CSAMP Delta Smelt Structured Decision Making – Round 1 Evaluation Report

Prepared for

Collaborative Science and Adaptive Management Program (CSAMP)

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Executive Summary

This report documents the findings to date of the Collaborative Science and Adaptive Management Program's (CSAMP's) implementation of a Structured Decision Making (SDM) process in support of increasing the Delta Smelt population. The CSAMP Delta Smelt Technical Working Group (TWG) identified management actions with hypothesized benefits for Delta Smelt and applied four life cycle models and expert input to quantitatively evaluate effects of those actions on population growth. Comparing results across models strengthens conclusions when they agree and generates new insights when they diverge. The SDM process also estimated the effects of actions on other objectives in a coarse manner for the purposes of making relative comparisons of benefits and costs. Other objectives included salmon, water resources, and capital and operating costs. The results of this multi-objective evaluation of actions and portfolios (i.e., combinations of actions: Table ES-1) are presented in Consequence Tables (Table ES-2 and ES-3). CSAMP participants vary in their opinions on whether there is sufficient information and/or confidence in the results to make definitive decisions on which management actions to advance or drop. To better understand where there are areas of agreement and disagreement with respect to how best to recover Delta Smelt, the next step in the SDM process would be deliberation on the trade-offs identified in the Consequence Tables and associated uncertainties.

The SDM process first modeled a subset of current management actions targeted at Delta Smelt[1] to address the question: if the same management actions had been implemented throughout the entire 1995-2014 period (i.e., the model period used in the evaluation), how might this have altered the growth of the Delta Smelt population in comparison to the model baseline of observed, historical conditions? All models predicted that these Delta Smelt actions would increase population growth, relative to the 1995-2014 model baseline, but the population was predicted to decline in the absence of consecutive wet years, similar to what was actually observed. The result suggests the selected subset of actions (which did not include all the mandated management actions: e.g., tidal wetland restoration) are not sufficient to achieve the CSAMP goal of self-sustaining Delta Smelt population growth.

Through modeling several other actions and portfolios, results showed that growing the Delta Smelt population might be possible through management actions that increase combinations of food, turbidity, flows, and/or improve survival via contaminant reduction and further entrainment mitigation. Results showed the additive and synergistic effects of combining multiple actions, demonstrating the benefits of concurrently targeting multiple population drivers. The portfolios that grew the population fastest involved expanded spatial scales and larger numbers of actions – and thus had significant trade-offs with time to implementation and resource costs (Table ES-2). All actions have important uncertainties around their resource costs and effectiveness or feasibility when implemented at scale as well as bottlenecks to their implementation. The uncertainties surrounding how well actions are expected to perform are multi-faceted and derive from limitations of the models, available data, and scope of this SDM process. These limited the TWG's confidence in a more specific ranking of drivers or actions beyond broader strategic guidelines.

Given the uncertainties, bottlenecks, and direction from the CSAMP Policy Group to not do additional iterations of the SDM process at this time, it was the TWG's judgement that the most effective next step in advancing Delta Smelt recovery would be to improve knowledge of effects and feasibility/cost of a few specific actions that target improvements in food, turbidity, and flows, and increased survival through contaminant reduction and entrainment mitigation. Seven next steps for actions are identified below for decision makers to consider advancing through Adaptive Management (AM) or research studies. Pursuing combinations of these next steps concurrently could represent a robust strategy for Delta Smelt recovery that provides opportunities to coordinate actions targeting multiple population drivers while reducing existing uncertainties.

[1] These actions included: Old and Middle River (OMR) management, fall X2 management at <80 km in wet and above normal water years, North Delta Food Subsidies, and summer/fall operation of the Suisun Marsh Salinity Control Gates. These management actions are specified in the 2019 Biological Opinion (BiOp) and 2020 Incidental Take Permit (ITP) to mitigate the effects of the Central Valley Project (CVP) and State Water Project (SWP) on Delta Smelt.

1. Managed Wetlands Food Production: **Implement Adaptive Management for managed wetlands food production in Suisun Marsh, while investigating ways to scale up actions.** Managed wetland productivity experiments are being implemented at small scales with some empirical evidence that food can be exported. The action was predicted to have benefits to Delta Smelt, especially if scaled up (e.g., 2-4K ac) and/or combined with turbidity actions.

2. Aquatic Weed Control: **Implement Adaptive Management for different methods of aquatic weed control and their effectiveness of enhancing turbidity and food.** Location, spatial scales, and timings of herbicide application should all be considered. Aquatic weeds have increased coverage in the San Francisco Estuary, reaching up to 6,000 acres in some recent years. Pilot implementation of weed control has been conducted, but evidence of efficacy is limited. This action was predicted to have relatively high potential benefits to Delta Smelt via increasing turbidity, and it is implementable at a smaller scale in the near-term. AM could investigate turbidity benefits, as well as monitor for any adverse effects of different methods and scales of the action.

3. Physical Point Source Contaminants Reduction: **Implement Adaptive Management to test reduction in contamination by constructed wetlands at Ulatis Creek, which may reveal benefits from improving survival in a critical Delta Smelt habitat (Cache Slough).** Reducing contaminants from stormwater runoff at key hot spots with constructed wetlands has been effective in other systems but have only sparingly been implemented in the San Francisco Estuary. Reduction of contaminants (e.g., pyrethroids and fiproles) is expected to have Delta Smelt and ecosystem-wide benefits, especially if the action can be scaled up. Piloting a constructed wetlands project could inform whether and how the action could be scaled up.

4. Outflow Actions: **Operations modeling to confirm the availability of water and the feasibility of operations to achieve various X2 management scenarios, with a focus on a summer flow action.** Outflow actions were predicted to have Delta Smelt population benefits, especially if targeted in summer months. These actions also have substantial trade-offs with water resources, as well as high uncertainty around operations that could generate the required flows due to lack of operations modeling. Operations modeling can help characterize the feasibility, costs, and benefits.

5. Sediment Supplementation: **Feasibility studies are necessary to identify potential sources of sediment and transport methods to the reintroduction point; hydrodynamic modeling of different reintroduction points to inform implementation; and timing/locations where smaller scale supplementation improves conditions for Delta Smelt.** Sediment supplementation was predicted to have some of the highest benefits to Delta Smelt and was one of the few actions tested that could increase turbidity (along with aquatic weed control). However, substantial uncertainties remain for how the action could be implemented. Feasibility studies are a prerequisite before considering any small-scale pilot implementation.

6. Engineered First Flush: **Integrate existing and new climate forecasting tools to predict first flush conditions; begin development of a condition-dependent Adaptive Management framework for testing the action through coordination with natural resource and water agencies.** Engineering a first flush in years when it would not occur naturally has been proposed to increase turbidity that attracts spawning Delta Smelt to the North Delta and reduces risk of entrainment. It may require fewer water resources than other flow-related actions and be technically implementable in the near-term. A next step focused on forecasting first flush conditions could inform when water resources could be deployed most effectively with this action and potentially lead to pilot implementation.

7. Tidal Habitat Restoration: **Research to quantify local and system-wide contributions of restored tidal wetlands to Delta Smelt diets, and the effects of tidal wetland restoration on water temperature.** Tidal wetland restoration is ongoing in the San Fransisco Estuary with more planned. A large portion of implemented and planned tidal wetland restoration is an action under the 2008 BiOp with hypothesized food benefits for Delta Smelt. However, at present, monitoring has not observed changes in food density. Additional research to quantify food and other effects could inform whether and how the action is implemented in the future for the purpose of increasing food for Delta Smelt.

Section 6 provides more detailed description of the above seven next steps.

AM and research next steps were not identified for the North Delta Food Subsidies and Summer/Fall operation of the Suisun Marsh Salinity Control Gates as AM is ongoing for those actions through the Delta Coordination Group. These AM efforts will create additional evidence that can be used to update the modeling of these actions in SDM processes. Next steps were not identified for Old and Middle River (OMR) management action because the models showed that action is supporting population growth (through decreasing entrainment mortality) and considerable study and refinement of that action has occurred to date. While supplementation is widely recognized by CSAMP participants as being necessary and experimental release of cultured fish is ongoing, supplementation was not identified as a next step by the TWG because the SDM process focused on actions to enhance self-sustaining population growth.

Table ES-1. Summary of management actions included in 8 portfolios modeled in the CSAMP Delta Smelt SDM evaluation. Actions in grey are the same as actions included in the Reference Portfolio (1b, current management approx.). Actions in blue were adjusted or additional to the Reference Portfolio. Different scales or timings are noted for some actions that differed across portfolios. Actions are described further in main report.

	Portfolios							
Action name	1b Current mgmt (approx.)	2a Full-year flows	2b Cache Slough	2c Cache Slough & Suisun Marsh	3c Summer flow & tidal wetlands[1]	3a Self-sustaining/ permanent mgmt	3d Focus on food	3e Habitat connectivity
North Delta Food Subsidies	✓	✓	✓	✓	✓	✓	✓	✓
Deep Water Ship Channel food			✓	✓			✓	
Managed wetlands for food				✓ 2K ac			✓ 4K ac	
Tidal wetland restoration					✓ 9K ac	✓ 9K ac	✓ 30K ac	✓ 2K ac
Suisun Marsh Salinity Control Gates	✓	✓	✓	✓	✓	✓	✓	✓
Outflow/X2 management	Fall (W,AN)	All seasons / yrs	Fall (W,AN)	Fall (W,AN)	Sum-Fall (W,AN)	Fall (W,AN)	Fall (W,AN)	Fall (W,AN)
Sediment supplementation								✓
Aquatic Weed Control			✓ 1 subregion	✓ 1 subregion			✓ 5 subregions	✓ 3 subregions
Franks Tract						✓		✓
OMR management	✓	✓	✓	✓	✓	✓	✓	✓
Engineered First Flush		✓						
Contaminant reduction						✓ 12 subregions	✓ 12 subregions	✓ 8 subregions

[1] Portfolio 3c included multiple versions/model runs that varied X2 targets in summer and fall. Specific X2 targets are given when presenting and discussing results in subsequent sections of the report.

Table ES-2. Consequence Table of predicted outcomes for portfolios (combinations of actions) and objectives/performance measures in the CSAMP Delta Smelt SDM evaluation. Green cells indicate performance measures where higher values (darker shades) are preferred. Orange cells indicate metrics where lower values (lighter shades) are preferred.

	Portfolios								
Objective & Performance Measure	**1b** Current mgmt (approx)	**2a.1** Full-year flows	**2b** Cache Slough	**2c** Cache Slough & Suisun Marsh	**3c.2** Summer flow & tidal wetlands (X2: Summer 65/70km)	**3c.4** Summer flow & tidal wetlands (X2: Summer 70/75km)	**3a** Self-sustaining/ permanent mgmt	**3d** Focus on food	**3e** Habitat connectivity
Delta Smelt Population									
Population Growth rate[1] (average lambda: 1995-2014)									
IBMR	1.00	1.21	1.12	1.25	1.13	1.10	1.40	1.96	2.23
LCME	1.09	1.15	-	-	1.25	1.19	1.21	1.50	1.31
LF	0.91	0.93	1.05	1.27	1.07	1.06	1.11	1.43	1.29
% change in population growth[1] (from 1995-2014 model baseline)									
IBMR	1%	23%	14%	27%	15%	12%	42%	99%	126%
LCME[2]	20%	25%	-	-	33%	27%	27%	58%	38%
MDR[2]	29%	15%	-	-	24%	17%	13%	33%	90%
LF	5%	8%	22%	47%	22%	21%	29%	64%	48%
% change in population growth[1] (from Reference Portfolio 1b)									
IBMR	-	22%	13%	25%	14%	11%	40%	97%	124%
LCME	-	6%	-	-	14%	9%	10%	38%	20%
LF	-	2%	16%	40%	17%	16%	22%	57%	42%
Dynamic Habitat Suitability Index[3] (overlap)									
Yolo/Cache Slough	20%	20%	32%	32%	21%	21%	21%	33%	20%
Confluence & Lower Rivers	7%	7%	7%	7%	7%	7%	7%	12%	30%
Suisun Marsh & Bay	20%	23%	20%	21%	23%	23%	21%	21%	21%
Uncertainty[4] (TWG group scores)									
Confidence in action effect assumptions: TWG avg (range of actions; scale: 1 to 5)	3.0 (food) to 4.0 (OMR)	2.4 (distrib) to 4.0 (OMR)	2.4 (food) to 4.0 (OMR)	2.4 (food) to 4.0 (OMR)	2.3 (food) to 4.0 (OMR)	2.3 (food) to 4.0 (OMR)	2.3 (food) to 4.0 (OMR)	2.3 (food) to 4.0 (OMR)	2.3 (food) to 4.0 (OMR)
Time to implementation[5] (TWG group scores)									
# of actions implementable < 5 yrs (TWG avg)	-	1	1	2	1	1	0	0	1
# of actions that may be implementable > 5 yrs (TWG avg)	-	0	1	1	1	1	3	5	4
Salmon effects[6] (expert group scores)									
Potential benefits: Expert avg (scale: 0 to 3)	0	1	1	1	1	1	2	3	1
Potential risks: Expert min (scale: -3 to 0)	0	0	-1	-1	0	0	0	-2	-1
Water / Resource Costs[7] (ballpark estimates, relative to Reference Portfolio 1b, for comparative purposes only)									
Water[8] (TAF/yr): All yrs	-	212	0	0	495	127	0	0	0
Water[8] (TAF/yr): W / AN	-	232	0	0	1100	283	0	0	0
Water[8] (TAF/yr): BN	-	337	-	-	-	-	-	-	-
Water[8] (TAF/yr): D / C	-	114	-	-	-	-	-	-	-
Costs ($ million / yr): Total[9]	$0	$151-$200	$1-$5	$1-$5	$401-$450	$101-$150	$101-$150	$151-$200	$76-$100
Costs ($ million / yr): Water[10]	-	$173	$0	$0	$404	$104	$0	$0	$0
Costs ($ million / yr): Capital & operating[11]	-	None	$1-$5	$1-$5	$21-$30	$21-$30	$101-$150	$151-$200	$76-$100

[1] Delta Smelt population metrics were calculated in three ways: (1) annual predicted population growth rate (lambda) from the portfolio, (2) the percent change in annual population growth from the portfolio relative to baseline, historical conditions between 1995-2014, where values > 0% indicate increased population growth relative to baseline, and (3) the percent change in annual population growth from the portfolio relative to Reference Portfolio 1b (current management approx.). Metrics were averaged over the 20-yr period.

[2] The LCME and MDR models used different versions (with different sets of covariates) to evaluate different actions, which leads to variation in % change from baseline. These models often could only include effects of an action for a portion of months even if it was specified to have year-round effects. MDR results were only available for % change from baseline.

[3] Dynamic Habitat Suitability Index (between 0 and 100%) was calculated as the percentage of months (over the 20-year model period) when all four dynamic habitat attributes (temperature, turbidity, salinity, and prey) are in "suitable" ranges (i.e., suitable conditions overlap), defined by existing studies and the TWG.

[4] Effect uncertainty was scored by TWG members to indicate their level of confidence in the assumed/quantified proximate effects (e.g., on food, turbidity) of each management action using a constructed scale (1 [lowest confidence] to 5 [greatest confidence]). Reported as the range of actions in a portfolio with the lowest and highest average TWG score.

[5] Time to implementation is defined in this process as how long it will take to achieve full implementation, including research of technical aspects of the action and generation of expected benefits for Delta Smelt, while not considering time needed for permitting. Time to implementation was scored by TWG members. Values in different time to implementation categories reflect the number of actions in a portfolio additional to actions included in Reference Portfolio 1b, based on average TWG scores.

[6] Salmon effects of actions (sometimes at different scales) were scored by subject matter experts from -3 (greatest risks) to +3 (greatest benefits). Individual action scores were summed within a portfolio and rescaled from 0 (no benefits) to +3 (greatest benefits). Scores for individual actions deemed by experts as having any potential direct risk were summed within a portfolio and rescaled from -3 (greatest risks) to 0 (no risks). Potential benefits are reported as average scores; potential risks are reported as minimum scores to represent any degree of risk to salmonids expressed by experts. Salmon experts noted potential negative risks to juvenile Chinook from AWC, as there is some evidence that higher turbidity can decrease foraging rates, and juveniles can use submerged aquatic vegetation to avoid predation. There is also the potential for direct mortality from mechanical (or chemical) removal. Effects to salmon of flow actions reflect potential direct, within-year benefits/risks of changing flow in a given season. Experts did not consider carry-over effects of flow actions, and modeling how operations would achieve flow actions is needed to better estimate effects to salmon.

[7] All water and resource costs: Water resources and capital and operating costs of portfolios were calculated relative to Reference Portfolio 1b (current management approx.). Costs for individual management actions are reported relative to baseline, historical conditions – not Reference Portfolio 1b. Therefore, water volumes and resource costs are slightly different between the tables. Ballpark values were estimated through coarse methods and meant for comparative purposes only.

[8] Additional water (relative to outflow under Reference Portfolio 1b) is averaged across all 20 years and is presented for comparative purposes only. The source of water needed to implement flow actions was not identified and water was not balanced within or among years in the SDM process. The water resource volume represents the net volume of water necessary to move X2 from its position in Reference Portfolio 1b to a target condition, based on equations in Monismith et al. (2002) and Denton (1993).

[9] Total cost was calculated as the sum of monetized water and capital & operating costs, annualized over the 20-yr period without a discount rate.

[10] Monetization of water used $815 per acre foot of water, annualized over the 20-yr period, as discussed and agreed to by the CSAMP Policy Group Steering Committee. See Appendix 3 – Water Resources Methods – Monetized water cost.

[11] Includes ballpark estimates of capital & operating costs, annualized without a discount rate.

Table ES-3. Consequence Table of predicted outcomes for individual management actions and objectives/performance measures in the CSAMP Delta Smelt SDM evaluation. Actions are grouped by expected time to implementation. Green cells indicate performance measures where higher values (darker shades) are preferred. Orange cells indicate metrics where lower values (lighter shades) are preferred. Management action names are shaded by their primary effect: blue = flow and food, green = food, orange = turbidity, and purple = survival/other.

Objective & Performance Measure	Management Actions[1]																			
	Current management				Can implement in < 5 yrs[2]						May be able to implement in > 5 yrs[2]									
	North Delta Food Subsidies[3]	Fall X2/Outflow (X2 ≤ 80 for Sept/Oct)[4]	Suisun Marsh Salinity Control Gates (SMSCG)[4]	Old & Middle River Management (2008/2009/2019 BiOps)	Managed Wetlands Food Production[3]	Summer Outflow (X2 ≤ 70/75 for July/Aug)[4]		Full-year Flow[4]	Engineered First Flush	Aquatic weed control	Tidal Wetland Restoration in North Delta Arc		Managed Wetlands Food Production[3]	DWSC Food[3]	Franks Tract Restoration	Aquatic weed control		Sediment supplementation	Contaminant reduction	
		W/AN			1K ac in SM	W/AN	W/AN/BN	W/AN/BN/D/C		600 ac in CS	9K ac	30K ac	4K ac			1.4K ac	3.5K ac		Yolo / CS	Delta-wide
Delta Smelt Population																				
Delta Smelt Population Growth[5] (average lambda 1995-2014)																				
IBMR	0.98	0.98	0.98	1.00	0.98	1.04	1.09	1.15	1.05	1.04	1.04	1.12	0.98	0.98	1.14	1.28	1.47	1.70	1.00	1.14
LCME	-	0.94	-	1.09	-	0.99	1.05	0.99	-	-	1.00	1.14	-	-	-	-	1.00	1.01	-	-
LF	0.87	-	-	-	-	-	-	-	-	0.87	0.98	1.10	1.15	0.97	0.98	-	-	1.00	-	-
Delta Smelt Population Growth[5] (% change from 1995-2014 baseline)																				
IBMR	0%	0%	0%	2%	0%	6%	11%	17%	7%	6%	5%	13%	0%	0%	16%	30%	49%	73%	1%	16%
LCME[6]	-	0%	-	16%	-	5%	12%	5%	-	-	5%	20%	-	-	-	-	4%	11%	-	-
MDR[6]	-	0%	-	29%	-	-	-	-	-	-	8%	17%	-	-	-	-	-	-	-	-
LF	0%	-	-	-	-	-	-	-	-	2%	16%	30%	36%	14%	16%	-	-	15%	-	-
Uncertainty[7] (TWG group scores)																				
Confidence in action effect assumptions: TWG avg score (scale: 1 [low] to 5 [high] confidence)	Food: 3.0	IBMR salinity-zoop model: 3.0; LF flow-zoop model: 2.0	IBMR salinity-zoop model: 3.1; LF flow-zoop model: 2.3	OMR flows: 4.4	Food: 3.0	IBMR salinity-zoop model: 3.0; LF flow-zoop model: 2.0			IBMR distrib: 2.4	Turbidity: 3.3	Food: 2.3	Food: 2.3	Food: 3.0	Food: 2.4	Food: 2.3	Turbidity: 3.3		Turbidity: 2.5	Contaminants: 3.1	
Salmon effects[8] (expert group scores)																				
Potential benefits: Salmon expert avg score (scale: 0 to 3)	0	Not assessed	0	Not assessed	2	0	0	3	2	0	2	2	2	2	1	0	0	1	2	2
Potential risks: Salmon expert min score (scale: -3 to 0)	0	Not assessed	-1	Not assessed	0	0	0	0	0	-1	0	0	0	0	0	-1	-1	0	0	0
Water / Resource Costs[9] (ballpark estimates for comparative purposes only)																				
Water[10] (TAF/yr) – All yrs	Financial and water costs were only evaluated for actions additional to current management, per agreement by the SDM Policy Group Steering Committee.				-	157	319	248	23	-	-	-	-	-	-	-	-	-	-	-
Water[10] (TAF/yr) – W / AN					-	350	350	361	-	-	-	-	-	-	-	-	-	-	-	-
Water[10] (TAF/yr) – BN					-	-	810	300	38	-	-	-	-	-	-	-	-	-	-	-
Water[10] (TAF/yr) – D / C					-	-	-	72	43	-	-	-	-	-	-	-	-	-	-	-
Costs ($ million / yr) – Total[11]					$1	$128	$260	$192	$18	$2	$22	$63	$2	$1	$29	$5	$13	$5	$7	$84
Costs ($ million / yr) – Water[12]					-	$128	$260	$192	$18	-	-	-	-	-	-	-	-	-	-	-
Costs ($ million / yr) – Capital & operating[13]					$1	-	-	-	-	$2	$22	$63	$2	$1	$29	$5	$13	$5	$7	$84

[1] The management action effect assumptions used in the Delta Smelt modeling are summarized in Table 2.
[2] Actions are grouped by relative time to implementation. Time to implementation is defined in this process as how long it will take to achieve full implementation, including research of technical aspects of the action and generation of expected benefits for Delta Smelt, while not considering time needed for permitting. Time to implementation was scored by TWG members, and average scores were used to group actions in implementation categories.
[3] Small-scale actions that are predicted to have a 0% population growth when modeled individually with the IBMR contribute to positive population growth when modeled with other actions in a portfolio (see Sections 4.4 and 5).
[4] There were 9 W/AN years, 4 BN years, and 7 D/C years in the 20-yr model period. Fall X2 action: X2 was set to 80 km in Sept/Oct in W and AN water year types when historical X2 locations were > 80 km (this occurred in 10 months out of the 18 applicable months across the 20-yr model period). Summer X2 action: X2 was set to targets in July/Aug only for months when historical X2 locations were > 70/75, respectively. This occurred in 12 of the 18 applicable months for the W/AN action and 20 of the 26 months for the W/AN/BN action (across the 20-yr model period). For the Full-year Flow action, X2 was set to month-specific targets in 30 months across the 20-yr model period.
[5] Delta Smelt population metrics were calculated in two ways: (1) annual predicted population growth rate (lambda) from the action, and (2) the percent change in annual population growth from the portfolio relative to baseline, historical conditions between 1995-2014, where values > 0% indicate increased population growth relative to baseline. Predicted lambdas under baseline conditions varied by model (from 0.86 to 1.13) and are shown in Table 22 (Appendix 1). Metrics were averaged over the 20-yr period.
[6] The LCME and MDR models used different versions (with different sets of covariates) to evaluate different actions, which leads to variation in % change from baseline. These models often could only include effects of an action for a portion of months even if it was specified to have year-round effects.
[7] Effect uncertainty was scored by TWG members to indicate their level of confidence in the assumed/quantified proximate effects (e.g., on food, turbidity) of each management action using a constructed scale (1 [lowest confidence] to 5 [greatest confidence]). Reported as the average TWG score.
[8] Salmon effects of actions (sometimes at different scales) were scored by subject matter experts from -3 (greatest risks) to +3 (greatest benefits). Individual action scores were summed within a portfolio and rescaled from 0 (no benefits) to +3 (greatest benefits). Scores for individual actions deemed by experts as having any potential direct risk were summed within a portfolio and rescaled from -3 (greatest risks) to 0 (no risks). Potential benefits are reported as average scores; potential risks are reported as minimum scores to represent any degree of risk to salmonids expressed by experts. Salmon experts noted potential negative risks to juvenile Chinook from AWC, as there is some evidence that higher turbidity can decrease foraging rates, and juveniles can use submerged aquatic vegetation to avoid predation. There is also the potential for direct mortality from mechanical (or chemical) removal. Effects to salmon of flow actions reflect potential direct, within-year benefits/risks of changing flow in a given season. Experts did not consider carry-over effects of flow actions, and modeling how operations would achieve flow actions is needed to better estimate effects to salmon.
[9] All water and resource costs: Water resources and capital and operating costs of actions were calculated relative to baseline, historical conditions. Ballpark values were estimated through coarse methods and meant for comparative purposes only.
[10] Additional water (relative to outflow under baseline, historical conditions between 1995-2014) is averaged across all 20 years and is presented for comparative purposes only. The source of water needed to implement flow actions was not identified in this SDM process. The water resource volume represents the estimated net volume of water necessary to move X2 from its historical monthly position to a target condition, based on equations in Monismith et al. (2002) and Denton (1993).
[11] Total cost was calculated as the sum of monetized water and capital & operating costs, annualized over the 20-yr period without a discount rate.
[12] Monetization of water used $815 per acre foot of water, annualized over the 20-yr period, as discussed and agreed to by the CSAMP Policy Group Steering Committee. See Appendix 3 – Water Resources Methods – Monetized water cost.
[13] Includes ballpark estimates of capital & operating costs, annualized without a discount rate, for comparative purposes only.

Executive Summary Appendix from CSAMP Delta Smelt TWG

This Executive Summary Appendix is intended as a bridge between the short Executive Summary and the full report. It supplements the narrative Executive Summary by summarizing additional evidence and interpretation from findings to date in the SDM process, which is organized around key takeaways (shown in blue boxes below). These takeaways culminate in the seven next steps that could be considered to advance through Adaptive Management (AM) or research studies. For complete details of the SDM process methods and results, see the main report, including further discussion of key findings and next steps in Section 5 and 6, respectively.

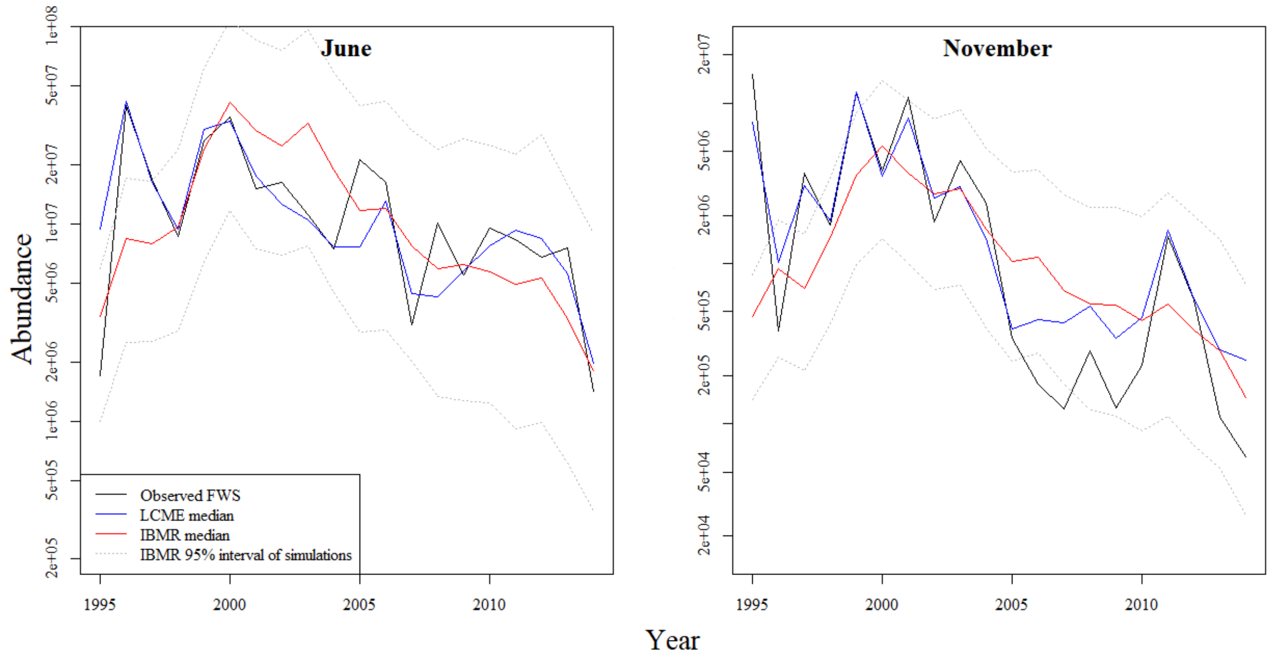
Using multiple Delta Smelt life cycle models offers opportunities to test competing hypotheses, quantitatively evaluate effects of management actions on population growth, and strengthen conclusions.

Newly developed Delta Smelt life cycle models used in the SDM process are the best tools available to predict the potential effects of management actions on the Delta Smelt population. Four Delta Smelt life cycle models were applied in the SDM process: one mechanistic and three statistical models. This multi-model approach recognizes that all models are imperfect and there are many uncertainties in how the systems (the Delta and Delta Smelt) work. Comparing results across models strengthens conclusions when they agree and generates new insights when they diverge. Figure ES-1A and B shows agreement of three models with the 1995-2014 observed, baseline data to which they were calibrated. Despite differences in model structures, Figure ES-1A shows that the mechanistic model (IBMR) and a statistical model (LCME) both generally predict the trend observed in the USFWS surveys of Delta Smelt population across the 20-yr timeframe used in this process. The LCME generally had better agreement to historical data than the IBMR, which is expected since the LCME is a statistical model fit to these data whereas the IBMR is a more complex mechanistic model that is calibrated to the data. Figure ES-1B shows agreement between mean predictions from the Limiting Factors model in a leave-one-out cross validation and observed population trends.

Model predictions of Delta Smelt population growth were based on the quantified, proximate effects of management actions, which have their own uncertainties that must be considered. Generally, management actions were first described in influence diagrams (e.g., Figure ES-2) to show their hypothesized effects on Delta Smelt habitat factors (e.g., food, turbidity, salinity) and demographics (e.g., spatial distribution, survival). Hypothesized effects were then quantified and input into Delta Smelt life cycle models to predict effects on population growth. The evidence basis for quantifying proximate effects varies across management actions. In some cases, field data or existing research studies could be used to infer management action effects. In other cases, no data were available and more theoretical, ad-hoc estimates were needed. All possible effects of actions were not captured in this SDM process due to insufficient evidence that would require more information or modeling that was outside the scope of the process. Those effects that were quantified represent the primary hypothesized benefit of an action for Delta Smelt. For example, the effect on food was quantified for tidal wetland restoration as this is the intended benefit of that action for Delta Smelt. Other potential effects of tidal wetland restoration (e.g., salinity, water temperature, turbidity, Delta Smelt distribution: Figure ES-2) were discussed but not quantified, needing more information or modeling. The SDM process quantitatively assessed the sensitivity of some models to some actions' effects, but uncertainty around most actions' effects was not propagated in Delta Smelt models and predictions. Although the SDM process used the best available information and a multi-model approach to predict Delta Smelt outcomes, it also highlighted many existing uncertainties around management actions' potential effects and feasibility that could be investigated with further Adaptive Management and research (described in Section 6).

Figure ES-1. Comparison of Delta Smelt model predictions and data to which they were fit or calibrated. (A) Observed Delta Smelt abundance (USFWS catch density expansion estimates: black solid line) and median predicted Delta Smelt abundances for the IBMR (red) and LCME (blue). Dashed lines indicate the 95% confidence interval (2.5th and 97.5th percentiles from the distribution of model predictions) for the IBMR. Observed and model-predicted abundances are shown for June and Nov across model years (1995-2014). (B) Comparison of mean predicted Delta Smelt population growth rate (lambda: abundance change ratio) using the Limiting Factors model in a leave-one-out cross validation with historical, actual lambda. Actual lambda is calculated by dividing the FMWT Index in one year by the FMWT Index in the previous year.

(A)



(B)

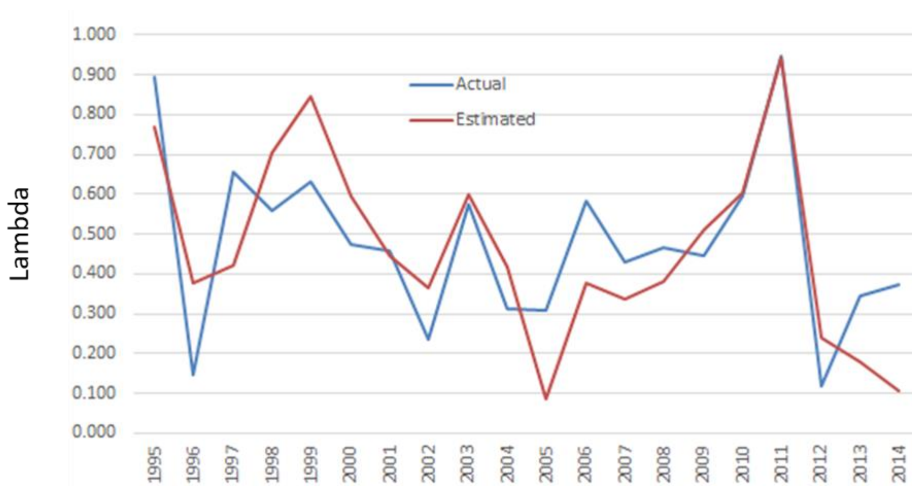
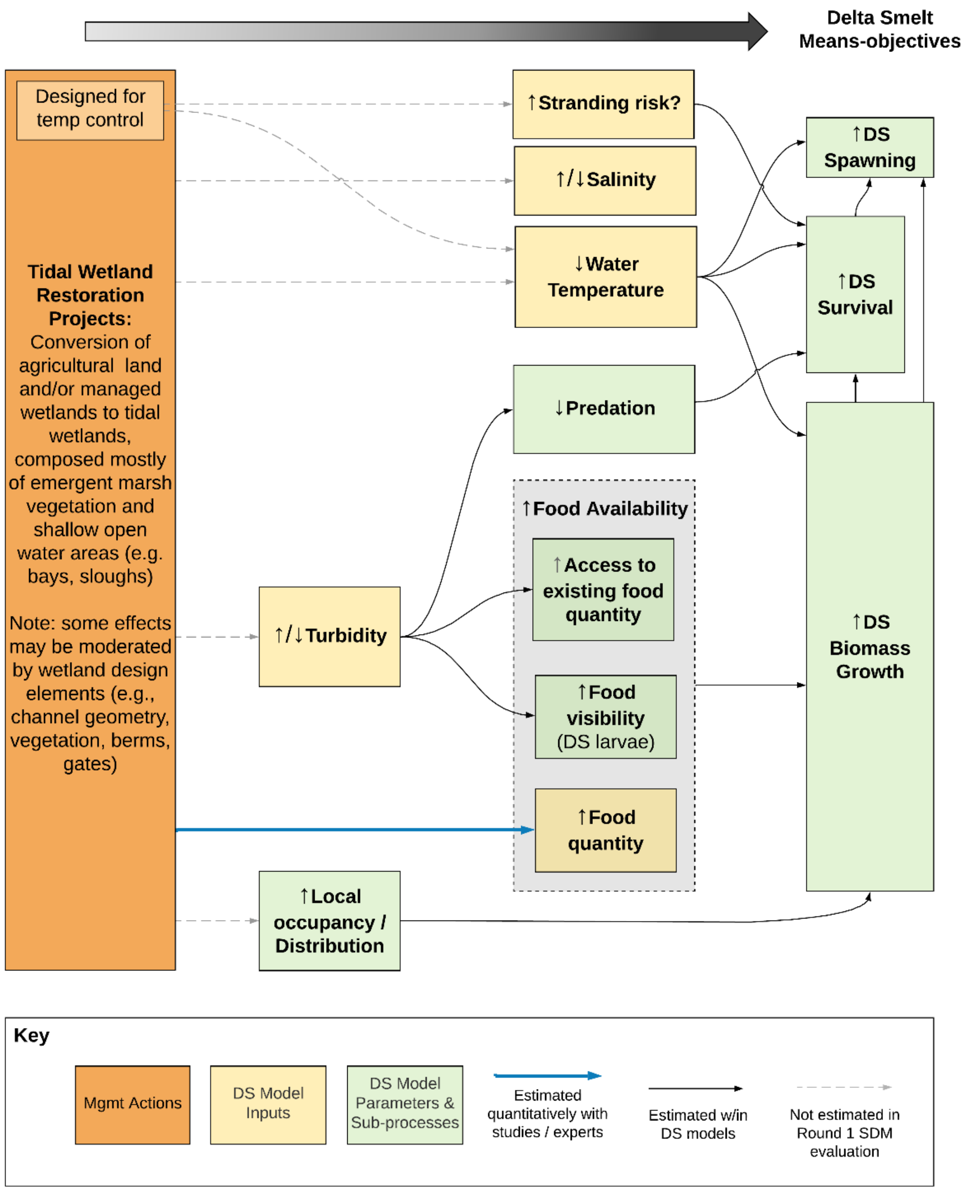


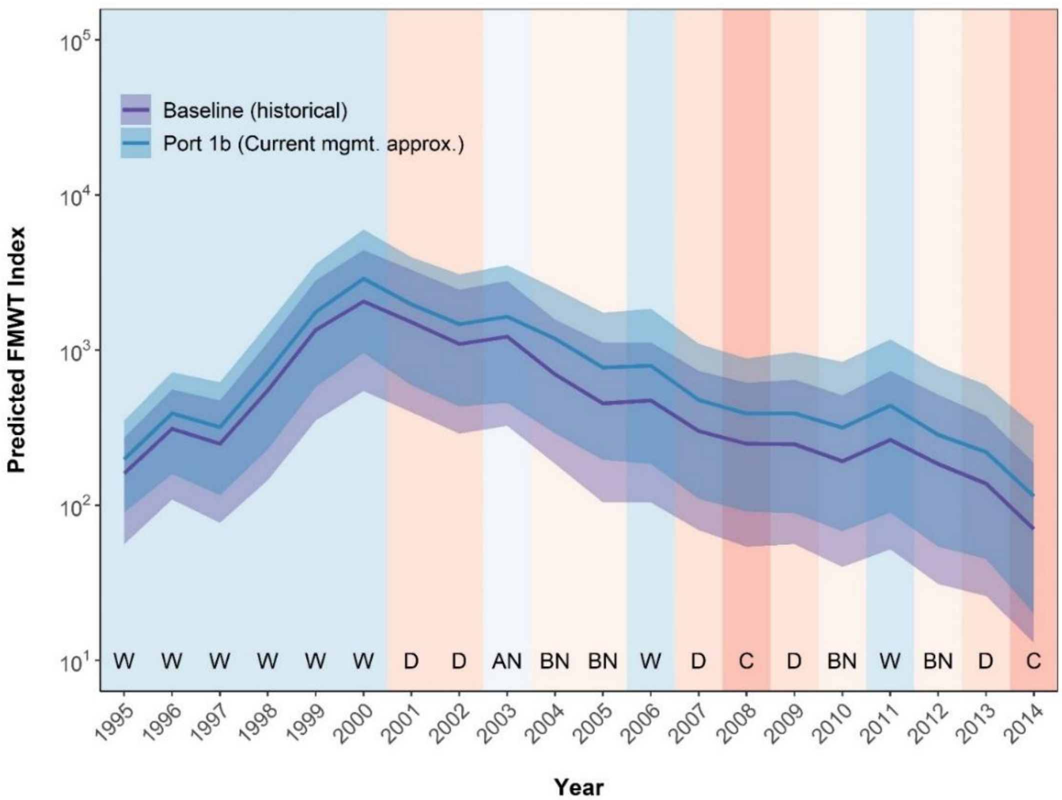
Figure ES-2. Influence diagram of potential effects of tidal wetland restoration on environmental/biological drivers (yellow boxes) and subsequent Delta Smelt population dynamics (green boxes). For most actions, the SDM evaluation only quantified some of the potential, hypothesized effects on Delta Smelt. In this case, the effect on food (blue line) was quantified while all other effects (dashed lines: e.g., turbidity, Delta Smelt distribution) were discussed but not quantified, needing more information or modeling outside of the scope of this process.



Actions targeted at Delta Smelt that are currently being implemented (as modeled) are predicted to not be sufficient for achieving self-sustaining Delta Smelt population growth.

A subset of the management actions specified in the 2019 Biological Opinion (BiOp) and 2020 Incidental Take Permit (ITP) that target Delta Smelt were modeled to address the question: if the same management actions had been implemented throughout the entire 1995-2014 period, how might this have altered the growth of the Delta Smelt population in comparison to the model baseline of observed, historical conditions? These actions included: Old and Middle River (OMR) management, fall X2 management, North Delta Food Subsidies, and summer/fall operation of the Suisun Marsh Salinity Control Gates. All models predicted that these Delta Smelt actions would increase population growth, relative to the 1995-2014 observed baseline (Table ES-2), but both the model predictions and the Delta Smelt catch data show that was not sufficient to avoid a declining population over the full 20-yr period. The population was predicted to increase for the first six consecutive years under wet conditions (1995-2000) but then decline steadily as drier years became more common (2001-2014: Figure ES-3). These modeling results, together with the Delta Smelt catch data, suggest that more needs to be done to achieve self-sustaining Delta Smelt population growth.

Figure ES-3. Average predicted Delta Smelt FMWT Index across model years (1995-2014) for predicted baseline, historical conditions (purple) and Portfolio 1b (select Delta Smelt management actions in 2019 BiOp/2020 ITP approx.; blue) in the IBMR. The shaded ribbons show the 95% confidence interval (2.5th and 97.5th percentiles from the distribution of model predictions) encompassing uncertainty (stochasticity, process variation) in the IBMR. Water year types are indicated by letters at bottom of figure and blue-red bars.



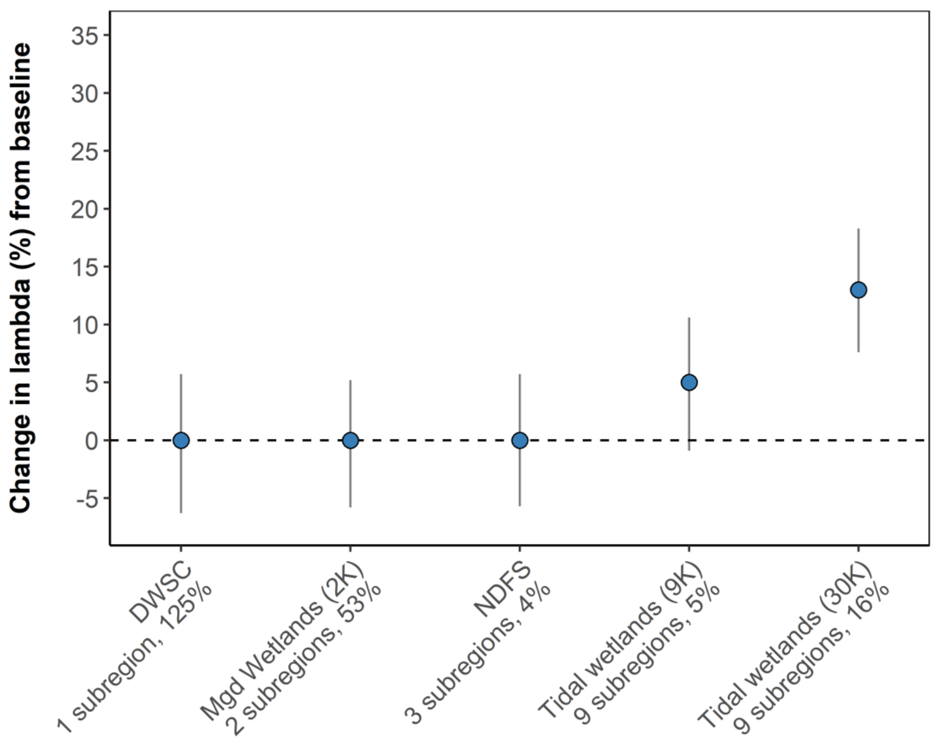
The historical, baseline conditions captured in the models (1995-2014) represent a mix of regulatory actions that were not consistent across the entire 20-yr model period. For example, the 2008 Biological Opinion for the Long-Term Operations of the Project (BiOp) included Old and Middle River (OMR) management and fall X2 management actions for Delta Smelt intended to mitigate entrainment and improve habitat conditions, respectively. Starting in 2007, the OMR management action was implemented annually (8 of 20 model years), resulting in OMR flow being > -5,000 cfs from Jan to June in each year. The fall X2 action targeted an X2 location in Sept and Oct of < 75 km in Wet years and < 81 km in Above Normal water years. These X2 targets were achieved in the fall of 2011 (the only Wet or Above Normal year in the post-2008 model period). Fall X2 and OMR actions evaluated in this SDM process were the updated versions of these actions specified under the 2019 BiOp and 2020 ITP, which differed from the versions implemented under the 2008 BiOp. Therefore, comparisons of X2 and entrainment actions against the baseline cannot be viewed as comparisons with and without such actions. Population models require calibration against real world data to improve reliability, and modeling a "no action' scenario vs. actions scenarios was beyond the scope of this process. **Predicted population benefits for management actions evaluated in the SDM process are best interpreted relative to each other and this baseline, rather than as absolute estimates of predicted population benefits**.

Models show that actions can enhance Delta Smelt population growth to different degrees if they increase food availability, turbidity, flows, or improve survival via contaminant reduction. Effectiveness depends upon the scale and timing of actions.

Food

Models agreed that increasing food – especially at large scales – would increase Delta Smelt population growth. Actions that increased food across multiple subregions increased population growth more than when food was increased in 1-3 subregions (Figure ES-4). An explanation for these model results is that more food in more places benefits a larger proportion of the Delta Smelt population, as fish occupy multiple subregions at any point in time throughout the year. Management actions that increase food in multiple places also increase the likelihood that at least some of those places have adequate habitat conditions (i.e., turbidity, salinity, temperature) that facilitate Delta Smelt accessing those food resources. Because of these patterns, any increase in food should benefit Delta Smelt, assuming an adequate level of flow, turbidity, and other factors.

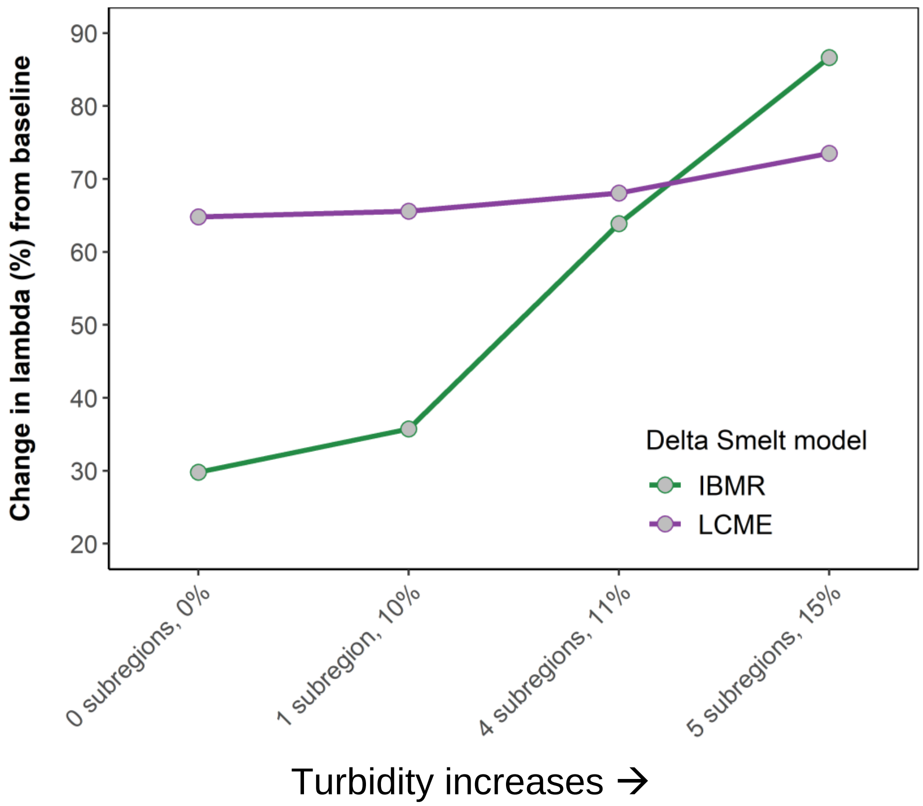
Figure ES-4. Predicted percent change in Delta Smelt population growth from baseline for model runs of representative food actions with the IBMR. Labels indicate the action, the number of subregions where food was increased, and the average % change in food (across those subregions and 20-yr model timeframe).



Turbidity

Models agreed that increasing turbidity would increase Delta Smelt population growth. Turbidity is hypothesized to benefit Delta Smelt through reducing predation risk and giving them better access to food. Similar to results from food actions (and portfolios), increasing turbidity across multiple subregions increased population growth more than when it was increased in one subregion (Figure ES-5); i.e., more turbidity in more places benefits a larger proportion of the Delta Smelt population. Models differed more in their predicted relationships between turbidity and population growth than for food (Table ES-3; Figure ES-5), suggesting more research could improve our understanding of the relationships between turbidity and population growth.

Figure ES-5. Predicted percent change in Delta Smelt population growth from baseline for model runs in a sensitivity analysis that varied turbidity effects with the IBMR and LCME. Labels indicate the number of subregions where turbidity was increased and the average % change in turbidity (across those subregions and 20-yr model timeframe). All runs included the following actions while turbidity varied: 2K ac of Suisun Marsh managed wetlands, NDFS, DWSC, SMSCG, OMR, 9K ac of tidal wetland restoration, and additional outflow to meet X2 targets of 70/75 km in summer (July/Aug) and 80 km in fall (Sept/Oct) in W and AN years.



Flow

Models agreed that increasing outflow would increase Delta Smelt population growth, but the magnitude and consistency of predicted benefits depended on the action's timing and flow/X2 target (Table ES-3 and ES-4). There are multiple known and hypothesized effects of outflow on Delta Smelt population (e.g., increasing the size of the Low Salinity Zone, food and foraging opportunities), and models differed in how they considered these complexities. Both the IBMR (a mechanistic model with subregion dynamics) and the LCME (a statistical, regional model) agreed that summer flow actions were predicted to increase population growth when X2 was ≤ 75 km in the summer in some years (Table ES-4), with greater population benefits as the flow action was applied to more years (i.e., W/AN years vs. W/AN/BN years: Table ES-3). Models also agreed that a fall flow action where X2 was ≤ 80 km in W/AN years (approximating the current action specified in the 2019 BiOp/2020 ITP) had negligible effects to population growth (Table ES-3)[2]. Finally, a "full-year flow" action that strategically deployed flow actions in spring, summer, and fall to meet minimum flow targets in all year types was predicted to increase population growth rate from baseline by 5-17% across models (Table ES-3). The differences in population growth with differences in timing suggested further investigation of this aspect of flow management could benefit Delta Smelt.

[2] When simulating the fall X2 action, X2 was set to 80 km in Sept/Oct in W and AN water year types when historical X2 locations were > 80 km (this occurred in 10 months out of the 18 applicable months across the 20-yr model period).

Table ES-4. Predicted Delta Smelt population growth rate (lambda) for X2/outflow sensitivity runs across the IBMR and LCME population models. Sensitivity runs simulate five levels of X2 locations in summer or fall for W and AN years. All IBMR runs in this table apply the median prediction for zooplankton from the Salinity-food model and the TWG method for Delta Smelt distribution.

X2 Scenario Name	Average population growth rate (lambda) (1995-2014)		
	Location targets in W and AN years (summer = July/Aug; fall = Sept/Oct)[1]	IBMR	LCME
X2 summer low	59 / 66	1.10	1.10
X2 summer, inc 1	65 / 71	1.06	1.04
X2 summer, inc 2	70 / 75	1.02	0.98
X2 summer, inc 3	75 / 80	0.96	0.90
X2 summer high	80 / 84	0.87	0.81
X2 fall low	68 / 72	1.05	0.94[2]
X2 fall, inc 1	74 / 76	1.02	
X2 fall, inc 2	80 / 80	0.96	
X2 fall, inc 3	83 / 84	0.94	
X2 fall high	87 / 88	0.94	

[1] 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. X2 was changed in 18 months per run (out of 240 months in the 20-yr model period).

[2] For the LCME, low evidence found with the LCMG (on which the LCME was based) between fall outflow and survival resulted in no change in population growth rate for any model run that varied fall X2 in the absence of other changes. The LCMG was fit to historical data, including X2 locations, between 1994-2015 (Polansky et al. 2021), which captures the same range of X2 locations above.

There are three important considerations for interpreting these results. First, population growth results are reported as averages across the 20-yr model period, and it is possible that annual population growth is higher than the average in specific years when flow actions were simulated. Second, the modeling of X2 actions in this SDM process did not isolate the effect of those actions due to the mix of regulatory targets represented in the baseline model conditions (described above). Therefore, modeling results are appropriate for relative comparisons, and further modeling would improve estimation of the isolated effect of X2 actions on Delta Smelt.

Third and finally, the results from the X2 sensitivity analysis (Table ES-4) – which systematically set X2 to different X2 locations in summer and fall in all W/AN years – provide additional information about the built-in relationships between seasonal outflow/X2 and population growth in the models. Both the IBMR and the LCME predicted population growth would increase with higher summer outflow (lower X2); the IBMR also predicted population growth would increase with higher fall outflow, although the LCME predicted no effect of fall outflow on survival and population growth (Table ES-4). Note that the results from the X2 sensitivity analysis cannot be directly compared to the action/portfolio analysis described above because they used different "rule sets" for changing X2. Model runs of individual outflow/X2 management actions and portfolios were intended to simulate (approximately) how those actions would be implemented. These runs reduced X2 only in months when the historical X2 location was higher than the target (e.g., 80 km); if the historical X2 location was lower than the monthly target (e.g., in 2011), the historical X2 location was used in the model run (no change). Therefore, flow was only increased relative to the baseline in the action/portfolio analysis. Alternatively, in the X2 sensitivity analysis, X2 locations were set at a consistent location in the summer or fall months, which meant that the model runs were simulating a decrease in flow for some months and years, relative to the historical baseline (Section 3.2).

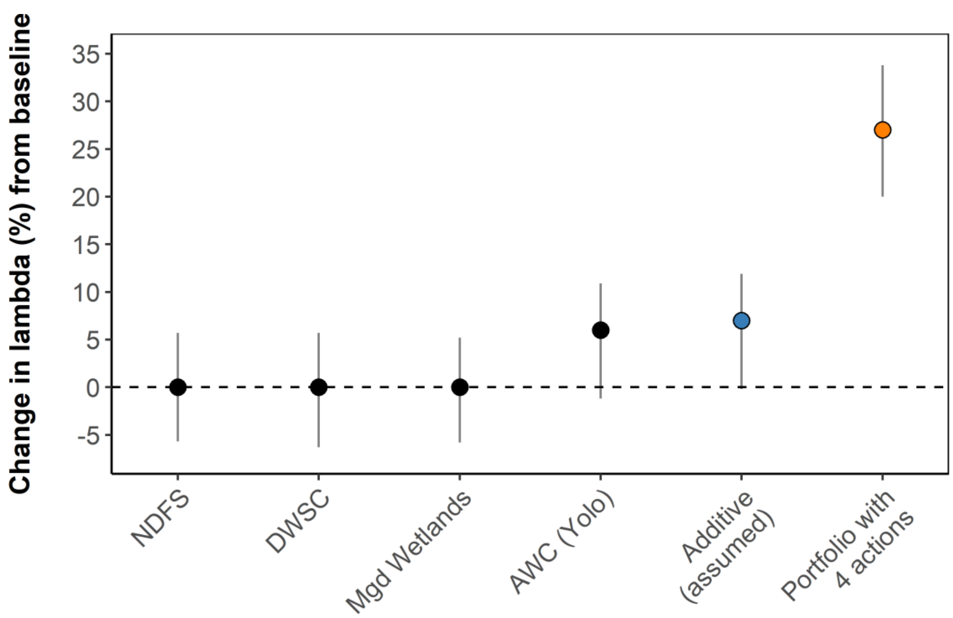
Contaminants

Models agreed that reducing contaminants at hotspots in the Delta – especially at large scales – could increase Delta Smelt survival and hence population growth. Contaminants can cause direct sublethal and lethal effects to Delta Smelt, as well as negative effects to aquatic food webs and other species of interest. Modeling showed that reducing contaminants in the Yolo/Cache Slough subregion increased Delta Smelt population growth from baseline by 1%; reducing contaminants Delta-wide increased population growth by 16% (Table ES-3). Additional benefits from contaminant reduction were predicted when combined with food and turbidity actions.

Models show additive and synergistic effects of combining multiple actions, demonstrating the benefits of concurrently targeting multiple population drivers.

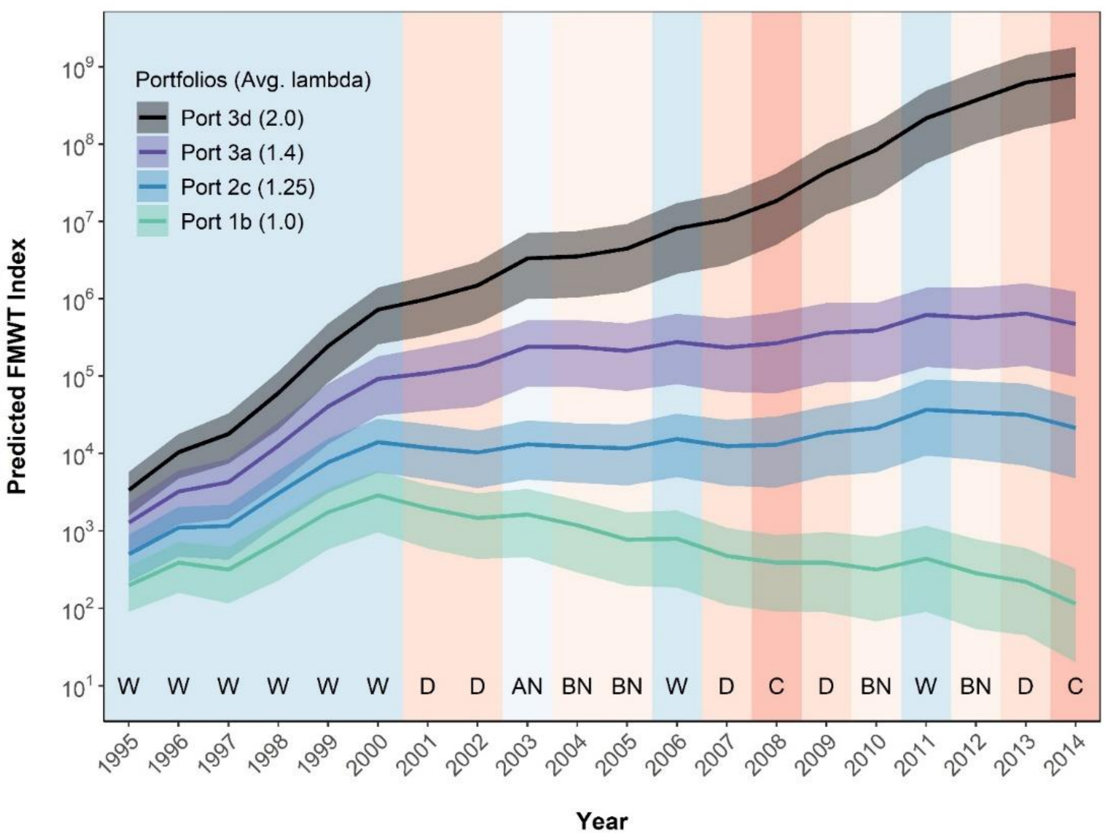
Models showed that increasing turbidity appeared to have interactive effects with food that can lead to synergistic benefits to Delta Smelt. Turbidity can reduce predation risk and allow Delta Smelt to better access food resources, including those higher food resources generated by actions. For example, small-scale actions that increased food or turbidity alone were predicted to increase population growth by 0-6% (Figure ES-6, black points) in the IBMR. A portfolio that combined food and turbidity actions was predicted to increase population growth from baseline by 27% (Figure ES-6, orange point).

Figure ES-6. Predicted percent change in Delta Smelt population growth from baseline for model runs with the IBMR of representative small-scale food and turbidity actions (black points) and a portfolio that combined those actions (orange). The blue point shows the assumed outcome if action effects were additive and not synergistic.



Eight portfolios were modeled with combinations of management actions in addition to current Delta Smelt management actions in the 2019 BiOp and 2020 ITP (Tables ES-1 and ES-2). Most of these portfolios were predicted to stabilize or grow the population over the long-term – even during dry year periods (i.e., 2001-2014; Figure ES-7). The top three lines in the figure below are example portfolios that had at least one food, one turbidity, and one fall outflow action. Two portfolios also included contaminant reduction actions. Portfolios with the highest Delta Smelt population benefits included actions that concurrently targeted multiple population drivers in multiple regions, such as: growing food in managed wetlands; large-scale tidal wetland restoration to increase food; large-scale aquatic weed control to increase turbidity; additional outflow in the summer to improve food and other Delta conditions; and large-scale contaminant reduction to improve survival. Population growth was generally higher for portfolios targeting multiple drivers compared to predicted benefits from single management actions. Delta Smelt declines are attributed to multiple factors, and these findings support that a combination of management actions addressing multiple factors (e.g., food, turbidity, flow, contaminants) could reverse those declines. The models suggest that stable and increasing population growth is possible over the long-term when wet and dry periods are expected.

Figure ES-7. Average predicted Delta Smelt FMWT Index across model years (1995-2014) for four portfolios that varied by average growth rate (lambda) in the IBMR. The shaded ribbons show the 95% credible interval encompassing uncertainty (stochasticity, process variation) in the IBMR. Water year types are indicated by letters at bottom of figure and blue-red bars. All portfolios assumed fall X2 ≤ 80 km in W and AN years. Portfolio names: 1b – Current management (approximation); 2c – Cache Slough & Suisun Marsh focus, including localized food and turbidity actions; 3a – Self-sustaining / permanent management, including large-scale habitat restoration and contaminant reduction; 3d – Focus on food, including multiple food actions, large-scale habitat restoration, aquatic weed control, and contaminant reduction.



Management actions and portfolios vary in their expected resource costs and time to implementation; higher predicted Delta Smelt benefits generally require higher investment of resources and time.

Relative to model-based approaches for predicting Delta Smelt population growth, the SDM process used coarser methods to estimate ballpark resource costs (capital, operating, water[3]) and time to implementation of actions and portfolios. Still, these ballpark estimates allow for making initial, **relative benefit-cost comparisons** across actions and portfolios.

[3] Estimated water volumes and costs associated with management actions were especially coarse in this process, given that more complex modeling of water operations was not possible within the process timeframe. Methods are further described in Appendix 3. Operations modeling could refine the estimated costs (and benefits) of outflow actions evaluated in the SDM process, and this modeling is further described as a possible next step in Section 6.

The management actions evaluated in the SDM process showed a range of direct water resource and capital and operating costs (Table ES-3). Non-flow actions ranged in capital and operating costs from $1 to $10s of millions/yr. Water resource costs were estimated in terms of water volumes (TAF/yr). Furthermore, the estimated water volumes were converted through simple linear calculation into monetized cost ($/yr) based on the unit cost ($/AF) suggested by the CSAMP Policy Group[4]. The costs of the flow actions ranged from 10s to 100s of TAF/yr in water volume and from $10s to $100s of millions/yr in monetized cost, on average. However, hydrological modeling was not conducted to estimate the water volumes, so there is uncertainty that is not propagated through the estimates of monetized water cost, which has its own underlying uncertainties. Estimating the broader benefits and costs to society of these actions was outside the scope of the SDM process and not factored into these estimates.

Management actions also varied in their expected time to implementation. Actions were grouped into three broad categories, based on TWG survey responses: (1) actions currently being implemented (2) actions that may be implemented and achieve benefits within ~5 years and (3) actions that may be implemented and achieve modeled benefits in more than 5 years (Table ES-5).

Table ES-5. Management actions evaluated in the SDM process categorized by approximate time to implementation. Actions were grouped to be implementable within vs. beyond 5 years based on TWG members' average scores (n=9) of the action's technical feasibility (time to implementation).

Currently being implemented	May be implementable within ~5 years	May be implementable in more than 5 years
• Fall X2/Outflow (X2 ≤ 80 km for Sept/Oct, W/AN years) • Suisun Marsh Salinity Control Gates (SMSCG) • North Delta Food Subsidies • Old & Middle River Management (2008/2009/ 2019 BiOps)	• Additional outflow actions (e.g., increased summer flow) • Engineered First Flush • Managed wetlands for food production (~1K ac) • Aquatic weed control (~600 ac)	• Tidal wetland restoration (9-30K ac) • Managed wetlands for food production (2-4K ac) • Sacramento Deep Water Ship Channel (DWSC) food transport and subsidies • Aquatic weed control (1.4-3.5K ac) • Sediment supplementation • Franks Tract restoration • Physical point-source contaminant reduction (1 or more locations)

Consequence Tables summarize the predicted benefits to Delta Smelt with time and resource costs (Portfolios – Table ES-2; Actions – Table ES-3). Smaller-scale actions that could be implemented in the near-term tended to have lower predicted population benefits (Table ES-3). Higher predicted increases in Delta Smelt population were generally achieved by large-scale actions and portfolios that would require higher resource costs and time to implement. Overall, potential population benefits increased as the scale, time to implementation, and resource costs of management options increased.

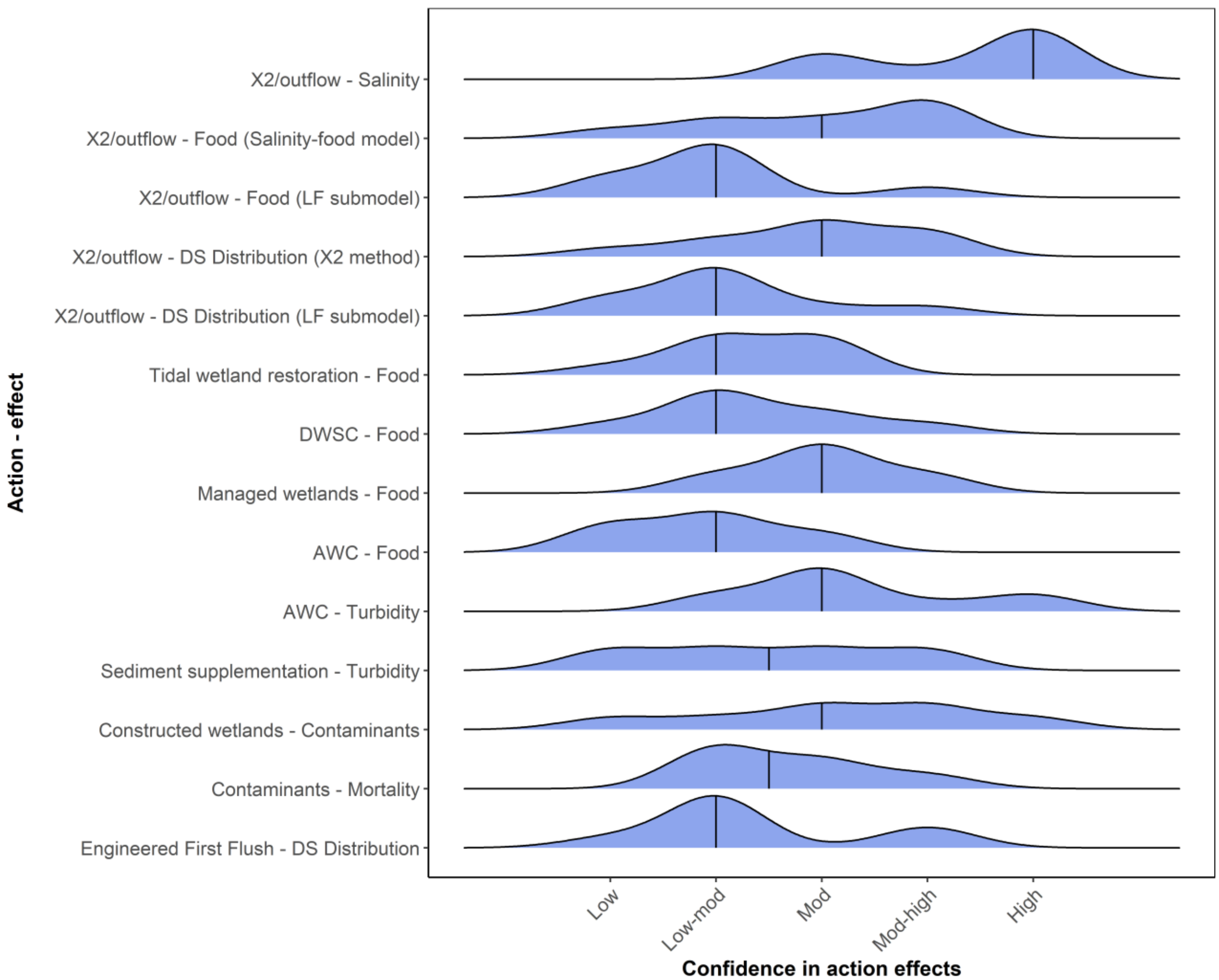
There are effects uncertainties for all actions. The degree of uncertainty is not related to predicted population benefits.

