Action Specification Sheet:

Tidal Wetland Restoration (with and without temperature focus)

1 Short Description and Hypothesized Bottleneck

This action involves the construction of tidal wetland restoration projects that are likely to benefit Delta Smelt. Restoration in this case means the conversion of agricultural land and/or managed wetlands to tidal wetlands, composed mostly of emergent marsh vegetation and shallow open water areas (e.g., bays, sloughs). Land use change in the San Francisco Estuary has decreased the area of tidal and other wetlands by >90%, resulting in roughly the same decrease in primary productivity for the Estuary region (SFEI-ASC 2020). Tidal wetlands are important for sustaining food webs that benefit Delta Smelt and other species, as well as providing suitable abiotic conditions (e.g., climate refugia) for species (Sherman et al., 2017; SFEI-ASC 2020).

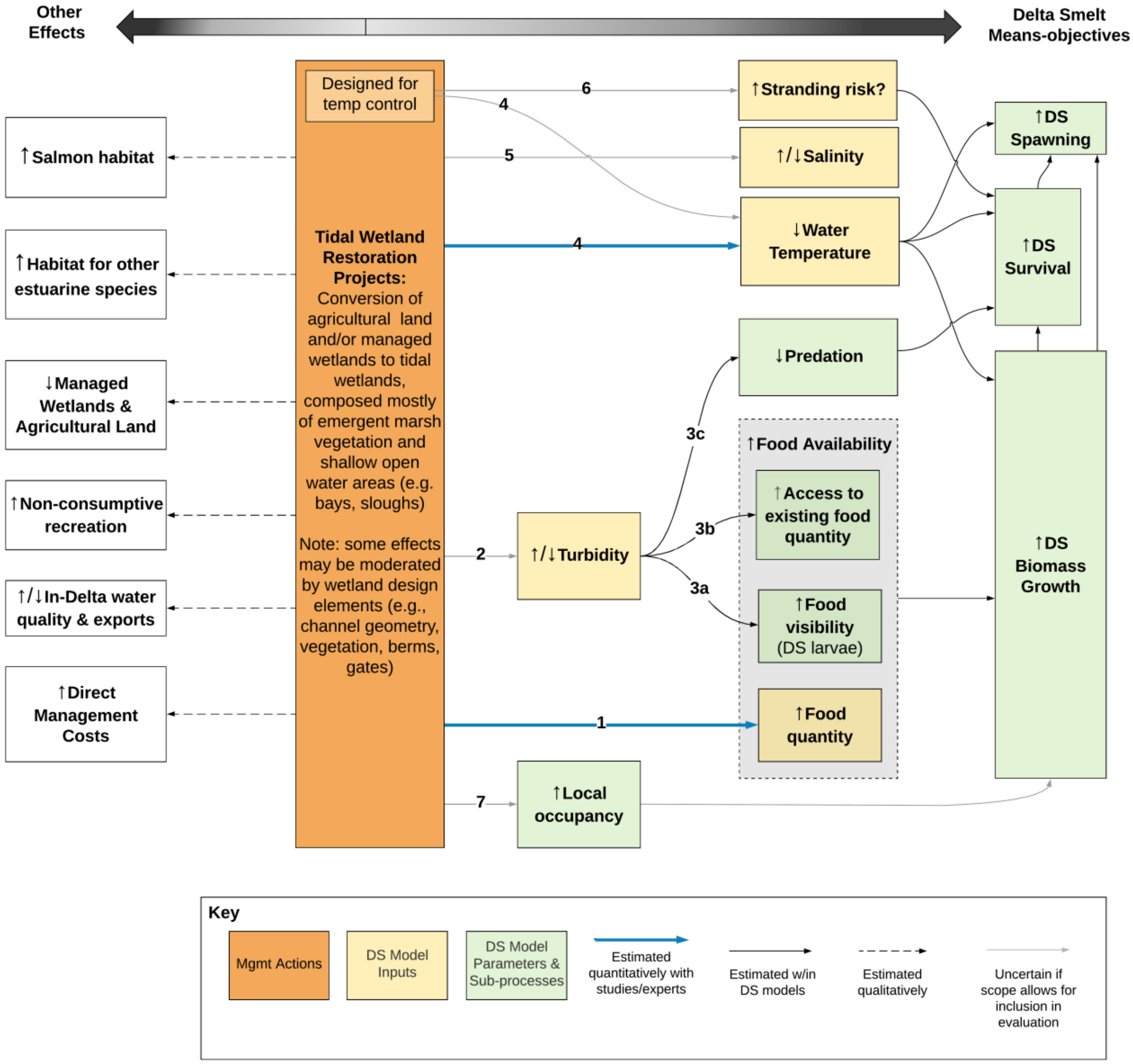
1.1 Habitat restoration with temperature focus

A unique design for habitat restoration has been proposed and is currently being piloted that uses tidal gates to flood wetland areas at night during high tide events and drain during the day to efficiently cool local water bodies. Pilot studies have begun testing the impacts of wetlands with this design in the Cache Slough Complex (Stumpner et al., 2021). Preliminary results showed that the wetland with a temperature-focused design provided “temperature refugia” conditions for Delta Smelt in the spring and summer where temperatures remained lower than lethal thresholds in this wetland while exceeding lethal thresholds more often in reference sites (shallow open water area and leveed channel). The results also showed that these pilot wetlands were too small to cool a relatively large surrounding area, and Delta Smelt may be unable to find and benefit from these localized cooling effects. The researchers suggested that scaling up this design to larger wetland areas could provide more substantial cooling effects in larger neighboring areas of the Delta. They also hypothesized that wetlands with this temperature-focused design may have some risk of stranding Delta Smelt, but it is unknown to what extent this may occur.

Besides temperature and stranding risk, we assume the effects on all other system components will be the same for restored wetlands with and without this temperature-focused design. The temperature-focused design is depicted with the small orange inset box in the influence diagram (below).

Although habitat restoration with temperature focus (and the assumed temperature effect) was included in preliminary model runs (described below), the TWG opted to only include “generic” tidal wetland restoration (not designed to reduce temperature) in the majority of Round 1 evaluation, including all portfolios. Their rationale was that there is preliminary evidence of a potential, small reduction of temperature from tidal wetlands, but the underlying mechanisms are not well understood. Continued temperature and hydrodynamic monitoring at more restoration sites could be warranted.

2 Influence Diagram



3 Action Evaluation

The table below describes each effect hypothesis identified in the Tidal Wetland Restoration influence diagram in Section 2 and describes the latest information that this project has identified to date on how each effect pathway could be characterized in the SDM evaluation. Note that Compass has identified in this table where the Individual-based Model in R (IBMR) can be used to quantify a pathway, but we have not done this same review for the other Delta Smelt models that will be used in this project – input is welcome from the Modeling sub-group on how these other models could be used for this action.

