliminary conclusions include:

- Again, the lack of evidence with the LCME between fall outflow and survival resulted in no difference between versions of a portfolio with current or historical fall X2 locations while other actions stayed the same (e.g., 3c1 and 3c2). The IBMR also predicted negligible differences between portfolios with current vs. historical fall X2 (e.g., 3c1 and 3c2). We note that current fall X2 is simulated in the models by lowering X2 to 80 in only 10 months (out of 240) across the model timeframe. The effects of lowering X2 in more years or using a target lower than 80 have not been evaluated to date.
- Population growth increases as summer outflow increases (lower X2). This can be seen by comparing results for 3c1 vs. 3c3 or 3c2 vs. 3c4.
- Population growth also increased in versions of Portfolio 2a that increased flows in specific months (spring to fall) across all water year types.
- All analyses done to date have incorporated effects of flow on Delta Smelt distribution, salinity, and food. Other potential effects (e.g., temperature, turbidity) have not been included due to lack of clear evidence to quantify those relationships in the models.

Portfolio	# of years (out of 20) and months (out of 240) that X2 was adjusted from baseline	% change in average lambda from baseline (1995-2014)	
		IBMR	LCME
Port 1b – Current Mgmt reference case (Fall X2, OMR mgmt, NDFS, SMSCG)	6 yr, 10 mo	1%	20%
Port 2a1 - No water budget	14 yr, 28 mo	23%	25%
Port 2a2 - 700 TAF	14 yr, 25 mo	23%	25%
Tidal wetland low bookend food effect runs			
Port 3c1 - Summer X2 (65/70km), historical fall X2 (< 88km)	8 yr, 14 mo	16%	33%
Port 3c2 - Summer X2 (65/70km), current fall X2 (80km)	8 yr, 24 mo	15%	33%
Port 3c3 - Summer X2 (70/75km), historical fall X2 (< 88km)	7 yr, 12 mo	14%	27%
Port 3c4 - Summer X2 (70/75km), current fall X2 (80km)	7 yr, 22 mo	12%	27%
Tidal wetland high bookend food effect runs			
Port 3c5 - Summer X2 (65/70km), historical fall X2 (< 88km)	8 yr, 14 mo	29%	40%
Port 3c6 - Summer X2 (65/70km), current fall X2 (80km)	8 yr, 24 mo	28%	40%
Port 3c7 - Summer X2 (70/75km), historical fall X2 (< 88km)	7 yr, 12 mo	27%	33%
Port 3c8 - Summer X2 (70/75km), current fall X2 (80km)	7 yr, 22 mo	25%	33%

Footnotes: (1) Results are % change from baseline, and average predicted lambda under baseline conditions differs for the IBMR and LCME. (2) X2 was only reduced to portfolio and month-specific targets in months where the historical X2 location was higher than the target; if the historical X2 location was lower than the monthly target, the historical location was used in the model run (no change). (3) All portfolios except for 2a included X2/outflow management in W and AN water years; Portfolio 2a included X2/outflow management in all water year types. (4) For the LCME, low evidence found with the LCMG (on which the LCME was based) between fall outflow and survival resulted in 0% change in population growth rate for any model run that varied fall X2 in the absence of other changes.

5 Outflow/X2 Water Resources

5.1 Water Resources Performance Measures

The table below describes performance measures (PM) used in the Round 1 SDM Evaluation to quantify affects of outflow/X2 actions on water resource costs.

Table 1. Water resource cost Performance Measures for CSAMP Delta Smelt SDM Project

Performance Measure	Preferred direction	Description
Water resource (net additional water volume: TAF/yr)	Lower	Average net additional water TAF/yr (includes additional water needed and potential 'water savings'), relative to water required for Portfolio 1b (approx. current management) for wetter (W and AN) and drier (BN, D, and C) water year types in the 20-year model period. Calculated as the net of any additional water needed for pushing X2 further west and any water savings from allowing X2 to be further east, compared to the water required for Portfolio 1b, reported as an annual average over the

Performance Measure	Preferred direction	Description
		model period 1995-2014. The annual minimum and maximum net additional water (TAF/yr) – as well as net additional water for each year – are also provided. The PM is calculated based on a coarse hydrology analysis method summarized in Section **Error! Reference source not found.**.
Water resource cost ($ million / yr)	Lower	Monetization of water used $815 per acre foot of water, annualized over the 20-year period, as discussed and agreed to by the CSAMP Policy Group Steering Committee.
Additional Performance Measures		
Water resource (additional water volume: TAF/yr)	Lower	Average additional TAF/yr, relative to water required for Portfolio 1b (approx. current management) for wetter (W and AN) and drier (BN, D, and C) water year types in the 20-year model period. Calculated as the sum of any additional water needed for pushing X2 further west, compared to the water required for Portfolio 1b, reported as an annual average over the model period 1995-2014. The annual minimum and maximum additional flow (TAF/yr) are also provided.
Water resource (potential 'water savings' volume: TAF/yr)	Lower	Average potential water savings TAF/yr, relative to water required for Portfolio 1b (approx. current management) wetter (W and AN) and drier (BN, D, and C) water year types in the 20-year model period. Calculated as the sum of any water savings from allowing X2 to be further east, compared to the water required for Portfolio 1b, reported as an annual average over the model period 1995-2014. The annual minimum and maximum potential water savings (TAF/yr) are also provided.

5.2 Estimating Water Resources: Coarse Water Analysis Methods

The CSAMP Delta Smelt SDM Project evaluated portfolios that are currently quite broad and exploratory in nature; therefore, detailed hydrology and operations modeling (e.g., with CalSim 3) is not possible at this point in the process, but there is still a desire to compare the 'water cost' of portfolios with different X2 management scenarios. To meet this need, Compass worked with Ching-Fu Chang and Deana Serrano (Contra Costa Water District) and Chandra Chilmakuri (State Water Contractors) to develop a coarse-level method of comparing the water cost associated with different X2 management scenarios. The method involves the following steps:

1. Define a reference scenario with monthly X2 values.

- For the CSAMP Delta Smelt SDM Project, the reference portfolio ("1b") includes the current fall X2 management action for Delta Smelt of X2 less than or equal to 80 km in Wet and Above Normal years. X2 values in the reference portfolio are shown in Table 7, where months/years when X2 was reduced to 80 are in orange.

2. Define alternative scenarios that have different monthly X2 values than the reference scenario.

- These alternative scenarios will either reduce X2 in the summer and/or fall with the hypothesis that this could benefit Delta Smelt populations, or the alternative scenario might replace the fall X2 management action with summer X2 management, as well as other actions.

3. **Estimate the difference in Delta Outflow between the alternative X2 scenario and reference X2 scenario.**
    - We first calculated the steady-state Delta outflow for each month, given the X2 value, using equations (9) and (10) in Monismith et al. (2002).
    - We then used the G-model (Denton 1993, equation 5) to refine the steady-state outflow estimates. A steady-state model such as Monismith et al. (2002) will underestimate the outflow needed when X2 is being moved from a higher to a lower position and overestimate outflow needed when X2 is being moved from a lower to a higher position. To correct for this, the G-model calculates "transient outflows" that factors in the outflow in the previous month and thus the degree of change in outflow.
4. **Calculate the difference in water volume (in thousand acre feet [TAF]) between the alternative X2 scenario and the reference scenario.**
    - We calculated the difference in water volume for each month that X2 was adjusted in the scenario.
    - For each year, we summed all positive and negative values separately to get annual totals.
        i. Positive numbers represent a 'water cost' or an additional volume of water needed in the months where X2 is changed from the reference scenario.
        ii. Negative numbers represent the potential for "water savings," meaning an alternative X2 meaning the alternative X2 scenario would have no water cost and would potentially have water 'savings'; however, other constraints in the system might prevent the realization of these savings and more detailed modeling would be needed to confirm any savings. This method allows for coarse comparison of the **relative** differences in water cost across alternative X2 scenarios compared to a reference scenario. For more precise estimates of absolute differences in water cost and other effects to water supply, more detailed modeling would be required as a next step (if desired).
    - Lastly, we calculated annual "net water costs" as the annual additional outflow needed plus the potential water 'savings.'

Again, these methods are coarse in nature, and estimates of net water costs are intended to be used for relative comparisons between alternative scenarios. There are certain aspects of the methods that could introduce error around the absolute numbers being estimated, which could be improved with more detailed hydrology and operations modeling in the future. For example, we summarized monthly averages for X2 inputs from daily estimates from Dayflow data. Averaging X2 across a month can obscure changes and estimates of outflow that are happening at a more frequent scale – especially when X2 is lower, which could lead to error when estimating net additional water needed for an alternative X2 scenario.

5.3 Water Resources Results

Table 2. Water resource costs (TAF) for management portfolios. Results are shown for a) additional water needed, b) potential 'water savings', and c) net additional water – the primary Performance Metric used in the Delta Smelt SDM process. All water volumes are relative to the Reference Portfolio 1b. Positive numbers for net additional water indicate additional water is required, relative to the Reference; negative numbers indicate potential overall 'water savings', relative to the Reference. Results are summarized by wetter and drier water year types. Results are not given for portfolios that did not affect water supply in drier years.