The current state of knowledge about potential effects of actions is sufficiently limited, therefore making it difficult to identify "optimal" or "cost-effective" strategies in the face of these uncertainties. From surveying TWG members, confidence was relatively high for only one action's effects as quantified in the SDM process (i.e., effect of outflow actions on salinity), whereas the estimated effects of most actions had low-moderate to moderate confidence (Figure ES-8). Low to moderate scores represented that "few data/studies exist" to "some

[4] Monetized water costs were calculated using an assumption of $815/acre foot of water (See Appendix 3 – Water Resources Methods – Monetized water cost).

data and coarse or theoretical modeling results are used to estimate action's effects." Since almost all management actions had similar degrees of effects uncertainties, there was no discernable pattern between uncertainty and predicted benefits to Delta Smelt.

Figure ES-8. Median (lines) and distribution of TWG members' scores (n=10) of confidence in quantified, proximate effects of management actions in the SDM process. TWG survey question: *"What is your level of confidence in the quantified proximate effect of Action [X] (e.g., on food, turbidity, salinity, flow) that are used as inputs to the Delta Smelt Population Models? Scale: Low, Low-Moderate, Moderate, Moderate-High, High, Unsure / Not enough information to answer."*



Because of the uncertainties about effects and feasibility, the next steps could address knowledge and feasibility gaps with Adaptive Management and research (as described in the Executive Summary).

When there is high uncertainty in actions' effects and time to implementation as in the context of Delta Smelt management, a strategy robust to these uncertainties could be considered – i.e., a combination of actions that is expected to perform at least satisfactorily and that can generate improved knowledge of effects over time. Investing in and advancing multiple AM and research next steps discussed in this report could represent a tractable, robust strategy for Delta Smelt conservation.

Further discussion of next steps is provided in Section 6.

Contents of Report

Response documents from two TWG members, Scott Hamilton and Sam Luoma, are appended at the end of the report. The documents convey those individual's own interpretations and points of emphasis from the SDM evaluation. The main report acknowledges some specific areas of different interpretations among TWG members when they arose, but these response documents provide further details from those individual voices. As these are individual responses, they have not been discussed and reviewed by the TWG.

Contents in Supporting Documents

This report is accompanied by several supplemental documents that provide additional data/methods, results, and references. Supplemental documents are organized into the following folders:

"Appendix 1" – This folder contains complete documentation of the models used in the SDM process. Each of the four Delta Smelt population models has a subfolder with primary publications and other supplemental technical reports. The "Additional effects models for IBMR" subfolder contains technical memos describing methods and results for four other effects models that were developed with the TWG during the SDM process.

"Appendix 2" – This folder contains full details on the evidence, assumptions, methods, and predicted consequences of each management action that was evaluated in the SDM process. Information on each action is contained in a "Management Action Specification Sheet" document.

"Appendix 5" – This folder contains documentation of the Dynamic Habitat Suitability Index tool developed by the TWG during the SDM process. Documents include details on the methods used to develop the tool, a user guide, and the tool itself (in an Excel workbook).

"References" – This folder contains additional memos and documents produced by or for CSAMP members that were cited in the report but not easily accessible online.

Figures

Tables

Acknowledgements

This SDM process has been an ambitious, multi-year, and multi-party effort that was driven by collaborative input from dozens of scientists and managers working in the San Francisco Estuary. We thank the CSAMP Policy Group and CAMT members for their overarching contributions to developing the effort's goals, process, scientific methods, and connections between science and policy. We thank the CSAMP Delta Smelt SDM Steering Committee for navigating tough conversations and providing essential guidance on the design and execution of the process. Steering Committee members included Kaylee Allen and Donnie Ratcliffe (USFWS), Steve Arakawa and Nina Hawk (Metropolitan Water District), Gary Bobker (The Bay Institute), Brooke Jacobs and Carl Wilcox (CDFW), Cindy Messer (CDWR), Dave Mooney (USBR), and the two CAMT Co-Chairs – Darcy Austin (SWC) and Sam Luoma (UC Davis). We thank the Delta Smelt Technical Working Group (TWG) for contributing to the bulk of the work with great insight, respect, and perseverance over many years and meetings. TWG contributions included informing the effort's design, developing and validating evaluation methods, interpreting conclusions and limitations from the results, and providing feedback on technical memos and this report. TWG members who were involved at the end of the process included Mike Eakin (CDFW), Will Smith and Matt Nobriga (USFWS), Brian Mahardja (USBR), Steve Culberson (IEP), Shawn Acuña (Metropolitan Water District), Ching-Fu Chang (CCWD), Scott Hamilton (PWA, Hamilton Resource Economics), Sam Luoma (UC Davis), and Sam Bashevkin (SWB). Past TWG members included Randy Mager, Ted Sommer, and Erik Loboschefsky (DWR), Erin Cole (USFWS), Mike Beakes (USBR), Lauren Damon (IEP), and Deanna Sereno (CCWD). We especially want to thank and honor two former TWG members – Larry Brown and Bill Bennett, who passed away during this process – for their dedication and enthusiasm for conservation and their contributions that greatly improved the quality of the work. Working closely with the TWG, we also thank the lead Delta Smelt population modelers for adapting and using existing models to generate key predictions in this process. Lead modelers were Will Smith, Scott Hamilton, and Mike Tillotson and John Brandon (ICF).

We thank the many individuals who generously contributed data, time, and expert judgment that facilitated this work, especially the development of methods and quantification of management action effects. These individuals include but are not limited to: Christy Bowles (CDFW), Brad Cavallo (Cramer Fish Sciences), Chandra Chilmakuri (SWC), Amanda Cranford (NOAA), John Durand (UC Davis), Rene Henery (Trout Unlimited), Wayne Landis (Western Washington University), Steve Lindley (NOAA), Peter Nelson (DWR), Kyle Philips (UC Davis), Deana Serrano (CCWD), Erwin Van Nieuwenhuyse (formerly USBR), as well as the IEP's Project Work Teams for Aquatic Vegetation and Zooplankton.

Finally, we acknowledge and thank the State Water Contractors for funding and supporting the SDM process.

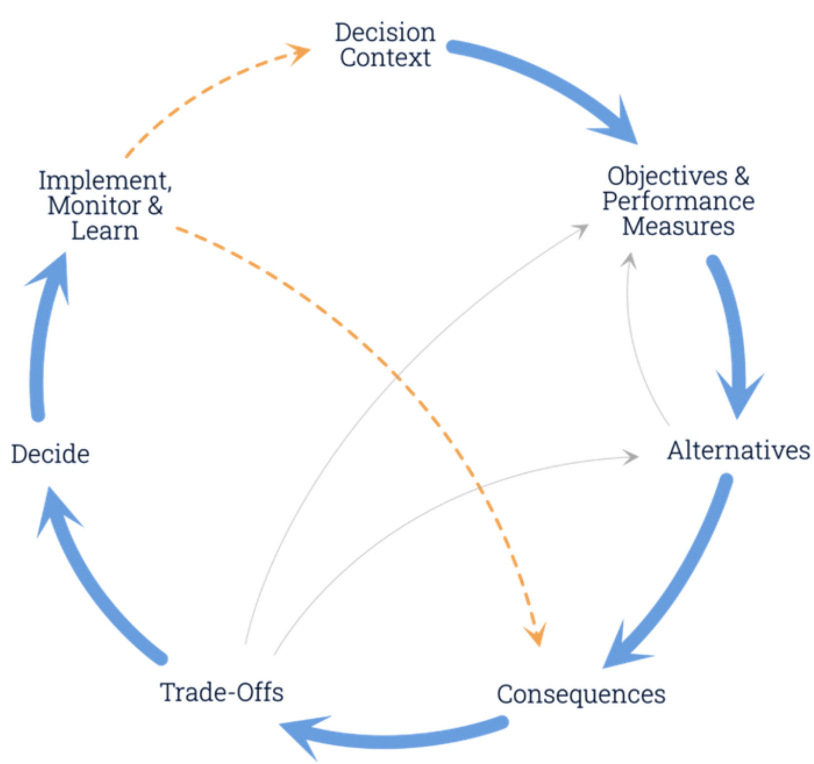
Acronyms & Definitions of Key Terms

Acronym / Key Term	Definition
BiOp	Biological Opinion
Covariate	A predictor variable in a model that explains some of the variation of the dependent variable. For example, food density is a covariate (predictor variable) that explains some of the variation in life-stage-specific survival (dependent variable) in some Delta Smelt life cycle models. Models estimate the relationships between covariates and dependent variables.
DWSC	Deep Water Ship Channel
IBMR	Individual-based life cycle model in R (Smith 2022; updated from Rose et al. 2013 bioenergetics model)
ITP	Incidental Take Permit
LCME	Fish and Wildlife Service's life cycle model (Smith et al. 2021)
LF	Hamilton & Murphy (2022) limiting factors model
MDR	Maunder & Deriso life cycle model in R (updated from Maunder & Deriso 2011 model)
North Delta Arc	The area between and including Suisun Marsh and Bay, the Confluence, Sacramento River, and the Yolo Bypass/Cache Slough Complex. Delta Smelt have more commonly been observed in these areas relative to the Lower San Joaquin, East Delta, and South Delta areas.
OMR	Old and Middle River
Portfolios	Combinations of management actions that represent distinct approaches to increasing the Delta Smelt population.
ROD	Record of Decision
Round 1 evaluation	"Round 1 evaluation" refers to the SDM iteration of developing and evaluating management actions and portfolios that is reported on in this Report. A future project may choose to do a "Round 2" with updated management actions/portfolios, data and methods.
SDM	Structured Decision Making
Time to implementation	Ballpark estimate of how long it will take to achieve full implementation of an action, including research of technical aspects of the action and generation of expected benefits for Delta Smelt, while not considering time needed for permitting.
TWG	Delta Smelt Technical Working Group with representatives from CAMT member organizations.
X2	The distance (in km) from the Golden Gate to the point in the San Francisco Estuary where the tidally averaged bottom salinity is 2 ppt.

1 Introduction

This effort is the continuation of efforts by the Collaborative Science and Adaptive Management Program (CSAMP) to implement a Structured Decision Making (SDM) process in support of Delta Smelt recovery. SDM is an organized framework for informing choices in situations where there are multiple interests, high stakes, and uncertainty. SDM helps inform decisions that are values-based (based on "what matters"), evidence-based (informed by best available information), and transparent (based on clearly communicated reasons and information). SDM is based on well-recognized methods developed in the decision sciences (Gregory et al. 2012). SDM generally follows an iterative process as shown in Figure 1, which involves clarification of the decision context, definition of objectives, development of alternatives, prediction of the consequences of each alternative on each objective using performance measures, and deliberation on next steps given findings of the analysis (benefits, costs, trade-offs, uncertainties) and preferences/responsibilities of decision makers and participating parties. SDM processes for complex decisions are often structured as iterative rounds of alternative development and evaluation to allow groups to learn over time. This SDM process completed a "Round 1" evaluation, which involved the multiple-objective evaluation of 12 Delta Smelt management actions at the individual-scale and portfolio-scale (combinations of actions). A future project may choose to do a "Round 2" with updated management actions/portfolios, data, and methods. The Round 1 evaluation gave specific focus to predicting effects on Delta Smelt and conducted over 130 model runs with one or more population models to explore outcomes of actions, portfolios, and additional sensitivity analyses.

Figure 1. Structured Decision Making Process.[5] The diagram shows features of an SDM process, including advancing through the core steps (blue arrows), iterating by using things learned at later steps in the process to refine earlier work (grey arrows), and using SDM for recurrent decisions (Adaptive Management: orange arrows).



[5] For more information on the SDM process, see https://www.structureddecisionmaking.org/

CSAMP is not a decision-making body, but many CSAMP members are continually making decisions related to Delta Smelt, for example:

- Should current management actions for Delta Smelt be adjusted or replaced?
- Which new management actions should be implemented to increase the Delta Smelt population?
- What flow/water quality objectives/actions for the Delta should be in place?
- Which science activities should be prioritized?
- What CSAMP activities for Delta Smelt would be most value-added?

These decisions could be informed and benefit from a higher-level strategy that identifies priority Delta Smelt management and science actions. For this reason, this SDM process was scoped to inform the development of an "ongoing, living strategy to advance Delta Smelt goals that all CSAMP members support" (CRM, 2019) and an early activity in the process was to define the CSAMP Management Goal for Delta Smelt (see text box on the right). Consistent with this broader scope, the process did not identify one decision to focus on but rather scoped its analysis to be informative to the multiple decisions that are being made with respect to Delta Smelt. The assumption is that individual decision makers will still need to go through their individual decision processes and complete any necessary analysis and engagement for those processes. This process is intended to be complementary and informative to these processes and not replace them.

CSAMP MANAGEMENT GOAL FOR DELTA SMELT

Reverse the trajectory of the Delta Smelt population from one in decline to one experiencing overall increases within 5-10 generations with the long-term aim of establishing a self-sustaining population. To achieve this goal, CSAMP members will work collaboratively, and with urgency, to prioritize and implement management actions that are targeted at known or hypothesized stressors, habitat needs or other critical factors affecting the Delta Smelt population, and to learn through implementation.

Endorsed by Policy Group, Oct. 30, 2019.

This Report documents how SDM was applied in this process including:

- **Section 2 (Delta Smelt Population Drivers & Modeling):** Describes the Delta Smelt population drivers that are able to be influenced by management actions and the four Delta Smelt population models and other supporting models that were used to predict the consequences of management actions on Delta Smelt.

- **Section 3 (Management Action Evaluation for Delta Smelt):** Describes the management actions modeled in the Round 1 evaluation, including the evidence, assumptions and uncertainties related to estimating the Delta Smelt effects of the Round 1 management actions.

- **Section 4 (Multiple-objective Action & Portfolio Evaluation):** Summarizes the methods and results for the Round 1 multiple-objective evaluation of 12 management actions and 8 portfolios, as well as summarizes a sensitivity analysis that systematically combined different combinations of food, turbidity, and flow actions.

- **Section 5 (Key Takeaways & Discussion – Action & Portfolio Evaluation):** Identifies key takeaways with additional discussion of the Round 1 evaluation results.

- **Section 6 (Next Steps: Adaptive Management & Research Studies):** Identifies possible next steps in the form of candidate adaptive management and research studies for consideration by implementing agencies.

Compass Resource Management (Compass or CRM) provided facilitation and analytical support to carry out this SDM process in a collaborative manner that engaged CSAMP members through CSAMP's technical, management, and policy committees. This report was written by Compass in collaboration with the CSAMP Delta Smelt Technical Working Group (TWG) and with review by the Policy Group SDM Steering Committee (see Appendix 8 for more information on the TWG and Steering Committee).

2 Delta Smelt Population Drivers & Modeling

In this section, we provide an overview of the environmental and biological drivers of Delta Smelt population dynamics in Section 2.1. Next, we introduce the multiple Delta Smelt population models used in this process in Section 2.2 and additional effects models developed during the process in Sections 2.3 and 2.4. Lastly, we discuss model limitations to consider when interpreting results in Section 2.5.

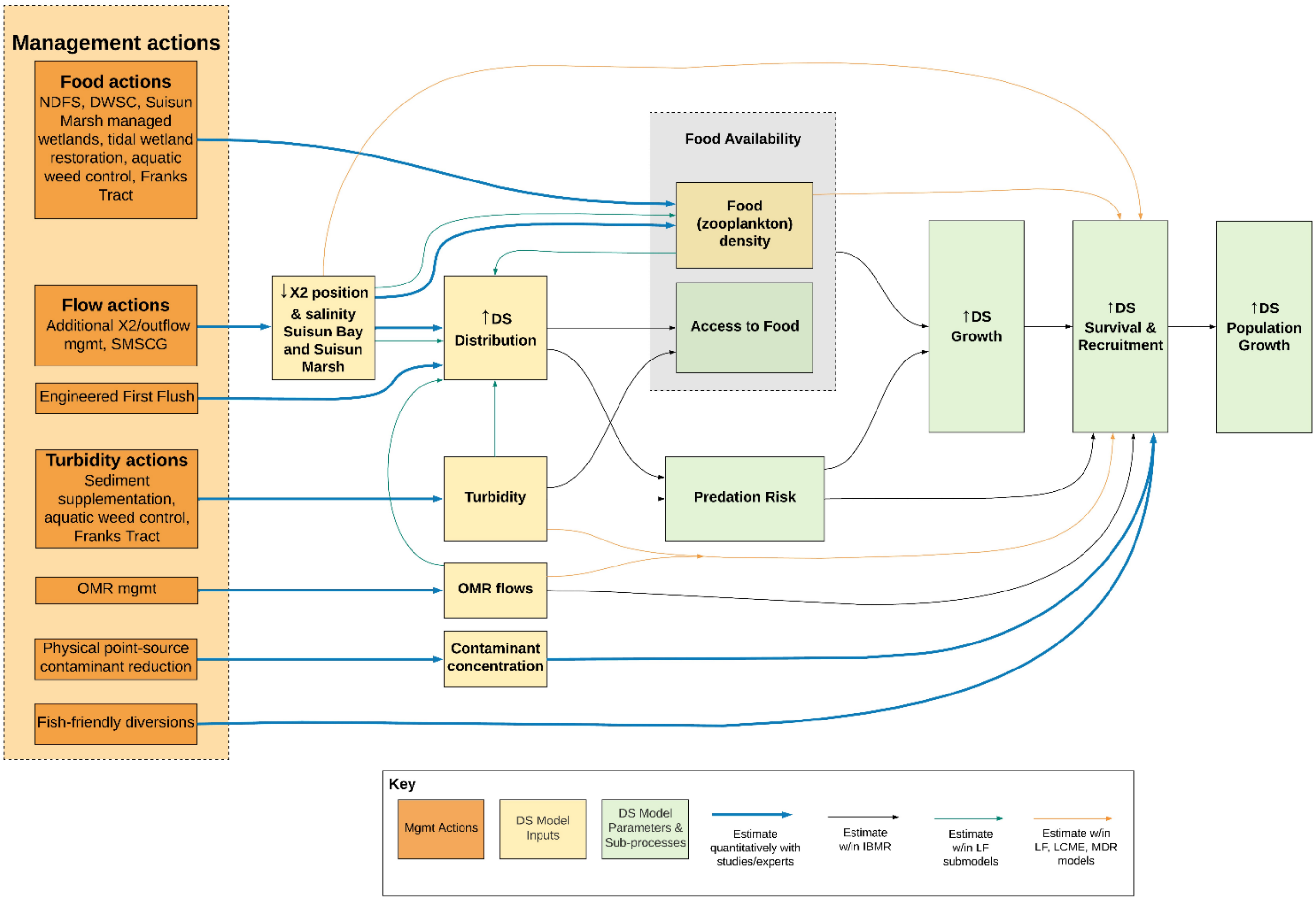
2.1 Delta Smelt Population Drivers

Considerable research has improved understanding of Delta Smelt population dynamics and the underlying drivers, with many uncertainties remaining (Moyle et al. 2016, Bennett and Luoma 2023, and citations within). Furthermore, the relationships between environmental/biological drivers (yellow boxes in Figure 2) and Delta Smelt population outcomes (shown in green boxes in Figure 2) have been estimated and documented in reports and publications of Delta Smelt models, including the ones used in the Round 1 evaluation (see Appendix 1 – Delta Smelt Modeling and primary publications in the References section). Although not a complete and exhaustive list, the Round 1 evaluation focused on several key drivers of Delta Smelt dynamics that were included in population models that could be affected by candidate management actions. Those drivers were the following:

- **Outflow/salinity:** Increasing outflow increases the size, location, and physical function of the Low Salinity Zone. Increasing outflow is also hypothesized to influence food and foraging opportunities for Delta Smelt. In turn, these known and hypothesized benefits are thought to lead to increased Delta Smelt access to suitable habitat conditions (e.g., salinity, food, turbidity, temperature) and ultimately survival.
- **Food:** Increasing food can have benefits for Delta Smelt energy consumption, growth, and survival.
- **Turbidity:** Increasing turbidity is hypothesized to have interactive effects with food, since turbidity can reduce predation risk and give Delta Smelt better access to food resources, including those higher food resources generated by actions.
- **Contaminants:** Reducing concentrations of contaminants (e.g., insecticides, herbicides) can have benefits to Delta Smelt growth, survival, and recruitment, as contaminants can decrease growth and reproductive success, and increase mortality.
- **Entrainment:** Increasing Old & Middle River (OMR) flows can have direct benefits to Delta Smelt survival, as more negative flows are associated with higher direct entrainment mortality of fish in the CVP/SWP pumps and higher indirect entrainment mortality in the South Delta, an area of poor habitat where fish survival is lower.

Evaluating management actions' effects on Delta Smelt in the SDM process required capturing two types of effects: (1) the quantified effect of an action on environmental/biological drivers of population dynamics (i.e., food [zooplankton density], turbidity, outflow, salinity, OMR, contaminants, Delta Smelt distribution; shown in yellow boxes in Figure 2) that also represent inputs for Delta Smelt population models, and (2) the effects of those environmental/biological drivers on Delta Smelt outcomes (shown in green boxes in Figure 2) that are captured within Delta Smelt population models' relationships and structure.

Figure 2. General influence diagram connecting effects of food, turbidity, flow, and other actions that were captured in the Delta Smelt Round 1 evaluation. The IBMR Delta Smelt model includes more mechanistic pathways between action effects and Delta Smelt consumption, growth, and survival. The LF, LCME, and MDR include more direct, statistical pathways between action effects and survival or recruitment. The LF model also uses submodels that relate action effects to food and Delta Smelt distribution.



Other habitat attributes, such as water temperature, have been shown by Delta Smelt population models to be influencing Delta Smelt population growth (Smith et al. 2021), but are not shown in Figure 2 because this SDM process did not identify ways to influence them that were judged to be sufficiently implementable. For example, ways for reducing water temperatures, especially in the important spring spawning season, were explored within the process but were not modeled in Round 1 due to technical feasibility or effectiveness questions. Some candidate management actions, such as silverside population management to reduce Delta Smelt egg/larvae predation, are not shown in Figure 2 and were not evaluated in Round 1 because preliminary work with the Delta Smelt population models did not show that they could influence population growth. See Appendix 7 on candidate action screening for more information on all management actions explored in this process and reasons for not including them as Round 1 management actions.

2.2 Delta Smelt Population Models

Newly developed Delta Smelt life cycle models used in the Round 1 evaluation are the best tools available to predict the potential effects of management actions on the Delta Smelt population. The SDM process adopted a multi-model approach for evaluating the consequences of management actions on Delta Smelt population outcomes. The multi-model approach recognizes that all models are imperfect and that there are many uncertainties in how the systems (the Delta and Delta Smelt) actually work. Comparing results across models strengthens conclusions when they agree and generates new insights when they diverge. Predicted population outcomes from management actions and portfolios were evaluated in Round 1 using four Delta Smelt population models (Table 1):

1) **IBMR** – Individual-based life cycle model in R (Smith 2022; updated from Rose et al. 2013 bioenergetics model);
2) **LCME** – USFWS life cycle model (Smith et al. 2021);
3) **MDR** – Maunder & Deriso life cycle model in R (updated from Maunder & Deriso 2011 model, Tillotson and Brandon 2022);
4) **LF** – Hamilton & Murphy (2022) limiting factors model.

We strived for consistency across models to improve the comparability of their results. All models evaluated population conditions between 1995-2014 (20-yr period) and used the same data inputs from Delta monitoring programs within this period. Data are described in more detail in Smith (2022), but generally included:

- **Daily flow** data from Dayflow of net Delta outflow as measured past Chipps Island to San Francisco Bay (available on https://data.cnra.ca.gov/dataset/dayflow);
- **Water quality** data (turbidity/clarity, temperature, salinity) from multiple monitoring surveys (available on https://github.com/CSAMP/delta-secchi-temperature-data). Data were pulled from the discretewq package (Bashevkin et al. 2022) which integrated the following sources: EMP (Environmental Monitoring Program), STN (Summer Townet Survey), FMWT (Fall Midwater Trawl), EDSM (Enhanced Delta Smelt Monitoring), DJFMP (Delta Juvenile Fish Monitoring Program), 20mm (20mm Survey), SKT (Spring Kodiak Trawl), Bay Study, USGS San Francisco Bay Surveys), USBR (United States Bureau of Reclamation Sacramento Deep Water Ship Channel data), and Suisun Marsh Fish Study;
- **Zooplankton biomass** from IEP's integrated zooplankton dataset accessed through the zooper package in R (Bashevkin et al. 2023b), available on Zenodo;
- **Delta Smelt distribution** data from 20-mm, Midwater Trawl, and Spring Kodiak Surveys estimated for the IBMR subregions (additional methods and details at https://github.com/CSAMP/fish-distribution-data).

All models incorporated the influence of turbidity, temperature, and prey density on population outcomes. All models estimated population growth rate on an annual basis and across the 20-yr period, and we worked with modelers to ensure that key outputs (e.g., % change in population growth rate from baseline conditions) represented Delta Smelt Performance Measures (PMs) and were comparable across models. All models also showed general agreement between population predictions and observed, historical data under baseline conditions across the 20-yr timeframe (ES-1). For more details on model relationships and structure, see Appendix 1 – Delta Smelt Modeling and primary publications in the References section.

Table 1. Delta Smelt population model descriptions and references. See Appendix 1 for more details.

Model	Short description and references
Individual-based model in R (IBMR) *Lead modeler: Will Smith (USFWS)*	The IBMR (Smith 2022) is a mechanistic model modified from a previous version (Rose et al. 2013 bioenergetics model). It simulates reproduction, movement among 12 spatial strata, growth, and mortality of a closed Delta Smelt population between 1995 and 2014 at a monthly time step. The IBMR was calibrated to abundances and growth rates estimated for the wild Delta Smelt population.
Life Cycle Model with Entrainment (LCME) *Lead modeler: Will Smith (USFWS)*	The LCME (Smith et al. 2021) is a statistical model modified from a previous version (Polansky et al. 2021). It estimates the relationship between ecosystem conditions and Delta Smelt reproductive and mortality rates using 21 years of abundance, entrainment, and ecosystem covariate data. The model is nonspatial – it does not account for Delta Smelt movement or environmental conditions that occur locally (subregion-specific). LCME models seven consecutive, 1- to 3-month life stages, that vary in which covariates influence population dynamics. To avoid overfitting and ensure adequate model performance, several versions of the LCME were used (varying by management actions and portfolios) that included different sets of covariates across time periods. The covariates with effects included in any life stage were water temperature, outflow, turbidity, striped bass density, and prey on natural mortality and South Delta turbidity and OMR on entrainment mortality (see Appendix 1).
Maunder and Deriso model in R (MDR) *Lead modeler: Mike Tillotson & John Brandon (ICF)*	The MDR is a statistical life cycle model modified from a previous version (Maunder and Deriso 2011). It included a similar structure and methods to the LCME, with four consecutive life stages within a year, no spatial structure, and using several alternate versions to evaluate different management actions and portfolios. Although versions of the MDR with density dependence and density independence were originally developed and discussed with the TWG, the TWG agreed to use and present results for the density independent model runs only in the Round 1 evaluation.
Limiting Factors (LF) model *Lead modeler: Scott Hamilton (Hamilton Resource Economics)*	The LF (Hamilton and Murphy 2022) is a statistical model using a multiple regression, limiting environmental factors approach. It tested relationships between >62 covariates and annual population change (represented as the change between consecutive years in FMWT Index) using a non-linear optimization algorithm in Excel fit to historical data and used a subset of best-supported covariates to simulate population outcomes under management effects. The final set of covariates were: exports, end of spawning (length of spawning window), Secchi depth, food, water temperature, and EC. The model incorporates a submodel that simulates movement of Delta Smelt across 10 subregions (Hamilton 2022), as well as a submodel that estimates effects of flow and other factors on subregion-specific food density (Hamilton 2022, 2023; Hamilton et al. 2020).

Figure 3. Spatial extent of the Delta Smelt Round 1 evaluation, including 12 subregions used by the IBMR.

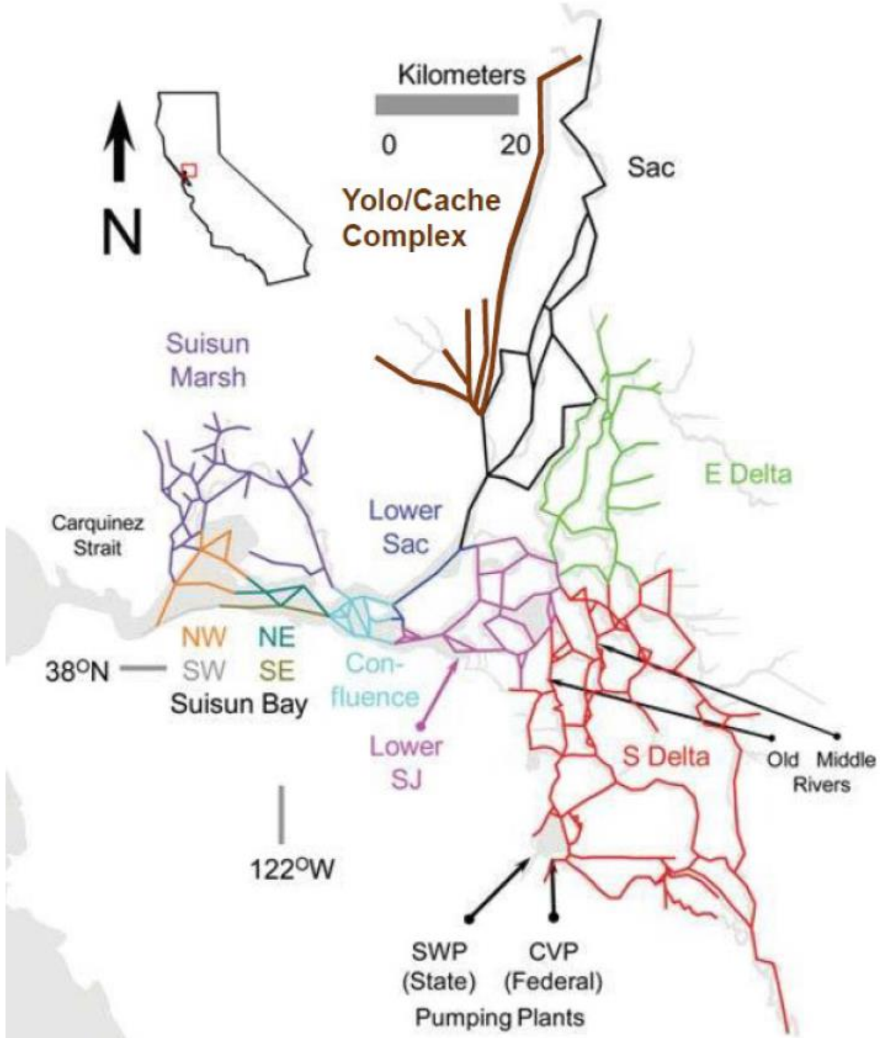
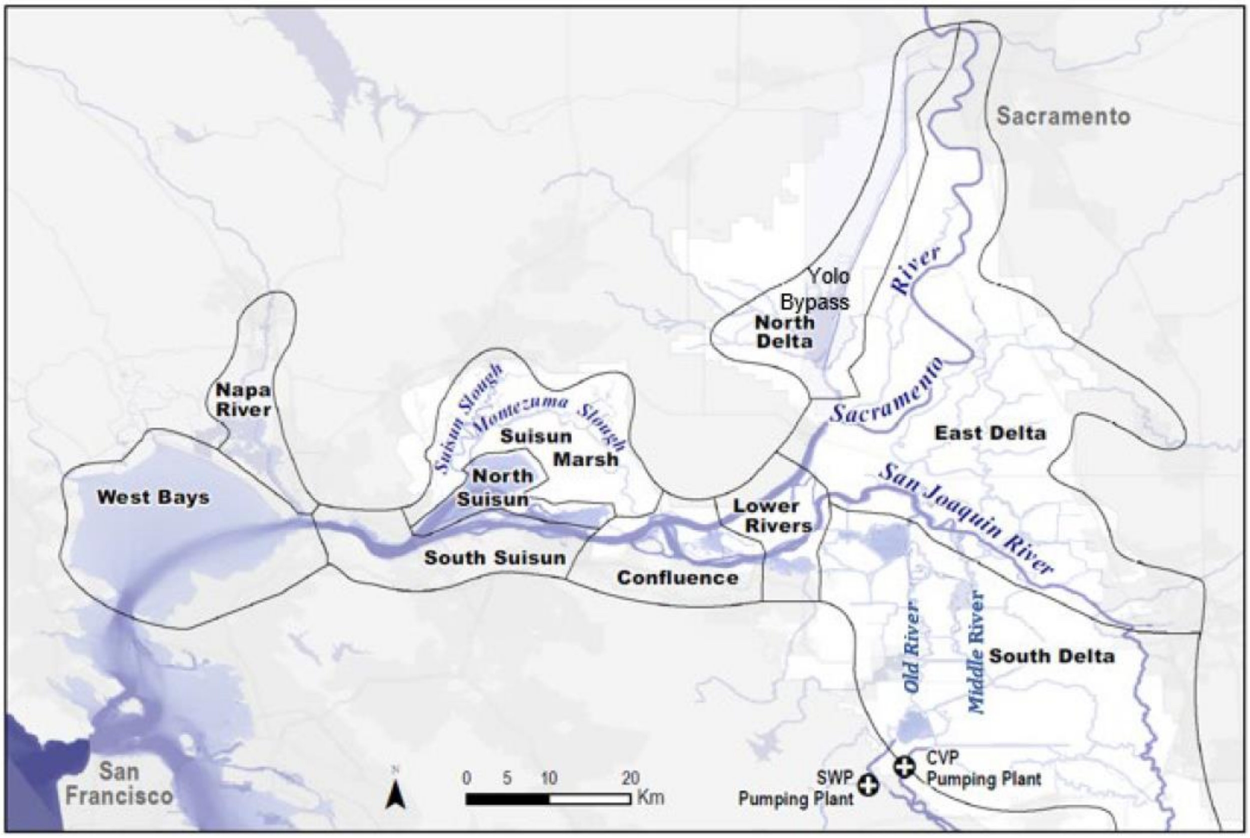


Figure 4. Ten subregions used in the Limiting Factors model.



2.3 Additional Effects Models for the IBMR

In addition to the four Delta Smelt population models, four other effects models were developed with the TWG for use in the SDM process. All four models were fit to historical data used in the IBMR and other Delta Smelt population models. They predicted outcomes for all months and 12 subregions to align with inputs needed for the IBMR. These month- and subregion-specific predicted effects were then adapted for inputs to the other Delta Smelt population models when appropriate. These models were developed using simple approaches designed to reasonably approximate system dynamics, fit the needs of this process for quantifying management action effects, and be achievable within the Round 1 evaluation timeframe. In the future, more complex modeling efforts of Delta and Delta Smelt dynamics can continue to improve predictions of the influence of management actions and drivers on population outcomes (e.g., Hendrix et al. 2023). Briefly, additional models included:

- **Flow-salinity model:** predicted effects of changing X2/outflow on subregion-specific salinity (CRM 2022b). The model used generalized linear regression with a gamma distribution where mean year-month-subregion salinity was the response variable influenced by month, X2 location, subregion, and an X2 x subregion interaction effect (allowing for the effect of X2 on salinity to vary by subregion).
- **TWG Delta Smelt spatial distribution model:** predicted effects of changing X2 location from a given flow management action on Delta Smelt distribution (CRM 2022a). This "model" used a simple approach developed by the TWG that resampled historical observed Delta Smelt spatial distributions, conditional on monthly X2 locations specified in a management action.
- **Salinity-food model:** predicted effects of subregion-specific salinity on taxa-specific food biomass density using a generalized additive model (CRM 2022c). The model also accounts for 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. 2023a). This model predicts changes in zooplankton for the Confluence and Suisun Marsh and Bay. It does not capture the effect of flows on zooplankton in the Delta subregions (east of the Confluence). 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 east of the Confluence across historical X2/outflow conditions (CRM 2022b). The model's structure does not capture the potential mechanism of downstream transport of zooplankton from flow, except to the extent that this mechanism would be capture by the collinearity of salinity and flow. One member was concerned about the degree to which salinity captured all the influences on food. All model code, performance information, and results are available on GitHub here.

- **Contaminants-mortality model:** predicted effects of reducing contaminants on subregion-specific Delta Smelt mortality rates (CRM 2022d). The model assumed proportional reductions in contaminant concentrations, given a management action, based on historical concentration data from Wayne Landis (Western Washington University). The model then simulated reductions in Delta Smelt mortality from reduced contaminant concentrations using modeled relationships between contaminant loads and Mississippi silverside mortality (as a surrogate species) developed in Landis et al. (2023).

See the separate memos that accompany this report (Appendix 1) for more details on each model.

2.4 Additional Effects Models for the LF Model

The LF model was employed in conjunction with two other models. The first was a monthly food model (Hamilton 2022, 2023; Hamilton et al. 2020). That model explains density of calanoid copepods by subregion in the Delta as a function of water temperature, flow, salinity, upstream abundance of copepods and prior abundance of copepods. As an action changes flow or salinity, the distribution of calanoid copepods throughout the estuary changes. The second model predicts changes in Delta Smelt distribution. That model (Hamilton 2022) estimates the distribution of Delta Smelt by month as a function of region, outflow, prior distribution, temperature, turbidity, salinity, food, and OMR flows (the latter just for 4 regions). For both models, relationships were estimated by fitting coefficients that produced the minimum residual sum of squares, using the GRG nonlinear routine in Excel (Solver). Some TWG members were concerned about the validity of these models and their assumptions for the reasons described in section 2.5. See the separate memos that accompany this report (Appendix 1) for more details on each model.

2.5 Delta Smelt Model Differences & Limitations

As the four Delta Smelt population models were originally built for different purposes, key differences exist between models that should be considered when interpreting results. Differences across models include the following:

- **Model classes:** The models represent two different classes of models that differ in how they estimate relationships between the inputs and outputs. The IBMR is a mechanistic simulation model, meaning it assumes many biological mechanisms, based on current understanding of Delta Smelt ecology, like Delta Smelt food consumption, biomass growth, predation, survival, and distribution. Conversely, the other models are statistically fit, meaning they are fit to actual observations and are limited to more general relationships between environmental or biological conditions and survival for particular life stages. Both mechanistic and statistical models can predict changes in population growth rate by assuming a change in the model's input data (e.g., food, turbidity, salinity, Delta Outflow, etc.).

- **Spatial structure:** Two models (IBMR and LF: see Figure 3 and Figure 4) have a spatial component that allows them to simulate local effects of actions and changes in Delta Smelt movement, whereas two models (LCME and MDR) are non-spatial and were only used to evaluate actions that affect a broad scale (e.g., tidal wetland restoration across the North Delta Arc).

- **Temporal / life stage structure:** All models except the LF model explicitly separate out Delta Smelt life stages. The IBMR uses a monthly time step, whereas the LCME and MDR use 1- to 3-month time steps related to different life stages. The LF model operates on an annual time step (represented as the change in FMWT Index from one year to the next), although covariates may be associated with a certain month or seasonal period.

- **Covariates:** Although all models incorporate effects of food, turbidity, and OMR, they vary in other factors that are included, such as salinity, Delta outflow or X2, and predator density.

- **Number and timing of covariates included:** The IBMR could incorporate any management action effects in any and all time periods for which they were hypothesized, whereas the LCME, MDR, and LF restricted the number of covariates to varying degrees to avoid overfitting, which was done through covariate and model selection procedures. Therefore, these models could often not include all effects in all life stages of an action or portfolio even if they were quantified in the Round 1 evaluation. For example, tidal wetland restoration had a quantified effect on food in all months, but the LCME only included the food effect in Feb through Aug based on findings that other factors were more significant drivers of Delta Smelt survival in other time periods. Models could also not capture all possible interactions among covariates that likely occur in the complex system of the San Francisco Estuary (see Bennett and Luoma 2023, included in Reference materials accompanying this report). Multiple versions of the LCME and MDR were used to evaluate different management actions and portfolios that differ in the sets of covariates included, which included key covariates influenced by actions (e.g., food or X2). This process was done to maximize the number of hypothesized action effects captured in the model (see Appendix 1 – Delta Smelt Modeling for more details). Models are always limited in the number of covariates they can include (see below); however, we acknowledge that other factors with potential influence on Delta Smelt population dynamics were not or could not be captured within these models.

- **Overfitting:** The TWG discussed the potential for overfitting with the LF model, which typically causes a model to fit observed data well but perform poorly for predicting new, unobserved conditions. The LCME and MDR restricted the number of covariates per life stage to avoid overfitting and collinearity among predictors within individual models. Alternate model versions of the LCME and MDR were screened for diagnostic flags (posterior evidence and model residuals); not all alternate models were suitable for further inference. The LF model included more covariates than the LCME and MDR in an attempt to capture more effects of management actions across more time periods, which warranted a closer look at potential overfitting. In response to concerns raised by some TWG members about overfitting, Scott Hamilton (lead LF modeler) performed cross-validation and presented results from the model that the TWG discussed at the 3 June 2022 meeting (ES-1B). However, some members still contend that the model is overfit and could produce unreliable predictions.

- **Supplementation:** Experimental release of cultured Delta Smelt into the Delta has occurred in recent years and broader supplementation efforts are expected in the future. The population models used in this SDM process are based on wild Delta Smelt data. A supplemented Delta Smelt population may respond differently than the purely wild Delta Smelt population that the models are based on.

- **Model updates:** Although this limitation applies to any modeling exercise, we emphasize that the versions of the Delta Smelt population models used in this process incorporated the best available information at the time (~2022-2023). These models continue to be updated with new information. This was especially true of the LF model, where new versions were developed later in the Round 1 evaluation to capture additional action effects. There was not sufficient time for documentation and TWG review of these newer versions, so the results from the first LF version are represented in this report. However, updated versions of the LF and other models could be available for future analyses.

3 Management Action Evaluation for Delta Smelt

A key task in the Round 1 evaluation was predicting Delta Smelt population growth from management actions. Delta Smelt population models already include relationships between environmental and biological drivers and Delta Smelt population growth. Thus, evaluating management action effects on Delta Smelt required estimating the proximate effect(s) of an action on those environmental/biological drivers (or model inputs), such as, food (zooplankton density), turbidity, outflow, salinity, OMR flow, contaminants, life-stage specific survival or mortality, and Delta Smelt distribution.

In this section, we describe the methods and evidence used to estimate effects of each management action on Delta Smelt model inputs (Section. 3.1). Next, we describe additional analyses for outflow management and tidal wetland restoration that explored the sensitivity of population growth to varying the timing, intensity, and effects assumptions for those actions (Sections 3.2 and 3.3). We then characterize effect uncertainty and time to implementation for management actions, which should be considered when interpreting Delta Smelt population growth predictions (Section 3.4). Lastly, we provide Delta Smelt population growth predictions for Round 1 management actions and discuss relevant takeaways (Section 3.5).

3.1 Estimating Effects of Management Actions on Delta Smelt Model Inputs

Model predictions of Delta Smelt population growth were based on the quantified, proximate effects of management actions. Generally, management actions were first described by the TWG in influence diagrams to show their hypothesized effects on Delta Smelt habitat factors (e.g., food, turbidity, salinity) and demographics (e.g., spatial distribution, survival). We present representative influence diagrams for a food action (tidal wetland restoration) in Figure 5, a turbidity action (sediment supplementation) in Figure 6, and a flow action (outflow/X2 management) in Figure 7. An action's primary hypothesized benefit for Delta Smelt were quantified using either existing research or new analyses done within the SDM process; however, the evidence basis for estimating effects is variable across management actions. In some cases, field data existed that could be used to infer management action effects. In other cases, no data were available and more theoretical, back-of-the envelope estimates needed to be made with input from the TWG. Section 3.4 summarizes TWG level of confidence in the management effect assumptions used in the Delta Smelt modeling.

Not all possible effects of actions were captured in the Round 1 evaluation due to insufficient evidence that would require more information or modeling that was outside the scope of this process. Those that were quantified generally represent the primary effects of an action with the least, relative uncertainty and that had existing empirical studies from which we could draw information. For example, the effect on food was quantified for tidal wetland restoration, while other potential effects (e.g., salinity, water temperature, turbidity, Delta Smelt distribution) were discussed but not quantified, needing more information or modeling outside of the scope of this process (Figure 5).

For each management action included in the Round 1 evaluation, we summarize the evidence and key uncertainties with respect to quantifying effects on environmental/biological conditions below (Table 2). Since many Round 1 actions had intended benefits to food and/or turbidity but varied in their timings and spatial scales, we present a summary comparing their average proximate effects (% change from baseline in food and/or turbidity) in Table 3. Note that this table does not report effects for outflow actions on food, since these were taxa-specific and predicted within the Salinity-food and flow-food models as inputs for the IBMR and LF, respectively. Additional background information, methods, and action influence diagrams are provided in Appendix 2 – Management Action Specification and Evaluation Sheets.

Figure 5. Influence diagram of potential effects of tidal wetland restoration on environmental/biological drivers (yellow boxes) and subsequent Delta Smelt population dynamics (green boxes). The effect on food (blue line) was quantified while all other effects (dashed lines: e.g., turbidity, Delta Smelt distribution) were discussed but not quantified, needing more information or modeling outside of the scope of this process.

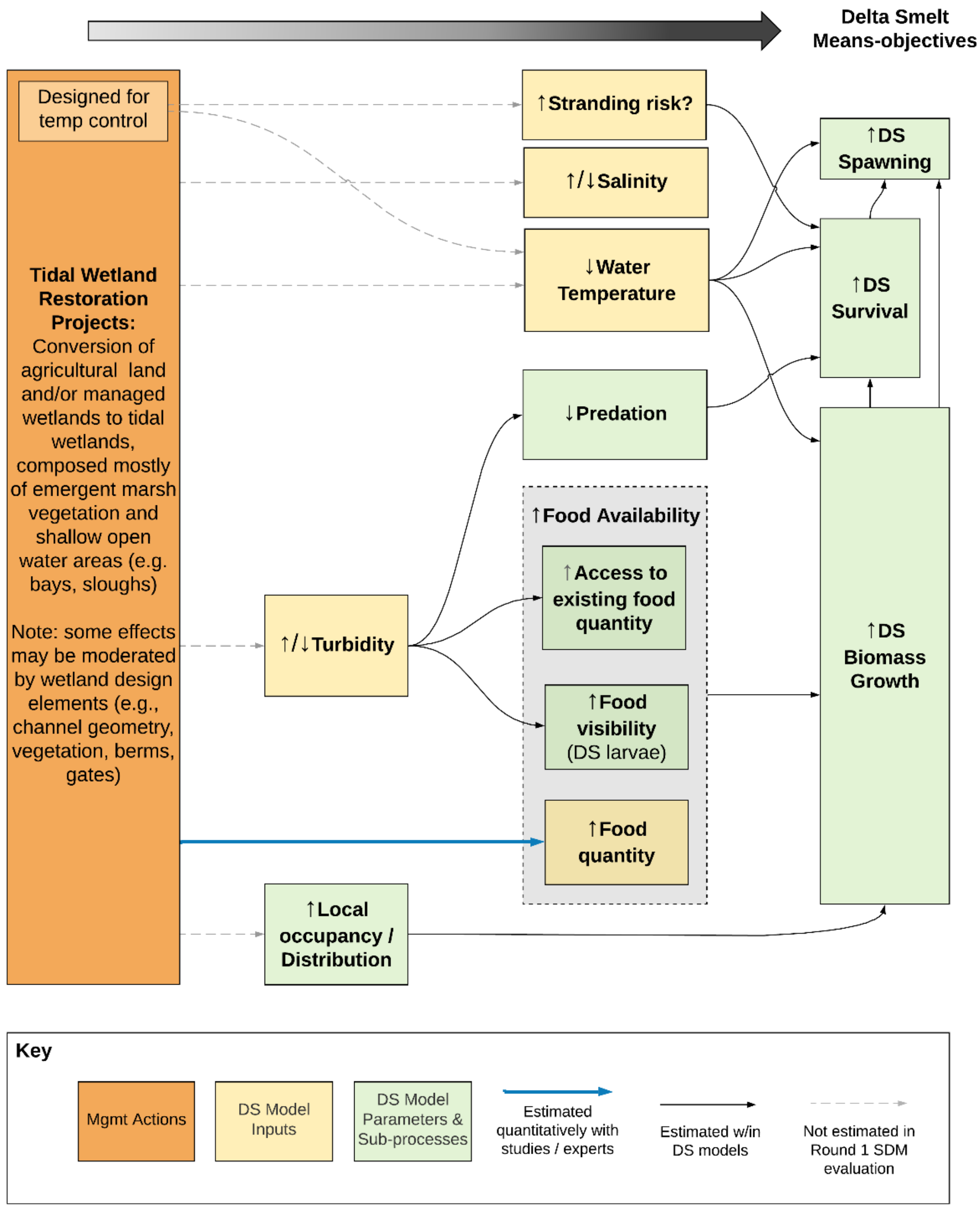


Figure 6. Influence diagram of potential effects of sediment supplementation on environmental/biological drivers (yellow boxes) and subsequent Delta Smelt population dynamics (green boxes).

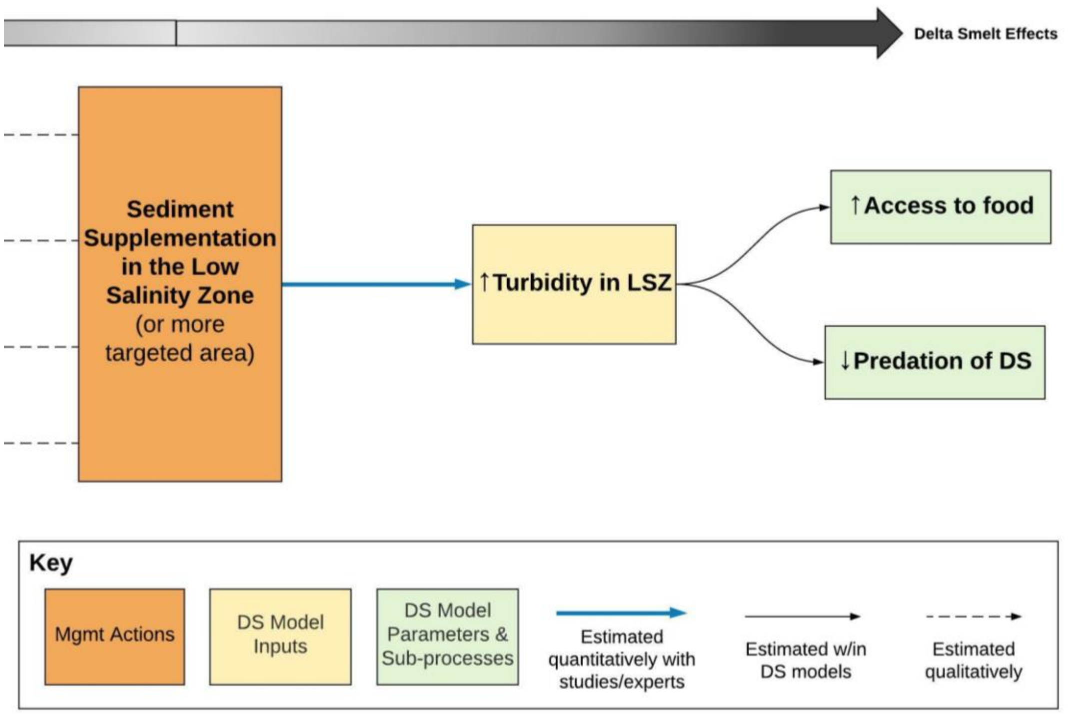


Figure 7. Influence diagram of potential effects of outflow/X2 management on environmental/biological drivers (yellow boxes) and subsequent Delta Smelt population dynamics (green boxes).

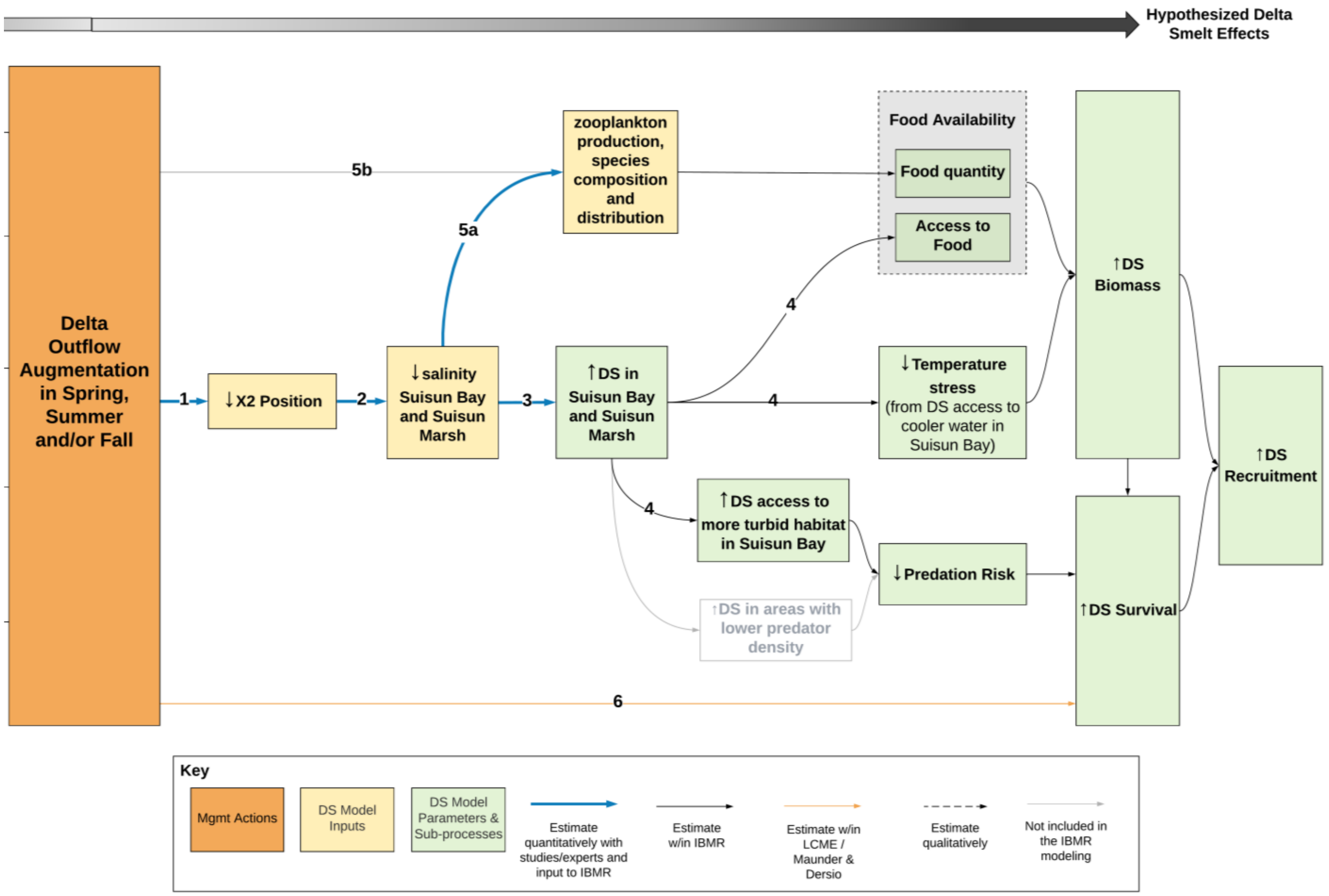


Table 2. Summary of management action effect hypotheses, model input assumptions, evidence, and uncertainties related to Delta Smelt modeling of Round 1 management actions. Actions are grouped into categories representing their primary intended effects.

Action	Temporal and spatial scales	Modeled effects	Effect hypotheses, evidence, and uncertainty of effects
Flow and Food actions			

Delta Outflow/X2 Management	Tested multiple versions that varied in timing, water year types, and magnitude of additional outflow. Outflow actions used in portfolios fell into three categories: (1) outflow in the fall representing current or historical regulations (2) additional summer outflow (3) Full-year flows.	**Flow, salinity, food, Delta Smelt distribution**	**Effect hypothesis:** Increasing Delta Outflow will lower salinity in the Confluence and Suisun Marsh and Bay and also result in changes in zooplankton density and Delta Smelt distribution.
			Model input assumptions/evidence/uncertainties: The relationship between target X2 positions of an action and additional outflow required to meet that X2 position, relative to baseline (observed 1995-2014 flows), was estimated using a coarse hydrology analysis method linking steady-state and transient flows (Denton 1993, Monismith et al. 2002). Water balancing within or across years was not done, meaning a source for the additional outflow has not been identified. Effects of additional outflow on subregion-specific salinity were estimated from a flow-salinity model (CRM 2022b). For the IBMR, effects of subregion-specific salinity on taxa-specific food density were estimated from the Salinity-food model (CRM 2022c); effects of changes in X2 position on Delta Smelt distribution were estimated from the TWG distribution model (CRM 2022a). For the LF model, effects of flow on food and Delta Smelt distribution were estimated from the Hamilton flow-food and distribution models (Hamilton 2022). No effects of flow/salinity on food or distribution were included in the LCME and MDR (as these models have a covariate for outflow that directly affects life stage survival and do not include spatial subregions that could capture distribution changes).
			For modeling outflow/X2 actions in Round 1, the following X2 targets were used[6]:
			• "Current management" fall outflow: X2 ≤ 80 km in W/AN yrs
			• Summer outflow: X2 ≤ 70 km in July and ≤ 75 km in Aug in W/AN (or W/AN/BN) yrs
			• Full-year flows: Additional spring/summer/fall outflow when minimum flow thresholds are triggered:
			  ○ Mar-May: < 25,000 cfs (X2 ≤ 66 km) in W or AN yrs; < 11,700 cfs (X2 ≤ 74 km) in BN, D, and C yrs
			  ○ June: < 12,400 cfs (X2 ≤ 73 km) in W yrs; < 11,400 cfs (X2 ≤ 74 km) in AN or BN yrs
			  ○ July-Aug: < 7,500 cfs (X2 ≤ 78 km) in W, AN, or BN yrs
			  ○ Sept-Oct: "Current management" of X2 ≤ 80 km in W/AN yrs

[6] Model runs of outflow/X2 actions 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).

Action	Temporal and spatial scales	Modeled effects	Effect hypotheses, evidence, and uncertainty of effects
Suisun Marsh Salinity Control Gates (SMSCG)	June-Oct in condition-specific years; Suisun Marsh	**Salinity, food, Delta Smelt distribution**	**Effect hypothesis:** Summer/fall operation of the SMSCG will lower Suisun Marsh salinity, increasing Delta Smelt dynamic habitat and resulting in changes in zooplankton density. **Model input assumptions/evidence/uncertainties:** The action was modeled using the salinity targets as defined in the 2019 BiOp and 2020 ITP. See Additional Delta outflow action (above) for methods estimating effects of salinity on food and Delta Smelt distribution. This action was implemented through a pilot study in Aug 2018, which demonstrated that the gates can successfully be operated in the summer to reduce salinity in Suisun Marsh.
Food actions			
North Delta Food Subsidies (NDFS)	Aug-Oct in AN, BN, and D years; Yolo/Cache Slough, Upper/Lower Sacramento	**Food**	**Effect hypothesis:** Increasing flow across the Yolo Bypass will increase zooplankton production both locally and downstream. **Model input assumptions/evidence/uncertainties:** The assumed effect of NDFS on food is based on Delta Coordination Group (DCG) modifications of RMA (2021) simulation modeling and empirical data from its implementation in 2016 (Frantzich et al. 2021). RMA's approach incorporated observed calanoid copepod catch per unit effort (CPUE) data, conservative tracer simulations and a simplified representation of copepod growth to estimate calanoid copepod biomass per unit effort (BPUE) with augmented flow across Yolo Bypass (RMA 2021, Calanoid Copepod Analysis Addendum). **Other Assumptions:** Assumed no impact from potential increases in contaminant loading.
Sacramento Deep Water Ship Channel (DWSC) food transport and subsidies	Mar-Apr, July-Oct in all years; Yolo/Cache Slough	**Food**	**Effect hypothesis:** Adding nutrients to the Sacramento DWSC will increase zooplankton and re-connecting the North end of the channel to the Sacramento River will increase flow through the channel to move zooplankton downstream to the turbidity maximum zone, where Delta Smelt tend to be most concentrated. **Model input assumptions/evidence/uncertainties:** Used coarse estimate based on data and expert knowledge from Erwin Van Nieuwenhuyse (previous USBR lead for this action, now retired), who was involved in a pilot application of nutrients in the Sacramento DWSC in 2019. See Appendix 2 of the DWSC Food Action Specification Sheet for details on Erwin's methods, which considered both the RMA (2021) results of the transport effect and the nutrient addition effect. Exploratory model runs also tested RMA (2021) simulation modeling results of the transport effect only.
Suisun Marsh Managed wetland food production	Tested three time periods: Mar-Apr, July-Aug, and/or Sept-Oct in all years. Tested multiple spatial scales	**Food**	**Effect hypothesis:** Flooding/draining of managed wetlands in Suisun Marsh in different seasons will produce more food within wetlands and release it into adjacent Delta Smelt habitat (Suisun Marsh and NW Suisun Bay). **Model input assumptions/evidence/uncertainties:** Model input assumptions are based on empirical monitoring data and expert judgment from Kyle Philips (Durand Lab, UC Davis). Data

Action	Temporal and spatial scales	Modeled effects	Effect hypotheses, evidence, and uncertainty of effects
	(from 1K to 4K ac) in Suisun Marsh.		come from 7 sites monitoring flood/drain operations in Mar-Apr. Effects for other time periods were based on expert judgment, since flooding/draining typically is not conducted in summer or fall. Model results in this report represent model runs that assumed benefits to food in all three time periods. Additional exploratory runs tested food benefits in single time periods.
Tidal wetland restoration	All months and years. Tested multiple scales (from 9K to 30K ac) across Delta/Suisun. Note that 14K ac are currently being implemented or planned in EcoRestore.	**Food**	**Effect hypothesis:** Converting agricultural land and/or managed wetlands to tidal wetlands, composed mostly of emergent marsh vegetation and shallow open water areas will increase food for Delta Smelt (inclusive of zooplankton, benthic invertebrates, fish eggs/larvae) that can be accessed by Delta Smelt. **Model input assumptions/evidence/uncertainties:** Food effect is modeled by increasing the baseline zooplankton density covariate in models proportionally to new open water acres created through tidal wetland restoration. Exploratory model runs also tested a higher bookend effect on food based on SFEI (Cloern et al. 2021) and RMA (2021) using theoretical modeling to link restored areas to phytoplankton and zooplankton production. There is mixed evidence regarding the food benefits of restored tidal wetlands for Delta Smelt that is discussed further in Sections 3.3 and 6.7.
Turbidity actions			
Aquatic weed control + sediment agitation	All months and years. Tested multiple scales (from 600 ac and 3.5K ac) across Delta.	**Turbidity, food**	**Effect hypothesis:** Submerged aquatic weeds slow water movement in the area, which removes suspended particles. Assuming the action reduces 100% of submerged aquatic weeds in an area, it is correlated with increasing turbidity in that area and will create more open water habitat. There may also be increased access to food from more open water areas. **Model input assumptions/evidence/uncertainties:** Effects on turbidity from removing aquatic weeds were based on estimates from Hestir et al. (2016), which used a combination of assumptions and regression models fit to historical data. Effects on food were based on coarse methods assuming increases in food proportional to new open water acres, the reverse of the mechanism hypothesized for food production by tidal wetland restoration. To our knowledge, no data/studies exist that could inform the estimate of a change in food with a change in aquatic weeds. Spatial coverage of aquatic weed areas that could be removed Came from data from Ustin et al. (2021). **Other Assumptions:** Aquatic weeds could be removed in a way that does not inhibit zooplankton production or have adverse effects to Delta Smelt.

Action	Temporal and spatial scales	Modeled effects	Effect hypotheses, evidence, and uncertainty of effects
Sediment supplementation	May-Nov, all years except 2001 and 2002; Lower Sacramento and westward	**Turbidity**	**Effect hypothesis:** Adding sediment at Decker Island (just upstream from the Confluence) will increase downstream turbidity. **Model input assumptions/evidence/uncertainties:** Effects on turbidity were based on results from Bever and MacWilliams (2017), who used the hydrodynamic UnTrim San Francisco Bay-Delta Model coupled with a sediment transport model to simulate this action. These methods increased turbidity to ≥ 15 NTU, on average, across subregions.
Other / Entrainment actions			
Franks Tract restoration	All months and years; Lower San Joaquin	**Turbidity, food, Delta Smelt distribution**	**Effect hypothesis:** Restoring this area will alter flow patterns and is hypothesized to reduce Delta Smelt movement into the South Delta (and subsequently reduce entrainment mortality). As this action included aquatic weed control and tidal wetland restoration, the same effect hypotheses apply as described above for those actions. **Model input assumptions/evidence/uncertainties:** Assumed a 25% reduction in South Delta distribution in Mar-May based on particle tracking studies (CDFW 2020). Assumed effects on turbidity and food using the same methods described above for aquatic weed control and tidal wetland restoration.
Old & Middle River Management (2008/2009/2019 BiOps)	June-Oct in condition-specific years; Suisun Marsh	**OMR flows**	**Effect hypothesis:** OMR flow is an indicator of the influence of export pumping on Delta Smelt entrainment mortality, and managing OMR flows above minimum thresholds during strategic times mitigates entrainment. **Model input assumptions/evidence/uncertainties:** This action has been implemented since the 2008 BiOp and so model baseline data for OMR flows already represents the effects of changes in pumping on OMR flows. On advice from FWS (Matt Nobriga), we used historical OMR flow data from the post-2008 BiOp period to simulate this action in the pre-2008 period. We also simulated the new Integrated Early Winter Pulse Protection from the 2020 ROD as a component of this OMR management action by assuming a reduction of exports for 14 days so that the 14-day average OMR indices for the period are not more negative than -2000 cfs in response to First Flush conditions in the Delta.
Engineered First Flush	Dec-Jan in condition-specific years; Suisun Marsh	**Delta Smelt distribution**	**Effect hypothesis:** A winter flow pulse over the Yolo Bypass in years when this pulse would not occur naturally would produce a pulse of fresh, turbid Sacramento flow that could attract Delta Smelt to move into spawning locations in the North Delta and reduce the risk of entrainment of adults and larvae. **Model input assumptions/evidence/uncertainties:** In the IBMR, assumed 50% of Delta Smelt distribution that historically was in the Lower San Joaquin, East Delta, and South Delta subregions is distributed in the Yolo/Cache subregion instead. This distribution effect was assumed to occur in Feb-June following the action. Exploratory model runs (not presented)

Action	Temporal and spatial scales	Modeled effects	Effect hypotheses, evidence, and uncertainty of effects
			tested shifting 100% of distribution to Yolo/Cache. Assumptions are informed by observations of increased Delta Smelt entrainment in the Pumps in years with no first flush, however there is a lack of data to understand the proportion of the population that this influences.
Physical point-source contaminant reduction	All months and years; Tested multiple spatial scales: (1) Ulatis Creek hotspot in Yolo/Cache at (2) Delta-wide	**Natural mortality**	**Effect hypothesis:** Building constructed wetlands at contaminant hotspots can reduce contaminant loadings and increase Delta Smelt survival. **Model input assumptions/evidence/uncertainties:** Assumed a 5% reduction in contaminants at the subregion level (50% local reduction in contaminants from the constructed wetland in which Ulatis or similar source contributed to 10% of subregion's inflows). Wayne Landis's lab (Western Washington University) provided historical concentration data for four insecticides of key concern to Delta Smelt; other contaminants were not tested/included. Effects of contaminant reduction on survival were estimated with studies from the Landis Lab, which were estimated from lab studies with a surrogate fish species (Inland silversides), which is an EPA model toxicity testing species for estuarine fish and has a similar life history to Delta Smelt (USEPA 2002). As a standard model species and its similar life history it was assumed silversides were affected by contaminants in a similar way as Delta Smelt (Hutton et al 2023). Methods for predicting the effects of contaminant reduction on fish mortality were based on Landis et al. (2023) and adapted for this process (CRM 2022d).
Supplementation			
Supplementation of hatchery-origin fish	Different life stages, from eggs to adults	**Abundance**	The Round 1 evaluation assessed population outcomes under an array of supplementation scenarios with the LCME. Scenarios tested stocking of different life stages and number of individuals, including: 200,000 or 1,500,000 eggs; and 20,000 to 500,000 post-larvae, juveniles, subadults, or adults. The TWG reviewed results from these scenarios, tested with the LCME (Smith 2021). The group determined that supplementation is an ongoing component of Delta Smelt recovery and could be added to any action or portfolio to improve population outcomes. Therefore, the Round 1 evaluation tested portfolios without supplementation to focus on potential benefits of other actions that could address the CSAMP management goal of a *self-sustaining* population. See Smith 2021 for full documentation of methods and results.