#	Effect Hypothesis	Effect Characterization for Round 1 SDM
1	**Restoration of tidal wetlands → food quantity** **Zooplankton:** Converting agricultural or managed wetlands to tidal wetlands will	Estimated with available data & expert judgment. *The TWG discussed using two bookends for estimating this effect pathway at the 13 May 2022 meeting. Across methods, it is assumed*

#	Effect Hypothesis	Effect Characterization for Round 1 SDM
	provide a net increase in zooplankton simply through converting land to water. Depending on the design of a restored tidal wetland site, the shallow open water around and within the site may have higher productivity on account of having higher water residence time and greater land/water interaction (SFEI-ASC 2020). Mahardja et al. (2019) found food density was higher in tidal wetlands in the Yolo Bypass relative to other regions, and Delta Smelt had higher growth rates. **Benthic Invertebrates:** Diet studies have found that Delta Smelt eat benthic invertebrates. The TWG for the SDM Demo project thought that the hypothesis that tidal wetlands provide greater access to benthic invertebrates (see #4) for Delta Smelt is more likely than the hypothesis that tidal wetlands have a higher density of benthic invertebrates (TWG call, Dec. 15, 2017). Overall, the loss and conversion of tidal wetlands since the early 1800s has decreased primary production by > 90% in the Delta (SFEI-ASC 2020).	*that 50% of a wetland restoration project's footprint, on average, becomes shallow open water that could generate zooplankton (Randy Mager, DWR, online meeting with Compass, 21 Apr 2022).* 1) *Low bookend: Demo Project methods with expert judgment (see Demo Project, pp. 99):* There is currently no evidence that restored tidal wetlands produce a significant net increase in zooplankton. Therefore, a low bookend assumes areas in and around restored wetlands would have the same zooplankton density as surrounding areas. This was used as a low bookend in the Demo Project. They applied an increase in zooplankton equal to the proportional increase in wetland area in a subregion. For example, if a management scenario restored 14% of a subregion's area to tidal wetlands, the low estimate was a 14% increase in zooplankton. We adapted these methods assuming that 50% of a wetland restoration project's area becomes shallow open water that could generate zooplankton. Therefore, if 14% of a subregion's area was restored to tidal wetlands, that would equal a 7% increase in open water and zooplankton. 2) *High bookend: SFEI + RMA methods:* This approach combines two existing methods/analyses. First, changes in phytoplankton density, given scenarios of tidal wetland restoration in this process, were estimated using an analysis done by SFEI see (SFEI report [SFEI-ASC 2020], pp. 27 and Cloern et al. 2021). The methods and predicted changes in phytoplankton are further described in Section 6.3. Second, changes in zooplankton density, given the changes in phytoplankton from tidal wetland restoration, were based on RMA copepod modeling methods (RMA 2021, pp. 6-7). These were used by the DCG to evaluate changes in zooplankton density for the North Delta Flow Action and Deepwater Ship Channel Action. These methods were adapted for this process to estimate change in zooplankton density in a subregion, given tidal wetland restoration. The RMA study estimated the relationship between

#	Effect Hypothesis	Effect Characterization for Round 1 SDM
		zooplankton and chlorophyll a, and the current SDM process assumes chlorophyll a is equivalent to phytoplankton.
2	**Restoration of tidal wetlands → Turbidity** Increasing shallow open-water areas increases turbidity from wind and wave interaction with the sediment (Sherman et al., 2017). Mahardja et al. (2019) found turbidity was higher in tidal wetlands in the Yolo Bypass relative to other regions, and Delta Smelt had higher growth rates. Preliminary hydrodynamic modeling from RMA found the effect on turbidity varied based on specific location of restored wetland (S. Andrews, RMA, call with Compass, Aug. 25, 2021).	This pathway was not captured in this SDM process. The TWG discussed this at the Aug.12 meeting. Opinions were split on whether to incorporate the pathway but ultimately it was decided to not incorporate at this time. Possibilities for future evaluation: P. Stumpner (USGS) and S. Andrews (RMA) are available to estimate this effect using existing hydrodynamic models and restoration grids that represent site-specific restoration for each of the proposed alternatives. Paul and Stephen have prepared a Statement of Work for the TWG's consideration that could help with quantifying this pathway. Christy Bowles (CDFW, FRP) may have preliminary results for effects (change from baseline/reference sites) of restored tidal wetlands and could provide mean and uncertainty around those effects. The change in turbidity (in a subregion) due to restoration may need to be estimated from expert judgment. John Burau (USGS) may also have expert knowledge valuable for characterizing this effect pathway.
3a	**Turbidity → Increased Food Visibility** Studies have shown that Delta Smelt larvae benefit from turbidity to see their prey, which increases consumption and growth rates (Baskerville-Bridges et al., 2004; Hasenbein et al., 2016; Moyle et al., 2016).	Estimated/accounted for in IBMR. The IBMR indirectly incorporates effects of turbidity on increased food visibility. It includes a direct relationship between turbidity and consumption (which affects growth, and survival rates). It scales the effect of turbidity on these rates using the following relationship: rates are at their maximums (dependent on smelt length and other factors) when Secchi depth < 24 cm and rates decline to 85% of their maximum value when Secchi depth >84 cm (Smith 2022a).
3b	**Turbidity → Increased Food Access** Hammock et al. (2019) found that stomach fullness of Delta Smelt was positively associated with turbidity and tidal wetland area. Turbidity was expected to increase Delta Smelt access to food – especially through greater access to benthic invertebrates swept into pelagic zone through bottom water	Estimated/accounted for in IBMR. The IBMR indirectly incorporates effects of turbidity on increased food access. It includes a direct relationship between turbidity and consumption (which affects growth, and survival rates). It scales the effect of turbidity on these rates using the following relationship: rates are at their maximums (dependent on smelt length and other factors) when Secchi depth < 24 cm and rates decline to 85% of their

#	Effect Hypothesis	Effect Characterization for Round 1 SDM
	mixing into the water column (TWG, pers. comm., Demo Project).	maximum value when Secchi depth >84 cm (Smith 2022a).
3c	**Turbidity → Reduced predation** The translucent body color and small size of Delta Smelt may make them less visible to predators in moderately turbid water (Moyle et al., 2016). Ferrari et al. (2014) found that adult Delta Smelt predation was lower in more turbid water. Bennett and Burau (2015) also found Delta Smelt migration movements were positively associated with turbidity and hypothesized this was due to lower risk of predation.	Estimated/accounted for in IBMR. The IBMR includes equations for mortality and growth rates that represents the following pattern: Delta Smelt experience lower predation risk as turbidity increases. As turbidity increases and predation risk declines, Delta Smelt respond by increasing foraging rates and growth. The IBMR incorporates effects of turbidity on consumption, growth, and survival rates. It scales the effect of turbidity on these rates using the following relationship: rates are at their maximums (dependent on smelt length and other factors) when Secchi depth < 24 cm, and rates decline to 85% of their maximum value when Secchi depth >84 cm (Smith 2022a).
4	**Restoration of tidal wetlands → Reduce thermal stress** Tidal wetlands can provide pockets of thermal refugia for Delta Smelt – i.e., areas where temperatures do not exceed “lethal” conditions in summer months and “stressful” conditions in spring months (P. Stumpner, pers. comm., Temperature subgroup meeting, 11 June 2021). Recent evidence suggests temperatures may be slightly lower in areas adjacent to tidal wetlands (Gustine et al. 2022). Additional lab and field studies found that higher temperatures exceeding certain thresholds can increase mortality (Komoroske et al. 2014, Swanson et al. 2000) and sublethal stress (Komoroske et al. 2015). Other studies have found correlations between lower temperature and higher Delta Smelt outcomes, such as consumption rates (Eder et al. 2013; Rose et al. 2013), occurrence (Sommer & Meija 2013), affinity and habitat suitability (Hamilton & Murphy, 2020) and population change (S. Hamilton, pers. comm.).	Estimated with available data & expert judgment. NASA JPL has remote-sensing water temperature data and has recently evaluated pre-post effects of restoration at Tule Red and Winter Island (Gustine et al. 2022). This study showed that water temperatures in areas surrounding restored wetlands within a 100, 500, and 2000-m buffer had mean temperatures that were between 0.25 and 0.57°C lower following restoration between June and September. For Round 1, we assumed a temperature reduction of 0.5°C in June through September. We added this effect to a full build-out scenario of restoration to test Delta Smelt outcomes with and without this effect included (see Section 4). See Section 6.4 for more details on the JPL analysis.
5	**Restoration of tidal wetlands → Salinity** Tidal wetlands may influence local or regional salinity dynamics. The effects may be variable and dependent based on the location of a restored wetland. “Habitat that is along the main channels tends to increase salinity (even with current sea level) while habitat that is out of tidal phase with the confluence	This pathway was not captured in this SDM process. Possibilities for future evaluation: P. Stumpner (USGS) and S. Andrews (RMA) are available to estimate this effect using existing hydrodynamic models and restoration grids that represent site-specific restoration for each of the proposed alternatives.

