Summer-Fall Habitat Action

2020 numerical modeling results

Information sheets

Third Draft provided to the DCG by the Bay-Delta Office, USBR

09/29/2021

CONTENTS

OVERVIEW

The Delta Smelt Summer-Fall Habitat Action aims to improve the recruitment, growth and survival of Delta Smelt by implementing distinct management actions designed to increase the quantity and quality of Delta Smelt abiotic habitat (salinity, turbidity, current speed, temperature) and food supply. In September 2020, the Delta Coordination Group selected the PrOACT model to inform Summer-Fall Habitat Action (SFHA) decision-making. In a memo to the United States Fish and Wildlife Service, the NOAA National Marine Fisheries Service, and the California Department of Fish and Wildlife, the DCG identified SFHA objectives and potential Performance Measures (PMs) for evaluating different action alternatives.

The action alternatives included combinations of three different actions:

1. Suisun Marsh Salinity Control Gates (SMSCG) action operates the SMSCGs tidally to move water from the Sacramento River near Collinsville into the Suisun Marsh through the eastern end of Montezuma Slough to freshen Suisun Marsh for two months in June through October of wet, above normal, and below normal years.
2. North Delta Food Subsidies (NDFS) action was modeled to redirect 28 TAF of water from Colusa Basin agricultural drainage or the Sacramento River through the Yolo Bypass Toe Drain from August 29 to September 21 in order to increase food web productivity and export of food to downstream regions. This exceeds the upper end of what is targeted for an agricultural action (20-25 TAF) and is much great than the volume of water rerouted for a 2016 Sacramento River action (~15 TAF).
3. Sacramento Deepwater Ship Channel action (DWSC) was modeled to redirect 39 TAF from the Sacramento River in July to stimulate primary and secondary production and/or transport of production in the shipping channel to other portions of the North Delta

<u>Water cost and supply</u>. The U.S. Bureau of Reclamation (USBR) Division of Planning provided water cost and supply metrics from CalSim2 simulations used to simulate dry, below normal, above normal, and wet water year type hydrology with and without the SMSCG action in all but dry water years, which did not include a SMSCG action. CalSim2 simulations include maintaining X2 at 80 km during above normal and wet years in both the without SMSCG action scenario and the with SMSCG action scenario.

The California Department of Water Resources (DWR) modeled the North Delta Food Subsidies (NDFS) action, which redirects water from the Sacramento River or the Colusa Basin agricultural drain into the Yolo Bypass Toe Drain. DWR assumed that the same amount of water that is redirected water from the Sacramento River or the Colusa Basin Drain is discharged into the Delta at the base of the Toe Drain, effectively assuming the rerouted water is not subject to evaporation or seepage through Yolo Bypass. DWR then used DSM2 to analyze the change in salinity that is due to the change in water route (entering the Delta at the toe drain instead of Freeport). DWR determined that simply rerouting the water does not significantly change salinity intrusion and therefore does not cost any additional water to maintain D-1641 compliance. The food actions involve rerouting water in the system, and the rerouted water is assumed to not be subject to evaporation or seepage through the Yolo Bypass. Per an analysis of possible operations in 2020-2021, simply rerouting the water does not change salinity intrusion and therefore does not cost any additional water to maintain D-1641 compliance. Therefore, no modifications to CVP or SWP reservoir operations or deliveries are anticipated and all water supply metrics for the food actions are zero.

Abiotic habitat. Resource Management Associates (RMA) conducted numerical modeling of baseline conditions and the following eight different management scenarios under three or four different water year types (dry, below normal, above normal, wet).

Suisun Marsh Salinity Control Gates action (SMSCG)*
North Delta Food Subsidies action (NDFS)
Sacramento Deepwater Ship Channel action (DWSC)
SMSCG and NDFS*
SMSCG and DWSC*
NDFS and DWSCS
All three actions*

* Dry water year type not modeled for these scenarios

The following abiotic habitat metrics were simulated at a monthly temporal scale.

Maximum current speed (m s-1)
Salinity < 6 psu habitat suitability criterion (% of time)
Water temperature < 25˚C habitat suitability criterion (% of time)
Habitat suitability (Bever et al. 2016) with and without a temperature effect included

Turbidity was included as monthly-averaged secchi depth based on historical observations for 2018 (applied to dry and below normal years) and 2019 (applied to above normal and wet years). Therefore, a change in response to the action(s) could not be simulated.

Model simulations can be viewed interactively at RMA Shiny Demo (rmanet.app) and a final report (RMA 2021a) was provided to USBR and distributed to the DCG.

Biotic Habitat. RMA developed a simple copepod model to estimate the effects of the NDFS and DWSC on total calanoid copepod biomass and transport under the four water year types. A draft report (RMA 2021b) was provided to USBR and distributed to the DCG.

Delta Smelt Growth. Delta Smelt growth rate potential was calculated using the bioenergetics model from the Rose et al. (2013) individual-based model for Delta Smelt. The model's zooplankton densities were modified by multiplying the density of each calanoid copepod taxon by the percent change in total calanoid copepods for the NDFS and DWSC actions separately (action biomass/no action biomass).

METRIC INFORMATION SHEETS

Below are a series of information sheets that summarize each abiotic and biotic metric along with calculations/scoring, major assumptions and uncertainties, initial modeling results, and information and context for interpreting the results. These sheets are intended to accompany a SFHA Consequence Table, provided to the DCG separately as an .xlsx file. Figure 1 illustrates how the different metrics are expected to influence Delta Smelt biomass and survival. Figures 2 and 3 show the spatial regions that were applied to the model output for calculating mean seasonal values for the abiotic (Figure 2) and biotic (Figure 3) metrics.