Table 3. Average proximate effects on food and turbidity (% change from baseline) for Round 1 management actions, with descriptions of action timing and spatial scales. Actions are grouped into categories representing their primary intended effects.

Main effects	Action name	Months	Years	Spatial scale	% change of food from baseline[1]	% change of turbidity from baseline[1]
Food	North Delta Food Subsidies	Aug-Oct	AN, BN, D years	3 subregions	4%	-
Food	Sacramento DWSC food transport and subsidies	Mar-Apr, July-Oct	All	1 subregion	125%	-
Food	Tidal wetland restoration	Year-round	All	9 subregions (9K ac)	5%	-
				9 subregions (30K ac)	16%	-
Food	Suisun Marsh Managed wetland food production	Mar-Apr, July-Oct	All	2 subregions (1K ac)	27%	-
				2 subregions (2K ac)	53%	-
				2 subregions (4K ac)	106%	-
Turbidity	Aquatic weed control + sediment agitation	Year-round	All	1 subregion (600 ac)	5%	10%
				4 subregions (1.4K ac)	4%	11%
				5 subregions (3.5K ac)	6%	15%
Turbidity	Franks Tract restoration[2]	Year-round	All	1 subregion	7%	30%
Turbidity	Sediment supplementation	May-Dec	All (except 2001 and 2002)	8 subregions	-	35%

[1] % change from baseline represents an average across the subregions affected by the management action over the 20-yr model timeframe.
[2] Franks Tract also includes an assumed effect on Delta Smelt distribution that reduces distribution in the South Delta by 25% in Mar-May.

3.2 X2 Sensitivity Analysis

Round 1 included numerous model runs testing the sensitivity of Delta Smelt population outcomes to a range of X2 targets. Across these sensitivity runs, the overarching purpose was to test Delta Smelt population responses to varying X2 in three dimensions:

- **Water year type**: (1) Wet (W) and Above Normal (AN) and (2) W, AN and Below Normal (BN)
- **X2 location target**: up to 5 locations – (1) low bookend, (2) high bookend, and (3 to 5) three points in between
- **Season**: (1) summer (July to Aug), (2) fall (Sept to Oct), and (3) summer/fall (July to Oct)

The TWG defined the low and high bookend X2 locations using the minimum and maximum monthly X2 values observed in historical data between July and Oct across W/AN/BN years in 1995-2014 (the baseline period for Delta Smelt models used in the Round 1 evaluation: Table 4). The middle scenario for fall was defined as 80 km in Sept/Oct (which is the maximum X2 location required in these months by the 2020 ROD/ITP). The other scenarios for summer and fall were defined with X2 locations in regular increments between the bookends and the middle scenario.

Table 4. X2 location targets used in the X2 sensitivity analysis model runs, based on the range of historically observed monthly mean X2 locations in the model time period (1995-2014).

Location target	Summer		Fall		Rationale for values
	July	Aug	Sept	Oct	
Low bookend (1998 values)	59	66	68	72	Minimum values observed in July-Oct, 1995-2014
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 (July - 2004 values Aug – 2010 values Sept – 2012 values Oct – 2003 values)	80	84	87	88	Maximum values observed in July-Oct in Wet, AN, and BN years, 1995-2014

Different "rulesets" for changing X2 locations were used between (a) the Round 1 evaluation of individual outflow actions/portfolios and (b) the sensitivity analysis (Table 5). The Round 1 evaluation of individual outflow/X2 management actions and portfolios that included these actions was intended to simulate (approximately) how these actions would be implemented, given the range of flow conditions across the 20-yr model period. These runs reduced X2 only 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 X2 location was used in the model run (no change). Therefore, flow was only increased relative to the baseline in these runs. In the X2 sensitivity analysis, X2 locations were set at a consistent location in the summer or fall months, which meant that the model runs were simulating a decrease in flow relative to baseline (observed) flow for some years and model runs. Therefore, results from X2 sensitivity runs are intended to inform the relationship between X2 targets and population outcomes and are best interpreted relative to other sensitivity runs – and not directly compared to action/portfolio runs.

Table 5. Comparison of "rulesets" used for changing X2 in sensitivity model runs vs. Round 1 action/portfolio runs.

Model Year	Water Year Type (SVI) Oct 1 to Sept 30	Historical X2				X2 in sensitivity runs				X2 in action/portfolio runs			
						Summer Outflow Aug. (X2 = 70/75 for July/Aug)		Fall Outflow (X2 = 80 for Sept/Oct)		Summer Outflow Aug. (X2 ≤ 70/75 for July/Aug)		Fall Outflow (X2 ≤ 80 for Sept/Oct)	
		J	A	S	O	J	A	S	O	J	A	S	O
1995	W	62	71	72	72	70	75	80	80	62	71	72	72
1996	W	75	77	78	85	70	75	80	80	70	75	78	80
1997	W	78	78	83	86	70	75	80	80	70	75	80	80
1998	W	59	66	68	72	70	75	80	80	59	66	68	72
1999	W	75	79	84	86	70	75	80	80	70	75	80	80
2000	W	78	80	84	87	70	75	80	80	70	75	80	80
2003	AN	77	79	86	88	70	75	80	80	70	75	80	80
2006	W	69	77	79	84	70	75	80	80	69	75	79	80
2011	W	65	76	75	74	70	75	80	80	65	75	75	74

Iterative sets of model runs were conducted that simulated changes in only X2 location (no other changes were included).

3.2.1 X2 and Delta Smelt distribution sensitivity analysis

The first set of model runs tested the sensitivity of Delta Smelt population growth to variations in fall and summer X2 in W, AN, and BN years, while exploring differences between two Delta Smelt distribution models. The first distribution model – the Smith Distribution model, originally built within the IBMR (Smith 2022) – predicts changes in Delta Smelt distribution across subregions in a given month as a function of salinity and temperature. Smith (2022) developed a Dirichlet regression model, fit to trawl survey data covering the entire Delta Smelt range and life cycle. Other covariates were assessed, including X2, Secchi depth, and prey density; however, models showed no effect of these other covariates on distribution. Despite lengthy exploratory analyses, even the best model showed some lack of fit to observed data. The second distribution model was the TWG distribution model described in Section 2.3, which used a simple approach that resampled historical observed Delta Smelt spatial distributions, conditional on monthly X2 locations specified in a management action (CRM 2022a). These model runs do not include an effect between changes in flow/salinity and zooplankton.

The table below compares IBMR and LCME 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 June-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). Therefore, the LCME was insensitive to changes in fall outflow in these model runs. However, summer outflow and fall X2 are highly correlated. The highest summer outflow years are the lowest fall X2 years, and vice versa.

Table 6. Predicted Delta Smelt population growth rate (lambda) for X2 and distribution model sensitivity analysis with the IBMR. Results are also shown for the LCME, which included a direct effect of flow on summer survival but did not incorporate effects on Delta Smelt distribution. Action runs simulate two levels of X2 targets in summer or fall for W, AN, and BN years. All IBMR runs in this table do not include any effect of X2/flow on food.

X2 Scenario Name (X2 targets for W, AN, and BN years)[1]	**Average population growth rate (lambda) (1995-2014)**		
	IBMR – No food, Smith method distribution	**IBMR – No food, TWG method distribution**	**LCME – No food, no distribution**
X2 summer low (59/66 km)	0.98	0.98	1.26
X2 summer high (80/84 km)	0.98	0.95	0.80
X2 fall low (68/72 km)	0.99	1.01	0.94[2]
X2 fall high (87/88 km)	0.99	0.98	

[1] 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.
[2]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.

Following TWG review of the two distribution models and these results, the TWG moved forward with the "TWG method" for modeling changes to distribution for the remaining sensitivity runs and the Round 1 evaluation of actions and portfolios.

3.2.2 X2 and food sensitivity analysis

The second set of model runs tested the sensitivity of Delta Smelt population growth to variations in fall and summer X2 in W, AN, and BN years, while exploring uncertainty around the potential effects of flow on food. Using the IBMR, we tested no food effect from changes to flow alongside predicted changes to food with a Salinity-food model (described in Section 2.3). We also explored the effects of uncertainty in the Salinity-food model through runs that used the median and lower and upper 95% credible intervals from the Salinity-food model. All IBMR model runs in this sensitivity analysis used the TWG method for Delta Smelt distribution.

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. 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 growth rates between low and high X2 in fall (range = 0.03 no food effect; 0.12 low food effect; 0.14 high food effect). Differences in the range of population growth rates between low and high X2 in summer were larger for both the IBMR (range = 0.03, 0.30, 0.32) and LCME (range = 0.46). Note that the LCME has direct relationships between X2/outflow and life-stage specific survival rates and does not include relationships between X2, food, and Delta Smelt distribution.

Table 7. Predicted Delta Smelt population growth rate (lambda) for X2/outflow actions and different effects of flow on food used with the IBMR. Results are also shown for the LCME, which included a direct effect of flow on summer survival but did not incorporate effects on food or Delta Smelt distribution. Action runs simulate two levels of X2 targets in summer or fall for W, AN, and BN years. All IBMR runs in this table included the TWG method for Delta Smelt distribution.

	Average population growth rate (lambda) (1995-2014)			
X2 Scenario Name (X2 targets for W, AN, and BN years)[1]	**IBMR - TWG distribution, No food effect**	**IBMR - TWG Distribution, Sal-food low 95% CI**	**IBMR - TWG distribution, Sal-food high 95% CI**	**LCME**
X2 summer low (59/66 km)	0.98	1.12	1.25	1.26
X2 summer high (80/84 km)	0.95	0.82	0.93	0.80
X2 fall low (68/72 km)	1.01	1.05	1.15	0.94[2]
X2 fall high (87/88 km)	0.98	0.93	1.01	

[1] 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.

[2] 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.

Following TWG review of the two distribution models and these results, the TWG moved forward with the "TWG method" for modeling changes to distribution and the median effect on food from the Salinity-food model for the remaining sensitivity runs and the Round 1 evaluation of actions and portfolios.

3.2.3 Summer and fall X2 sensitivity analysis

We conducted a final set of X2 sensitivity runs with the IBMR and LCME to test the sensitivity of Delta Smelt population growth to varying X2 locations in summer and fall in W and AN years. The IBMR modeling for this sensitivity analysis used the TWG method for modeling changes to Delta Smelt distribution and the median effect on food from the Salinity-food model.

Table 8 compares IBMR and LCME results for the summer and fall X2 sensitivity analysis. The range in population growth rates between low and high X2 in the summer was 0.23 and 0.29 for the IBMR and LCME, respectively. The difference in the range of population growth rates between low and high X2 in fall was 0.11 and 0 for the IBMR and LCME, respectively. Comparing IBMR results from Table 7 (where X2 management was simulated for W, AN, and BN years) and Table 8 (W and AN years), population growth increases when more years of X2 are low in summer and/or fall; population growth decreases when more years of X2 are high in summer and/or fall. More specifically, increases in population growth were predicted when X2 was set to ≤ 75 km in the summer or < 80 km in the fall in W and AN years; decreases in population growth were predicted when X2 was set to ≥ 75 km in summer and ≥ 80 km in the fall (Table 8). In the summer, these patterns were supported by both the IBMR (a mechanistic model with subregion dynamics) and the LCME (a statistical, regional model). In the fall, these patterns were supported by the IBMR. Again, the LCME only included an effect of X2 in the summer but not fall, following results from a previous version (LCMG: Polansky et al. 2021) that found evidence for a summer outflow – but not fall outflow – effect on survival. Note that population growth results are reported as averages across the 20-yr model period and thus annual changes in years with flow actions would be higher than the average across all years.

Table 8. Predicted Delta Smelt population growth rate (lambda) for X2/outflow sensitivity runs across the IBMR and LCME population models. Sensitivity runs simulate five levels of X2 locations in summer or fall for W and AN years. All IBMR runs in this table apply the median prediction for zooplankton from the Salinity-food model and the TWG method for Delta Smelt distribution.

X2 Scenario Name	Average population growth rate (lambda) (1995-2014)		
	Location targets in W and AN years (summer = July/Aug; fall = Sept/Oct)[1]	IBMR	LCME
X2 summer low	59 / 66	1.10	1.10
X2 summer, inc 1	65 / 71	1.06	1.04
X2 summer, inc 2	70 / 75	1.02	0.98
X2 summer, inc 3	75 / 80	0.96	0.90
X2 summer high	80 / 84	0.87	0.81
X2 fall low	68 / 72	1.05	0.94[2]
X2 fall, inc 1	74 / 76	1.02	
X2 fall, inc 2	80 / 80	0.96	
X2 fall, inc 3	83 / 84	0.94	
X2 fall high	87 / 88	0.94	

[1] X2 was set to month-specific locations 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 modeled locations. X2 was changed in 18 months per run (out of 240 months in the 20-yr model period).

[2] For the LCME, low evidence found with the LCMG (on which the LCME was based) between fall outflow and survival resulted in no change in population growth rate for any model run that varied fall X2 in the absence of other changes. The LCMG was fit to historical data, including X2 locations, between 1994-2015 (Polansky et al. 2021), which captures the same range of X2 locations above.

3.3 Tidal Wetland Restoration Sensitivity Analysis

If and to what degree tidal wetland restoration increases food for Delta Smelt is a complex question that requires consideration of theoretical and empirical evidence (see Bennett and Luoma 2023 and sources within). Theoretical modeling suggests tidal wetland restoration could increase primary productivity with subsequent increases to zooplankton densities (Cloern et al. 2021). Empirical evidence regarding the food benefits of tidal wetlands for Delta Smelt is mixed. Previous studies (Kimmerer et al. 2018; Yelton et al. 2022; Herbold et al. 2014) have found evidence of no meaningful export of zooplankton from restored tidal wetlands to the nearby channels where Delta Smelt occur. Conversely, there is evidence of greater Delta Smelt gut fullness in areas adjacent to large wetlands (Hammock et al. 2019) and predicted improvements in primary production (Cloern et al 2021). However, a TWG member suggested that this study was spatially confounded, and the metric of adjacency to wetlands was not separable from other well-known spatial differences in habitat quality between Suisun Bay and Marsh (which have relatively abundant wetlands but also other benefits to food concentration like the location of the estuarine turbidity maximum zone) and the Delta (with limited wetlands). For more discussion of the uncertainty of this action, see the Tidal Wetland Restoration Management Action Specification Sheet (Appendix 2), and the Tidal Wetland Restoration AM and research next steps sheet (Section 6.7).

The Round 1 evaluation included exploratory sensitivity runs for tidal wetland restoration, given that the action is currently being implemented and planned while the uncertainty of its potential effects is relatively high. We reached out to scientists engaged in food web monitoring of recently completed tidal wetland restoration projects to see if this data could be used, but the recommendation was that it was premature to use this data at this time (in 2022). As a result, the TWG defined two “bookends” for quantifying effects of tidal wetland restoration on Delta Smelt food (zooplankton) that relied on theoretical models and assumptions:

1. The **low bookend** was based on a coarse assumption that the food benefit would be at least proportional to new open water acres created through tidal wetland restoration. This simple method was used to represent the hypothesis that tidal wetland restoration has some positive increase to food density for Delta Smelt in proportion to its scale and location.
2. The **high bookend** was based on adapting and combining two theoretical modeling efforts that predicted (a) the change in phytoplankton from restored wetlands (SFEI-ASC 2020; Cloern et al. 2021) and (b) the change in zooplankton, given the change in phytoplankton (RMA 2021).

As part of the sensitivity analysis, we also tested an effect of tidal wetland restoration on temperature reduction. We assumed a temperature reduction in subregions with tidal wetland restoration of 0.5°C, which was informed through collaboration and a recent study by NASA JPL (Gustine et al. 2022). The study used remote-sensing data to estimate pre-post effects of restoration at Tule Red and Winter Island. Results showed that water temperatures in areas surrounding restored wetlands had mean temperatures that were between 0.25 and 0.57°C lower following restoration between June and Sept. These trends align with other studies that suggest tidal wetlands could decrease temperature (e.g., Enright et al. 2013). However, the results were not statistically significant – likely due to the low sample size of sites and years, which could be increased in the future. Therefore, we only included this temperature effect in this exploratory sensitivity analysis and not in any action or portfolio (combination of actions) evaluation.

Multiple variations of tidal wetland restoration were evaluated within a sensitivity analysis where the intensity (i.e., acreage restored) and magnitude of food effects varied across model runs. We defined **two intensity levels for tidal wetland restoration** using spatial information in the SFEI Landscape Scenario Planning Tool (https://www.sfei.org/projects/delta-landscapes-scenario-planning-tool).

1. The **lower intensity** level used EcoRestore project footprints and acres of expected restored tidal wetlands (~9,000 ac, additional to current wetlands);
2. The **higher intensity** level included those EcoRestore project footprints as well as areas in the intertidal zone that could potentially support tidal emergent wetlands across the Delta based on elevation and current land use (~30,000 ac, additional to current wetlands).

Five scenarios of tidal wetland restoration were modeled in the sensitivity analysis:

1. EcoRestore projects [8,902 ac of tidal wetlands additional to current]; low bookend effect for zooplankton
2. EcoRestore projects [8,902 ac of tidal wetlands additional to current]; high bookend effect for zooplankton
3. More than EcoRestore [29,348 ac of tidal wetlands additional to current]; low bookend effect for zooplankton
4. More than EcoRestore [29,348 ac of tidal wetlands additional to current]; high bookend effect for zooplankton
5. More than EcoRestore [29,348 ac of tidal wetlands additional to current]; high bookend effect for zooplankton + effect of local temperature reduction

Delta Smelt population growth predictions for the five scenarios are presented in Table 9.

Through meeting with the IEP Zooplankton Project Work Team in Oct 2023 after tidal wetland restoration actions and portfolios had been modeled, that team advised that the RMA (2021) study used for the high bookend likely overestimates effects on zooplankton. They further discussed that the true food effect of tidal wetland restoration could be between 0 (no effect), the "low bookend," or higher, but they did not define a "high bookend." Therefore, the low bookend food effect (implemented at varying spatial scales) was used as the "primary" model effect for the Round 1 evaluation and the high bookend model results are not included in this Report except for in this section.

We did not perform model runs with a food effect of "0" for this action since we can assume this would result in a 0% change to Delta Smelt population growth.

See the Tidal Wetland Restoration Management Action Specification Sheet (Appendix 2) for more details.

Table 9. Predicted Delta Smelt population growth across the 20-yr model timeframe for several versions of the tidal wetland restoration action that were tested in an exploratory sensitivity analysis with all 4 Delta Smelt population models.

		Population Growth Rate				% Change in Population Growth Rate from Baseline			
Run #	Scenario name	IBMR	LF	LCME	MDR	IBMR	LF	LCME	MDR
4.1	EcoRestore 9K ac; low bookend	1.04	0.98	1.00	1.24	5%	16%	5%	8%
4.2	EcoRestore 9K ac; high bookend	1.16		1.16	1.39	18%	-	22%	19%
4.3	More than EcoRestore 30K ac; low bookend	1.12	1.10	1.14	1.37	13%	30%	20%	17%
4.4	More than EcoRestore 30K ac; high bookend	1.33		1.70	2.04	35%	-	78%	62%
4.5	More than EcoRestore 30K ac; high bookend + temp	1.39	1.52			41%	79%	-	-

3.4 Action Uncertainty & Time to Implementation

The TWG characterized the uncertainty and time to implementation of management actions to improve interpretation of predicted outcomes, trade-offs, and next steps for management and science actions to contribute to Delta Smelt recovery. Note that three sources of uncertainty are already captured – at least to some extent – through the Delta Smelt population models:

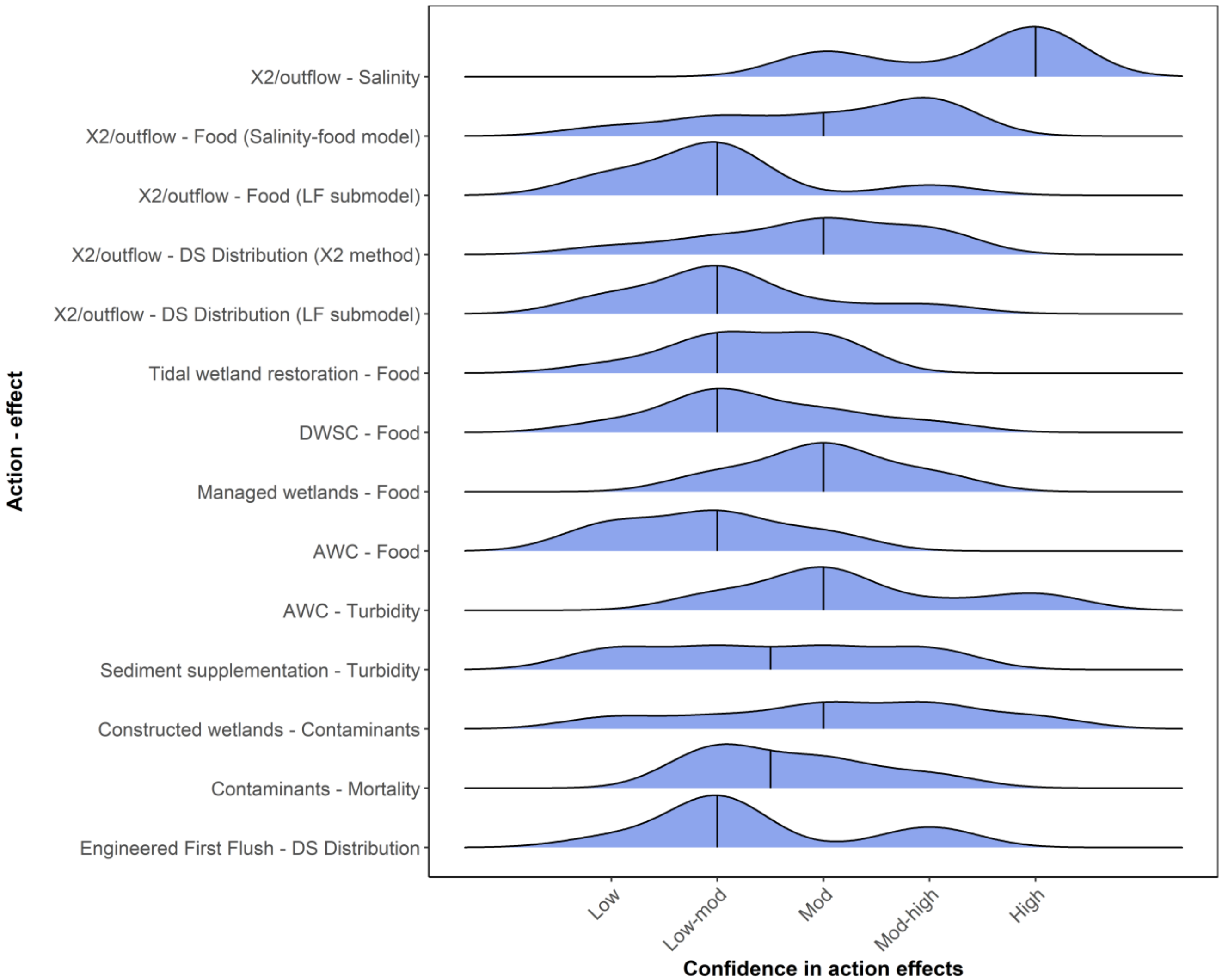
- **Structural (model) uncertainty** represents the uncertainty of relationships (e.g., between environmental factors and Delta Smelt demographic rates) across different, possible models of the underlying system. Many efforts use model selection to explore structural uncertainty. The Delta Smelt SDM process explored structural uncertainty by using 4 population models in parallel. The LCME, MDR, and LF population models also used model selection to identify the best-supported sets of covariates.
- **Parameter uncertainty** represents the uncertainty in estimation of the parameter of interest. This captures the potential error between the true parameter values (e.g., a mean survival rate) and the values estimated through experiments or statistical models using data. Some models (LCME and MDR) in the SDM process accounted for this uncertainty by using multiple (thousands) model iterations where each iteration samples a specific value from the distributions (often based around a mean and variance) of parameter estimates. This can potentially be reduced with more data/information.
- **Aleatory (stochastic, process) uncertainty** represents the inherent, random variability in the system. The SDM process accounted for this uncertainty using the IBMR, LCME, and MDR, which each simulated large (hundreds of thousands) random draws of time-specific demographic rates or outcomes. High process variation is characteristic of species, like the Delta Smelt, exhibiting an opportunistic life history strategy, and this uncertainty cannot be reduced with more data/information.

A fourth source of uncertainty, **action effect uncertainty,** represents the uncertainty in the estimation of an effect of an action on environmental or biological conditions (e.g., food, turbidity, Delta Smelt distribution) that are inputs to the Delta Smelt population models. It represents uncertainty in the extent to which the estimated effect quantified using available data or other methods/assumptions represents the true effect. Another key consideration, **time to implementation**, represents the ease of implementing an action and the expected time it would take to achieve full implementation, including research of technical aspects of the action and generation of expected benefits for Delta Smelt. A characterization of action effect uncertainty and time to implementation across all Round 1 management actions was done qualitatively and in a coarse manner through a survey of TWG members. Additional data, expertise and time would be needed for more precise characterization. Still, these coarse estimates allow for making initial, relative comparisons across all Round 1 management actions and portfolios. That being said, for some actions, we performed a quantitative analysis of action effect uncertainty through sensitivity testing of different effect assumptions. These sensitivity runs were described previously for X2 management and tidal wetlands restoration.

Below, we summarize TWG survey responses and takeaways for characterizing (1) the confidence/uncertainty of assumed/quantified proximate effects (e.g., on food, turbidity) of each management action and (2) the expected time to implementation of each management action. See Appendix 6 – Uncertainty & Time to Implementation Survey for more details of questions, scales used, and individual responses.

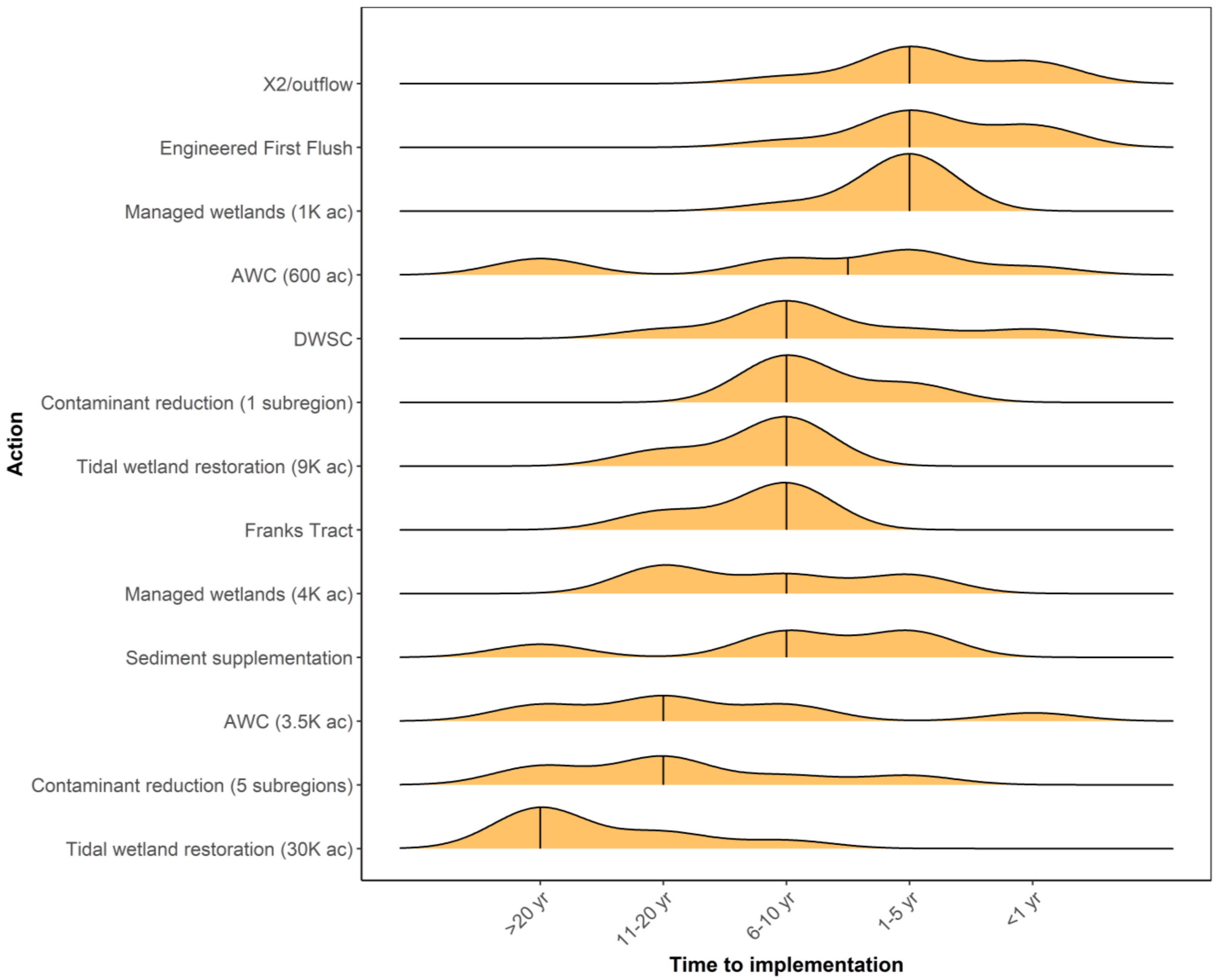
Confidence/uncertainty: Although TWG confidence was relatively high for one action effect (i.e., effects of outflow actions on salinity), there was low to moderate confidence in most action effects as quantified in the Round 1 evaluation (Figure 8). Low to moderate scores represented that “few data/studies exist” to “some data and coarse or theoretical modeling results are used to estimate action’s effects.” We discuss effect uncertainties further in Section 5 for interpreting predicted benefits and costs of management options and ways to reduce key uncertainties with AM and research next steps in Section 6.

Figure 8. Median (lines) and distribution of TWG members' scores (n=10) of confidence in quantified, proximate effects of management actions in Round 1 of the SDM process. TWG survey question: *"What is your level of confidence in the quantified proximate effect of Action [X] (e.g., on food, turbidity, salinity, flow) that are used as inputs to the Delta Smelt Population Models? Scale: Low, Low-Moderate, Moderate, Moderate-High, High, Unsure / Not enough information to answer."*



Time to implementation: TWG responses showed a range of expected time to implementation, which was defined in this process as the time to achieve full implementation and generation of benefits for Delta Smelt assuming no roadblocks to developing the action, such as time needed for permitting. (Figure 9).

Figure 9. Median (lines) and distribution of TWG members' scores (n=9) of time to implementation of new candidate management actions (i.e., those additional to current actions) in Round 1 of the SDM process. Actions are generally sorted from shortest time to implementation (top) to longest (bottom). TWG survey question: *"Assuming a decision is made to advance the action toward implementation in 2024, what's your best guess of how long it will take to achieve full implementation, including research of technical aspects of the action and generation of expected benefits for Delta Smelt? Assume that any necessary permitting issues for the action can be resolved. Response options: <1 year, 1-5 years, 6-10 years, 11-20 years, 20+ years, Unsure / Not enough information to answer."*



Given the spread of TWG survey responses, actions additional to current management were grouped into two broad categories of time to implementation based on the TWG average score: (1) actions that can be implemented and achieve benefits within ~5 years and (2) actions that may be implemented and achieve benefits in more than 5 years (Table 10). For example, within 5 years, it is possible to continue implementing or modify actions that are already underway, such as outflow/X2 management. Actions where agencies have some experience with implementation (e.g., managed wetlands for food, aquatic weed control) were also judged to be implementable at small scales in the near-term but would require longer for implementation at larger scales. Actions where agencies represented in the TWG in the Delta have no prior experience with implementation, such as sediment supplementation and physical point-source contaminants reduction, will require efforts longer than 5 years to research technical aspects, plan and implement the action, and generate benefits for Delta Smelt. These longer-term efforts would still require initiating research and planning processes soon. In other words, implementable and effective Delta Smelt management actions do not just 'appear', they need to be developed through persistent processes of inquiry and experimentation.

Adaptive Management and research next steps could be used to address implementation questions for actions of interest, and these are discussed further in Section 6.

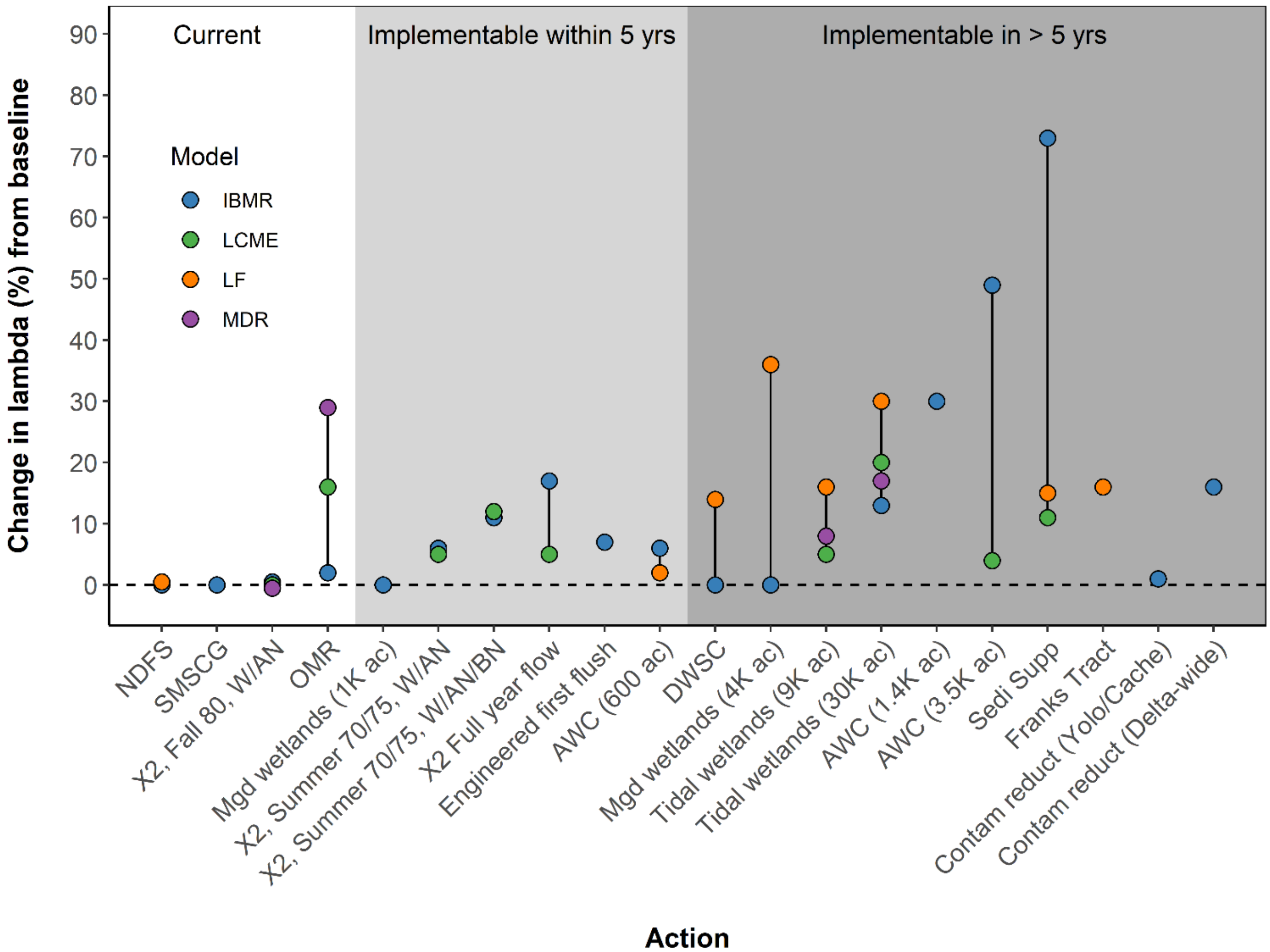
Table 10. Management actions evaluated in Round 1 categorized by approximate time to implementation. Actions were grouped to be implementable within vs. beyond 5 years based on TWG members' average scores (n=9) of the action's time to implementation.

Currently being implemented	Implementable within ~5 years	May be implementable in more than 5 years
• Fall X2/Outflow (X2 ≤ 80 km for Sept/Oct, W/AN years) • Suisun Marsh Salinity Control Gates (SMSCG) • North Delta Food Subsidies • Old & Middle River Management (2008/2009/ 2019 BiOps)	• Additional outflow actions (e.g., increased summer flow) • Engineered First Flush • Managed wetlands for food production (~1K ac) • Aquatic weed control (~600 ac)	• Tidal wetland restoration (9-30K ac) • Managed wetlands for food production (2-4K ac) • Sacramento Deep Water Ship Channel (DWSC) food transport and subsidies • Aquatic weed control (1.4-3.5K ac) • Sediment supplementation • Franks Tract restoration • Physical point-source contaminant reduction (1 or more locations)

3.5 Predicted Delta Smelt Population Outcomes for Individual Management Actions

This section reports on the predicted Delta Smelt population outcomes from modeling individual Round 1 management actions. Predicted population outcomes (reported as % change in population growth rate from baseline, historical conditions in the 20-yr model timeframe) across all management actions and models are shown in Figure 10. These results are also provided in tabular form alongside predicted outcomes for other objectives in Section 4.3.

Figure 10. Predicted percent change in Delta Smelt population growth from baseline for Round 1 management actions across four Delta Smelt population models. Not all actions were evaluated with all four models, given model limitations. Actions are ordered from left to right by expected time to implementation.



For many actions, models tended to agree in the predicted Delta Smelt population benefits. The largest ranges of results – representing model uncertainty – were seen for OMR management, small-scale food actions (e.g., managed wetlands), and turbidity actions of aquatic weed control and sediment supplementation:

- **OMR management:** The MDR and LCME were more sensitive to OMR flow changes, relative to other models, which led to greater increases in predicted Delta Smelt population growth from baseline conditions. Note that the LCME was specifically designed to investigate questions on entrainment mortality and Delta Smelt population effects. The MDR was not designed to investigate entrainment mortality; nevertheless, the high correlation between OMR and Delta Smelt survival was consistent with LCME. The IBMR was also not developed with a focus on modeling entrainment and the OMR flows to survival relationship. The IBMR entrainment model was missing the turbidity driver of entrainment probability, so the simple relationship modeled could overestimate the benefit of the OMR management action in some scenarios and underestimate the benefit in other scenarios.

- **Small-scale food actions:** For small-scale food actions such as managed wetlands, the LF model tended to be more sensitive to these changes in food and predicted higher population benefits, relative to the IBMR. This difference may be because the LF modeling included a Delta Smelt distribution submodel, where distribution in a subregion was influenced by food. Therefore, small-scale increases in food also increased the proportion of the population in those areas and subsequently increased population growth. The IBMR did not have a relationship between Delta Smelt distribution and food.

- **Turbidity actions:** For turbidity actions, the high uncertainty was mainly attributable to the high sensitivity of the IBMR to changes in turbidity. Unlike other models, the IBMR included multiple mechanistic effects of turbidity on Delta Smelt feeding and growth, which in turn influenced survival in all months. As a reminder, the IBMR is able to include all quantified effects from actions in all months during the 20-yr period, but the three other models restrict the number of covariates to varying degrees to avoid overfitting. Therefore, these statistical models could often not include all effects in all life stages of an action even if they were quantified in the Round 1 evaluation. This limitation could lead to the LCME, MDR, and LF potentially underpredicting benefits from actions. On the other hand, the IBMR may be overpredicting benefits as the mechanistic turbidity effects were based on laboratory studies. The TWG discussed that the 'true benefit' of turbidity actions is likely in between the benefit predicted by the statistical models and the IBMR.

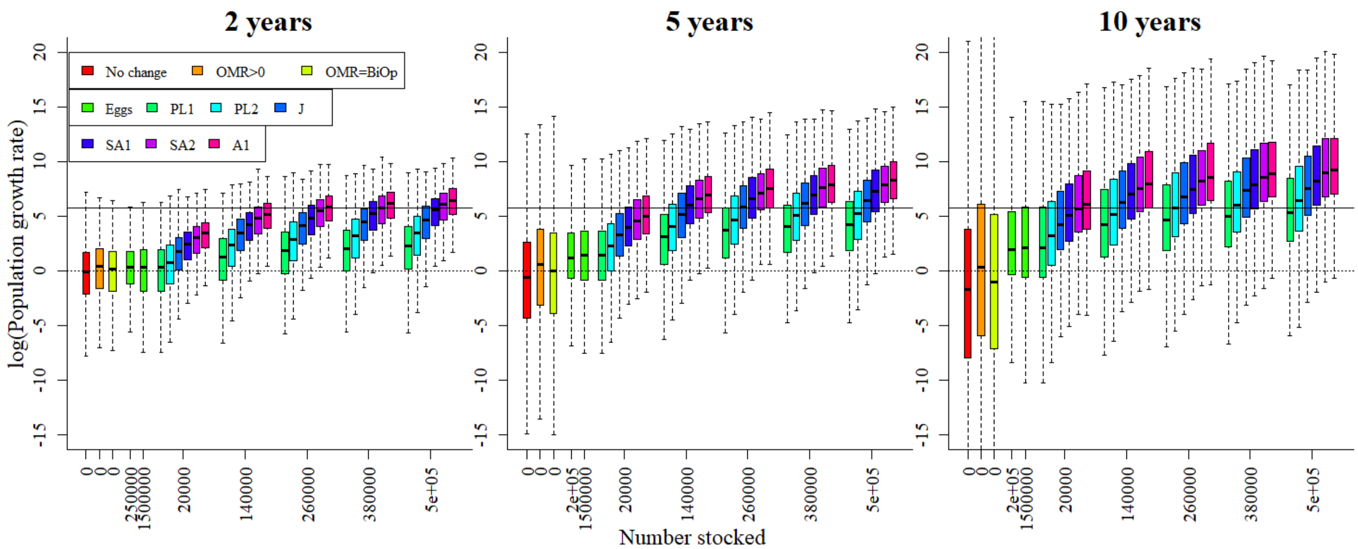
Management action results are discussed further in Sections 4.3 and 5 as part of the key takeaways from the Round 1 evaluation.

Supplementation

Although supplementation of hatchery-origin Delta Smelt was not incorporated further in the Round 1 evaluation of management portfolios (see next section), the results of the Smith (2021) analysis are briefly summarized here. Across scenarios, predicted population growth rate increased with the number of individuals released as well as the age of the life stage released (Figure 11). The highest population growth rates were predicted in scenarios that released larger numbers of sub-adults and adults, and these scenarios also had the highest likelihood of meeting the target abundance (solid reference line, Figure 11). The lowest population growth rates were predicted in scenarios that released eggs.

These results reflect the key assumption used in the modeling that survival and reproduction rates of hatchery-origin fish are equivalent to natural-origin fish following release, although the model assumed 25-75% of stocked fish die upon release. Research and monitoring of survival, reproduction, behavior, and genetic effects of hatchery-origin fish on the natural Delta Smelt population can accompany the continued use of supplementation to reduce these uncertainties and refine implementation methods.

Figure 11. Simulated population growth rates after 2, 5, and 10 years under several example management scenarios, including no change (baseline conditions between 1995-2014; red), entrainment management (orange and yellow), and supplementation (green to purple boxes) with the LCME. Solid horizontal reference lines indicate the growth rate required to reach the target abundance (set from EDSM 2017 estimate: 83,787 adult Delta Smelt), and dotted references lines indicate the point between positive and negative projected population growth. Adapted from Figure 3 in Smith 2021.



4 Multiple-objective Action & Portfolio Evaluation

The Round 1 evaluation focused on predicting effects for Delta Smelt (as described in Section 3), but the process was designed more broadly as a multiple-objective evaluation of management actions at the action-scale and portfolio-scale. In this section, we describe the multiple objectives and metrics used to quantify outcomes of management options in this process (Section 4.1). Next, we describe development of Round 1 portfolios (combinations of management actions) evaluated in the SDM process (Section 4.2). We then provide predicted outcomes across Delta Smelt and other objectives/metrics in "Consequence Tables" for Round 1 management actions (Section 4.3) and portfolios (Section 4.4). We also describe an additional sensitivity analysis of management portfolios that varied food, turbidity, and flow alongside other actions to better understand relationships between these drivers and Delta Smelt population outcomes (Section 4.5). Finally, we discuss key takeaways and limitations from the collective Round 1 evaluation of management actions and portfolios in Section 5.

4.1 Objectives and Performance Measures

The SDM process focused on several **objectives** – i.e., things that matter and need to be factored into strategic discussions on Delta Smelt management. For each objective, **Performance Measures** (PMs) were developed to evaluate the relative performance of management actions and portfolios. At the beginning of the SDM process, six objectives were identified as being relevant, but these were narrowed to four (Table 11) as the process proceeded given the number of candidate management actions and portfolios for Delta Smelt that CSAMP members wanted to evaluate and depth of Delta Smelt modeling desired. A Round 2 SDM evaluation may consider evaluating more objectives than included in Round 1 if capacity and expertise is available. We describe each of the Round 1 objectives and their corresponding PMs and methods first generally below, with PMs described more specifically in Table 12.

Table 11. Objectives for CSAMP Delta Smelt SDM process.

Process Initiation		Round 1 SDM Evaluation	
Objective	Preferred Direction of Change (all else equal)	Objective	Preferred Direction of Change (all else equal)
Delta Smelt population	↑	Delta Smelt population	↑
Salmon populations	↑	Salmon populations	↑
Water supply reliability	↑	Water resources	↓
Financial costs	↓	Financial costs	↓
Protection of other listed and native aquatic species (e.g., longfin smelt)	↑		
Water quality for in-Delta water supply	↑		

Objective 1: Delta Smelt

Sub-objective 1.1: Maximize Potential Delta Smelt Population Growth

This objective represents a core interest for this SDM process, driven by the CSAMP Management Goal for Delta Smelt. The main PM for this objective was the percent change in mean population growth from the model baseline, which is quantifiable by all four Delta Smelt population models. Any percent change greater than zero indicates benefits to the Delta Smelt population, relative to baseline conditions. Additional population outcomes were calculated for some, but not all four, models due to model differences.

There is uncertainty around predicted population outcomes that is partially captured within and across the multiple population models (i.e., model and parameter uncertainty, stochasticity – see Section 3.4). There is also uncertainty in the estimation of an effect of an action on environmental or biological conditions (e.g., food, turbidity, Delta Smelt distribution) that are inputs to the Delta Smelt population models. The TWG scored their level of confidence in the assumed/quantified proximate effects of each action used in Round 1. Average group scores for action effect uncertainty are reported in Consequence Tables.

Sub-objective 1.2: Minimize the time to implementation and benefits

The CSAMP Delta Smelt Management Goal contains a target of reversing Delta Smelt declines in the next 5-10 years. All else equal, management actions that require less time to implement and deliver benefits to Delta Smelt are preferred. Where actions that are currently being implemented require scaling up (e.g., tidal wetland restoration) or new actions would need to be implemented (e.g., contaminant reduction through constructed wetlands), there will likely be technical challenges that need to be overcome to implement the action. Moreover, for some actions, even once they are implemented, there will be a time lag for when benefits are actually felt by Delta Smelt. To capture these differences across the actions, the TWG scored the expected time for the action to be implemented and achieve benefits for Delta Smelt. Average group scores were used to report the number of actions in each portfolio that are (1) implementable within 5 years and (2) potentially implementable in more than 5 years.

Objective 2: Salmon effects

This objective represents an interest in maximizing co-benefits and minimizing risks for Central Valley salmonids from any management activities targeting Delta Smelt, all else being equal. Benefits and risks to salmon for each management action and portfolio were estimated in a qualitative manner by a group of 5 salmon experts. Only benefits and risks within the year that a management action was implemented were estimated. Carry-over effects to the next year (e.g., effects to coldwater pool storage) could not be factored in because water operations modeling was not available for this process. For more details on the methods and results for salmon effects, see Appendix 4.

Objective 3: Water Resources

This objective represents the interest in minimizing impacts to water supply and its reliability of delivery, all else being equal. Although water operations modeling was not available for the process, we calculated ballpark estimates of water volumes required for an action using relationships between Delta outflow and the X2 locations targeted in an action, while accounting for flow conditions in the previous month to capture the degree of change in flow required. Methods were based on equations in Monismith et al. (2002) and Denton (1993) linking steady-state to transient flows. Water balancing within or across years was not done, meaning a source for the additional outflow has not been identified. Methods were developed with Ching-Fu Chang and Deana Serrano (Contra Costa Water District) and Chandra Chilmakuri (State Water Contractors). As this is a coarse method for estimating water volumes, the estimates are suitable for comparative purposes only.

Objective 4: Capital and Operating Costs

This objective represents an interest in minimizing resource costs allocated toward Delta Smelt management, all else being equal. The total resource cost was calculated as the sum of capital, operating and water costs and reported as an annualized average cost over the 20-yr period. These are ballpark estimates for comparative purposes only and are provided to inform strategic level discussions, not implementing decisions. We expect that implementing organizations would do their own cost analysis. Ballpark capital and operating costs were estimated by people familiar with the implementation of the management actions – more details on these cost assumptions are in Appendix 2 – Management Action Specification Sheets. Ballpark water cost was calculated by monetizing the estimated water volumes (i.e., the first water resources PM) using a value of $815 per acre foot of water. This value of water was recommended by Bill Phillimore and discussed by the CSAMP Policy Group (Dec 2023 meeting; see Appendix 3).

Table 12. Performance Measures (PMs) for the CSAMP Delta Smelt SDM process.

Objective	Performance Measure	Description
Delta Smelt population	Population growth rate (lambda, λ)	Annual population growth rate (lambda) is summarized over the entire model period (20 years) by calculating the median annual growth across model simulations and then taking the geometric mean across the 20 annual medians. Separate estimates provided for three models.
	% change in population growth rate from baseline (baseline = observed conditions)	The % change is calculated as the mean population growth rate (over 20 years) for a given action or portfolio divided by the mean population growth rate (over 20 years) estimated for the baseline (no action) minus 1. Therefore, a % change greater than 0 indicates an increased population growth rate, relative to the baseline. Separate estimates provided for four models.
	% change in population growth rate from Reference Portfolio 1b[7]	Calculated for portfolios only. The % change is calculated as the mean population growth rate (over 20 years) for a given portfolio divided by the mean population growth rate (over 20 years) estimated for the Reference Portfolio (1b, current management approx.) minus 1. Therefore, a % change greater than 0 indicates a portfolio increased population growth rate, relative to the Reference Portfolio 1b. Separate estimates provided for three models.
	Dynamic Habitat Suitability Index (DHSI)	Calculated for portfolios only. An index (between 0 and 100%) showing the percentage of months (over the 20-yr model period) when all four dynamic habitat attributes (temperature, turbidity, salinity, and prey) are in "suitable" ranges (i.e., suitable conditions overlap), defined by existing studies and the TWG. The DHSI is calculated for each subregion but reported for the Yolo/Cache Slough subregion, the subregion with the maximum value in the Confluence and Lower Rivers, and the subregion with the maximum value in Suisun Marsh and Bay. See Appendix 5 for more details.
	Effect uncertainty	TWG members scored their level of confidence in the assumed/quantified proximate effects (e.g., on food, turbidity) of each management action using a constructed scale (1 [lowest confidence] to 5 [greatest confidence]). Represented as the group average and range of responses.
	Time to implementation	TWG members scored the time to implementation of each management action using a constructed scale (1 [potentially implementable in > 20 yrs] to 5 [implementable now or within 1 year]). Scores represent the ease of implementing an action and the expected time it would take to achieve full implementation, including research of technical aspects of the action and generation of expected benefits for Delta Smelt. Because TWG members did not feel confident about precisely scoring action time to implementation,

[7] Reference Portfolio 1b (Current management [approx.]) includes management actions targeted at Delta Smelt in the 2020 ROD/ITP that are currently being implemented – see Table 13 for full description.

Objective	Performance Measure	Description
		average group responses were used to categorize actions as (1) currently being implemented, (2) implementable within 5 years, and (3) potentially implementable in more than 5 years. See Section 3.4.
Salmon populations	Potential direct benefits	A group of 5 salmon experts scored the effects of individual actions using a constructed scale (-3 [greatest risks] to +3 [greatest benefits]) based on the expected magnitude of effects and spatial/temporal extent of the action.
	Potential direct risks	Individual action scores were combined within a portfolio and rescaled from 0 (no benefits) to +3 (greatest benefits). Scores for individual actions deemed by experts as having any potential direct risk were summed within a portfolio and rescaled from -3 (greatest risks) to 0 (no risks). Indirect risks (e.g., the effects of flow actions on flows later in the year or in the next year) were not evaluated in Round 1. See Appendix 4 for more details.
Water resources	Annual average net additional water (TAF/yr)	Average net additional water in thousand acre fee (TAF) per year (includes additional water needed and potential 'water savings'), summarized for water year types (W and AN, BN, and D and C) in the 20-yr model period. Operations modeling was not available for Round 1. The PM is calculated using a coarse hydrology analysis method based on equations in Monismith et al. (2002) and Denton (1993) linking steady-state to transient flows. Water balancing within or across years was not done, meaning a source for the additional outflow has not been identified. For example, potential water savings might not actualize because of other constraints in the system (e.g., flood control requirements). For actions, net additional water is calculated relative to historical, baseline conditions for the 1995-2014 model period. For portfolios, the above metric represents average net additional water relative to Portfolio 1b (approx. current management: X2 ≤ 80 km in Sept and Oct in W and AN years). All water resource values are provided for comparative purposes only. See Appendix 3 for more details.
Capital & operating costs	Ballpark cost estimate ($ Million / yr)	The total capital and operating cost was calculated and reported as an annualized average cost. To make resource costs comparable with the Delta Smelt population growth PM, resource costs were annualized through summing up the capital and operating costs during the 20-yr model period (1995-2014) and dividing by 20. A discount rate was not applied when annualizing resource costs. Ballpark capital and operating costs were estimated by people familiar with the implementation of the management actions – more details on these cost assumptions are in Appendix 2 (Manage Action Specification Sheets). The water cost was calculated by monetizing the estimated water volumes (PM: "Annual average net additional water") using a value of $815 per acre foot of water. This value of

Objective	Performance Measure	Description
		water was recommended by Bill Phillimore and accepted by the CSAMP Policy Group (Dec 2023 meeting). For portfolios, resource costs were calculated as costs above Reference Portfolio 1b and represented as a range of costs over the 20-yr modeling period ($ Million / yr). Other potential economic effects and resource benefits of these actions were outside the scope of the Round 1 evaluation and not factored into these estimates. All resource costs are provided for comparative purposes only.

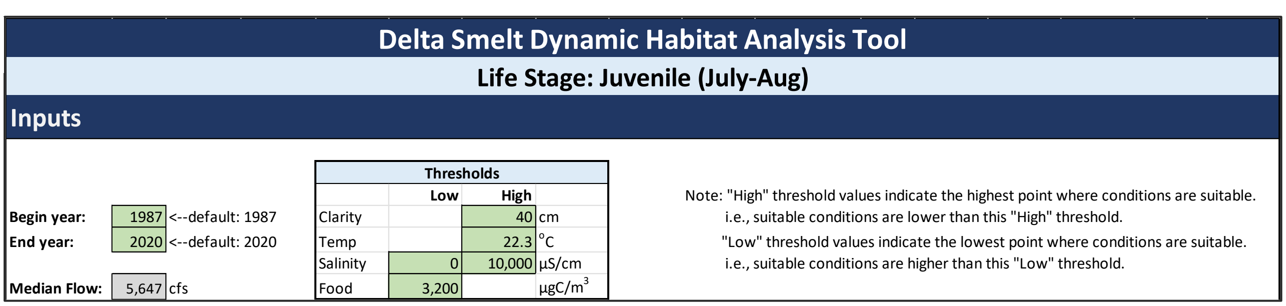
4.2 Management Portfolio Descriptions

In addition to evaluating management actions individually, Round 1 evaluated several management portfolios – combinations of management actions that represent distinct approaches to increasing the Delta Smelt population. The goal of evaluating portfolios in Round 1 was to learn and generate insights that can be used to further improve portfolios and to identify science actions that can inform future management decision making. The goal with Round 1 was not to design an 'optimal' or 'balanced' portfolio that is ready for implementation.

The TWG developed Round 1 portfolios through iterative steps. First, the TWG brainstormed opportunities for increasing dynamic habitat for Delta Smelt – which was defined as the overlap of suitable temperature, turbidity, salinity, and food conditions. This step used a Dynamic Habitat Tool (see Appendix 5 – Dynamic Habitat Tool for more details) to identify time periods and subregions where conditions were suitable/unsuitable for a given dynamic habitat attribute (e.g., turbidity). As part of this step, the TWG identified threshold values for separating suitable vs. unsuitable conditions, specific for each habitat attribute and time period/life stage, which were based on existing studies (see Appendix 5 and sources within). Figure 12 provides an example of how the Dynamic Habitat Tool summarized historical data to highlight certain subregions and habitat attributes that were less often suitable for Delta Smelt in different time periods (e.g., clarity/turbidity in the Yolo/Cache Slough Complex and Sacramento River; salinity in Suisun Marsh and Bay). This process yielded a list of general strategies for what habitat attributes could be improved with management (and when and where they needed improvements). Second, the TWG drafted candidate portfolios of management actions, built on insights from using the Dynamic Habitat Tool and existing evidence and ecological theory of population bottlenecks. The TWG reviewed and discussed candidate portfolios and specified a final set for evaluation.

Figure 12. Screenshot of the Delta Smelt Dynamic Habitat tool. (A) Users can adjust values in green cells for the year range for summarizing habitat conditions and threshold values for each dynamic habitat attribute. (B) Results are displayed in tables showing the proportion of sampled days across years when habitat attributes were suitable for higher flow (left) and lower flow (right) years. This example is for the July-Aug period.

(A)



(B) **Results**

HIGHER FLOW - JULY & AUGUST					
Subregion	Clarity OK	Temp OK	Salinity OK	Prey OK	Smelt Distr. (1995-2014)
Yolo/Cache	25%	37%	100%	100%	8.2%
Upper Sacramento	4%	85%	100%	73%	0.1%
East Delta	1%	58%	100%	46%	0.1%
South Delta	32%	26%	100%	100%	0.1%
Lower Sacramento	31%	68%	100%	86%	7.8%
Lower San Joaquin	2%	47%	100%	99%	2.0%
Confluence	39%	72%	99%	93%	11.3%
Suisun Marsh	88%	66%	89%	90%	2.9%
NE Suisun	76%	89%	79%	61%	12.2%
SE Suisun	51%	84%	93%	77%	14.4%
NW Suisun	86%	90%	38%	80%	37.6%
SW Suisun	64%	95%	27%	64%	3.3%

Table: Clarity, temp, salinity and prey columns show the percentage of sampled days across Jul-Aug periods that each of the four attributes were "more suitable". The last column shows proportion of delta smelt observations. All results by subregion in HIGHER FLOW Jul-Aug periods.

LOWER FLOW - JULY & AUGUST					
Subregion	Clarity OK	Temp OK	Salinity OK	Prey OK	Smelt Distr. (1995-2014)
Yolo/Cache	24%	26%	100%	100%	18.4%
Upper Sacramento	9%	66%	100%	73%	0.1%
East Delta	1%	29%	100%	55%	0.2%
South Delta	42%	7%	100%	100%	0.2%
Lower Sacramento	51%	81%	99%	87%	38.2%
Lower San Joaquin	7%	51%	100%	100%	7.2%
Confluence	46%	86%	99%	82%	11.6%
Suisun Marsh	67%	75%	33%	70%	1.1%
NE Suisun	70%	94%	17%	57%	9.1%
SE Suisun	40%	94%	41%	63%	10.3%
NW Suisun	72%	98%	2%	85%	3.4%
SW Suisun	56%	99%	2%	65%	0.1%

Table: Clarity, temp, salinity and prey columns show the percentage of sampled days across Jul-Aug periods that each of the four attributes were "more suitable". The last column shows proportion of delta smelt observations. All results by subregion in LOWER FLOW Jul-Aug periods.

Eight Round 1 portfolios tested distinct, hypothesis-based approaches for advancing Delta Smelt recovery. Portfolios used different combinations of flow and/or non-flow actions, where "flow action" is defined as an action requiring additional water to the current management. Each portfolio is specified with details concerning the time (month), place (Delta subregion; see Figure 3), and intensity of management actions for Delta Smelt, as well as assumptions around the continuation or adjustment of existing management actions. Portfolios focused on different time periods related to when management actions could be implemented and produce benefits for Delta Smelt:

- **Group 1 Reference/current**: A reference portfolio including the management actions related to Delta Smelt in the 2020 Record of Decision (ROD)/Biological Opinion (BiOp) and Incidental Take Permit (ITP).
- **Group 2 "Immediate/near-term":** Portfolios with near-term actions that can be implemented within the next ~5 years.
- **Group 3 "Near and long-term":** Portfolios with near-term and one or more long-term actions that cannot be implemented within the next 5 or fewer years, acknowledging that some planning, resourcing, research, implementation, etc. would likely begin sooner.

Note that portfolios in Groups 2 and 3 generally reflect more "near-term" vs. "long-term" strategies, but portfolios in these groups may have a combination of actions expected to be implementable within and beyond 5 years. The number of actions in each time to implementation category per portfolio is included when presenting results across multiple objectives (Section 4.4).

The final management portfolios evaluated in Round 1 are described in detail in Table 13. A quick reference table to compare the management actions and their scales included in each portfolio is also provided in Table 14.

Table 13. Summary of management portfolios developed by the Technical Working Group for Round 1 of the CSAMP Delta Smelt Round 1 evaluation.

Short ID & name	Category	Description	Actions & effects included
1b: Current management (approximation)	Current (reference);	Includes actions/regulations targeted at Delta Smelt that are currently being implemented under the State's Incidental Take Permit (ITP) and the 2020 federal ROD and BiOp for the long-term operation of the Projects (see specific actions in right-hand column). **All subsequent portfolios are additive to this reference portfolio unless otherwise specified.**	• Fall X2 ≤ 80 km in W and AN years • OMR management • Suisun Marsh Salinity Control Gates (SMSCG) • North Delta Food Subsidies (NDFS) **Effects:** Flow, salinity, food, OMR flows, Delta Smelt distribution

2a: Full-year flows	Near-term; flow actions	Deploys flow actions, which could be implemented immediately (i.e., beginning in 2022/23), across a year that reactively mitigate poor conditions to create full good years for Delta Smelt (i.e., target the predicted bottleneck for each life stage in each year). Two versions of the portfolio tested different annual water budgets: (1) No annual water budget (flows necessary to meet minimum thresholds year-round); (2) Annual water budget of 700 TAF.	• Actions from Portfolio 1b
			• Engineered First Flush
			• Additional spring/summer/fall outflow when minimum flow thresholds are triggered:
			  ○ Mar-May: < 25,000 cfs (X2 ≤ 66 km) in W or AN yrs; < 11,700 cfs (X2 ≤ 74 km) in BN, D, and C yrs
			  ○ June: < 12,400 cfs (X2 ≤ 73 km) in W yrs; < 11,400 cfs (X2 ≤ 74 km) in AN or BN yrs
			  ○ July-Aug: < 7,500 cfs (X2 ≤ 78 km) in W, AN, or BN yrs
			  ○ Sept-Oct: "Current management" of X2 ≤ 80 km in W/AN yrs
			Effects (additive to 1b): Flow, salinity, food, Delta Smelt distribution

2b: Cache Slough	Near-term; non-flow actions	Deploys actions in the short-term to create year-round refuges in Cache Slough – especially in the Deep Water Ship Channel (DWSC), where significant numbers of Delta Smelt adults and larvae have been found in more recent years. The DWSC is hydrodynamically isolated, relative to other areas, which may increase success of mgmt (e.g., invasive predators and SAV removal).	• Actions from Portfolio 1b • Sacramento Deep Water Ship Channel (DWSC) Food Transport & Production • Aquatic weed control (AWC) + sediment agitation (Yolo/Cache Slough) **Effects (additive to 1b):** Food, turbidity

Short ID & name	Category	Description	Actions & effects included
2c: Cache Slough & Suisun Marsh	Near-term; non-flow actions	Builds on Portfolio 2b: includes all the same actions as in Portfolio 2b plus short-term actions in Suisun Marsh. These two areas are hypothesized to have the best conditions for growth and survival of Delta Smelt and should be maintained and enhanced to reduce extinction risk.	• Actions from Portfolio 1b • Sacramento Deep Water Ship Channel (DWSC) Food Transport & Production • Aquatic weed control (AWC) + sediment agitation (Yolo/Cache Slough) • Managed wetlands in Suisun Marsh / Roaring River Distribution System (2,000 ac) **Effects (additive to 1b):** Food, turbidity
3a: Self-sustaining/ permanent mgmt	Long-term; non-flow actions	Deploys actions aimed to benefit all life stages that could be implemented in the long-term and are more self-sustaining or permanent in nature and thus require less oversight and continual intervention.	• Actions from Portfolio 1b • Tidal wetland restoration (~9,000 ac) • Franks Tract restoration • Physical point source contaminant restoration (12 subregions) **Effects (additive to 1b):** Food, turbidity, Delta Smelt distribution, natural mortality

3c: Summer flow & tidal wetlands	Near-term; flow + non-flow actions	Building on important factors identified in recent work using the Life Cycle Model (Polansky et al. 2020, Smith et al. 2021), focuses on actions to promote good conditions for spawning and larval survival, with additional flow actions during summer and fall. Hypothesizes that mgmt resources allocated to spawning/larvae stages may produce largest population benefits.	• Actions from Portfolio 1b (with variations in fall X2 as noted below)
			• Tidal wetland restoration (~9,000 ac)
			• X2/outflow management (4 variants):
			  ○ **3c1:** Lower summer X2 (65 km in July, 70 km in Aug), historical fall X2
			  ○ **3c2:** Lower summer X2 (65 km in July, 70 km in Aug), current fall X2 (80 km in Sept/Oct)
			  ○ **3c3:** Low summer X2 (70 km in July, 75 km in Aug), historical fall X2
			  ○ **3c4:** Low summer X2 (70 km in July, 75 km in Aug), current fall X2 (80 km in Sept/Oct)
			Effects (additive to 1b): Flow, salinity, food, Delta Smelt distribution

Short ID & name	Category	Description	Actions & effects included
3d: Focus on food	Near and Long-term; non-flow actions	Building on recent research using a limiting factor analysis (Hamilton & Murphy 2018, 2021, 2022), this portfolio focuses on food actions to address hypothesized limiting factors to the Delta Smelt population.	• Actions from Portfolio 1b • Tidal wetland restoration (~30,000 ac) • Sacramento Deep Water Ship Channel (DWSC) Food Transport & Production • Managed wetlands in Suisun Marsh / Roaring River Distribution System (4,000 ac) • Aquatic weed control (AWC) (5 subregions) • Physical point source contaminant restoration (12 subregions) **Effects (additive to 1b):** Food, turbidity, natural mortality
3e: Habitat connectivity	Near and Long-term; non-flow actions	Specifies restoration and other non-flow actions to improve and connect habitat in the Confluence and Lower Rivers, between areas that currently have relatively good habitat (Suisun Marsh and DWSC).	• Actions from Portfolio 1b • Tidal wetland restoration (~2,000 ac) • Franks Tract restoration • Aquatic weed control (AWC) (3 subregions) • Sediment supplementation • Physical point source contaminant restoration (8 subregions) **Effects (additive to 1b):** Food, turbidity, Delta Smelt distribution, natural mortality

Table 14. Summary of management actions included in 8 portfolios modeled in the Round 1 evaluation. Actions in grey are the same as actions included in the Reference Portfolio (1b, current management approx.). Actions in blue were adjusted or additional to the Reference Portfolio. Different scales or timings are noted for some actions that differed across portfolios.