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	(think upper reaches of Cache or Suisun Marsh) tends to decrease salinity" (TWG member, TWG meeting, July 29, 2021). Additional analyses found that higher salinities may influence the distribution of fish (e.g., "high salinity in November and December may induce movement of Delta Smelt away from productive spawning areas" [Hamilton *in prep*, Performance Analysis]). Salinity was also proposed to negatively influence Delta Smelt growth and survival (Smith, et al. 2020).	
6	**Restoration of tidal wetlands → Stranding risk (Delta Smelt mortality)** Tidal wetlands designed with gates or permanent berms (e.g., for restoration designed to reduce temperatures by facilitating flooding at night during spring tide cycles) may be associated with some probability of Delta Smelt being stranded in wetlands as temperatures reach levels to induce stress (P. Stumpner, pers. comm., Temperature subgroup meeting, 11 June 2021). The probability or total occurrence of stranding and mortality has not been quantified in this context to our knowledge.	This pathway was not captured in this SDM process. This pathway may need to be estimated from expert judgment, given specific wetland designs (i.e., temperature-focused tidal wetland restoration.
7	**Restoration of tidal wetlands → Local occupancy** Increased tidal wetland habitat could increase local occupancy in and around restored sites due to cumulative direct and indirect effects including and in addition to those effects already captured in this table.	This pathway was not captured in this SDM process. Possibilities for future evaluation: There are two existing models that estimate changes in Delta Smelt distribution across subregions with changes in salinity, turbidity, and other factors: • Smith (2022b) Delta Smelt Distribution Model • Hamilton (2022) Delta Smelt Distribution Model It is unclear how changes in restored habitat could be incorporated into these models, other than through indirect effects of temperature and food.
Financial and water resources		
	Restoration of tidal wetlands → Increased direct management costs **Upfront Costs:** Rule of thumb is that it costs between $20,000 to $30,000/acre to restore	Estimated with available data & expert judgment. The ballpark cost assumptions used in the SDM Demo project (see left-hand column) were used again.

#	Effect Hypothesis	Effect Characterization for Round 1 SDM
	tidal wetlands. This includes planning, buying land, permitting and construction. A key factor in the upfront cost is the cost of land and how much land adjacent to the wetland needs to also be protected (pers. Comm., C. Wilcox, Aug. 10, 2017). • Assumption for capital costs used in the SDM Demo project was: Low end - $20,000 per acre • High end - $30,000 per acre **Operating costs:** If there's no levee, ongoing operational costs for tidal wetlands are low. Costs could include some policing of the site (access, dumping) and vegetation management. If there is a levee or water control structure, then costs would be quite a bit higher. If the site is designed well and water velocity through tidal channels is high enough, aquatic weeds will not establish themselves. The more saline sites (e.g. Suisun Marsh sites) will face less risk of aquatic weed intrusion than the fresher water sites (pers. Comm., C. Wilcox, Aug. 10, 2017). For the 8,000 acres that are mitigation for the water projects, the long-term operations and management of these projects will be covered by the projects. For additional acres identified under EcoRestore, long-term funding will be more challenging. The capital portion of these projects is payed for through bonds, which can not be used for ongoing management. The McCormick-Williamson project is currently facing issues along these lines – it's owned by the Nature Conservancy, but they do not have operational funding so they are looking for a state agency to take over the land and manage (pers. Comm., C. Wilcox, Aug. 10, 2017). Assumption for operating costs used in the SDM Demo Project (C. Wilcox, Jan. 2018): • Low end – $250 / acre High end – $500 / acre	Final annualized cost estimates per ac included initial costs and annual operating costs and used an average of the upper and lower estimates. See Section 14 for details. **Final financial resource estimate:** **$2,450,000 per year per 1,000 ac**

We note that other pathways in the influence diagram above are accounted for in the structure of the IBMR and other models that will be used in the SDM evaluation. For example, the IBMR incorporates effects of temperature on consumption, growth, and survival rates. It scales the effect of temperature on these rates using the following relationship: rates are at their maximums (dependent on smelt length and other factors) when temperature < 23 °C, and rates decline to 0% of their maximum value when temperature >27 °C.

4 Intensity & Locations

At TWG meetings between May 7, 2021 and January 21, 2022, the group agreed to specify multiple levels of intensity for stationary habitat restoration for Delta Smelt. Evaluating multiple amounts of restoration across portfolios, including a higher, aspirational target, will provide insight to the effects of various levels of restoration on Delta Smelt and identify any non-linear patterns that may inform if additional restoration has the same or lower returns on investment. At the July 29, 2021 TWG meeting, the group discussed additional considerations (e.g., spatial distribution of restored wetlands across Delta subregions) that could be used to create more than two levels. Compass worked with Carl Wilcox and GIS analysts at SFEI to access the SFEI Landscape Scenario Planning Tool (https://www.sfei.org/projects/delta-landscapes-scenario-planning-tool) and download spatial data layers for (a) existing tidal wetlands, (b) EcoRestore project footprints and acres of expected restored tidal wetlands, and (c) areas in the intertidal zone that could potentially support tidal emergent wetlands across the Delta based on elevation and current land use. Three levels specified below are proposed by Compass, based on previous TWG input.

Restoration Level 1: Baseline conditions (15,375 acres of tidal wetlands)

- Proposed portfolios for this level: Reference #1a (Post-2008 BiOp)
- Reflects baseline/reference conditions that includes all areas classified as tidal wetlands in the modern habitat types layer in the SFEI LSPT.
- We removed any areas of tidal wetlands in the original modern habitat types layer that overlapped with EcoRestore project footprints, since these areas reflect restoration that occurred after 2008 and contribute toward Restoration Level 2 (below).

Restoration Level 2: EcoRestore projects (8,902 acres of tidal wetlands, additional to Level 1)

- Proposed portfolios for this level: Reference #1b (Post-2020 BiOp/ITP); all other non-reference portfolios unless specified in Level 3 below
- Reflects additional tidal wetland restoration from EcoRestore projects that have already been implemented or are planned, as of 2022.
- We selected tidal wetland habitat types from the EcoRestore spatial layer in the SFEI LSPT.
- We excluded any tidal wetland acres in EcoRestore project footprints that were in the East and South Delta subregions so that this Restoration Level reflects BiOp guidelines to focus on subregions in the North Delta Arc.
- The list of projects included in the SFEI LSPT was checked against and confirmed to align with a list of tidal wetland restoration projects provided by Carl Wilcox (see Section 13, Table A1).
- USFWS created a crediting table for restoration projects and Delta Smelt benefits – this table addresses which life stage will benefit from projects.