Portfolio	Water year types	Annual additional outflow needed for 1995-2014 (TAF)			Annual potential 'water savings' (TAF)			Annual net volume (additional outflow - 'savings') (TAF)		
		Average	Min	Max	Average	Min	Max	Average	Min	Max
2a1: Full-year flows; no water budget	W, AN	232	0	885	0	0	0	232	0	885
	BN	337	111	504	0	0	0	337	111	504
	D, C	114	0	225	0	0	0	114	0	225
2a2: Full-year flows; water budget of 700TAF	W, AN	212	0	700	47	0	194	165	0	522
	BN	337	111	504	0	0	0	337	111	504
	D, C	114	0	225	0	0	0	114	0	225
3c1: Summer flow & tidal wetlands: Lower Summer X2 (65/70km for Jul/Aug); historical Fall X2	W, AN	1214	0	1882	180	271	0	1033	0	1645
3c2: Summer flow & tidal wetlands: Lower Summer X2 (65/70km for Jul/Aug); current Fall X2 (X2 ≤ 80km)	W, AN	1214	0	1882	113	206	0	1100	0	1759
3c3: Summer flow & tidal wetlands: Low Summer X2 (70/75km for Jul/Aug); historical Fall X2	W, AN	357	0	697	142	276	0	216	0	456
3c4: Summer flow & tidal wetlands: Low Summer X2 (70/75km for Jul/Aug); current Fall X2 (X2 ≤ 80km)	W, AN	357	0	697	74	163	0	283	0	570

Table 3. Annual net additional water (TAF) required for outflow management actions, relative to historical, baseline flow conditions. Cell shadings: red = net additional water required; white = no additional water required.

		Actions			
Year	Water year type	Summer Outflow (X2 ≤ 70/75 for Jul/Aug, W/AN)	Summer Outflow (X2 ≤ 70/75 for Jul/Aug, W/AN/BN)	Full-year Flow	Engineered First Flush
1995	W	0	0	0	0
1996	W	245	245	69	0
1997	W	423	423	1064	0
1998	W	0	0	0	0
1999	W	456	456	399	0
2000	W	385	385	747	0
2001	D	0	0	0	150
2002	D	0	0	0	0
2003	AN	318	318	894	0
2004	BN	0	1079	479	0
2005	BN	0	408	111	0
2006	W	48	48	79	0
2007	D	0	0	23	0
2008	C	0	0	129	0
2009	D	0	0	0	150
2010	BN	0	759	256	0
2011	W	66	66	0	0
2012	BN	0	995	354	150
2013	D	0	0	123	0
2014	C	0	0	225	0

Table 4. Annual net additional water (TAF) required for management portfolios, relative to the Reference Portfolio 1b. Positive numbers indicate additional water is required, relative to the Reference; negative numbers indicate potential 'water savings', relative to the Reference. Cell shadings: red = net additional water required; white = no additional water required.

		Portfolios					
Year	Water year type	2a1 Full-year flows: no water budget	2a2 Full-year flows: water budget of 700TAF	3c1 Summer flow & tidal wetlands (X2: Summer 65/70km; Fall relaxed)	3c2 Summer flow & tidal wetlands (X2: Summer 65/70km; Fall current)	3c3 Summer flow & tidal wetlands (X2: Summer 70/75km; Fall relaxed)	3c4 Summer flow & tidal wetlands (X2: Summer 70/75km; Fall current)
1995	W	0	0	102	102	0	0
1996	W	0	0	1322	1387	245	310
1997	W	885	522	1566	1713	423	570
1998	W	0	0	0	0	0	0
1999	W	165	165	1645	1759	456	569
2000	W	459	412	1552	1666	385	499
2001	D	150	150	0	0	0	0
2002	D	0	0	0	0	0	0
2003	AN	583	388	1516	1619	318	421
2004	BN	479	479	0	0	0	0
2005	BN	111	111	0	0	0	0
2006	W	0	0	1117	1182	48	112
2007	D	23	23	0	0	0	0
2008	C	129	129	0	0	0	0
2009	D	150	150	0	0	0	0
2010	BN	256	256	0	0	0	0
2011	W	0	0	476	476	66	66
2012	BN	504	504	0	0	0	0
2013	D	123	123	0	0	0	0
2014	C	225	225	0	0	0	0

5.4 Water Resources Limitations

In Round 1, we have used a coarse water analysis to estimate additional water needed, relative to operations approximating current management, to meet targets of flow actions in the months they are applied. We have not done full "water balancing" (e.g., via hydrology/operations models) within and across years for these actions, even though actions are expected to have potential effects on river flows and water supply in the same year (within-year effects) and the year after (carry-over effects) they are applied.

Compass met with hydrology/operations experts Chandra Chilmakuri (SWC) and Ching-Fu Chang (CCWD) on 25 Apr 2023 to narratively describe potential within-year and carry-over effects of flow actions on operations that can aid in interpretation of Round 1 predicted impacts to water resource costs. Below are the key takeaways from the discussion:

1. Water operations in the Delta are complex, making it difficult to predict effects from flow actions to water supply, in-stream flows, and Delta Outflow with only expert judgment. More precise estimates of water resources required from flow actions that account for within-year and carry-over effects are only possible with hydrology/operations modeling.
2. It can be assumed that any additional water needed for a flow action in one period will change operations and flow in the same year or the following year. The magnitude of change increases with the amount of additional water needed for the flow action in a given month/season/year.
3. Potential within-year and carry-over effects are generally greater if flow actions occur in drier years, relative to wetter years. Effects would be lowest if flow actions occur in wet years and are followed by wet years.
4. Potential within-year and carry-over effects from flow actions depend on whether the additional water for those actions is taken from future (a) reservoir releases or (b) exports/deliveries. Assuming additional water for flow actions **comes from increasing reservoir releases**, potential effects in the same year or following year include:
    a. Reduced releases and in-stream flows in rivers downstream (in periods outside of the flow action).
    b. Reduced coldwater pool in reservoirs, with potential subsequent impacts to salmon (restrict timing of migration, decrease habitat quantity and quality, increase temperature, and decrease growth and survival).
    c. Reduced storage volumes for maintaining water quality standards in the Delta.
    d. Reduced water deliveries to water users.

    Assuming additional water for flow actions **comes from decreasing exports/deliveries**, potential effects in the same year or following year include:
    a. Reduced water deliveries to water users and wildlife refuges.

Conclusion: Any management portfolio evaluated in the Delta Smelt SDM process that includes actions that require additional flows for a given month could potentially result in effects in the same year or the following year that include effects to Delta outflow, water quality, Delta Smelt, salmon, storage, and deliveries to water users. Round 1 of the SDM evaluation has quantified a coarse metric – average net additional water TAF/yr – that is useful for making relative, ballpark comparisons among portfolios and identify uncertainties that could be resolved with further analysis (e.g., designing new portfolios that test optimal flow timing, conducting additional hydrology/operations modeling).

6 100 / 150 TAF Additional Outflow Actions in Portfolio #1b

Portfolio #1b (Post 2020 BiOp/ITP – Current Management) has two additional outflow actions for Delta Smelt:

1. 100 TAF Additional Outflow associated with Condition of Approval #8.19 in ITP (2020).
2. 150 TAF Additional Outflow (or Spring Outflow Block) associated with Condition of Approval 8.17 in ITP (2020) (pg. 40-41 in ITP Attachments 1-6)

Condition of Approval #8.19 in ITP (2020)

CDFW's Table of Mitigation Measures describes the additional 100 TAF for Delta Outflow action as follows (see Attachment 1 to the ITP, pg. 43):

"**Additional 100 TAF for Delta Outflow.** To provide benefits to DS or LFS during a critical part of their life histories Permittee shall operate the project to provide a flexible block of water to enhance Delta outflow during the spring, summer, or fall months. Permittee shall provide 100 TAF of water to supplement Delta outflow (Additional 100 TAF) as approved by CDFW. Permittee shall provide the Additional 100 TAF of water subject to the following conditions:

• This water may be used in June through September of wet and above normal water years, and the October immediately following, to supplement Delta outflow in addition to flow required to meet the criteria in Condition of Approval 9.1.3.1, Table 9-A, and improve DS habitat.

• As approved by CDFW, the Additional 100 TAF of water available in a wet or above normal water year may instead be deferred and redeployed in the following water year to supplement Delta outflow during the March through September time period, or the October immediately following the end of that water year. The Additional 100 TAF shall be provided in addition to outflow required to meet the criteria in Table 9-A of Condition of Approval 9.1.3.1 in that following year, except if the following year is dry. The Additional 100 TAF is not required to be provided if the following water year is critical as determined by the May forecast with planning beginning in February each year as described in Condition of Approval 8.20, Delta Outflow Operations Plan and Report.