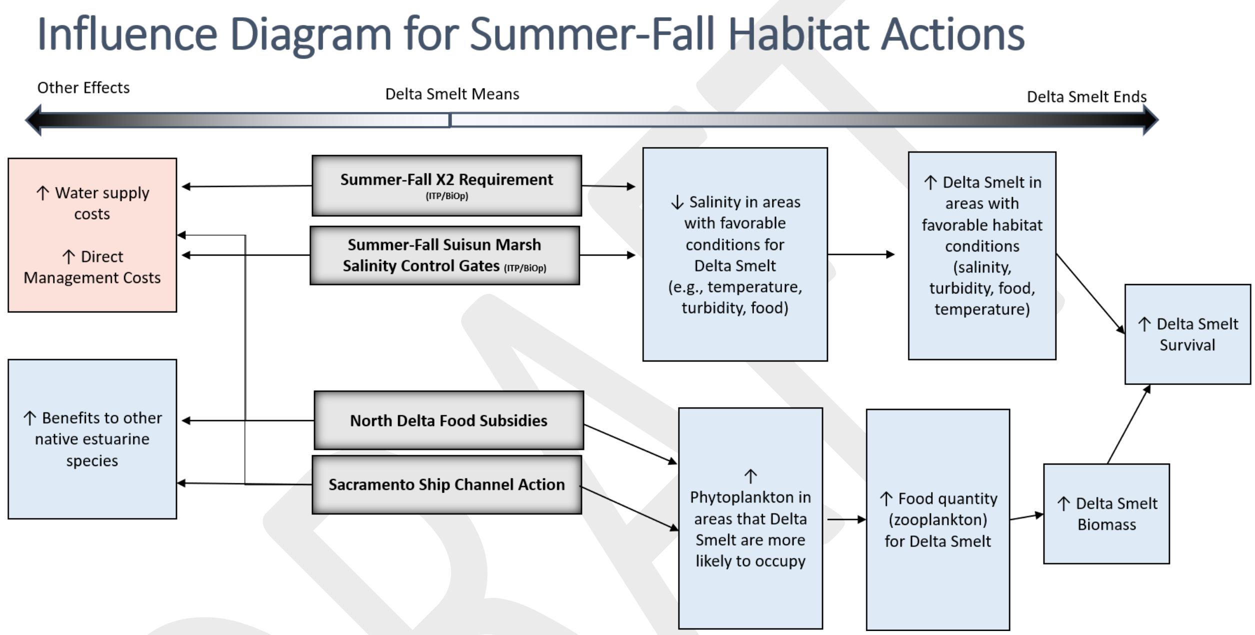


Figure 1. Influence diagram for the Summer-Fall Habitat Action from CSAMP Delta Smelt SDM (provided by Compass).

For this analysis, the Summer-Fall X2 requirement of maintaining X2 at 80 km in September and October of wet and above normal water years is assumed to occur with or without the other actions. Therefore, the effects of the Summer-Fall X2 requirement have not been separately quantified in this document.

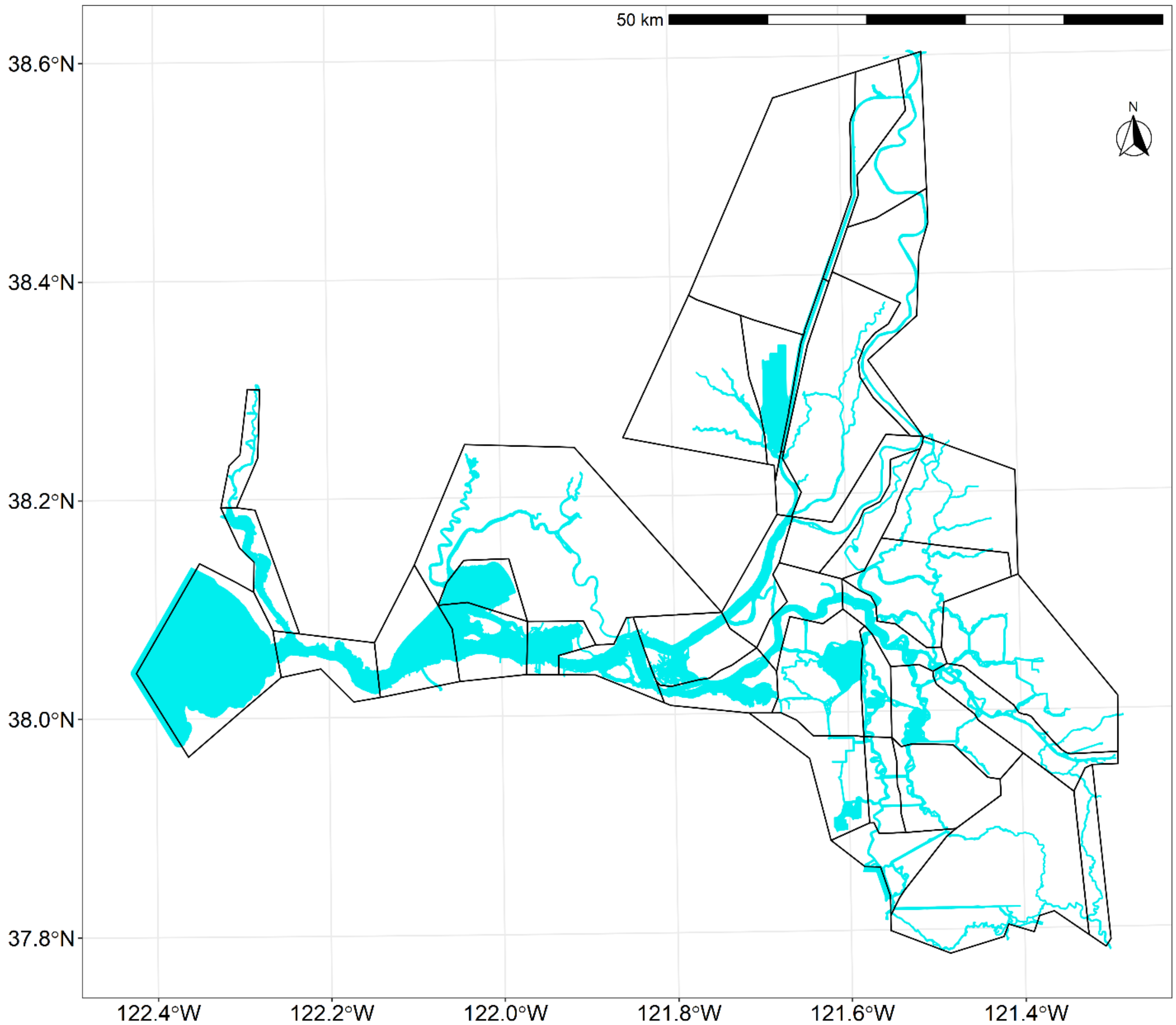


Figure 2. EDSM regions used to calculate abiotic habitat metric means.