Restoration Level 3: More than EcoRestore (20,447 acres of tidal wetlands, additional to Level 2)

- Proposed portfolios for this level: Long-term portfolios #3a (Self-sustaining/permanent strategies), 3d (Remove food and temperature limitations and reduce larval predation), and 3e (Improve habitat connectivity)
- Reflects high benchmark of potential restored wetland area beyond EcoRestore projects that are currently implemented or planned.
- We captured the total and distribution of acreage of potential restored tidal wetlands using the "Landscape potential tidal marsh intertidal areas" layer in the SFEI LSPT. This layer identifies areas in the intertidal zone that could potentially support tidal emergent wetlands (i.e., would not

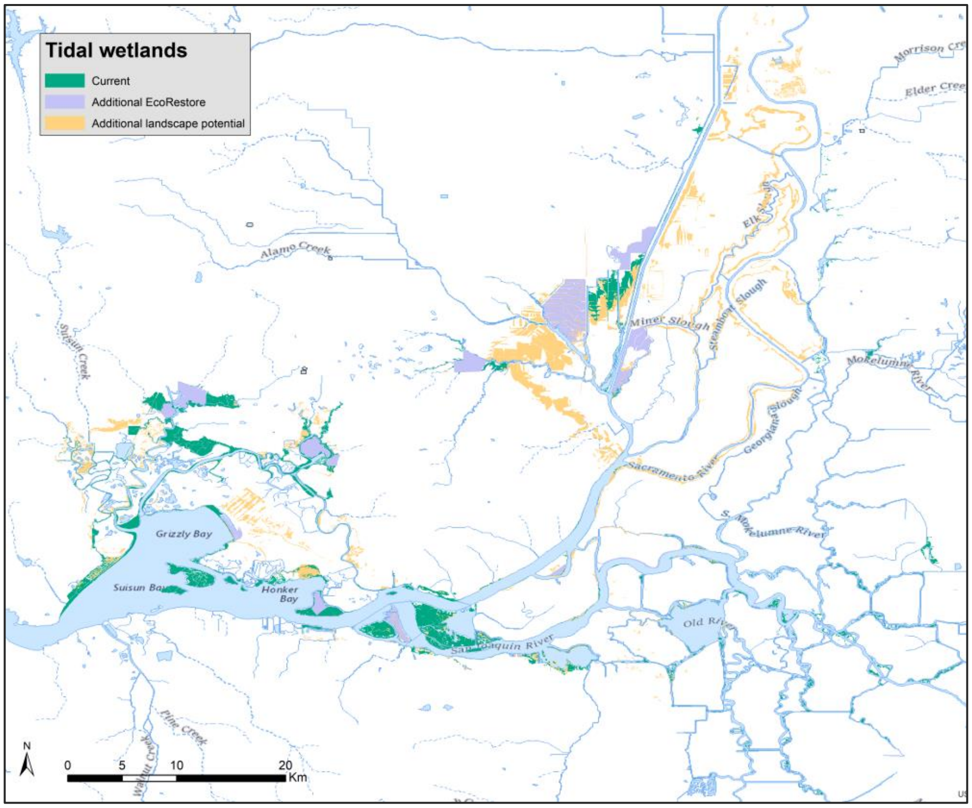
require major subsidence-reversal efforts). It does not include areas that already support emergent wetlands or areas currently classified as urban development.

- Similar to Level 2, we excluded any tidal wetland acres from this layer that were in the East and South Delta subregions so that this Restoration Level reflects BiOp guidelines to focus on subregions in the North Delta Arc.

Table 1. Acres of tidal wetlands by subregion under each "Restoration Level" reflecting a range of intensities of restoration to use within portfolios in Round 1 of the SDM evaluation.

Subregion	Level 1 – Current	Level 2 – EcoRestore	Level 3 – More than EcoRestore
Yolo Bypass	1890	4797	14521
Sacramento River	75	860	6318
South Delta	1165	0	19729
East Delta	529	0	11051
Lower Sacramento River	108	112	272
Lower San Joaquin River	873	184	859
Confluence	2908	430	697
SE Suisun	535	337	396
NE Suisun	1275	78	130
Suisun Marsh	5563	1937	5930
SW Suisun	0	0	0
NW Suisun	456	167	227
Total	15375	8902	29348

Figure 1. Map of Restoration Levels of tidal wetlands across the Delta, based on datasets from the beta version of the SFEI Landscape Scenario Planning Tool: (a) existing tidal wetlands, (b) acres of expected restored tidal wetlands within EcoRestore project footprints, and (c) areas in the intertidal zone that could potentially support tidal emergent wetlands based on elevation and current land use.



For Restoration Level 3, it is unknown how many planned restoration projects could employ a temperature-focused design that is currently being studied in a pilot project by Paul Stumpner (USGS) and colleagues. The TWG will need to consider specifying restoration acres with and without temperature focus in all portfolios that use Restoration Level 3.

4.1 Sensitivity Analysis

Multiple variations of this action were evaluated within a “sensitivity analysis” where the intensity and effects of tidal wetland restoration vary and the action is added to the Reference Portfolio 1a (while all other actions in the portfolio remain the same).

Five versions of tidal wetland restoration were evaluated that vary in total area of restored tidal wetlands and the magnitude of predicted effects on zooplankton biomass (see effects table in Section 3 for more detailed methods):

1) Restoration Level 2 (EcoRestore projects [8,902 acres of tidal wetlands additional to current]); low bookend effect for zooplankton
2) Restoration Level 2 (EcoRestore projects [8,902 acres of tidal wetlands additional to current]); high bookend effect for zooplankton
3) Restoration Level 3 (More than EcoRestore [29,348 acres of tidal wetlands additional to current]); low bookend effect for zooplankton
4) Restoration Level 3 (More than EcoRestore [29,348 acres of tidal wetlands additional to current]); high bookend effect for zooplankton

5) Restoration Level 3 (More than EcoRestore [29,348 acres of tidal wetlands additional to current]); high bookend effect for zooplankton + effect of local temperature reduction

4.2 Final scenario(s) to evaluate in the SDM process

Level	Acres	Portfolio	Effects/bookends
1 – existing	**15,375 acres** (existing, not restored)	Portfolio #1a	NA (baseline conditions)
2 – planned in EcoRestore	**8,902 acres restored (additional to Level 1)** in North Delta Arc (NDA) from EcoRestore projects.	Portfolio #1b	Low and high bookend food effects for preliminary sensitivity runs; low bookend food effects for Round 1 portfolios and food, turbidity, and flow sensitivity analysis.
3 – More than current & planned projects (North Delta Arc focus + Lower San Joaquin)	**29,348 acres restored (additional to Level 1)** in North Delta Arc and Lower San Joaquin using potential intertidal areas [from SFEI GIS data].	Subset of long-term portfolios (3a, 3d)	

5 Life stage

Restoration of stationary tidal wetland habitat will influence different life stages of Delta Smelt depending on where habitat is located. Merz et al. (2011) synthesized historical observation data for Delta Smelt across life stages and subregions. They reported subregions with the highest relative presence of Delta Smelt by life stage that could reflect priorities for restoration (see Merz et al. 2011, Fig 6 and Discussion). Note that the table below shows coarse results from Merz et al. (2011) related to relative priority areas by life stage and should be interpreted along with other ecological information and management goals when targeting areas for restoration. Delta subregions not listed below had relatively lower frequencies of Delta Smelt observations.