• The Additional 100 TAF shall be stored in Oroville Reservoir and will be subject to spill from Oroville Reservoir if redeployed to the following year. The Additional 100 TAF from a wet or above normal water year may be deferred only to the following water year, or the October immediately following the end of that water year. Permittee shall provide the Additional 100 TAF as described in the CDFW-approved Delta Outflow Plan (Condition of Approval 8.20). In determining the use of the Additional 100 TAF, CDFW and Permittee will plan for the possibility that the following year is dry and this water would be needed to operate the SMSCG for 60 days during the June – October time period. Sixty days of SMSCG operations in the summer of a dry year is anticipated to require an additional 60-70 TAF of Delta outflow to ensure that other Project operating requirements (including Delta salinity standards) are met. CDFW anticipates that another high-priority use of the Additional 100 TAF, if deferred and redeployed to the following year, would be to supplement outflow in the spring of below normal water years. Permittee shall ensure that the water provided by the SWP achieves the defined purpose in the CDFW-approved Delta Outflow Operations Plan by dedicating the 100 TAF to outflow for the duration of this ITP through agreements with downstream water users, a term-limited Section 1707 dedication as provided under the California Water Code, reliance on Term 91 conditions as enforceable by the SWRCB, or other means to ensure the water is not diverted for any intended use other than Delta outflow."

To simulate the 100/150 TAF additional outflow actions in Portfolio #1b, the proposal is to use the following assumptions to determine how much additional outflow to include in each model year 1995-2014:

- 100 TAF becomes available in wet and AN water years and is stored for use in the next year;
- Stored 100 TAF is not spilled (i.e., it is available for use in the year after it is allocated);
- In wet, AN, BN and dry years following wet years, 100 TAF is used to push X2 further westward than it otherwise would be. 100 TAF is used for this purpose in August or September in wet and AN years (since Fall X2 action is in September and October). In BN and dry years, it is used in whatever spring/summer month keeps X2 below 80 km for longer than it otherwise would be.
- 150 TAF becomes available in wet years and is used in wet years for the purposes of pushing X2 further westward than baseline.

Through applying the above assumptions, the additional outflow that is added to each model year is shown in Table 5 below. These assumptions likely overestimate the frequency in which these additional blocks of water would become available and so can be considered the upper bookend of frequency for these outflow actions.

Table 5. Assumptions for the years between 1995-2014 when 100 / 150 TAF additional outflow blocks are used for the purposes of moving X2 further westward than baseline

		100 TAF Assumptions		150 TAF Assumptions		
Model Year Jan. 1 to Dec. 31	**Water Year Type (SVI) Oct 1 to Sept 30**	New block of 100TAF becomes available?	100 TAF assumed to be used in this year and for what purpose (X2 or SMSCG)?	New block of 150 TAF becomes available?	150 TAF assumed to be used and for what purpose?	**Total Additional Outflow (TAF)** (Assumptions for the 100/150 TAF additional Delta outflow actions in Portfolio #1b)
1995	W	Yes	No	Yes	Yes - X2	150
1996	W	Yes	Yes - X2	Yes	Yes - X2	250
1997	W	Yes	Yes - X2	Yes	Yes - X2	250
1998	W	Yes	Yes - X2	Yes	Yes - X2	250
1999	W	Yes	Yes - X2	Yes	Yes - X2	250
2000	W	Yes	Yes - X2	Yes	Yes - X2	250
2001	D	No	Yes - SMSCG	No	No	0
2002	D	No	No	No	No	0
2003	AN	Yes	No	No	No	0
2004	BN	No	Yes - X2	No	No	100
2005	BN	No	No	No	No	0
2006	W	Yes	No	Yes	Yes - X2	150
2007	D	No	Yes - SMSCG	No	No	0
2008	C	No	No	No	No	0
2009	D	No	No	No	No	0
2010	BN	No	No	No	No	0
2011	W	Yes	No	Yes	Yes - X2	150
2012	BN	No	Yes - X2	No	No	100
2013	D	No	No	No	No	0
2014	C	No	No	No	No	0
Summary			100 TAF is used in 9 out of 20 years.		150 TAF is used in 8 out of 20 years.	

7 Evidence / Examples

7.1 MacWilliams and Bever (2014)

The figures below from MacWilliams and Bever (2014) show the relationship between X2 location and salinity across the Delta and Suisun Bay/Marsh.

Figure 5. X2=64

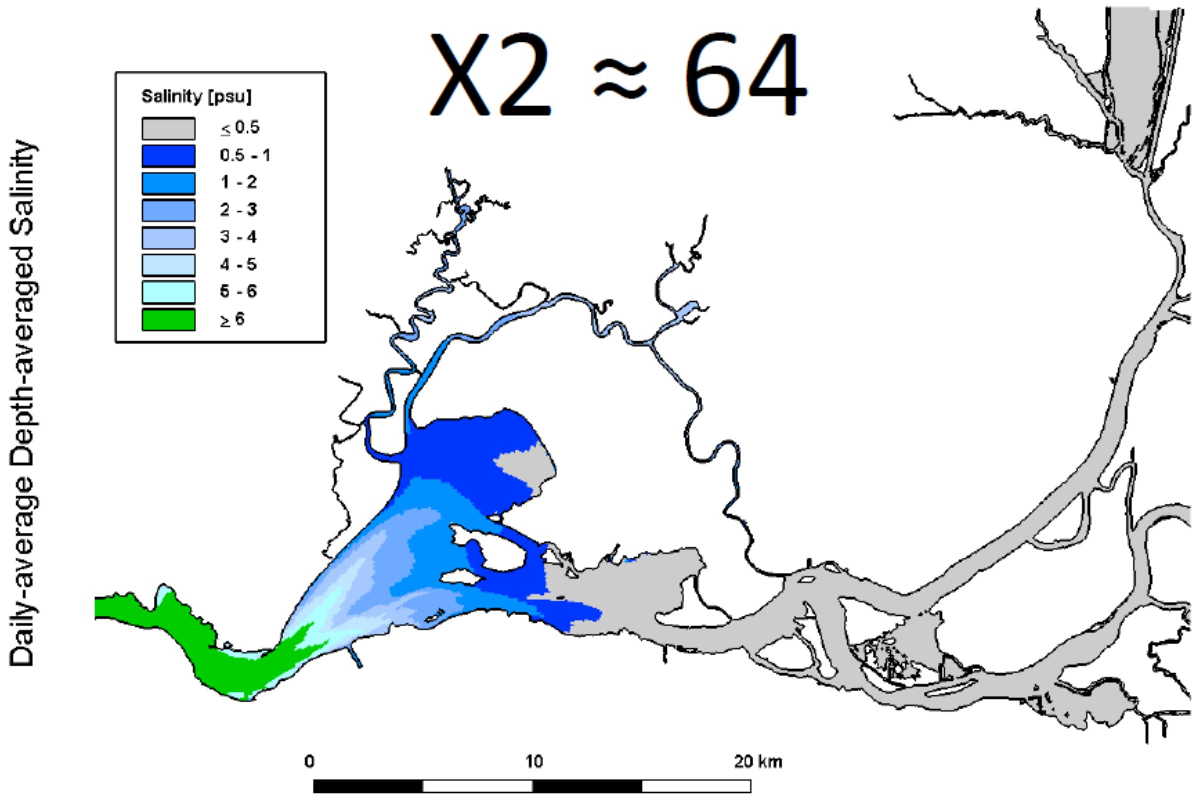


Figure 6. LSZ when X2=74. This level of X2 is in Portfolio #1a (Post-2008 BiOp) in September and October of Wet Years.

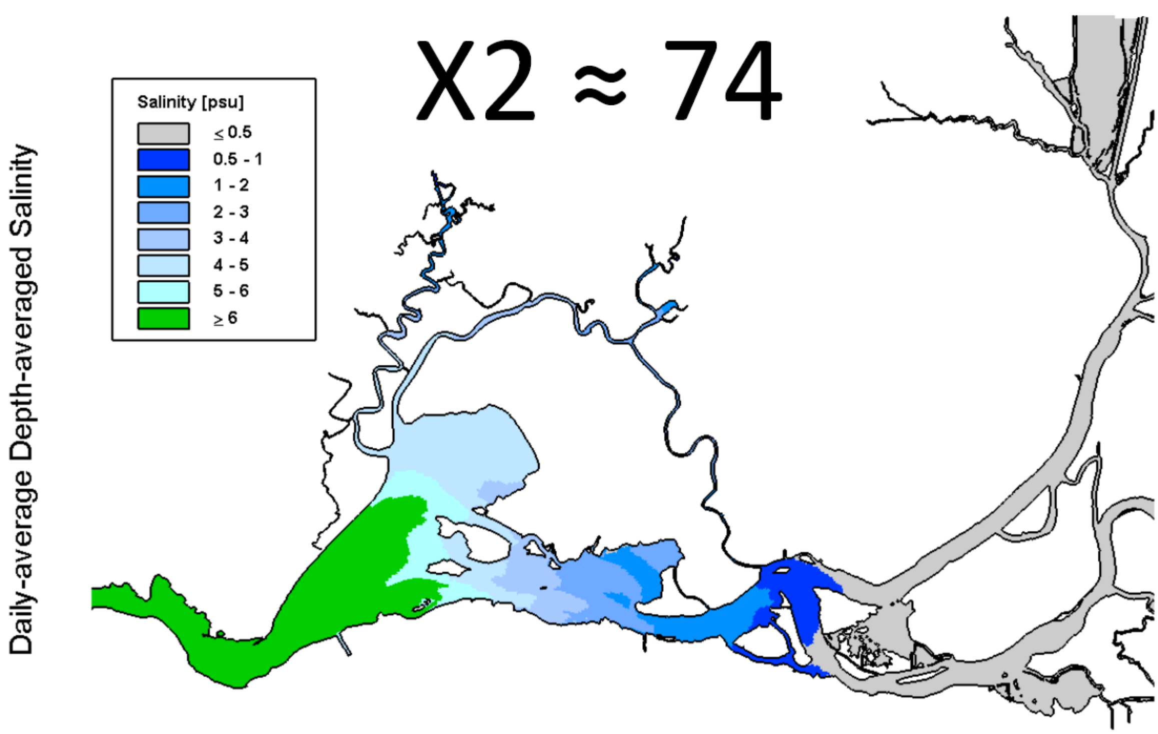


Figure 7. LSZ when X2=80. This level of X2 is in Portfolio #1b (Post-2020 BiOp/ITP) in Wet and Above Normal water years in September and October.