	Portfolios							
Action name	1b Current mgmt (approx.)	2a Full-year flows	2b Cache Slough	2c Cache Slough & Suisun Marsh	3c Summer flow & tidal wetlands[1]	3a Self-sustaining/ permanent mgmt	3d Focus on food	3e Habitat connectivity
NDFS	✓	✓	✓	✓	✓	✓	✓	✓
DWSC Food			✓	✓			✓	
Managed wetlands				✓ 2K ac			✓ 4K ac	
Tidal wetlands					✓ 9K ac	✓ 9K ac	✓ 30K ac	✓ 2K ac
SMSCG	✓	✓	✓	✓	✓	✓	✓	✓
X2/outflow	Fall (W,AN)	All seasons / yrs	Fall (W,AN)	Fall (W,AN)	Sum-Fall (W,AN)	Fall (W,AN)	Fall (W,AN)	Fall (W,AN)
Sediment supp								✓
Aquatic Weed Control			✓ 1 sub-region	✓ 1 sub-region			✓ 5 sub-regions	✓ 3 sub-regions
Franks Tract						✓		✓
OMR mgmt	✓	✓	✓	✓	✓	✓	✓	✓
Engineered First Flush		✓						
Contaminant reduction						✓ 12 sub-regions	✓ 12 sub-regions	✓ 8 sub-regions

[1] Portfolio 3c included multiple versions/model runs that varied X2 targets in summer and fall. Specific X2 targets are given when presenting and discussing results in subsequent sections of the report.

4.3 Multiple-objective Consequences: Management Actions

This section reports on the results from the multiple-objective evaluation of individual Round 1 management actions – evaluated individually – through a Consequence Table (Table 15). Actions are ordered in the table according to three groups of expected time to implementation:

- Current management actions related to Delta Smelt in the 2020 Record of Decision (ROD)/Biological Opinion (BiOp) and Incidental Take Permit (ITP);
- Candidate actions beyond current management that can be implemented within the next 5 years; and,
- Candidate actions that may be implementable in more than 5 years.

This categorization for management actions is based on the professional judgment of the TWG concerning expected time to implement actions (see Section 3.4). A description of the performance measures in the Consequence Table is provided in Section 4.1, Table 12. The management action effect assumptions used in the Delta Smelt modeling are summarized in Section 3.1, Table 2.

Summary of Consequence Table findings by objective:

- **Delta Smelt:** Predicted Delta Smelt population benefits (% change from baseline) over the 20-yr model period ranged from 0% (many small-scale actions, such as NDFS and managed wetlands for food production) to 73% (sediment supplementation), depending on the model used. Small-scale food actions that were predicted to have a 0% population growth benefit when modeled individually with the IBMR contributed to positive population growth when modeled with other actions in a portfolio (see next section). As expected, population benefits increased as the scale of an action increased (e.g., 9K vs. 30K ac of tidal wetland restoration), likely because the assumed effects of an action (e.g., increasing food) benefitted a larger portion of the Delta Smelt population. Population benefits from outflow/X2 actions varied by the seasonal timing and water year types those actions would be implemented, with the highest benefits predicted for the summer outflow/X2 action in W/AN/BN years and the full-year flow action that deployed water in all water year types. For many actions, models tended to agree in the predicted Delta Smelt population benefits. The largest ranges of results – representing model uncertainty – were seen for OMR management, small-scale food actions (e.g., managed wetlands), and turbidity actions of aquatic weed control and sediment supplementation. This was due to different model structures and sensitivities; for example, the IBMR was more sensitive to changes in turbidity relative to other models and subsequently predicted higher population benefits for turbidity actions. Delta Smelt outcomes are further discussed in Takeaways #2 and #3.

- **Effects uncertainty:** Average TWG confidence in most actions' effects, as quantified in this process, was between 2 to 3 (out of 5), representing that "few data/studies exist" to "some data and coarse or theoretical modeling results are used to estimate action's effects." The effects of OMR, as well as the effect of outflow/X2 management on salinity (not shown in table), received higher confidence scores. Because most actions had similar scores for effects uncertainties, the degree of uncertainty was not related to predicted population benefits.

- **Salmon:** Most actions had neutral effects or potential benefits to salmon, based on expert judgement. Actions with co-benefits to salmon and Delta Smelt included full-year flows, large-scale food actions (e.g., tidal wetland restoration and managed wetlands), and contaminant reduction. Two actions were identified as having potential risks to salmon. (1) There are potential risks to adult fall-run Chinook from SMSCG if operations allow for adults to enter but not be able to exit, potentially affecting survival and migration timing. This could be mitigated with re-engineering gates. (2) There are potential risks to juvenile Chinook from AWC, as there is some evidence that higher turbidity can decrease foraging rates, and juveniles can use submerged aquatic vegetation to avoid predation. There is also the potential for direct mortality from mechanical (or chemical) removal. Effects to salmon of flow actions reflect potential direct, within-year benefits/risks of changing flow in a given season. Experts did not consider carry-over effects of flow actions, and modeling how operations would achieve flow actions is needed to better estimate effects to salmon.

- **Water resources:** Estimates of additional water resources used coarse methods in this process and are only suitable for relative, comparative purposes. Outflow/X2 actions were estimated to require an average of 157–319 TAF per year across the 20-yr model period; however, additional water needed to meet management targets varied considerably from year to year based on historical conditions (0–1,079 TAF/yr: see Appendix 3). Years with larger estimates of additional water occurred when the action's X2 target was much lower than the historical X2 location. The summer outflow/X2 action in W/AN/BN years required the highest estimated additional water, relative to other actions (including summer outflow/X2 action in W/AN years), driven by higher amounts of water required in BN years to meet the X2 targets when historical X2 locations were much higher. The full-year flow action that strategically deployed flows between Jan-Oct in all water year types was predicted to require more additional water than the summer action in W/AN years but not as much water as the summer action in W/AN/BN years.

- **Capital & operating costs:** Costs of actions ranged from \$1 to \$10s of millions/yr over the 20-yr model period. Costs increased as the scale of an action increased. Highest costs were estimated for large-scale tidal wetland restoration, Franks Tract restoration, and large-scale contaminant reduction.

See Section 5 – Key Takeaways & Discussion – Action & Portfolio Evaluation for more discussion of results.

Table 15. Consequence Table of predicted outcomes for individual management actions and objectives/performance measures in the CSAMP Delta Smelt Round 1 evaluation. Actions are grouped by expected time to implementation. Green cells indicate performance measures where higher values (darker shades) are preferred. Orange cells indicate metrics where lower values (lighter shades) are preferred. Grey cells indicate water/cost metrics that are components of aggregated totals in the top water/cost row. Management action names are shaded by their primary effect: blue = flow and food, green = food, orange = turbidity, and purple = other/entrainment.

	Management Actions[1]																			
	Current management				Can implement in < 5 yrs[2]						May be able to implement in > 5 yrs[2]									
	North Delta Food Subsidies[3]	Fall X2/Outflow (X2 ≤ 80 for Sept/Oct)[4]	Suisun Marsh Salinity Control Gates (SMSCG)[4]	Old & Middle River Management (2008/2009/2019 BiOps)	Managed Wetlands Food Production[3]	Summer Outflow (X2 ≤ 70/75 for July/Aug)[4]		Full-year Flow[4]	Engin-eered First Flush	Aquatic weed control	Tidal Wetland Restoration in North Delta Arc		Managed Wetlands Food Production[3]	DWSC Food[3]	Franks Tract Restora-tion	Aquatic weed control		Sediment supple-mentation	Contaminant reduction	
Objective & Performance Measure		W/AN			1K ac in SM	W/AN	W/AN/BN	W/AN/BN/D/C		600 ac in CS	9K ac	30K ac	4K ac			1.4K ac	3.5K ac		Yolo / CS	Delta-wide
Delta Smelt Population																				
Delta Smelt Population Growth[5] (average lambda 1995-2014)																				
IBMR	0.98	0.98	0.98	1.00	0.98	1.04	1.09	1.15	1.05	1.04	1.04	1.12	0.98	0.98	1.14	1.28	1.47	1.70	1.00	1.14
LCME	-	0.94	-	1.09	-	0.99	1.05	0.99	-	-	1.00	1.14	-	-	-	-	1.00	1.01	-	-
LF	0.87	-	-	-	-	-	-	-	-	0.87	0.98	1.10	1.15	0.97	0.98	-	-	1.00	-	-
Delta Smelt Population Growth[5] (% change from 1995-2014 baseline)																				
IBMR	0%	0%	0%	2%	0%	6%	11%	17%	7%	6%	5%	13%	0%	0%	16%	30%	49%	73%	1%	16%
LCME[6]	-	0%	-	16%	-	5%	12%	5%	-	-	5%	20%	-	-	-	-	4%	11%	-	-
MDR[6]	-	0%	-	29%	-	-	-	-	-	-	8%	17%	-	-	-	-	-	-	-	-
LF	0%	-	-	-	-	-	-	-	-	2%	16%	30%	36%	14%	16%	-	-	15%	-	-
Uncertainty[7] (TWG group scores)																				
Confidence in action effect assumptions: TWG avg score (scale: 1 [low] to 5 [high] confidence)	Food: 3.0	IBMR salinity-zoop model: 3.0; LF flow-zoop model: 2.0	IBMR salinity-zoop model: 3.1; LF flow-zoop model: 2.3	OMR flows: 4.4	Food: 3.0	IBMR salinity-zoop model: 3.0; LF flow-zoop model: 2.0			IBMR distrib: 2.4	Turbidity: 3.3	Food: 2.3	Food: 2.3	Food: 3.0	Food: 2.4	Food: 2.3	Turbidity: 3.3		Turbidity: 2.5	Contaminants: 3.1	
Salmon effects[8] (expert group scores)																				
Potential benefits: Salmon expert avg score (scale: 0 to 3)	0	Not assessed	0	Not assessed	2	0	0	3	2	0	2	2	2	2	1	0	0	1	2	2
Potential risks: Salmon expert min score (scale: -3 to 0)	0	Not assessed	-1	Not assessed	0	0	0	0	0	-1	0	0	0	0	0	-1	-1	0	0	0
Water / Resource Costs[9] (ballpark estimates for comparative purposes only)																				
Water[10] (TAF/yr) — All yrs	Financial and water costs were only evaluated for actions additional to current management, per agreement by the SDM Policy Group Steering Committee.				-	157	319	248	23	-	-	-	-	-	-	-	-	-	-	-
Water[10] (TAF/yr) — W / AN					-	350	350	361	-	-	-	-	-	-	-	-	-	-	-	-
Water[10] (TAF/yr) — BN					-	-	810	300	38	-	-	-	-	-	-	-	-	-	-	-
Water[10] (TAF/yr) — D / C					-	-	-	72	43	-	-	-	-	-	-	-	-	-	-	-
Costs ($ million / yr) — Total[11]					$1	$128	$260	$192	$18	$2	$22	$63	$2	$1	$29	$5	$13	$5	$7	$84
Costs ($ million / yr) — Water[12]					-	$128	$260	$192	$18	-	-	-	-	-	-	-	-	-	-	-
Costs ($ million / yr) — Capital & operating[13]					$1	-	-	-	-	$2	$22	$63	$2	$1	$29	$5	$13	$5	$7	$84

[1] The management action effect assumptions used in the Delta Smelt modeling are summarized in Table 2.
[2] Actions are grouped by relative time to implementation. Time to implementation is defined in this process as how long it will take to achieve full implementation, including research of technical aspects of the action and generation of expected benefits for Delta Smelt, while not considering time needed for permitting. Time to implementation was scored by TWG members, and average scores were used to group actions in implementation categories.
[3] Small-scale actions that are predicted to have a 0% population growth when modeled individually with the IBMR contribute to positive population growth when modeled with other actions in a portfolio (see Sections 4.4 and 5).
[4] There were 9 W/AN years, 4 BN years, and 7 D/C years in the 20-yr model period. Fall X2 action: X2 was set to 80 km in Sept/Oct in W and AN water year types when historical X2 locations were > 80 km (this occurred in 10 months out of the 18 applicable months across the 20-yr model period). Summer X2 action: X2 was set to targets in July/Aug only for months when historical X2 locations were > 70/75, respectively. This occurred in 12 of the 18 applicable months for the W/AN action and 20 of the 26 months for the W/AN/BN action (across the 20-yr model period). For the Full-year Flow action, X2 was set to month-specific targets in 30 months across the 20-yr model period.
[5] Delta Smelt population metrics were calculated in two ways: (1) annual predicted population growth rate (lambda) from the action, and (2) the percent change in annual population growth from the portfolio relative to baseline, historical conditions between 1995-2014, where values > 0% indicate increased population growth relative to baseline. Metrics were averaged over the 20-yr period.
[6] The LCME and MDR models used different versions (with different sets of covariates) to evaluate different actions, which leads to variation in % change from baseline. These models often could only include effects of an action for a portion of months even if it was specified to have year-round effects.
[7] Effect uncertainty was scored by TWG members to indicate their level of confidence in the assumed/quantified proximate effects (e.g., on food, turbidity) of each management action using a constructed scale (1 [lowest confidence] to 5 [greatest confidence]). Reported as the average TWG score.
[8] Salmon effects of actions (sometimes at different scales) were scored by subject matter experts from -3 (greatest risks) to +3 (greatest benefits). Individual action scores were summed within a portfolio and rescaled from 0 (no benefits) to +3 (greatest benefits). Scores for individual actions deemed by experts as having any potential direct risk were summed within a portfolio and rescaled from -3 (greatest risks) to 0 (no risks). Potential benefits are reported as average scores; potential risks are reported as minimum scores to represent any degree of risk to salmonids expressed by experts. Salmon experts noted potential negative risks to juvenile Chinook from AWC, as there is some evidence that higher turbidity can decrease foraging rates, and juveniles can use submerged aquatic vegetation to avoid predation. There is also the potential for direct mortality from mechanical (or chemical) removal. Effects to salmon of flow actions reflect potential direct, within-year benefits/risks of changing flow in a given season. Experts did not consider carry-over effects of flow actions, and modeling how operations would achieve flow actions is needed to better estimate effects to salmon.
[9] All water and resource costs: Water resources and capital and operating costs of actions were calculated relative to baseline, historical conditions. Ballpark values were estimated through coarse methods and meant for comparative purposes only.
[10] Additional water (relative to outflow under baseline, historical conditions between 1995-2014) is averaged across all 20 years and is presented for comparative purposes only. The source of water needed to implement flow actions was not identified in Round 1. The water resource volume represents the estimated net volume of water necessary to move X2 from its historical monthly position to a target condition, based on equations in Monismith et al. (2002) and Denton (1993).
[11] Total cost was calculated as the sum of monetized water and capital & operating costs, annualized over the 20-yr period without a discount rate.
[12] Monetization of water used $815 per acre foot of water, annualized over the 20-yr period, as discussed and agreed to by the CSAMP Policy Group Steering Committee. See Appendix 3 – Water Resources Methods – Monetized water cost.
[13] Includes ballpark estimates of capital & operating costs, annualized without a discount rate, for comparative purposes only.

4.4 Multiple-objective Consequences: Management Portfolios

This section reports on the results from the multiple-objective evaluation of Round 1 management portfolios (combinations of actions) through a Consequence Table (Table 16).

A description of the performance measures in the Consequence Table is provided in Section 4.1, Table 12. Portfolio descriptions are provided in Section 4.2.

Summary of Consequence Table findings by objective:

- **Delta Smelt:** Predicted Delta Smelt population benefits (% change from baseline) over the 20-yr model period ranged from 1% (1b – Current management [approximation]) to 126% (3e – Habitat connectivity), depending on the model used. Within each model's results, portfolios tended to rank the same: generally, the lowest population benefits were predicted for Portfolio 1b – Current management (approximation), and the highest benefits were predicted for Portfolio 3d – Focus on food and 3e – Habitat connectivity. Portfolios with the highest predicted population benefits (e.g., 3a, 3d, and 3e) included actions with assumed effects on multiple factors (i.e., food, turbidity, contaminants) at large scales. The largest ranges of results across models were seen for Portfolios 1b, 3a, 3d, and 3e. Reasons for this include that the LCME and MDR were more sensitive to OMR, resulting in higher predictions under Portfolio 1b than other models; the IBMR was more sensitive to turbidity, resulting in higher predictions to portfolios that included turbidity actions (3d and 3e: see Section 3.5). Note that the LCME and MDR used different model versions to simulate different portfolios, which accounts for some variation in population predictions. These models also could not include all effects in all time periods, unlike the IBMR. For example, the IBMR captured the increase in survival from contaminant reduction actions in Portfolios 3a, 3d, and 3e; effects from contaminant actions were not included in the LCME and MDR, which would have likely increased the predicted population benefits from these portfolios. Delta Smelt outcomes are further discussed in Takeaways #2 (Section 5.2) through #4 (Section 5.7).
- **Time to implementation:** Most portfolios included a mix of actions that may be implementable within and beyond 5 years. Portfolios 3a and 3d were the only ones that did not include any nearer-term actions – at least 5 or more years would be required to implement any of the portfolios' actions, such as large-scale tidal wetland restoration and contaminant reduction. Higher predicted Delta Smelt benefits were generally achieved by portfolios that would require actions with longer times to implement.
- **Salmon:** All portfolios that included Delta Smelt management actions additional to what is currently being implemented (approximated in Portfolio 1b) had potential benefits to salmon. Portfolios that included AWC were expected to have some potential risks to salmon, and the degree of risk increased with the scale of the action. Effects to salmon of flow actions reflect potential direct, within-year benefits/risks of changing flow in a given season. Experts did not consider carry-over effects of flow actions, and modeling how operations would achieve flow actions is needed to better estimate effects to salmon.
- **Water resources:** Again, estimates of additional water resources used coarse methods in this process and are only suitable for relative, comparative purposes. Portfolio 2a (which included the full-year flow action and engineered first flush) and Portfolio 3c (which had different versions varying summer X2 targets alongside tidal wetland restoration) were the only portfolios evaluated that would require additional water resources. Portfolio 3c2 (summer X2 of 65/70 km in W/AN years) required the highest additional water of the three portfolios – 495 TAF/yr, on average across the 20-yr model period, in addition to water required for current outflow management in Portfolio 1b. Portfolio 2a (Full-year flow) and 3c4 (summer X2 of 70/75 km in W/AN years) were estimated to require an average of 127–212 TAF/yr. Additional water estimates varied considerably from year to year based on historical conditions (0–1,759 TAF/yr: see Appendix 3), and were especially high in years (e.g., 1997 and 1999) when historical X2 locations were much higher than management targets.

- **Capital & operating costs:** Costs of portfolios ranged from $1-5 millions/yr to $151-200 millions/yr over the 20-yr model period. Costs increased as the number and scales of actions included in the portfolio increased. Highest costs were estimated for Portfolios 3a, 3d, and 3e, due to their multiple, large-scale actions such as tidal wetland restoration, Franks Tract restoration, and contaminant reduction. Higher predicted Delta Smelt benefits were generally achieved by portfolios that would require higher resource costs.

Trade-offs among portfolios: Multi-objective SDM applications like this one typically examine the trade-offs among PMs and alternatives in a consequence table. Trade-offs that have already been mentioned above and are further discussed in the Takeaways in Section 5 include: (a) portfolios with higher Delta Smelt population benefits generally require higher water resources and/or capital and operating costs, (b) portfolios with higher Delta Smelt benefits generally require actions that will not be implementable within 5 years, meaning there will be delays in potential benefits, and (c) some portfolios with benefits to Delta Smelt also have potential risks to salmon, namely via potential risks from AWC.

Pairwise comparisons of portfolios can highlight the key trade-offs among alternatives and help decision makers consider their own preferences. We highlight three example pairwise comparisons for illustrative purposes below. Decision makers will need to consider how much they value each PM/objective and differences in performance among alternatives, how to address roadblocks to implementing management actions, and how to reduce uncertainties of actions' effects in order to make choices and implement effective management for Delta Smelt. The results in the Consequence Tables and report are meant to inform those next steps.

First, we can compare the two versions of Portfolio 3c, which specified different summer X2 targets alongside tidal wetland restoration. The version that targets summer X2 at 65/70 km (Portfolio 3c2) had predicted population benefits that were 1-7% (change from baseline) higher than the version that targets summer X2 at 70/75 km (3c4). However, targeting X2 at 65/70 km would require ~4x the amount of additional water as targeting X2 at 70/75 km in the summer. The two portfolios performed the same for all other PMs. When directly comparing these two alternatives, decision makers could consider how much they value the additional predicted Delta Smelt benefits vs. the additional required water resources.

Second, we can compare Portfolio 2b (Cache Slough) with Portfolio 2c (Cache Slough and Suisun Marsh). Portfolio 2b included the DWSC action and AWC in Yolo/Cache Slough. Portfolio 2c included those actions as well as 2K ac of managed wetlands in Suisun Marsh. The addition of managed wetlands in 2c, which allowed the portfolio to target food in multiple subregions alongside a small-scale turbidity action, resulted in predicted Delta Smelt benefits from 2c that were 13-25% (change from baseline) higher than 2b. Portfolio 2c also had higher potential benefits to salmon. The two portfolios performed the same for all other PMs, although capital and operating costs of 2c would be higher due to the inclusion of managed wetlands. In this case, Portfolio 2c focusing on Cache Slough and Suisun Marsh has substantially higher Delta Smelt population benefits and a relatively small additional cost of managed wetlands in Suisun Marsh, relative to Portfolio 2b focusing on Cache Slough alone.

Third, we can compare Portfolio 3a (Self-sustaining/permanent management) with Portfolio 3e (Habitat connectivity). Portfolio 3a included 9K ac of tidal wetland restoration, Franks Tract restoration, and Delta-wide contaminant reduction. Portfolio 3e focused on improving conditions in fewer subregions (the Confluence and Lower Rivers) with 2K ac of tidal wetland restoration, sediment supplementation, AWC, Franks Tract, and contaminant reduction. Importantly, 3e included more turbidity actions (alongside food and contaminant actions) than 3a while also downscaling some of the actions included in 3a. Portfolio 3e (Habitat connectivity) had higher predicted benefits from all four Delta Smelt population models and lower capital and operating costs than 3a (Self-sustaining/permanent management). However, 3e also had some potential risks to salmon due to AWC. In this case, decision makers could consider how much they value the better Delta Smelt and cost outcomes predicted for Portfolio 3e vs. its potential risks to salmon. Both portfolios have multiple actions with high effects uncertainties and longer times to implementation, which again would need to be investigated further to inform decisions.

See Section 5 – Key Takeaways & Discussion – Action & Portfolio Evaluation for more discussion of results.

Table 16. Consequence Table of predicted outcomes for portfolios and objectives/performance measures in the CSAMP Delta Smelt Round 1 evaluation. Green cells indicate performance measures where higher values (darker shades) are preferred. Orange cells indicate metrics where lower values (lighter shades) are preferred. Grey cells indicate water/cost metrics that are components of aggregated totals in the top water/cost row.

Objective & Performance Measure	Portfolios								
	1b Current mgmt (approx)	**2a.1** Full-year flows	**2b** Cache Slough	**2c** Cache Slough & Suisun Marsh	**3c.2** Summer flow & tidal wetlands (X2: Summer 65/70km)	**3c.4** Summer flow & tidal wetlands (X2: Summer 70/75km)	**3a** Self-sustaining/ permanent mgmt	**3d** Focus on food	**3e** Habitat connectivity
Delta Smelt Population									
Population Growth rate[1] (average lambda: 1995-2014)									
IBMR	1.00	1.21	1.12	1.25	1.13	1.10	1.40	1.96	2.23
LCME	1.09	1.15	-	-	1.25	1.19	1.21	1.50	1.31
LF	0.91	0.93	1.05	1.27	1.07	1.06	1.11	1.43	1.29
% change in population growth[1] (from 1995-2014 model baseline)									
IBMR	1%	23%	14%	27%	15%	12%	42%	99%	126%
LCME[2]	20%	25%	-	-	33%	27%	27%	58%	38%
MDR[2]	29%	15%	-	-	24%	17%	13%	33%	90%
LF	5%	8%	22%	47%	22%	21%	29%	64%	48%
% change in population growth[1] (from Reference Portfolio 1b)									
IBMR	-	22%	13%	25%	14%	11%	40%	97%	124%
LCME	-	6%	-	-	14%	9%	10%	38%	20%
LF	-	2%	16%	40%	17%	16%	22%	57%	42%
Dynamic Habitat Suitability Index[3] (overlap)									
Yolo/Cache Slough	20%	20%	32%	32%	21%	21%	21%	33%	20%
Confluence & Lower Rivers	7%	7%	7%	7%	7%	7%	7%	12%	30%
Suisun Marsh & Bay	20%	23%	20%	21%	23%	23%	21%	21%	21%
Uncertainty[4] (TWG group scores)									
Confidence in action effect assumptions: TWG avg (range of actions; scale: 1 to 5)	3.0 (food) to 4.0 (OMR)	2.4 (distrib) to 4.0 (OMR)	2.4 (food) to 4.0 (OMR)	2.4 (food) to 4.0 (OMR)	2.3 (food) to 4.0 (OMR)	2.3 (food) to 4.0 (OMR)	2.3 (food) to 4.0 (OMR)	2.3 (food) to 4.0 (OMR)	2.3 (food) to 4.0 (OMR)
Time to implementation[5] (TWG group scores)									
# of actions implementable < 5 yrs (TWG avg)	-	1	1	2	1	1	0	0	1
# of actions that may be implementable > 5 yrs (TWG avg)	-	0	1	1	1	1	3	5	4
Salmon effects[6] (expert group scores)									
Potential benefits: Expert avg (scale: 0 to 3)	0	1	1	1	1	1	2	3	1
Potential risks: Expert min (scale: -3 to 0)	0	0	-1	-1	0	0	0	-2	-1
Water / Resource Costs[7] (ballpark estimates, relative to Reference Portfolio 1b, for comparative purposes only)									
Water[8] (TAF/yr) — All yrs	-	212	0	0	495	127	0	0	0
W / AN	-	232	0	0	1100	283	0	0	0
BN	-	337	-	-	-	-	-	-	-
D / C	-	114	-	-	-	-	-	-	-
Costs ($ million / yr) — Total[9]	$0	$151-$200	$1-$5	$1-$5	$401-$450	$101-$150	$101-$150	$151-$200	$76-$100
Water[10]	-	$173	$0	$0	$404	$104	$0	$0	$0
Capital & operating[11]	-	None	$1-$5	$1-$5	$21-$30	$21-$30	$101-$150	$151-$200	$76-$100

[1] Delta Smelt population metrics were calculated in three ways: (1) annual predicted population growth rate (lambda) from the action/portfolio, (2) the percent change in annual population growth from the portfolio relative to baseline, historical conditions between 1995-2014, where values > 0% indicate increased population growth relative to baseline, and (3) the percent change in annual population growth from the action/portfolio relative to Reference Portfolio 1b (current management approx.). Metrics were averaged over the 20-yr period.

[2] The LCME and MDR models used different versions (with different sets of covariates) to evaluate different actions, which leads to variation in % change from baseline. These models often could only include effects of an action for a portion of months even if it was specified to have year-round effects. MDR results were only available for % change from baseline.

[3] Dynamic Habitat Suitability Index (between 0 and 100%) was calculated as the percentage of months (over the 20-year model period) when all four dynamic habitat attributes (temperature, turbidity, salinity, and prey) are in "suitable" ranges (i.e., suitable conditions overlap), defined by existing studies and the TWG.

[4] Effect uncertainty was scored by TWG members to indicate their level of confidence in the assumed/quantified proximate effects (e.g., on food, turbidity) of each management action using a constructed scale (1 [lowest confidence] to 5 [greatest confidence]). Reported as the range of actions in a portfolio with the lowest and highest average TWG score.

[5] Time to implementation is defined in this process as how long it will take to achieve full implementation, including research of technical aspects of the action and generation of expected benefits for Delta Smelt, while not considering time needed for permitting. Values in different time to implementation categories reflect the number of actions in a portfolio additional to actions included in Reference Portfolio 1b.

[6] Salmon effects of actions (sometimes at different scales) were scored by subject matter experts from -3 (greatest risks) to +3 (greatest benefits). Individual action scores were summed within a portfolio and rescaled from 0 (no benefits) to +3 (greatest benefits). Scores for individual actions deemed by experts as having any potential direct risk were summed within a portfolio and rescaled from -3 (greatest risks) to 0 (no risks). Potential benefits are reported as average scores; potential risks are reported as minimum scores to represent any degree of risk to salmonids expressed by experts. Salmon experts noted potential negative risks to juvenile Chinook from AWC, as there is some evidence that higher turbidity can decrease foraging rates, and juveniles can use submerged aquatic vegetation to avoid predation. There is also the potential for direct mortality from mechanical (or chemical) removal. Effects to salmon of flow actions reflect potential direct, within-year benefits/risks of changing flow in a given season. Experts did not consider carry-over effects of flow actions, and modeling how operations would achieve flow actions is needed to better estimate effects to salmon.

[7] All water and resource costs: Water resources and capital and operating costs of portfolios were calculated relative to Reference Portfolio 1b (current management approx.). Costs for individual management actions are reported relative to baseline, historical conditions – not Reference Portfolio 1b. Therefore, water volumes and resource costs are slightly different between the tables. Ballpark values were estimated through coarse methods and meant for comparative purposes only.

[8] Additional water (relative to outflow under Reference Portfolio 1b) is averaged across all 20 years and is presented for comparative purposes only. The source of water needed to implement flow actions was not identified and water was not balanced within or among years in Round 1. The water resource volume represents the net volume of water necessary to move X2 from its position in Reference Portfolio 1b to a target condition, based on equations in Monismith et al. (2002) and Denton (1993).

[9] Total cost was calculated as the sum of monetized water and capital & operating costs, annualized over the 20-yr period without a discount rate.

[10] Monetization of water used $815 per acre foot of water, annualized over the 20-yr period, as discussed and agreed to by the CSAMP Policy Group Steering Committee. See Appendix 3 – Water Resources Methods – Monetized water cost.

[11] Includes ballpark estimates of capital & operating costs, annualized without a discount rate.

4.5 Sensitivity Analysis of Food, Turbidity, & Flow

In addition to sensitivity analyses of individual actions (e.g., outflow/X2 and tidal wetland restoration – see Section 3.2), the TWG conducted a sensitivity analysis of 13 model runs to further understanding of Delta Smelt population responses to varying levels of food, turbidity, and flow actions (Table 17). The motivation was to test population responses to increasing food, turbidity, and flow that allowed for interactions among their effects, unlike "action-only" model runs. In addition, the analysis allowed for a more systematically model combinations of actions, unlike the Round 1 portfolio model runs. First, a "Core Scenario" was created that included actions that increased food, turbidity, and flow to at least some degree, relative to baseline. The subsequent scenarios kept most of the actions the same as the Core Scenario but adjusted (1) the assumed increase in food via intensity of tidal wetland restoration, (2) the assumed increase in turbidity via aquatic weed control, and (3) a range of different outflow/X2 actions in the summer and fall. Note that these sensitivity model runs only reduced X2 in months where the historical X2 location was higher than the target to better simulate how this action is expected to be implemented; if the historical X2 location was lower than the monthly target, the historical location was used in the model run (no change). This "ruleset" was the same used as the action/portfolio model runs and different than the X2 sensitivity analysis (described in Section 3.2). Delta Smelt outcomes were predicted with two population models (the IBMR and LCME), and resource costs were calculated relative to baseline, historical conditions using the same methods as in the multiple-objective evaluation of management actions.

We present the predicted outcomes across sensitivity model runs for % change in Delta Smelt population growth (from baseline) along with predicted outcomes for resource costs in Table 18. We discuss key takeaways from this analysis alongside the Round 1 portfolio results in Section 5.

Table 17. Description of 13 model runs used in the sensitivity analysis testing effects of varying levels of food, turbidity, and flow actions.

Level		**Core Scenario**	**Food** varies on top of Core Scenario			**Turbidity** varies on top of Core Scenario			**Flow** varies on top of Core Scenario					
			1	2	3	1	2	3	1	2	3	4	5	6
Tidal wetland restoration - includes Franks Tract in levels 2 and 3		9K ac	0 ac	20K ac	30K ac	9K ac			9K ac					
Aquatic weed control		Yolo/Cache (~600 ac)	Yolo/Cache (~600 ac)			0 ac	4 sub-regions (~1.4K ac)	5 sub-regions (~3.5K ac)	Yolo/Cache (~600 ac)					
Additional outflow to 1995-2014 baseline	Summer[1] X2	70/75	70/75			70/75			Baseline	Baseline	70/75	70/75	70/75	65/70
	Fall[1] X2	80	80			80			Baseline	80	Baseline	80	74/76	74/76
	Water year type	W/AN	W/AN			W/AN			-	W/AN	W/AN/BN	W/AN/BN	W/AN/BN	W/AN
	# yrs (out of 20 model yrs)	7	7			7			0	7	11	11	11	8
Actions held constant across runs		North Delta Food Subsidies; Suisun Marsh Salinity Control Gates; OMR management; DWSC Food Subsidies; SM Managed Wetlands food production - 2,000 ac												

[1] Summer = July/Aug; Fall = Sept/Oct.

Table 18. **Consequence Table of predicted outcomes for sensitivity runs across a subset of objectives/performance measures. The "Levels" in the food, turbidity, and flow sections correspond to levels of those actions described in Table 17, where Level 1 represents lower food, turbidity, or flow to the Core Scenario. For food and turbidity scenarios, Levels 2+ indicate higher food and turbidity than the Core Scenario. For flow scenarios, Levels 4+ indicate higher flow conditions than the Core Scenario. Green cells indicate performance measures where higher values (darker shades) are preferred. Orange cells indicate metrics where lower values (lighter shades) are preferred. Grey cells indicate water/cost metrics that are components of aggregated totals in the top water/cost row.**

		Core Scenario	**Food** varies on top of Core Scenario			**Turbidity** varies on top of Core Scenario			**Flow** varies on top of Core Scenario					
	Level		1	2	3	1	2	3	1	2	3	4	5	6
Delta Smelt Population[1] – *Percent Change in population growth (from baseline = observed conditions; 1995-2014)*														
IBMR		36%	32%	39%	42%	30%	64%	87%	34%	33%	42%	38%	41%	40%
LCME – food model[2]		66%	58%	77%	85%	65%	68%	74%						
LCME – X2 model[3]		34%	32%	37%	40%	34%	37%	41%	28%	28%	43%	43%	43%	41%
Water / Resource Costs[4] - *Ballpark estimates, relative to 1995-2014 baseline, for comparative purposes only*														
Water (TAF/yr)[5]	All yrs	188	188	188	188	188	188	188	-	60	319	372	661	699
	W / AN	417	417	417	417	417	417	417	-	134	350	417	799	1553
	BN	-	-	-	-	-	-	-	-	-	810	924	1507	-
Costs ($ million / yr)	Total[6]	$151-$200	$151-$200	$201-$250	$201-$250	$151-$200	$151-$200	$151-$200	$26-$30	$51-$100	$251-$300	$301-$350	$551-$600	$551-$600
	Water[7]	$153	$153	$153	$153	$153	$153	$153	-	$49	$260	$303	$538	$569
	Capital & operating[8]	$26-$30	$1-$5	$51-$60	$61-$70	$21-$25	$26-$30	$36-$40	$26-$30	$26-$30	$26-$30	$26-$30	$26-$30	$26-$30

[1] Delta Smelt population metric was calculated as the percent change in annual population growth from the action/portfolio relative to baseline, historical conditions between 1995-2014 and averaged over the 20-yr period, where values > 0% indicate increased population growth relative to baseline.

[2] Included food effects from all actions in Feb-Aug; included turbidity effects from all actions in Sept-Nov; did not include effects of additional outflow. Delta-wide effects of food and turbidity were calculated using volume-weighted approach that multiplied subregion-specific effects from the IBMR with the % of total Delta water volume in each subregion.

[3] Included food effects from all actions in Feb-May; included turbidity effects from all actions in Sept-Nov; included effects of additional summer outflow from June-Aug; did not include effects of additional fall outflow. Delta-wide effects of food and turbidity were calculated using volume-weighted approach that multiplied subregion-specific effects from the IBMR with the % of total Delta water volume in each subregion.

[4] All water and resource costs: Water resources and capital and operating costs of actions were calculated relative to baseline, historical conditions. Ballpark values were estimated through coarse methods and meant for comparative purposes only.

[5] Additional water (relative to outflow under baseline, historical conditions between 1995-2014) is averaged across all 20 years and is presented for comparative purposes only. The source of water needed to implement flow actions was not identified in Round 1. The water resource volume represents the estimated net volume of water necessary to move X2 from its historical monthly position to a target condition, based on equations in Monismith et al. (2002) and Denton (1993).

[6] Total cost was calculated as the sum of monetized water and capital & operating costs, annualized over the 20-yr period without a discount rate.

[7] Monetization of water used $815 per acre foot of water, annualized over the 20-yr period, as discussed and agreed to by the CSAMP Policy Group Steering Committee. See Appendix 3 – Water Resources Methods – Monetized water cost.
[8] Includes ballpark estimates of capital & operating costs, annualized without a discount rate, for comparative purposes only.

5 Key Takeaways & Discussion – Action & Portfolio Evaluation

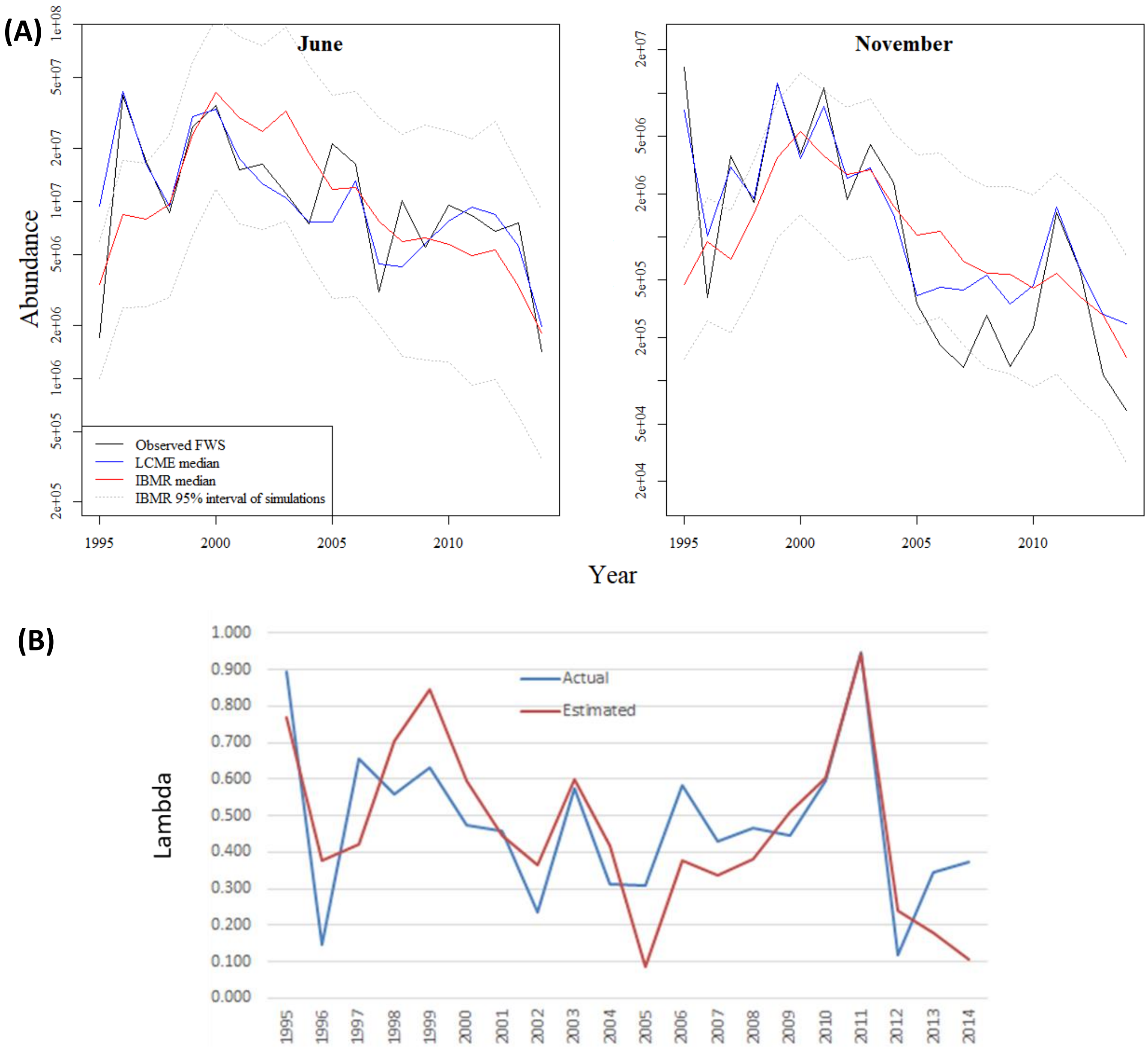
The following section highlights holistic takeaways from the Round 1 evaluation of Delta Smelt management actions and portfolios. It includes the content from the Executive Summary Appendix with additional results, discussion, and references.

5.1 Takeaway #1: Using multiple Delta Smelt life cycle models offers opportunities to test competing hypotheses, quantitatively evaluate effects of management actions on population growth, and strengthen conclusions.

Newly developed Delta Smelt life cycle models used in the SDM process are the best tools available to predict the potential effects of management actions on the Delta Smelt population. Four Delta Smelt life cycle models were applied in the SDM process: one mechanistic and three statistical models. This multi-model approach recognizes that all models are imperfect and there are many uncertainties in how the systems (the Delta and Delta Smelt) work. Comparing results across models strengthens conclusions when they agree and generates new insights when they diverge. Figure 13A and B shows agreement of three models with the 1995-2014 observed, baseline data to which they were calibrated. Despite differences in model structures, Figure 13A shows that the mechanistic model (IBMR) and a statistical model (LCME) both generally predict the trend observed in the USFWS surveys of Delta Smelt population across the 20-yr timeframe used in this process. The LCME generally had better agreement to historical data than the IBMR, which is expected since the LCME is a statistical model fit to this data whereas the IBMR is a more complex mechanistic model that is calibrated to the data. Figure 13B shows agreement between mean predictions from the Limiting Factors model in a leave-one-out cross validation and observed population trends.

Model predictions of Delta Smelt population growth were based on the quantified, proximate effects of management actions, which have their own uncertainties that must be considered. Generally, management actions were first described in influence diagrams (e.g., Figure 5) to show their hypothesized effects on Delta Smelt habitat factors (e.g., food, turbidity, salinity) and demographics (e.g., spatial distribution, survival). An action's primary effects were quantified using either existing research or new analyses done within the SDM process; however, the evidence basis for estimating effects is variable across management actions. In some cases, field data existed that could be used to infer management action effects. In other cases, no data were available and more theoretical, ad-hoc estimates needed to be made. All possible effects of actions were not captured in the SDM evaluation due to insufficient evidence that would require more information or modeling that was outside the scope of the SDM process. Those effects that were quantified generally represent the primary hypothesized benefit of an action for Delta Smelt. For example, the effect on food was quantified for tidal wetland restoration as this is the intended benefit of that action for Delta Smelt. Other potential effects of tidal wetland restoration (e.g., salinity, water temperature, turbidity, Delta Smelt distribution) were discussed but not quantified, needing more information or modeling (Figure 5). The Round 1 evaluation quantitatively assessed the sensitivity of some models to some actions' effects, but uncertainty around most actions' effects was not propagated in Delta Smelt models and predictions. Although the SDM process used the best available information and a multi-model approach to predict Delta Smelt outcomes, it also highlighted many existing uncertainties around management actions' potential effects and feasibility that could be investigated with further research and Adaptive Management (described in Section 6).

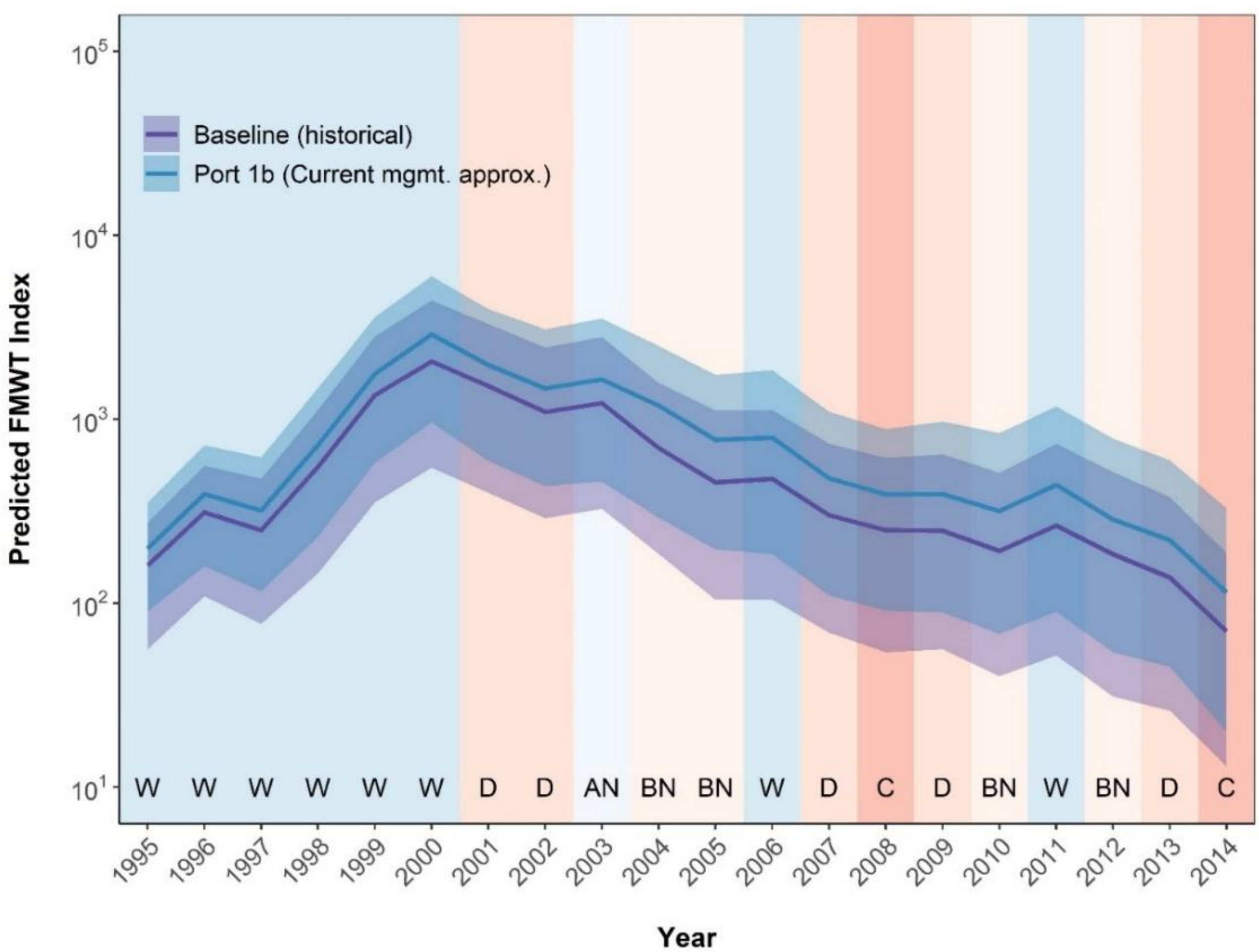
Figure 13. Comparison of Delta Smelt model predictions and data to which they were fit or calibrated. (A) Observed Delta Smelt abundance (USFWS catch density expansion estimates: black solid line) and median predicted Delta Smelt abundances for the IBMR (red) and LCME (blue). Dashed lines indicate the 95% confidence interval (2.5th and 97.5th percentiles from the distribution of model predictions) for the IBMR. Observed and model-predicted abundances are shown for June and Nov across model years (1995-2014). (B) Comparison of mean predicted Delta Smelt population growth rate (lambda: abundance change ratio) using the Limiting Factors model in a leave-one-out cross validation with historical, actual lambda. Actual lambda is calculated by dividing the FMWT Index in one year by the FMWT Index in the previous year.



5.2 Takeaway #2: Actions targeted at Delta Smelt that are currently being implemented (as modeled) are predicted to not be sufficient for achieving self-sustaining Delta Smelt population growth.

A subset of the management actions specified in the 2019 Biological Opinion (BiOp) and 2020 Incidental Take Permit (ITP) that target Delta Smelt were modeled to address the question: if the same management actions had been implemented throughout the entire 1995-2014 period, how might this have altered the growth of the Delta Smelt population in comparison to the model baseline of observed, historical conditions? These actions included: Old and Middle River (OMR) management, fall X2 management, North Delta Food Subsidies, and summer/fall operation of the Suisun Marsh Salinity Control Gates. All models predicted that these Delta Smelt actions would increase population growth, relative to the 1995-2014 observed baseline (Figure 14), but both the model predictions and the Delta Smelt catch data show that was not sufficient to avoid a declining population over the full 20-yr period. The population was predicted to increase for the first six consecutive years under wet conditions (1995-2000) but then decline steadily as drier years became more common (2001-2014: Figure 14). These modeling results, together with the Delta Smelt catch data, suggest that more needs to be done to achieve self-sustaining Delta Smelt population growth.

Figure 14. Average predicted Delta Smelt FMWT Index across model years (1995-2014) for predicted baseline, historical conditions (purple) and Portfolio 1b (select Delta Smelt management actions in 2019 BiOp/2020 ITP approx.; blue) in the IBMR. The shaded ribbons show the 95% confidence interval (2.5th and 97.5th percentiles from the distribution of model predictions) encompassing uncertainty (stochasticity, process variation) in the IBMR. Water year types are indicated by letters at bottom of figure and blue-red bars.

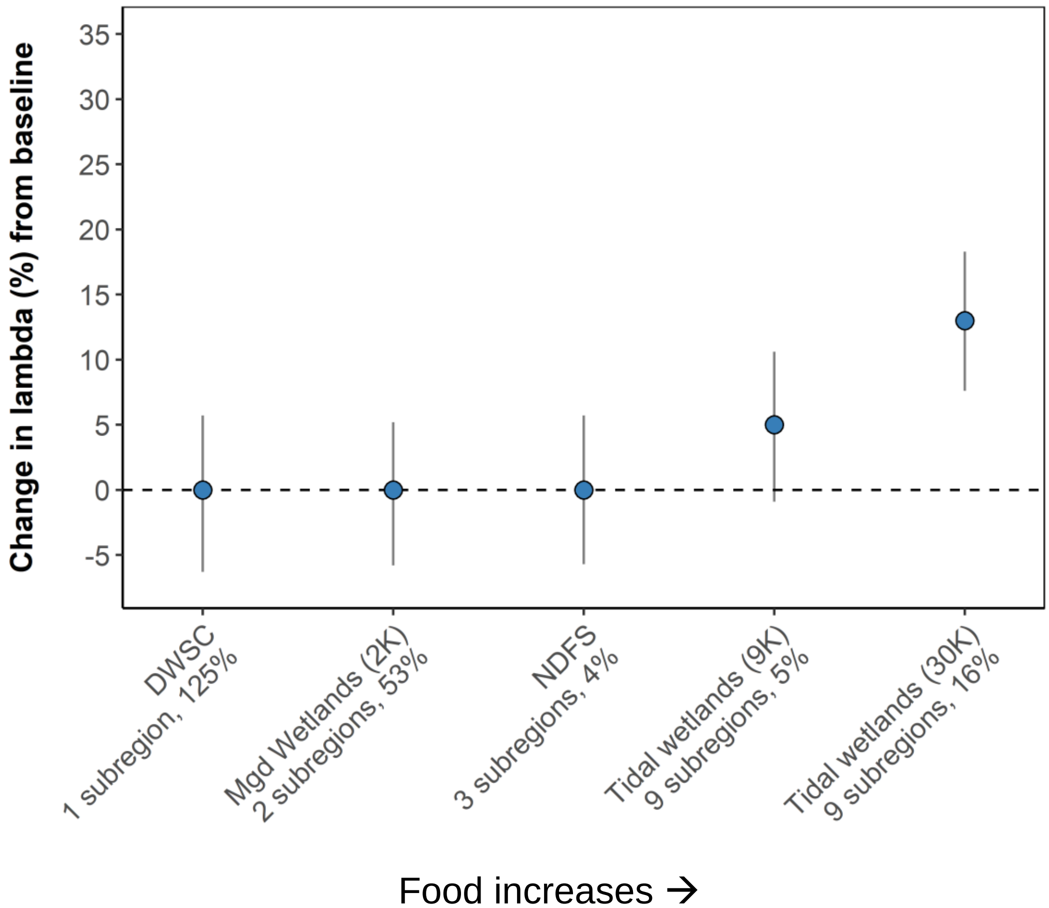


The historical, baseline conditions captured in the models (1995-2014) represent a mix of regulatory actions that were not consistent across the entire 20-yr model period. For example, the 2008 Biological Opinion for the Long-Term Operations of the Project (BiOp) included Old and Middle River (OMR) management and fall X2 management actions for Delta Smelt intended to mitigate entrainment and improve habitat conditions, respectively. Starting in 2007, the OMR management action was implemented annually (8 of 20 model years), resulting in OMR flow being > -5,000 cfs from Jan to June in each year. The fall X2 action targeted an X2 location in Sept and Oct of < 75 km in Wet years and < 81 km in Above Normal water years. These X2 targets were achieved in the fall of 2011 (the only Wet or Above Normal year in the post 2008 model period). Fall X2 and OMR actions evaluated in Round 1 were the updated versions of these actions specified under the 2019 BiOp and 2020 ITP, which differed from the versions implemented under the 2008 BiOp. Therefore, comparisons of X2 and entrainment actions against the baseline cannot be viewed as comparisons with and without such actions. Population models require calibration against real world data to improve reliability, and modeling a "no action' scenario vs. actions scenarios was beyond the scope of Round 1. **Predicted population benefits for Round 1 management actions are best interpreted relative to each other and this baseline, rather than as absolute estimates of predicted population benefits**.

5.3 Takeaway #3a (Food): Models show that actions can enhance Delta Smelt population growth to different degrees if they increase food availability, turbidity, flows, or improve survival via contaminant reduction. Effectiveness depends upon the scale and timing of actions.

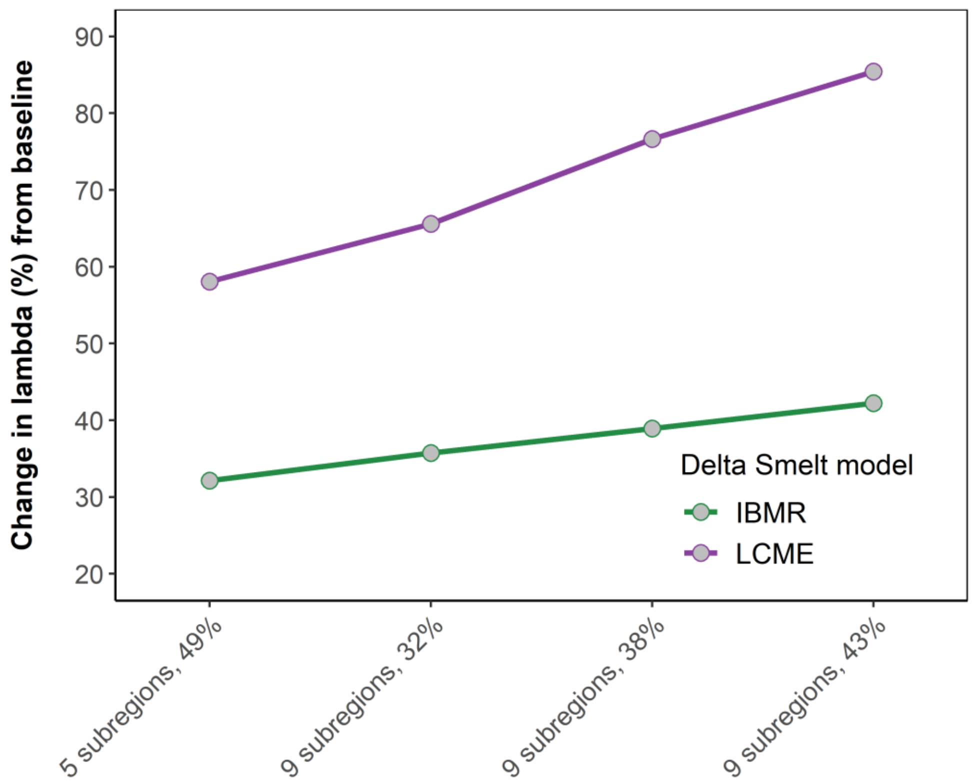
Across the evaluation of actions, portfolios, and sensitivity model runs, models agreed that increasing food – especially at large scales – would increase Delta Smelt population growth. Actions that increased food across multiple subregions increased population growth more than when food was increased in 1-3 subregions (Figure 15). An explanation for these model results is that more food in more places benefits a larger proportion of the Delta Smelt population, as fish occupy multiple subregions at any point in time throughout the year. Management actions that increase food in multiple places also increase the likelihood that at least some of those places have adequate habitat conditions (i.e., turbidity, salinity, temperature) that facilitate Delta Smelt accessing those food resources. Because of these patterns, any increase in food should benefit Delta Smelt, assuming an adequate level of flow, turbidity, and other factors.

Figure 15. Predicted percent change in Delta Smelt population growth from baseline for model runs of representative Round 1 food actions with the IBMR. Labels indicate the action, the number of subregions where food was increased, and the average % change in food (across those subregions and 20-yr model timeframe).



The sensitivity analysis showed population growth increased linearly with food across the scales of actions tested for both the IBMR and LCME (Figure 16, Table 18). The Round 1 portfolio evaluation also supported this finding, where Portfolio 3d included multiple large-scale food actions, alongside other turbidity and contaminant actions, and was predicted to have among the largest increases in Delta Smelt population growth (Table 16).

Figure 16. Predicted percent change in Delta Smelt population growth from baseline for model runs in a sensitivity analysis that varied food effects with the IBMR and LCME. Labels indicate the number of subregions where food was increased and the average % change in food (across those subregions and 20-yr model timeframe). All runs included the following actions while food varied: 2K ac of Suisun Marsh managed wetlands, NDFS, DWSC, summer/fall SMSCG, OMR, and additional outflow to meet X2 targets of 70/75 km in summer (July/Aug) and 80 km in fall (Sept/Oct) in W and AN years.



Given the findings of the Round 1 evaluation on food, the TWG developed the following candidate AM and research next steps for consideration by implementing agencies:

AM & research next step: Research to quantify local and system-wide contributions of restored tidal wetlands to Delta Smelt diets, and the effects of tidal wetland restoration on water temperature.

AM & research next step: Implement Adaptive Management for managed wetlands food production in Suisun Marsh, while investigating ways to scale up actions.

More details on these AM and research next steps are provided in Section 6.

5.4 Takeaway #3b (Turbidity): Models show that actions can enhance Delta Smelt population growth to different degrees if they increase food availability, turbidity, flows, or improve survival via contaminant reduction. Effectiveness depends upon the scale and timing of actions.

Models agreed that increasing turbidity would increase Delta Smelt population growth. Higher turbidity can enhance foraging opportunities for fish like Delta Smelt while also reducing the risk of predation from larger species (Pangle et al. 2012). Several lab studies found evidence of turbidity benefits to Delta Smelt foraging rates and survival (predation rates)(Baskerville-Bridges et al. 2004, Ferrari et al. 2014, Hassenbein et al. 2016), although these relationships are more difficult to measure in situ. Similar to results from food actions and portfolios, increasing turbidity across multiple subregions increased population growth more than when it was increased in one subregion (Figure 17). This can also be seen in the results from management actions (Figure 10), as predicted population growth increases as the scale of aquatic weed control increases. This finding agrees with patterns for increasing food (Takeaway #3a) and could be explained because more turbidity in more places benefits a larger proportion of the Delta Smelt population and increases the likelihood that at least some of those places have other adequate habitat conditions (i.e., food, salinity, temperature) that facilitate Delta Smelt growth and survival.

However, relative to predicted benefits from food, models varied more in their predicted relationships between turbidity and population growth (Figure 17). This variation in model predictions can also be seen in the population growth results for Portfolio 3e (Habitat connectivity), which included the most large-scale turbidity actions among portfolios and also had the largest range of population growth predictions across models (38% - 126% change from baseline: Table 16). The IBMR's population predictions were more sensitive to changes in turbidity relative to the other models, such as the LCME. The IBMR includes multiple mechanistic effects of turbidity on Delta Smelt feeding and growth, which in turn influence survival in all months. The LCME only included a beneficial effect of turbidity on survival in the fall. These differences across models suggest that more research could improve our understanding of the relationships between turbidity and population growth.

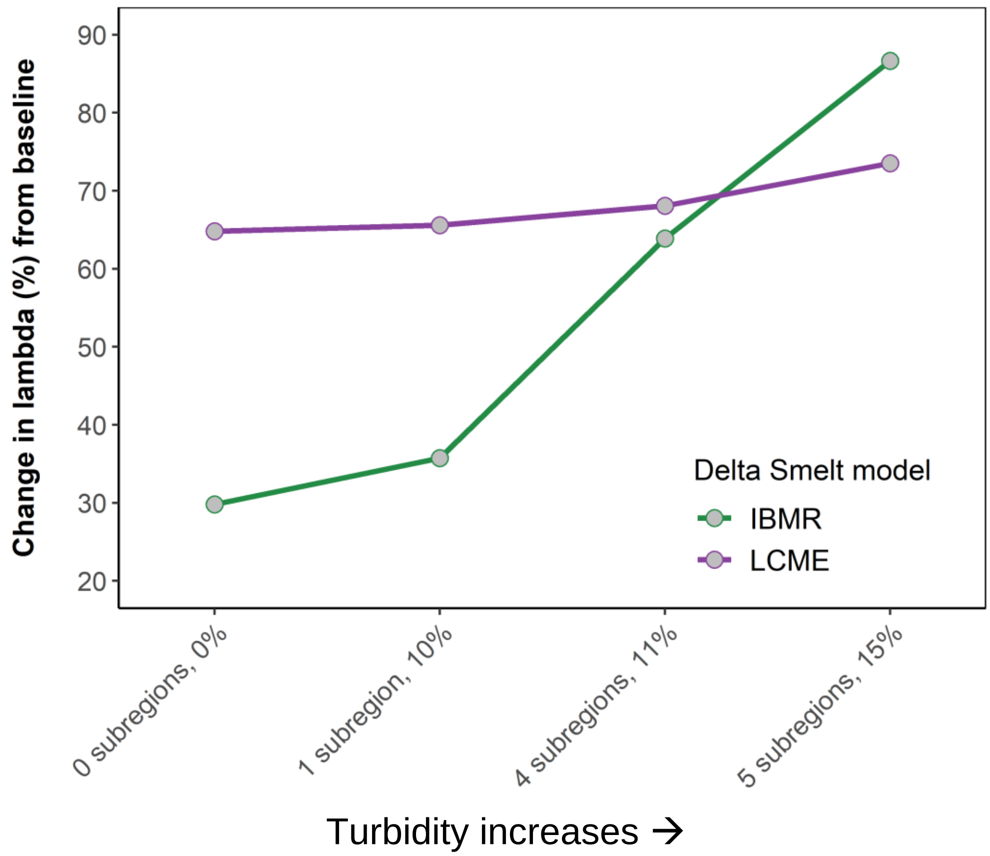
Given the findings of the Round 1 evaluation on turbidity, the TWG developed the following candidate AM and research next steps for consideration by implementing agencies:

AM & research next step: Feasibility studies are necessary to identify potential sources of sediment and transport methods to the reintroduction point; hydrodynamic modeling of different reintroduction points to inform implementation; and timing/locations where smaller scale supplementation improves conditions for Delta Smelt.

AM & research next step: Implement Adaptive Management for different methods of control for invasive aquatic weeds, and their effectiveness of enhancing turbidity and food.

More details on these AM and research next steps are provided in Section 6.

Figure 17. Predicted percent change in Delta Smelt population growth from baseline for model runs in a sensitivity analysis that varied turbidity effects with the IBMR and LCME. Labels indicate the number of subregions where turbidity was increased and the average % change in turbidity (across those subregions and 20-yr model timeframe). All runs included the following actions while turbidity varied: 2K ac of Suisun Marsh managed wetlands, NDFS, DWSC food, summer/fall SMSCG, OMR management, 9K ac of tidal wetland restoration, and additional outflow to meet X2 targets of 70/75 km in summer (July/Aug) and 80 km in fall (Sept/Oct) in W and AN years.



5.5 Takeaway #3c (Flow): Models show that actions can enhance Delta Smelt population growth to different degrees if they increase food availability, turbidity, flows, or improve survival via contaminant reduction. Effectiveness depends upon the scale and timing of actions.