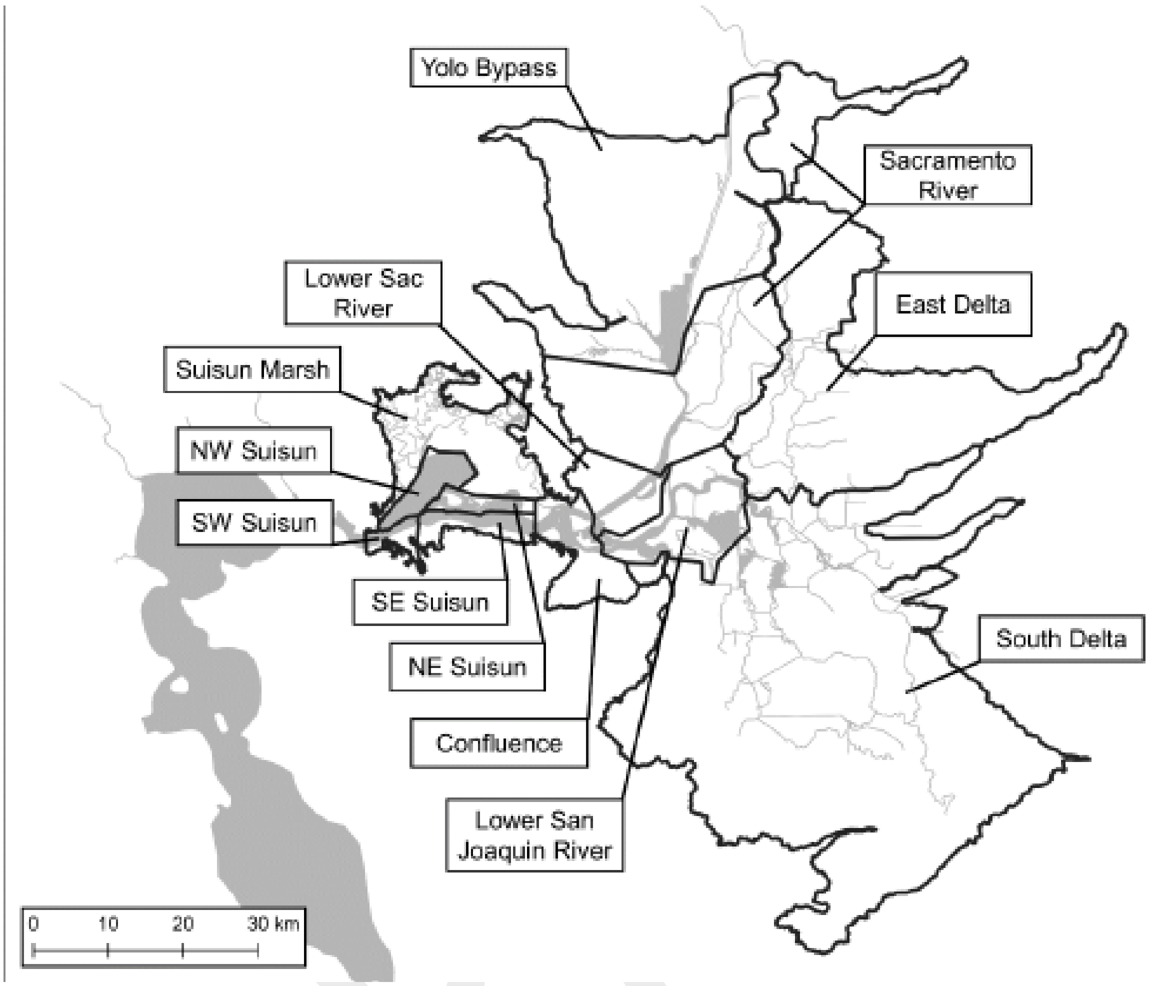


Figure 3. Rose et al. (2013) regions used to calculate mean copepod biomass per unit effort and mean Delta Smelt growth rate potential.

REFERENCES

Bever AJ, MacWilliams ML, Herbold B, Brown LR, Feyrer F V. 2016. Linking Hydrodynamic Complexity to Delta Smelt (Hypomesus transpacificus) Distribution in the San Francisco Estuary, USA. San Fr Estuary Watershed Sci. 14(1). doi:10.15447/sfews.2016v14iss1art3. http://escholarship.org/uc/item/2x91q0fr.

Resource Management Associates (RMA). 2021a. Numerical Modeling in Support of Reclamation Delta Smelt Summer/Fall Habitat Analysis.

RMA. 2021b. Numerical modeling in support of Reclamation Delta Smelt summer/fall habitat analysis: Calanoid copepod analysis addendum. Draft Report (May 14 2021).

WATER COST

WATER COST MEASURE SUMMARY

Measure	Units	Description
Total volume of additional Delta outflow necessary to operate the SMSCG and still meet D-1641 salinity objectives	TAF / yr	Operation of the SMSCG reduces salinity in Suisun Marsh, but increases salinity in the western Delta. If D-1641 salinity standards are controlling project operations when the SMSCGs are operated, additional Delta outflow will be necessary to offset the increased western Delta salinity to continue compliance with D-1641 salinity objectives at Jersey Point and Emmaton. For these simulations, the flow surrogate of 500 cfs of Delta outflow was applied regardless of controlling factors in CalSim.
Change in volume of CVP and SWP exports for all conditions	TAF / yr	Change in volume of CVP and SWP exports to supply the additional water necessary for the actions.

CALCULATIONS / SCORING

CalSim II is a monthly model developed for planning-level analyses. The model is run for an 82-year historical hydrologic period, at a projected level of hydrology and demands, and under an assumed framework of regulations. Therefore the 82-year simulation does not provide information about historical conditions but does provide information about variability of conditions that would occur at the assumed level of hydrology and demand with the assumed operations, under the same historical hydrologic sequence. Because it is not a physically based model, CalSim II is not calibrated and cannot be used in a predictive manner; instead, it is intended to be used in a comparative manner, as is done in this analysis, comparing conditions with an action to without an action.

In CalSim II, operational decisions are made on a monthly basis, based on a set of pre-defined rules that represent the assumed regulations. Modifications by the model user would be required to allow for variation in these rules based on a sequence of hydrologic events such as a prolonged drought, or statistical performance criteria such as meeting a storage target in an assumed percentage of years. While certain components in the model are downscaled to a daily time step (simulated or approximated hydrology), such as an air-temperature based trigger for a fisheries action, the results of those daily conditions are always averaged to a monthly time step. For example, a certain number of days with and without the action is calculated and the monthly result is calculated using a day-weighted average based on the total number of days in that month. Operational decisions based on those components are again made on a monthly basis.

For the calculations described below, water cost is distributed between reduced exports, reservoir releases and other available excess water in the system.

1. **Total volume of SMSCG outflow adjustment under balanced conditions:** CalSim2 assumes that the SMSCG action has an effect on salinity intrusion equivalent to a change in Delta outflow of 500 cfs. If salinity in the western Delta is close to the D-1641 salinity objectives such that CVP and SWP are operating to provide outflow to help meet salinity, then operation of the SMSCG would require additional outflow to offset the increase in salinity intrusion that is caused by the SMSCG operation. This possible need for additional Delta outflow is tracked in CalSim2. The total volume of the additional SMSCG outflow under balanced conditions is calculated by summing the need for Delta outflow for the SMSCG, whenD-1641 salinity objectives are controlling CVP and SWP operations, on an annual basis, and then averaging by water year type. For these simulations, the 500 cfs of Delta outflow was applied regardless of controlling factors in CalSim.

2. **Change in volume of CVP and SWP exports (TAF) for all conditions:** Because the food actions only reroute water and do not require additional water, they are assumed to not affect CVP and SWP exports. For the SMSCG action, the change in CVP exports is calculated by comparing the volume of water pumped at Jones (on an annual basis, summed by water year) in the model without the SMSCG action to the Jones pumping in the model with the SMSCG action. The difference is then averaged by water year type. The same comparison and calculations are done for any water pumped for the CVP at Banks. The values for CVP pumping at Banks and Jones are combined to calculate the change in CVP exports.

   The SWP export change is calculated by comparing the volume of water pumped at Banks (on an annual basis, summed by water year) for SWP uses in the model without the SMSCG action to the volume of water pumped for the SWP in the model with the SMSCG action. The difference is then averaged by water year type.

KEY ASSUMPTIONS AND UNCERTAINTIES

- Not applicable

ROUND 1 RESULTS

Results for combined action alternatives (e.g., SMSCG x NDFS) not shown because no additive or interactive effects are expected to occur among the three actions (SMSCG, NDFS, and DWSC).