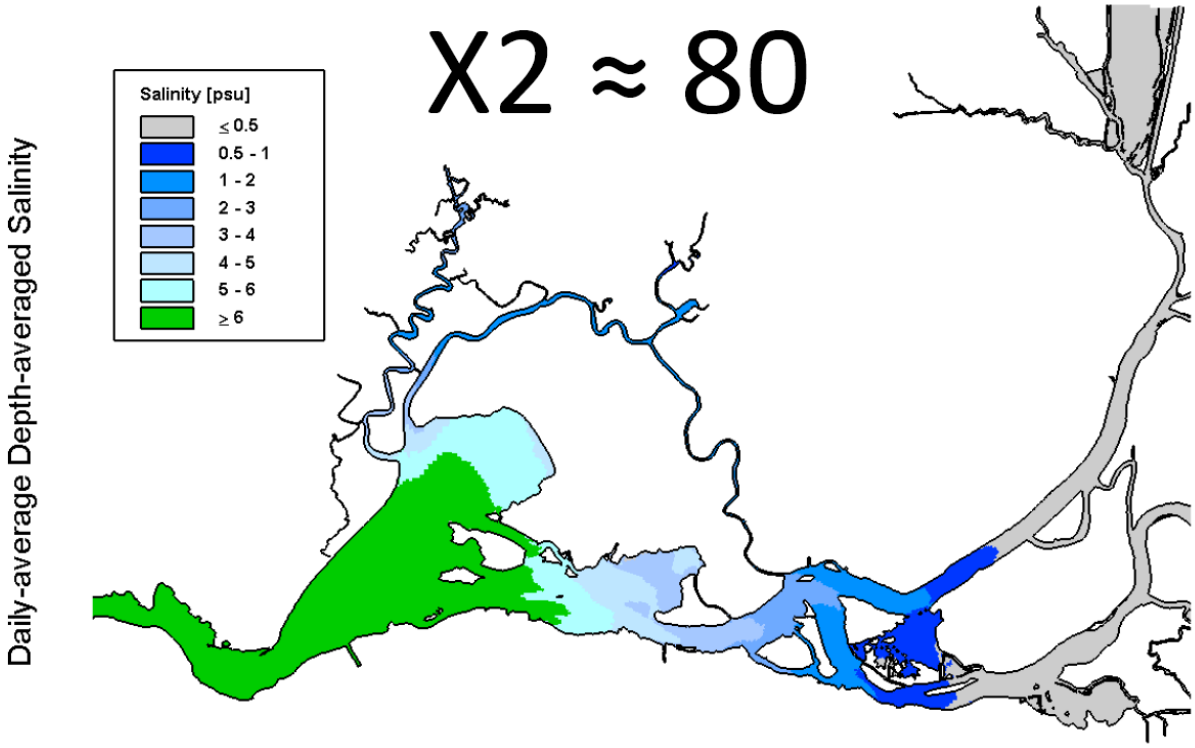


Figure 8. LSZ when X2=81. This level of X2 is in Portfolio #1a (Post-2008 BiOp) in Above Normal water years.

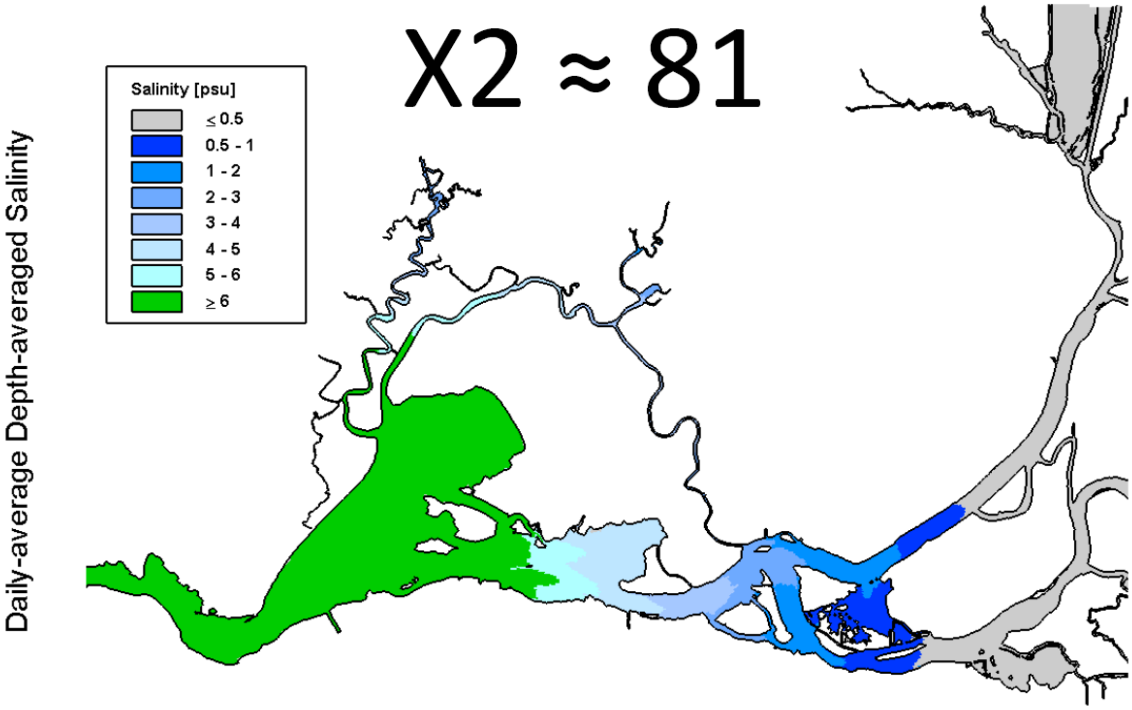
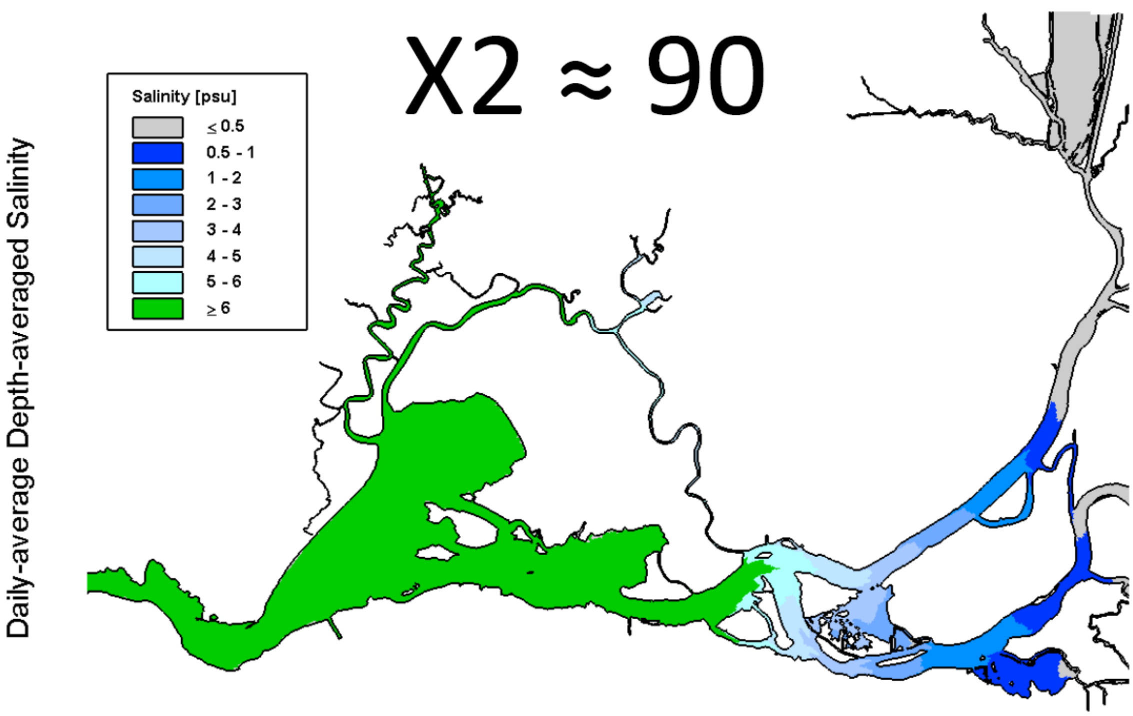


Figure 9. LSZ with X2=90.



