FOIA EXEMPT – DELIBERATIVE PRIVILEGE

Delta Smelt Summer-Fall Habitat Seasonal Report for WY 2021

Central Valley Project and State Water Project
California

U.S. Department of the Interior and State of California **December 2021**

Mission Statements

The Department of the Interior (DOI) conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

The mission of the California Department of Water Resources is sustainably manage the water resources of California, in cooperation with other agencies, to benefit the state's people and protect, restore, and enhance the natural and human environments.

Delta Smelt Summer-Fall Habitat Seasonal Report for WY 2021

Central Valley Project and State Water Project
California

Authored by

United States Bureau of Reclamation

California Department of Water Resources

In coordination with the California's Department of Fish and Wildlife, United States Fish and Wildlife Service, National Marine Fisheries Service and Delta Coordination Group

Photo Credit: CDFW

Contents

Page

Purpose ... **8**
Preliminary Data ... 8
Background ... **8**
Delta Coordination Group ... 12
Decision Support Models and Tools ... 13
Operations ... **15**
Salinity Control Gates Operations ... 15
Delta Outflow ... 17
Food Enhancement Actions ... 22
North Delta Food Subsidies-Colusa Basin Drain Study ... 21
Sacramento Deep Water Ship Channel Food Web study ... 25
Suisun Marsh and Roaring River Distribution System Food Subsidies Study ... 27
Monitoring ... 28
Fish Monitoring ... 28
Water Quality Monitoring ... 28
Phytoplankton and Zooplankton ... 29
Microcystis ... 30
Clam Density and Biomass ... 31
Results ... **31**
Modeling results ... 31
Resource Management Associates – Habitat Suitability ... 31
Resource Management Associates – Copepods ... 33
Rose et al. (2013) bioenergetics model ... 34
SCHISM ... 35
Abiotic Habitat Attributes ... 48
Salinity ... 49
Turbidity ... 49
Temperature ... 50
Extent of Contiguous Low Salinity Habitat ... 50
Abiotic Limiting Factors ... 52
Biotic Habitat Attributes ... 52
Chlorophyll ... 52
Phytoplankton ... 55
Zooplankton ... 57
Microcystis ... 62
Clam Density and Biomass ... 64
Biotic Limiting Factors ... 66
Food Enhancement Actions ... 66
North Delta Food Subsidies-Colusa Basin Drain Study ... 66
Fish Status ... 76
Delta Smelt Status ... 76

Abundance ... 76
Distribution ... 77
Delta Smelt Supplementation ... 78
Fish Assemblage ... 79
Native vs Non-Native Fish Species ... 79
Abundance of POD Species ... 80
Discussion ... 81
Abiotic Habitat Attributes ... 81
Extent of Contiguous Low Salinity Habitat ... 82
Biotic Habitat ... 83
North Delta Food Subsidies-Colusa Basin Drain Study ... 83
Sacramento Deep Water Ship Channel Food study ... 84
Fish Status ... 84
Delta Smelt Status ... 84
Management Summary ... 85
References ... 86
Personal Communications ... 93
Attachments ... 94
Appendix A - Abiotic Habitat Figures ... 94
Appendix B - Monitoring ... 94
Appendix C - RMA Report ... 94
Appendix D - Performance Metric Information Sheets ... 94
Appendix E - Sacramento Valley Water Index

Figures

Figure 1 Map of the Sacramento- San Joaquin Delta (Credit: Google Earth) ... 9
Figure 2 Flow Chart for additional Suisun Marsh Salinity Control Operations and X2 location as part of the Delta Smelt Summer Fall Habitat Action ... 15
Figure 3 Salinity at Belden's Landing from June through October (Station BDL at CDEC) ... 17
Figure 4 Delta Exports at SWP and CVP pumping facilities... 18
Figure 5 Delta Outflow (Black line and black bars) and SWRCB's D-1641 Outflow Standards for a critically dry year including 2021 TUCOs (Red Line). For June (A), Delta Outflow was calculated as a 14-day rolling average, while monthly average values were used for July to September (B) ... 18
Figure 6 Top: Modeled daily Delta outflow from DWR Dayflow model from 2016 to 2020, plotted alongside 2021 Net Delta Outflow Index (NDOI) from DWR. Bottom: Modeled daily X2 from DWR Dayflow model (with the exception of 2021), plotted alongside calculated X2 for 2021 using X2 equation used in Dayflow and NDOI data (bottom). Dark red bold line indicates the year 2021 ... 20
Figure 7 Top: Modeled daily Delta outflow from DWR Dayflow model for all critically dry years since 1997 (with the exception of 2021), plotted alongside 2021 NDOI from DWR. Bottom: Modeled daily X2 from DWR Dayflow model (with the exception of 2021), plotted alongside calculated X2 for 2021 using X2 equation used in Dayflow and NDOI data (bottom). Dark red bold line indicates the year 2021 ... 21
Figure 8 Decision diagram for implementing a Sacramento River (MA-SR) vs. agricultural (MA-Ag) flow action. The type of flow action in any year will depend on (left to right): Projected water year type (wet to critically dry) with the final hydrologic forecast in May, and inflow to Shasta Dam in May or June (critical or non-critical); however, implementation