Water Cost

Measure	Units	Preferred Direction	No Action - W (X2@80)	No Action - AN (X2@80)	No Action - BN	No Action - D	NDFS - W (X2@80)	NDFS - AN (X2@80)	NDFS - BN	NDFS - D	SMSCG – W (X2@80)	SMSCG – AN (X2@80)	SMSCG – BN	DWSC – W (X2@80)	DWSC – AN (X2@80)	DWSC – BN	DWSC – D
Total volume of SMSCG outflow adjustment	TAF / year	Minimize	0	0	0	0	0	0	0	0	51.3	61	58.9	0	0	0	0
Change in volume of CVP and SWP exports for all conditions	TAF / year	Minimize	0	0	0	0	0	0	0	0	-2.7; 1.3	-6.4; 15.7	5.4; -31.4	0	0	0	0

ADDITIONAL INFORMATION AND CONTEXT FOR INTERPRETING RESULTS

Storage compensates for the SMSCG action significantly, and subsequent reoperation of storage leads to a fairly complete reset of operations. As a result, long-term Delta exports change little.

REFERENCES

U.S. Department of the Interior, Bureau of Reclamation (Reclamation). 2008. Biological Assessment on the Continued Long-Term Operations of the Central Valley Project and State Water Project, Appendix W Sensitivity and Uncertainty Analysis.

WATER SUPPLY

Measure	Units	Description
Change in north of Delta CVP and SWP carryover storage	TAF in September	Compares the end of September storage volumes in Shasta and Folsom Reservoirs (CVP) and Oroville Reservoir (SWP) with and without the SMSCG action.
Change in CVP and SWP deliveries	TAF / yr	Compares the simulated deliveries to CVP municipal and industrial (M&I) and agricultural contractors in model without the SMSCG action to the deliveries in the model with the SMSCG action.

CALCULATIONS / SCORING

See the Water Cost information sheet for a full description of CalSim II.

For the food actions, the water that is rerouted is assumed to not be subject to evaporation or seepage through the Yolo Bypass. Per a modeling analysis of possible operations in 2020-2021, simply rerouting the water does not change salinity intrusion and therefore does not cost any additional water to maintain D-1641 compliance. For this reason, the food actions are assumed not to affect CVP and SWP reservoir operations or deliveries, and the results for each of the PMs in each water year type for the food actions is zero.

The following is the calculation methodology for the SMSCG action:

1. **Change in north of Delta CVP and SWP carryover storage(TAF in September):** The change in north of Delta CVP storage carryover is calculated by comparing the Shasta

end of September storage in model without the SMSCG action to the Shasta end of September storage in the model with the SMSCG action (during below normal, above normal and wet water year types). The difference is then averaged by water year type. The same comparison and calculations are done for Folsom end of September storage. The values for Shasta and Folsom are combined to calculate the change in north of Delta CVP Carryover storage.

The SWP north of Delta carryover storage change is calculated by comparing the Oroville end of September storage in model without the SMSCG action to the Oroville end of September storage in the model with the SMSCG action. The difference is then averaged by water year type.

2. **Change in CVP and SWP deliveries for all conditions (TAF / year):** The change in a CVP deliveries is calculated by comparing the simulated deliveries to CVP municipal and industrial (M&I) and agricultural contractors in model without the SMSCG action to the deliveries in the model with the SMSCG action. The difference is then averaged by water year type.

   The change in a SWP deliveries is calculated by comparing the simulated deliveries to SWP contractors under Article 21 and the changes to SWP deliveries to south of delta municipal and industrial (M&I) and agricultural contractors in model without the SMSCG action to the deliveries in the model with the SMSCG action. The difference is then averaged by water year type.

KEY ASSUMPTIONS AND UNCERTAINTIES

- Not applicable

ROUND 1 RESULTS

Results for combined action alternatives (e.g., SMSCG x NDFS) not shown because no additive or interactive effects are expected to occur among the three actions (SMSCG, NDFS, and DWSC). CVP estimates are shown in the top number (left of semicolon); SWP estimates are shown in the bottom number (right of semicolon).

Water Supply

Measure	Units	Preferred Direction	No Action - W (X2@80)	No Action - AN (X2@80)	No Action - BN	No Action - D	NDFS - W (X2@80)	NDFS - AN (X2@80)	NDFS - BN	NDFS - D	SMSCG – W (X2@80)	SMSCG – AN (X2@80)	SMSCG – BN	DWSC – W (X2@80)	DWSC – AN (X2@80)	DWSC – BN	DWSC – D
Change in North of Delta CVP and SWP carryover storage for all conditions	TAF (Sep)	Minimize	0	0	0	0	0	0	0	0	-10.7; -32.9	-37.3; -11.1	-15.9; 22.3	0	0	0	0
Changes in CVP and SWP deliveries for all conditions	TAF (Sep)	Minimize	0	0	0	0	0	0	0	0	-1.2; -1.0	-4.6; 16.1	-3.4; -12.2	0	0	0	0

ADDITIONAL INFORMATION AND CONTEXT FOR INTERPRETING RESULTS

Storage compensates for the SMSCG action significantly, and subsequent reoperation of storage leads to a fairly complete reset of operations. As a result, long-term Delta exports change little.

REFERENCES

SALINITY AT BELDEN'S LANDING

PERFORMANCE MEASURE (PM) SUMMARY

PMs	Units	Description
Percentage of time Belden's Landing station is below 6 parts per thousand	%	Percentage of time Belden's Landing water quality station is below 6 parts per thousand (ppt) between June 1st and October 31st.
Percentage of time Belden's Landing station is below 4 parts per thousand	%	Percentage of time Belden's Landing water quality station is below 4 parts per thousand (ppt) between June 1st and October 31st.

CALCULATIONS / SCORING

The 2019 Delta Smelt Biological Opinion (USFWS 2019) stated that habitat acreages in Suisun Marsh, Grizzly Bay, and other adjacent areas should be considered when evaluating the success of Summer-Fall Habitat Actions. An example given is whether Belden's Landing, a location in Montezuma Slough roughly at the center of Suisun Marsh, has a salinity range between 0 to 6 parts per thousand (a range deemed suitable for Delta Smelt). In Suisun Marsh, higher summer salinities were generally predicted to occur in about half of the water years (USFWS 2019).

Resource Management Associates (RMA) produced simulations of various Summer-Fall Habitat Action scenarios using input from CalSim II and DSM2 (RMA 2021). The results of the RMA simulation are saved at 15-minute intervals and depth-averaged. These results were then analyzed to calculate monthly metrics from June to October, including the percent of time salinity was below 4 and 6 ppt at Belden's Landing.

KEY ASSUMPTIONS AND UNCERTAINTIES

- This index assumes that Belden's Landing is indicative of low salinity habitat in Suisun Marsh as a whole.
- No other Delta Smelt habitat requirements (e.g., temperature, turbidity, food) are considered under this performance metric.