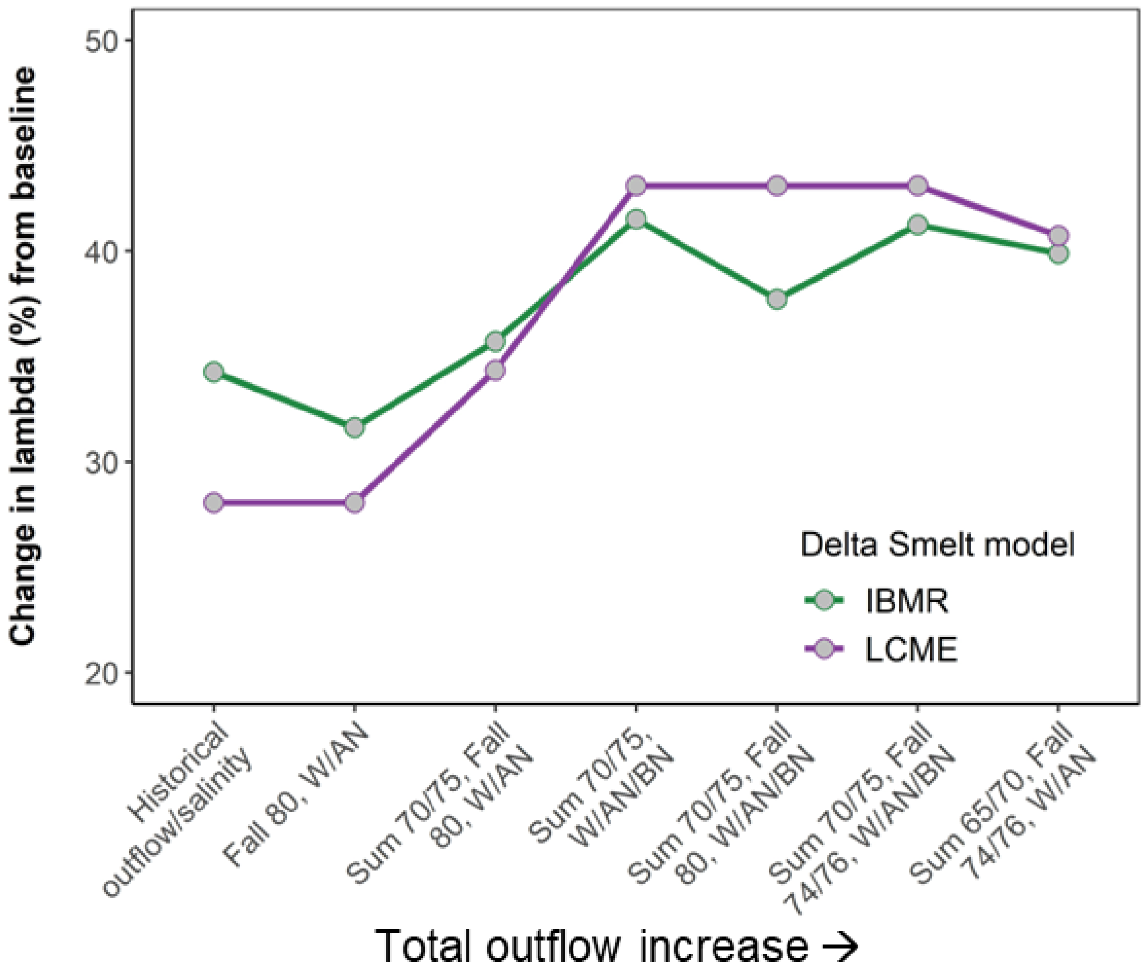
Models agreed that increasing outflow would increase Delta Smelt population growth, but the magnitude and consistency of predicted benefits depended on the action's timing and flow/X2 target. There are multiple hypothesized effects of outflow on Delta Smelt population. Increasing outflow increases the size, location, and physical function of the Low Salinity Zone (MacWilliams and Bever 2014). Increasing outflow is hypothesized to influence food and foraging opportunities for Delta Smelt (e.g., Lee et al. 2023). In turn, these known and hypothesized benefits are thought to lead to increased Delta Smelt access to suitable habitat conditions (e.g., salinity, food, turbidity; Moyle et al. 2018). Increasing spring outflow is also hypothesized to expand the spawning window and provide suitable conditions for increasing larval survival. The statistical models include direct relationships between outflow during specific periods and Delta Smelt survival. The IBMR includes relationships between outflow and habitat variables (salinity, food) and relationships between X2 position and Delta Smelt distribution. In this way, the IBMR simulates the interactive effects of changes in food and changes in access to food and changes in the overlap of other suitable habitat conditions (e.g., overlap of suitable temperature, salinity and turbidity conditions). Other potential effects (e.g., temperature, turbidity) of flow have not been captured in models in the Round 1 evaluation due to lack of clear evidence to quantify those relationships.

Both the IBMR (a mechanistic model with subregion dynamics) and the LCME (a statistical, regional model) agreed that **summer flow actions** were predicted to increase population growth when X2 was ≤ 75 km in the summer in some years (Table 15, Figure 10), with greater population benefits as the flow action was applied to more years (i.e., W/AN years vs. W/AN/BN years: Table 15, Figure 10). In the sensitivity analysis that varied outflow actions alongside consistent food, turbidity, and other actions (Section 4.5), population growth also increased when adding summer outflow in more years (from no years to W/AN years to W/AN/BN years: Figure 18). The X2 sensitivity analysis (Section 3.2, Table 8) population growth was predicted to increase when X2 was set to ≤ 75 km in the summer in W/AN years; decreases in population growth were predicted when X2 was set to ≥ 75 km in summer.

Models also agreed that a **fall flow action** where X2 was ≤ 80 km in W/AN years (approximating the current action specified in the 2019 BiOp/2020 ITP) had negligible effects to population growth (Table 15, Figure 10)[8]. The sensitivity analysis that varied outflow actions alongside other actions (Section 4.5) showed no increase in population growth between scenarios with and without a fall outflow action (X2 ≤ 80 km: Figure 18). Note that these scenarios included other actions that increased food, turbidity, other factors, and sometimes summer outflow. These patterns were supported by both the IBMR and LCME. The LCME is insensitive to changes in fall X2 because it only includes an effect of X2 in the summer and not the fall, following results from a previous version of the LCME (LCMG: Polansky et al. 2021) that found evidence for a summer outflow – but not fall outflow – effect on survival. In the X2 sensitivity analysis (Section 3.2), the IBMR predicted population growth would increase with higher fall outflow (Section 3.2, Table 8). Notably, the IBMR predicted the population to slightly decrease when fall X2 was set to 80 km but increase when fall X2 was < 80 km, although the LCME predicted no effect of fall outflow on survival and population growth.

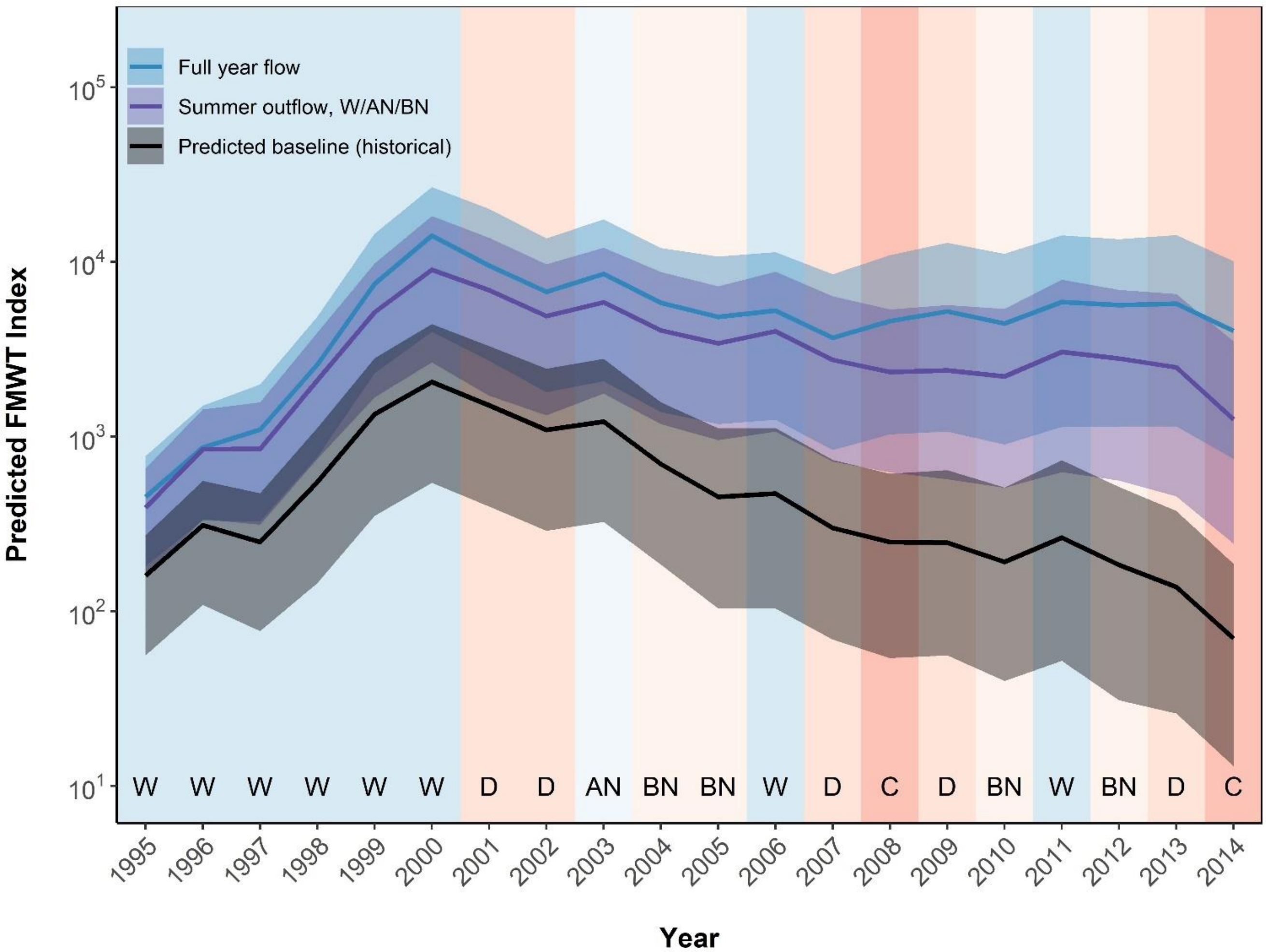
[8] When simulating the fall X2 action, X2 was set to 80 km in Sept/Oct in W and AN water year types when historical X2 locations were > 80 km (this occurred in 10 months out of the 18 applicable months across the 20-yr model period).

Figure 18. Predicted percent change in Delta Smelt population growth from baseline for model runs in a sensitivity analysis that varied outflow by season (summer and/or fall) and X2 target with the IBMR and LCME. All runs included the following actions while outflow varied: 2K ac of Suisun Marsh managed wetlands, NDFS, DWSC food, summer/fall SMSCG, OMR management, and 9K ac of tidal wetland restoration.



Another outflow action, called "**full-year flow**", strategically deployed flow actions in spring, summer, and fall to meet minimum flow targets in all years. This action was also predicted to increase population growth rate from baseline by 5% (LCME) to 17% (IBMR: Table 15, Figure 10). In the LCME, there is a stronger effect of summer flow, relative to spring flow, on Delta Smelt survival. The full-year flow action used a higher summer X2 target (X2 ≤ 78 km) compared to the summer outflow action (X2 ≤ 70/75 km in July/Aug), but it applied the summer target in W/AN/BN years alongside additional outflow in the spring. This mix of X2 targets and timings in the full-year flow action yielded a predicted population increase from the LCME that was similar to the summer flow action in W/AN years. We can also compare the relative population trends from different flow actions over time using the IBMR's annual predictions. Results showed greater population growth under both the full-year flow and summer outflow actions, relative to the baseline, with some evidence that these could help sustain the Delta Smelt population through drier periods (Figure 19). The full-year flow action was also included in Portfolio 2a.1 (alongside current management actions of Portfolio 1b), which was predicted to increase population growth rate from baseline by 8-25% across models.

Figure 19. Average predicted Delta Smelt FMWT Index across model years (1995-2014) for predicted baseline, historical conditions (black), increasing summer outflow so that X2 is ≤ 70 km in July and 75 km in Aug in W/AN/BN years (purple), and increasing outflow to meet minimum thresholds year-round (Full-year flow with no annual water budget; blue). The shaded ribbons show the 95% credible interval encompassing uncertainty (stochasticity, process variation) in the IBMR. Water year types are indicated by letters at bottom of figure and blue-red bars.



We can also see similar predicted population increases from the **Engineered First Flush** action compared to the summer outflow action simulated in W/AN years (Table 15, Figure 10). However, we note that Engineered First Flush was classified as an entrainment action in the Round 1 evaluation and only had quantified effects on Delta Smelt distribution. This differs from "outflow/X2" actions where effects were quantified for Delta Smelt distribution and food, as well as direct effects on survival in the three statistical models.

There are three important considerations for interpreting these results. First, population growth results are reported as averages across the 20-yr model period, and it is possible that annual population growth is higher than the average in specific years when flow actions were simulated. Second, the modeling of X2 actions in this process did not isolate the effect of those actions due to the mix of regulatory targets represented in the baseline model conditions (described in Takeaway #2). Therefore, modeling results are appropriate for relative comparisons, and further modeling would be required to estimate the isolated effect of X2 actions on Delta Smelt growth.

Third and finally, the results discussed above came from both (1) Round 1 model runs of outflow management actions and portfolios and (2) the X2 sensitivity analysis (Section 3.2, Table 8) – which systematically set X2 to different targets in summer and fall in all W/AN years. Both sets of results provide additional information about the built-in relationships between seasonal outflow/X2 and population growth in the models, but they cannot be directly compared to one another because they used different "rulesets" for changing X2. Round 1 model runs of individual outflow/X2 management actions and portfolios were intended to simulate (approximately) how those actions would be implemented. These runs reduced X2 only in months when the historical X2 location was higher than the target (e.g., 80 km); if the historical X2 location was lower than the monthly target (e.g., 2011), the historical X2 location was used in the model run (no change). Therefore, flow was only increased relative to the baseline in the action/portfolio analysis. Alternatively, in the X2 sensitivity analysis, X2 locations were set at a consistent location in the summer or fall months, which meant that the model runs were simulating a decrease in flow for some months and years, relative to the historical baseline (see Section 3.2).

Given the findings of the Round 1 evaluation on outflow/X2 actions, the TWG developed the following candidate AM and research next steps for consideration by implementing agencies:

AM & research next step: Operations modeling to confirm the availability of water and the feasibility of operations necessary to achieve the various X2 management scenarios, with a focus on summer X2 action.

AM & research next step: Integrate existing and new climate forecasting tools to predict when first flush conditions are expected and not expected to develop; begin development of a condition-dependent Adaptive Management framework for testing the action through coordination with natural resource and water agencies.

More details on these AM and research next steps are provided in Section 6.

5.6 Takeaway #3d (Contaminants): Models show that actions can enhance Delta Smelt population growth to different degrees if they increase food availability, turbidity, flows, or improve survival via contaminant reduction. Effectiveness depends upon the scale and timing of actions.

Models agreed that reducing contaminants at hotspots in the Delta – especially at large scales – could increase Delta Smelt population growth. Recent studies using water from Delta Smelt habitat found sublethal effects to Delta Smelt (Stillway-Garcia et al., in press). Other studies found negative impacts of contaminant concentrations in Cache Slough to aquatic food webs, including near total mortality of a test species (Weston et al. 2019). Collectively, contaminants are hypothesized to have direct sublethal and lethal effects to Delta Smelt, as well as negative effects to aquatic food webs and other species of interest.

In Round 1, the TWG evaluated an action to reduce contaminant concentrations at hotspots in one subregion (Yolo/Cache Slough Complex) and Delta-wide. The effect of the action on reducing Delta Smelt mortality was predicted through collaboration with Dr. Wayne Landis and his lab at Western Washington University, who provided historical contaminant concentration data and quantitative relationships between concentration and fish mortality from lab studies (CRM 2022d, Landis et al. 2023). Round 1 results showed that reducing contaminants in Ulatis Creek in the Yolo/Cache Slough subregion increased Delta Smelt population growth from baseline by 1%; reducing contaminants Delta-wide increased population growth by 16% (Table 15, Figure 10). Similar to patterns of food and turbidity actions, applying contaminant reduction actions at broader scales benefits a larger proportion of the Delta Smelt population. Additional benefits from contaminant reduction were predicted when the action was combined with food and turbidity actions in Round 1 portfolios (e.g., 3e – Habitat connectivity).

Given the findings of the Round 1 evaluation on contaminants, the TWG developed the following candidate AM and research next step for consideration by implementing agencies:

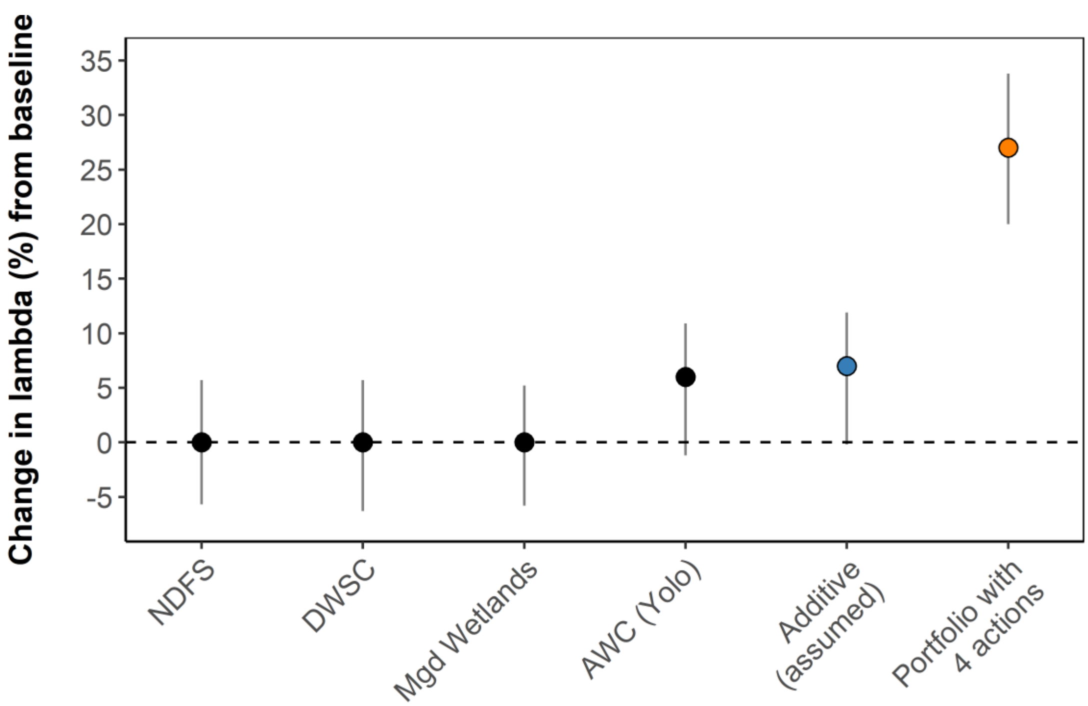
AM & research next step: Implement Adaptive Management to test reduction in contamination by constructed wetlands at Ulatis Creek, which could reveal benefits from improving survival in a critical Delta Smelt habitat (Cache Slough).

More details on this AM and research next steps are provided in Section 6.

5.7 Takeaway #4: Recovery is possible through combinations of actions (i.e., portfolios) with additive and synergistic effects. Portfolios that concurrently target multiple population drivers in multiple regions can achieve higher population growth than single actions.

Models showed that increasing turbidity appeared to have interactive effects with food that can lead to synergistic benefits to Delta Smelt. Increasing turbidity is hypothesized to have interactive effects with food that can lead to synergistic benefits to Delta Smelt. Turbidity can reduce predation risk and allow Delta Smelt to better access food resources, including those higher food resources generated by actions. The IBMR, as a mechanistic model, includes relationships that represent positive effects of turbidity on Delta Smelt foraging time, growth, and survival (or reduced mortality from predation). IBMR modeling demonstrated these synergistic effects, as when small-scale actions that only increased food or turbidity were modeled individually, they were predicted to increase population growth from baseline by 0-6% (Figure 20, black points). The assumed increase in population growth from baseline if adding these actions' effects together was 7% (Figure 20, blue point); however, a portfolio (Portfolio 2c: Cache Slough & Suisun Marsh) that combined these small-scale food and turbidity actions was predicted to increase population growth from baseline by 27% (Figure 20, orange point).

Figure 20. Predicted percent change in Delta Smelt population growth from baseline for model runs with the IBMR of representative Round 1 small-scale food and turbidity actions (black points) and a portfolio that combined those actions (orange). The blue point shows the assumed outcome if action effects were additive and not synergistic.

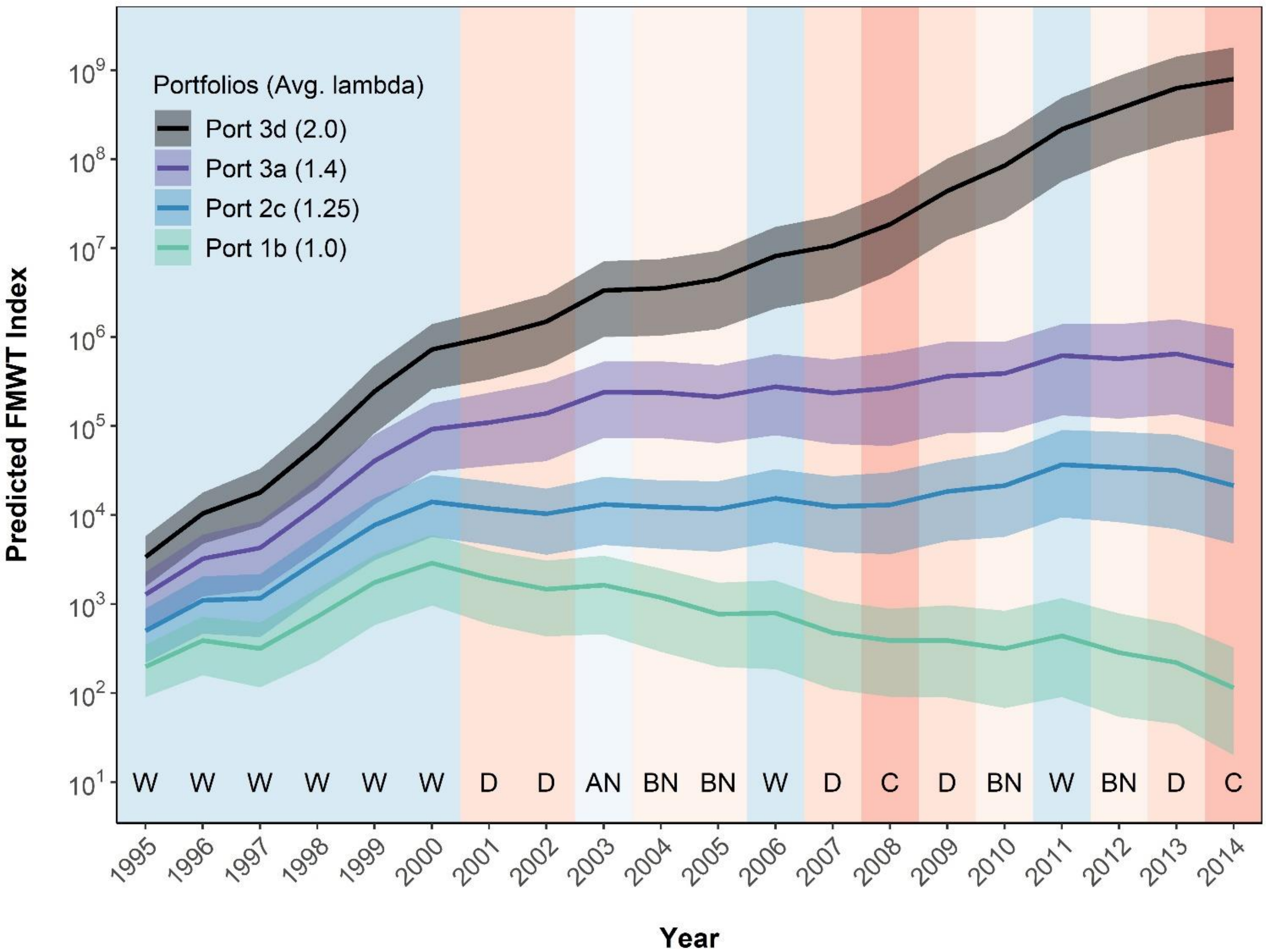


The Round 1 evaluation modeled eight portfolios with distinct combinations of management actions in addition to current management actions (Table 16). Most of these portfolios were predicted to stabilize or grow the population over the long-term – even during dry year periods (i.e., 2001-2014; Figure 21). The top three lines in the figure below are example portfolios that were predicted to achieve a stable or growing population over the 20-yr period. All three portfolios had at least one food and turbidity action, with two portfolios (3a: Self-sustaining/permanent management; and 3d: Focus on food) also including contaminant reduction actions. Portfolios with the highest Delta Smelt population benefits included actions that concurrently targeted multiple population drivers in multiple regions, such as: growing food in managed wetlands; large-scale tidal wetland restoration to increase food; large-scale aquatic weed control to increase turbidity; additional outflow in the summer to improve food and other Delta conditions; and large-scale contaminant reduction to improve survival. Population growth was generally higher for portfolios targeting multiple drivers compared to predicted benefits from single management actions.

The sensitivity analysis that tested varying combination of food, turbidity, and flow actions predicted average population growth rates (lambdas) between 1.2 and 1.8 (Table 18: roughly between the trajectories of Portfolios 2c and 3d in the figure below). In that analysis, scenarios with the highest Delta Smelt population benefits included actions that targeted increases of food, turbidity, and flow. On one hand, population benefits could be achieved without all three types of actions, such as “level 1” in the turbidity section (Table 18) that did not include turbidity actions, or level 1 in flow that had only historical outflow conditions (although the X2 baseline did implicitly include actions taken under 2008 BiOp). However, the largest increases in Delta Smelt population growth occurred for scenarios with large increases in food (level 4: 30K ac of tidal wetland restoration), turbidity (level 4: 3.5K ac of aquatic weed control), or flow (level 3: additional summer outflow in W, AN, and BN years) with complementary actions across all three types (see Table 18).

Delta Smelt declines are attributed to multiple factors, and these findings support that a combination of management actions addressing multiple factors (e.g., food, turbidity, flow, contaminants) could reverse those declines. The models suggest that stable and increasing population growth is possible over the long-term when wet and dry periods are expected.

Figure 21. Average predicted Delta Smelt FMWT Index across model years (1995-2014) for four portfolios that varied by average growth rate (lambda) in the IBMR. The shaded ribbons show the 95% credible interval encompassing uncertainty (stochasticity, process variation) in the IBMR. Water year types are indicated by letters at bottom of figure and blue-red bars. All portfolios assumed fall X2 ≤ 80 km in W and AN years. Portfolio names: 1b – Current management (approximation); 2c – Cache Slough & Suisun Marsh focus, including localized food and turbidity actions; 3a – Self-sustaining / permanent management, including large-scale habitat restoration and contaminant reduction; 3d – Focus on food, including multiple food actions, large-scale habitat restoration, aquatic weed control, and contaminant reduction.



5.8 Takeaway #5: Management actions and portfolios vary in their expected resource costs and time to implementation; higher predicted Delta Smelt benefits generally require higher investment of resources and time.

Relative to model-based approaches for predicting Delta Smelt population growth, the Round 1 evaluation used coarser methods to estimate ballpark resource costs (capital, operating, water) and time to implementation of actions and portfolios. The management actions evaluated in Round 1 showed a range of direct water resource and capital and operating costs (Table 15). Non-flow actions ranged in capital and operating costs from $1 to $10s of millions/year. Water resource costs were estimated in terms of water volumes (TAF/yr). Furthermore, the estimated water volumes were converted through simple linear calculation into monetized cost ($/yr) based on the unit cost suggested by the Policy Group [9]. The costs of the flow actions ranged from 10s to 100s of TAF/yr in water volume and from $10s to $100s of millions/yr in direct monetized cost, on average.

Estimated water volumes and costs associated with management actions were especially coarse in this process, given that more complex modeling of water operations was not possible within the process timeframe. Methods are further described in Appendix 3. Because hydrological modeling was not conducted to estimate the additional water needed for actions, the uncertainty around these estimates was not propagated through the estimates of monetized water cost, which has its own underlying uncertainties. Estimating the broader benefits and costs to society of these actions was outside the scope of the Round 1 evaluation and not factored into these estimates. Operations modeling could refine the estimated costs (and benefits) of outflow actions evaluated in Round 1, and this modeling is further described as a candidate AM and research next step in Section 6. Still, these ballpark estimates allow for making initial, relative comparisons across actions and portfolios.

Management actions also varied in their expected time to implementation, which was defined in this process as the time to achieve full implementation and generation of benefits for Delta Smelt if the necessary resources were invested in developing the action (Figure 9, Table 10).

Generally, the evaluation showed that higher predicted increases in Delta Smelt population were achieved by large-scale actions (Table 15) and portfolios (Table 16) that would require higher resource costs and time to implement. Smaller-scale actions that could be implemented in the near-term tended to have lower predicted population benefits (Table 15). For example, the three management portfolios (3a, 3d, and 3e) that tended to have the highest predicted Delta Smelt population growth across models included combinations of large-scale habitat restoration, turbidity, and contaminant reduction actions; they also had high resource costs ranging from $76 – $200 M/year and at least three management actions that were expected to not be implementable within the next 5 years. Again, these longer efforts would still require initiating research and planning processes soon. Overall, potential population benefits increased as the scale, time to implementation, and resource costs of management options increased. Adaptive Management and research next steps could be used to address implementation questions for actions of interest, and these are discussed further in Section 6.

5.9 Takeaway #6: There are effects uncertainties for all actions. The degree of uncertainty is not related to predicted population benefits.

The current state of knowledge about potential effects of management actions is limited, therefore making it difficult to identify "optimal" or "cost-effective" strategies in the face of these uncertainties. From surveying TWG members, confidence was relatively high for only one actions' effects as quantified in Round 1 (i.e., effects of outflow actions on salinity), whereas the estimated effects of most actions were given scores of low to moderate confidence (Figure 8). Low to moderate scores represented that "few data/studies exist" to "some data and coarse or theoretical modeling results are used to estimate action's effects." Since almost all management actions had similar degrees of effects uncertainties, there was no discernable pattern between uncertainty and predicted benefits to Delta Smelt (see Table 15 and Table 16).

Given the uncertainty in action effect quantifications, the TWG concluded that broad conclusions are more appropriate based on this Round 1 analysis (e.g., conclusions in Takeaways #3 and #4), rather than specific conclusions on management action effectiveness. In addition, implementing agencies that are contemplating any Round 1 management actions should use the analysis documented in this report as a starting point to do their own analysis to inform implementation decisions.

[9] Monetized water costs were calculated using an assumption of $815/acre foot of water (See Appendix 3 – Water Resources Methods – Monetized water cost).

SDM processes typically take an iterative approach to effects prediction. If limited data exists for the effects of a management action, a process can predict effects to align with hypothesized benefits based on available data and methods that are achievable within the process timeframe. Decision makers can then consider which uncertainties, if reduced, would influence management choices and monitoring or studies can be implemented to target those uncertainties where appropriate. Adaptive Management and research next steps are discussed further in Section 6.

6 Next Steps: Adaptive Management & Research

A key goal of this SDM process was to provide opportunities for analysis and dialogue on the question **"What are the best management and science actions to advance CSAMP's Delta Smelt management goal, in consideration of uncertainties and trade-offs with other objectives?"** Several management actions have potential benefits for Delta Smelt – both individually and in combination; however, remaining uncertainties around actions' proximate effects and implementation make it difficult to identify options that are "best" or most "cost-effective," given the current state of knowledge. Each decision maker and party involved will need to develop their own judgements on what is "best" based on how they weigh the predicted consequences and uncertainties across alternatives.

With the conclusion of the "Round 1 Evaluation," the immediate next step is for CSAMP members to review this report, discuss the results with their TWG representative and others, and think critically about what the results mean for how to advance the CSAMP Delta Smelt Management goal. Typical of other SDM processes, a future project may choose to do a "Round 2" with updated management actions/portfolios, data, and methods. For example, a Round 2 could focus on better characterizing uncertainty of a subset of management actions of interest and facilitate deliberative assessments of "best" options, given these uncertainties and trade-offs. To help implementing agencies consider other possible next steps, TWG members identified seven candidate Adaptive Management (AM) and research next steps associated with seven management actions evaluated in Round 1. These next steps were developed to target the high priority roadblocks with respect to advancing the decision making and/or implementation of the management actions.

The AM and research next steps address gaps in knowledge – both in the methods used within the SDM process and more broadly in efforts in the San Francisco Estuary – that could use additional focus and funding. They also broadly represent different types of next steps, including implementation of actions (typically at smaller scales) with continued research and monitoring in an AM framework and science and research studies (e.g., modeling). Adaptive Management[10] is useful for initiating decisions and implementation in the face of uncertainty, and then learning and adjusting management over time.

Adaptive Management (AM) and research next steps for Round 1 actions:

a) **Managed Wetlands for Food:** Pilot implementation of managed wetlands with AM in Suisun Marsh, while investigating ways to scale up action.
b) **Aquatic Weed Control:** Pilot studies testing different spatial scales, timings of application, and methods of control for invasive aquatic weeds.
c) **Physical Point Source Contaminants Reduction:** An adaptive management action to test implementing constructed wetlands at Ulatis Creek.

[10] "Adaptive Management" is defined as structured decision making for recurrent decisions, where uncertainty is an impediment and can be reduced over time with science and monitoring. For more details, see: Williams BK, Szaro RC, Shapiro CD. 2007. Adaptive Management: The U.S. Department of the Interior Technical Guide. Adaptive Management Working Group.

d) **Outflow Actions:** Operations modeling to confirm the availability of water and the feasibility of operations to achieve the various X2 management scenarios, with a focus on summer X2 action.
e) **Sediment Supplementation:** Feasibility studies to identify potential sources of sediment and transport methods to the reintroduction point; hydrodynamic modeling of different reintroduction points to inform implementation.
f) **Engineered First Flush:** Integrate existing and new climate forecasting tools to predict first flush conditions; begin development of a condition-dependent adaptive management framework for testing the action through coordination with natural resource and water agencies.
g) **Tidal Habitat Restoration:** Research to quantify local and system-wide contributions of restored tidal wetlands to Delta Smelt diets, and the effects of tidal wetland restoration on water temperature.

Other management actions evaluated in Round 1 were not included in the list of AM and research next steps because they are already being sufficiently studied and/or implemented with AM. AM and research next steps were not identified for the North Delta Food Subsidies and summer/fall operation of the Suisun Marsh Salinity Control Gates as AM is ongoing for those actions through the Delta Coordination Group. These AM efforts will create additional evidence that can be used to update the modeling of these actions in SDM processes. Next steps were not identified for Old and Middle River (OMR) management action because the models showed that action is supporting population growth (through decreasing entrainment mortality), and considerable study and refinement of that action has occurred to date. While supplementation is widely recognized by CSAMP participants as being necessary and experimental release of cultured fish is ongoing, supplementation was not identified as a next step by the TWG because the SDM process focused on actions to enhance self-sustaining population growth.

When there is high uncertainty in actions' effects and time to implementation as in the context of Delta Smelt management, a strategy robust to these uncertainties could be considered – i.e., a combination of actions that is expected to perform at least satisfactorily and that can generate improved knowledge of effects over time. Investing in and advancing multiple (or all of) the AM and research next steps to some degree could represent a tractable, robust strategy for Delta Smelt conservation for several reasons.

First, advancing multiple next steps is a means to address multiple factors (food, turbidity, flow, contaminants) that could achieve stable and increasing population growth over the long-term (ES Takeaways #3 and #4). For example, implementing food actions (e.g., managed wetlands or tidal wetland restoration) alongside turbidity actions (e.g., aquatic weed control) even through smaller-scale AM experiments could facilitate synergistic benefits for Delta Smelt (ES Takeaway #4), provided the actions generate their intended benefits.

Second, some redundancy in implementing multiple next steps for actions with the same intended benefit (e.g., food) could account for effect uncertainty and improve the likelihood that at least one action has a measurable benefit (ES Takeaway #6). For example, while tidal wetland restoration is underway in the Bay-Delta, there is not currently evidence that restored tidal wetlands will export food for use by pelagic fish like Delta Smelt. Relative to tidal wetland restoration, managed wetlands food production may be more likely to measurably increase zooplankton, but there's still questions on whether this action would produce the right kind of zooplankton for Delta Smelt and whether the action could be implemented without adverse effects (e.g., to dissolved oxygen concentrations). Advancing the research, implementation, and monitoring of both actions could increase the likelihood of generating more food to Delta Smelt in at least some areas.

Third, advancing multiple next steps from the list above could account for differences in technical feasibility that would provide opportunities to (a) implement (or continue to implement) and study actions that can improve Delta Smelt outcomes in the near-term, as well as (b) use focused science and research to investigate the technical feasibility of new actions with high potential benefits to Delta Smelt that could add tools to the management toolbox over the longer term (ES Takeaway #5).

We also acknowledge that the time to implement certain actions is contingent not just on technical knowledge but complex policy processes. For example, flow actions (e.g., increasing summer outflow) were predicted to have potential benefits for Delta Smelt and be technically implementable in the near-term (within 5 years). Flow actions also have the potential to have impacts on other water users and often involve lengthy decision processes before changes occur, which could delay the realized time to implementation. Agencies with a mandate for managing flow in the Delta are best placed to take the next steps of further analysis on the potential benefits and impacts of flow actions.

Lastly, we note that perfect information is not needed to make good management decisions. Adaptive Management is a means to implement actions that could benefit Delta Smelt in the short-term, accompanied by a formal plan for science and monitoring efforts that can reduce key uncertainties and improve management efforts over time. Reducing these key uncertainties through advancing multiple AM and research next steps can improve confidence in an action's predicted outcomes and help managers better assess which actions are preferred based on their expected benefits and costs.

The sections below describe each key AM and research next steps in more detail that was associated with seven management actions evaluated in Round 1. This information was developed by the Delta Smelt TWG. Each section first summarizes the focal management action and its Round 1 findings and knowledge gaps. Then the section states the AM and research next step and describes key uncertainties/roadblocks intended to be addressed with the action, relevance to management decisions, and any other technical considerations for implementation and monitoring.

6.1 Managed Wetlands for Food Production

Management action description: Voluntary and incentivized flooding/draining of managed wetlands in different seasons (spring, summer, and/or fall) is expected to produce more food (zooplankton, invertebrates) for Delta Smelt within wetlands that can then be released into adjacent Delta Smelt habitat.

Round 1 analysis and findings: The Round 1 effects analysis used empirical monitoring data and expert judgment from Kyle Philips (Durand Lab, UC Davis). Data came from 7 sites monitoring flood/drain operations in Mar-Apr. Effects for other time periods were based on expert judgment, since flooding/draining typically is not currently conducted in summer or fall. The quantified increase in food was ~1 mgC/m^3 per 1,000 ac of wetlands. Round 1 results showed no substantial increases to Delta Smelt population growth when this action was run individually; however, substantial benefits were predicted when the action was combined with other small-scale food and turbidity actions (e.g., aquatic weed control). The TWG believed, on average, that the action could be implemented at a smaller scale (e.g., 1,000 ac) in the next 5 years.

AM & research next step: Implement Adaptive Management for managed wetlands food production in Suisun Marsh, while investigating ways to scale up actions. Pilot implementation of managed wetlands food production and pond draining with adaptive management in Suisun Marsh, while investigating ways to scale up action in this and other areas in the North Delta Arc through coordination/incentivization with landowners. Emphasis on experimental/management approach will be to answer several near-scale and broader-scale management questions regarding food production and related operational impacts (see below).

Key uncertainties and/or roadblocks to address: Uncertainty around (1) the magnitude of zooplankton and other food source increases from managed wetlands using different timing for flood and drain practices; (2) access to land/cooperation with landowners to implement action at larger scales; and (3) effectiveness of getting newly created food resources (if any, in net production terms) to Delta Smelt and Longfin Smelt using "habitat overlap."

Relevance for management decisions: Managed wetlands may be a less expensive and more feasible action to increase Delta Smelt food sources compared to other actions evaluated in Round 1. Pilot implementation of managed wetlands food production at a smaller scale can provide data to: (a) quantify the magnitude of any food subsidies and under what conditions these subsidies occur, (b) better understand the factors that influence food output from managed wetlands, and (c) discover if proposed operations can be made without impacts to surrounding water bodies (e.g., dissolved oxygen sags). This additional experience can be used to consider trade-offs between food benefits and other factors (e.g., costs) associated with managed wetlands when compared to other food actions (e.g., tidal wetland restoration) over the long term. Engagement and outreach with landowners will inform the feasibility and cost to scale up the action, if desired.

Technical considerations for implementation & monitoring:

- Consider pilot wetland management actions in Suisun Marsh at a scale of ~1,000 ac total that follow protocols and recommendations outlined in the July 2021 *Suisun Ponds Productivity Report,"* by Tung et al. (2021).
- Investigate means for coordinating the delivery of food subsidies from local managed wetlands with operations of the Suisun Marsh Salinity Control Gate to maximize retention of these resources within the Marsh.
- Integrate managed wetland actions with pilot aquatic weed control methods (or other turbidity-related science actions) to more completely understand synergistic effects of small-scale food and turbidity subsidies in the field. Synergistic benefits were predicted in the Round 1 results and could be verified using this combined experimental approach.
- Provide guidance for monitoring protocols to effectively track taxa-specific Delta Smelt prey items to documenting the magnitude of increase (if any) associated with the managed wetland action (locally and regionally) -- see, for example, documentation of monitoring protocols within the Interagency Ecological Program (IEP) Tidal Wetlands Monitoring Program at: https://iep.ca.gov/Science-Synthesis-Service/Monitoring-Programs/Tidal-Wetland.
- Employ additional techniques to assess the impact of the additional food production (if any) on the health and survival of the target fish individuals and populations (e.g., stable isotope studies to assess if food is getting to the smelt and assimilated effectively).
- **Questions to Guide Funding/Action Proposals:**
  1) Do food subsidies derived from managed wetland operations add detectable food resources to the local or regional Delta Smelt-associated food web? What taxa seem to provide most of the added food value?
  2) Does delivery of food resources to adjacent waterways from managed wetlands cause unwanted side effects that need to be mitigated or accounted for (dissolved oxygen sags, for example)?
  3) Can we detect the quantity of additional food resources that Delta Smelt have access to or actually ingest?
  4) Can we use available techniques (likely analytical or simulation models) to assess how much additional productivity (and by association, how much managed wetland) we would need to increase Delta Smelt populations solely as the result of the associated food-web subsidy?

6.2 Aquatic Weed Control

Management action description: The current Invasive Aquatic Weed Control Program by the Division of Boating and Waterways objective is to maintain navigable waters and clear obstructions to water diversions. This proposed action would go beyond those objectives and build from the current control program by controlling aquatic weeds along the shorelines to maximize more open water habitat and increase turbidity to benefit Delta Smelt. The action will be conducted in key habitats for Delta Smelt (i.e., the freshwater portions of the North Delta Arc) and would be implemented during times of the year when the lifecycle models have identified when turbidity and/or prey are limiting. Increased intensity and scale of the control methods (which will primarily be the use of herbicides) would potentially result in more open water habitat which may increase available habitat for Delta Smelt and potentially increase pelagic prey. When possible, the action will integrate non-chemical control methods such as mechanical controls methods.

Round 1 analysis and findings: The Round 1 effects analysis used estimates of acres of submerged aquatic vegetation from Ustin et al. (2021) and based the effect of turbidity on estimates from Hestir et al. (2016), which used a combination of assumptions and regression models fit to historical data. Effects on food were estimated by assuming an increase in the baseline zooplankton density covariate in models proportional to new open water acres created through this action, which was the same method used for tidal wetland restoration. However, it is important to note that the tidal wetland restoration action assumed the opposite effect directionality: that the increased residence time, detrital matter, and other features of vegetation common to tidal wetlands and areas with submerged aquatic vegetation would increase food density whereas the analysis of aquatic weed control assumed these same features would reduce food density. It is also important to note that there is high uncertainty if either action can increase food, based on current evidence (see the AM and research next step for tidal wetland restoration for more details). The analysis assumed 100% effectiveness of aquatic weed control and was agnostic towards methods used (e.g., mechanical, chemical). The quantified increase in turbidity was 10-30% of baseline, historical conditions, depending on the subregion (e.g., assuming ~600 ac of aquatic weeds removed in Yolo/Cache Slough equated to a 10% increase in turbidity). Round 1 results showed that ~600 ac of aquatic weed control in Yolo/Cache Slough increased Delta Smelt population growth by 6–13% (across 2 population models used); 3.5K ac of aquatic weed control across 5 subregions increased population growth by 4–49% (across 3 population models used). Round 1 results also showed more substantial benefits when the action was combined with other food actions (e.g., tidal wetland restoration), even at a small scale. The TWG believed, on average, that the action could be implemented at a smaller scale (e.g., 600 ac) in the next 5 years but larger scales would require more than 5 years to implement.

AM & research next step: Implement Adaptive Management for different methods of control for invasive aquatic weeds, and their effectiveness of enhancing turbidity and food. Investigate ways of scaling up aquatic weed control, given region and species-specific interactions, target different temporal application methodologies, or use different methods in an integrated pest management approach to balance the costs of (financial and non-target effects) and the benefits of reduced weed coverage, reduced predation, and increased turbidity and prey.

Key uncertainty(ies) to address: Uncertainty around (1) the magnitude of turbidity and zooplankton change from aquatic weed control with different scales and methods for control, (2) secondary effects of different methods of control on non-target species, and (3) the efficacy of different methods and approaches (i.e., targeting nursery habitats during senesces) on controlling aquatic weeds.

Relevance for management decisions: Aquatic weeds have been increasing in density and area for decades, and their impacts on the environment can be detected in the change in the amount of pelagic habitat, turbidity, species composition, and food web function (Ustin et al. 2021; Hestir et al. 2016; Grimaldo et al. 2009). There is potential for multiple benefits from the improved control of aquatic weeds. Pilot implementation of aquatic weed control has been conducted, but the results determined that there are likely regional differences in the efficacy of the control methods (Rasmussen et al. 2022). There is a need to have better information on the regional differences and to improve the efficacy of control methods and approaches. These additional data can then be used to improve control methods and consider tradeoffs between the cost and impacts of the action compared to the potential benefits of those control methods on turbidity and food. Engagement and outreach with interested parties will inform the feasibility and cost of future areas for implementation to scale up the action, if desired.

Technical considerations for implementation & monitoring:

- Consider implementing alternative control methods that would include different application times and different controls such as non-herbicide approaches to determine regional and method effects on the control of aquatic weeds and the non-target effects.
- Consider integrating managed wetland or habitat restoration actions with pilot aquatic weed control methods (or other turbidity actions) to better understand synergistic effects of small-scale food and turbidity actions in the field. Synergistic benefits were predicted in the Round 1 results.
- Develop monitoring protocols for Delta Smelt prey including specific zooplankton taxa to evaluate how they change aquatic vegetation establishment or after aquatic vegetation removal and other Delta Smelt prey items to estimate magnitude of increase.

6.3 Physical Point-source Contaminant Reduction

Management action description: Implement constructed wetlands at key locations to reduce the loading of contaminants from the upper watershed into Delta Smelt habitat to improve fish survival.

Round 1 analysis and findings: Toxic contaminant effects in the Delta have been suggested to be the result of multiple "hot spots" of contamination with different contaminants, rather than system-wide chemical enrichment (NRC 2012, p. 89-96). Mitigating hot spots of toxic chemical input has reduced ecological effects of contaminants in San Francisco Bay (NRC 2012). Opportunities for such mitigation occur in the Delta (see Weston and Lydy 2010; Weston et al. 2019) but to date have been only sparingly implemented.

To evaluate the possible benefits of an example of toxic contaminant mitigation on Delta Smelt, given present levels of contamination, the action was modeled in the Yolo/Cache Slough Complex. The modeling assumed mitigation of contamination in the main source of the contamination (Ulatis Creek). The effect of mitigation on pesticide loadings was then upscaled to the region. The effect of that change in pesticide loading was modelled as a benefit to Delta Smelt survival and the population. The Round 1 effects analysis used empirical monitoring data, a model developed for the Upper San Francisco Estuary by Dr. Wayne Landis (Western Washington University), and assumptions from previous studies by the Landis lab. The Landis Lab provided historical concentration data for four insecticides of key concern to Delta Smelt. The Round 1 analysis assumed a 5% reduction in contaminants at the subregion level (50% local reduction and 10% of subregion's flows was assumed to go through managed area), which was informed by discussions with Delta hydrology experts in the absence of empirical data. Round 1 results showed that implementing the action in Ulatis Creek in the Yolo/Cache Slough subregion increased Delta Smelt population growth by 1-6% (across 2 population models used). Implementing the action at all 12 subregions increased population growth by 15-16%. Additional benefits were predicted when the action was combined with other small-scale food and turbidity actions (e.g., aquatic weed control). The TWG believed, on average, that the action could be implemented as a long-term action with realized benefits after 5 years.

AM & research next step: Implement Adaptive Management to test reduction in contamination by constructed wetlands at Ulatis Creek, which could reveal benefits from improving survival in a critical Delta Smelt habitat (Cache Slough). An adaptive management action to test using constructed wetlands at a contaminant hot spot important to Delta Smelt to mitigate contaminant inputs and monitor outcomes. To be feasible, such an action should take place in a location that meets the following criteria: (a) the location is important to Delta Smelt; (b) the location is a serious contaminant hot spot (enriched concentrations documented); (c) adverse effects of contaminants in the location of interest are documented by field evidence and/or advanced toxicity testing; and (d) the location is amenable to mitigation with a known technology. Ulatis Creek in the Cache Slough Complex meets these criteria (see below) and could be an ideal candidate site for implementing and testing constructed wetlands for contaminant reduction.

Key uncertainty(ies) to address: (1) the degree to which a constructed wetland (e.g., on Ulatis Creek) will reduce (e.g. 5% reduction due to the action) the priority contaminants in the specific habitat of interest (Yolo/Cache Slough), (2) how much (and what kind of) contaminant reduction is necessary to benefit food webs that support Delta Smelt growth, 3) how much contaminant reduction is necessary to reduce direct contaminant effects on reproduction and survival, and the availability of the land available to build the action. The uncertainty depends upon the degree to which the model may over-estimate contaminant removal or the toxic effects of contaminants vs. under-estimates acute toxicity due to modelled assumptions and the use of only a subset of the biologically available contaminants.

Relevance for management decisions: Toxic contaminants were determined to be likely "having deleterious effects on the health of organisms in the Delta" (DISB 2018). Few actions to date have targeted this specific potential source of stress for Delta Smelt. There are a range of possible actions to reduce contaminants in the Delta, including constructed wetlands, label changes, stormwater treatment, vegetated swales, etc. New measures to reduce contamination (label changes, stormwater treatment) are limited in efficacy. For example, the 2017 Amendment to the Water Quality Control Plan for the Sacramento and San Joaquin River Basins included a Pyrethroid Control Program (Water Board 2017), but that is largely limited to an individual contaminant class in which only one of the contaminants was identified by the Landis Lab.

However, hot spot mitigation with constructed wetlands could broadly reduce most of the contaminants identified as deleterious to Delta Smelt by the Landis Lab and seems feasible if the criteria cited above are followed. For example, Ulatis Creek/Cache Slough contaminant mitigation seems to meet all criteria for a feasible adaptive management experiment. The Cache Slough Complex of the North Delta is an important habitat for Delta Smelt. Chemical and toxicological testing in the complex indicated the aquatic biota are exposed to a variety of wastewater-derived food additives, pharmaceuticals, and personal care products in highest concentration during dry periods, and many insecticides, herbicides, and fungicides with peak concentrations after winter rains (Weston and Lydy 2010; Weston et al. 2019). The most important source of toxic chemicals is Ulatis Creek which carries stormwater from a watershed that contains urban and agriculture landuse into Cache Slough resulting in pesticide concentrations that pose a threat to aquatic life (Weston and Lydy 2010; Weston et al. 2019). When the commonly used testing species, *Hyalella azteca*, was placed in Cache Slough, toxicity — and, at times, near total mortality — was seen over at least an 8-km reach of Cache Slough that extended from the uppermost end almost to the junction with the Sacramento Deep Water Ship Channel (Weston et al. 2019). Recent studies using water from Delta Smelt habitat show sub-lethal effects to Delta Smelt also occur (Stillway-Garcia et al., in press). Finally, mitigating inputs of a broad suite of chemicals from Ulatis Creek to Cache Slough with a constructed wetland seems feasible based upon studies in other locations; targeting effects on specific chemicals would be both less efficient and less effective.

Testing the effect of mitigating one hotspot near an important Delta Smelt habitat could help managers decide whether and how to address this issue on a broader scale. Constructed wetlands could also be a design feature included in other restoration projects when the locations overlap a hotspot, possibly resulting in greater benefit than contaminant reduction alone. Outreach should be conducted with water quality and pesticide regulators on the details of how to most effectively control contaminant effects both for the AM study described here, and regionally. Some of the uncertainty regarding contaminant concentration targets could be determined using the Bayesian Network Relative Risk Model by the Landis Lab. These additional data can then be used to consider trade-offs between implementing the action to meet those targets contaminant effects and the cost of that action.

Technical considerations for implementation & monitoring:

- Consider implementing a restoration action to include contaminant mitigation in an Adaptive Management manner. Constructed wetlands can be part of the design for tidal wetland restoration projects in the vicinity of known contaminant inputs.
- Consider conducting outreach to regulators to inform them of which contaminants may be a significant hazard risk to the population. This is already in progress under the Delta Science Program, Metropolitan Water District, and the Contaminant Project Work Team.
- Develop controlled studies and monitoring protocols for taxa-specific zooplankton and other Delta Smelt prey items to estimate how toxicity affects opportunities for foraging and growth.

Pathways to implementation:

- Begin with one constructed wetland at one hotspot (see criteria above; e.g. Ulatis Creek).
- Monitor reduction of contaminants and changes in rates of zooplankton production. If feasible, estimate the effect of the wetland on Delta Smelt.
- Expand to other locations in the region as hotspots are identified and feasibility of constructing wetlands to mitigate contamination are evaluated.

6.4 Outflow Actions

Management action description: Outflow additional to the 1995-2015 observed conditions, either over a whole year or specific seasons, is expected to increase the quantity and quality of habitat for Delta Smelt, where suitable conditions of salinity, turbidity, temperature, and food better overlap, and thereby improve Delta Smelt growth and survival.

Round 1 analysis and findings: The Round 1 effects analysis assumed that X2 would be managed to specific levels (target X2 locations, e.g., 75 km) depending on water year type and month. Empirical models fit to historical data were used to quantify effects of outflow/X2 management on Delta Smelt distribution (CRM 2022a, Hamilton 2022), subregion-specific salinity (CRM 2022b), and subregion- and taxa-specific zooplankton density (CRM 2022c, Hamilton 2022). Water costs were estimated by applying published relationships between X2 and net Delta outflow to the difference in X2 between the observed conditions and the modeled condition given antecedent conditions (Denton 1993, Monismith et al. 2002). Water balancing within or across years was not completed, meaning a source for the additional outflow has not been identified so the feasibility of this action is currently undetermined. Round 1 results generally supported the expected trend where higher outflow resulted in positive Delta Smelt population growth and lower outflow resulted in negative growth. Increasing outflow in the summer to achieve X2 of 70 and 75 km in July and Aug, respectively, increased population growth by 5-12% (across 2 population models used, depending on water year types when action was implemented: Table 15). A separate outflow management strategy that increased flow in Jan-Oct to meet minimum thresholds ("full-year flows") increased population growth by 5-17% (across 2 population models used: Table 15). For model runs that included additional summer outflow, increasing flow in the fall did not further increase population growth. Again, the predicted Delta Smelt benefits from the outflow actions in the models were largely driven by modelled changes to fish distribution and food. The TWG believed, on average, that outflow actions could be implemented in the next 5 years. The TWG had moderate to high confidence on the flow/salinity effects of the action but low to moderate confidence regarding the distribution and food effects used in the analysis.

AM & research next step: Operations modeling to confirm the availability of water and the feasibility of operations necessary to achieve the various outflow/X2 management scenarios, with a focus on summer outflow/X2 actions.

Key uncertainty(ies) to address: (1) the availability of water and the operational feasibility to sustain the outflow action (to be addressed by the AM and research next step), 2) the effect size of the action on the performance metrics.

Relevance for management decisions: The Round 1 evaluation did not include detailed hydrological and operations modeling, given time and resource constraints of the process, and therefore simply assumed that outflow or X2 could be managed to the chosen targets. Detailed operational modeling – which would include balancing of water within and among years – is critical to confirm the fundamental feasibility of such operation, its sustainability, and the compliance with other regulations while implementing the action. Water cost estimates should also be updated based on the results of the operation modeling. This would better characterize the potential costs and benefits of outflow actions and inform decisions that could be implemented in the near-term (perhaps through an adaptive management framework).

Technical considerations for implementation & monitoring:

- Reviewed, commonly used, and stable versions of operations models (e.g., CalSim models) should be used to ensure reproducibility and representativeness of the model results.
- Determination of how the flow action is expected to be implemented, such as source(s) of water, the allocation of responsibility between CVP and SWP, and their interannual variability, which will then guide the development of the operation model.
- Operation baseline should represent the status quo but could potentially represent a future condition that is highly likely and reasonably foreseeable, and also overlaps with the time when the flow actions are expected to be implemented.
- Consider evaluating management scenarios that may increase the feasibility and/or reduce the cost of a summer X2 action (e.g., if summer X2 was to replace fall X2 as an action during wet years).
- Methods of spatiotemporal coupling between the operations models and the Delta Smelt and zooplankton models is a key consideration in the AM and research next step.
- Estimated water supply impacts, and the associated spatiotemporal distribution of such impacts, from the operations model should be used to update the water cost evaluation on Round 1.
- Depending on the results of this AM and research next step, it may be important to follow-up with a study on the cost of the water either in terms of monetary costs of bypassed diversions and/or the environmental impacts such as water release for salmonids (e.g., coldwater pool, redd dewatering).

6.5 Sediment Supplementation

Management action description: Reintroducing sediments upstream of or in the Delta is expected to temporarily increase turbidity in the Delta, which would provide better habitat conditions for all life stages of Delta Smelt. Increased turbidity in the low salinity zone is expected to reduce predation and increase food visibility for larvae.

Round 1 analysis and findings: The Round 1 effects analysis assumed the action would be implemented to achieve a turbidity increase as modeled in Bever and MacWilliams (2017), which includes a turbidity increase ranging from 2 to 18 NTU from May through Dec in the area from Lower Sacramento River and Lower San Joaquin River to Suisun Bay. The Round 1 results showed that the action increased Delta Smelt population growth by 11-73% (across 3 population models used). A turbidity increase is also expected to be synergistic with a food increase in terms of increasing modeled population growth rate, but the specific synergy between sediment supplementation and food actions was not modeled. The TWG believed, on average, that sediment supplementation would require more than 5 years to implement and expressed uncertainty in the feasibility of the action.

AM & research next step: Feasibility studies to identify potential sources of suitable sediment and practically and economically feasible engineering solutions to transport sediment from the source location to the reintroduction point. Additional hydrodynamic modeling of different reintroduction points could also be conducted to inform practical considerations for implementing the action.

Key uncertainty(ies) to address: (1) the availability, location, yield, and sustainability of sources of suitable sediment, and (2) practical obstacles of implementing the action, such as cost, excavation, transportation, and storage of sediment, potential negative environmental impacts, and permitting pathways.

Relevance for management decisions: Sediment supplementation was identified as the action with the highest predicted increase in Delta Smelt population growth in two models used in Round 1; however, the action was implemented in the models with the assumption that it can be implemented as what was modeled in MacWilliams and Bever (2017), and that the simulated effect in MacWilliams and Bever (2017) can still be achieved when the action is implemented under different conditions. TWG generally agrees that the highest uncertainty stems from action implementation. It is thus critical to confirm the fundamental feasibility of the action (e.g., whether there is sediment that can be practically reintroduced to the Delta). The AM and research next step is a prerequisite for any subsequent next step on this subject, such as a small-scale local experiment of sediment supplementation.

Technical considerations for implementation & monitoring:

- Consider whether the sediment source would allow repetition of this management action (i.e., longer-term sustainability).
- Consider evaluating the possible regulatory requirements for the excavation, transport, storage, and introduction of sediments.
- Consider implementing the AM and research next step via a feedback loop between source identification and additional modeling, where the sediment reintroduction in the models should be bounded by practical feasibility and cost. Any potentially negative environmental impacts (e.g., introduction of contaminants) identified in the feasibility study should be evaluated against the expected Delta Smelt benefits in the SDM process.

6.6 Engineered First Flush

Management action description: Through a combination of modified exports and water releases, this action would provide flows to approximate a hydrologic event that creates 'first flush' like conditions on the Sacramento River in years that otherwise would not reach a flow threshold. This action is expected to produce a pulse of fresh, turbid flow and could attract Delta Smelt to move into spawning locations in the North Delta and reduce the risk of entrainment of adults and subsequent larvae and juveniles (Sommer et al. 2011). This action would require a pathway for generating sufficient turbidity to create a signal for adult Delta Smelt to detect and respond to in addition to the flow. Such turbidity could be generated through the Yolo Bypass or other novel concepts such as turbidity supplementation.

Round 1 analysis and findings: The Round 1 effects analysis assumed that either 50% or 100% of Delta Smelt distribution that historically was in the Lower San Joaquin, East Delta, and South Delta subregions would be distributed in the Yolo/Cache subregion instead in Feb-June following the action. Assumptions were informed by observations of increased Delta Smelt entrainment in the Export Pumps in years with no first flush; however, there is a lack of data to understand the proportion of the population that this influences. Round 1 results using the IBMR model predicted a 7 and 12% increase in Delta Smelt population growth from baseline/historical conditions when 50 or 100% of fish were assumed to move to Yolo/Cache, respectively. The TWG believed, on average, that the action could be implemented in the next 5 years.

AM & research next step: Integrate existing and new climate forecasting tools to predict when first flush conditions are expected and not expected to develop; begin development of a condition-dependent adaptive management framework for testing the action through coordination with natural resource and water agencies.

Key uncertainty(ies) and/or roadblocks to address: (1) Generating enough turbidity to create a sufficient signal, (2) forecasting precipitation and first flush conditions ~1-2 months in advance, (3) optimal timing and volume of first flush, and (4) the effects of the action on Delta Smelt entrainment and movement now that most of the spawning population is hatchery fish released in the vicinity of Rio Vista.

Relevance for management decisions: Using an engineered first flush action in years where it was not expected to occur naturally could attract Delta Smelt to move into spawning locations in the North Delta and reduce the risk of entrainment of adults and larvae in the winter/spring. This could potentially reduce restrictions at the South Delta water pumps but would require reservoir releases and/or export reductions to implement. The anticipated water volume required for this action (~150TAF) is lower than other flow actions considered in the Delta Smelt SDM evaluation.

Implementing this action within an adaptive management framework would first hinge on the development of tools that could forecast precipitation and other climatic factors (e.g., temperature) ~1-2 months in advance and ultimately predict the likelihood that a first flush would occur naturally in the winter/spring. With these forecasting tools in hand, a collaborative effort between natural resource and water agencies could develop a decision framework that specifies “triggering conditions” for when to deploy the action when a first flush was not expected to occur on its own and monitor outcomes. In addition to monitoring Delta Smelt movement and entrainment outcomes, this AM framework could include research to understand the relationships between volume of water deployed in this action and expected effects of increased turbidity delivered from the Yolo Bypass.

Technical considerations for implementation & monitoring:

- Consider coordinating engineered first flush action with sediment supplementation to synergistically increase turbidity in the Sacramento River.
- For developing an adaptive management framework, consider testing different timings of the action to compare effects on Delta Smelt and water supply from earlier (Dec) vs. later (Feb) first flushes. Different approaches/policies to test could include:
    - (1) wait for natural first flush, and if one doesn’t occur, implement action in Feb. This would reduce forecasting uncertainty and generally save water; or
    - (2) regardless of forecasts, implement engineered first flush in Dec, Jan, and Feb in different years. This would strategically test which month is best for Delta Smelt.
- Consider using supplemented Delta Smelt to test action.
- Consider pre-post monitoring when evaluating effects of action.

6.7 Tidal Wetland Restoration

Management action description: Converting agricultural land and/or managed wetlands to tidal wetlands, composed mostly of emergent marsh vegetation and shallow open water areas, is intended to increase food (including of zooplankton, benthic invertebrates, fish eggs/larvae), habitat, and foraging space for Delta Smelt.

Round 1 analysis and findings: Although Delta Smelt are a primarily open-water pelagic species, it is hypothesized that tidal wetland restoration could improve conditions for Delta Smelt by 1) increasing food concentration within the wetland greater than it is in nearby open-water channel habitat, assuming that Delta Smelt regularly forage in or near tidal wetlands, 2) exporting food into nearby open channels to increase the food concentration in surrounding pelagic habitat, 3) increasing overall productivity in surrounding channels and system-wide, leading to greater zooplankton biomass, or 4) decreasing water temperatures within the wetland and in surrounding channels through the mechanisms identified in Enright et al. (2013).

The TWG reached out to scientists engaged in food web monitoring of recently completed tidal wetland restoration projects to see if this data could be used, but the recommendation was that it was premature to use this data for the SDM process at this time (in 2022). As a result, the TWG relied on theoretical models and assumptions to estimate a low and high bookend food effect for tidal wetland restoration in Round 1. The high bookend was based on adapting and combining two theoretical modeling efforts that predicted (a) the change in phytoplankton from restored wetlands (SFEI-ASC 2020; Cloern et al. 2021) and (b) the change in zooplankton, given the change in phytoplankton (RMA 2021). The low bookend was based on a coarse assumption that the food benefit would be at least proportional to new open water acres created through tidal wetland restoration. Through meeting with the IEP Zooplankton Project Work Team in Oct 2023 after tidal wetland actions and portfolios had been modeled, that team advised that the RMA (2021) study likely overestimated effects on zooplankton. They further discussed that the true food effect of tidal wetland restoration could be between 0 (no effect), our "low bookend," or higher, but they couldn't define a "high bookend". Therefore, we used model runs with the low bookend effect of tidal wetlands when reporting Round 1 results in process deliverables. The low bookend method estimated a 5% increase in food with ~8,900 ac of restored tidal wetlands, and a 16% increase in food with ~30,000 ac across the North Delta Arc, resulting in a 4-8% and 6%-20% increase in Delta Smelt population growth, respectively, across the 4 population models used.

There is mixed evidence regarding the food benefits of tidal wetlands for Delta Smelt. For instance, there is evidence that tidal wetlands do not export zooplankton to nearby channels where Delta Smelt occur (Kimmerer et al. 2018; Yelton et al. 2022; Herbold et al. 2014) even when this exportation might be expected based upon casual observation or first principles. To date, quantitative monitoring of restored wetlands has not observed changes in potential prey density for Delta Smelt, but more years of monitoring are likely required to detect any changes. Delta Smelt gut fullness was reported to be higher in areas adjacent to large wetlands (Hammock et al. 2019). However, a TWG member suggested that this study was spatially confounded, and the metric of adjacency to wetlands was not separable from other well-known spatial differences in habitat quality between Suisun Bay and Marsh (which have relatively abundant wetlands but also other benefits to food concentration like the location of the estuarine turbidity maximum zone) and the Delta (with limited wetlands). While tidal wetland restoration may provide some benefits for Delta Smelt diets, no research to date supports the assumption that food density or flux would increase proportionally with the quantity of new open water acres created through tidal wetland restoration. This makes the estimated increase in food based on this assumption uncertain and propagates through to uncertainty in the population-level benefits of this action for Delta Smelt. Given this uncertainty, caution should be used when comparing the benefits of tidal wetland restoration for Delta Smelt with benefits of other actions.

As part of the Delta Smelt SDM evaluation, we also collaborated with NASA JPL to estimate the effects of tidal wetland restoration on temperature. The study (Gustine et al. 2022) used remote-sensing data to estimate pre-post effects of restoration at Tule Red and Winter Island. Results showed that water temperatures in areas surrounding restored wetlands had mean temperatures that were between 0.25 and 0.57°C lower following restoration between June and Sept. These trends align with other studies that suggest tidal wetlands could decrease temperature (e.g., Enright et al. 2013). However, the results were not statistically significant – likely due to the low sample size of sites and years, which could be increased in the future. This study was also a methodological pilot rather than a test of the overall cooling effect of tidal wetland restoration. Future studies could leverage the Gustine et al. methodology for further insights into this potential benefit.

AM & research next step: Research to quantify local and system-wide contributions of restored tidal wetlands to Delta Smelt diets, and the effects of tidal wetland restoration on water temperature.

Key uncertainties and/or roadblocks to address: (1) the magnitude and direction of zooplankton biomass change relevant to Delta Smelt diets from restored tidal wetlands both within the wetland and in nearby channel habitat, (2) the extent to which Delta Smelt utilize tidal wetlands to forage, (3) better understanding of when and where prey density versus some other foraging constraint is limiting Delta Smelt growth and survival, (4) the extent to which increased productivity would result in increased zooplankton biomass relevant to Delta Smelt, and (5) the magnitude and direction of temperature change from tidal wetland restoration both within the wetland and in nearby channel habitats.

Relevance for management decisions: Tidal wetland restoration is a management action that is currently being implemented in the San Francisco Estuary – including ~9,000 ac of tidal wetland restoration projects that have been implemented or planned at specific sites with an additional ~5,000 ac at other stages of planning in the EcoRestore initiative (https://water.ca.gov/Programs/All-Programs/EcoRestore). Some of these acres were previously required to mitigate for the long-term operations of the State Water Project and Central Valley Project under the hypothesis that they would contribute to Delta Smelt food (USFWS, 2008; Sherman et al., 2017). Reducing the key uncertainties identified in the prior section would contribute to future decision making on whether to implement more tidal wetland restoration for the benefit of Delta Smelt. Improving confidence in the predicted Delta Smelt population growth benefits would support cost-effectiveness comparisons with alternative actions to increase food or reduce water temperatures.