Life stage	Suisun Marsh	Suisun Bay	Grizzly Bay	Confluence	Lower Sacramento River	Cache Slough Complex
Larva/subjuv	✓	✓	✓	✓	✓	✓
Juveniles	✓	✓	✓		✓	✓
Subadults				✓	✓	
Pre-spawn adults	✓	✓	✓		✓	✓
Spawning adults	✓				✓	✓

The above life stage / subregion priorities agree with the 2008 FWS BiOp Draft Delta Smelt Crediting Decision Model for assigning credits to restoration projects. Projects are given highest priority scores if located in the Suisun Marsh, Cache Slough Complex, Confluence, and Lower River subregions.

6 Evidence / Examples

This section documents key references that have not yet been described in the above sections. Compass presented methods used in the SDM evaluation to IEP's Zooplankton Project Work Team on 25 Oct 2023 and received feedback on reasonable methods/assumptions to use. Overall, that group summarized:

- **Evidence TWs may not have zooplankton benefit:** Zooplankton monitoring of tidal wetlands (Kimmerer et al. 2018), Sherman and Bowles (CDFW) monitoring of restored tidal wetlands
- **Evidence that TWs may have food benefit:** Studies show evidence of increased amphipods and insects from restored wetlands that could be Delta Smelt prey, which is not directly captured in Delta Smelt modeling. Hammock et al. (2019) found two-fold greater gut fullness in Delta Smelt sampled at locations adjacent to larger wetland areas compared to those locations near fewer wetlands.
- **Key Takeaway:** TWG should consider changing the 'bookends" for tidal wetland food effects – maybe low bookend should be a 0% change in food and then the current low bookend should be the 'high bookend" (% change in zooplankton density covariate in DS models = % change in open water from TW restoration).

6.1 Evidence of effects: restored tidal wetlands → zooplankton

Research on the effects of restored tidal wetlands on zooplankton (or other ecological outcomes) in the Delta is sparse and has not found ecologically significant increases in zooplankton. Particularly in the Delta, tidal wetland restoration projects have only been recently implemented, meaning that monitoring programs only have a few years (at most) of post-restoration data. The following is a summary of current evidence to the effects of restored wetlands on zooplankton density.

- The Fish Restoration Program (FRP) Monitoring Team of CDFW is monitoring changes in zooplankton and other ecological outcomes at 11 tidal wetland restoration projects under a before-after-control-impact monitoring scheme. Preliminary data has not detected changes in zooplankton, nor does the data have power to detect any changes at present until additional years of monitoring data are acquired (Christy Bowles, CDFW, online meeting with Compass, 26 Apr 2022).
- Empirical research by Yelton et al. (2022; and sources within) found little evidence that zooplankton within restored tidal wetlands in the Delta were being transported to surrounding areas due to interactions between daily tidal patterns and diel behavioral patterns of zooplankton. Evidence has shown zooplankton in tidal wetlands is highest at the ends of sloughs (John Durand and Kyle Phillips, UC Davis, online meeting with Compass, 2 May 2022). If any change in zooplankton density mostly occurs locally within restored wetlands near the ends of sloughs, the degree to which Delta Smelt could access these resources is uncertain.

6.2 Evidence of effects: restored tidal wetlands → primary production

Research on the effects of restored tidal wetlands on primary production (chlorophyll a, NPP, etc.) is also sparse. The following is a summary of current evidence to the effects of tidal wetlands (existing and restored) on primary production outcomes.

- The FRP Monitoring Team of CDFW is monitoring changes in zooplankton and other ecological outcomes at 4 tidal wetland restoration projects under a before-after-control-impact monitoring scheme (Daniel Cox, IEP conference presentation, available here). Restored sites monitored were Yolo Flyway Farms, Decker Island, Winter Island, Tule Red. Preliminary analyses found chlorophyll a was similar or marginally greater in restored sites during the period following restoration, relative to reference sites. It is important to note that chlorophyll a was lower across all sites in the time period following restoration, relative to pre-restoration (perhaps due to annual factors not measured in this study), which could have limited the power of the analysis to detect significant effects.

- The Durand Lab (UC Davis) has monitored chlorophyll a at four wetland sites capturing a range of "natural" to "impaired" conditions near the upper end of Suisun Slough (First Mallard, Shell Drake, Peytonia Slough, and Hill Slough). Preliminary data showed no ecologically significant net export of chlorophyll a from wetlands into surrounding water bodies. Tidal wetlands may not provide a net increase in primary production because the constant tidal flux may limit water residence times needed for producing large blooms of phytoplankton (and subsequently, zooplankton). There is also the potential for clams and other fish species (e.g., Mississippi silversides) to colonize restored tidal wetlands, and these species are efficient competitors that exhibit high feeding rates on primary production and zooplankton. (John Durand and Kyle Phillips, UC Davis, online meeting with Compass, 2 May 2022).
- The relationship between primary production and zooplankton is uncertain. Rosemary Hartman (DWR) has done preliminary analyses that has found no clear relationship between chlorophyll a and zooplankton (Christy Bowles, CDFW, online meeting with Compass, 26 Apr 2022). A complicating factor that should also be considered is that clams and other fish species (e.g., Mississippi silversides) compete for phytoplankton and zooplankton and are more efficient consumers than Delta Smelt (John Durand, UC Davis, online meeting with Compass, 2 May 2022). It is reasonable that Delta Smelt would not be able to access 100% of resources that are produced from restored wetlands due to these competing species.
- Jim Cloern and others at SFEI have conducted theoretical modeling that is described more fully below.

6.3 SFEI methods estimating restored tidal wetland effects on primary production

Analyses used in the SFEI report (SFEI-ASC 2020) and Cloern et al. (2021) predicted changes in phytoplankton and overall Net Primary Production (NPP) from restoring 32,500 ac of tidal marsh in the Delta, relative to modern baseline conditions. The spatial extent of the analysis was the total hydrologically connected area in the Delta (at present and under the future restoration scenario), which included all areas of open water, tidal and non-tidal wetlands, and seasonally flooded habitats that were connected via surface flows. Resulting changes in production were summarized by habitat type, including tidal wetlands, which can be extracted for the SDM process. The analysis did not include a temporal component – meaning estimated changes in production outcomes can be interpreted as stable future conditions after wetlands have been restored.

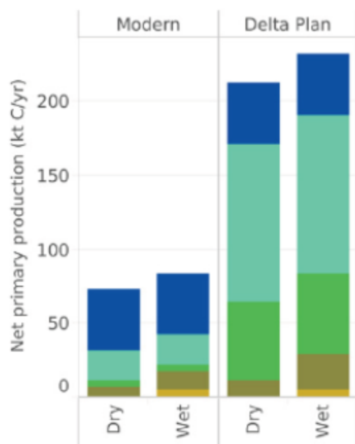
Results showed phytoplankton increased from 0 to 1 kt C/yr in both dry and wet years in tidal wetland habitat (Cloern et al. 2021, Table 3). However, these results were rounded, and Jim Cloern confirmed with Compass that the more precise estimates for modern conditions were 0.2 kt C/yr in dry years and 0.3 kt C/yr in wet years (J. Cloern, pers. comm., 28 Apr 2022). Total NPP increased from 21 to 110 kt C/yr in dry and wet years in tidal wetland habitat (SFEI report 2020, pp. 27).