ROUND 1 RESULTS

Salinity at Belden Landing

Performance Measure	Units	Preferred Direction	No Action - W (X2@80)	No Action - AN (X2@80)	No Action - BN	No Action - D	NDFS - W (X2@80)	NDFS - AN (X2@80)	NDFS - BN	NDFS - D	SMSCG – W (X2@80)	SMSCG – AN (X2@80)	SMSCG – BN	DWSC – W (X2@80)	DWSC – AN (X2@80)	DWSC – BN	DWSC – D
Salinity < 4	% time	Maximize	18	16	23	0	18	16	23	0	58	56	43	18	16	23	0
Salinity < 6	% time	Maximize	62	60	53	35	62	60	53	35	97	95	92	62	60	53	35

Performance Measure	Units	Preferred Direction	SMSCG x NDFS – W (X2@80)	SMSCG x NDFS - AN (X2@80)	SMSCG x NDFS – BN	SMSCG x DWSC – W (X2@80)	SMSCG x DWSC – AN (X2@80)	SMSCG x DWSC – BN	NDFS x DWSC – W (X2@80)	NDFS x DWSC – AN (X2@80)	NDFS x DWSC - BN	NDFS x DWSC - D	All Actions – W (X2@80)	All Actions – AN (X2@80)	All Actions - BN
Salinity < 4	% time	Maximize	58	56	43	58	56	43	18	16	23	0	58	56	43
Salinity < 6	% time	Maximize	97	95	92	97	95	92	62	60	53	35	97	95	92

ADDITIONAL INFORMATION AND CONTEXT FOR INTERPRETING RESULTS

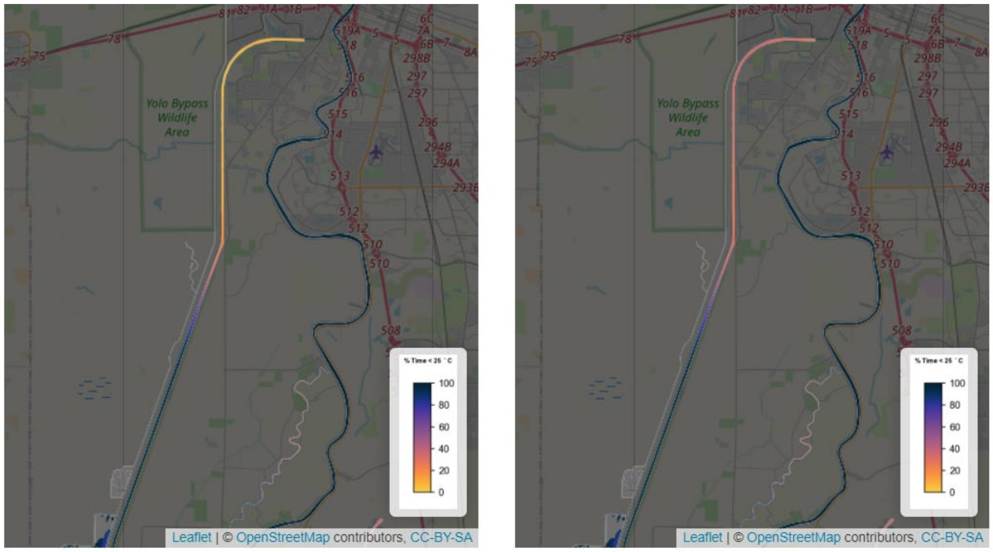
None

REFERENCES

Resources Management Associates (RMA). 2021. Numerical Modeling in Support of Reclamation Delta Smelt Summer/Fall Habitat Analysis.

United States Fish and Wildlife Service (USFWS). 2019. Biological Opinion: For the Reinitiation of Consultation on the Coordinated Operations of the Central Valley Project and State Water Project.

TEMPERATURE REFUGIA



PM SUMMARY

PMs	Units	Description
Temperature refugia (< 25 ˚C)	% time	Metric used to evaluate how suitable a location/habitat is for Delta Smelt based on maximum water temperature tolerance.

CALCULATIONS / SCORING

A temperature threshold of 25 °C was identified, based on input from Ted Sommer and consistent with existing literature (Nobriga et al. 2008; Brown et al. 2013; Sommer and Mejia 2013; Komoroske et al. 2014). The proportion of time that temperature is less than 25 °C was calculated for model grid cells while wet (RMA 2021). In order to reduce the time required to calculate the values, resolution of geo tiff data from RMA was reduced by a factor of 10 by calculating the mean values of the smaller cells to generate a single value for the larger cells. Subsequently, data outside the typical distribution of Delta Smelt was excluded by using only values within the EDSM's largest sampling extent (Figure 2), as seen in Mahardja et al. (2021). To acquire a single value for each scenario, these monthly calculations were then averaged across the four summer-fall months (July-October).

KEY ASSUMPTIONS AND UNCERTAINTIES

- Temperature refugia was calculated using the 2D model output, so any effect of temperature stratification is not incorporated into this metric.

ROUND 1 RESULTS

Temperature Refugia

Performance Measure	Units	Preferred Direction	No Action - W (X2@80)	No Action - AN (X2@80)	No Action - BN	No Action - D	NDFS - W (X2@80)	NDFS - AN (X2@80)	NDFS - BN	NDFS - D	SMSCG – W (X2@80)	SMSCG – AN (X2@80)	SMSCG – BN	DWSC – W (X2@80)	DWSC – AN (X2@80)	DWSC – BN	DWSC – D
Temperature < 25 °C	% time	Maximize	96.8	98.7	99.1	98.9	96.8	98.7	99.1	98.9	96.8	98.7	99.1	96.8	98.7	99.1	99.0

Performance Measure	Units	Preferred Direction	SMSCG x NDFS – W (X2@80)	SMSCG x NDFS - AN (X2@80)	SMSCG x NDFS – BN	SMSCG x DWSC – W (X2@80)	SMSCG x DWSC – AN (X2@80)	SMSCG x DWSC – BN	NDFS x DWSC – W (X2@80)	NDFS x DWSC – AN (X2@80)	NDFS x DWSC - BN	NDFS x DWSC - D	All Actions – W (X2@80)	All Actions – AN (X2@80)	All Actions - BN
Temperature < 25 °C	% time	Maximize	96.8	998.7	99.1	96.8	98.7	99.1	96.8	98.7	99.1	98.9	96.8	98.7	99.1

ADDITIONAL INFORMATION AND CONTEXT FOR INTERPRETING RESULTS

The habitat suitability index with temperature (HSI_{BT}) uses the same upper threshold for temperature (see Habitat Suitability Index Performance Metric information sheet).

REFERENCES

Brown LR, Bennett WA, Wagner RW, Morgan-King T, Knowles N, Feyrer F, Schoellhamer DH, Stacey MT, Dettinger M. 2013. Implications for Future Survival of Delta Smelt from Four Climate Change Scenarios for the Sacramento-San Joaquin Delta, California. Estuaries and Coasts. 36(4):754–774. doi:10.1007/s12237-013-9585-4.

Komoroske LM, Connon RE, Lindberg J, Cheng BS, Castillo G, Hasenbein M, Fangue NA. 2014. Ontogeny influences sensitivity to climate change stressors in an endangered fish. Conserv Physiol. 2. doi:10.1093/conphys/cou008.

Mahardja B, Mitchell L, Beakes M, Johnston C, Graham C, Goertler P, Barnard D, Castillo G, Matthias B. 2021. Leveraging Delta Smelt Monitoring for Detecting Juvenile Chinook Salmon in the San Francisco Estuary. San Fr Estuary Watershed Sci. 19(1). doi:10.15447/sfews.2021v19iss1art2.