Technical considerations for implementation & monitoring:

- Consider the spatial scale of the analysis. There are uncertainties at both small and large scales: do restored tidal wetlands increase local biomass of zooplankton and other Delta Smelt prey such as larval fishes? And do restored tidal wetlands create system-wide increases in zooplankton biomass? What scale of alteration is necessary to detect system-wide change?
- Especially when evaluating export of zooplankton, primary productivity, detritus, or temperature, consider the spatiotemporal scale and tidal cycles since prior research has shown that intensive temporal sampling is necessary to quantify plankton import/export from wetlands and temperature changes from wetlands (Yelton et al. 2021; Enright et al. 2013).
- Consider the relevance of zooplankton for Delta Smelt diets. All zooplankton are not equivalent food sources, some are nutritionally better or more preferred than others.
- Consider the metric that would be most helpful for management decisions. If there is a benefit of tidal wetland restoration for food production or temperature reduction, it would be helpful to know how much food is produced per acre of restored habitat, or how much temperature is reduced for each acre of restored habitat or quantity of flow moving through the habitat.
- **Questions to Guide Funding/Action Proposals:**
    1) Do food subsidies derived from tidal wetlands add detectable food resources to the local or regional Delta Smelt-associated food web? What taxa seem to provide most of the added food value?
    2) Can we detect the quantity of additional food resources that Delta Smelt have access to or actually ingest as the result of completing tidal marsh restorations?
    3) Can we use available techniques (likely analytical or simulation models) to assess how much additional productivity (and by association, how much tidal wetland) we would need to increase Delta Smelt populations solely as the result of the associated food-web subsidy?

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Appendix 1 – Delta Smelt Modeling: Details & Resources

Individual-based Model in R (IBMR)

Lead Modeler for CSAMP Delta Smelt SDM Process: Will Smith, USFWS

The IBMR Version 3 (Smith 2022; Figure 22) includes cohorts spawned from 1995 to 2014. A cohort year begins at the beginning of simulated spawning in Feb and ends the following Jan. Reproduction, movement among 12 spatial strata (Figure 3), growth, and mortality of a closed population are modeled. The simulated population in one year depends on the characteristics of the simulated population in the previous year.

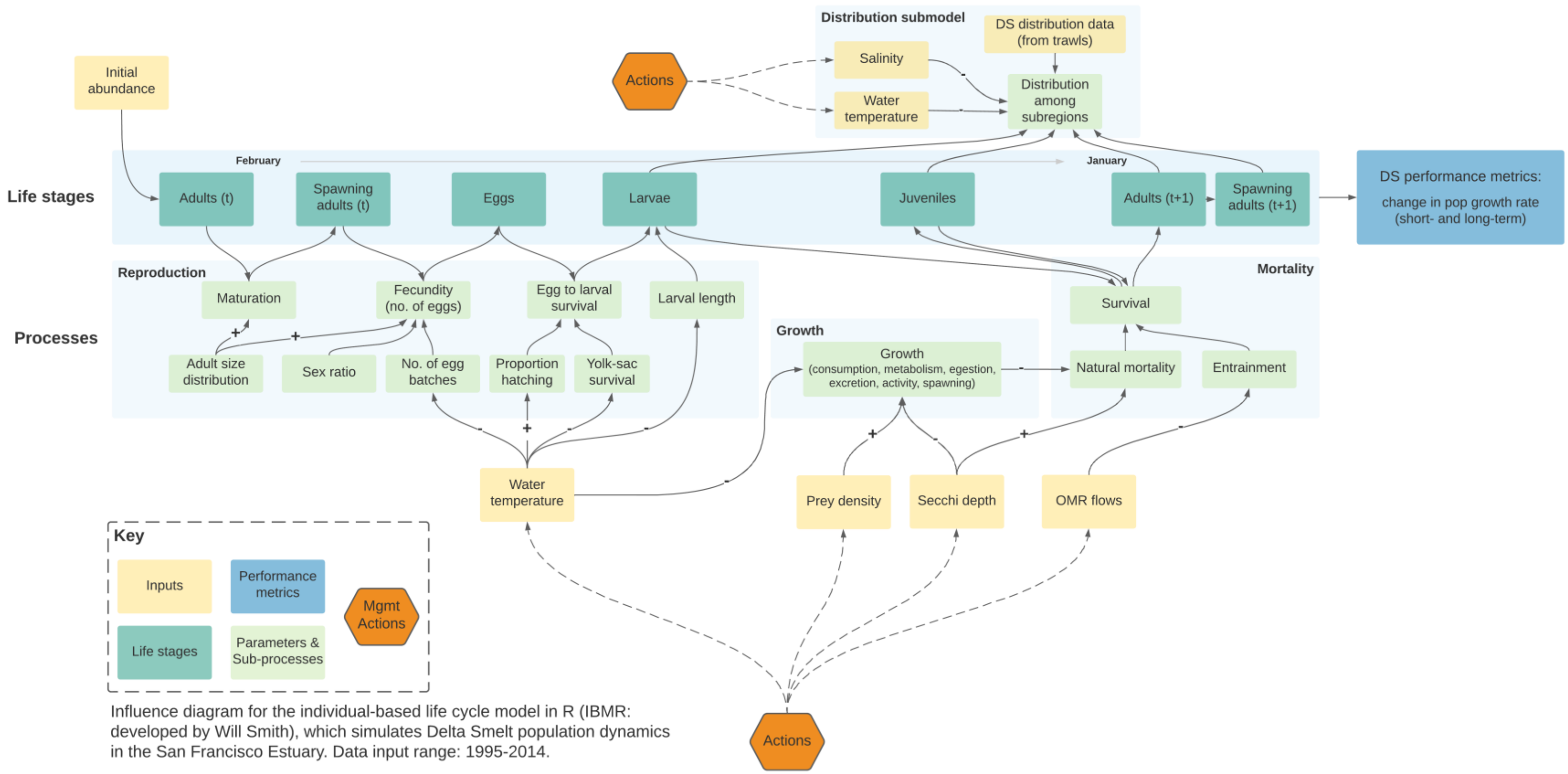
The IBMR is a modification of the IBM in Fortran (DSIBM), presented by Rose et al. (2013a and 2013b). By design, many features of IBMR are identical to Rose's original DSIBM, but IBMR was developed to be more accessible by using a more common statistical program and providing a set of open-source code that can be accessed and run by any R-user.

IBMR was calibrated to abundances and growth rates estimated for the wild Delta Smelt population. The model is suitable for assessing relative changes in population growth rates for Delta Smelt given changes to abiotic and biotic conditions in the San Francisco Estuary (SFE).

A single "model run" of the IBMR consisted of predicting population dynamics for 20 years using 300 independent iterations to account for uncertainty of model parameters and stochasticity. The model produces results where median (across the 300 iterations) annual Delta Smelt population growth rate (or lambda), calculated as the number of adult breeders in one year divided by adult breeders in the previous year. The geometric mean of these median annual growth rates is calculated to represent average growth rate across 1995 to 2014 for each action run, and this value is then used to calculate the performance measure of % change in population growth from the baseline.

Baseline predictions were generated by fitting the IBMR to historical data 10 different times to independently estimate parameters and predict population growth rates. The background variation in model predictions was captured by results for the "Min base" and "Max base", which represent the lowest and highest estimates of population growth rates, respectively, from these baseline runs. The final % change in population growth from the baseline was calculated as the average growth rate from the action model run divided by the average growth rate for the min and max base runs minus 1. This produces a final metric where: values above 0 indicate increased population growth relative to the baseline; values below 0 indicate decreased population growth relative to the baseline; and values near 0 indicate no substantial change in population growth relative to the baseline.

Figure 22. IBMR Conceptual Diagram showing model structure and effect pathways between actions, inputs, parameters, population outcomes.



Influence diagram for the individual-based life cycle model in R (IBMR: developed by Will Smith), which simulates Delta Smelt population dynamics in the San Francisco Estuary. Data input range: 1995-2014.

Life Cycle Model Entrainment

Lead Modeler for CSAMP Delta Smelt SDM Process: Will Smith, USFWS

The Delta Smelt Life Cycle Model with explicit modeling of entrainment (LCME; Smith et al. 2021) is a statistical model that estimates the relationship between ecosystem conditions and Delta Smelt reproductive and mortality rates using 21 years of abundance, entrainment, and ecosystem covariate information. The model is nonspatial – it does not account for Delta Smelt movement or environmental conditions that occur locally (subregion-specific). The LCME tested a variety of covariates indexing Delta ecosystems conditions, for association with Delta Smelt recruitment, natural mortality, and entrainment mortality. An earlier version of the LCME (LCMG: Polansky et al. 2021, see Appendix C, Table C.2, Figure C.1; Figure 23 in this report) found substantial evidence for the effect of summer outflow on survival (in June-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). This set of covariates is shown in the "Preferred" model in Table 19. 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."

A simulation model was integrated with the LCME to use the estimated relationships and modified covariate values (representing changes from management actions) to project growth of the Delta Smelt population under management actions and portfolios for 20 years (Smith 2021b).

Table 19. Alternate models for the LCME that were fit and validated by Will Smith for evaluation of different Delta Smelt management actions and portfolios included in the Round 1 evaluation. Each model differs in the set of covariates that was included across time periods. "-" indicates models with the same set of covariates as the preferred model in a given time period.

Model	Actions	Portfolios	Covariate(s) included by time period					
			Apr-May	June-Aug	Sept-Nov	Dec-Jan	Feb	Mar
Preferred	Summer outflow sensitivity	Portfolio 1b	Temp Turb (South Delta) OMR	Outflow Turb (South Delta) OMR	Turb (Delta-wide)	Age 1+ striped bass Turb (South Delta) OMR	Prey Turb (South Delta) OMR	Prey Turb (South Delta) OMR
Spring outflow	NA	Portfolio 2a	Outflow Turb (South Delta) OMR	-	-	-	-	-
X2	Summer X2 sensitivity	Portfolio 3c	-	X2 Turb (South Delta) OMR	-	-	-	-

Model	Actions	Portfolios	Covariate(s) included by time period					
			Apr-May	June-Aug	Sept-Nov	Dec-Jan	Feb	Mar
Food	Tidal wetland restoration sensitivity	Portfolios 3a, 3d, 3e	Prey Turb (South Delta) OMR	Prey Turb (South Delta) OMR	-	-	-	-

Figure 23. From Polansky et al. 2021 (Appendix C, portion of Figure C.1): Relationships estimated previously in the LCMG (Life Cycle Model – General), showing a positive relationship between outflow and survival of postlarvae (PL: June-Aug) and a relatively flat relationship between outflow and survival of juveniles (J: Sept-Nov) and subadults (SA: Dec-Feb). "Predicted vital rates for preliminary models using a single predictor variable of the same type for each state process model. Each panel row corresponds to a different model and the columns are the different vital rates. The solid curved lines show expected values, dark and light grey shadings show the 100(1-α)% central credible intervals for α = 0:5 and α = 0:05, respectively, and include posterior parameter estimate uncertainty. The dashed and dotted lines show the 50% and 95%, respectively, central credible intervals using the mean values of the posterior. Units are multi-day totals (outflow), over the time step of each vital rate."

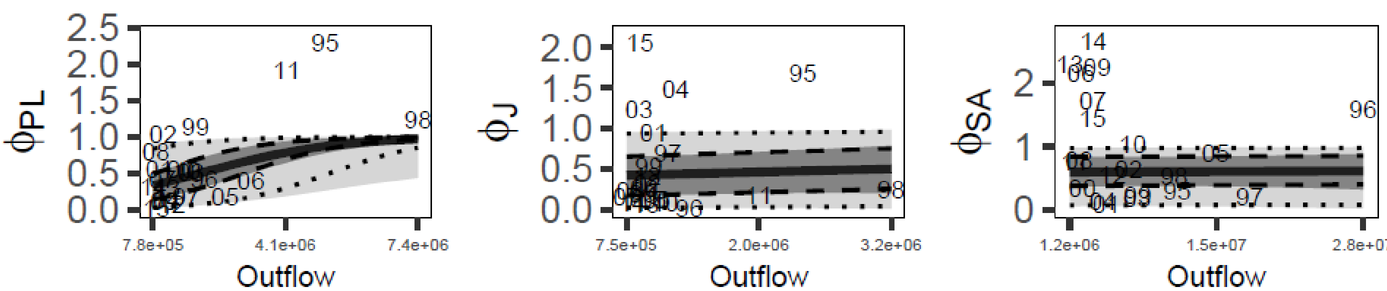


Table 20. Alternate models for the LCME that were tested by Will Smith for the purpose of evaluating a management action but were not applied because there was insufficient evidence to support the model.

Covariate(s) included by time period						
Model	Apr-May	June-Aug	Sept-Nov	Dec-Jan	Feb	Mar
X2 summer/ fall	Temp Turb (South Delta) OMR	X2 Turb (South Delta) OMR	X2	Age 1+ striped bass Turb (South Delta) OMR	Prey Turb (South Delta) OMR	Prey Turb (South Delta) OMR
Silversides 1	Silversides Turb (South Delta)	Outflow Turb (South Delta)	Turb (Delta-wide)	Age 1+ striped bass Turb (South Delta)	Prey Turb (South Delta)	Prey Turb (South Delta)

Covariate(s) included by time period						
Model	**Apr-May**	**June-Aug**	**Sept-Nov**	**Dec-Jan**	**Feb**	**Mar**
	OMR	OMR		OMR	OMR	OMR
Silversides 2	Silversides + Temp Turb (South Delta) OMR	Outflow Turb (South Delta) OMR	Turb (Delta-wide)	Age 1+ striped bass Turb (South Delta) OMR	Prey Turb (South Delta) OMR	Prey Turb (South Delta) OMR
Food 2	Prey Turb (South Delta) OMR	Prey Turb (South Delta) OMR	Prey	Age 1+ striped bass Turb (South Delta) OMR	Prey Turb (South Delta) OMR	Prey Turb (South Delta) OMR
Food 3	Prey Turb (South Delta) OMR	Prey Turb (South Delta) OMR	Turb (Delta-wide) + Prey	Age 1+ striped bass Turb (South Delta) OMR	Prey Turb (South Delta) OMR	Prey Turb (South Delta) OMR
Turbidity	Turb (Delta-wide) OMR	Turb (non-South Delta) OMR	-	-	-	-

Maunder & Deriso Model in R

Lead Modelers for CSAMP Delta Smelt SDM Process: Michael Tillotson (Senior Fisheries Biologist, ICF) and John Brandon (Senior Biometrician, ICF)

The MDR is a statistical life cycle model modified from a previous version (Maunder and Deriso 2011, Tillotson and Brandon 2022). It included a similar structure and methods to the LCME, where it captured life stages within a year, was non-spatial, and used several versions to evaluate different management actions and portfolios. Although versions of the MDR with density dependence and density independence were originally developed and discussed with the TWG, the TWG agreed to use and present results for the density independent model runs only in the Round 1 evaluation.

Table 21. Alternate models for the MDR that were fit and validated by ICF for evaluation of different Delta Smelt management actions and portfolios included in Round 1 evaluation. Each model differs in the set of covariates that was included across time periods. Different covariates were used for the Mar-May time period in models that included density dependence (DD) and those that did not include density dependence (no-DD).

Model	Portfolios	Apr-June/June-Aug	Sept-Nov	Dec-Feb	Mar-May
OMR	Portfolio 1b, 3a, 3d, 3e	OMR (Apr-June) Temperature	Turbidity (Delta Wide) Temperature	Age 1+ striped bass Prey OMR	Temperature (No-DD) Lagged Fall X2 (DD)
X2	Portfolio 2a, 3c	X2 Temperature	Turbidity (Delta Wide) Temperature	Age 1+ striped bass Prey OMR	Temperature (No-DD) Lagged Fall X2 (DD)
Food	Portfolio 3a, 3d, 3e	Prey Temperature	Turbidity (Delta Wide) Temperature	Age 1+ striped bass Prey OMR	Temperature (No-DD) Lagged Fall X2 (DD)

Limiting Factors model

Lead Modeler for CSAMP Delta Smelt SDM Process: Scott Hamilton

The Limiting Factors model (previously called the "Hamilton & Murphy model") applies a multiple regression analytical technique that incorporates the recognition of limiting environmental factors – i.e., the concept that certain factors influence abundance in certain seasons or years but may have no influence on the species' performance at other times. The model is generally described in Hamilton and Murphy (2022) and its specific adaptation for the CSAMP Delta Smelt SDM process is explained in this document.

The Limiting Factors model first selects the covariates that best explain variation in historical Delta Smelt performance from 62 covariates, which include factors such as X2 location, magnitude and timing of first flush, flows in Yolo bypass, power plant operations, adult and juvenile salvage, the spawning window, exports, predation, and average Secchi depth, temperature, salinity, and food experienced by Delta Smelt. Many covariates are specified for a two-month period (Mar-Apr, May-June, July-Aug, etc.). The final model used in the Round 1 evaluation contained 9 covariates: (1) Exports in Mar-Apr, (2) End of spawning (essentially spawning duration), (3-4) Secchi depth in Mar-Apr, May-June, (6-7) Food in Apr, June-Aug, (8) Water Temperature in July-Aug, and (9) EC in July-Aug. The model's R^2 was 0.94 for the 20-yr period from 1995 to 2014 (ES-1). Similar to the LCME and MDR, some actions and portfolios manipulated covariates that were not included in the model.

The LF model was employed in conjunction with two other models. The first was a monthly food model (Hamilton 2022, 2023; Hamilton et al. 2020). That model explains density of calanoid copepods by subregion in the Delta as a function of water temperature, flow, salinity, upstream abundance of copepods and prior abundance of copepods. As an action changes flow or salinity, the distribution of calanoid copepods throughout the estuary changes. The second model predicts changes in Delta Smelt distribution. That unpublished model (Hamilton 2022) estimates the distribution of Delta Smelt by month as a function of region, outflow, prior distribution, temperature, turbidity, salinity, food, and OMR flows (the latter just for 4 regions). For both models, relationships were estimated by fitting coefficients that produced the minimum residual sum of squares, using the GRG nonlinear routine in Excel (Solver).

The LF model version used in the Round 1 evaluation estimates 18 parameters (for 9 covariates) using 24 observations with a resulting R^2 of 0.94. Similar to the original model version (Hamilton and Murphy 2022), Scott Hamilton recognized that some overfitting was likely and conducted a cross-validation analysis that produced an R^2 of 0.70. These results were reviewed with the TWG, and Scott interpreted that this cross-validated R^2 was likely the more accurate indication of the explanatory power of the model.

Model Baseline Predictions

Table 22. Mean predicted population growth rates for each Delta Smelt model (and alternate model version) under baseline, historical conditions between 1995-2014.

Model	Statistic	Population Growth = N(t)/N(t-1)	Description of baseline calculation
IBMR	Min - Median	0.98	The IBMR was fit to historical data using 10 different replicates of 300 simulated time series to capture background variation in model predictions. For each replicate, median Delta Smelt population growth rate (λ) was calculated for each year, as well as the geometric mean of these medians across all years. The IBMR baseline is presented as the minimum and maximum mean λ from the 10 replicates. Annual medians of simulated lambdas for a given year are also available in other spreadsheets.
	Max - Median	0.99	
LF	Average	0.86	The LF was fit to historical conditions and applied a multiple regression analytical technique that incorporates the recognition of limiting environmental factors. An optimization algorithm fit model parameters to historical conditions for 9 covariates, and it did not incorporate parameter uncertainty or stochasticity.
LCME (best)	Median	0.91	The LCME projection model makes a large number of stochastic projections. Each of those is a time series, with 21 annual lambdas. The median of all simulated lambdas (median among 2.1 million values) is the baseline median reported for the LCME. Annual medians of simulated lambdas for a given year are also available in other spreadsheets.
LCME (X2)	Median	0.94	
LCME (Turbidity)	Median	1.00	
LCME (Food)	Median	0.95	
LCME (Spr-Sum outflow)	Median	0.92	
MDR (sum X2)	Average	1.12	The most recent set of MDR runs did not include an exhaustive covariate/model selection procedure. Hence no "best" estimate of lambda is presented. Rather, the goal of the current set of runs has been to provide a side-by-side
MDR (Turbidity)	Average	1.10	
MDR (Food)	Average	1.10	

Model	Statistic	Population Growth = N(t)/N(t-1)	Description of baseline calculation
MDR (OMR)	Average	1.13	comparison between MDR predictions of lambdas and those from other models by running the MDR with sets of covariate values that match, as closely as feasible, those used in other models (i.e. the LCME). Lambdas are calculated from the expectations of annual predicted adult abundance given alternative environmental covariate values for each action. The projections/predictions run "forward" from 2015 abundance, and are a function of the maximum likelihood parameter estimates for each scenario, estimated by fitting the MDR with the historical set of environmental covariate values for each scenario.

Model Documentation

Complete documentation of the models used in the Round 1 evaluation are provided in the “Delta Smelt Modeling Details and Resources” folder of this report’s supplemental material. Each of the four Delta Smelt population models has a subfolder with primary publications and other supplemental technical reports. The “Additional effects models for IBMR” subfolder contains technical memos describing methods and results for the following additional models:

- **Flow-salinity model:** “CRM 2022b…”
- **TWG Delta Smelt distribution model:** “CRM 2022a…”
- **Salinity-food model:** “CRM 2022c…” and Bashevkin et al. 2023a documents.
- **Contaminants-mortality model:** “CRM 2022d…”

Technical memos describing the methods for the submodels of the Limiting Factors model for predicting changes to food and Delta Smelt distribution are included in the “LF” subfolder.

Appendix 2 – Management Action Specification and Evaluation Sheets

Full details on the evidence, assumptions, methods, and predicted consequences of each management action are provided in the "Management Action Specification Sheets" folder of this report's supplemental material. All files begin with "Action summary" and are provided for the 12 actions evaluated in Round 1:

- Outflow/X2 management
- Suisun Marsh Salinity Control Gates
- North Delta Food Subsidies
- Sacramento Deep Water Ship Channel
- Managed wetlands for food production
- Tidal Wetland Restoration
- Aquatic weed control
- Sediment supplementation
- Franks Tract restoration
- Old & Middle River management
- Engineered First Flush
- Physical point source contaminant reduction

Appendix 3 – Outflow/X2 Water Resources

Water Resources Methods – Additional water volume

The CSAMP Delta Smelt SDM process evaluated flow actions and portfolios that are currently quite broad and exploratory in nature; therefore, detailed hydrology and operations modeling (e.g., with CalSim 3) was not conducted at this point in the process, but there was still a desire to compare the 'water cost' of actions/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 method of comparing the additional water volumes associated with different X2 management scenarios. The method involved the following steps:

1. **Define a reference scenario with monthly X2 values.**
   - For the SDM process, 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 23, 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 spring, 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).

$$X_2(t) = 0.919X_2(t-1) + 13.57Q^{-0.141}.$$ and $$X_2 = 167Q^{-0.141}.$$

   - We then used the G-model (Denton 1993, equation 5) to refine the steady-state outflow estimates

$$G = \frac{\bar{Q}}{\left(1 + (\bar{Q}/G_0 - 1)e^{-\bar{Q}t/\beta}\right)},$$

   - where G_0 is the value of G – the steady-state flows estimated from the Monismith equations – just before the step increase in outflow, and Q is the (constant) value of Q over the time interval (i.e., the focal value being calculated). 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 factor 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. However, other operations in the system might reduce or increase these costs and more detailed modeling would be needed to confirm any costs.

    ii. Negative numbers represent the potential for "water savings," 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. Negative values can occur for a given month if an outflow/X2 action specified a lower X2 value than historical in a previous month. The action would simulate using additional outflow (relative to historical) in the previous month to move X2 to a lower position. Therefore, the next month could require less flow (relative to historical) to meet the X2 position.

    iii. 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 resources are intended to be used for relative comparisons between Round 1 actions and portfolios. 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.

Table 23. Historical X2 locations used in "baseline" model runs (left); X2 inputs for model runs for Reference Portfolio 1b (current management approximation, including Fall X2 ≤ 80km in W and AN years)(right). 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 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

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
69	54	51	48	50	55	62	71	72	72	79	73
69	56	50	57	60	65	75	77	78	80	82	67
47	45	56	69	72	76	78	78	80	80	83	74
69	49	47	49	53	53	59	66	68	72	73	62
64	56	52	59	64	70	75	79	80	80	84	79
78	62	52	62	65	73	78	80	80	80	85	84
80	74	68	74	76	78	83	87	88	88	85	74
64	72	72	73	74	77	81	85	88	87	84	80
63	62	69	71	63	69	77	79	80	80	84	76
65	66	57	65	71	81	80	82	85	84	81	81
70	68	64	62	62	61	72	80	82	84	86	79
55	55	53	46	48	57	69	77	79	80	86	83
79	75	71	75	76	79	82	87	86	88	88	86
75	68	71	77	78	79	84	89	88	90	87	85
84	77	69	74	72	76	82	85	87	86	86	84
79	66	68	70	67	69	78	84	85	85	84	72
60	66	59	51	56	59	65	76	75	74	79	81
81	76	74	67	70	78	79	82	87	86	85	71
65	70	75	75	76	78	81	84	84	86	86	84
85	81	77	79	84	85	86	88	89	88	84	74

Water Resources Methods – Monetized water cost

In order to represent the monetary cost of additional water required for flow actions, a per acre foot dollar value of water was recommended by Bill Phillimore and discussed by the CSAMP Policy Group (Dec 2023 meeting). Bill's memo to the Policy Group is provided below.

Again, these methods and subsequent results are coarse in nature and are intended to be used for relative comparisons between Round 1 actions and portfolios. There are certain aspects of the methods that could be improved with more detailed hydrology and operations modeling in the future. In addition, the availability, applicability, and the monetary cost of the water are all highly dependent on the source. One should therefore caution against interpreting the monetized water cost as if one could purchase such water with the estimated amount of funding. Other potential economic effects and resource benefits related to flow actions were outside the scope of the Round 1 evaluation and not factored into these estimates.

Memo sent from Bill Phillimore that was distributed in the pre-reading materials for the Dec 2023 Policy Group meeting:

Toward addressing the marginal cost of water in conservation planning: valuation in support of assessing and prioritizing alternative management actions in the Delta

In a recent CSAMP policy group meeting, during an update presentation from the Structured Decision-making process, the facilitators from Compass posed an important question. What should be the operational cost of water used in costs-benefits assessments? The answer to the question becomes an essential parameter in the program's analyses and informs the project's "consequences table" deliverable. It is understood that the value or range of values of water will serve as a basis for comparisons of candidate management actions and prioritization of actions that emerge from structured decision-making to be implemented in an adaptive-management framework.

For the reasons given below, the cost of **$815 per acre-foot** is recommended to be used for the water lost from diversion and export as a result directed management actions in the Delta that are intended to benefit listed fish species and other resources of conservation concern.

The cost of water that might otherwise be diverted to management actions in the Delta can be calculated using a variety of methods. Although the cost of water to potential users may vary from year to year, depending on the precipitation in the previous winter and reservoir levels at those times, a water-cost valuation should integrate values expected over multiple years, reflecting the terms of proposed management actions. That value cannot be dependent on a spot-price of water at any given moment.

A reasonable method of valuation is to draw from water-cost projections that will be borne by participants in the proposed off-stream Sites Reservoir project in the Sacramento Valley. It is the latest large project to be planned for either the State or Federal systems. It has participants that include both agricultural and urban contractors who understand that the projected cost of Sites water must be affordable. The valuation is conservative, given that the reservoir is not expected to be completed for a number of years yet, and significant unknowns attend both the ultimate yield and the construction costs.

The most recent source of public information about the cost of water comes from the *Sites Project Value Planning Alternative Appraisal Report* (dated Apr 2020). After examination of various alternative yields and construction costs (pages 24-26), an "ad hoc value planning" group established a recommended water cost of $611 per acre foot.

Note, however, that that cost assumes delivery into the north Delta, so carriage losses across the Delta also need to be added. Average carriage losses from 2011 to 2022 were 27%. A future value of 25% might reasonably be assumed. That would increase the $611 valuation to **$815 per acre foot**. That value should reasonably serve as the marginal cost that both agricultural and urban contractors are prepared to pay for water delivered to the Banks and Jones pumping plants in the south Delta.

Water Resources Results

Results are presented below for additional water volumes required for actions and portfolios, including annual water volumes estimated for each year in the model period. Additional summary results are provided for portfolios that summarize additional water volume by water year types across the 20-yr period. Results are then presented for the % of water supply required for actions and portfolios, which were based on the annual water volume estimates.

Table 24. 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 July/Aug, W/AN)	Summer Outflow (X2 ≤ 70/75 for July/Aug, W/AN/BN)	Full-year Flow	Engineered First Flush
1995	W	0	0	0	0
1996	W	310	310	69	0
1997	W	705	705	1064	0
1998	W	0	0	0	0
1999	W	703	703	399	0
2000	W	696	696	747	0
2001	D	0	0	0	150
2002	D	0	0	0	0
2003	AN	555	555	894	0
2004	BN	0	1079	479	0
2005	BN	0	408	111	0
2006	W	112	112	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 25. Annual net additional water (TAF) required for management portfolios, relative to the Reference Portfolio 1b.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

Table 26. 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 Measure used in the Delta Smelt SDM process. All water volumes are <u>relative to the Reference Portfolio 1b</u>. 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 for drier years are not given for portfolios that did not affect water supply in those water year types.

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 July/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 July/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 July/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 July/Aug); current Fall X2 (X2 ≤ 80km)	W, AN	357	0	697	74	163	0	283	0	570

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 coarse metrics – average net additional water TAF/yr, % of water supply – that are 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).

Appendix 4 – Salmon Performance Measures

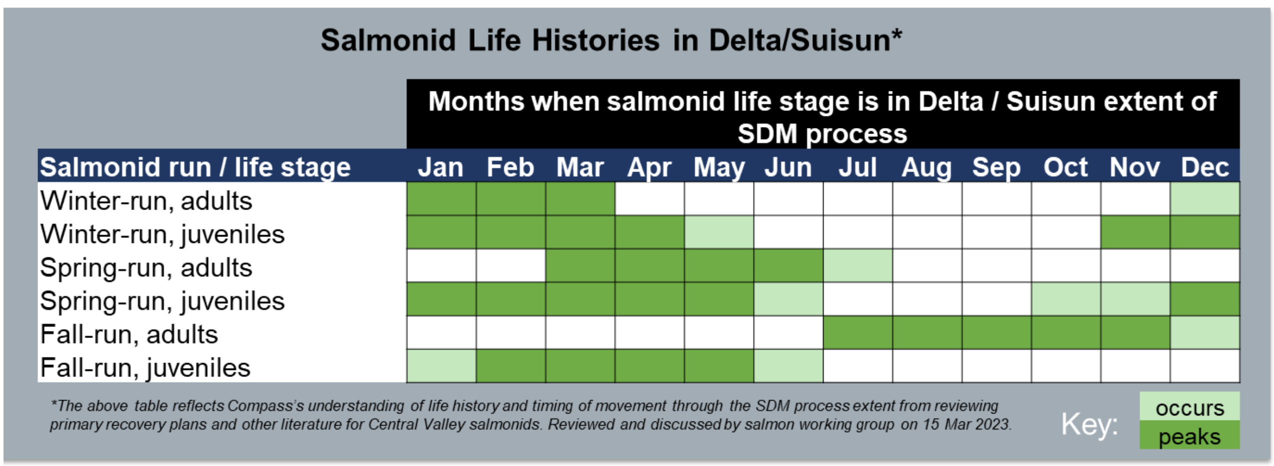
Expert engagement

Performance measures for salmon population outcomes were developed and scored by a group of Central Valley salmonid experts (Salmon Working Group [WG]) in workshops conducted in Mar and Apr 2023. The Salmon WG members were reviewed with CAMT on 21 Feb 2023 and included: Steve Lindley (NOAA), Amanda Cranford (NOAA), Peter Nelson (DWR), Rene Henery (Trout Unlimited), and Brad Cavallo (Cramer Fish Sciences).

During the Mar workshop, Compass presented an overview of the CSAMP Delta Smelt SDM process to the Salmon Working Group (WG). Information included the SDM process purpose, the process spatial extent that covered the Delta and Suisun Marsh and Bay regions, and the decision objectives being considered (Delta Smelt, salmon, water resource costs, financial resource costs).

The Salmon WG reviewed, discussed, and approved the characterization of the timing of salmon movement (by run and life stage) through the SDM process extent (Table 27). This timing was considered when interpreting and scoring potential effects of management actions, based on the action's timing and spatial extent.

Table 27. Salmonid life history, by run and life stage, as it relates to use and movement through the SDM process extent in the Delta and Suisun region.



Salmonid Life Histories in Delta/Suisun*

	Months when salmonid life stage is in Delta / Suisun extent of SDM process											
Salmonid run / life stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Winter-run, adults	peaks	peaks	peaks									occurs
Winter-run, juveniles	peaks	peaks	peaks	peaks	occurs						peaks	peaks
Spring-run, adults			peaks	peaks	peaks	peaks	occurs					
Spring-run, juveniles	peaks	peaks	peaks	peaks	peaks	occurs				occurs	occurs	peaks
Fall-run, adults							peaks	peaks	peaks	peaks	peaks	occurs
Fall-run, juveniles	occurs	peaks	peaks	peaks	peaks	occurs						

*The above table reflects Compass's understanding of life history and timing of movement through the SDM process extent from reviewing primary recovery plans and other literature for Central Valley salmonids. Reviewed and discussed by salmon working group on 15 Mar 2023.

Key: occurs / peaks

Note: Information was obtained from the USFWS (1996) and NMFS (2014) Recovery Plans, with additional information from other studies and expert input from the Salmon WG.

Action scoring

A constructed scale was developed and used by salmonid experts in the workshops. The levels in the constructed scale range from -3 (highest expected risk) to 0 (no expected risks or benefits) to +3 (highest expected benefits). For each Round 1 management action, the magnitude of its effects (e.g., the % change in food) and the temporal and spatial overlap between the action and salmonids was considered in scoring. Figure 24 shows the constructed scale used by experts when scoring effects of actions on salmonids.

Figure 24. Constructed scale used to score the relative effects of management actions on salmonids from -3 (most negative effects) to 0 (little to no effects) to +3 (most positive effects).

	Geographic Extent Affected	
Magnitude of effect	Low	High
Low	1	2
High	2	3

0	0

Magnitude of effect	Low	High
Low	-1	-2
High	-2	-3

The Salmon WG completed iterations of scoring actions and discussing scores and rationale to capture the relative effects of each action on salmonids over the course of two workshops. Experts used a Google Sheet for scoring where individual responses could be summarized in real time for the group to discuss. The exercise used the following process:

1. Compass described each action, in turn, as it had been defined within the Delta Smelt SDM process. Details were provided on the action's description, timing, spatial extent, factors being affected (e.g., salinity, prey), and the relative magnitude of those effects.
2. Each expert provided individual scores in real time as the action was presented. The WG could ask questions to clarify the actions.
3. After all actions were presented and scored, experts had the opportunity to review all scores and make any adjustments to capture relative effects.
4. Individual scores were aggregated (average, min, max) and presented to the WG for further discussion.

Salmon WG members were given the following guidance for scoring:

- Consider the extent of the spatial/temporal overlap between the action and salmon use.
- If the effects of an action vary by runs or life stages (including steelhead), assign a score that generally reflects the "worst" effects to any salmon run or life stage. In this way, the scores will allow future conversations to focus on potential risks to salmon.
- Experts should document any key rationale for the scores, including which runs/life stages were believed to be most affected.

Results: Action effects on salmon

After the Salmon WG individually scored effects for each action, they discussed any rationale, evidence, or other considerations that were used when assigning scores. Compass synthesized the group's rationale behind potential effects for each action, as well as which run(s) and life stage(s) were believed to be negatively or positively affected. The group's rationale is presented in Table 28 alongside the average scores (across the 5 Salmon WG members) and the minimum and maximum score any single member assigned to each action.

Scoring summary:

- The group expressed that there was a lot of agreement for the scores of many actions among experts.

- Negative scores were only assigned by at least one expert to three actions: (1) Suisun Marsh Salinity Control Gates, (2) relaxing Fall X2/outflow management, and (3) aquatic weed control.
- The WG discussed the complexity and uncertainty around effects of turbidity on salmonid outcomes. There may be multiple positive and negative effects from turbidity actions (such as aquatic weed control or sediment supplementation), and aquatic weed control had the largest range of scores given by experts (-1 to +2), relative to any other action.
- On average, the actions that had the highest potential benefits to salmon were (1) X2/outflow management in Spring to release additional flows, (2) tidal wetland restoration (EcoRestore+) that involved 29,000 ac of restored wetlands, and (3) physical point-source contaminant reduction.
- The group did not highlight any risks to steelhead.

Table 28. Summary of initial scores given to management actions' relative effects on salmonids and rationale for those expected effects, given by 5 salmon experts. If effects vary by runs or life stages, scores generally reflect "worst" effects to a run/life stage.

Action name	Avg score	Min score	Max score	Rationale of scores/effects, with comments for specific effects to runs and life stages.
Salinity & flow actions				
Suisun Marsh Salinity Control Gates (SMSCG)	**-0.4**	**-1**	**0**	No or potential negative effects for adults (fall-run). Negative effects possible if SMSCG operations allow for adults to enter and not be able to exit. Could delay migration. However, not many salmon migrating through during action timing. No effects to juveniles. Negative effects could be mitigated with re-engineering gates and monitoring.
X2/outflow management (Fall, relaxed)	**-0.8**	**-2**	**0**	No or potential negative effects for adults (fall-run). Any reduction in flow could negatively impact diversity of migration timing. New research in review shows that flow releases can have temperature effects further downstream than previously thought, so reducing flows could increase temperatures and negatively impact survival. Negative effects would be greater if relaxing Fall X2 results in reduced river flows. Effects would be smaller if relaxing Fall X2 results in increased exports.
X2/outflow management (Summer, 65/70)	**0.4**	**0**	**1**	Little to no effect. Summer action timing may only affect some early fall-run adults.
X2/outflow management (Summer, 70/75)	**0.3**	**0**	**1**	Little to no effect. Summer action timing may only affect some early fall-run adults.
X2/outflow management (Spring)	**2.8**	**2**	**3**	Potential positive effects for juveniles (all runs) and adults (spring-run). For juveniles, increasing spring flows could help migration, decrease temperatures, promote faster travel times, decrease predation risk, and increase survival. For adults, higher flows and lower temperatures could lead to decreased travel time and higher survival. Benefits would be greater if action is achieved through increasing river flows; little benefit if achieved through reducing exports.
Engineered First Flush	**1.6**	**1**	**2**	Potential positive effects for juveniles (winter and spring-run) and adults (winter-run). For juveniles, increasing winter flows could help migration, decrease temperatures, promote faster travel times, decrease predation risk, and increase survival. For adults, higher flows and lower temperatures could lead to decreased travel time and higher survival.
Habitat creation & maintenance actions				
Tidal wetland restoration (EcoRestore)	**1.4**	**1**	**2**	Potential positive effects for juveniles (all runs). Could increase rearing habitat, prey, and survival. Could also have eventual effects for reducing contaminants and increasing survival.
Tidal wetland restoration (EcoRestore+)	**2.2**	**2**	**3**	Potential positive effects for juveniles (all runs). Could increase rearing habitat, prey, and survival – across a larger area.

Aquatic weed control + sediment agitation	**0.6**	**-1**	**2**	Mixed effects, with potential negative effects to juveniles (all runs). Some evidence that higher turbidity can decrease predation; other evidence shows that higher turbidity can decrease foraging rates. Evidence that juveniles can use SAV to avoid predation. Potential for direct mortality from mechanical (or chemical) removal in action.
Franks Tract restoration	**0.8**	**0**	**2**	No or positive effects for juveniles (spring- and fall-run). There is potential for some negative and positive effects from aquatic weed removal (described above), but this action has a smaller footprint. Tidal wetland restoration component of action could increase rearing habitat, prey, and survival.
Prey actions				
North Delta Food Subsidies	**0**	**0**	**0**	Little to no effect. Action timing does not align with salmon, and change in food is relatively small.
Sacramento DWSC food transport and subsidies	**1.6**	**1**	**3**	Potential positive effects for juveniles (all runs). More food in Mar-Apr benefits juvenile salmonids.
Managed wetland food production	**1.6**	**1**	**3**	Potential positive effects for juveniles (all runs). More food in Mar-Apr benefits juvenile salmonids. No substantial benefits in summer and fall.
Turbidity actions				
Sediment supplementation	**0.8**	**0**	**2**	No or positive effects for juveniles (spring- and fall-run). There is potential for some negative or positive effects from increased turbidity on predator-prey dynamics and salmonid survival. Relative to AWC, this action doesn't have components of pesticides or mechanical that would negative affect mortality. Timing of action does not overlap substantially with juveniles, so they would have limited exposure to any potential negative or positive effects.
Contaminant actions				
Physical point-source contaminant reduction	**2**	**1**	**3**	Potential positive effects for juveniles and adults (all runs). Could improve health and survival.

Results: Portfolio effects on salmon

The Salmon WG discussed appropriate ways to capture the overall potential benefits and risks to salmonids from combinations of actions in portfolios and how this could translate to Performance Measures (PMs) to compare portfolios. Through WG input, Compass constructed multiple PMs to capture the benefits and risks of portfolios:

Potential risks PMs: The group agreed that documenting any potential risks to salmon from actions included in a portfolio was essential, and it would not be appropriate to assume benefits of some actions in a portfolio would "balance out" risks of other actions. Therefore, potential risks were calculated by taking the average or minimum scores for each action in Table 4 that had any potential risk (SMSCG, relaxed Fall X2 mgmt, and aquatic weed control), summing all scores for actions included in the portfolio, and rescaling the final value to be between -3 (greatest risks to salmon) and 0 (no risks to salmon). A PM for potential risk using the maximum action scores was not calculated because all portfolios would have received a score of 0.

Potential benefits PMs: Potential benefits of a portfolio were calculated by taking the average, minimum, or maximum scores for each action in Table 28, summing all scores for actions included in the portfolio, and rescaling the final value to be between 0 (no benefits to salmon) and +3 (greatest benefits to salmon). Actions with potential risks (SMSCG, relaxed Fall X2 mgmt, and aquatic weed control) were not included when calculating benefits scores. Scores for each action were modified to account for the spatial and temporal extent the action was applied, if it varied by portfolio.

Calculating PMs for risks and benefits used average, minimum, and maximum scores for each action followed Salmon WG guidance around the importance of capturing the range of uncertainty for the effects of specific actions to salmonids. Potential risks and benefits for each Round 1 portfolio are reported in Table 29.

Limitations

Round 1 of the SDM evaluation used expert-based metrics to capture coarse, relative benefits and risks to salmon from management actions, and there were a few key limitations important to consider when interpreting results.

First, experts' scores for benefits/risks of each action were based on the "full build out" version of each action, where actions are applied at the maximum spatial and temporal extents being considered in Round 1. Therefore, benefits and risks to salmon could change if actions were to be implemented at different scales. Scores also reflect the current assumptions of how actions would be implemented and what would be their hypothesized effects. Benefits and risks to salmon could change as new information emerges regarding action design, implementation, and effect uncertainty (e.g., potential risks of salmon from aquatic weed control could change if new methods for weed control are developed to minimize direct mortality to salmon).

Second, portfolio scores for benefits and risks were kept separate for transparency at this stage, and explicit population modeling would likely be needed to predict the net effect of each management portfolio on salmon.

Third, Round 1 included coarse hydrology analysis to capture effects of flow actions on water supply, Delta Smelt, and other interests. The complex effects of flow to salmon were discussed in detail by the WG, and we describe limitations in capturing flow action effects below.

Table 29. Summary of scores for potential benefits and risks to salmonids for each portfolio in the Delta Smelt Round 1 evaluation. Portfolio scores were calculated from action-specific scores given by 5 salmon experts. If effects were expected to vary by runs or life stages, scores generally reflect "worst" effects to a run/life stage.

	Portfolios											
	1b	2a1	2a2	2b	2c	3a	3c1	3c2	3c3	3c4	3d	3e
Performance Measure	Current mgmt (approx)	Full-year flows - no water budget	Full-year flows - 700 TAF	Cache Slough	Cache Slough & Suisun Marsh	Self-sustaining/ permanent mgmt	Summer flow & tidal wetlands (X2: Summer 65/70 km; Fall historical)	Summer flow & tidal wetlands (X2: Summer 65/70 km; Fall current)	Summer flow & tidal wetlands (X2: Summer 70/75 km; Fall historical)	Summer flow & tidal wetlands (X2: Summer 70/75 km; Fall current)	Focus on food	Habitat connectivity
Potential benefits (avg scores)*	0	1	1	1	1	2	1	1	1	1	3	1
Potential benefits (min scores)	0	0	0	0	1	1	0	0	0	0	2	0
Potential benefits (max scores)	0	1	1	1	3	3	1	1	1	1	3	3
Potential risks (avg scores)**	0	0	0	0	0	0	-1	0	-1	0	0	0
Potential risks (avg scores)**	0	0	-1	0	0	0	-3	0	-3	0	-2	-1

* Potential benefits of a portfolio were calculated by taking the average, minimum, or maximum scores for each action in Table 1, summing all scores for actions included in the portfolio, and rescaling the final value to be between 0 (no benefits to salmon) and 3 (greatest benefits to salmon). Actions with potential risks (SMSCG, relaxed Fall X2 mgmt, and aquatic weed control) were not included when calculating benefits scores. Scores for each action were modified to account for the spatial and temporal extent the action was applied, if it varied by portfolio.

** Potential risks were calculated by taking the average or minimum scores for each action in Table 1 that had any potential risk (SMSCG, relaxed Fall X2 mgmt, and aquatic weed control), summing all scores for actions included in the portfolio, and rescaling the final value to be between -3 (greatest risks to salmon) and 0 (no risks to salmon). Scores for each action were modified to account for the spatial and temporal extent the action was applied, if it varied by portfolio.

Limitations in capturing flow action effects

During the second workshop, the Salmon WG discussed the potential different effects from X2/outflow actions in the year they occur (e.g., via increasing flows) vs. carry-over effects the following year (e.g., via restricting operations to control temperature). The effects to salmon that the group had considered previously reflect potential within-year effects but not carry-over effects. The WG described the potential effect pathway between flow management and salmon impacts in the following year:

- Without reductions in water demand, changing operations to increase flows in one year could restrict water storage and flow releases in the following year. Carry-over effects in the following year could occur if storage and flows are reduced. Reduced flows can restrict timing of migration, decrease habitat quantity and quality, increase temperature, and decrease growth and survival. These carry-over effects are expected to primarily impact winter-run salmon, which are spawning in summer and are most sensitive to flow/temperatures. The group acknowledged that fall-run, spring-run, and steelhead could also experience negative carry-over effects.

The WG described conditions when carry-over effects to salmon would have a higher risk to salmon:

- Risk may be higher when there is a dry year **following** the management action, since flows would be naturally lower and storage may have decreased from deploying water for management in the year prior and not been replenished.
- Risk may be higher when there is a string of dry years **prior to** the flow management action, since overall water storage is likely lower. Storage and operations could maintain acceptable flow conditions after a flow management action occurred if the action was preceded by a string of wet years, even if the year after was drier.

Ultimately, the Salmon WG acknowledged the difficulty in knowing how operations would change from flow actions in the same year or year after the action occurs. Therefore, the WG supported engaging operations experts to better inform expected changes to operations and any subsequent carry-over effects to salmon.

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:

b. 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 evaluation has captured effects to salmon using coarse, expert-based methods. The metrics and results presented are useful for making relative comparisons of the direct risks (and benefits) to salmon among portfolios. These coarse results can also inform the value of designing new portfolios with flow actions and improving how effects are captured for salmon with explicit hydrology/operations and salmon population modeling.

References

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U.S. Fish and Wildlife Service [USFWS], 1996. Recovery Plan for the Sacramento / San Joaquin Delta Native Fishes. U.S. Department of the Interior Fish and Wildlife Service Region 1, Portland, Oregon. 26 Nov 1996. 208 pages. https://ecos.fws.gov/docs/recovery_plan/961126.pdf

Appendix 5 – Dynamic Habitat Tool

The Dynamic Habitat Suitability Index (DHSI) is an indicator of the overlap of suitable temperature, turbidity, salinity, and prey conditions – which was hypothesized as a bottleneck by the TWG in Phase 2 of the SDM process. It was motivated by an interest in understanding when and where conditions for Delta Smelt might be in unsuitable ranges thereby helping direct and identify management actions that could potentially enhance Delta Smelt dynamic habitat. In that sense it was developed as a tool to aid the creative process, but it also provides an indication of how actions and portfolios modify habitat conditions for Delta Smelt. It is not strictly a Delta Smelt "performance measure" because is does not consider the performance (the growth, survival and recruitment) of Delta Smelt. Compass developed DHSI metrics with TWG input using the following steps.

First, we identified threshold values separating more or less suitable conditions for Delta Smelt across the four dynamic habitat attributes for each month of the year (Table 30). These threshold values were informed by empirical studies (e.g., Bever et al. 2016; Hamilton and Murphy 2020; other sources within Crawford and Rudd 2021) and used by the TWG in the July – Sept 2021 workshops.

Table 30. Threshold values (informed by empirical studies and TWG expert review in 2021) separating more or less suitable conditions for Delta Smelt across four dynamic habitat attributes for each month of the year. Suitable conditions are interpreted as being below threshold values for turbidity, temperature, and salinity and above values for prey.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Turbidity (Secchi depth cm)	40	40	40	40	40	40	40	40	40	40	40	40
Temperature (°C)	20	20	15.8	15.8	20	20	22.3	22.3	20	20	20	20
Salinity (µS/cm)	2000	2000	2000	2000	2000	2000	10000	10000	10000	10000	10000	10000
Prey (µgC/m^3)	300	300	3000	3000	2900	2900	3200	3200	3100	3100	800	800

Second, we accessed the input data for the IBMR that measured mean conditions for the four dynamic habitat attributes for each month, year, and subregion under baseline conditions or the management action (if the action affected any of the attributes). We converted threshold units to align with IBMR input data (e.g., converted prey thresholds that were in µgC/m^3 to mgC/m^3).

Lastly, we calculated two versions of the DHSI – DHSI (overlap) and DHSI (additive). Table 31 presents a brief description of each DHSI, how to interpret their values, and methodological details. We also calculated and saved results showing the percentage of months for each subregion when each of the four dynamic habitat attributes was suitable. To capture spatial variation of effects, the DHSI is calculated for each IBMR subregion and results are reported as follows: (1) Yolo/Cache Slough subregion, (2) the subregion with the maximum value in the Confluence and Lower Rivers, and (3) the subregion with the maximum value in Suisun Marsh and Bay.

These supplemental results could be used for interpretation of which attributes were unsuitable when DHSI metrics were low for a given management action. For simplicity, the DHSI (overlap) metric results are reported for portfolios later in this document, and DHSI (additive) metrics are available upon request.

Complete documentation of the Dynamic Habitat Suitability Index tool is provided in the "Appendix 5_Dynamic Habitat Tool" folder of this report's supplemental material.

Table 31. Description and methods for two Dynamic Habitat Suitability Indices.

Metric	DHSI (overlap)	DHSI (additive)
Short description	An index showing the percentage of months when all four dynamic habitat attributes are in "suitable" ranges (i.e., suitable conditions overlap)	An index that averages the number of dynamic habitat attributes in "suitable" ranges across months for each subregion
Example interpretation	DHSI (overlap) of 75% for a subregion means that 75% of months between 1995 and 2014 had all four dynamic habitat attributes in "suitable" ranges	DHSI (additive) of 75% means that, on average, 3 of 4 dynamic habitat attributes were in "suitable" ranges between 1995 and 2014
Methods	For each month and subregion, the four dynamic habitat attributes are assessed if in a suitable range (1=yes, 0=no), then the overlap is assessed (1=if all four attributes are suitable, 0=any attribute is unsuitable). A mean value is calculated for each subregion, representing the % of months when all four habitat attributes were suitable.	For each month and subregion, the four dynamic habitat attributes are assessed if in a suitable range (1=yes, 0=no), then weighted (currently we give equal weights of 0.25 across the four habitat attributes, but this can be adjusted). These weighted values for each month are summed such that the metric has a range from 0 to 100%. A mean value is calculated for each subregion, representing the average number of habitat attributes out of four that were suitable.

Appendix 6 – Uncertainty & Time to Implementation Survey

The following questions were asked to TWG members in the survey:

1. **Confidence in quantified, proximate effects of actions:** What is your level of confidence in the assumed/quantified proximate effect of Action [X] (e.g., on food, turbidity, salinity, flow, contaminants/mortality) that are used as inputs to the Delta Smelt modeling? Note that, for flow actions, separate scores are requested for different models that translated effects into the IBMR and LF models.

Constructed scale	**1: Low confidence.** (e.g., No data/studies exist to estimate action's effects)
	2: Low-moderate confidence. (e.g., Few data/studies exist)
	3: Moderate confidence. (e.g., Some data and coarse or theoretical modeling results are used to estimate action's effects.)
	4: Moderate-high confidence. (e.g., predictions based on existing data/models)
	5: High confidence. (e.g., Empirical data and results confirming the estimation of an action's effects have high precision and/or been published in scientific journals)
	Unsure / not enough info to answer

2. **Time to implementation:** Assuming a decision is made to advance the action toward implementation in 2024, what's your best guess of how long it will take to achieve full implementation of the action, including research of technical aspects of the action (if necessary) and generation of expected benefits for Delta Smelt? Assume that any necessary permitting issues for the action can be resolved.

Constructed scale	**1: >20 yrs**
	2: 11-20 yrs
	3: 6-10 yrs
	4: 1-5 yrs
	5: <1 yr (immediately)
	Unsure / not enough info to answer

3. **Science suggestions for next steps:** Thinking holistically across the actions evaluated in Round 1, key issues of uncertainty and feasibility, and the existing body of knowledge about Delta Smelt and the system, list and describe up to three ideas for priority science actions (e.g., feasibility studies, pilot implementation with AM, etc.) that would advance decision-relevant knowledge for Delta Smelt.

Summarized TWG response scores and rationales are provided in Table 32 for effect uncertainty and in Table 33 for technical feasibility.

Table 32. Synthesis of TWG Survey Response for Confidence in the action effect assumptions/methods used as inputs to the Delta Smelt population models for new candidate management actions.

Action-effect pathway	Methods used	TWG Confidence Score Average (Range)	Rationale for confidence score
X2/outflow actions			
1. X2/outflow – salinity (input to Salinity-food model)	Estimated subregion-specific salinity with Compass/TWG model, fit to historical data (IBMR and LF)	Mod-High - 4.3 (3 to 5)	• Higher: Salinity-flow relationship well understood • Moderate: No hydrodynamics model, and salinity model is not multivariate; Hydrodynamic model would be better (or GAM to capture non-linear relationships) • Lower: N/A
2. Salinity-food model (Input to IBMR)	Estimated taxa-specific food density with Salinity-food model, fit to historical data (IBMR)	Moderate - 3.0 (1 to 4)	• Higher: Well known that salinity controls distribution of aquatic species, inc zooplankton • Moderate: Output showed large uncertainties; Salinity not only factor driving prey availability & composition; Model could be improved to better predict in freshwater • Lower: Correlation between X2/outflow & food seems weak/negligible; Not enough info on validation in model (too few covariates); Model predictions inconsistent w/ historical data
3. X2/outflow – DS Distribution (TWG method and input to IBMR)	Estimated from Compass/TWG model, fit to historical data (IBMR)	Moderate - 2.9 (1-4)	• Higher: N/A • Moderate: Hard to statistically capture complex reactions to flow; While most DS pop move with X2, uncertainty related to freshwater resident pop; Approach is resampling past distributions, not a model • Lower: Factors affecting distribution are more complex than just X2; Distribution effects always low certainty (not catching enough DS to evaluate effect on proximate factor; all based on historical understanding/models)
4. X2/Outflow-zooplankton (LF submodel)	Estimated food density with Hamilton flow-food model, fit to historical data (LF)	Low-Mod – 2.0 (1-4)	• Higher: Derived from historical data • Moderate: Outputs showed large uncertainties; Overdispersed model (more parameters than data) • Lower: Differs from Salinity-food model; Concerns about overfitting, coefficients, arbitrary modeling decisions; No model selection, high reliance on variables to explain autocorrelation, manual adjustment of July model?

Action-effect pathway	Methods used	TWG Confidence Score Average (Range)	Rationale for confidence score
5. X2/Outflow – DS Distribution (LF submodel)	Estimated from Hamilton distribution model, fit to historical data (IBMR)	Low-Mod – 2.1 (1-4)	• Higher: Model is better than using X2 alone, but varies in explanatory power • Moderate: Output showed large uncertainties; Unfamiliar with model, but makes sense that these variables could affect distribution; Overdispersed model (more parameters than data) • Lower: Concerns about overfitting, arbitrary modelling decisions; Distribution effects always low certainty (not catching enough DS to evaluate effect on proximate factor; all based on historical understanding/models)
Actions with food as primary hypothesized benefit			
6. Tidal wetland restoration - food	Assumed increases in food were proportional to new open water acres	Low-Mod – 2.3 (1-3)	• Higher: N/A • Moderate: Restoration will increase zooplankton; uncertainty whether this will benefit DS; Consistent with historical ecology; real benefits uncertain; Restored sites could become food sinks, or food densities could differ outside of restored site • Lower: Low confidence in calcs/ assumptions (assumption that % prey increase = % area restored); Increasing phytoplankton doesn't always increase zooplankton in SFE; Field studies could use more validation w/ additional sites and comparisons; Assumptions inconsistent w/ literature; low end estimate should be "no change in prey", high end estimate too high
7. Managed Wetlands - food	Used empirical monitoring data and expert judgment from Kyle Philips (Durand Lab, UC Davis). Data comes from 7 sites monitoring flood/drain operations in Mar-Apr. Effects for other time periods were based on expert judgment.	Moderate - 3.0 (2-4)	• Higher: Data suggests this could generate prey; Consistent with historical ecology • Moderate: Field studies could use more validation w/ additional sites and comparisons; Unclear what biomass increases were assumed and how they were estimated in studies; Fair amount of zooplankton in wetlands; Studies: UCD study, Kimmerer studies, FRP pre-restoration monitoring • Lower: Concept is good, but it's still conceptual
8. DWSC Food - food	Used coarse estimate based on data and expert knowledge from Erwin Van Nieuwenhuyse (previous	Low-Mod – 2.4 (1-4)	• Higher: This has been measured • Moderate: No demonstrated effect in one test; caveats but awaits demonstration; Still a concept, but concept seems beneficial;

Action-effect pathway	Methods used	TWG Confidence Score Average (Range)	Rationale for confidence score
	USBR lead for this action), which considered both the RMA (2021) results of the transport effect and the nutrient addition effect		Zooplankton has been studied in ship channel, but transport effects are lacking • Lower: Coarse estimates & lots of assumptions; Modelling doesn't actually show that food will be transported; No evidence of increased zooplankton from fertilization; RMA model showed minimal increases in zooplankton
Actions with turbidity as primary hypothesized benefit			
9. AWC-turbidity	Spatial coverage of aquatic weed areas that could be removed came from data from Ustin et al. (2021). Effects on turbidity from removing aquatic weeds were based on estimates from Hestir et al. (2016), which used a combination of assumptions and regression models fit to historical data.	Mod-High - 3.3 (2-5)	• Higher: Supported by multiple studies; SAV known to trap sediment & slow flows; successful mgmt. can promote increased turbidity; Logical & works elsewhere • Moderate: Supported by studies in Delta/elsewhere; Theoretically sound but uncertain magnitude of effect; Studies support correlation between veg and turbidity • Lower: Conceptually sound but, doubt as to whether it has been tested; Concern of assumptions
10. AWC-food	Assumed increases in food were proportional to new open water acres	Low – 1.9 (1-3)	• Higher: N/A • Moderate: No reasons given • Lower: Increasing phytoplankton doesn't always increase zooplankton in SFE; Field studies could use more validation w/ additional sites and comparisons; Prey density more important than distribution; Too many assumptions; Many important prey items associated w/ aquatic weeds
11. Sediment Supplementation - turbidity	Used results from Bever and MacWilliams (2017), who used the hydrodynamic UnTrim San Francisco Bay-Delta Model coupled with a sediment transport model to simulate this action	Low-Mod – 2.5 (1-4)	• Higher: Modelling available for this action; Engineering problem (can be solved w/ enough resources, but feasibility is limited) • Moderate: Hydrodynamic model of sediment transport has a lot of assumptions; Feasibility is greater concern than uncertainty in effect • Lower: Further work required to quantify relationship between DS and turbidity before proceeding w/ sediment supplementation
Actions to reduce contaminant concentrations			

Action-effect pathway	Methods used	TWG Confidence Score Average (Range)	Rationale for confidence score
12. Physical point-source contaminants reduction through constructed wetlands – contaminant concentrations	Assumed a 5% reduction in contaminants at the subregion level (50% local reduction and 10% of subregion's flows go through managed area). Wayne Landis's lab (Western Washington University) provided historical concentration data for four insecticides of key concern to Delta Smelt.	Moderate - 3.1 (1-5)	• Higher: Lots of demonstrations elsewhere, should work in Ulatis Creek; High confidence based on Delta RMP per discussion at TWG with Shawn; Significant precedent for removal of contaminants • Moderate: Other cases of ponds/wetlands used for contaminant treatment; and makes conceptual sense • Lower: Contaminant concentrations difficult to measure in field; Doubt as to whether this has ever been done inside this system
13. Contaminant concentrations – DS survival	Estimated with studies from the Landis Lab, which were estimated from lab studies with a surrogate fish species (Mississippi silversides) (IBMR and LF)	Low-Mod – 2.7 (1-4)	• Higher: Mod-high confidence based on toxicity testing and demonstrated effects in field; but quantitative cause-effect link uncertain • Moderate: Moderate confidence based on silversides; We are likely underestimating effects of contaminants; surrogate species is less sensitive than DS and additive assumption on response curve is conservative • Lower: Effect of contaminants on survival is hard to quantify; no relationship demonstrated between DS survival in wild and contaminant concentrations (may not be a primary effect pathway for DS)
Actions with primary hypothesized benefit to mitigate entrainment in the South Delta and CVP/SWP Project Pumps			
14. Engineered First Flush – DS Distribution	Assumed 50% of Delta Smelt distribution that historically was in the Lower San Joaquin, East Delta, and South Delta subregions go to the Yolo/Cache subregion instead in Feb-June following the action (IBMR and LF)	Low-Mod – 2.4 (1-4)	• Higher: Mod-high confidence due to history; first flush is important for spawning, but uncertain whether we can generate enough turbidity w/ managed flows • Moderate: Turbidity-flow relationship is complex and may differ when flow comes from reservoir release vs precip; Action is feasible, but relative changes in flow are likely too small for models to properly reflect change; Action may not be ineffective, but analytical approach is tenuous • Lower: Predicting distribution on one factor has been found to lead to biologically impossible distributions; Cannot fit statistical model of DS movement probabilities (this is an assumption); Distribution

Action-effect pathway	Methods used	TWG Confidence Score Average (Range)	Rationale for confidence score
			effects always low certainty (not catching enough DS to evaluate effect on proximate factor; all based on historical understanding/models)
15. Franks Tract Restoration – DS Distribution	Assumed a 25% reduction in South Delta distribution in Mar-May based on particle tracking studies (CDFW 2020) (IBMR and LF)	Low-Mod – 2.6 (1-4)	• Higher: Based on FT particle tracking models • Moderate: Based on FT particle tracking models; however DS only behave like passive particles as larvae; Uncertain why particle tracking models appropriate for modeling fish movement; Approach based on principles of Turbidity Bridge management which has been successful • Lower: Models not designed for determining distribution at such a fine resolution; Distribution effects always low certainty given low recapture of species; experimental supplementation & release can help

Table 33. Synthesis of TWG Survey Response for Time to implementation of for new candidate management actions.

Action	TWG Tech Feasibility Score Average (Range)	Rationale for feasibility score
X2/outflow actions		
1. X2/outflow management (Summer outflow augmentation, W/AN yrs)	0-5 yrs – 4.3 (4-5)	• 0-5 yrs: this is already called for in state regulations; requires regulatory change that would take at least a year; relatively easy to implement, but challenging to get buy-in for summer X2 • 6-11 yrs: N/A • 11-20+ yrs: N/A
2. X2/outflow management (Summer outflow augmentation, W/AN/BN yrs)	0-5 yrs – 4.2 (3-5)	• <1 yr/1-5 yrs: Action during BN years would be costly and require regulatory change; relatively easy to implement, but challenging to get buy in for summer X2 • 6-11 yrs: Expectation of significant political resistance • 11-20/>20 yrs: N/A
Actions with food as primary hypothesized benefit		
3. Tidal wetland restoration (~9K ac)	6-11 yrs – 2.8 (2-3)	• 0-5 yrs: N/A • 6-11 yrs: Based on timeframe for past tidal wetland restoration; physically feasible, but restoration proceeds slowly • 11-20+ yrs: 8k acres from 2008 BiOp are estimated to take nearly 20 years to completion
4. Tidal wetland restoration (~20K ac)	11-20 yrs – 2.0 (1-3)	• 0-5 yrs: N/A • 6-11 yrs: Based on assumptions for construction time • 11-20+ yrs: 8k acres from 2008 BiOp are estimated to take nearly 20 years to completion; completion time scales up as size increases (need to consider property acquisition, construction, response time for fish, etc.)
5. Tidal wetland restoration (~30K ac)	11-20+ yrs – 1.5 (1-3)	• 0-5 yrs: N/A • 6-11 yrs: Based on assumptions for construction time • 11-20+ yrs: 8k acres from 2008 BiOp are estimated to take nearly 20 years to completion; completion time scales up as size increases (need to consider property acquisition, construction, response time for fish, etc.)
6. Managed wetland food production (1K ac)	0-5 yrs – 3.9 (3-4)	• 0-5 yrs: Could be implemented quickly at small scale (could encounter political challenges for larger projects); coordination & regulatory change could take time (1-5 years); while construction still takes time, should be quicker than restoration projects; good concept, but conflicts between land use and fish needs must be considered; more landowner buy-in needed • 6-11 yrs: No reasons given • 11-20+ yrs: N/A

Action	TWG Tech Feasibility Score Average (Range)	Rationale for feasibility score
7. Managed wetland food production (2K ac)	0-5 yrs – 3.3 (3-4)	• 0-5 yrs: While construction still takes time, should be quicker than restoration projects • 6-11 yrs: Time to completion would increase as scale increases; good concept, but conflicts between land use and fish needs must be considered; more landowner buy-in needed • 11-20+ yrs: N/A
8. Managed wetland food production (4K ac)	6-11 yrs – 2.9 (2-4)	• 0-5 yrs: While construction still takes time, should be quicker than restoration projects • 6-11 yrs: Good concept but conflicts between land use and fish needs must be considered; more landowner buy-in needed • 11-20+ yrs: Time to completion would increase as scale increases
9. DWSC food	6-11 yrs – 3.3 (2-5)	• 0-5 yrs: No reasons given • 6-11 yrs: Need to demonstrate feasibility; based on assumption of construction of gates on North end; based on assumption that city of W Sacramento will fix locks in this timeframe; based on assumption that current designs are implemented • 11-20+ yrs: Based on discussion of Army Corps and W Sacramento
Actions with turbidity as primary hypothesized benefit		
10. Aquatic weed control (600 ac)	0-5 yrs – 3.1 (1-5)	• 0-5 yrs: Would require some ingenuity to develop methods, but could be implemented in near-term • 6-11 yrs: Requires demonstration of feasible method at scale; currently no way to efficiently and semi-permanently remove AV; could take years to develop method & acquire permits • 11-20+ yrs: Uncertain of feasibility of current methods (e.g., mechanical, herbicide applications)
11. Aquatic weed control (1.4K ac)	6-11 yrs – 2.8 (1-5)	• 0-5 yrs: Would require some ingenuity to develop methods, but could be implemented in near-term • 6-11 yrs: Could advance rapidly once scalable method demonstrated • 11-20+ yrs: Currently no way to efficiently and semi-permanently remove AV; could take years to develop method & acquire permits; no current methods to sustain AWC
12. Aquatic weed control (3.5K ac)	6-11 yrs – 2.4 (1-5)	• 0-5 yrs: No reasons given • 6-11 yrs: Could advance rapidly once scalable method demonstrated; would require some ingenuity to develop methods, but could be implemented in near-term • 11-20+ yrs: Currently no way to efficiently and semi-permanently remove AV; could take years to develop method & acquire permits; no current methods to sustain AWC
13. Sediment supplementation	6-11 yrs - 3.0 (1-4)	• 0-5 yrs: Needs additional research, but should be faster than wetland restoration/construction or AWC; based on assumption of timely acquisition of materials and construction

Action	TWG Tech Feasibility Score Average (Range)	Rationale for feasibility score
		• 6-11 yrs: based on assumption of significant pressure to obtain permits • 11-20+ yrs: Unlikely for many reasons (e.g., water quality regulations, obtaining sediment); concern action may be infeasible (although resuspending fine sediments w/ air may be feasible in some areas); multiple questions about feasibility and timeline
Actions to reduce contaminant concentrations		
14. Physical point-source contaminant reduction (1 subregion)	6-11 yrs – 3.3 (3-4)	• 0-5 yrs: Expectation of at least one year to implement; treatment has been applied elsewhere, just need site-specific research • 6-11 yrs: Could be feasible/ effective for Ulatis Crk source, but slough will take time to recover; based on assumptions for construction time • 11-20+ yrs: N/A
15. Physical point-source contaminant reduction (3 subregions)	6-11 yrs – 2.6 (2-4)	• 0-5 yrs: No reasons given • 6-11 yrs: Expectation of longer timeframe to implement based on size; must be demonstrated first; based on assumptions for construction time • 11-20+ yrs: No reasons given
16. Physical point-source contaminant reduction (5+ subregions)	11-20+ yrs – 2.1 (1-4)	• 0-5 yrs: No reasons given • 6-11 yrs: Based on assumptions for construction time • 11-20+ yrs: Expectation of longer timeframe to implement based on size
Actions with primary hypothesized benefit to mitigate entrainment in the South Delta and CVP/SWP Project Pumps		
17. Engineered First Flush	0-5 yrs – 3.9 (1-5)	• 0-5 yrs: Physically feasible and likely effectiveness will improve political possibility; required regulatory change would take at least a year; relatively easy to implement • 6-11 yrs: No reasons given • 11-20+ yrs: Analysis suggests this action is ineffective; further, distribution is not the key challenge
18. Franks Tract Restoration	6-11 yrs – 2.7 (2-3)	• 0-5 yrs: N/A • 6-11 yrs: Very feasible, however will to implement seems low; based on timeframe for past tidal wetland restoration construction; based on assumptions of construction time; though well planned out, scale of FT will slow implementation timeline • 11-20+ yrs: No reasons given
19. Fish Friendly Diversions	11-20+ yrs – 1.7 (1-4)	• 0-5 yrs: No reasons given • 6-11 yrs: Technical probability of success is high, but permitting has significant uncertainty

Action	TWG Tech Feasibility Score Average (Range)	Rationale for feasibility score
		• 11-20+ yrs: Based no significant uncertainties; a 90% reduction in mortality would entail full conversion of Delta export facilities; major infrastructure project w/ significant hurdles related to siltation and effectiveness

Appendix 7 – Candidate Action Screening

In Phase 2 of the SDM process, the Delta Smelt TWG reviewed available evidence of Delta Smelt population bottlenecks or limiting factors and brainstormed ~40 candidate management actions that could increase the Delta Smelt population (see Phase 2 Report for more background). At the beginning of Phase 3, the Delta Smelt TWG reviewed and discussed these actions with respect to their potential benefits for Delta Smelt and their technical feasibility. Based on these discussions at the TWG and feedback from CAMT and Policy Group meetings, Compass developed a proposed binning of these actions into four categories:

(1)	Include in Round 1 SDM Evaluation
(2)	Potentially include in Round 1 SDM Evaluation (if DS sensitivity modeling shows meaningful benefit)
(3)	Continue to research & re-consider for Round 2 SDM Evaluation
(4)	Drop or park indefinitely for SDM process

Compass' proposed binning of the actions provided a scope for the Round 1 SDM Evaluation and the binning of was updated throughout the process based on ongoing discussions between the TWG, the Steering Committee and the Policy Group. A description of the candidate management actions and their final binning at the end of the process is shown in Table 34.