7.2 FWS Life Cycle Model

The figure below is an analysis of FWS's Life Cycle Model (LCM) done by Will Smith – see Technical Note written by Will for the TWG in May 2021 for more information (Smith 2021). These findings are also described in the peer-reviewed version of this work in Smith et al. (2021).

Figure 10. Comparative Predictor Strength of Delta Smelt Life Cycle Model Covariates with Vital Rates
The figure estimates the relative[1] magnitude of influence and effect size of each covariate for each vital rate, represented as the product of evidence and the absolute value of effect size (Evidence*Effect). Vital rates are recruitment, post-larval survival, juvenile survival, and sub-adult survival. Covariates are averaged over the following months for each vital rate: recruitment (April-May), post-larval survival (June-August), juvenile survival (September-November), and Sub-adult survival (December-February). Covariates with the greatest support for each life stage and vital rate are circled or boxed. If, as in LCME, South Delta Secchi depth and OMR (circled) were assumed to index December-February entrainment mortality, the next best covariates age 1+ striped bass (STB1+) and Food may have indexed the remaining December-February natural mortality.

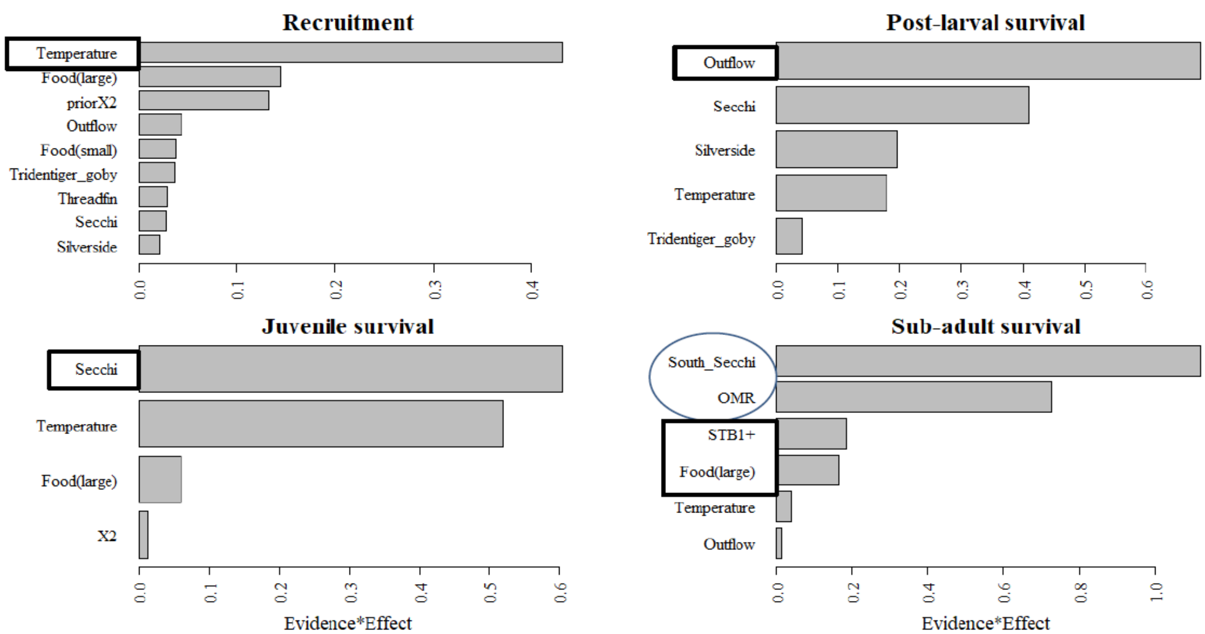


Figure above indicates that:

- **Recruitment** is most strongly correlated with water temperature (cooler is better) and the availability of large food items (more is better) in the April to May period. To a lesser degree, relative to temperature, recruitment is also correlated with the position of X2 from the previous fall (lower – i.e., further west – is better). A number of other covariates show relatively little influence on recruitment including outflow, food (small)[2], abundance of competitor species (Tridentiger goby, Threadfin, and Inland silverside) and turbidity.
- **Post-larval survival** is most strongly correlated with **outflows[3]** (higher is better) and turbidity (higher is better) in the **June to August period**. Inland silverside abundance (less is better), water

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[1] Note that the absolute numbers on the x-axis cannot be compared between the charts. The degree of difference between the influences should be understood only as relative to each other for each vital rate.
[2]Small and large food are only meaningful in that they matched the particular life stage of Delta Smelt (e.g., post-larval Delta Smelt are not matched with large food).

[3] Note that summer outflow and fall X2 are highly correlated. The highest summer Outflow years are the lowest fall X2 years, and vice versa. So management for one, is to some extent management for the other. Fall X2 has a management definition, but it is just an index of favorable fall conditions. Outflow is also highly correlated with food and temperature.

temperature (lower is better), and Tridentiger goby abundance (lower is better) in that same period were less highly correlated with post-larval survival.

- **Juvenile survival** is most strongly correlated with turbidity (higher is better) and water temperatures (lower is better) in the September to November period. Food (large) and X2 in that same period are correlated with juvenile survival but are a much weaker relative influence. It is important to note that juvenile survival connected observations from the July-August Townet Survey and the October-November Fall Midwater Trawl Survey. Neither survey was designed for Delta Smelt and may be subject to greater observation error compared to 20-mm and Spring Kodiak surveys. This observation error likely limited power to detect juvenile survival effects and distinguish among covariates.
- **Sub-adult survival** is strongly correlated with turbidity in the South Delta (lower is better) and Old and Middle River flows (positive, or less negative, is better) in the December to February period. Other covariates in this period that are influencing survival include striped bass (lower is better) and food (more is better). Water temperatures and outflow show a relatively weak influence.

8 Discussion and Next Steps

Summary of X2 sensitivity results:

- Predicted Delta Smelt population benefits were relatively consistent across the IBMR and LCME for X2 action runs.
- Population growth increases as summer outflow increases (lower X2). This can be seen by comparing results from X2 action runs and the set of 3c portfolios.
- Population growth also increased in Portfolio 2a, which increased flows in specific months (spring to fall) across all water year types, but there was a range of predicted benefits across models.
- All analyses done to date have incorporated effects of flow on Delta Smelt distribution, salinity, and food. Other potential effects (e.g., temperature, turbidity) have not been included due to lack of clear evidence to quantify those relationships in the models. Flow could have complex interactions with other factors that these models are not capturing.

9 Relationships With Other Actions

The TWG conducted a sensitivity analysis to further understanding of Delta Smelt population responses to varying levels of food, turbidity, and flow actions. The results of that analysis are further discussed in the Round 1 Final Report, but a key finding was that synergistic benefits to Delta Smelt population growth when increasing flow alongside food and turbidity.

10 Action Specification

- TWG meetings in February and March 2022 provided advice on the structure and principles for undertaking an X2 sensitivity analysis. A proposed approach was presented to the Policy Group SDM Steering Committee in April 2022 and received qualified support, with the qualification being that there would likely be operational limitations to achieving some of the X2 scenarios proposed for inclusion in the analysis (e.g., the low bookend scenario), but that including those X2 scenarios could support learning about operational limitations and thus may be useful for learning purposes.

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Appendix 1 – X2 monthly location tables

Table 6. Historical X2 locations used in "baseline" model runs and adjusted for sensitivity analyses. Outlined cells and footnotes describe X2 locations used in the 'action' sensitivity analysis.

Model Year Jan. 1 to Dec. 31	Water Year Type (SVI) Oct 1 to Sept 30	Baseline Model Inputs Variable: X2											
		J	F	M	A	M	J	J	A	S	O	N	D
1995	W	69	54	51	48	50	55	62	71	72	72	79	73
1996	W	69	56	50	57	60	65	75	77	78	85	82	67
1997	W	47	45	56	69	72	76	78	78	83	86	83	74
1998	W	69	49	47	49	53	53	59	66	68	72	73	62
1999	W	64	56	52	59	64	70	75	79	84	86	84	79
2000	W	78	62	52	62	65	73	78	80	84	87	85	84
2001	D	80	74	68	74	76	78	83	87	88	88	85	74
2002	D	64	72	72	73	74	77	81	85	88	87	84	80
2003	AN	63	62	69	71	63	69	77	79	86	88	84	76
2004	BN	65	66	57	65	71	81	80	82	85	84	81	81
2005	BN	70	68	64	62	62	61	72	80	82	84	86	79
2006	W	55	55	53	46	48	57	69	77	79	84	86	83
2007	D	79	75	71	75	76	79	82	87	86	88	88	86
2008	C	75	68	71	77	78	79	84	89	88	90	87	85
2009	D	84	77	69	74	72	76	82	85	87	86	86	84
2010	BN	79	66	68	70	67	69	78	84	85	85	84	72
2011	W	60	66	59	51	56	59	65	76	75	74	79	81
2012	BN	81	76	74	67	70	78	79	82	87	86	85	71
2013	D	65	70	75	75	76	78	81	84	84	86	86	84
2014	C	85	81	77	79	84	85	86	88	89	88	84	74

[1] Monthly X2 values between July and October were used as a LOWER bookend in the sensitivity analysis.
[2] Monthly X2 value for October 2003 used as upper bookend.
[3] Monthly X2 value for July 2004 used as upper bookend.
[4] Monthly X2 value for August 2010 used as upper bookend.
[2] Monthly X2 value for September 2012 used as upper bookend.