Nobriga ML, Sommer TR, Feyrer F, Fleming K. 2008. Long-Term Trends in Summertime Habitat Suitability for Delta Smelt, Hypomesus transpacificus. San Fr Estuary Watershed Sci. 6(1). doi:10.15447/sfews.2008v6iss1art1. https://escholarship.org/uc/item/5xd3q8tx.

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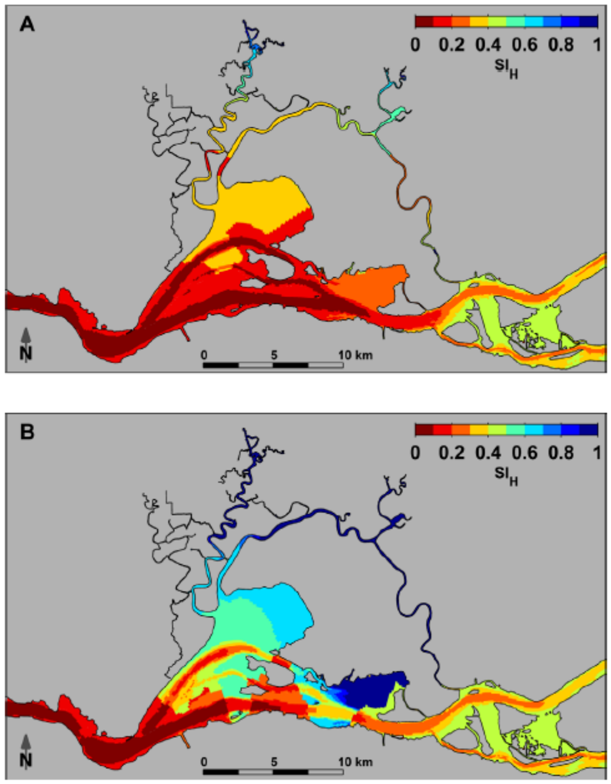
Sommer T, Mejia F. 2013. A Place to Call Home: A Synthesis of Delta Smelt Habitat in the Upper San Francisco Estuary. San Fr Estuary Watershed Sci. 11(2). doi:10.15447/sfews.2013v11iss2art4. https://escholarship.org/uc/item/32c8t244.

HABITAT SUITABILITY INDEX (HSI) FOR DELTA SMELT



PM SUMMARY

PMs	Units	Description
Habitat Suitability Index (HSI) for Delta Smelt	Value between 0 and 1	Metric used to evaluate how suitable a location/habitat is for Delta Smelt based on water velocity, salinity, and turbidity, as calculated in a previous study (Bever et al. 2016)
HSI for Delta Smelt, with temperature included	Value between 0 and 1	Metric used to evaluate how suitable a location/habitat is for Delta Smelt, as above, but with temperature suitability added as part of the calculation.

CALCULATIONS / SCORING

Certain water quality parameters are well understood to be associated with Delta Smelt occurrence in the fish survey data (Feyrer et al. 2007; Nobriga et al. 2008). These relationships have been used to define the extent of suitable abiotic habitat of Delta Smelt under different scenarios (Feyrer et al. 2011). Bever et al.'s (2016) Habitat Suitability Index (HSI) is a recently developed Delta Smelt habitat suitability metric that incorporated salinity, turbidity, and water velocity. This HSI was chosen by Resource Management Associates (RMA) and Bureau of Reclamation as a performance metric to evaluate Summer-Fall habitat actions. For this HSI, suitable conditions for Delta Smelt for the three water quality parameters were measured as:

- Water Velocity/Current Speed: monthly maximum depth-averaged current speed (m s^{-1})
- Salinity Suitability: Percent of time during a month with salinity < 6 psu
- Turbidity Suitability: monthly-averaged Secchi depth < 0.5 m

All three parameters were then combined to estimate HSI using the following equations:

$$HSI_B = C_1 S + C_2 V \; if \; Secchi < 0.5$$
$$HSI_B = C_3 \times (C_1 S + C_2 V) \; if \; Secchi \geq 0.5$$

where HSI_B is the HSI from Bever et al. (2016), S is the proportion of time that salinity is less than 6 psu, V is the peak monthly current speed in m s^{-1}, $Secchi$ is Secchi depth in meters, and the constants are C_1= 0.67, C_2 = 0.33 and C_3 = 0.42. Note that HSI_B is discontinuous at Secchi depth of 0.5 meters.

An additional HSI was also used to incorporate temperature effect on Delta Smelt. Based on input from Ted Sommer, and consistent with existing literature, temperature threshold of 25 °C was used (Nobriga et al. 2008; Brown et al. 2013; Sommer and Mejia 2013; Komoroske et al. 2014). Specifically, HSI_{BT} is calculated by adding a temperature effect to the Bever et al.'s (2016) equation as follows:

$$HSI_{\mathrm{BT}} = HSI_B \times T$$

where T is proportion of time that temperature is less than 25 °C. These two HSI calculations are applied to RMA's monthly average model predictions for secchi depth (interpolated from 2018-2019 monitoring data), salinity, water velocity, and temperature (RMA 2021). In order to reduce the time required to calculate the HSI values, resolution of geo tiff data from RMA was reduced by a factor of 10 by calculating the mean values of the smaller cells to generate a single value for the larger cells. Subsequently, data outside the typical distribution of Delta Smelt was excluded by using only HSI values within the EDSM's largest sampling extent (Figure 2), as seen in Mahardja et al. (2021). To acquire a single value for each scenario, these monthly calculations were then averaged across the four summer-fall months (July-October).

KEY ASSUMPTIONS AND UNCERTAINTIES

- Currently, turbidity values produced from RMA's modeling effort is estimated by interpolating historical data. Data from 2018 (Below Normal) were used for Below Normal and Dry year conditions, while data from 2019 (Wet) were used for Above Normal and Wet year conditions.

- HSI calculation with temperature effect included assume that temperatures below 25 C is suitable for Delta Smelt, but evidence suggests that temperature above 20 C could induce stress to Delta Smelt (Nobriga et al. 2008; Brown et al. 2016; Davis et al. 2019) and higher summer-fall temperatures in general can lead to low survival (Mac Nally et al. 2010; Polansky et al. 2020).

- Some disagreements exist on the extent to which the relationship between turbidity and Delta Smelt is due to an issue of catchability versus habitat association (Hasenbein et al. 2016; Latour 2016; Peterson and Barajas 2018; Tobias 2020).