will be decided by the DCG. In addition, summer air temperature and the timing of agricultural planting in the north Delta region will both affect the timing of an agricultural action. Monitoring timing depends on the type and timing of the flow action. *Note that a flow action will not normally be conducted in a wet year, except under certain circumstances such as a wet winter and a dry spring. In addition to current year hydrology, DWR and BOR will consider previous year hydrology, storage capacity, available cold-water pool for salmon, and water quality in the Delta when determining which type of flow action to conduct 23
Figure 9 CDEC flow data from Lisbon Weir at the Yolo Bypass Toe Drain (station LIS) from June through October 24th of 2021, taken at 15-minute intervals. Blue line indicates LOESS smoothing line ± 1 SE of daily average flow. Points are daily average flow. Gray boxes indicated the period of the small, non-managed flow pulse. Data from CDEC are provisional, did not undergo QA/QC and are subject to change. Panel a) flow data over the entire interval from June through October; b) September flow data including the 4-day period of the non-managed flow pulse when the maximum daily average flow was 31.3 CFS................................. 24
Figure 10 Longitudinal and temporal variation in specific conductance, dissolved inorganic nitrogen, chlorophyll concentration and zooplankton biomass recorded by monthly fixed-station discrete sampling 2012 – 2019 26
Figure 11 Continuous Monitoring Stations - with nitrate and chlorophyll fluorescence – for September 2021. Sacramento River below Toland (TOL) is new station that replaces the Decker Island station (decommissioned in April 2021). Report also includes station data collected at Walnut Grove (SDC), Cache Slough (RYF), Jersey Point (SJJ), Confluence (CFL, Sacramento Deep Water Shipping Channel Marker 72 (CM72). Flow stations used to estimate flux at CFL include SJJ, Rio Vista (SRV), Three Mile Slough (TMS), and Dutch Slough (DCH). TOL does not yet have a discharge rating – for the purpose of this report, the SRV discharge is used to estimate flux at TOL. Black boxes indicate wastewater-derived nitrogen input. Source: Brian Bergamaschi, USGS 27
Figure 12 Map of the general low salinity zone within the San Francisco Bay-Delta and the CDEC stations used to create figures in this document. HUN = Hunter's Cut, BDL = Belden's Landing, NSL = National Steel, GZL = Grizzly Bay West, GZB = Grizzly Bay Buoy East, TRB = Tule Red, GZM = Grizzly Bay at Montezuma Slough, MAL = Sacramento River at Mallard Island, SDI = Sacramento River at Decker Island, RVB = Sacramento River at Rio Vista 29
Figure 13 Map of the Directed Outflow Project Study Area depicting sampling strata 30
Figure 14 The percent of time the < 4 ppt (upper panel) and < 6 ppt (lower panel) salinity thresholds were met at Beldon Landing with and without the SMSCG action for each water year type. Simulations were not run for the SMSCG action for dry water year types 32
Figure 15. Example HSI difference from 2D model output in Suisun Marsh: difference between NDFS+SMSCG+DWSC and No Action August, Below Normal (1979 CS) monthly-averaged HSI 33
Figure 16 Simulated calanoid copepod biomass per unit effort (BPUE) for no action (tan), the DWSC action (blue), and NDFS action (teal) for the upper regions in the Delta 34
Figure 17. The difference in daily growth rate potential (GRP) between each action and the non-action scenario. The DWSC action is shown in blue and the NDFS action in teal. Boxplots show the median (horizontal line), minimum and maximum (bottom and top of shaded box), and first and third quartiles (vertical lines) across months 35
Figure 18. Stations used to interpolate turbidity (full station names are provided in Table 3) 36
Figure 19. Interpolated turbidity in units of NTU for a) two-week average starting 2020-08-15 and b) two-week average starting 2020-09-12 38
Figure 20. Interpolated turbidity in units of NTU for a) two-week average starting 2021-08-15 and b) two-week average starting 2021-09-12 38