Table 7. X2 inputs for model runs for Reference Portfolio 1b (current management approximation, including Fall X2 ≤ 80km in W and AN years). Orange cells indicate X2 values that were adjusted from historical conditions.

Model Year Jan. 1 to Dec. 31	Water Year Type (SVI) Oct 1 to	Reference values (Fall X2, X2 <= 80km in Sept/Oct of W and AN years)											
		J	F	M	A	M	J	J	A	S	O	N	D
1995	W	69	54	51	48	50	55	62	71	72	72	79	73
1996	W	69	56	50	57	60	65	75	77	78	80	82	67
1997	W	47	45	56	69	72	76	78	78	80	80	83	74
1998	W	69	49	47	49	53	53	59	66	68	72	73	62
1999	W	64	56	52	59	64	70	75	79	80	80	84	79
2000	W	78	62	52	62	65	73	78	80	80	80	85	84
2001	D	80	74	68	74	76	78	83	87	88	88	85	74
2002	D	64	72	72	73	74	77	81	85	88	87	84	80
2003	AN	63	62	69	71	63	69	77	79	80	80	84	76
2004	BN	65	66	57	65	71	81	80	82	85	84	81	81
2005	BN	70	68	64	62	62	61	72	80	82	84	86	79
2006	W	55	55	53	46	48	57	69	77	79	80	86	83
2007	D	79	75	71	75	76	79	82	87	86	88	88	86
2008	C	75	68	71	77	78	79	84	89	88	90	87	85
2009	D	84	77	69	74	72	76	82	85	87	86	86	84
2010	BN	79	66	68	70	67	69	78	84	85	85	84	72
2011	W	60	66	59	51	56	59	65	76	75	74	79	81
2012	BN	81	76	74	67	70	78	79	82	87	86	85	71
2013	D	65	70	75	75	76	78	81	84	84	86	86	84
2014	C	85	81	77	79	84	85	86	88	89	88	84	74

Table 8. X2 inputs for model runs for versions of Portfolio 3c. Orange cells indicate X2 values that were adjusted from historical conditions.

Model Year	Water Year Type	Historical X2			
		J	A	S	O
1995	W	62	71	72	72
1996	W	75	77	78	85
1997	W	78	78	83	86
1998	W	59	66	68	72
1999	W	75	79	84	86
2000	W	78	80	84	87
2003	AN	77	79	86	88
2006	W	69	77	79	84
2011	W	65	76	75	74

Model Year	Water Year Type	Portfolio 3c1				Portfolio 3c2			
		J	A	S	O	J	A	S	O
1995	W	62	70	72	72	62	70	72	72
1996	W	65	70	78	85	65	70	78	80
1997	W	65	70	83	86	65	70	80	80
1998	W	59	66	68	72	59	66	68	72
1999	W	65	70	84	86	65	70	80	80
2000	W	65	70	84	87	65	70	80	80
2003	AN	65	70	86	88	65	70	80	80
2006	W	65	70	79	84	65	70	79	80
2011	W	65	70	75	74	65	70	75	74

Model Year	Water Year Type	Portfolio 3c3				Portfolio 3c4			
		J	A	S	O	J	A	S	O
1995	W	62	71	72	72	62	71	72	72
1996	W	70	75	78	85	70	75	78	80
1997	W	70	75	83	86	70	75	80	80
1998	W	59	66	68	72	59	66	68	72
1999	W	70	75	84	86	70	75	80	80
2000	W	70	75	84	87	70	75	80	80
2003	AN	70	75	86	88	70	75	80	80
2006	W	69	75	79	84	69	75	79	80
2011	W	65	75	75	74	65	75	75	74

Table 9. X2 inputs for model runs for versions of Portfolio 2a. Orange cells indicate X2 values that were adjusted from historical conditions.

Model Year Jan. 1 to	Water Year Type	Scenario: Portfolio 2a1 - no water budget											
		Variable: X2											
		J	F	M	A	M	J	J	A	S	O	N	D
1995	W	69	54	51	48	50	55	62	71	72	72	79	73
1996	W	69	56	50	57	60	65	75	77	78	80	82	67
1997	W	47	45	56	66	72	73	78	78	80	80	83	74
1998	W	69	49	47	49	53	53	59	66	68	72	73	62
1999	W	64	56	52	59	64	70	75	79	80	80	84	79
2000	W	78	62	52	62	65	73	78	78	80	80	85	84
2001	D	80	74	68	74	76	78	83	87	88	88	85	74
2002	D	64	72	72	73	74	77	81	85	88	87	84	80
2003	AN	63	62	66	71	63	69	77	78	80	80	84	76
2004	BN	65	66	57	65	71	74	78	78	85	84	81	81
2005	BN	70	68	64	62	62	61	72	78	82	84	86	79
2006	W	55	55	53	46	48	57	69	77	79	80	86	83
2007	D	79	75	71	74	76	79	82	87	86	88	88	86
2008	C	75	68	71	74	78	79	84	89	88	90	87	85
2009	D	84	77	69	74	72	76	82	85	87	86	86	84
2010	BN	79	66	68	70	67	69	78	78	85	85	84	72
2011	W	60	66	59	51	56	59	65	76	75	74	79	81
2012	BN	81	76	74	67	70	74	79	78	87	86	85	71
2013	D	65	70	74	75	76	78	81	84	84	86	86	84
2014	C	85	81	77	74	84	85	86	88	89	88	84	74

Model Year Jan. 1 to	Water Year Type	Scenario: Portfolio 2a2 - 700 TAF water budget											
		Variable: X2											
		J	F	M	A	M	J	J	A	S	O	N	D
1995	W	69	54	51	48	50	55	62	71	72	72	79	73
1996	W	69	56	50	57	60	65	75	77	78	80	82	67
1997	W	47	45	56	66	72	73	78	78	83	86	83	74
1998	W	69	49	47	49	53	53	59	66	68	72	73	62
1999	W	64	56	52	59	64	70	75	79	80	80	84	79
2000	W	78	62	52	62	65	73	78	78	80	81	85	84
2001	D	80	74	68	74	76	78	83	87	88	88	85	74
2002	D	64	72	72	73	74	77	81	85	88	87	84	80
2003	AN	63	62	66	71	63	69	77	78	81	88	84	76
2004	BN	65	66	57	65	71	74	78	78	85	84	81	81
2005	BN	70	68	64	62	62	61	72	78	82	84	86	79
2006	W	55	55	53	46	48	57	69	77	79	80	86	83
2007	D	79	75	71	74	76	79	82	87	86	88	88	86
2008	C	75	68	71	74	78	79	84	89	88	90	87	85
2009	D	84	77	69	74	72	76	82	85	87	86	86	84
2010	BN	79	66	68	70	67	69	78	78	85	85	84	72
2011	W	60	66	59	51	56	59	65	76	75	74	79	81
2012	BN	81	76	74	67	70	74	79	78	87	86	85	71
2013	D	65	70	74	75	76	78	81	84	84	86	86	84
2014	C	85	81	77	74	84	85	86	88	89	88	84	74

Appendix 2 – IBMR Annual Results for Outflow/X2 Action Model Runs

Conditional Formatting – blue/red indicates increased/decreased population growth compared to baseline

Population Growth Rate = nAB(t+1)/nAB(t) , where nAB = number of adult breeders; e.g.: population growth rate in 1996 = nAB(1996)/nAB(1995)

Baseline = Population Growth Rate predicted from models based on observed conditions from 1995-2014