Figure 2. Predicted potential increases in phytoplankton (Cloern et al. 2021, top) and Net Primary Production (NPP: SFEI-ASC 2020, bottom) in tidal wetland habitat under a future scenario of restoring 32,500 ac of tidal wetlands included in the Delta Plan, relative to modern baseline conditions. These results came from the same analysis, and red boxes were added to highlight results for tidal wetlands that could be extracted for use in the SDM evaluation. *Note that Jim Cloern later confirmed the more precise estimates for phytoplankton under modern conditions were 0.2 kt C/yr in dry years and 0.3 kt C/yr in wet years.

Table 3

Estimated potential aquatic net primary production (PANPP, kt C yr^{-1}) across three Delta landscapes and two water-year types for five primary-producer groups (bold), binned by habitat types.

Primary producer group Source habitat type	Historical		Modern		Future	
	Dry	Wet	Dry	Wet	Dry	Wet
Phytoplankton	**12**	**20**	**11**	**16**	**12**	**19**
Open water	6	6	11	11	11	11
Tidal marsh	7	7	0.2*	0.3*	1	1
Nontidal marsh	0	8	0	0	0	2
Other seasonal floodplain			0	5	0	5



Habitat Type	Modern (kt C/yr) Dry	Modern (kt C/yr) Wet	Delta Plan (kt C/yr) Dry	Delta Plan (kt C/yr) Wet
Open water	41	41	41	41
Tidal marsh	21	21	110	110
Non tidal marsh	4.0	4.1	54	55
Riparian forest/ scrub	7.4	13	11	24
Other seasonal floodplain	0.0	5.0	0.0	5.0
TOTAL	74	84	210	230

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If we assume a linear relationship between restored acres and primary production outcomes, the SFEI results would translate to a 9% increase in phytoplankton and a 13% increase in total NPP for every additional 1,000 acres of restored tidal wetlands. However, as other research and conversations with experts has revealed, there is little evidence to specify a relationship between changes in phytoplankton or NPP and zooplankton density.

6.4 JPL study assessing effects of tidal wetland restoration on temperature

Cassie Nickles (NASA Jet Propulsion Lab [JPL]) provided Compass with a brief description of methods used to assess pre-post changes in water temperature for the Tule Red and Winter Island Tidal Restoration Projects (below). Full documentation can be found in Gustine et al. (2022).

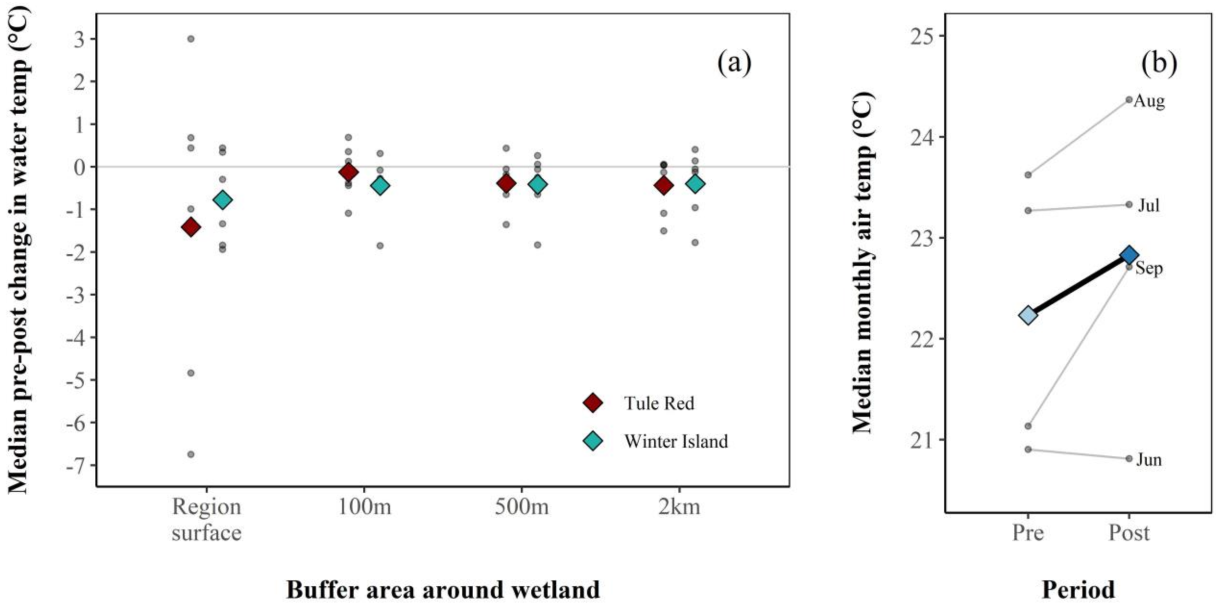
"We assess changes in temperature for the Tule Red and Winter Island Tidal Restoration Project regions by obtaining all ECOSTRESS images and subsetting them by regional shapefiles. We analyze the surface temperature obtained directly from ECOSTRESS for the wetland regions themselves and then analyze bulk water temperature at depth from the adjacent aquatic area around each project. The bulk water temperature at 1 m depth is found using a simple harmonic regression model relating temperature at the surface to temperature at depth informed by four representative California Data Exchange Center (CDEC) stations in the region (Gustine et al. 2022). The adjacent aquatic area is studied in three different buffer regions with 100 m, 500 m, and 2 km radii. 100 meters was selected to represent the most adjacent aquatic area, capturing about one 70 m ECOSTRESS pixel along the study region. 500 meters was chosen to obtain a fair amount of ECOSTRESS pixels yet still limiting the impact of intrusive flow paths on temperature, especially surrounding Winter Island. The 2 km buffer region was selected for a bigger picture of surrounding regions. The buffer distance was kept uniform for both regions. Since high temperatures are of greatest concern in summer months, we create boxplots of temperatures from the summer temperature acquisitions (June to September) pre (2018, 2019) and post (2020, 2021) project completions. We group the boxplots by time of day: morning (4 to 11 AM), midday (12 to 7 PM), and evening (8 PM to 3 AM). We also group the images by tidal stage: flood vs ebb, and only compare images with similar stage heights when the most data was captured, between 2-4ft, though tidal stages range from 0-6ft from NOAA's nearby Port Chicago Station (ID: 9415144).” (emailed to Compass on 16 May 2022).

Compass summarized JPL’s results to estimate average pre-post change in in summer (Jun-Sep: 2018-2021) water temperature by restoration project site (Tule Red and Winter Island) and buffer area of adjacent aquatic habitat (Figure 3a). Temperatures tended to decrease between 0.25 and 0.57°C, on average, in adjacent aquatic habitat following restoration.

Compass performed a supplemental analysis to estimate median air temperatures in the same pre-post restoration periods that were used in the JPL study. Compass accessed hourly air temp data from the nearest station to the restoration sites available on the California Data Exchange Center (CDEC) Data Archive (https://cdec.water.ca.gov/dynamicapp/wsSensorData: Station = MAL, near Chipps Island). Compass downloaded and summarized median hourly temperatures from Jun-Sep 2018-2021 to correspond with the water temperature analysis.

Air temperature data showed that median temperatures in these months post restoration (2020 and 2021) were 1.3°F (~ 0.7°C) higher than pre restoration (2018 and 2019: Figure 3b). Therefore, air temperatures recorded nearby increased in the period following restoration while the JPL analysis showed a ~0.5°C decrease in water temperature. This provides some evidence that decreases in water temperature were not due to air temperature conditions.