Figure 21. Processed remote sensing images of turbidity [source: https://nasa.baydeltalive.com/research/map-story] 39
Figure 22. Modeled average salinity for paired periods before and after gate operations in 2020 (top) and 2021 (bottom) 40
Figure 23. Time evolution of Suitable Habitat Acreage and Low Salinity Zone Acreage in Suisun Marsh from 08/01/20 to 9/24/20 41
Figure 24. Time evolution of low salinity zone acreage (top) and suitable marsh habitat (bottom) from 08/15/21 to 08/28/21. A hypothetical alternative with no False River Drought Barrier is also shown..... 42
Figure 25. Time evolution of low salinity zone acreage (top) and suitable marsh habitat (bottom) from 09/12/21 to 09/24/21. A hypothetical alternative with no False River Drought Barrier is also shown 43
Figure 26. Fraction of time low salinity conditions were met from 9/12/21 to 9/24/21 44
Figure 27. Fraction of time habitat suitability conditions were met from 9/12/20 to 9/24/20 with gate ops (temperature criterion was always met during the period) 45
Figure 28. Fraction of time habitat suitability conditions were met for two consecutive weeks in August 2020 (top) and fraction of time the temperature was below 23.9°C in both periods (bottom) 46
Figure 29 Change in mean salinity with and without barrier during the period August 15-28 2021, given equal hydrology 47
Figure 30 Heat map demonstrating proportion of time in each day that each water quality parameter was suitable for Delta Smelt at the stations shown in Figure 12 (i.e., salinity ≤ 6 ppt, turbidity ≥ 12 NTU, temperature ≤ 23.9° C). Note that data has not undergone quality control/ check and that stations may actually record formazin nephelometric units (FNU) instead; however, the general turbidity patterns observed should remain valid 48
Figure 31 Map of the San Francisco Bay-Delta depicting location of X2 based on distance from the Golden Gate Bridge according to UnTRIM Bay-Delta model taken from MacWilliams et al. (2015) 51
Figure 32 Daily- Average Depth-averaged Salinity when X2 is located at 89km (Delta Modeling Associates 2014), the maximum X2 value between June and October 2021 based on the X2 calculation with CDEC DTO station data 51
Figure 33. Daily average Chlorophyll fluorescence (in relative fluorescence units) from continuous sondes in 2021 53
Figure 34 Variation in Chlorophyll a (µg/l) across regional strata as measured during 2021 DOP and EMP sampling 54
Figure 35. Biovolume of 70 samples collected by EMP, Summer Townet, and Fall Midwater Trawl - the Environmental Monitoring Program in the Lower Sacramento region. Data from the other regions was available in time of this report 56
Figure 36. Biovolume of all phytoplankton (left) and diatoms (right) based on samples collected during 2021 56
Figure 37. Mean biomass per unit effort of major zooplankton taxa contributing to Delta Smelt diets in regions surrounding the SMSCG 57
Figure 38 Variation in monthly zooplankton biomass (mean µg C/m3 + SE) across regional strata as measured during 2020 DOP sampling 59
Figure 39 Variation in monthly zooplankton abundance (individuals/m3 + SE) across regional strata as measured during 2020 DOP sampling 60
Figure 40 Variation in monthly zooplankton biomass (µg C/m3) across regional strata as measured during 2021 DOP sampling 61
Figure 41 Variation in monthly zooplankton abundance (individuals/m3) across regional strata as measured during 2021 DOP sampling 62
Figure 42 Summer-Fall Microcystis bloom intensity based on visual ranking data from EMP, Summer Townet, and FMWT comparing previous years to 2021. These data were only from stations within regions shown in (Figure 13). Microcystis bloom presence and intensity are