ROUND 1 RESULTS

Habitat Suitability Index

Performance Measure	Range	Preferred Direction	No Action - W (X2@80)	No Action - AN (X2@80)	No Action - BN	No Action - D	NDFS - W (X2@80)	NDFS - AN (X2@80)	NDFS - BN	NDFS - D	SMSCG – W (X2@80)	SMSCG – AN (X2@80)	SMSCG – BN	DWSC – W (X2@80)	DWSC – AN (X2@80)	DWSC – BN	DWSC – D
HSI_B	0-1	Maximize	0.24	0.24	0.22	0.21	0.24	0.24	0.22	0.21	0.24	0.25	0.22	0.24	0.24	0.22	0.21
HSI_{BT}	0-1	Maximize	0.23	0.24	0.22	0.21	0.23	0.24	0.22	0.21	0.24	0.25	0.22	0.23	0.24	0.22	0.21

Performance Measure	Units	Preferred Direction	SMSCG x NDFS – W (X2@80)	SMSCG x NDFS - AN (X2@80)	SMSCG x NDFS – BN	SMSCG x DWSC – W (X2@80)	SMSCG x DWSC – AN (X2@80)	SMSCG x DWSC – BN	NDFS x DWSC – W (X2@80)	NDFS x DWSC – AN (X2@80)	NDFS x DWSC - BN	NDFS x DWSC - D	All Actions – W (X2@80)	All Actions – AN (X2@80)	All Actions - BN
HSI_B	0-1	Maximize	0.24	0.25	0.22	0.24	0.25	0.22	0.24	0.24	0.22	0.21	0.24	0.25	0.22
HSI_{BT}	0-1	Maximize	0.24	0.25	0.22	0.24	0.25	0.22	0.23	0.24	0.22	0.21	0.24	0.25	0.22

ADDITIONAL INFORMATION AND CONTEXT FOR INTERPRETING RESULTS

Performance metric is calculated based on area rather than volume.

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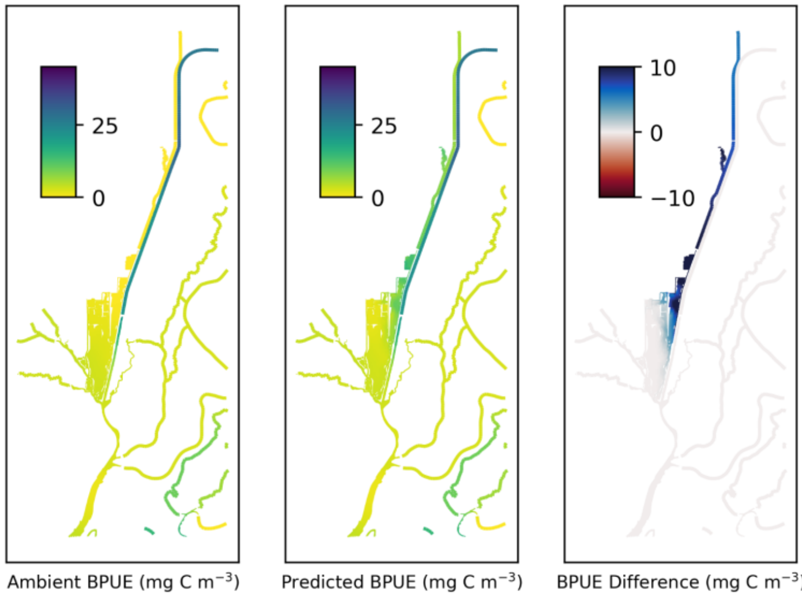
CALANOID COPEPOD BIOMASS PER UNIT EFFORT



PM SUMMARY

PMs	Units	Description
Total adult and juvenile calanoid copepod biomass for no action, Sacramento deep water ship channel (DWSC), and North Delta Food subsidy action (NDFS) scenarios.	BPUE / season	Biomass per unit effort in milligrams dry carbon weight. Seasonal (July – October) means for the entire Delta were calculated from regional, monthly means. Regions were from Rose et al. (2013). The actions were simulated to occur during July (DWSC) and from late August through late September (NDFS).

CALCULATIONS / SCORING

The North Delta Food Subsidies Action (NDFS) and Sacramento Deep Water Ship Channel (DWSC) are food web subsidy actions aimed at transporting and/or stimulating zooplankton production during the summer and fall. Model simulations were designed to provide an upper estimate of each action's impact on total calanoid copepod density (biomass per unit effort, BPUE), the primary prey of Delta Smelt (*Hypomesus transpacificus*). For both the NDFS and DWSC actions, total calanoid copepod (hence copepod) biomass density (biomass per unit effort, BPUE) was a combination of ambient (observed) adult and juvenile copepod biomass density and source water (pulsed) copepod biomass density and population growth.

Ambient/"No Action" BPUE. Monthly ambient BPUEs were estimated for June – October, 2018 and 2019, using monitoring data accessed using the Zooplankton Data Synthesizer (https://deltascience.shinyapps.io/ZoopSynth/; Bashevkin et al. 2020), which includes the following data sources: the Environmental Monitoring Program; the 20-mm, fall midwater trawl, and summer townet surveys; and the Fish Restoration Program (see Kayfetz et al. [2021] for additional information about the surveys and datasets). Catch per unit effort for each reported taxa at each station were converted to BPUE using dry carbon weights for juvenile and adult life stages (see Table 1, RMA 2021). The spatial distribution of BPUE was estimated by interpolating monthly station BPUE estimates using a diffusion solution on the model grid, which accounted for hydraulic connectivity (RMA 2021). The 2018 BPUE estimates were used for ambient/"No Action" BPUE in both Dry and Below Normal water year type simulations; the 2019 BPUE estimates were used for ambient/"No Action" BPUE in both Above Normal and Wet water year type simulations.

Source water copepod BPUE and chlorophyll a concentration. For both the NDFS and DWSC actions, source water is modeled to contain elevated copepod BPUE and chlorophyll a concentration; however, DWR monitoring data show higher cyclopoid copepod and cladoceran CPUE in source water, but not higher calanoid copepod CPUE. NDFS source water copepod BPUE was 5.4 mg C m^{-3}, the 75^{th} percentile calculated from DWR zooplankton data collected approximately monthly in the Toe Drain from July through September, 2016-2019 (see Frantzich et al. 2018 for methods). DWSC source water copepod BPUE was 19.5 mg C m^{-3}, the 75^{th} percentile calculated using the 2018 and 2019 Zooplankton Synthesizer data from DWSC stations during June and July. The 75^{th} percentile for Chlorophyll a concentrations were calculated similarly and were 23.0 mg m^{-3} and 2.1 mg m^{-3}, respectively, for the NDFS and DWSC actions. NDFS action source water entered the NDFS model domain at the Yolo Bypass Toe Drain near I80; "new" source water enters the domain throughout the action simulation. DWSC action source water is the water that is initially present in the DWSC, with no "new" source water entering the DWSC model domain after the initial pulse.

Total copepod BPUE. The spatial distribution and age of source water was tracked throughout the simulated action. Predicted copepod BPUE associated with the source water changed over time following Wang et al. (2019). The growth rate (i.e., increase in BPUE) of copepods was 0.4 day-1, based on the highest rate for *Pseudodiaptomus forbesi* in Owens et al (2019) and was limited to prevent unrealistic BPUE estimates from unbounded growth. Source water copepod BPUE was calculated at 2-hour intervals for each grid node throughout the simulation. Total copepod BPUE was estimated as the weighted average of source water BPUE and ambient BPUE. See RMA (2021) for a detailed explanation, including calculations.