Table 34. Candidate Delta Smelt management actions to include in Round 1 SDM evaluation, consider for Round 2, or drop/park indefinitely for the SDM process.

Action Name	Description	Reasons/Considerations for Binning
Included in Round 1 SDM Evaluation & modeled with Delta Smelt Population Models		
Delta Outflow/X2 Management	Manage Delta outflow/X2 position at levels hypothesized to increase Delta Smelt population. The Round 1 SDM evaluation did not specify the source for this water with the assumption that this would be a logical next step if there was support for advancing this action. Means for acquiring water to support this action that were discussed within the SDM process included construction of new off-stream reservoirs with dedicated use for Delta Smelt and reserving water in existing reservoirs.	• Delta outflow is currently managed through the Delta Outflow requirements in the State Water Board Revised Water Right Decision 1641, as well as the requirements in the 2020 ROD/ITP to maintain a monthly average 2ppt isohaline (X2 position) at 80 km from the Golden Gate Bridge in Sept and Oct for Wet and Above Normal water year types. • Including this action in Round 1 allowed analyses of Delta Smelt population effects of different timings and scales of Delta Outflow/X2 management and of different combinations of this action with other management actions.
Suisun Marsh Salinity Control Gates	Operate the Suisun Marsh Salinity Control Gates to reduce salinity in the summer-fall period in Suisun	• This is a current action in the 2020 ROD/ITP

Action Name	Description	Reasons/Considerations for Binning
	Marsh and surrounding waters.	
North Delta Food Subsidies	Re-direct 1) agricultural drainage or 2) Sacramento River water through the Yolo Bypass Toe Drain as a flow-pulse to increase food web productivity and transport of food to downstream regions (Cache Slough Complex and lower Sacramento River) to benefit Delta Smelt.	• The TWG identified lack of prey (zooplankton) as an important bottleneck for the DS population. • Zooplankton modeling for these two actions is available (done in 2021 for DCG through Bureau contract with RMA) • This action is in the 2020 ROD/ITP
Sacramento Deep Water Ship Channel (DWSC) food transport and subsidies	Build on previous efforts to stimulate plankton in the channel through the addition of nitrogen.	
Suisun Marsh managed wetland food production	Managed wetland flood and drain operations that can promote food export from the managed wetlands to adjacent tidal sloughs and bays.	• The TWG identified lack of prey (zooplankton) as an important bottleneck for the DS population. • Research is ongoing at the UC Davis Center for Watershed Sciences to quantify the zooplankton and other effects of flooding and draining managed wetlands (key researchers are Alice Tung, Kyle Phillips and John Durand). • DWR, through a contract with the Suisun Resource Conservation District, completed a study that can inform assumptions on the scale of participating wetlands in this action.
Tidal wetland restoration	Construction of tidal wetland restoration projects to produce food and other benefits for Delta Smelt.	• The TWG identified lack of prey (zooplankton) as an important bottleneck for the DS population. • Tidal wetland restoration projects have already been implemented and there are plans and commitments related to expanding tidal wetland restoration.
Aquatic weed control	Removal of aquatic weeds in the Delta to increase turbidity for Delta Smelt. A method was not specified for how weeds wood be removed – herbicide treatment, biological methods and mechanical removal was discussed.	• Increasing turbidity has many potential benefits for Delta Smelt • Research exists to support evaluation of this action. • Includes the benefits to zooplankton densities which was identified as an important limiting factor.
Sediment supplementation	Reintroduce sediment in the Delta to increase turbidity to	• Increasing turbidity has many potential benefits for Delta Smelt

Action Name	Description	Reasons/Considerations for Binning
	provide better habitat conditions for all life stages of Delta Smelt	• Evaluation of this action can build off of the hydrodynamic modeling that was completed by Anchor QEA in 2017 (funded by SWC). • The 2020 ROD includes undertaking a feasibility study on sediment supplementation. A key outstanding question for this action is whether there is a source for this much sediment. In Round 1, we assumed that a sediment supply could be available.
Franks Tract Restoration	Restore Franks Tract and adjacent areas to create large open water areas connected by tidal wetlands and navigable channels to improve conditions for Delta Smelt and other objectives. The action includes an aquatic weed control program to improve turbidity.	• Action is hypothesized to reduce entrainment in the South Delta, increase turbidity, and produce food. • TWG evaluated the preferred alternative for Franks Tract Restoration as identified in the Franks Tract Futures Study.
OMR Management	Manage OMR flows to reduce entrainment risk as per 2020 ROD/BiOp.	• This is an action in the 2020 ROD • This SDM process has access to modeling tools that can evaluate the benefits of this action to Delta Smelt.
Engineered First Flush	Modify project operations to provide flows to approximate a 'first flush' in years that otherwise would not reach a flow threshold.	• Action has the potential to affect Delta Smelt distribution and entrainment, given some evidence that the absence of a first flush could increase Delta Smelt entrainment in the South Delta and the Project pumps.
Physical point-source contaminant reduction	Physical treatment of non-point contaminant sources, likely through constructed wetlands. Analysis would first focus on Ulatis Creek, which acts as a pinch point for contaminants entering Cache Slough and then would consider scaling up the action to other contaminant hot spots.	• There is evidence that contaminants are having adverse effects on Delta Smelt prey (e.g., zooplankton: Weston et al. 2014, 2019) and Delta Smelt directly (Fong et al. 2016). • Dr. Wayne Landis, professor of environmental toxicology at University of Western Washington, is undertaking an Ecological Risk Assessment for the Delta, and Shawn Acuna facilitated a collaboration with Wayne Landis to model this action in this SDM process. • Dr. Landis' work has shown adverse effects of contaminants on Mississippi silversides in the lab, a surrogate species to Delta Smelt.
Researched and discussed in Round 1 SDM Evaluation but not included in Round 1 Portfolios		
Fish friendly diversions	Construct and operate a number of fish friendly diversions at strategic	• There has been engineering and effects analysis work done on this over the last 10 years.

Action Name	Description	Reasons/Considerations for Binning
	locations throughout the Delta. Fish friendly diversions (FFDs) make use of infiltrationgalleries to remove water from the bottom of the water column rather than the side, thus potentially eliminating direct entrainment.	• Scott Hamilton drafted action specification details (rationale, design details, assumed effects, estimated costs, and water supply benefits). • Initial, exploratory model runs were conducted with the IBMR and LF models that assumed 0% entrainment (completely effective action). • There was insufficient time to seek agreement in the TWG on how to model this action and so it was not included in the Round 1 Portfolios. •
Cold water flow pulses to extend spawning season	In years with abundant water (likely wet and above normal years), when temperatures approach 15°C in Mar or 17°C in Apr, release a block of water to reduce water temperatures in the Northern Delta in the hope that this creates further time for an additional spawning event.	• Water temperature during the spawning season was identified by the TWG and the FWS life cycle and LF modeling as a potentially significant DS population bottleneck. • Back-of-the envelope analysis by Ching-Fu Chang raised doubts on whether this action is feasible and so it was not included in Round 1 SDM portfolios or modeled with Delta Smelt population models. Some TWG members still had questions about feasibility and water temperature modeling would be needed to provide more conclusive information.
Silversides population management	Remove/control inland silversides from likely Delta Smelt spawning locations through the most effective means (which is unknown at this time) to reduce predation on Delta Smelt eggs and larvae.	• The predation of Delta Smelt eggs and larvae by inland silversides is a hypothesized bottleneck on the Delta Smelt population. • Exploratory modeling with the USFWS LCM by Will Smith in Phase 3 found a lack of evidence to support this hypothesis and so this action was not modeled further or included in Round 1 Portfolios.
Tidal wetland restoration with temperature focus	Reduce water temperatures through specialized design of tidal wetland restoration sites. Two scales were contemplated: (1) Little Holland Tract as a pilot and (2) scaled up over multiple sites.	• Larry Brown initiated research within the USGS on this action in 2020 and Paul Stumpner (USGS) is continuing with this research. • Paul Stumpner presented to the TWG on his research in 2021 and there was considerable interest in this action. • The NASA JPL used remote-sensing to assess pre-post changes in water temperatures in areas adjacent to two tidal wetland restoration projects (Gustine et al. 2022). Findings suggest the possibility of temperature reduction in adjacent habitat following restoration, but more replication of years and sites is needed. • P. Stumpner and RMA have a draft Statement of Work for further analysis that would advance the modeling of water temperature benefits of this

Action Name	Description	Reasons/Considerations for Binning
		action but this has not been funded to our knowledge.
Hatchery supplementation	Increase Delta Smelt population through supplementing with cultured Delta Smelt.	• The 2020 ROD included funding for annual supplementation of Delta Smelt. • USFWS is leading the experimental release of cultured Delta Smelt adults to learn and prepare for scaling up of this action. • The TWG reviewed modeling from the USFWS LCM on hatchery supplementation, but this modeling assumed the same survival and recruitment for cultured fish as wild fish.
Risk-based OMR management	Identify high-risk circumstances for Delta Smelt entrainment when OMR flow should be more restrictive than current regulations and identify low-risk circumstances when OMR could be less restrictive, thereby improving water supplies without jeopardizing Delta Smelt.	• Scott Hamilton is undertaking analysis to identify high-risk and low-risk circumstances. A preliminary analysis was shared with TWG for feedback. Analysis is ongoing and was not complete enough to model this action in the Round 1 SDM evaluation.
Continue to research & re-consider for Round 2 SDM Evaluation		
Barker Slough – Nurse Slough fish passageway	Construct and maintain a fish passageway between Barker Slough and Nurse Slough with operable gates to increase dynamic habitat for Delta Smelt and provide a means for Delta Smelt to escape the North Delta when summer temperatures become too high.	• At the Mar 12, 2021 TWG meeting, it was agreed that this is a worthwhile action to explore but there are many technical questions to answer about how this action would affect water quality (salinity, turbidity, contaminants) before the benefits can be estimated for Delta Smelt.
Increase turbidity in Delta Smelt habitat	A number of ways for increasing turbidity were identified by the TWG including (1) altering the timing and deposition of regular dredging operations (2) develop infrastructure to transport sediment over/through dams, (3) encourage bank erosion and channel migration below dams (4) supplement erodible sediments below dams.	• All of these ideas are in the 'early conceptual' phase and would require additional information and expertise to evaluate that was outside the scope of the SDM process. • These actions could be reconsidered depending on the results of the sediment supplementation action.

Action Name	Description	Reasons/Considerations for Binning
Spawning habitat augmentation (restoring beaches taken over by invasive species)	Remove invasive *Arundo Donax* from the beaches on the Sacramento River to increase spawning substrates for Delta Smelt in suitable locations.	• Lack of data to determine whether spawning habitat is a limiting factor for Delta Smelt or not. • Insufficient information to model.
Restoration of rip rap levees	Restoration of rip rap levees across the Delta could potentially help to reduce water temperatures and produce food for Delta Smelt. A set-back levee restoration design likely has the best potential for meeting flood protection and habitat objectives.	• There is a high degree of uncertainty in the benefits of this action to Delta Smelt and the action would likely need to be done on a large scale to have significant benefits. • Pilot studies are ongoing by DWR on the benefits of set-back levees to fish (e.g., set-back levee projects at Sherman Island, Staten Island and Twitchell Island) and results and analysis from monitoring will be available in the coming years. Note that this action would consider that some restoration is happening anyway, for flood protection purposes, so adding on a habitat restoration element to this restoration would only add a much smaller incremental cost compared to the baseline cost of restoring for only flood protection purposes.
Protective nursery on Delta Islands for young hatchery fish	Construct a protected nursery, free of predatory fish, to distribute propagated eggs.	• Early concept action
Clifton Court Predation Reduction / Predator hot spot removal	Reduce mortality from predation of ESA listed fish species at Clifton Court or other predator hot spots.	• Under the 2020 ROD, the Bureau is setting up a Delta Predator Hotspot Removal Project that will involve setting up a technical team that aims to identify proposed projects in 2022.
Mitigate contaminants from irrigation drainage	Use appropriate methods to treat, restore or divert contaminated agricultural run-off.	• This action could be re-considered after evaluation of the physical point-source contaminants reduction action.
Drop or Park indefinitely for the SDM process		
Construct temporary/permanent salinity control devices	Place rock barriers or other salinity control devices (e.g., salinity sill @ Carquinez Strait) in the Delta to limit the encroachment of high salinity water to high habitat value areas.	At the Mar 12, 2021 TWG meeting: • the group agreed to drop the consideration of rock barriers because a location could not be identified to put these barriers that would benefit DS and not obstruct important navigation pathways. • some group members thought the idea of a Salinity sill @ Carquinez Strait is the kind of large-scale action that could be beneficial in the future

Action Name	Description	Reasons/Considerations for Binning
		for native fish and water quality objectives, but it was also recognized that there would be many social and economic considerations for this action and evaluating it is likely out of scope for this process.
Cooling devices in key habitats	Some form of large engineering infrastructure (geothermal heat pumps?) could theoretically reduce the temperature in localized areas of hypothesized high spawning activity during the critical months of Feb and Mar to extend the spawning season.	• TWG decided to drop this action from further consideration at their Jan. 29, 2021 meeting due to the significant and likely infeasible energy costs that this action would require.
Adjust fish salvage operations during summer and fall	Adjust summer salvage operations so that non-native salvaged fish will not be returned to the Delta.	• This is an action in the 2016 Delta Smelt Resiliency Strategy. • In the CSAMP SDM Demo Project, the Technical Working Group for that project recommended to drop this action because there was likely minimal benefit to Delta Smelt (Mahardja and Sommer, 2017). No new information has been brought forward in this process to indicate that this previous recommendation should be changed.
Move intakes to the Sacramento River - Delta Conveyance Project	Move intakes to the Sacramento River - Delta Conveyance Project	• This SDM process lacks adequate resources to evaluate this action along with the other actions identified for Round 1.
Sacramento Wastewater Treatment Plant Upgrade	The biological nutrient removal (BNR) treatment became operational in Apr 2021, and the tertiary filtration treatment became operation in 2023.	• This action has been implemented and so there is no further decision making needed. • Still useful to track the implementation of this action as it is changing ambient conditions in the Delta and could have benefits for Delta Smelt and other species, and interactive effects with other management actions.

Appendix 8 – Process

The sections below provide an overview of (1) the main phases of work in the SDM process and associated timelines, (2) who was involved in process committees, and (3) the goals of the process.

SDM Process Phases

The process involved three phases:

1. **Phase 1 – Process Initiation:** Set up the necessary structures and processes to manage and implement the multi-year process including the CSAMP Steering Committee and Technical Working Group. *COMPLETED in 2019.*
2. **Phase 2 – Foundation Work:** Focus on foundational work necessary for the Delta Smelt-related components of the SDM process. *COMPLETED in 2020.*
3. **Phase 3 – Round 1 SDM Evaluation:** Formal evaluation of candidate Delta Smelt management actions across multiple objectives – Delta Smelt population growth, effects to salmon and resource costs (financial and water). *COMPLETED in 2024.*

The key deliverable in **Phase 1** was the development of Process Guidelines (CRM, 2019) that describe how CSAMP would work through the SDM process. This included the following process principles:

- All participants will recognize multiple interests and the need for considering trade-offs in decisions related to water supply, endangered species and other related policy issues.
- The process will respect and does not alter existing legal rights, authorities and responsibilities.
- Meaningful participation will be facilitated.
- The process will strive for consensus.
- All relevant and acceptable information will be used.
- The process will support decision making under uncertainty on an ongoing basis and improve information over time to inform future decisions.

Phase 2 focused on the necessary foundational work to collectively understand and document i) the bottlenecks to Delta Smelt recovery, ii) the potential management actions that should be explored, and iii) the information basis and methods that will be used to estimate Delta Smelt-related consequences within an SDM process. The key outputs from Phase 2 included the identification of ~40 candidate management actions for Delta Smelt and the review and updating (if necessary) of four Delta Smelt population models that could be used to predict the effects of management actions on Delta Smelt population growth.

Phase 3 began with an update of the Process Guidelines (CRM, 2021) for this SDM process and outlined three workstreams:

1. **CSAMP Organizational Framework for Delta Smelt** (hereafter referred to as "Organizational Framework"): Compass worked with CAMT and the Policy Group to develop an Organizational Framework that articulates the shared vision of how CSAMP members will work together and with others to advance CSAMP's management goal for Delta Smelt. The latest version of this Organizational Framework was finalized in July 2021 (CSAMP, 2021) and the intention is for it to be a living document that will be updated as necessary.

2. **Pre-feasibility analysis of early concept management actions:** This workstream involved a screening-level review of the ~40 candidate management actions for Delta Smelt that were identified in Phase 2. This workstream informed which management actions advanced for a full, multiple-objective, evaluation as part of the Round 1 SDM evaluation. This workstream was the focus of the TWG at the start of Phase 3 and activity tapered off in late 2021 as the list of management actions to include in the Round 1 SDM Evaluation became more finalized. See Appendix 7 for more details.

3. **Round 1 SDM evaluation:** This workstream involved estimating the effects of alternative management actions and portfolios on Delta Smelt, resource costs (water and financial) and salmon. Compass and the TWG undertook most work related to this work stream in 2022 & 2023, which included two substantive presentations to CAMT and the CSAMP Policy Group in July 2023 and Dec 2023. The first half of 2024 focused on writing up the evaluation and options for next steps to advance Delta Smelt recovery.

Who Was Involved

The Process Guidelines set up the roles and membership for two key groups to serve the process and collaboration needs of the process – an SDM Steering Committee composed of Policy Group representatives (Table 35) and a Delta Smelt Technical Working Group (TWG) composed of representatives of CAMT members (Table 36).

The role of the SDM Steering Committee was to provide direction on the implementation of the process. Areas where direction was sought included:

- Articulation of CSAMP's Delta Smelt goal statement;
- Scope-related decisions that affected tasks and timelines in consideration of available budget and human resources;
- Direction on products and decisions that should be brought to the broader CAMT and Policy Group for input and/or direction;
- Decisions on the scope of actions to be investigated.

The key responsibilities for the Delta Smelt TWG were:

- Identify and specify candidate management actions to model in the SDM process;
- Seek agreement on how to model the effects of management actions on Delta Smelt, including the proximate effects of actions on Delta Smelt habitat attributes and vital rates and the selection of population models to use;
- Review and provide interpretation of the results of Delta Smelt modeling and other supplemental analysis;
- Identify candidate science and adaptive management actions;
- Review and seek agreement on SDM process reports prepared by Compass.

Compass provided facilitation and analytical support for the SDM process and worked closely with the Delta Smelt TWG and the Policy Group SDM Steering Committee. CAMT co-chairs also helped Compass set up and engage other technical groups for hydrology and salmon to support coarse analysis of Delta Smelt management actions with respect to water resource costs and salmon effects. At key milestones, Compass presented to CAMT and the Policy Group to get feedback on process scope questions and emerging results. Compass developed these presentations in close collaboration with the TWG and with direction from the SDM Steering Committee.

Table 35. Steering Committee members.

Organization	Name
Metropolitan Water District	Nina Hawk, Steve Arakawa
The Bay Institute	Gary Bobker
USBR	Dave Mooney
CDFW	Brooke Jacobs, Carl Wilcox

CDWR	Cindy Messer
USFWS	Donnie Ratcliffe, Kaylee Allen
SWC	Darcy Austin (observer, CAMT Co-chair)
UC Davis	Sam Luoma (observer, CAMT Co-chair)

Table 36. Delta Smelt TWG members (*marks the members participating at the conclusion of the SDM process and who had an opportunity to review and provide input on this Report).

CAMT Member Organization	Technical Representatives
DWR	Randy Mager, Ted Sommer and Erik Loboschefsky (Phase 2)
CDFW	Mike Eakin*
USFWS	Will Smith*, Matt Nobriga*, Erin Cole (Phase 2)
USBR	Brian Mahardja*, Mike Beakes (Phase 2), Larry Brown (USGS – Phase 2)
IEP	Lauren Damon, Steve Culberson*
Metropolitan Water District	Shawn Acuña*
CCWD	Deanna Sereno, Ching-Fu Chang*
PWA	Scott Hamilton*
NGOs	Sam Luoma* and Bill Bennett
SWB	Sam Bashevkin (end of Phase 3)*

SDM Process Goals

The *Process Guidelines* (CRM, 2019) defined two main goals for this SDM process:

1. Build consensus across CSAMP membership on a portfolio of recommended management and science actions to advance Delta Smelt goals; and

2. Support more coordinated management of Delta Smelt, where possible, to integrate three important spheres of activity: science, decision making, and implementation of management actions.

The CSAMP Delta Smelt Organizational Framework further articulated SDM process goals in describing the effort as focused on providing analysis and opportunities to deliberate across CSAMP membership on the following question:

What are the best management and science actions to advance CSAMP's Delta Smelt management goal, in consideration of uncertainties and trade-offs with other socio-economic objectives?

While it would be desirable for all CSAMP members to reach agreement on what the 'best' management and science actions are, full agreement is not the measure of success for this SDM process. As per the second guiding principle in the Organizational Framework, "CSAMP will seek consensus where possible, and even if consensus is not reached, a valuable outcome is the opportunity for dialogue and development of a shared understanding across CSAMP membership."

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resource management

A Response to the SDM Draft Round 1 Report

Scott Hamilton, Ph.D.
Center for California Water Resources Policy and Management

Contents

Executive Summary

Delta smelt are confronted with multiple limiting environmental factors, therefore require the implementation of multiple management actions if recovery efforts are to succeed. While food supplies in the northern arc in summer appear to be essential in efforts to increase the size of the delta smelt population (Figure 1), management actions that contribute to improving turbidity in the upper San Francisco Estuary and reducing contaminants are also likely to contribute to increasing delta smelt abundance. We suggest the following actions will have significant benefits for delta smelt with attending costs that are far less than those currently being expended, and urge implementation of those projects in an adaptive management framework. The actions include 1) restoring 4000 acres of managed wetlands in Suisun Marsh, 2) adding nutrients to the deep water ship channel, 3) carrying out 600 acres of aquatic weed control, 4) initiating sediment supplementation into the Delta, 5) reconnecting wetlands in three wildlife refuges to the estuary, and 6) reducing contaminants in two Delta subregions. Those actions should be initially implemented on small spatial scales to assess their effectiveness before committing to larger investments in them. Since direct sediment supplementation has permitting challenges, as an alternative we suggest monitoring some of the existing projects that have reconnected floodplains to rivers to observe whether those projects contribute to increasing sediment loads entering the Delta.

The SDM modeling indicated that some of the currently implemented actions are not providing the expected benefits to delta smelt and are costly. We suggest redirection of resources used to support conservation of delta smelt to more beneficial uses.

A review of recent modeling results indicates that delta smelt respond to through-Delta flows -- specifically to large inflow events in December and early January that are hypothesized to deliver nutrients and turbidity into the Delta. While through-Delta flows later in the year can be correlated with the performance of delta smelt, a compelling causal mechanism is yet to be identified. Outflow augmentation in the Delta -- the release of water from reservoirs to increase flow in rivers in summer and fall -- does not produce the physical and biotic responses in the Delta or benefits to delta smelt that do large storm events in winter.

Introduction

CSAMP employed a structured decision-making (SDM) process, led by Compass Resource Management (Compass), engaging an evaluation of the effectiveness of alternative management actions in improving the size and growth over time of delta smelt population, while considering tradeoffs, such as management costs and effects on other species. The most promising of those candidate actions were grouped into portfolios of actions. Using four different predictive quantitative models[1], the candidate actions and portfolios were evaluated by a Technical Working Group (TWG), for their potential contribution to delta smelt recovery while accounting for tradeoffs. The results, model outputs, were summarized in “consequences tables.” From that, Compass produced a “Round 1” Report. Different participants within the TWG had different perspectives on what information should be reported to the CSAMP Policy Group. To allow for a full presentation of perspectives, members of the TWG were provided an opportunity to develop and present “response documents”. The document here represents the perspective of one contributing member of the TWG’s intensive modeling effort. I have worked on quantitative modelling and simulation for 40 years with publications beginning in 1984[2]. I have been the lead author or coauthored seven published journal articles on delta smelt and this is my third involvement in an SDM process targeting delta smelt[3]. This document is intended to highlight management-relevant information from the SDM effort, intending to facilitate discussion. It draws primarily from the consequences tables in the Round 1 Report (also provided at the end of this document).

This document was designed to minimize the need to continually cross-reference the Round 1 Report; therefore, it duplicates some material from, and notes similar findings with that report. It contains an Appendix with a summary of the SDM process and some of the key tables Appendix A. Given the controversy and confusion over the benefits of flows to delta smelt, we review recent studies and present an explanation that clarifies when flows benefit delta smelt and when they do not, and apparently cannot, in Appendix B. While no prioritization of management actions or action portfolios was conducted in Round 1, here in Appendix C we conduct an optimization exercise to illustrate and underscore its importance. The results therein are provocative and compelling.

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[1] The four models were a simulation model (IBMR), two state-space models (LCM and Mauder-Deriso), and a Limiting Factor (LF) model. See Round 1 Report, Table 1 for a description of each model.

[2] Adams RM, Hamilton SA and McCarl BA (1984) *The Economic Effects of Ozone on Agriculture*. Environmental Protection Agency, Office of Research and Development, Technical Report, EPA 600/3-84-090, September 1984.

Hamilton SA, McCarl BA and Adams RM (1985) *The Effects of Aggregate Response Assumptions on Environmental Impact Analyses.* American Journal of Agricultural Economics, 67:407-413.

[3] Two prior SDM efforts include Compass Resource Management (2018) *Structured Decision Making for Delta Smelt Demo Project*, prepared for CSAMP/CAMT and Peterson J T. McCreless E, Duarte A, Wohner P, Hamilton S, Medellín-Azuara J, Escriva-Bou A. (2024) *Prototyping structured decision making for water resource management in the San Francisco Bay-Delta*. Environmental Science & Policy 157, 103775.

1. What are the key findings?

1.1 All models predict that the implementation of certain management actions could lead to the recovery of Delta Smelt

The Round 1 Report presents a metric "λ" (lambda) which is calculated as the geometric mean of the projected Delta Smelt population in one year divided by the projected population in the previous year, averaged over the 20-year study period. A λ with a value greater than one indicates that the population is increasing, and less than one, that it is decreasing.

All models projected two food-focused portfolios would provide the greatest population growth rates for Delta Smelt – Portfolio 3d (the "Focus on Food" portfolio) and 3e ("Habitat Connectivity")[4]. The average of λ across 3 models was 1.63 for Portfolio 3d, and 1.61 for Portfolio 3e[1]. Portfolio 3d contained management actions for tidal wetland restoration, managed wetlands in Suisun Marsh, nutrient supplementation in the Sacramento Deep Water Ship Channel, aquatic weed control and contaminant reduction, in addition to some "current management" actions. Portfolio 3e contained management actions for tidal wetland restoration, aquatic weed control, contaminant reduction, restoration of Franks Tract, and sediment supplementation in addition to some "current management" actions. These portfolios had actions in common that **improved food availability and turbidity conditions and reduced contaminants and aquatic weeds[5].** Neither portfolio includes any new flow-augmentation actions[6] suggesting relatively large population increases could be possible without using expensive flow augmentation actions. To be effective, some food-focused actions will require implementation over a sustained period, for example, management of wetlands requires annual implementation to achieve benefits.

Given that adequate food supplies appear critical to improving abundances of Delta Smelt, it can be inferred that other management actions that also enhance food supplies in spring and summer could further increase recovery rates of delta smelt.

1.2 Some models showed a benefit to summer flow augmentation

Two of three models predicted positive population growth for "Full Year Flows" (Portfolio 2a.1), with λ= 1.21 & 1.15 for IBMR and LCME models respectively, with small benefits to salmon but no risks, and a cost in the range of $151 to $200 mill/year (Round 1 Report, Table ES-2). The results suggest some possible benefits to flow augmentation although it still needs to be determined if water operations are capable

[4] See Tables A-2 and A-3 for details of actions included in each portfolio.
[5] By incrementally adding and subtracting actions to portfolios it is possible to isolate the value of any individual action to a portfolio. That exercise was conducted using the LF model, but the TWG did not have the time to review the results.
[6] See Table A-2

of this type of implementation and whether the realized effects being assumed by this portfolio are worth the costs in the face of other alternative portfolios.

1.3 Food-based actions are likely to be more cost-effective than flow augmentation actions

The costs to implement management actions vary significantly across portfolios[7]. Round 1 portfolios were not optimized to identify the most cost-effective portfolios. Despite the preliminary cost estimates, two of the portfolios appeared to be significantly more cost effective than others - Portfolios 2b and 2c. Portfolios 2b and 2c added actions to "Current Management" - a food action in the Deep Water Ship Channel, aquatic weed control in Yolo Bypass and Cache Slough, but no new flow actions. Portfolio 2c also added 2,000 ac of managed wetlands in Suisun Marsh and in doing so became the most cost-effective portfolio. That is, **Portfolio 2c showed the greatest predicted increase in the size of the Delta Smelt population per unit of cost** (Table 1)[8]. More cost-effective and efficient portfolios could be developed by optimizing the level of actions in Portfolio 3d (which already includes all of the actions in Portfolio 2c) and removing current management actions that have not shown benefits to Delta Smelt.

Table 1. *Cost effectiveness of portfolios modelled in Round 1 calculated from data in Table ES-2 of the Round 1 Report. Only the IBMR model results were used for this calculation because it was the only model that analyzed all the listed portfolios. The cost of actions in the SDM process were "coarse ballpark estimates" and were expressed as a range, thereby recognizing the uncertainty in the cost estimates. For simplicity, only the mid-point of the range is used here. See Table A-2 for more complete cost information.*

Portfolio	IBMR	Avg Cost	Cost per percent gain
	Lambda-1	$mill/yr	$mill/yr/1% gain
1b	0.00		
2a.1	0.21	175.5	8.36
2b	0.12	3.0	0.25
2c	0.25	3.0	0.12
3c.2	0.13	425.5	32.73
3c.4	0.10	125.5	12.55
3a	0.40	125.5	3.14
3d	0.96	175.5	1.83
3e	1.23	88.0	0.72

[7] It should be noted that costs for actions were estimated at a high level and were intended to be "ballpark estimates" and should not be interpreted to have precision.
[8] Table A-5 was derived from the Round 1 Report, Table ES-2.

2. Are the findings credible?

2.1 The findings are consistent with results from earlier studies showing flows during the first flush and availability of food largely determine population responses in Delta Smelt

Results from the Limiting Factors[9] model supported elements common in conceptual models – that the magnitude and timing of the first flush has a major bearing on hydrologic conditions and food-web status for the year with corresponding influences on flows across floodplains that increase nutrients and turbidity entering the Delta [10]. Flows in the summer and fall are correlated with flows in the winter and spring [11]. Numerous researchers have mischaracterized the correlation between flows in summer and food availability in summer as cause and effect. However, augmentation of flows via reservoir does not produce flows across flood plains that are hypothesized to transport sediment and nutrients into the Delta[12]. The primary cause of food availability in summer is due to the magnitude of the first flush and the associated introduction of nutrients and turbidity into habitat area supporting Delta Smelt [5]. Regardless of the research evaluating the relationship between specific actions like flow or habitat restoration on food supply, the results were clear across multiple models, more food resulted in greater population growth. While a first flush cannot be replicated artificially, it is possible to manage food production to benefit Delta Smelt.

2.2 Some findings are supported by time series data

Supporting the modelling conclusion, historic data suggests that a **shortage of food from June through August limits the population growth of Delta Smelt** (see Figure 1).

2.3 The findings related to synergism are consistent with the theory of limiting factors

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[9] See also Hamilton and Murphy (2022) next footnote.

[10] Hamilton SA, Murphy DD (2022) *Identifying Environmental Factors Limiting Recovery of an Imperiled Estuarine Fish*. Frontiers in Ecology and Evolution 10:826025. doi: 10.3389/fevo.2022.826025

[11] The correlations (r) between seasonal X2 values from DWR's Dayflow database (1956-2022).

	Dec-Feb	*Mar-May*	*Jun-Aug*
Mar-May	0.69		
Jun-Aug	0.61	0.87	
Sep_Nov	0.78	0.80	0.73

[12] See Appendix B for more on the influence of flows on the abundance of delta smelt.

An understanding of thresholds and limiting factors is fundamental to understanding the modeling results. Results of individual management actions are provided in Table A-5 (Table ES-3 of the Round 1 Report). While it is tempting to apply significance to the findings relating to individual actions, such results should be interpreted with great caution. In real-world ecosystems, more than one factor usually limits abundance. Hypothetically, if one factor limits recovery in summer and a different one would limit recovery in spring but for summer constraint, just looking at the spring action by itself will show no benefit because the summer constraint is limiting. If just the summer factor is addressed through an action, the action will show limited benefit because the spring constraint will be realized. Only when both limiting factors are addressed simultaneously are the potential benefits realized. Therefore, the results from the analysis of management portfolios have more relevance than those of individual actions.

2.4 The findings are consistent with an earlier SDM effort[13]

The Compass "SDM Demo" Project[14] identified a set of management actions that were "considered relatively higher priority because they appear to offer a good benefit to cost ratio. In all cases, there appears either to be good or some prospect of expected benefits to delta smelt and other ecological objectives, while negative impacts to socio-economic interests are smaller or commensurate with the degree of benefit." Those actions were: north Delta food web enhancement, reoperation of Suisun Marsh flood and drainage, tidal wetland restoration, establishment of a Rio Vista Research Station, reoperation of SMSCG, and Roaring River food production.

[13] A "protype SDM process - Peterson JT et al. (2024) Prototyping structured decision making for water resource management in the San Francisco Bay-Delta. *Environmental Science & Policy*, *157*, 103775 - also showed benefits of enhancing food for Delta Smelt. That analysis utilized an earlier version of the LF Model - Hamilton SA and Murphy DD (2018) Analysis of Limiting Factors Across the Life Cycle of Delta Smelt (*Hypomesus transpacificus*) Environmental Management. Because of the similarities of the models utilized in Peterson et al. in the Round 1 report, consistencies of results do not provide corroboration of the Round 1 findings.

[14] Compass Resource Management (2018) Structured Decision Making for Delta Smelt Demo Project, prepared for CSAMP/CAMT.

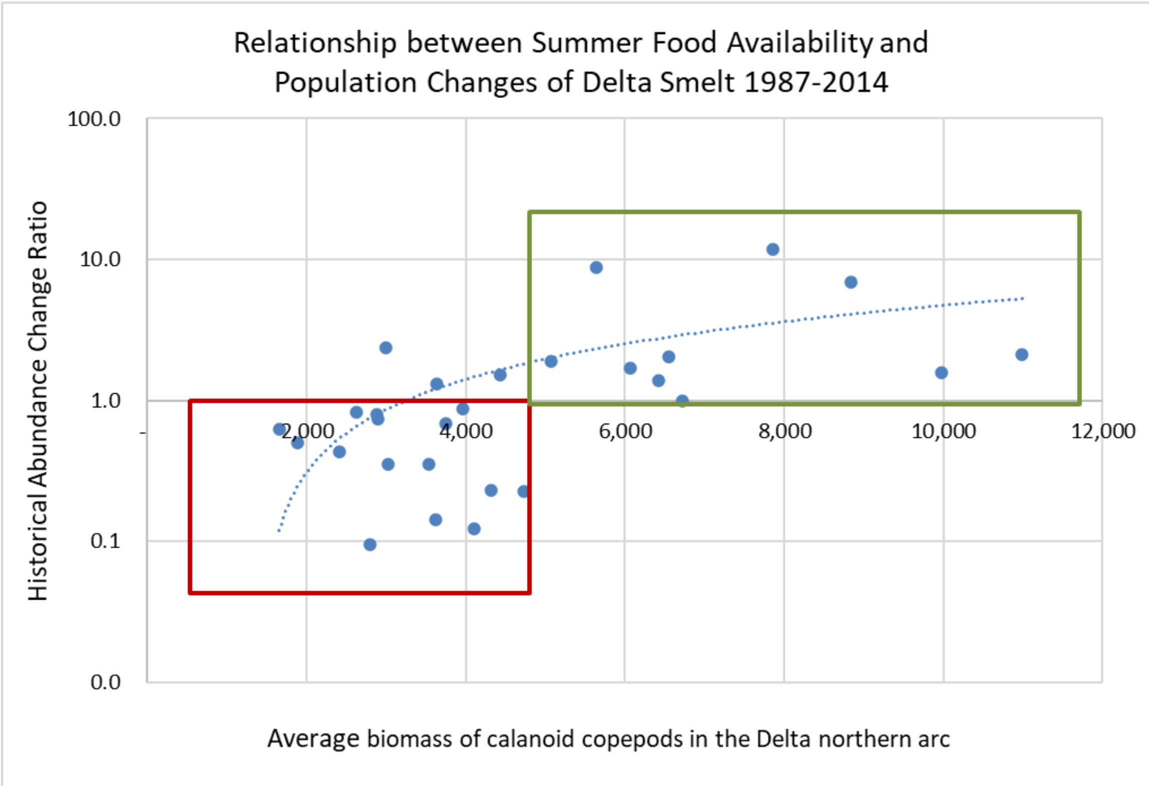

Figure 1. *The relationship between summer food availability and Delta Smelt population-size changes 1987-2014. A ratio greater than one indicates an increase in the population. Delta smelt abundances consistently increased when prey availability in the Delta northern arc exceeded an average of 5,000 µgC/m³ in the period from June through August. While univariate (one factor) analysis can be misleading, for example, if there is a more relevant covariate influencing the dependent variable, in this case, this figure helps to understand the findings in Table ES-2 of the Round 1 Report. (Note that the horizontal axis is the average biomass of adult calanoid copepods from June through August in the northern arc of Delta Smelt habitat [stations NZ028, NZ032, NZ054, NZ060, NZ064] from 1987 to 2014. The vertical axis is the FMWT Index in one year divided by the FMWT Index in the previous year).*

3. What are the implications of the findings for conservation management?

3.1 Implementing certain management actions is projected to lead to Delta Smelt recovery

It can be inferred from the results presented in the consequences tables that **certain management actions, implemented simultaneously, have the potential to have substantial benefits for Delta Smelt**, and could do so while keeping implementation costs at moderate levels.

At least two "next-step" options are available. One path forward would be to complete a full structured-decision-making analysis to better refine and clarify the next steps. Other decision-support analyses, such as Value of Information (which estimates "worth" that will come from knowledge that leads to a decision), could be useful in determining whether any reduction in uncertainty of an action is worth the investment.

Another approach is to select some actions for implementation in a rigorous adaptive management framework. At the end of Round 1 of the SDM process, considerable uncertainty exists regarding the performance and likelihood of success of any of the actions. Adaptive management aims to reduce this uncertainty by setting objectives, defining success, implementing management alternatives, instituting a monitoring program sufficient to determine effectives of the implemented actions, analysis, and review and modification of actions, as needed. Rigorous implementation of that process facilitates learning and continual improvement of implemented actions for the benefit of the species.

Actions that might be considered for immediate implementation in an adaptive management framework include:

a) Implementation and **adaptive management of wetlands in Suisun Marsh** to produce food from May through November to increase spring and summer food supplies (~4,000 acres). This suggestion is consistent with Next Steps #1 in the Round 1 Report, p.ii.

b) Implementation and **adaptive management of flow-through wetlands systems** in wildlife refuges in Suisun Marsh and Yolo Bypass to evaluate effects on summer food supplies (~17,000 ac). While this action was not the subject of modeling, the apparent benefit of summer food together with a potential June food gap under managed wetlands action suggests the action is worth pursuing in an adaptive management framework.

c) **Reconnection of floodplains to rivers** upstream of the Delta to increase sediment and fuel food webs. While this action was not modeled, benefits of increased turbidity for Delta Smelt are likely. Adding sediment directly to the Delta has permitting challenges and funding for additional removal of aquatic weeds has been challenging. Reconnection of floodplains to rivers restores pertinent natural processes and can be implemented in an adaptive management framework, allowing improvements in turbidity to be assessed. This suggestion provides a more pragmatic alternative to Next Steps #5 in the Round 1 Report, p.ii, because direct addition of sediment to Delta water proposed in Next Steps #5 may be very difficult to permit and expensive to implement annually.

d) **Nutrient addition** to the Sacramento deep water ship channel.

e) **Construction of wetlands at a contaminant hot spot** to mitigate contaminant inputs to the Delta. To be feasible, such an action should take place in a location that meets the following criteria: (a) the location supports or potential supports Delta Smelt; (b) the location is a serious contaminant hot spot (enriched contaminant concentrations documented); (c) adverse effects of contaminants in the candidate location are documented by field evidence and/or advanced toxicity testing; and (d) the location is amenable to mitigation with available technology. Ulatis Creek in the Cache Slough Complex meets these criteria (see below) and could be an ideal candidate site for implementing and testing constructed wetlands for contaminant reduction. This suggestion is consistent with Next Steps #3 in the Round 1 Report, p.ii.

3.2 Some of the remaining uncertainty can be resolved through application of adaptive management

Uncertainties regarding Delta Smelt ecology, behavior, and resource needs and tolerances exist; they are the reason to undertake an SDM process. Findings from this process to date should be interpreted cautiously, with numbers in tables reflecting general indications rather than precise findings. That said, the final step in the SDM process is to implement, monitor, and review management actions that are likely to be most effective and affordable (see Figure A-1). In that step, much uncertainty that existed prior to SDM can be resolved by implementing actions in an adaptive framework and effectiveness (performance) monitoring. The SDM process does not require, nor would it be possible, for all uncertainties to be resolved prior to implementation of actions. Delaying implementation of actions in order to reduce uncertainties could have adverse impacts for the species.

a. The policy group might consider if possibly ineffective management actions should be continued

The abundance of Delta Smelt in long-running surveys has trended downwards since the implementation of the Biological Opinion of 2008 suggesting that current management actions, which were only intended to mitigate water project operations, are by themselves, ineffective in recovering the species. However, modelling of individual management actions showed that only one of the "Current Management" actions (OMR Management) predicted population benefits. **Modeling did not show population benefits for other actions currently being implemented**. Those were North Delta Food web enhancement, Fall X2 (flow augmentation in wetter years) and Suisun Marsh Salinity Control Gate reoperation. In determining the best use of available resources, the policy group may want to consider the value of continuing management actions that are not well supported by the modelling.

3.4 Some further research and directed studies would facilitate adaptive management and accelerate learning

Further research, new directed studies, and funding are needed to improve the effectiveness and reduce risks when implementing management actions such as:

a) Monitoring to quantify local and **system-wide contributions of restored tidal wetlands** to Delta Smelt food availability and diets, and the effects of tidal wetland restoration on water temperature. Alternative studies have provided different assessments of the level of food production from tidal wetlands. Because tidal wetlands are expensive to restore, it would be worthwhile to confirm their expected benefits before expending more resources on such restoration. This suggestion is consistent within Next Steps #7 in the Round 1 Report, p.ii.

b) Identifying **cost-effective means of restoring tidal wetlands**. Creating extensive areas of inter-tidal wetlands can be expensive. But given sea level rise, highly engineered tidal wetlands may not be optimal. Evaluating alternative design concepts for tidal marsh restoration may lead to better use of existing resources and increasing long-term benefits for Delta Smelt.

c) **Increasing funding for aquatic weed control.** Fund different spatial and temporal aquatic weed control applications in an effort to scale up and increase effectiveness. This suggestion differs from Next Steps 2 in the Round 1 Report, p.ii, by suggesting that funding and permitting, and not the need for further assessment, is limiting expanded use of aquatic weed control

d) Reviewing and carrying out further studies of the effects of **predation by silversides.** Several studies have identified silversides as being a predator of importance on Delta Smelt eggs and larvae[15] but none of the four models in the current SDM process identified population level effects of predation by silversides. A review of more recent studies and DNA data may help resolve this discrepancy and, if appropriate, may lead to consideration of protective actions, for example, a program to establish propagated eggs in a nursery protective from silversides. This could help overcome constraints at propagation facilities.

e) Developing more efficient **alternatives to protect Delta Smelt from entrainment** in the short and long term. The modeling determined that entrainment management improved survival but at cost to water supply. Finding ways to reduce both entertainment and cost would provide dual benefits. This suggestion differs from Next Steps 6 in the Round 1 Report (page ii), because small and late first flushes are associated with low levels of entrainment (delta smelt do not disperse to areas near the pumps under these circumstances) and supplementing first flush under these circumstances, as proposed in next Steps #6 is unlikely to have much influence on entrainment). Rather, preliminary investigations suggest risk based OMR management is likely to be more effective in reducing entrainment in the short term[16] and strategically located fish friendly diversions are likely to be more effective in the long term.

f) Assessing the **effectiveness of actions that contribute to habitat connectivity**. Modeling showed benefits for the portfolio that focused on habitat connectivity. Another way to achieve that would be to connect Cache Slough to Suisun Marsh via a northern waterway and similar in design to the Deep-water Ship Channel, thereby allowing delta smelt to move between these two productive areas. However, such a radical change to the waterways may have unintended consequences. A preliminary step may be to utilize expert elicitation to analyze the concept.

Noteworthy, there is no science study proposed here that is consistent with Next Step #4 in the Round 1 Report (page ii) which proposes studying the feasibility of additional outflow actions. Several concerns reported in this document indicate that further study of flow augmentation may not be an appropriate next step. Those concerns include: the need to resolve differences in food modeling that may be overestimating

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[15] See Mahardja B. et al. (2016). Abundance Trends, Distribution, and Habitat Associations of the Invasive Mississippi Silverside (*Menidia audens*) in the Sacramento–San Joaquin Delta, California, USA. San Francisco Estuary and Watershed Science, 14(1).
Baerwald et al. (2012), Contents of the Invasive Mississippi Silverside in the San Francisco Estuary Using TaqMan Assays, Transactions of the American Fisheries Society. 141:1600-1607.
Hamilton SA and Murphy DD (2018) Analysis of Limiting Factors Across the Life Cycle of Delta Smelt (*Hypomesus transpacificus*) Environmental Management.
[16] Hamilton and Murphy (2024), Using predictive models to manage risk of entrainment for Delta Smelt, an imperiled estuarine fish. In review.

the benefits of flow actions, the cost effectiveness of flow actions relative to food actions, and the finding that recovery can likely be achieved without the need for expensive flow actions. Also, the impacts of flow action are difficult to analyze because of the potential impacts to cold water flows for salmon.

3.5 The SDM effort is not complete

The SDM effort was intended to be conducted in two rounds -- the first is completed. In Round 1, candidate actions were identified and evaluated and the most promising of these were grouped into portfolios that reflected different strategies. The actions and portfolios were evaluated using four different predictive quantitative models. The modeling focus in Round 1 was population growth of Delta Smelt. The consequences of candidate actions to salmonids and water supply were also estimated and the costs of candidate actions were tabulated. Compass took direction on study scope from the Steering Committee for Round 1. Effort was directed to investigating the sensitivity of outcomes to different levels (intensities) of summer/fall habitat actions, tidal wetland restoration, and aquatic weed control. Effort was also dedicated to documenting relative levels of uncertainty that accompany predicted management outcomes. It was not the intent in Round 1 to determine the “best” combinations of actions that would maximize the benefits to Delta Smelt while minimizing costs, nonetheless useful inferences can be drawn from the SDM consequences tables and some omitted information is noteworthy.

a) **The Round 1 Report does not consider or calculate the costs of current regulations.** The Steering Committee felt that a full financial analysis was not necessary in Round 1 if the analysis was structured to contrast the proposed actions against a baseline cost. The cost estimates of the portfolios in the report are compared to Portfolio 1b “Current Management.” As such, the costs for Portfolio 1b are not reported in Table ES-2 although some of the actions may be costly. For example, DWR estimated that the cost of the Fall X2 action in 2023 was on the order of 600,000 af[17]. At $815/af[18] that equates to $489 million. **If the Fall X2 action occurs in 30% of years[19], the average annual cost is around $147 million per year**.

b) **The Round 1 Report does not consider employment and other economic impacts**. Water can be used to meet many beneficial uses, such as in-stream flow requirements for salmonids, enhancement of water quality, diversions for

[17] J. Leahigh (2023) Presentation at ACWA Committee Meeting, November 2023.

[18] See Round 1 Report, Appendix 3 – Water Resources Methods – Monetized water cost.

[19] DWR data (http://cdec.water.ca.gov/cgi-progs/iodir/wsihist) indicate that wet years have historically occurred in a third of all years, and above-normal years in an eighth of all years. In some of those years Fall X2 requirements would be met without flow augmentation.

human uses or food production, or to meet health and human safety needs. Appropriate allocation of water resources involves evaluating challenging tradeoffs. Without being aware of these tradeoffs, policy makers are at a disadvantage. For example, Professor David Sunding, at UC Berkeley, estimated the consequences of water shortages in the San Joaquin Valley[20]. Interpolating his results, each 1,000 af reduction in water supply results in a loss of 17.5 FTE agricultural jobs, 9.8 FTE in indirect jobs in the San Joaquin Valley and 8 FTE jobs outside of the San Joaquin Valley for a total of 35.3 jobs lost per 1,000 acre-feet. The summer flows action in Portfolio 3c.2 is estimated to cost 495,000 af/year, which may equate to more than 17,000 jobs lost statewide. Many of the people that would be impacted are Hispanic workers in disadvantaged communities. Whether that is important or not is a value judgement. CSAMP and the Steering Committee directed Compass to scope what a full socioeconomic analysis would require. Compass engaged some social scientists from DSC's Social Science Community of Practice. Because the analysis would require engaging multiple outside experts, the Policy Group and Steering Committee then decided to table the analysis for after Round 1. There was not sufficient time or budget to do the socioeconomic analysis in this process. While the practical constraints necessarily limit the scope of work, without a more complete consequences table, policy makers are not fully informed.

c) **An iterative review of the Round 1 results would have highlighted the potential for additional actions to further aid recovery of Delta Smelt.** Due to direction from the Policy Group to stop further iterations and report on the results, necessary analyses were not fully completed. The analyses that were performed did include grouping individual management actions into portfolios and the consequences of different levels of implementation of some management actions. These steps further refined actions but there were much larger potentials for optimization. For example, modeling suggested that increases in managed wetlands are likely to benefit Delta Smelt, but the action as proposed does not produce food for Delta Smelt in June. That one-month gap in food production could potentially be overcome by combining the action with management of water in wildlife refuges, **supplementing June food supplies, and providing sustained food production through the spring and summer, thereby further increasing the projected recovery rates for Delta Smelt**.

d) Optimizing portfolios similarly could have led to increased projected population rates at decreased costs. Conservation managers have limited budgets and limited expert staff, requiring agencies to direct available resources to the areas where they are likely to be most effective. Because the portfolios in Round 1 were

[20] Microsoft Word - Blueprint.EIA.PhaseOne.2.28.docx (waterblueprintca.com)

not optimized, that is, the implementation level of each action within a portfolio was not optimized, **realistic costs for management-action portfolios were not calculated**. For example, Portfolio 3d (Focus on Food) had aquatic weed control being implemented in 5 regions and contaminant reduction in 12 regions[21]. Likely both of those actions achieve most of the benefit if implemented in just a few regions. Implementing those actions in fewer regions would have reduced the cost with little difference in benefits to Delta Smelt.

e) **Key technical issues were not resolved with the likelihood that certain benefits to Delta Smelt were overestimated**

One of the major factors influencing the predicted benefits of certain management actions was **the choice of the food models** used to inform the effects of flow augmentation. The SDM process did not resolve which of the alternative predictive food models represents the best available scientific information. The Flow/Food model used to provide inputs to the IBMR model was based on changes in salinity and only modelled conditions from the Confluence westward, ignoring changes in food in half of the subregions. Prey availability east of the Confluence can change substantially with seasons and inflows, while changes in salinity are small. Therefore, while this food model is good for some tasks, it may not be well suited to providing estimates of changes in food supply across the entire Delta or for some parts of the year when flow actions are applied. The differences in estimated population growth rates between the IBMR model and the LCME model when conducting sensitivity analyses were relatively small (less than 10%) suggesting that the bias, if there is any, may be small. The flow/food model and the flow/distribution model **led to the benefits of flow augmentation in the IBMR model which were not detected by the LF model for the same action in the Fall.** An alternative flow-food model[22] using 12 subregions covering the entire upper estuary, modeled the influence of flows directly. Other statistically significant covariates in that model included previous and upstream biomass, water temperature and the historic presence of the Asian clam. The use of this alternative model identified the benefits of flows to food production, which varied by season and region. Although, this model only considers one category of the prey for Delta Smelt (calanoid copepods), they are a preferred prey category. With two alternative models providing differing results important for evaluating

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[21] See Table A-2, a reproduction of Round 1 Report Table ES-1 .

[22] Hamilton S, Bartell S, Pierson J, Murphy D (2020). *Factors Controlling Calanoid Copepod Biomass and Distribution in the Upper San Francisco Estuary and Implications for Managing the Imperiled Delta Smelt* (*Hypomesus transpacificus*). Environmental Management 65: 587–601. https://doi.org/10.1007/s00267-020-01267-8

flow actions, CSAMP might consider requesting this scientific discrepancy be resolved prior to proceeding with flow augmentation actions.

Modeling in Round 1 predicted benefits for delta smelt of increased turbidity[23]. Two USFWS models (IBMR and LCME) offered differing predictions for benefits of turbidity. The turbidity response in the IBMR model, which showed a greater response to turbidity, was an assumed relationship. In contrast, the LCME relationship was empirically based. Because the turbidity relationship in the LCME model was empirically based, **it is likely that the assumed relationship between turbidity and Delta Smelt population responses in the IBMR model overestimates the importance of turbidity in that model.** Modelling suggested the benefits to Delta Smelt were sensitive to the turbidity responses, and addressing the difference may help reduce uncertainty.

[23] See for example, Section 5.4, pages 62-63.

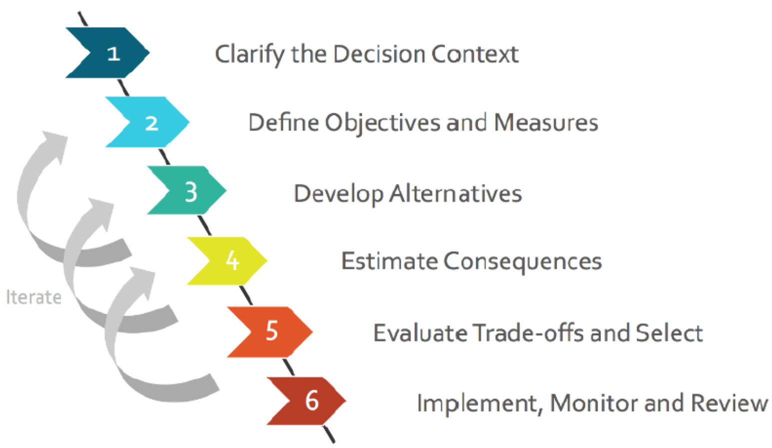
Appendix A

Summary of the SDM Process and Findings

This appendix is my condensed summary of the comprehensive and substantial SDM process that is documented in the Round 1 Report. Rather than a readable narrative, it is intended to provide a quick reference for the reader of the decision context, the objective and metrics used in the SDM process, all of the suggested management actions together with an explanation of why each was analyzed or not, and a condensed version of the key consequences table.

Introduction

The primary purpose of structured decision making is to aid and inform decision makers in an information-rich, defensible, and transparent manner, rather than to prescribe a preferred solution. It's founded on the idea that good decisions are based on an in-depth understanding of both values (what's important) and consequences (likely outcomes)[24]. The process recognizes and responds to planning processes in which the context may not be well resolved, the available science partial and uncertainties abundant, stakeholders can be disagreeable and participating entities have values that are entrenched.[25]



CSAMP has initiated a Structured Decision Making (SDM) Process to identify sets of management actions that are predicted to lead to the recovery of delta smelt.

Figure A-1. *The standard SDM process follows a six step process, with iterations as necessary. The structure of this Appendix follows the SDM steps through to evaluation of tradeoff in step 5. Because the participating agencies, and not CSAMP itself, have the authority to implement projects, the "select, implement, monitor and review" components of the SDM process are not addressed here.*

[24] Gregory et al. (2012) p. 2,6.
[25] Gregory et al. (2012) p. 2.

1. The Decision Context

The CSAMP Policy Group adopted the following recovery goal for delta smelt:

"Reverse the trajectory of the Delta Smelt population from one in decline to one experiencing overall increases within 5-10 generations with the long-term aim of establishing a self-sustaining population." [26]

The aim of the SDM process is to identify a portfolio of management and science actions that CSAMP members can support as likely to improve the abundance and contribute to sustaining delta smelt. [27]

2. Objectives and Measures

Objectives

Objectives were identified in the SDM process are summarized in (Table A-1)[28].

Table A-1. *SDM Objectives for Delta Smelt*

Objective	General Description of Metrics
Grow the Delta Smelt population	Metrics generated from the model outputs include: population growth rate (average population change from one year to the next), percent change in population growth rate from observed conditions) percent change in population growth rate from a Reference Portfolio, effect uncertainty (subjective qualitative score)
Protect Salmon	Potential direct benefits and risks to salmon derived from salmon expert elicitation (score -3 to +3 for management actions and 0 to 3 for portfolios).
Minimize capital and operating costs[29]	Estimates of "ballpark" costs for each management action over a 20-year period, including upfront capital costs, ongoing operating costs (e.g., staff time, annual monitoring), and water costs.
Minimize impacts to water supply[30]	Estimated changes in water supply resulting from a management action.
Meet Iin-Delta water quality standards	Estimated changes to water quality from an action that would impact in-Delta diversions for municipal and agricultural uses (e.g., increasing/decreasing salinity levels).

[26] Round 1 Report Ver. 2.4, p.2.
[27] Compass (2021) Process Guidelines, CSAMP Delta Smelt Structured Decision-making Project, p.7.
[28] See Round 1 Report , Table 11, for the full description.
[29] "This objective represents an interest in minimizing resource costs allocated toward Delta Smelt management, all else being equal". Round 1 Report page 36
[30] "This objective represents the interest in minimizing impacts to water supply and its reliability of delivery, all else being equal." Round 1 Report page 36

Measures

The following performance measures were developed to help evaluate tradeoffs between management actions and between action portfolios in the Structured Decision-making Process.

Delta Smelt[31]

Population growth rate (lambda, λ) – calculated as the estimated population in one year divided by the estimated population in the previous year. A number above one means the population is increasing and conversely a number less than one is decreasin. Annual population growth rates are summarized over the model period (20 years) by calculating the median and/or average population growth rate across model simulations.

Change in population growth rate from reference -- the estimated median population growth rate over 20 years for a given management action divided by the historical median population growth rate over 20 years minus one. A percentage change greater than zero indicates that a particular action increased population growth rate from its historical rate.

Effect uncertainty – A score between 1 (low uncertainty) and 3 (high uncertainty) indicates the degree of uncertainty of an management actions' effects on delta smelt, based on the amount and level of agreement regarding existing data/models/evidence.

Time to Implementation[32] – The range in years of the expected time to implement the management action and realize expected benefits from it, assuming normal permitting requirements and no litigation.

Salmon

Salmon effects from management actions - The metric describes the expected level of risks or benefits of each prospective management action to salmonids. A constructed scale was developed and scored by a group of Central Valley salmonid experts in workshops conducted in March and April 2023. The levels in the constructed scale range from -3 (highest expected risk) to 0 (no expected risks or benefits) to +3 (highest expected benefits). For each action, the magnitude of its effects (for example, the % change in food availability) and the temporal and spatial overlap between the action and salmonids was considered in scoring and the average was reported.

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[31] Adapted from Compass (2013) Delta Smelt PM Inf Sheet March 2023 on SharePoint
[32] Also referred to as "Technical Feasibility"

Salmon benefits from portfolios – Score (group average, minimum, and maximum). Potential benefits of a portfolio were calculated by taking the average, minimum, or maximum scores for each action, summing all scores for actions included in the portfolio, and rescaling the final value to be between 0 (no benefits to salmon) and +5 (greatest benefits to salmon). Actions with potential risks (SMSCG, relaxed Fall X2 management, and aquatic weed control) were not included when calculating benefits scores. Scores for each action were modified to account for the spatial and temporal extent the action was applied, if it varied by portfolio.

Salmon risks from portfolios - Score (group average, minimum). Potential risks were calculated by taking the average or minimum scores for each action that had any potential risk (SMSCG, relaxed Fall X2 management, and aquatic weed control), summing all scores for actions included in the portfolio, and rescaling the final value to be between -5 (greatest risks to salmon) and 0 (no risks to salmon). A performance measure for potential risk using the maximum action scores was not calculated because all portfolios would have received a score of 0.

Water Supply

Water resource costs are expressed in change in average annual exports (in thousands of acre feet/year) over the 20-year study period compared to the no-action case (Portfolio 1B). Historical hydrology (X2 location and average OMR) was modified to simulate the influence of current regulations on historical hydrology to generate Portfolio 1B flow conditions.

Financial Costs

Financial costs are comprised of three items – capital costs or one time implementation costs that occur when the action is first implemented, annual operating costs, and water costs, although not every action incurs all three components. Initial implementation costs are averaged over 20 years and added to annual operating costs and water costs to provide an annual cost per year. The unit water cost was set at $815/af per the decision of the Policy Group on December 6, 2023. The other costs were estimated and reported by Compass on SharePoint[33].

Cost per 1% average increase in abundance – while this metric was not in the original list of performance measures, it provides a means of accounting for benefits to Delta Smelt and annual costs simultaneously. It is calculated by applying the estimated population growth rate percentages from model estimates averaged over the 20-year study period and dividing by the average annual financial costs of the portfolio.

[33] Compass SharePoint>Documents>7. PM Info Sheets > 4. Financial Resource Costs

3. Management Alternatives[34]

The Delta Smelt Technical Work Group (TWG) reviewed available evidence of Delta Smelt population bottlenecks or limiting factors and brainstormed around 40 candidate management actions. Functionally, these were grouped into four categories: candidate actions for evaluation in the SDM process, management actions for which the decision to implement had already been made, candidate actions requiring more investigation to enable evaluation at a later time, and candidate actions withdrawn because they were considered infeasible or impractical. All of the candidate actions are described briefly below.

Candidate Management Actions for Evaluation

1 **North Delta Food Subsidies** - Re-direct 1) agricultural drainage or 2) Sacramento River water through the Yolo Bypass Toe Drain as a flow-pulse to increase food web productivity and transport of food to downstream regions (Cache Slough Complex and lower Sacramento River).

2 **Sacramento Deep Water Ship Channel** – Add nitrogen to the Sacramento Deep Water Ship Channel to stimulate plankton growth and abundance.

3 **Managed Wetlands Food Production** - Manage wetland flood and drain operations to promote food export from the managed wetlands to adjacent tidal sloughs and bays.

4 **Tidal Wetland Restoration** - Restore tidal wetlands in areas that are likely to benefit Delta Smelt (primarily Suisun Marsh, Grizzly Bay, and adjacent areas.

5 **Suisun Marsh Salinity Control Gate Reoperations** - Operate Suisun Marsh Salinity Control Gates during dry summer months to improve salinity and attract more delta smelt to Suisun Marsh and adjacent areas. The Suisun Marsh Salinity Control Gates, which are normally operated from October to May, prevent saltwater from entering the marsh during high tide and open to allow freshwater into the marsh during low tide, thereby reducing marsh salinity. The action suggests that through off-season operation of these gates during dry summer months, habitat suitability can be improved for Delta Smelt such that they will make more use of this area.

6 **Summer and Fall Outflow Actions** - Modify project operations to maintain lower salinity conditions in Suisun Marsh and Grizzly Bay in Wet and Above-Normal water-year types. This action is expected to increase the areal extent of suitable salinity, turbidity and possibly prey availability conditions and establish a contiguous range of suitable conditions from the Cache Slough Complex to Suisun Marsh.

[34] Descriptions of actions were obtained primarily from Compass (2021) Structured Decision Making for Delta Smelt, Phase 2 Report. Some listed actions were omitted from this summary because they were very similar to listed actions and were not subsequently considered.

7 **Sediment Supplementation**– Physically add sediment to the estuary to increase turbidity.

8 **Aquatic Weed Control** - Chemically treat or physically remove aquatic weeds in the Delta.

9 **Franks Tract Restoration** - Restore Frank's Tract Bay, and adjacent areas to create large open water areas connected by tidal wetlands and navigable channels to improve conditions for Delta Smelt

10 **OMR Management** - Manage OMR flows to reduce entrainment risk.

11 **Full-year flows** - Additional spring, summer, and fall outflow when minimum flow thresholds are triggered.

12 **Engineered Fist Flush** - Modify project operations to provide flows to approximate a 'first flush' in years that otherwise would not reach a flow threshold.

13 **Contaminants Reduction** - Construct wetlands designed to reduce contaminants entering the Delta.