measured on a qualitative scale with 5 categories: absent, low (widely scattered colonies), medium (adjacent colonies), high (contiguous colonies), and very high (concentration of contiguous colonies forming mats/scum) 63
Figure 43 Variation in visually detected Microcystis blooms among regional strata as measured during 2021 EMP, FMWT, DOP, and STN sampling. Microcystis presence and intensity were measured on a qualitative scale with 5 categories: absent, low (widely scattered colonies), medium (adjacent colonies), high (contiguous colonies), and very high (concentration of contiguous colonies forming mats/scum) 64
Figure 44. Map showing biomass of invasive bivalves Corbicula and Potamocorbula in Suisun Marsh from 2018-2020 65
Figure 45. Number of sites in Suisun Marsh at which more than trivial amounts of clam grazing occurred in 2018-2020 65
Figure 46. Total clam grazing as a function of water depth in Suisun Marsh 2018-200 66
Figure 47. Map of the NDFS study area. Red circles indicate monitoring sites for discrete water quality and biological responses to flow pulses. Circles with stars indicate sites that were monitored for continuous water quality. The red line separates monitoring sites into Upstream and Downstream regions. Upstream region sites for monitoring include Rominger Bridge (RMB), Ridge Cut Slough at Highway 113 (RCS), Woodland Wastewater Treatment (WWT), Toe Drain at Road 22 (RD22), Davis Wastewater Treatment (DWT), Toe Drain at I80 (I80), Toe Drain below Lisbon Weir (LIS), and Screw Trap at Toe Drain (STTD). Downstream region sites include Below Toe Drain in Prospect Slough (BL5), Liberty Island (LIB), Ryer Island (RYI), and Sacramento River at Rio Vista Bridge (RVB). Sacramento River at Sherwood Harbor (SHR) is a control site for biological monitoring. RMB and RCS are alternative sites for sampling the agricultural source water. RMB and RCS were sampled in 2020, but only RMB was sampled in 2021 for discrete monitoring when the channel was dry at RCS during part of the monitoring season 67
Figure 48. North Delta Food Subsidy study water quality measurements in 2020 from upstream and downstream regions and three transects in July and August, before the non-managed flow pulse. Mean (+ 1 SD) values for dissolved oxygen (mg/L), pH, secchi depth (m), specific conductivity (µS/cm at 25 ºC), temperature (ºC), and turbidity (FNU) were measured with a YSI ProDSS 68
Figure 49. North Delta Food Subsidy study nutrient concentrations in water from three transects in July and August 2020, before the non-managed flow pulse. Mean concentrations (mg/L+1 SD) for dissolved ammonia, dissolved nitrate + nitrite and dissolved ortho-phosphate for sites in upstream and downstream study regions 69
Figure 50. Mean of a) log total phytoplankton biovolume (µm3/mL + 1 SD) and b) log total zooplankton CPUE (catch per unit effort, number/m3 ± 1 SD) by NDFS study region for three transects in July and August before the small, 2020 non-managed flow pulse 70
Figure 51. 2020 NDFS zooplankton CPUE (catch per unit effort, number/m3) from three transects in July and August, before the non-managed flow pulse. Log of mean CPUE (± 1 SD) by zooplankton taxonomic group for sites in upstream and downstream study regions 71
Figure 52 Chlorophyll fluorescence data from continuous water quality stations. 2021 Chlorophyll fluorescence data from continuous water quality stations in order from most upstream site to downstream: Ridge Cut Slough at Highway 113 (RCS), Toe Drain at Road 22 (RD22), Toe Drain at I80 (I80), Toe Drain below Lisbon Weir (LIS), Screw Trap at Toe Drain (STTD), Liberty Island (LIB), and Sacramento River at Rio Vista Bridge (RVB) between June and November of 2021. Chlorophyll data are daily averaged. Shaded area indicates the days of the flow action (9/11-9/14). Upstream sites were QA/QC'd using procedures from the Resources Assessment Branch WQES Field Manual (06/2020). RCS data started later than others because the site was dry until mid- August. The break in RCS data is due to Sonde battery failure. Note that LIB, RYI (downloaded from USGS NWIS) and RVB (DWR EMP) data have not undergone QC 72