KEY ASSUMPTIONS AND UNCERTAINTIES

- A single carbon weight was used for all juveniles for each taxon, although actual carbon weight can vary greatly among different stages of juvenile copepods (Kimmerer et al. 2018).
- Ambient copepod BPUE may have been influenced by NDFS actions that occurred during September of 2018 and 2019; however, elevated calanoid BPUE was not evident (RMA 2021).
- NDFS source water continued to enter the model domain throughout the time period modeled as long as flow in the Toe Drain was directed seaward (i.e., positive). In contrast, DWSC source water was introduced at the beginning only, reflecting the movement of biomass in the upper DWSC in response to the introduced flow.
- Copepods are transported passively.
- Conversion of chlorophyll a to copepod BPUE included the following approximations:

- The proportion of chlorophyll a (i.e., phytoplankton biomass) that becomes copepod biomass was 0.35, similar to Cloern (2007); and
- Competition for phytoplankton was set at a possible upper bound 0.5, to account for grazing by clams and other zooplankton species; this value is highly uncertain.

- Growth and loss processes for copepods were in balance after source water chlorophyll a was taken up.

ROUND 1 RESULTS

Results for combined action alternatives (e.g., SMSCG x NDFS) are not shown because the SMSCG action was assumed to have no impact on calanoid copepod BPUE and the NDFS and DWSC actions were modeled independently only. BPUE effects are not additive (Ed Gross, personal communication) and therefore cannot be calculated using the data provided.

Calanoid Copepod BPUE

Performance Measure	Units	Preferred Direction	No Action - W (X2@80)	No Action - AN (X2@80)	No Action - BN	No Action - D	NDFS - W (X2@80)	NDFS - AN (X2@80)	NDFS - BN	NDFS - D	SMSCG – W (X2@80)	SMSCG – AN (X2@80)	SMSCG – BN	DWSC – W (X2@80)	DWSC – AN (X2@80)	DWSC – BN	DWSC – D
Biomass per unit effort	mg C m^{-3}	Maximize	6.96	6.96	7.62	7.62	7.50	7.52	8.13	8.25	6.96	6.96	7.62	7.22	7.19	7.88	7.91

ADDITIONAL INFORMATION AND CONTEXT FOR INTERPRETING RESULTS

See RMA (2021) for a complete description of the modeling approach, data sets used, and simulation results.

Calanoid copepod BPUE estimates were used to adjust calanoid copepod zooplankton densities in a version of the Rose et al. (2013) Delta Smelt bioenergetics model to evaluate the potential effect of the NDFS and DWSC actions on Delta Smelt growth rate potential (see “Delta Smelt Growth Rate Potential” information sheet).

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DELTA SMELT GROWTH RATE POTENTIAL

PM SUMMARY

PMs	Units	Description
Delta Smelt growth rate potential (mean) for no action, Sacramento deep water ship channel (DWSC), and North Delta Food subsidy action (NDFS) scenarios.	grams C / month	Growth rate potentials of juvenile Delta Smelt in grams of carbon per month, calculated from mean daily GRP values for 1000 simulated fish. Summer-fall (July – October) means calculated from regional, monthly means. Regions within the Sacramento-San Joaquin Delta were from Rose et al. (2013). The actions were simulated to occur during July (DWSC) and from late August through late September (NDFS)(see RMA 2021b).

CALCULATIONS / SCORING

The most recent Rose et al. (2013) bioenergetics model was provided by Will Smith (USFWS) and used to estimate mean daily growth rate potential (GRP) for juvenile Delta Smelt (*Hypomesus transpacificus*). Monthly GRP estimates were calculated for July – October for 12 scenarios: four water year types (dry, below normal, above normal, and wet) by three actions (no action, Sacramento deep water ship channel [DWSC] action, and the North Delta Food subsidy action [NDFS]). The DWSC and NDFS are food web subsidy actions aimed at transporting and/or stimulating zooplankton (i.e., calanoid copepod) biomass and production during the summer and fall to improve Delta Smelt growth. The SMSCG action is not expected to influence zooplankton biomass and production and therefore SMSCG scenarios are equivalent to the no action scenarios.

<u>Prey Densities</u>. The bioenergetics model includes monthly prey densities for 12 zooplankton taxa and monthly temperature data for each of 12 regions within the Sacramento-San Joaquin Delta. The bioenergetics model prey densities were used for the no action scenarios, which is equivalent to the SMSCG scenarios. Prey densities do not differ by water year type for these scenarios. For the DWSC and NDFS scenarios, the bioenergetics model prey densities were modified using the monthly total calanoid copepod BPUEs simulated for each region for the 12 scenarios described

above (see RMA 2021b and the Copepod BPUE Performance Measure information sheet). First, proportional changes in total calanoid copepods for the DWSC and NDFS actions were calculated for each scenario by dividing the total calanoid copepod BPUE simulated for the action by the BPUE simulated for no action. The bioenergetics model prey densities for each calanoid copepod taxon were then multiplied by appropriate proportional change. The Prey densities for taxa other than calanoid copepods were not modified.

Model Simulations. The bioenergetics model was run for each of the 12 scenarios, with daily GRP calculated for 1000 Delta Smelt in each region by month (July – October). The starting length for each individual fish was randomly selected from a monthly distribution of fork lengths ranging between the 10^{th} to 90^{th} percentiles of monthly fork length data collected using Kodiak trawls during 2017-2020 USFWS Enhanced Delta Smelt Monitoring (USFWS 2020). New starting lengths were assigned for each month, such that growth during one month was not carried over to the subsequent month.

Mean Growth Rate Potential. Daily GRPs for each region*month*scenario combination were averaged and multiplied by 30 to estimate monthly GRPs. Monthly regional GRPs were averaged for each scenario to calculate a summer-fall (July – October) estimate.

KEY ASSUMPTIONS AND UNCERTAINTIES

- Delta smelt growth does not carry over from one month to another.
- Delta smelt cannot move to more suitable habitat (within or between regions).
- Prey densities were altered for calanoid copepods only, with the same proportional change applied to each taxon.
- Bioenergetics model prey densities do not differ among water year types, whereas the proportional changes based on total calanoid copepod BPUE model simulations for the DWSC and NDFS actions do differ.
- Water temperature does not vary by water year type; in the future, temperature files produced from numerical models of each scenario (RMA 2021a) can be used. However, 2D model simulations show little to no change in temperature due to the actions, except for the upper portions of the DWSC during some months and water year types.

ROUND 1 RESULTS

Total calanoid copepod BPUE was the only factor that differed among the within WYT scenarios; therefore, results for combined action alternatives (e.g., SMSCG x NDFS) are not shown.

Delta Smelt Growth

Performance Measure	Units	Preferred Direction	No Action - W (X2@80)	No Action - AN (X2@80)	No Action - BN	No Action - D	NDFS - W (X2@80)	NDFS - AN (X2@80)	NDFS - BN	NDFS - D	SMSCG – W (X2@80)	SMSCG – AN (X2@80)	SMSCG – BN	DWSC – W (X2@80)	DWSC – AN (X2@80)	DWSC – BN	DWSC – D
Growth Rate Potential (GRP)	g C mo^{-1}	Maximize	0.832	0.832	0.832	0.832	0.839	0.839	0.837	0.838	0.832	0.832	0.832	0.834	0.834	0.834	0.834

ADDITIONAL INFORMATION AND CONTEXT FOR INTERPRETING RESULTS

The Calanoid Copepod BPUE information sheet and RMA 2021b describe the data, modeling approach, and simulated changes in total calanoid copepod biomass per unit effort due to the DWSC and NDFS actions for each water year type.

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