Actions Already Being Implemented or Evaluated

Yolo Bypass Big Notch – Construct an enlarged "notch" next to the Fremont Weir to allow more frequent and greater volumes of Sacramento River flows to enter the Bypass.

Target **zero entrainment via real-time monitoring** of fish movement - Reduce entrainment of delta smelt by reducing exports to achieve positive OMR flows when more Intensely fish monitor in Old River, turbidity at USGS stations, and modeling of fish distribution indicate heightened risk. A modified version of this is included in the CDFW's ITP.

Move intakes to the Sacramento River - Construct new water project intakes in the north Delta out of the normal range of the distribution of delta smelt. Delta Conveyance Project DWR has initiated the preparation of an Environmental Impact Report (EIR) for the Delta Conveyance Project, involving new intake facilities as points of diversion that would be located in the north Delta along the Sacramento River between Freeport and the confluence with Sutter Slough.

Sacramento Waste-Water Treatment Plant upgrade - Construct a tertiary wastewater treatment plant in Sacramento to reduce certain contaminants entering the Delta. This project is under construction.

Hatchery supplementation - Supplement the Delta population of delta smelt with propagated fish. As part of the 2019 BiOp, Reclamation proposed to fund annual supplementation of Delta Smelt. Supplementation began in 2022.

Roaring River Distribution System food production - Construct interconnections between the Roaring River distribution system and adjacent bays to enhance prey availability for delta smelt in open water adjacent to the distribution system. Construction of interconnections began in 2019.

Actions Requiring Further Research Prior to Evaluation

Silverside Predation Management - Construct a protected nursery in a natural setting in Suisun Marsh, free of predatory fish, in which propagated eggs would be distributed. The area of around 50 to 100 acres of marshes and waterways would be drained prior to operation, to remove any resident predators. The facility would have a constant inflow and outflow, serviced by screens to prevent entry by predators f and to retain young delta.

Partial reconnection of floodplains to rivers - Remove levees or divert water from selected rivers to restore flows across floodplains and partially restore natural sediment transport and food web processes.

Increase turbidity in Delta Smelt habitat - A number of ways for increasing turbidity were identified by the TWG including (1) altering the timing and deposition of regular dredging operations (2) develop infrastructure to transport sediment over/through dams, (3) encourage bank erosion and channel migration below dams (4) supplement erodible sediments below dams.

Encourage channel migration and bank erosion below dams – Construct setback levees on river reaches below dams and then encourage the river to cut new channels through existing sediment deposits.

Barker Slough – Nurse Slough fish passageway - Construct a new channel, similar is design to the Sacramento Deep Water Ship Channel to connect Barker Slough to Nurse Slough to provide habitat connectivity between Susin Marsh and the Cache Slough complex - two of the best areas for delta smelt.

Develop infrastructure to transport sediment over/through dams - Employ any of a variety of technologies (e.g. on-stream or off-stream bypassing, sluicing or drawdown routing, dredging and flushing) to move sediment through or around dams.

Spawning habitat augmentation (restoring beaches taken over by invasive species) - Remove invasive *Arundo donax* from the beaches on the Sacramento River to increase spawning substrates for Delta Smelt in suitable locations.

Salinity control devices - Place operable salinity control devices to limit the intrusion of high salinity water to the Delta (e.g., inflatable salinity sill at the bottom of Carquinez Strait to limit seawater intrusion) .

Actions Thought to be Infeasible or Ineffective

Other actions were not analyzed because, after preliminary review they were considered infeasible or ineffective:

Releases from Oroville to extend spawning season - Release a block of water from Oroville dam to cool water during the spawning window in the hope that this creates further time for an additional spawning event.

Cooling devices in key habitats - Some form of large engineering infrastructure (geothermal heat pumps?) could theoretically reduce the temperature in localized areas of hypothesized high spawning activity during the critical months of February and March to extend the spawning season.

Predator Host Spot Removal – removal of salvaged predators from tanks at salvage facilities prior to returning native fish to the Delta**.**

Evaluation of Management Alternatives

The CSAMP Delta Smelt Technical Working Group (TWG) predicted the relative performance for Delta Smelt across management options in two steps. First, existing studies, new analytical tools, and expert judgment were used to quantify 1) the effects of candidate management actions on environmental conditions relevant for delta smelt (e.g., salinity, turbidity, food), 2) Delta Smelt spatial distribution, and 3) Delta Smelt survival for specific life stages (e.g., larvae, juvenile, adult survival). Second, the predicted proximate effects of management actions were used as inputs into four quantitative Delta Smelt population models to estimate a percent change in mean population growth. Other (non-Delta Smelt) objectives were evaluated more coarsely by engaging subject matter experts, due to the wide-ranging and exploratory nature of the management options.

This "Round 1" of the SDM process evaluated outcomes of several management options, beginning with 12 candidate management actions with intended increases in flow, food, turbidity and survival and eight management portfolios, which were distinct combinations of actions. Additional exploratory and sensitivity analyses were conducted that predicted outcomes under varying intensities and timings of an action (e.g., outflow management) or under varying assumptions about an action's effects to capture uncertainty.

Portfolios – Round 1

In round 1, after specifying two reference portfolios against which other portfolios could be compared, the TWG developed portfolios around diverse themes[35]. It was typical to analyze a range of responses and implementation levels within each portfolio. Often the group was

[35] Adapted from Compass SharePoint > Documents > 4. Portfolios > 2_DS Portfolio Dev-May2022_v3.0, pp:7-9

interested in the bookends – the highest and lowest values at which to implement actions - because if the highest value had no benefit there was little point in pursuing the action. If there was little difference in benefits resulting from the highest and lowest levels of action implementation, other objectives could be given more consideration. The Round 1 modeling was focused on benefits for delta smelt and was completed without any real consideration of costs. The portfolios analyzed in round 1 are listed below. The actions comprising those portfolios are listed in Table A-2 and a high-level summary of those actions are listed in Table A-3.

1a. **Reference: Post-2008 BiOp** - Includes all actions/regulations that were being implemented after the 2008 federal Record of Decision (ROD) and Biological Opinion (BiOp) for the long-term operation of the Projects.

1b. **Preference: Post-2020 BiOp/ITP** - This portfolio includes actions and regulations that are being implemented under the State's Incidental Take Permit (ITP) and the 2020 federal ROD and BiOp for the long-term operation of the water projects: SMSCG operations, OMR Management, north Delta food web subsidies and flow augmentation in the fall of wetter years All subsequent portfolios are additive to this reference portfolio unless otherwise specified.

2a. **Immediate and intensive management** - This portfolio employs the strategical use of a range of flow actions combined with intensive monitoring with the intent of reactively mitigating the earliest predicted bottleneck in each year.

2b. **Cache Slough/DWSC focus** – This portfolio includes short term actions to improve food availability and reduce aquatic vegetation in Cache Slough and the Deep-water Ship Channel (DWSC), where higher numbers of Delta Smelt have been sampled, relative to other regions, in recent years. The DWSC is hydrodynamically isolated, relative to other areas, which may increase success of the proposed management action.

2c. **Cache Slough and Suisun Marsh focus** - This portfolio builds on Portfolio 2b by adding managed wetlands in Suisun Marsh. These two areas are hypothesized to have the best conditions for growth and survival of delta smelt and could function as core refuge from which to build the population of delta smelt.

3a. **Self-sustaining/permanent management** - In this portfolio a set of actions are proposed that are intended to be more self-sustaining or permanent in nature and thus require less oversight and continual intervention. It builds on Portfolio 2b by adding tidal wetland restoration, contaminant reduction at multiple sites and restoration of Franks Tract).

3c. **Summer Flow and Tidal Wetlands** – This portfolio builds on Portfolio 1b by adding tidal wetland restoration and summer flow actions. It is intended to improve conditions for juvenile survival, building on important factors identified in recent work using the Life Cycle Model (Polansky et al. 2020, Smith et al. 2021), with additional flow actions during summer.

3d. **Focus on food** - Building on recent research using a limiting factor analysis (Hamilton & Murphy 2018, 2021, 2022), this portfolio focuses on food actions to address hypothesized limiting factors to the Delta Smelt population.

3e. **Improve habitat connectivity** - Specifies restoration and other non-flow actions to improve and connect habitat in the Confluence and Lower Rivers, between Suisun Marsh and DWSC that have relatively good habitat (Suisun Marsh and DWSC).

Table A-2[36]. *Summary of management actions included in 8 portfolios modeled in the Round 1 evaluation. Actions in grey are the same as actions included in the Reference Portfolio (1b, current management approximation). Actions in blue were adjusted or additional to the Reference Portfolio. Different scales or timings are noted for some actions that differed across portfolios.*

	1b	2a	2b	2c	3c	3a	3d	3e
Action name	Current mgmt (approx.)	Full-year flows	Cache Slough	Cache Slough & Suisun Marsh	Summer flow & tidal wetlands[1]	Self-sustaining/ permanent mgmt	Focus on food	Habitat connectivity
NDFS	✓	✓	✓	✓	✓	✓	✓	✓
DWSC Food			✓	✓			✓	
Managed wetlands				✓ 2K ac			✓ 4K ac	
Tidal wetlands					✓ 9K ac	✓ 9K ac	✓ 30K ac	✓ 2K ac
SMSCG	✓	✓	✓	✓	✓	✓	✓	✓
X2/outflow	Fall (W,AN)	All seasons / yrs	Fall (W,AN)	Fall (W,AN)	Sum-Fall (W,AN)	Fall (W,AN)	Fall (W,AN)	Fall (W,AN)
Sediment supp								✓
Aquatic Weed Control			✓ 1 sub-region	✓ 1 sub-region			✓ 5 sub-regions	✓ 3 sub-regions
Franks Tract						✓		✓
OMR mgmt	✓	✓	✓	✓	✓	✓	✓	✓
Engineered First Flush		✓						
Contaminant reduction						✓ 12 sub-regions	✓ 12 sub-regions	✓ 8 sub-regions

[1] Portfolio 3c included multiple versions/model runs that varied X2 targets in summer and fall. Specific X2 targets are given when presenting and discussing results in subsequent sections of the report.

[36] Table A-2 is Table ES-1 from Round 1 Report.

Table A-3. *Details of actions included in Round 1 portfolios.*

	Action	Level	Response Assumption	Timing	Years to Implement[37]
1.1	North Delta Food Subsidies	25,000 af	Food	Aug-Oct	1
2.2	DWSC Food + Nutrients		Food		1-3
3.4	Managed Wetlands Spring to Fall – high response	4,000 af	Food	Mar-Apr, Jul-Oct	1-3
3.5	Managed Wetlands Spring to Fall – medium response	2,000 af	Food	Mar-Apr, Jul-Oct	1-3
4.1	Tidal wetlands	8,900 ac	Low food response	Perennial	1-3
4.2	Tidal wetlands	8,900 ac	High food response	Perennial	1-3
4.3	Tidal wetlands	20,000 ac	Low food response	Perennial	1-3
4.4	Tidal wetlands	20,000 ac	High food response	Perennial	1-3
5.2	Suisun Marsh Salinity Control Gate Reoperation		No food response	Jun-Oct	1
6.26	Flow Augmentation [a]		Medium food, fish distribution	Jul-Aug	1-3
6.31	Flow Augmentation [b]		Medium food, fish distribution	Sep-Oct	1-3
6.33	Flow Augmentation [c]		Size of LSZ	Mar-May, Aug-Oct	1-3
7.1*	Sediment Supplementation: Lower Sacramento to Suisun Bay	450,000 cu yd	Turbidity	May-Dec ’95-’97, ’04-‘14	3-5
8.1	Aquatic Weed Control – Yolo	600 ac	Turbidity & Food	All year	3-5
8.4	Aquatic Weed Control – North Delta	1,430 ac	Turbidity & Food	All year	3-5
8.5	Aquatic Weed Control – North Delta + Lower SJR	3,470 ac	Turbidity & Food	All year	3-5
9.2	Franks Tract Restoration		Low bookend		5-10
10.2	OMR Management 2008/09 BiOps plus OMR protection during first flush		Entrainment	Dec-Jun	1
11.2	Engineered First Flush	25,000 cfs	Low bookend	January	1-3
12.2	Contaminants Reduction – Yolo & Sacramento River	3 Sites	Survival	Perennial	5-10
13	Risk -Based OMR		Entrainment	Dec-Jun	1-3
14	Fish Friendly Diversions	15,000 cfs	Entrainment	Dec-Jun	5-10

[a] X2<70km in Jul, 75 km in Aug, in W, AN years
[b] X2<80km in Sep & Oct in W, AN years
[c] [a] +700 taf in Mar, Apr or May (2004, 2008, 2013, 2014). X2<75km in Aug 2002, 2010, X2<80km in Sep & Oct in W, AN years

[37] This metric does not include factors such as time for permitting and legislative changes in order to implement.

4. Estimated Consequences

The estimated consequences for each of the Round 1 portfolios are presented in Table A-4 (a condensed version of Table ES-2 from the Round 1 Report) for specified performance measures (see section 2). The possible ranges of scores, where relevant, are included in the first column. The original actions in each portfolio in round 1 are listed in Table A-2.

Table A-4. *Consequence Table of predicted outcomes for portfolios and objectives/performance measures in the CSAMP Delta Smelt Round 1 evaluation. Green cells indicate performance measures where higher values (darker shades) are preferred. Orange cells indicate metrics where lower values (lighter shades) are preferred. Grey cells indicate water/cost metrics that are components of aggregated totals in the top water/cost row. This table is a condensed version of Table ES-2 in the Round 1s Report.*

Objective & Performance Measure	**1b** Current manag.	**2a.1** Full-year flows	**2b** Cache Slough	**2c** Cache Slough & Suisun Marsh	**3c.2** Summer flow & tidal wetlands	**3c.4** Summer flow & tidal wetlands	**3a** Self-sustaining	**3d** Focus on food	**3e** Habitat connectivity
Delta Smelt Population									
Population Growth rate[1] (average lambda: 1995-2014)									
IBMR	1.00	1.21	1.12	1.25	1.13	1.10	1.40	1.96	2.23
LCME	1.09	1.15	-	-	1.25	1.19	1.21	1.50	1.31
LF	0.91	0.93	1.05	1.27	1.07	1.06	1.11	1.43	1.29
Dynamic Habitat Suitability Index[3] (overlap)									
Yolo/Cache Slough	20%	20%	32%	32%	21%	21%	21%	33%	20%
Confluence & Lower Rivers	7%	7%	7%	7%	7%	7%	7%	12%	30%
Suisun Marsh & Bay	20%	23%	20%	21%	23%	23%	21%	21%	21%
Uncertainty[4] (TWG group scores)									
Confidence in action effect assumptions: TWG avg (range of actions; scale: 1 to 5)	3.0 (food) to 4.0 (OMR)	2.4 (distribution) to 4.0 (OMR)	2.4 (food) to 4.0 (OMR)	2.4 (food) to 4.0 (OMR)	2.3 (food) to 4.0 (OMR)	2.3 (food) to 4.0 (OMR)	2.3 (food) to 4.0 (OMR)	2.3 (food) to 4.0 (OMR)	2.3 (food) to 4.0 (OMR)
Time to implementation[5] (TWG group scores)									
# actions < 5 yrs	-	1	1	2	1	1	0	0	1
# actions > 5 yrs	-	0	1	1	1	1	3	5	4
Salmon effects[6] (expert group scores)									

Objective & Performance Measure		1b Current manag.	2a.1 Full-year flows	2b Cache Slough	2c Cache Slough & Suisun Marsh	3c.2 Summer flow & tidal wetlands	3c.4 Summer flow & tidal wetlands	3a Self-sustaining	3d Focus on food	3e Habitat connectivity
Benefits: (scale: 0 to 3)		0	1	1	1	1	1	2	3	1
Risks:[3] (scale: -3 to 0)		0	-1	-1	0	0	0	0	-2	-1
Water / Resource Costs[7] (ballpark estimates, relative to Reference Portfolio 1b, for comparative purposes only)										
Water[4,5] (TAF/yr)	All yrs	-	212	0	0	495	127	0	0	0
Costs[4] ($ million / yr)	Total[9]	None	$151-$200	$1-$5	$1-$5	$401-$450	$101-$150	$101-$150	$151-$200	$76-$100
	Water[10]	-	$173	$0	$0	$404	$104	$0	$0	$0
	Capital & Operating[11]	-	None	$1-$5	$1-$5	$21-$30	$21-$30	$101-$150	$151-$200	$76-$100

[1] Delta Smelt population metrics were calculated in three ways: (1) annual predicted population growth rate (lambda) from the portfolio, (2) the percent change in annual population growth from the portfolio relative to baseline, historical conditions between 1995-2014, where values > 0% indicate increased population growth relative to baseline, and (3) the percent change in annual population growth from the portfolio relative to Reference Portfolio 1b (current management approx.). Metrics were averaged over the 20-yr period.

[3] Dynamic Habitat Suitability Index (between 0 and 100%) was calculated as the percentage of months (over the 20-year model period) when all four dynamic habitat attributes (temperature, turbidity, salinity, and prey) are in “suitable” ranges (i.e., suitable conditions overlap), defined by existing studies and the TWG.

[4] Effect uncertainty was scored by TWG members to indicate their level of confidence in the assumed/quantified proximate effects (e.g., on food, turbidity) of each management action using a constructed scale (1 [lowest confidence] to 5 [greatest confidence]). Reported as the range of actions in a portfolio with the lowest and highest average TWG score.

[5] Time to implementation is defined in this process as how long it will take to achieve full implementation, including research of technical aspects of the action and generation of expected benefits for Delta Smelt, while not considering time needed for permitting. Time to implementation was scored by TWG members. Values in different time to implementation categories reflect the number of actions in a portfolio additional to actions included in Reference Portfolio 1b, based on average TWG scores.

[6] Salmon effects of actions (sometimes at different scales) were scored by subject matter experts from -3 (greatest risks) to +3 (greatest benefits). Individual action scores were summed within a portfolio and rescaled from 0 (no benefits) to +3 (greatest benefits). Scores for individual actions deemed by experts as having any potential direct risk were summed within a portfolio and rescaled from -3 (greatest risks) to 0 (no risks). Potential benefits are reported as average scores; potential risks are reported as minimum scores to represent any degree of risk to salmonids expressed by experts. Salmon experts noted potential negative risks to juvenile Chinook from AWC, as there is some evidence that higher turbidity can decrease foraging rates, and juveniles can use submerged aquatic vegetation to avoid predation. There is also the potential for direct mortality from mechanical (or chemical) removal. Effects to salmon of flow actions reflect potential direct, within-year benefits/risks of changing flow in a given season. Experts did not consider carry-over effects of flow actions, and modeling how operations would achieve flow actions is needed to better estimate effects to salmon.

[7] All water and resource costs: Water resources and capital and operating costs of portfolios were calculated relative to Reference Portfolio 1b (current management approx.). Costs for individual management actions are reported relative to baseline, historical conditions – not Reference Portfolio 1b. Therefore, water volumes and resource costs are slightly different between the tables. Ballpark values were estimated through coarse methods and meant for comparative purposes only.

[8] Additional water (relative to outflow under Reference Portfolio 1b) is averaged across all 20 years and is presented for comparative purposes only. The source of water needed to implement flow actions was not identified and water was not balanced within or among years in Round 1. The water resource volume represents the net volume of water necessary to move X2 from its position in Reference Portfolio 1b to a target condition, based on equations in Monismith et al. (2002) and Denton (1993).

[9] Total cost was calculated as the sum of monetized water and capital & operating costs, annualized over the 20-yr period without a discount rate.

[10] Monetization of water used $815 per acre foot of water, annualized over the 20-yr period, as discussed and agreed to by the CSAMP Policy Group Steering Committee. See Appendix 3 – Water Resources Methods – Monetized water cost.

[11] Includes ballpark estimates of capital & operating costs, annualized without a discount rate.

Table A-5. *The consequences of management actions evaluated in Round 1 against the specified performance measures (see section 2). The possible ranges of scores, where relevant, are included in the first column.*

Table ES-3. Consequence Table of predicted outcomes for individual management actions and objectives/performance measures in the CSAMP Delta Smelt SDM evaluation. Actions are grouped by expected time to implementation. **Green cells indicate performance measures where higher values (darker shades) are preferred. Orange cells indicate metrics wh**ere lower values (lighter shades) are preferred. Management action names are shaded by their primary effect: blue = flow and food, green = food, orange = turbidity, and purple = survival/other.

Objective & Performance Measure	Management Actions[1]																			
	Current management				Can implement in < 5 yrs[2]						May be able to implement in > 5 yrs[2]									
	North Delta Food Subsidies[3]	Fall X2/Outflow (X2 ≤ 80 for Sept/Oct)[4]	Suisun Marsh Salinity Control Gates (SMSCG)[4]	Old & Middle River Management (2008/2009/ 2019 BiOps)	Managed Wetlands Food Production[3]	Summer Outflow (X2 ≤ 70/75 for July/Aug)[4]		Full-year Flow[4]	Engin-eered First Flush	Aquatic weed control	Tidal Wetland Restoration in North Delta Arc		Managed Wetlands Food Production[3]	DWSC Food[3]	Franks Tract Restora-tion	Aquatic weed control		Sediment supple-mentation	Contaminant reduction	
		W/AN			1K ac in SM	W/AN	W/AN/ BN	W/AN/ BN/D/C		600 ac in CS	9K ac	30K ac	4K ac			1.4K ac	3.5K ac		Yolo / CS	Delta-wide
Delta Smelt Population																				
Delta Smelt Population Growth[5] (average lambda 1995-2014)																				
IBMR	0.98	0.98	0.98	1.00	0.98	1.04	1.09	1.15	1.05	1.04	1.04	1.12	0.98	0.98	1.14	1.28	1.47	1.70	1.00	1.14
LCME	-	0.94	-	1.09	-	0.99	1.05	0.99	-	-	1.00	1.14	-	-	-	-	1.00	1.01	-	-
LF	0.87	-	-	-	-	-	-	-	-	0.87	0.98	1.10	1.15	0.97	0.98	-	-	1.00	-	-
Delta Smelt Population Growth[5] (% change from 1995-2014 baseline)																				
IBMR	0%	0%	0%	2%	0%	6%	11%	17%	7%	6%	5%	13%	0%	0%	16%	30%	49%	73%	1%	16%
LCME[6]	-	0%	-	16%	-	5%	12%	5%	-	-	5%	20%	-	-	-	-	4%	11%	-	-
MDR[6]	-	0%	-	29%	-	-	-	-	-	-	8%	17%	-	-	-	-	-	-	-	-
LF	0%	-	-	-	-	-	-	-	-	2%	16%	30%	36%	14%	16%	-	-	15%	-	-
Uncertainty[7] (TWG group scores)																				
Confidence in action effect assumptions: TWG avg score (scale: 1 [low] to 5 [high] confidence)	Food: 3.0	IBMR salinity-zoop model: 3.0; LF flow-zoop model: 2.0	IBMR salinity-zoop model: 3.1; LF flow-zoop model: 2.3	OMR flows: 4.4	Food: 3.0	IBMR salinity-zoop model: 3.0; LF flow-zoop model: 2.0			IBMR distrib: 2.4	Turbidity: 3.3	Food: 2.3	Food: 2.3	Food: 3.0	Food: 2.4	Food: 2.3	Turbidity: 3.3		Turbidity: 2.5	Contaminants: 3.1	
Salmon effects[8] (expert group scores)																				
Potential benefits: Salmon expert avg score (scale: 0 to 3)	0	Not assessed	0	Not assessed	2	0	0	3	2	0	2	2	2	2	1	0	0	1	2	2
Potential risks: Salmon expert min score (scale: -3 to 0)	0	Not assessed	-1	Not assessed	0	0	0	0	0	-1	0	0	0	0	0	-1	-1	0	0	0
Water / Resource Costs[9] (ballpark estimates for comparative purposes only)																				
Water[10] (TAF/yr): All yrs	Financial and water costs were only evaluated for actions additional to current management, per agreement by the SDM Policy Group Steering Committee.				-	157	319	248	23	-	-	-	-	-	-	-	-	-	-	-
Water[10] (TAF/yr): W / AN					-	350	350	361	-	-	-	-	-	-	-	-	-	-	-	-
Water[10] (TAF/yr): BN					-	-	810	300	38	-	-	-	-	-	-	-	-	-	-	-
Water[10] (TAF/yr): D / C					-	-	-	72	43	-	-	-	-	-	-	-	-	-	-	-
Costs ($ million / yr): Total[11]					$1	$128	$260	$192	$18	$2	$22	$63	$2	$1	$29	$5	$13	$5	$7	$84
Costs ($ million / yr): Water[12]					-	$128	$260	$192	$18	-	-	-	-	-	-	-	-	-	-	-
Costs ($ million / yr): Capital & operating[13]					$1	-	-	-	-	$2	$22	$63	$2	$1	$29	$5	$13	$5	$7	$84

[1] The management action effect assumptions used in the Delta Smelt modeling are summarized in Table 2.

[2] Actions are grouped by relative time to implementation. Time to implementation is defined in this process as how long it will take to achieve full implementation, including research of technical aspects of the action and generation of expected benefits for Delta Smelt, while not considering time needed for permitting. Time to implementation was scored by TWG members, and average scores were used to group actions in implementation categories.

[3] Small-scale actions that are predicted to have a 0% population growth when modeled individually with the IBMR contribute to positive population growth when modeled with other actions in a portfolio (see Sections 4.4 and 5).

[4] There were 9 W/AN years, 4 BN years, and 7 D/C years in the 20-yr model period. Fall X2 action: X2 was set to 80 km in Sept/Oct in W and AN water year types when historical X2 locations were > 80 km (this occurred in 10 months out of the 18 applicable months across the 20-yr model period). Summer X2 action: X2 was set to targets in July/Aug only for months when historical X2 locations were > 70/75, respectively. This occurred in 12 of the 18 applicable months for the W/AN action and 20 of the 26 months for the W/AN/BN action (across the 20-yr model period). For the Full-year Flow action, X2 was set to month-specific targets in 30 months across the 20-yr model period.

[5] Delta Smelt population metrics were calculated in two ways: (1) annual predicted population growth rate (lambda) from the action, and (2) the percent change in annual population growth from the portfolio relative to baseline, historical conditions between 1995-2014, where values > 0% indicate increased population growth relative to baseline. Metrics were averaged over the 20-yr period.

[6] The LCME and MDR models used different versions (with different sets of covariates) to evaluate different actions, which leads to variation in % change from baseline. These models often could only include effects of an action for a portion of months even if it was specified to have year-round effects.

[7] Effect uncertainty was scored by TWG members to indicate their level of confidence in the assumed/quantified proximate effects (e.g., on food, turbidity) of each management action using a constructed scale (1 [lowest confidence] to 5 [greatest confidence]). Reported as the average TWG score.

[8] Salmon effects of actions (sometimes at different scales) were scored by subject matter experts from -3 (greatest risks) to +3 (greatest benefits). Individual action scores were summed within a portfolio and rescaled from 0 (no benefits) to +3 (greatest benefits). Scores for individual actions deemed by experts as having any potential direct risk were summed within a portfolio and rescaled from -3 (greatest risks) to 0 (no risks). Potential benefits are reported as average scores; potential risks are reported as minimum scores to represent any degree of risk to salmonids expressed by experts. Salmon experts noted potential negative risks to juvenile Chinook from AWC, as there is some evidence that higher turbidity can decrease foraging rates, and juveniles can use submerged aquatic vegetation to avoid predation. There is also the potential for direct mortality from mechanical (or chemical) removal. Effects to salmon of flow actions reflect potential direct, within-year benefits/risks of changing flow in a given season. Experts did not consider carry-over effects of flow actions, and modeling how operations would achieve flow actions is needed to better estimate effects to salmon.

[9] All water and resource costs: Water resources and capital and operating costs of actions were calculated relative to baseline, historical conditions. Ballpark values were estimated through coarse methods and meant for comparative purposes only.

[10] Additional water (relative to outflow under baseline, historical conditions between 1995-2014) is averaged across all 20 years and is presented for comparative purposes only. The source of water needed to implement flow actions was not identified in this SDM process. The water resource volume represents the estimated net volume of water necessary to move X2 from its historical monthly position to a target condition, based on equations in Monismith et al. (2002) and Denton (1993).

[11] Total cost was calculated as the sum of monetized water and capital & operating costs, annualized over the 20-yr period without a discount rate.

[12] Monetization of water used $815 per acre foot of water, annualized over the 20-yr period, as discussed and agreed to by the CSAMP Policy Group Steering Committee. See Appendix 3 – Water Resources Methods – Monetized water cost.

[13] Includes ballpark estimates of capital & operating costs, annualized without a discount rate, for comparative purposes only.

5. Evaluation of Tradeoffs

Findings

Findings of management relevance are reported in the body of this document (pages 4 to 16)

Appendix B

Understanding Conflicting Science Regarding Flow Augmentation

Introduction

Ever since the listing of Delta Smelt under the federal Endangered Species Act in 1993 there have been contradictory findings reported regarding the benefit to delta smelt of augmenting freshwater outflow through the Sacramento-San Joaquin Delta. The most controversy has surrounded flow augmentation in the autumn of wetter than normal years – implemented as the “Fall X2 Action”. The Round 1 SDM process extended the controversy rather than resolving it. Here we provide a brief summary of the origin and perpetuation of the controversy and provide conclusions that can be reasonably derived from a review of the best available scientific information pertaining to the issue.

The Relationship between the Performance of Delta Smelt and Flows

The importance of through-Delta flows to delta smelt was confounded from the first empirical studies. Jassby et al. (1995) found no statistical relationship between Delta outflow, as measured by average X2 location in April through July and abundance of delta smelt in the following Fall Midwater Trawl Survey (Figure B-1). Kimmerer (2002) found a positive, rather than the expected negative relationship, between by average X2 location in April through July and delta smelt abundance in the FMWT prior to 1987 (that is, prior to the invasion of the Asian clam) and a negative but not significant relationship after that date. Those empirical results were not consistent with conceptual ecological models (Hamilton and Murphy 2018) that hypothesized delta smelt would benefit from flows across flood plains and marsh plains in wet years, which could be expected to introduce nutrients and turbidity into the Delta. Those conceptual models were also consistent with anecdotal evidence that abundance of delta smelt frequently increased from the previous year when the current year was wet, but data show that the relationship does not hold for every wet year.

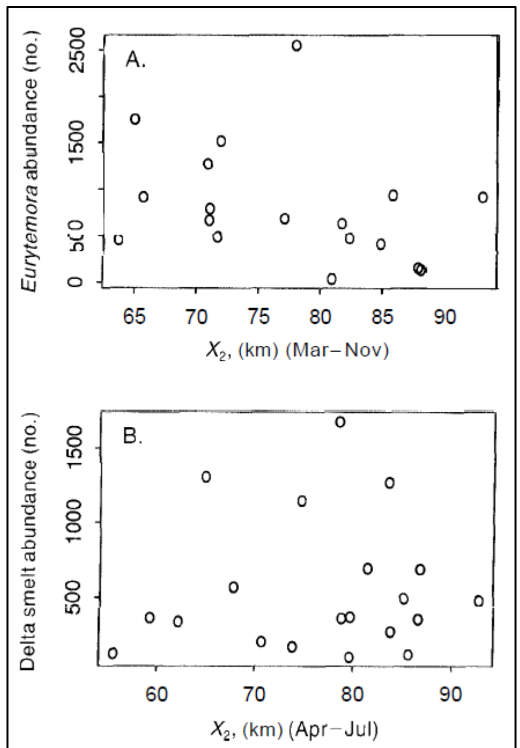

FIG. 6. (*A*), *Eurytemora affinis* abundance index vs. X_2; (B), delta smelt (*Hypomesus transpacificus*) abundance index vs. X_2. Months refer to averaging intervals.

Figure B-1. *Excerpt from Jassby et al (1995) showing delta smelt abundance in relation to X2 location.*

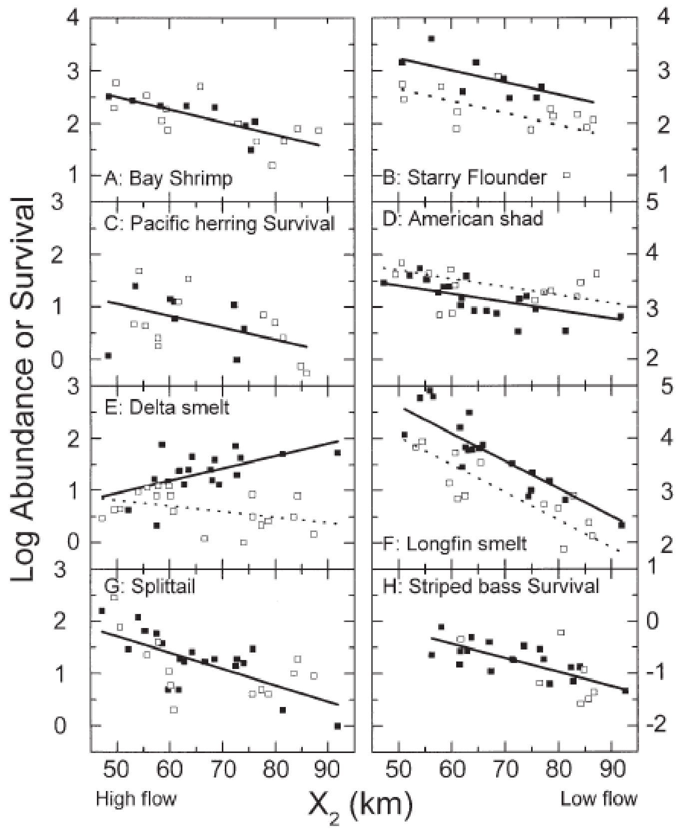

Fig. 8. Timescale of fish and shrimp abundance or, where noted, survival indices. Details as for Fig. 4. Regression statistics in Table 4. Taxa as for Fig. 5

Figure B-2. *Excerpt from Kimmerer 2002 showing abundance of delta smelt in relation to X2 location. (■) and lines, depict data up to 1987; (□) and dotted lines, depict 1988 to 1999.*

Hamilton and Murphy (2022) presented results from a limiting-factor model that helped explain the paradox. They showed that the size and timing of the winter first flush through the Delta had a critical influence on the performance of delta smelt. Their results also showed that in some years, high flows in May were detrimental to the performance of the species. They hypothesized that large flows after delta smelt start hatching from eggs serve to transport weak swimming juveniles downstream to areas that were unsuitable for survival. This phenomenon only occurred in a handful (4 of 23) years, so it is feasible that some other phenomenon in some wet years impacts delta smelt survival, but it represents the most plausible current explanation.

Why did Hamilton and Murphy (2022) find a response to flows when Jassby et al. and Kimmerer did not? There are four reasons. First, Hamilton and Murphy found that it is inflow to the Delta (the size of the first flush) in the winter (December and January) that is critical to the performance of Delta smelt and not flows later, in April through July. Second, Hamilton and Murphy (2018, 2022) found the abundance of delta smelt in a prior year has a statistically significant influence on the size of the population in a current year. Neither Jassby et al. nor Kimmerer included the abundance of the parent delta smelt generation when trying to explain abundance of the next generation. If one omits a significant covariate, it biases estimates of the remaining coefficients and reduces explanatory power (Rao and Miller 1971). Third, by not considering the adverse impact of particularly big outflows in May, those earlier authors' data set included years when delta smelt performance was good and years when it was poor at the same X2 location, confounding the analysis. Finally, Hamilton and Murphy considered Delta Inflow as a key covariate, whereas the other two studies considered outflow. The use of inflows is a better indicator of the potential inputs of nutrients and turbidity in the Delta, whereas outflow is confounded by in-Delta and export diversions.

The Origin of the Fall X2 Controversy

In the 2008 delta smelt Biological Opinion, the US Fish and Wildlife Service (the Service) deemed the Fall X2 Action necessary because operation of CVP and SWP facilities in the south Delta would have "significant adverse impacts on X2, which is a surrogate indicator of habitat suitability and availability for delta smelt in all years."[38] However, X2 is not a surrogate indicator of, or proxy for habitat extent and quality suitability (Murphy and Weiland 2019), because it only considers salinity and not food availability, and Suisun Bay has been food depleted since the invasion of the Asian clam (Kimmerer et al. 2018). The investigative work supporting the Service's conclusion was that of Feyrer et al. (2007), specifically the regression results reported in their Table 2 for the period from 1987 (post clam) to 2004. Recruitment (as the Summer Town Net Index) was regressed against stock (the prior FMWT Index) and specific conductance in the fall (EC during the FMWT survey September-November). However, the Feyrer et al. analysis excluded Spring X2 as an explanatory variable, a highly relevant variable the exclusion of which biased the results. If Spring X2 had been included, the fall X2 covariate would have been found to be statistically insignificant.

The Fall X2 Action drew support from a subsequent study, available as a draft manuscript at the time of the Biological Opinion -- Feyrer et al. 2011. In that article, the authors developed a delta smelt "habitat index" for delta smelt using data on three abiotic covariates – water temperature, turbidity (Secchi depth), and salinity (specific conductance). The habitat index was calculated as the weighted sum of those attributes multiplied by the water surface area that each station represented. This later study also used data from the FMWT. Probability of presence was explained primarily by salinity and turbidity, with water temperature adding little explanatory power. The authors found that the location of X2 in the upper San Francisco Estuary was an effective indicator of the extent of habitat and that habitat was related to the FMWT abundance index. Connecting these relationships provides a linkage between X2 in the autumn and abundance of delta smelt in the autumn. However, the statistical significance of the relationship relied on the inclusion of years prior to the invasion of the Asian clam. When only post-clam data were used, the relationship no longer existed.

The two quantitative analyses in two journal articles by Feyrer and colleagues used to justify the fall X2 action contained statistical errors. With the errors corrected no statistical support for the Fall X2 action is found.

[38] USFWS (2008) p.373

Mistaking Correlations for Causality

During the past three decades, numerous studies have found a correlation between the performance to delta smelt with Delta outflow in the summer or fall (Feyrer at al. 2007, Ferrer et al 2011, Mount et al (2013) Castillo 2019, Polansky et al 2021, Lee et al 2023). Based on those correlations, there has been support for increased outflow in the summer or fall but while there is a correlation, there is no causal mechanism.

The correlation is a result of a common driver influencing both delta smelt performance and outflow (Figure B-3). Large winter storms create flows across flood plains that introduce nutrients and turbidity into the Delta. The availability of nutrients drive the delta food web. Turbidity increases the effectiveness of feeding for delta smelt and provides increased protection from predators. The result is typically an increase in the size of the delta smelt over that in the previous year. The big winter storms also produce elevated snowpack in the Sierra Nevada. Increased snowpack leads to increased and extended runoff when snow melts and increased storage in reservoirs, resulting in higher-than-normal Delta inflows in the summer and fall. Accordingly, there is a correlation between summer and fall flows and the performance of delta smelt, but there is no causal mechanism. Augmenting flows in the summer and fall does not provide the mechanistic and deterministic benefits to delta smelt from large winter storms. Unfortunately, some sophisticated and respected empirical models have failed to recognize the causal mechanism, which has led to misplaced support for ineffective management actions (e.g. Polansky et al 2024).

The Need to Identify Suitable Conditions for Delta Smelt in Conservation Management Actions

Some previous studies and some models have been used to provide support for flow augmentation as a primary management action intended to benefit delta smelt based on two hypotheses. The first contends that increasing outflow increases the area of the low-salinity zone, thereby increasing the area in which delta smelt can locate cooler water, more turbid water, and more food. The second hypothesis asserts that increased flows move food downstream, presumptively serving delta smelt that occur lower in the upper estuary. The weight of evidence supports both of those hypotheses. However, the logic underlying these hypotheses fails to recognize what constitutes suitable conditions, actual habitat, for delta smelt.

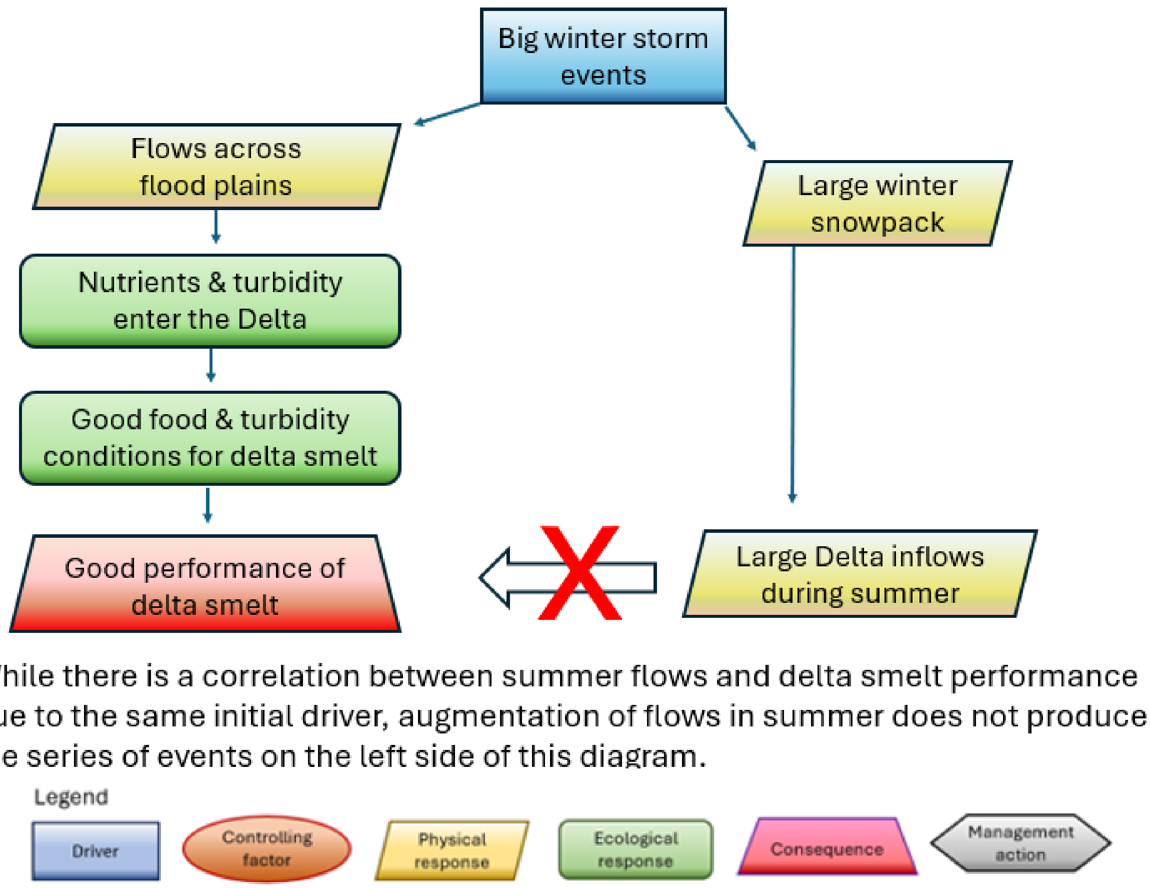

Figure B-3. *The role of big winter storms as a driver of environmental conditions in the Delta.*

Despite 30 years of study, the attention paid to identifying suitable conditions, defining habitat for delta smelt, has been limited. Hamilton and Murphy (2020) used data from multiple trawl surveys to identify the ranges of suitable conditions for delta smelt for salinity, turbidity, temperature, and food. Other studies have generally focused on fewer environmental factors (See Appendix 5, CSAMP Delta Smelt SDM Round 1 Report). The ranges of suitable conditions for delta smelt vary by life stage and season (Hamilton and Murphy 2020). For example, Figure 1 from this report shows that food levels of less than 4,800 µgC/m3 in the northern Delta arc of delta smelt habitat in summer is likely to lead to a decline in delta smelt abundance, that is, the availability of food is insufficient to sustain the population.

Kimmerer et al. (2018) demonstrated that Suisun Bay has been food depleted since the invasion of the Asian clam. Returning to the two hypotheses, freshwater flow augmentation to the Delta increases the areal extent of the low-salinity zone, moving food downstream (Kimmerer et al 2014, Hamilton et al. 2020). However, if for example, food for delta smelt in

Suisun Bay increased from 200 to 400 μgC/m3 as a result of a flow augmentation action, one might be tempted to conclude that the food supply has doubled and the action was a success. However, prey availability at a level of 400 μgC/m3 is insufficient to sustain the population. If delta smelt moved into Suisun Bay as a result of the action, following the lens of water at lower salinity, the action would be detrimental to the fish because some or many would have moved into a food-depleted area.

Within the Round 1 SDM process, the technical work group developed a “dynamic Habitat Tool” (CSAMP Delta Smelt SDM Round 1 Report, Appendix 5). Here we apply that tool to the conditions in July and August. Under higher flow conditions prey availability in the northern arc (Yolo, Lower San Joaquin, Lower Sacramento, Confluence and Suisun Marsh) is frequently good, while Suisun Bay is less so. Under low flow conditions there are fewer areas (Yolo and Lower San Joaquin) with such frequently good prey availability.

HIGHER FLOW - JULY & AUGUST

Subregion	Clarity OK	Temp OK	Salinity OK	Prey OK	Smelt Distr. (1995-2014)
Yolo/Cache	34%	40%	98%	98%	8.2%
Upper Sacramento	6%	86%	37%	65%	0.1%
East Delta	2%	63%	28%	29%	0.1%
South Delta	36%	29%	89%	98%	0.1%
Lower Sacramento	40%	68%	74%	80%	7.8%
Lower San Joaquin	3%	49%	76%	98%	2.0%
Confluence	49%	72%	92%	91%	11.3%
Suisun Marsh	91%	67%	100%	80%	2.9%
NE Suisun	86%	88%	99%	52%	12.2%
SE Suisun	64%	85%	96%	70%	14.4%
NW Suisun	90%	93%	89%	65%	37.6%
SW Suisun	70%	96%	69%	53%	3.3%

Table: Clarity, temp, salinity and prey columns show the percentage of sampled days across Jul-Aug periods that each of the four attributes were "more suitable". The last column shows proportion of delta smelt observations. All results by subregion in HIGHER FLOW Jul-Aug periods.

LOWER FLOW - JULY & AUGUST

Subregion	Clarity OK	Temp OK	Salinity OK	Prey OK	Smelt Distr. (1995-2014)
Yolo/Cache	24%	29%	100%	100%	18.4%
Upper Sacramento	9%	71%	89%	50%	0.1%
East Delta	1%	34%	88%	47%	0.2%
South Delta	50%	9%	100%	100%	0.2%
Lower Sacramento	55%	82%	98%	67%	38.2%
Lower San Joaquin	10%	57%	100%	95%	7.2%
Confluence	54%	89%	100%	71%	11.6%
Suisun Marsh	78%	79%	82%	63%	1.1%
NE Suisun	76%	95%	76%	27%	9.1%
SE Suisun	53%	94%	89%	51%	10.3%
NW Suisun	81%	97%	19%	66%	3.4%
SW Suisun	63%	98%	12%	51%	0.1%

Table: Clarity, temp, salinity and prey columns show the percentage of sampled days across Jul-Aug periods that each of the four attributes were "more suitable". The last column shows proportion of delta smelt observations. All results by subregion in LOWER FLOW Jul-Aug periods.

Begin year:	1987	<--default: 1987
End year:	2020	<--default: 2020
Median Flow:	6,688	cfs

Thresholds

	Low	High	
Clarity		44	cm
Temp		22.4	°C
Salinity	140	15,140	μS/cm
Food	4,500		$\mu gC/m^3$

Note: "High" threshold values indicate the highest point where conditions are suitable. i.e., suitable conditions are lower than this "High" threshold.
"Low" threshold values indicate the lowest point where conditions are suitable. i.e., suitable conditions are higher than this "Low" threshold.

Figure B-4. *Historical frequency of suitable conditions for delta smelt by subregion in July and August. Dark blue shows when conditions are frequently in suitable ranges, red when conditions are frequently unsuitable. Green bars in the right of each box show the average distribution of delta smelt in each subregion in July and August.*

Salinity is rarely an issue in the northern arc, and only in Suisun Bay in low flow years. What does this mean for conservation management? Moving delta smelt out of the northern arc during August and September moves from areas of high prey availability and salinity conditions in high flow circumstances are already frequently suitable for Delta smelt – there is no need to augment out flows moving freshwater westward in the Delta to make it “more suitable.”

Conclusion

A review of recent modeling results indicates that, contrary to earlier findings, delta smelt respond to flows -- specifically to large inflow events in December and early January that are hypothesized to deliver nutrients and turbidity into the Delta, but not to outflows in April through September, which cannot provide that service. While through-Delta flows during the year can be correlated with the performance of delta smelt, a compelling causal mechanism has not yet been identified. Outflow augmentation to the Delta in summer and fall -- the release of water from reservoirs to increase flow in rivers -- does not expand delta smelt habitat or provide direct ecological benefits to delta smelt. Large storm events in winter do exactly that.

Appendix C

Priority Actions for Conservation of Delta Smelt

As noted in section 3.5, the SDM process is not complete. There is more that could and should have been done in a completed Round 1 report. Not all of the management-relevant information that should be available from a SDM process has been developed. In this Appendix we illustrate the kind of information that can and should be derived from an SDM process. The Round 1 report identified and evaluated multiple portfolios, but there was no attempt to optimize the level, intensity, or location of activity associated with each management action within a portfolio, or to develop "better" portfolios that could be more effective or efficient. Here we conduct iterations between steps 3, 4 and 5, which would normally be conducted in a conventional SDM process (see Figure A-1).

What constitutes a "better" portfolio of prospective management actions depends on the values of conservation planners and decision makers. While numerous portfolio alternatives exist, for the purpose of example in this Appendix, we adopt as the selection criterion the maximum improvement in delta smelt abundance that can be achieved per unit of cost in dollars.

We employ the Limiting Factor model to identify the portfolio that best meets that criterion. We begin with 15 management actions and identify the single most cost-efficient action. With that specific action selected, we then evaluate the remaining 14 actions to see which among them, when combined with the selected action, provides the next most cost-efficient action. When management actions can be implemented at different levels, intensities, or locations (for example, contaminant reduction can be implemented in multiple subregions) we included the level of the action that is most cost efficient. We implemented this process through seven selection rounds that, in total, evaluated 84 different portfolios. We stopped after seven rounds, identifying six cost-efficient management actions because the incremental benefit of adding additional actions had become small.

The results from this exercise are presented in Figure C-1 and Table C-1 below. The actions introduced into a "preferred" portfolio, in order of their cost efficiency were -- 4000 acres of managed wetlands distributed in Suisun Marsh, adding nutrients to the deep water ship channel to increase food availability for delta smelt, 600 acres of aquatic weed control, sediment supplementation to the Delta, reconnecting wetlands in three wildlife refuges to the estuary, and contaminant reduction in two Delta subregions. With the addition of sediment supplementation, the expected ratio of change in year-over-year delta smelt abundance was 1.66 for an average annual cost of $9.4 million. While the costs estimates could be improved and the modeling will always include uncertainties and simplifications, this finding is worth noting: **the best available scientific information indicates that**

recovery of delta smelt can be achieved with the implementation of four actions at a cost of less than $10 million per year. By way of comparison, the set of actions currently implemented are estimated to cost around $300 million per year and have not proven sufficient to sustain the delta smelt population. This finding is not apparent in the Round 1 report.

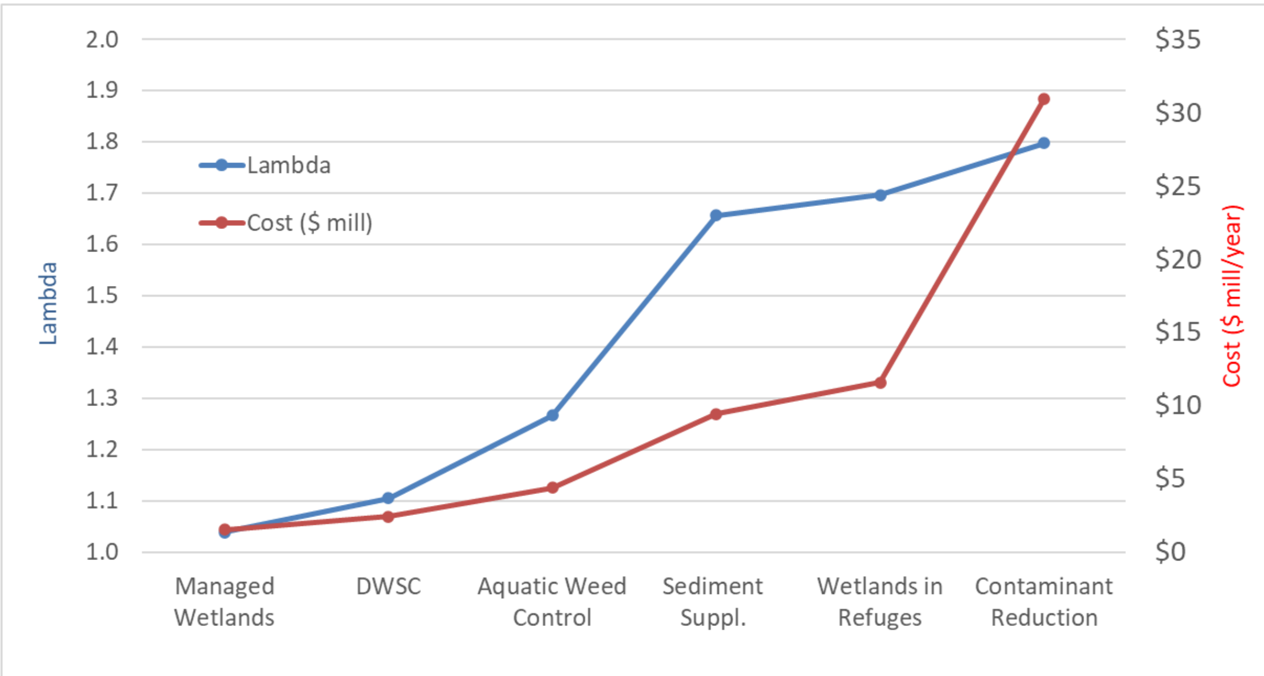

Figure C-1. *Results from an optimization routine to identify portfolios that meet a selection criterion, in this case, maximum improvement in abundance of delta smelt per unit of cost. The graph illustrates the benefit and cost of incrementally adding actions from left to right, to a portfolio. Managed Wetlands was selected first as being the most cost efficient, then adding nutrients to the Deep-water Ship Channel was added into the portfolio as the next most cost efficient action, and so on. After the inclusion of Sediment Supplementation, the incremental benefits become small. The inclusion of Contaminant Reduction actions does improve abundance but at a significantly increased cost.*

Interestingly, restoration of tidal marshlands was not selected in the first six actions both because of their expense and uncertainties regarding their benefits to food supplies.

While different members of the SDM technical working group have different preferences and opinions about models, the models employed were generally consistent with each other. That is, the results here might have differed slightly if different models had been used, but probably not so very different.

The purpose of the analysis presented here was to illustrate the additional information that can be obtained by taking the work in Round 1 through an optimization study. In the example here, the uncertainty of management effects wasn't included and I only used best estimates. Also, I recognize that identifying "best" portfolios also depends on decision makers' comfort with uncertainty of outcomes and tolerance to risks associated with those uncertainties. As noted previously, many of those uncertainties are best addressed by implementing actions on a small scale in an adaptive management framework.

Table C-1. Implementation of, and *results through seven rounds from an optimization routine to select a "preferred" portfolio. The six actions ultimately selected are highlighted in green in the left column. λ is the average year over year change in abundance. Color shading shows changes in λ from worst (red) to best (green) and associated lowest costs (green), to highest costs (red). Costs per unit increase in abundance were not calculated when there was no change in abundance.*

Action	Action Level	Order in	Round 1 λ	Round 1 Cost ($ mill)	Round 1 Cost per Unit incr.	Round 2 λ	Round 2 Incr. in Abund.	Round 2 Cost ($ mill)	Round 2 Cost per Unit incr.	Round 3 λ	Round 3 Incr. in Abund.	Round 3 Cost ($ mill)	Round 3 Cost per Unit incr.	Round 4 λ	Round 4 Incr. in Abund.	Round 4 Cost ($ mill)	Round 4 Cost per Unit incr.
						1.04		$1.53		1.10		$2.43		1.27		$4.39	
North Delta Food Subsidies	25,000 af		0.86	$0.14		1.04	1.00	$1.67		1.10	1.00	$2.57		1.27	1.00	$4.53	
Deep Water Ship Channel	Food + Nutrients ac	2	0.92	$0.90	$15	1.10	1.06	$2.43	$10								
Suisun Marsh Managed Wetlands	Mar-Apr, Jul-Oct 4,000	1	1.04	$1.53	$9												
Managed Wetlands in Refuges	17,000 ac	5	0.94	$2.15	$26	1.08	1.04	$3.68	$16	1.14	1.04	$4.58	$16	1.30	1.03	$6.54	$15
Tidal Wetland Restoration	Med Response 8,900 ac		0.91	$29	$615	1.09	1.05	$31	$136	1.15	1.04	$31	$110	1.30	1.03	$33	$76
Franks Tract Restoration	979 ac		0.99	$40	$300	1.18	1.14	$42	$128	1.26	1.14	$42	$106	1.43	1.13	$44	$77
Sediment Supplementation	450,000 cu yds	4	1.13	$5.04	$19	1.38	1.33	$6.57	$13	1.49	1.34	$7.47	$12	1.66	1.31	$9.43	$12
Aquatic Weed Control	600 ac	3	0.98	$1.96	$16	1.19	1.15	$3.49	$11	1.27	1.15	$4.39	$11				
Old & Middle River Management	53% effective		0.89	$307	$10,972	1.07	1.03	$309	$1,489	1.14	1.03	$309	$1,117	1.31	1.03	$311	$700
Risk-Based OMR	72% effective		0.90	$169	$4,688	1.08	1.04	$171	$786	1.15	1.04	$172	$596	1.32	1.04	$174	$379
Fish Friendly Diversions	90% effective		0.90	$84	$1,902	1.09	1.05	$86	$377	1.16	1.05	$87	$290	1.33	1.05	$89	$188
Contaminant Reduction	Yolo & Sac	6	0.92	$19	$351	1.10	1.06	$21	$88	1.17	1.06	$22	$71	1.34	1.06	$24	$49
SM Salinity Control Gate Reoperatior	Jun-Oct		0.86	$0.00		1.04	1.00	$1.53		1.10	1.00	$2.43		1.27	1.00	$4.39	
Year Round Flows*	Portfolio 2a1		0.86	$87		1.03	1.00	$88		1.11	1.00	$89		1.26	1.00	$91	
Summer and Fall Flow Augmentation	80km in Jul-Aug in BN,D		0.87	$23		1.05	1.01	$24		1.11	1.01	$25	$99	1.28	1.01	$27	$65

Action	Action Level	Order in	Round 5 λ	Round 5 Incr. in Abund.	Round 5 Cost ($ mill)	Round 5 Cost per Unit incr.	Round 6 λ	Round 6 Incr. in Abund.	Round 6 Cost ($ mill)	Round 6 Cost per Unit incr.	Round 7 λ	Round 7 Incr. in Abund.	Round 7 Cost ($ mill)	Round 7 Cost per Unit incr.
			1.66		$9.43		1.70		$11.58		1.80		$30.94	
North Delta Food Subsidies	25,000 af		1.66	1.00	$9.57		1.70	1.00	$12		1.80	1.00	$31	
Deep Water Ship Channel	Food + Nutrients ac	2												
Suisun Marsh Managed Wetlands	Mar-Apr, Jul-Oct 4,000	1												
Managed Wetlands in Refuges	17,000 ac	5	1.70	1.02	$12	$14								
Tidal Wetland Restoration	Med Response 8,900 ac		1.70	1.03	$38	$46	1.73	1.02	$41	$47	1.83	1.02	$60	$62
Franks Tract Restoration	979 ac		1.74	1.05	$49	$56	1.79	1.05	$52	$56	1.89	1.05	$71	$69
Sediment Supplementation	450,000 cu yds	4												
Aquatic Weed Control	600 ac	3												
Old & Middle River Management	53% effective		1.71	1.03	$316	$372	1.75	1.03	$319	$357	1.86	1.03	$338	$339
Risk-Based OMR	72% effective		1.73	1.04	$179	$206	1.77	1.04	$181	$199	1.88	1.04	$200	$197
Fish Friendly Diversions	90% effective		1.75	1.06	$94	$106	1.79	1.06	$96	$103	1.90	1.06	$115	$111
Contaminant Reduction	Yolo & Sac	6	1.76	1.06	$29	$32	1.80	1.06	$31	$33				
SM Salinity Control Gate Reoperatior	Jun-Oct		1.65	1.00	$9.43		1.69	1.00	$12		1.79	1.00	$31	$33
Year Round Flows*	Portfolio 2a1		1.65	1.00	$96.4		1.69	1.00	$99		1.79	1.00	$118	$126
Summer and Fall Flow Augmentation	80km in Jul-Aug in BN,D		1.67	1.01	$32.2	$40	1.72	1.01	$34	$40	1.82	1.01	$54	$56

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Next Steps in Response to the SDM Draft Round 1 Report Released June 6, 2024

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July 21, 2024

This report presents the outcomes of a remarkable four-year Structured Decision-Making collaboration among Delta Smelt experts, with a range of expertise and representing a range of interests, facilitated by Compass. The TWG's work was collaborative, creative, scientifically robust and professional. The report itself went through multiple drafts refined by innumerable comments from TWG members on both big picture conclusions and details. This should not be treated as just another report; it is a uniquely valuable product, representing a solid reflection of the state of knowledge about Delta Smelt, and new results from the best modeling tools available. The final version of the report represents the thinking of highly qualified experts as a group. Therefore it is a more robust weighing of evidence than alternatives from any one representative. More important than alternative conclusions is the question of what happens next? This work represents significant investments from all parties involved. What can we do to make sure that investment is not stranded?

The seven actions presented as next steps in the report represent an appropriate view of the state of knowledge and capabilities. I would venture that every TWG participant would have loved to have come up with a bold inexpensive action that would immediately reverse the decades-long trajectory of Delta Smelt populations. Based on this work, I think we can say with some confidence that no such simple "solution" exists. Augmenting each driver[1] comes with uncertainties as to how to do it. The report pragmatically recommends, in broad terms, next steps for important drivers. Beginning implementation of these seven steps, including adaptive

[1] Drivers in this context refer to food, turbidity, flows, and actions that increase mortality, like contaminants and entrainment.

management experiments, would be a bold next step toward a long-term strategy for recovering Delta smelt and otherwise improving ecosystem conditions in the Bay-Delta.

An important conclusion in the report is that recovery of Delta Smelt populations is conceivable. It would be ideal if one driver (e.g. augmenting food, turbidity, or flows) could bring about that recovery, thereby minimizing costs and difficult choices. Similarly it would be ideal if focus on a single region, or if intense focus in the next five years, were the answer. The TWG tested multiple focused strategies like these. Modeling of single actions, locally-focused actions and immediately available actions were informative, but none of these showed enough response to be confident they alone could result in recovery. The most positive responses were achieved in portfolios of actions that included augmenting food, increasing turbidity, augmenting flows *and* controlling sources of mortality like contaminants and entrainment; together. Eliminating one set of such drivers did not yield as much growth as portfolios of actions that combined the known drivers. Portfolios that expanded the spatial scale of actions like aquatic weed control; portfolios that will take considerable time to achieve (e.g. 30,000 acres of tidal wetland restoration) or that might require difficult political choices (e.g. summer outflow actions) resulted in the greatest population growth (go from left to right in Table ES2). That does not mean that doing all things with all drivers all at once (an impractical choice) is the only way to achieve progress. But the likelihood of recovery would be higher using a strategy that includes some augmentation or refinement of each driver over time, rather than focusing on only immediate returns, or one or two drivers. The report presents a framework for such a multi-faceted strategy. Further modeling and detailed planning will be necessary to fill in that framework. Many elements of that framework are not surprising, and at least some, if not most, are included in various proposals in progress or in planning. The models and the report provide evidence that moving together with these, in concert, is essential to optimizing investments in effective management. They provide evidence that progressively building from smaller actions, some of which are underway but insufficient themselves, is likely to be constructive and more effective than declaring today's actions a failure and starting over with untested concepts.

The professional judgement of uncertainty (Figure ES8) represents careful reflection on the state of knowledge and the limitations (and strengths) of the models. The TWG recognized that the data available for Delta Smelt have important limitations. The models were not able to quantify all possible responses to different drivers. Not enough was known to quantify temperature, a potentially important driver. On the other hand, there is sufficient data to justify modeling, even if quantification of all possible relationships is not yet possible. The model outcomes are informed quantifications from the best available numerical tools representing a multi-expert view of the present state of knowledge.

Uncertainties are resolved in modeling by making informed assumptions. Informed assumptions do not negate the outcomes of the models; they result in outcomes that reflect our best understanding of the state of the science. It is important that readers not over-interpret the outcomes of the study. But the modeling does provide a framework of informed hypotheses that could benefit present management. The continued testing of these hypotheses could address important questions for both present and future management. Where specific interests seek more specific conclusions about questions such as quantification of the effectiveness of today's regulations, the groundwork is laid and the tools are available to undertake additional modeling. Collaboratively addressing specific questions about regulatory approaches is another possible next step facilitated by this framework.

The seven recommendations for next steps recognize that uncertainties impede immediately improving the state of specific drivers. For example, aquatic weed control could augment turbidity, which could accelerate any benefits from food produced by tidal wetland restoration. But we simply do not know how to constructively accomplish large scale aquatic weed control at this point in time, and we cannot quantify how much food for Delt Smelt (if any) will be produced per acre of wetland restoration. Small scale adaptive management experiments with alternative approaches (or in alternative places; or at alternative times) could begin to flesh out the understanding necessary to control aquatic weeds at a scale sufficient to make a difference. Further efforts at resolving the links between tidal wetland restoration and export of food could do the same. Recognizing adaptive experimentation as a next step is not a failure to take bold action. It is a realistic assessment of what must come next to make larger scale, bold actions effective.

Uncertainties about costs, effectiveness of actions and interactions among actions were large enough that the TWG chose not to rank cost-effectiveness of each action. "Ball park" costs give those considering an action a sense of costs more consistent with the degree of uncertainty. The information is available in the body of the report to break apart monetized water "costs" (a narrow view of that driver) from physical costs of the action. This could provide a better sense of the cost question. Cost/benefit also might be narrowed as actions and costs are further detailed and modeled; another next step.

More model runs were conducted assessing sensitivity to different flow actions than with any other driver. The outcomes were informative both in terms of findings and in illustrating the complexity of evaluating such actions. The portfolios did not test the hypothesis that recovery could be achieved without management of flows and that was not a conclusion from this committee of experts. In fact, Tables 5 – 8 illustrate small positive population growth when Fall X2 was managed to distances less than 80Km in W and AN years (and moreso for the lowest X2's in summer). Just as important they showed negative effects (faster decline than observed historically) had X2's been managed in 1994-2014 to further distance than the current regulations (e.g. 87/88Km in Fall). The net benefit of management is the difference between the two. As noted above the benefits of flows were less evident if that single driver alone was managed (flow manifested as only salinity change) than if food was added to the mix (Table 7). The modeling raised intriguing hypotheses about how the timing of flow actions, or the number of years in which flows were augmented, could affect benefits to Delta Smelt. These same hypotheses might be applied to assess broader responses like specific ecosystem functions. Again, if effective use of water is a priority, then the present report sets the stage for further modeling and experiments as manageable next steps that could benefit future management choices.

This report, therefore, clarifies numerous opportunities for advancing efforts to recover Delta Smelt and benefit the Bay-Delta ecosystem. The set of recommendations are a stepping off point for new, informed, bold actions. The unanswered question is who is going to lead the effort to champion these findings, fit them into regulations and plans already in progress, help set priorities among the several possibilities for specific next steps and design/implement a long-term strategy that incorporates these recommendations for managing Delta Smelt into a larger ecosystem management strategy for the Bay-Delta? CSAMP participants sponsored a series of reports that had specific recommendations on leadership, modeling and decision support in this circumstance (Reed et al, 2021). The Independent Science Board (Wiens et al 2021) suggested assembling a collaborative Adaptive Management Team that could work toward such a goal. CSAMP, if it were to continue, could provide an assembly point or impetus to work out how to take advantage of the guidance from experts in the present report and these earlier works. It could be argued that the Bay-Delta is at a hinge point as a new phase of management begins, wherein implementation of a next step strategy for ecosystem recovery could be feasible. This report frames part of a collaborative path forward; a frame that should not be left stranded.