IBMR Change in Population Growth Rate from Baseline									
		6.12	6.13	6.15	6.16	6.18	6.19	6.21	6.22
Action year is bolded...		X2 summer low - X2-dist - sal-food low	X2 summer low - X2-dist - sal-food high	X2 summer high - X2-dist - sal-food low	X2 summer high - X2-dist - sal-food high	X2 fall low - X2-dist - sal-food low	X2 fall low - X2-dist - sal-food high	X2 fall high - X2-dist - sal-food low	X2 fall high - X2-dist - sal-food high
W	**1996**	15%	17%	-30%	-17%	8%	12%	-25%	-17%
W	**1997**	38%	52%	-26%	-10%	0%	15%	-13%	4%
W	**1998**	37%	54%	-14%	0%	23%	39%	-7%	6%
W	**1999**	6%	9%	-36%	-18%	0%	1%	-17%	-13%
W	**2000**	10%	18%	-23%	-15%	-6%	4%	-8%	2%
D	2001	17%	30%	-17%	-7%	-8%	4%	-8%	4%
D	2002	-1%	-2%	-2%	-3%	-4%	-2%	0%	-4%
AN	**2003**	2%	3%	3%	3%	0%	-3%	1%	-1%
BN	**2004**	12%	34%	-16%	-5%	37%	52%	1%	12%
BN	**2005**	49%	105%	20%	39%	18%	41%	9%	22%
W	**2006**	10%	46%	-28%	-10%	6%	34%	8%	24%
D	2007	13%	30%	-31%	-15%	1%	25%	-16%	4%
C	2008	-3%	2%	-6%	-5%	-3%	1%	-7%	-7%
D	2009	-2%	-3%	-3%	0%	-2%	-1%	-1%	-1%
BN	**2010**	-2%	0%	-3%	-2%	-1%	0%	-2%	-1%
W	**2011**	3%	26%	-31%	-23%	25%	39%	-4%	3%
BN	**2012**	-3%	12%	-61%	-41%	11%	20%	-30%	-17%
D	2013	57%	96%	9%	23%	7%	24%	-11%	-1%
C	2014	0%	2%	-1%	-1%	0%	1%	-2%	1%
	Medians across...								
	95 to 2015	14%	27%	-17%	-6%	7%	17%	-6%	2%
	07 to 2015	8%	19%	-18%	-9%	6%	14%	-8%	-1%
	05 to 2015	12%	28%	-16%	-5%	7%	19%	-5%	3%
	95 to 2006	19%	33%	-15%	-3%	8%	18%	-4%	5%
	wet	17%	30%	-29%	-14%	8%	20%	-13%	-1%
	dry	0%	2%	-1%	0%	0%	1%	0%	-1%
	00-2014	11%	25%	-14%	-4%	7%	17%	-4%	4%
	Averages across...								
	95 to 2015	12%	24%	-20%	-9%	5%	14%	-9%	-2%

IBMR Change in Population Growth Rate from Baseline											
		6.24	6.25	6.26	6.27	6.28	6.29	6.30	6.31	6.32	6.33
Action year is bolded...		X2 summer low_W, AN - X2 dist - sal-food med (Bashevkin)	X2 summer 1_W, AN - X2 dist - sal-food med (Bashevkin)	X2 summer 2_W, AN - X2 dist - sal-food med (Bashevkin)	X2 summer 3_W, AN - X2 dist - sal-food med (Bashevkin)	X2 summer high_W, AN - X2 dist - sal-food med (Bashevkin)	X2 fall low_W, AN - X2 dist - sal-food med (Bashevkin)	X2 fall 1_W, AN - X2 dist - sal-food med (Bashevkin)	X2 fall 2_W, AN - X2 dist - sal-food med (Bashevkin)	X2 fall 3_W, AN - X2 dist - sal-food med (Bashevkin)	X2 fall high_W, AN - X2 dist - sal-food med (Bashevkin)
W	**1996**	16%	10%	2%	-12%	-22%	10%	2%	-9%	-16%	-18%
W	**1997**	48%	34%	21%	1%	-18%	7%	6%	-5%	-7%	-5%
W	**1998**	50%	45%	36%	14%	-5%	30%	23%	7%	3%	-3%
W	**1999**	8%	6%	-2%	-15%	-26%	0%	-6%	-11%	-13%	-14%
W	**2000**	20%	12%	4%	-9%	-19%	0%	-4%	-14%	-10%	-2%
D	2001	25%	22%	15%	1%	-11%	-1%	-3%	-7%	-10%	-2%
D	2002	-1%	0%	-2%	-2%	-6%	-4%	-2%	-3%	-4%	-3%
AN	**2003**	4%	2%	2%	3%	2%	-3%	-3%	-3%	-3%	-2%
BN	2004	25%	19%	11%	-2%	-11%	45%	39%	17%	5%	8%
BN	2005	0%	1%	-1%	0%	-2%	1%	2%	-2%	-1%	-2%
W	**2006**	-2%	-3%	-4%	-4%	-5%	-3%	-4%	-3%	-3%	-3%
D	2007	23%	16%	5%	-9%	-21%	15%	9%	-8%	-11%	-7%
C	2008	-1%	-3%	-2%	-3%	-9%	-1%	-1%	-5%	-7%	-6%
D	2009	-1%	-1%	0%	-3%	-1%	-1%	-1%	-1%	-4%	-4%
BN	2010	1%	-1%	-2%	0%	-1%	-2%	-3%	-1%	-1%	0%
W	**2011**	-3%	-3%	-6%	-7%	-7%	-2%	-3%	-1%	-3%	-4%
BN	2012	-10%	-19%	-28%	-45%	-55%	5%	-4%	-20%	-26%	-27%
D	2013	-1%	-3%	-3%	-4%	-9%	3%	-1%	-3%	-2%	-2%
C	2014	-2%	-2%	0%	-1%	-2%	0%	-1%	-3%	-2%	-4%
	Medians across...										
	95 to 2015	11%	8%	3%	-5%	-12%	6%	3%	-3%	-5%	-4%
	07 to 2015	2%	-1%	-4%	-9%	-14%	3%	1%	-4%	-6%	-6%
	05 to 2015	1%	-1%	-4%	-8%	-12%	2%	0%	-4%	-5%	-5%
	95 to 2006	18%	14%	9%	-1%	-10%	8%	6%	-2%	-4%	-3%
	wet	24%	17%	8%	-9%	-21%	13%	8%	-4%	-8%	-7%
	dry	1%	1%	1%	0%	-2%	0%	-1%	-1%	-2%	-2%
	00-2014	5%	3%	0%	-5%	-10%	4%	3%	-2%	-4%	-3%
	Averages across...										
	95 to 2015	12%	8%	2%	-7%	-14%	5%	1%	-5%	-8%	-7%

Appendix 3 – X2/outflow modeled effects on salinity and turbidity

Figure 11. Salinity vs. X2 by subregion. Black points are the mean subregion-month conditions from Dayflow data (X2) and water quality monitoring data (salinity) in the Delta (between 1995 and 2014; n = 2880). The red lines are predicted values from a generalized linear model (GLM) with a gamma distribution (for when data is like the salinity data – always positive and skewed). There is a red line for each month.