Figure 53 Location of sampling stations (designated by channel markers; CM). b-g) Turbidity (NTU), nitrate concentration (mg N L-1), ammonium (mg N L-1), phosphate (mg P L-1), chlorophyll-a (µg L-1), and total zooplankton biomass Location of sampling stations (designated by channel markers; CM). b-g) Turbidity (NTU), nitrate concentration (mg N L-1), ammonium (mg N L-1), phosphate (mg P L-1), chlorophyll-a (µg L-1), and total zooplankton biomass (µg dw L-1) at each sampling station, including all sampling dates (2012-2019). Sampling stations on the x-axes are ordered from seaward to landward, and gray vertical lines denote site groupings based on hydrodynamic exchange zones (HE, LE, NE). (Figure prepared by Adrianne Smits, UC Davis) 73
Figure 54. Comparison of chlorophyll concentration and turbidity at USGS continuous monitoring station at CM72 in the low-exchange zone of the ship channel. Missing data interval coincides with COVID-19 shut down period. Data are provisional 75
Figure 55 Comparison of seasonal chlorophyll flux at USGS continuous monitoring stations in the Sacramento-San Joaquin Delta (see Figure x for station names). Fluxes are expressed in metric tons of chlorophyll a per quarter (value within circle) with warm colors signifying landward fluxes. Multiplying chlorophyll by 41 yields an estimate of phytoplankton carbon (Source: Brian Bergamaschi, USGS). Data are provisional 76
Figure 56 EDSM-ANNUAL. Weekly Delta Smelt abundance estimates from EDSM survey. Years indicates the years in which each Delta Smelt cohort was born. Phase 1 of EDSM runs from December through March and focuses on adult Delta Smelt. Phase 2 sampling takes place from April through June and targets post-larval and juvenile Delta Smelt. Phase 3 runs from July through November and targets juvenile and sub-adult Delta Smelt. Closed circles indicate normal sampling effort for the week and open circles indicate a reduced sampling effort. Figure was provided by Vanessa Tobias and Lara Mitchell (USFWS) 77
Figure 57 Estimated annual mean biomass per volume of nearshore fishes based on March-August beach seine catch data as calculated in Mahardja et al. (2017). *Reduced sampling in 2020 due to COVID-19. **No data from August of 2021 79
Figure 58 Mean Striped Bass catch per tow and standard deviation (error bars) from the CDFW Summer Townet Survey from all stations for each year since 2011 (left) and from the CDFW Fall Midwater Trawl Survey from all stations for each year since 2010 (right). Only data from September and October surveys were used for Fall Midwater Trawl Survey to ensure consistency with 2021 data 80
Figure 59 Mean Threadfin Shad catch per tow and standard deviation (error bars) from the CDFW Summer Townet Survey from all stations for each year since 2011 (left) and from the CDFW Fall Midwater Trawl Survey from all stations for each year since 2010 (right). Only data from September and October surveys were used for Fall Midwater Trawl Survey to ensure consistency with 2021 data 81
Figure 60 percentage of Day in the low salinity zone when X2 is located at 89km (Delta Modeling Associates 2014) 82

List of Abbreviations and Acronyms

Abbreviation	**Definition**
BiOp	2019 Biological Opinion
BPUE	Biomass per unit effort
CDFW	California Department of Fish and Wildlife
CVP	Central Valley Project
DCG	Delta Coordination Group
DOP	Directed Outflow Project
EDSM	Enhanced Delta Smelt Monitoring Program
EMP	Environmental Monitoring Program
FMWT	Fall Midwater Trawl Survey
FCCL	Fish Conservation and Culture Laboratory
FNU	Formazin nephelometric units
GRI	Growth model index
GRP	Growth rate potential
NTU	Nephelometric Turbidity Units
NDFS	North Delta Food Subsidies/Colusa Basin Drain Study
ROD	Record of Decision
RMA	Resource Management Associates
RRDS	Roaring River Distribution System Food Subsidies Study
SDWSC	Sacramento River Deepwater Ship Channel Food Study
SWP	State Water Project
SCHISM	Semi-Implicit Cross-scale Hydroscience Integrated System
Water Board	Model State Water Resources Control Board
SDM	Structured decision-making
SMSCBG	Suisun Marsh Salinity Control Gates
STN	Summer Townet Survey
SFHA	Summer-Fall Habitat Action
D-1641	Water Rights Decision 1641
WY	Water Year
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