Figure 3. (a) Median pre-post change in in summer (Jun-Sep: 2018-2021) water temperature by restoration project site (Tule Red and Winter Island) and buffer area of adjacent aquatic habitat. Grey points represent median pre-post changes for a given tide phase (ebb/flood) and time of day (morning, midday, evening). Diamonds represent the means of those medians for each site and buffer area. Note that results for temperature changes inside the project region for Tule Red reflect the change of that site from dry land to restored tidal wetland. **(b)** Median monthly air temperature in summer before (2018-2019) and after (2020-2021) tidal wetland restoration. Grey points represent median air temperature for specific months (Jun, Jul, Aug, Sep) in pre-post periods. Diamonds represent median air temperature across all months (Jun-Sep) in pre-post periods. Temperature data came from Black Diamond CBKD station near tidal wetland restoration projects (Tule Red and Winter Island), available on the California Climate Data Archive (https://calclim.dri.edu/pages/stationmap.html).



6.5 Delta Smelt Resiliency Strategy

The 2019 update to the Resiliency Strategy notes that:

"State, local, and federal agencies and private interests completed 6 projects totaling 2,322 acres of habitat and broke ground on 4 projects totaling 3,447 acres of habitat. Additionally, planning is underway on another 17 projects totaling an additional 33,949 acres of restored or enhanced habitat. Five major barriers to fish migration within the Yolo Bypass have also been addressed, and two more are in planning. Upon completion of the anticipated projects, tidal wetland habitat will have more than doubled what remains in the Delta. Partner agencies have also made significant strides towards reducing and resolving institutional barriers to project implementation including:

- initiating programmatic permitting efforts,
- streamlining contracting processes and engaging the private sector in project delivery,
- conducting regional planning to engage stakeholders early,
- securing funding for long-term operations and maintenance on habitat projects,
- working to resolve conflicts between agency directives."

6.6 EcoRestore

EcoRestore project footprints and descriptions (https://water.ca.gov/Programs/All-Programs/EcoRestore)

6.7 Conservation Banks

General information: https://wildlife.ca.gov/Conservation/Planning/Banking

List of conservation banks: https://wildlife.ca.gov/Conservation/Planning/Banking/Approved-Banks

6.8 Other

EcoAtlas: Web-based GIS information for habitat projects (https://www.ecoatlas.org/regions/ecoregion/bay-delta)

7 Delta Smelt Model Results

The table below shows predicted population outcomes across the 20-year model timeframe for several versions of the action that were tested with all 4 Delta Smelt population models.

		Population Growth Rate				% Change in Population Growth Rate from Baseline			
		IBMR	LF	LCME	MDR	IBMR	LF	LCME	MDR No DD, Full
Action run ID	Scenario name	Average lambda (1995-2014)	Average lambda (1995-2014)	Median lambda (1995-2014)	Average lambda (2015-2035)	% change in average lambda (1995-2014)	% change in average lambda (1995-2014)	% change in median lambda (1995-2014)	Average % change in annual lambda (2015-2035)
4.1	TidWet EcoRes (9K ac) low bookend	1.04	0.89	1.00	1.24	5%	4%	5%	8%
4.2	TidWet EcoRes (9K ac) high bookend	1.16	0.95	1.16	1.39	18%	10%	22%	19%
4.3	TidWet MoreRes (30K ac) low bookend	1.12	0.91	1.14	1.37	13%	6%	20%	17%
4.4	TidWet MoreRes (30K ac) high bookend	1.33	0.95	1.70	2.04	35%	11%	78%	62%
4.5	TidWet MoreRes (30K ac) high bookend + temp	1.39				41%	-	-	-

- Multiple runs were used to explore population outcomes while varying the methods for effects of food (low or high bookend effects) and spatial scale (9K or 30K ac) of the action (Action runs 4.1 – 4.4). An additional exploratory run (4.5) added in the effect of a small temperature reduction from the action.
- **The low bookend food effect (implemented at varying spatial scales) was used as the "primary" model effect for Round 1 portfolio evaluation and food, turbidity, and flow sensitivity analyses.**

8 Discussion & Next Steps

This action is currently being implemented at multiple locations, but key uncertainties remain around the effects of restored wetlands on food communities, temperature, turbidity, and other factors. Next steps to advance the evaluation and implementation of this action include:

- Continued hydrodynamic monitoring at more restoration sites could be warranted to better understand and estimate effects of restored tidal wetlands on temperature, turbidity, and food.
- Continue to update databases on the status, locations, and acreage of habitat construction activities for wetland restoration projects.

9 Relationships with other actions

Restored tidal wetlands and managed wetlands are both hypothesized to increase primary production and zooplankton. However, existing evidence and expert judgment suggests managed wetlands likely produce more zooplankton, relative to restored tidal wetlands, for several reasons that were discussed with Compass (John Durand and Kyle Phillips, UC Davis, online meeting with Compass, 2 May 2022).

- ***Water residence time:*** Managed wetlands are operated systematically to hold water on wetland floodplains for a few weeks to several months before being drained into surrounding water bodies. This increased residence time allows for plant decomposition, increases in algae and phytoplankton, and ultimately blooms of zooplankton. Conversely, restored tidal wetlands experience daily tidal patterns that do not allow for prolonged residence times that could produce blooms of zooplankton.
- ***Colonization of competitor species:*** Due to seasonal drying and operation of managed wetlands, these areas cannot be colonized by species that compete with Delta Smelt for zooplankton, compete with zooplankton for phytoplankton, or can depredate Delta Smelt directory. These species include invasive non-native clams and fish (e.g., Mississippi silversides). Conversely, restored tidal wetlands are open systems that can be colonized by these non-native clam and fish competitors (Williamshen et al. 2021). Since these species are efficient competitors that exhibit high feeding rates on primary production and zooplankton, Delta Smelt may only be able to access a portion of the total zooplankton being produced from restored tidal wetlands that are colonized by competitors.

10 Action Specification

Tidal wetland restoration for Delta Smelt was included in the 2008 BiOp, the 2016 Delta Smelt Resiliency Strategy, and the 2020 ROD/ITP. To specify the action as documented here, the following steps have been taken:

- Compass reviewed the SDM Demo Project and additional resources (see References) to inform the specification of this action in this document
- Compass met with the Stationary Habitat Sub-group on 16 April 2021 and the TWG on 7 May 2021
- 11 June 2021 - Paul Stumpner (USGS) presented to the TWG's Temperature Sub-group on a pilot study conducted by him, Larry Brown, and colleagues comparing effects of cooling from restored wetlands with tidal gates, a shallow, open water wetland, and a leveed channel. Based on the results, the group agreed that this action (i.e., restoring tidal wetlands in conjunction with using tidal gates to flood areas at night during spring tide events to efficiently cool the water) is worthwhile to pursue further specification and quantification of effects for SDM evaluation.
- Compass sent this document for review by the TWG, discussed it at the TWG meeting on 29 July 2021, and integrated comments and feedback in Aug 2021.
- Compass met Carl Wilcox on 5 January 2022 (Wilcox 2022). Carl provided preliminary data on restoration acres for current and planned projects.

- Compass compiled GIS data from the SFEI Landscape Scenario Planning Tool (https://www.sfei.org/projects/delta-landscapes-scenario-planning-tool) that included spatial layers for (a) existing tidal wetlands, (b) EcoRestore project footprints and acres of expected restored tidal wetlands, and (c) areas in the intertidal zone that could potentially support tidal emergent wetlands across the Delta based on elevation and current land use.
- The TWG discussed evaluating multiple levels of restoration intensity across portfolios in Round 1 of the SDM evaluation during the 21 January 2022 TWG meeting.