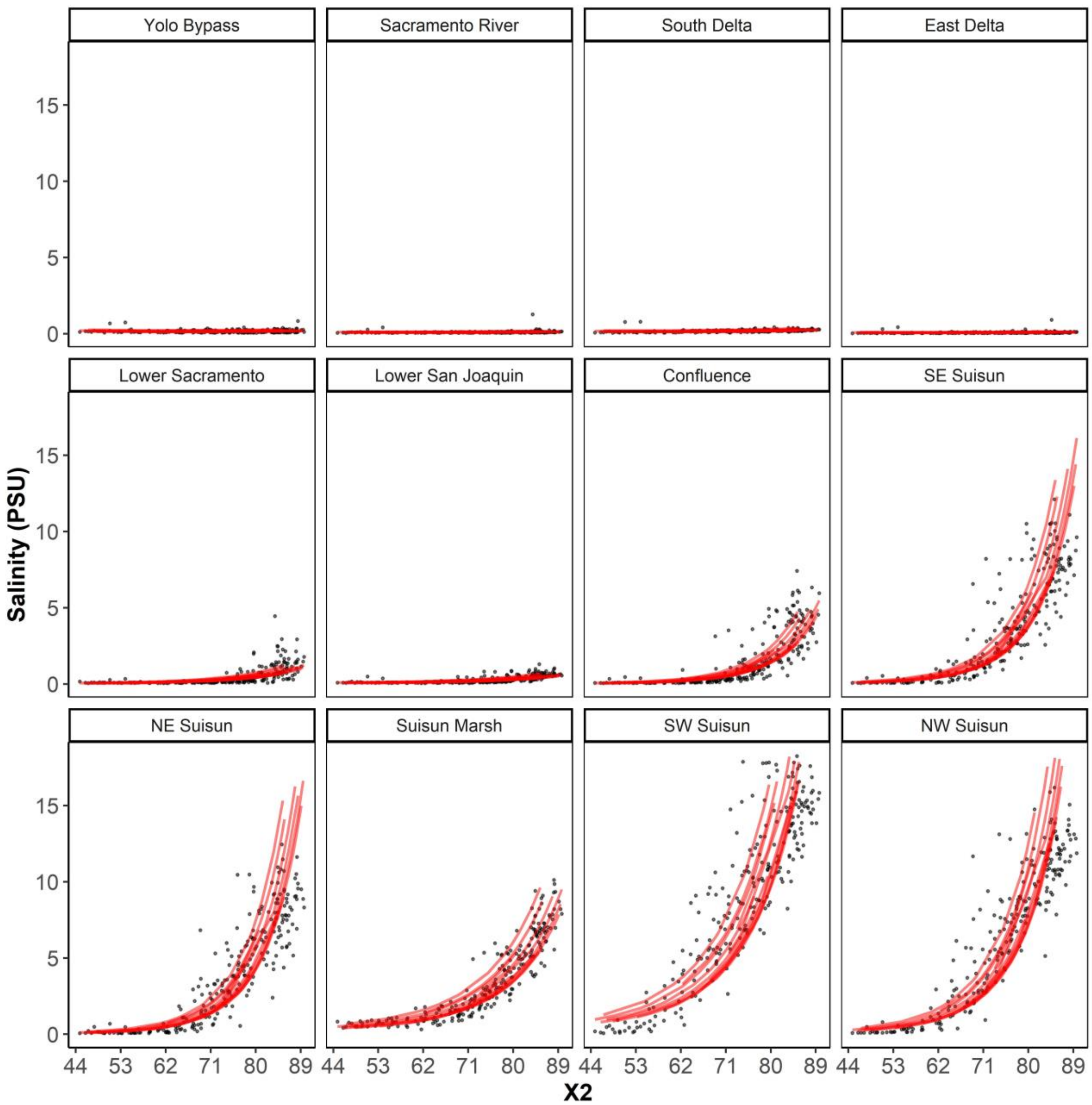
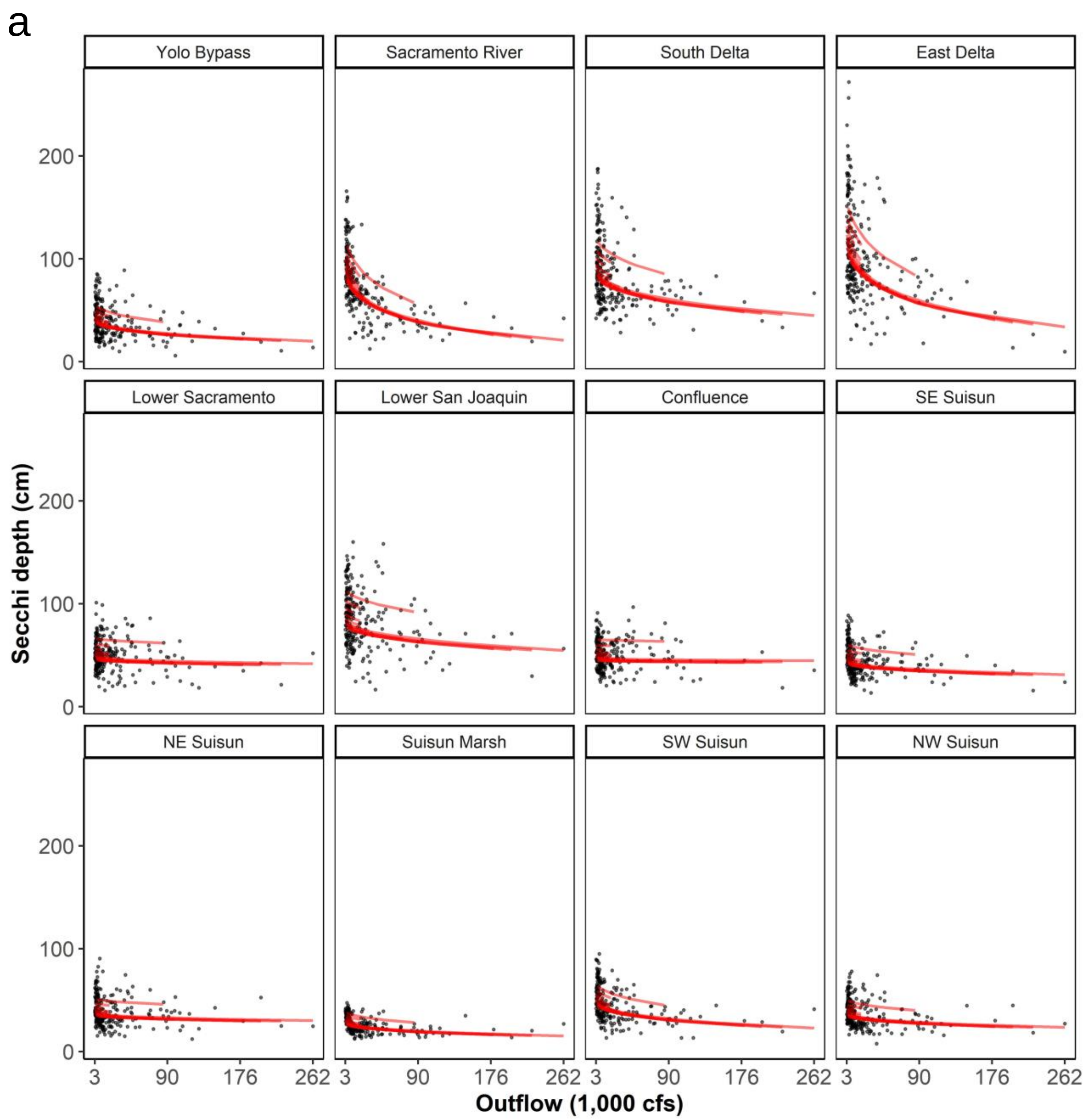
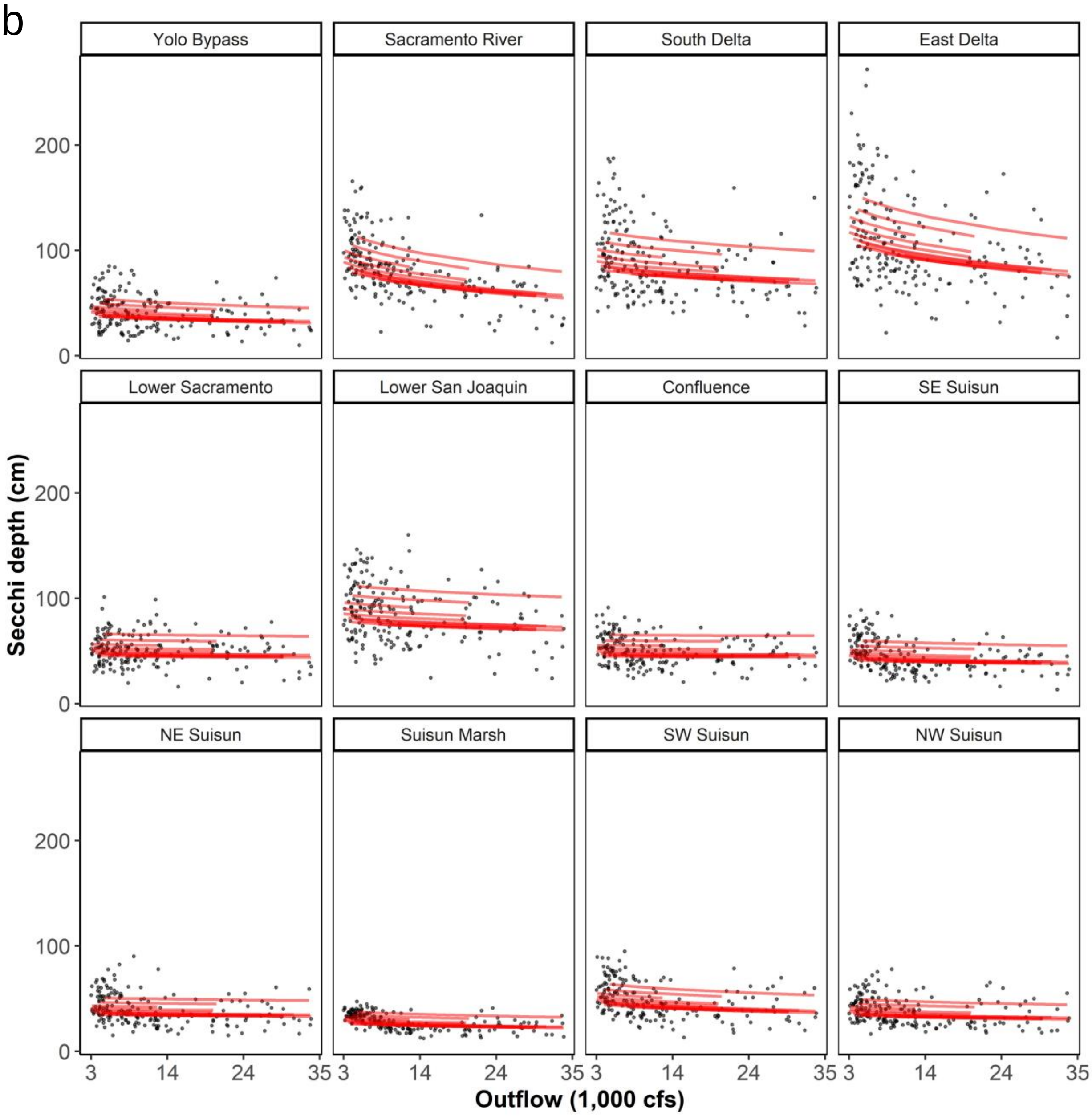


Figure 12. Turbidity vs. outflow by subregion. Black points are the mean subregion-month conditions from Dayflow data (outflow) and water quality monitoring data (turbidity) in the Delta (between 1995 and 2014; n = 2880). The red lines are predicted values from a generalized linear model (GLM) with a gamma distribution (for when data is like the turbidity data – always positive and skewed). There is a red line for each month. Results are shown for the full range of outflow values (a) and lower flow values < 35,000 cfs (b).



b



Yolo Bypass
Sacramento River
South Delta
East Delta
Lower Sacramento
Lower San Joaquin
Confluence
SE Suisun
NE Suisun
Suisun Marsh
SW Suisun
NW Suisun
Secchi depth (cm)
0
100
200
3
14
24
35
Outflow (1,000 cfs)