11 Key Contacts

Tidal wetland restoration is implemented by multiple agencies/organizations.

Key contacts that can provide information on the implementation status and planning for tidal wetland restoration are:

- Carl Wilcox (CDFW; Carl.Wilcox@wildlife.ca.gov): EcoRestore and other current planned project acreage; BiOp ITP restoration project locations and acreage
- Charlotte Biggs (DWR; charlotte.biggs@water.ca.govmailto:Christy.bowles@wildlife.ca.gov): EcoRestore project acreage; BiOp ITP restoration project locations and acreage
- Erik Loboschefsky (DWR; erik.loboschefsky@water.ca.gov): VA restoration projects locations and acreage
- Dan Riordan (DWR; Dan.Riordan@water.ca.gov): Fish Restoration Program Agreement (FRPA) that focuses on BiOp project locations and acreage
- Randall Neudeck (MWD: rneudeck@mwdh2o.com): Potential MWD opportunities for restoration projects
- Tara Kerss (CDFW; Tara.Kerss@wildlife.ca.gov) and Stephanie Buss (CDFW; Stephanie.buss@wildlife.ca.gov): Conservation banks restoration projects locations and acreage
- Letitia Grenier (SFEI; letitia@sfei.org), Sam Safran (SFEI; sams@sfei.org): Overall scope and scale of restoration opportunities
- Monique Fountain (monique@elkhornslough.org; Elkhorn Slough National Estuarine Research Reserve) for restoration projects locations and acreage
- Cassandra Nickles and Christine Lee (NASA JPL); has remote-sensing temperature data and is currently evaluating pre-post effects of restoration at Tule Red and Winter Island. This study may provide estimates of % change in temperature from tidal wetland restoration.

Experts that could be contacted for quantifying effects pathways include:

- Jim Cloern (USGS; jecloern@usgs.govmailto:Christy.bowles@wildlife.ca.gov): effects of restored tidal wetlands on net primary productivity that could be used to model changes in zooplankton (prey density) for Delta Smelt.
- Christy Bowles (CDFW, FRP; Christy.bowles@wildlife.ca.gov): effects of restored tidal wetlands on temperature, turbidity, and prey density.
- John Durand and his lab (UC Davis; jdurand@ucdavis.edu): effects of wetlands on prey density and temperature.
- Ted Sommer (DWR; Ted.Sommer@water.ca.gov): effects of wetlands on prey density.
- Wim Kimmerer (SFSU; kimmerer@sfsu.edu): effects of wetlands on prey density.
- John Burau (USGS; jrburau@usgs.gov): effects of wetlands on turbidity.

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13 Appendix 1 – Information on individual Restoration Projects

The information below was provided to Compass by Carl Wilcox (Wilcox 2022).

Lower Yolo Restoration Project – complete (article). Transformed acreage: 1,682 acres of tidal marsh restoration; 364 acres of transitional upland buffer habitat; 47 acres of enhanced existing riparian habitat; 35 acres of existing tidal marsh enhancement.

Yolo Flyway Farms Project – under construction (article). Will restore 359 acres with an 80 acre parcel that is for agricultural preservation. Therefore, restores 278 ac of tidal wetlands.

Lookout Slough Project – nearing construction (article). Will restore around 3,000 acres of tidal wetland. Once completed, this project will be the state's largest tidal habitat restoration project to date.

Other examples of projects include Lindsey Slough, Decker Island, Liberty Island/Kerry Parcel and Little Egbert Tract.

Table A1. Restored and anticipated tidal wetland restoration acreage (top) and specific projects by year (bottom); from Carl Wilcox (Jan 5, 2022). The right column indicates GIS-based estimates of total acres additional to existing wetlands in project footprints.

Anticipated year of implementation	Project size/footprint	Total tidal wetland acres	Additional restored acres (relative to existing tidal wetland areas)
Through 2020	5269.9	2591.12	2316.53
2021	5550.48	3215.72	2237.38
2022	2396	717.25	717.25
2023	25271	6670.1	5760.64
Total acres	38487.38	**13024.94**	**11031.8**

Projects through 2020
Sherman Island- Mayberry Slough Setback Levee
Sherman Island- Mayberry Farms Wetland
Twitchell Island- East End Wetland
Lindsey Slough Tidal Habitat Restoration
Sherman Island- Whale's Mouth Wetland
Decker Island Tidal Habitat Restoration
Yolo Flyway Farms Tidal Habitat Restoration
Tule Red Tidal Habitat Restoration
Winter Island Tidal Habitat Restoration
Twitchell Island- Setback Levee
Wings Landing Tidal Habitat Restoration
Projects for 2021
Arnold Slough Tidal Habitat Restoration
Dutch Slough Tidal Habitat Restoration
Hill Slough Tidal Habitat Restoration
Lower Yolo Ranch Tidal Habitat Restoration
Sherman Island - Whale's Belly Wetland
Southport Levee Setback and Floodplain Restoration
Projects for 2022

Twitchell Island - Mitigation and Enhancement
Bradmoor Island Tidal Habitat Restoration
Grizzly Slough Floodplain Restoration
Lower Elkhorn Basin Levee Setback
Projects for 2023
Yolo Bypass Salmonid Habitat Restoration and Fish Passage
Chipps Island Tidal Habitat Restoration
Lookout Slough Tidal Habitat Restoration and Flood Improvement
McCormack Williamson Tract Floodplain Restoration
Prospect Island Tidal Habitat Restoration
Twitchell Island- West End Wetland

14 Appendix 2 – Financial Resource Cost Calculations

The table below provides cost estimates and assumptions used for the action. It shows an example calculation for performing the action at 8,902 ac, which was applied to Portfolios 3a and 3c in the Round 1 evaluation. The orange cell indicates the annualized cost used for this action in those portfolios.

Tidal Wetland Restoration
Portfolio(s) **3a, 3c**
Source: See table notes

Component		Notes	Quantity		Unit Cost		Total	
Initial Cost								
	High		8,902	ac	$52,000.0	/ac	462,904,000	
	Best	[a]	8,902	ac	$40,000	/ac	356,080,000	
	Low	[b]	8,902	ac	$28,000	/ac	249,256,000	
Annual Operating Costs								
	High	[c]	8,902	ac	$600	/ac	5,341,200	/yr
	Low	[d]	8,902	ac	$300	/ac	2,670,600	/yr
Undiscounted annual costs			20	years				
High							28,486,400	/yr
Average of high and low							21,809,900	/yr
Low							15,133,400	/yr

Notes

[a] Based on recent Lookout Slough restoration project which was 3,000 acres and cost $120 million

[b] Lower cost estimate from C. Wilcox, Jan. 2018 (this number has been updated considering inflation from 2018 to 2023.

[c],[d] If no levee then ongoing costs are low; some policing and veg. If levee then costs are higher. (C. Wilcox, Jan 2018)

[c] High estimate from C. Wilcox (Jan. 2018)

[d] Low estimate from C. Wilcox (Jan. 2018)

Possible Improvements

In Jan 2023, Carl Wilcox suggested contacting Charlotte Biggs (Charlotte.Biggs@water.ca.gov) to get updated average costs for tidal wetland restoration. Charlotte runs DWR's EcoRestore Program