Purpose

This 2021 Seasonal Report for Delta Smelt Summer-Fall Habitat Action (SFHA) describes the operations of the Central Valley Project (CVP) and State Water Project (SWP) and Delta Smelt habitat conditions in water year (WY) 2021. This report may support adjustments, if necessary, to the Delta Smelt SFHA Guidance Document (Guidance Document) for WY 2022, and future operations, including Delta Smelt SFHA Plans, by documenting conditions without an action. The structure of the Seasonal Report for Delta Smelt SFHA will be modified for years when the action is implemented, and those modifications will be subject to coordinated agency review. This document also fulfills commitments under the Record of Decision (ROD) signed by the Bureau of Reclamation (Reclamation) for the Reinitiation of Consultation on the Coordinated Long-Term Operations of the CVP and SWP. Additionally, this Seasonal Report will be used to support the development of Reclamation's Annual Report on the Long-Term Operation of the Central Valley Project and State Water Project for Water Year 2021. This document will also act as the Delta Smelt SFHA report for a non-action year required by the California Department of Fish and Wildlife (CDFW) Incidental Take Permit for the SWP. Finally, this document will inform the Four-Year Review Panels adopted under the ROD and ITP. Compliance with the Incidental Take Statements, including the Reasonable and Prudent Measures and associated Terms and Conditions in the 2019 Biological Opinions (BiOp) from the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service adopted by the aforementioned ROD will be documented in the Annual Report and not in this document. This document strives to provide an integrated view of the factors affecting the low salinity zone habitat within the Sacramento- San Joaquin Delta. The results and discussion sections are focused on available Delta Smelt summer and fall habitat in WY 2021.

Preliminary Data

Real-time operations require compiling available data into seasonal reports to help inform the following year's management decisions on action implementation. The variables and data highlighted in this report were selected based on past Delta Smelt conceptual model work and the general understanding of Delta Smelt biology. However, some habitat information deemed important for Delta Smelt survival through the summer and fall (e.g., phytoplankton, benthic invertebrates, etc.) of 2021 were not yet available upon the completion of this report. In addition, the majority of 2021 data that are included in this report have not undergone final quality assurance and quality control procedures. Information presented in this report should be interpreted with some caution, as some datasets remain preliminary and subject to correction, revision, and improvement. A more complete, final dataset from WY 2021 will be captured in the seasonal report for WY 2022.

Background

The Delta Smelt SFHA provides for operational actions that improve habitat and food enhancement actions that may increase primary productivity (phytoplankton) and zooplankton. Potential operational actions are additional implementation of Suisun Marsh Salinity Control Gates (SMSCG) operations and Delta outflow augmentation, while food enhancement actions could include the

Sacramento Deep Water Ship Channel Food Web Study (SDWSC), North Delta Food Subsidies-Colusa Basin Drain Study (NDFS) and the Suisun Marsh and Roaring River Distribution System Food Subsidies Study (RRDS).

Most Delta Smelt complete their entire life cycle within or immediately upstream of the estuary's low salinity zone (Merz et al. 2011). Scientific research has generally shown that reducing salinity in Suisun Marsh and other areas within the Sacramento-San Joaquin Delta is beneficial for the Delta Smelt population due to increased distribution, foraging opportunities, and habitat complexity (Figure 1) (Sommer and Mejia 2013; Sommer et al. 2020). The highest quality habitat in this large geographical region includes areas with complex bathymetry, in deep channels close to shoals and shallows, and in proximity to extensive tidal or freshwater marshlands and other wetlands (Pg. 1 and 2, Guidance Document) (Bever et al. 2016; Hammock et al. 2019). Therefore, the ROD included a Delta Smelt SFHA intended to improve Delta Smelt access to food supply and habitat, thereby contributing to the recruitment, growth, and survival of Delta Smelt (Pg. 33, ROD). The Delta Smelt SFHA will investigate summer-fall habitat to better quantify and integrate information on how food, turbidity, salinity, velocity, and temperature interact with the species and contribute to the overall recruitment, growth, and survival of Delta Smelt (Pg. 1, Guidance Document). The ROD also provided a commitment to maintain X2 no more eastward than 80 km in above normal and wet years during September and October (Pg. 33 and 34, ROD). Overall, the Delta Smelt SFHA is intended to increase the spatial overlap of Delta Smelt habitat attributes with a focus on Suisun Marsh and experimental enhancements of prey supply from the Cache Slough Complex.

Figure 1 Map of the Sacramento- San Joaquin Delta (Credit: Google Earth)

Environmental and biological goals for summer and fall (June through October) of below normal, above normal and in wet years are (Pg. 4-72, BA):

(1) Maintain low salinity habitat in Suisun Marsh and Grizzly Bay when water temperatures are suitable;
(2) Manage the low salinity zone to overlap with turbid water and available food supplies; and
(3) Establish contiguous fresh water- low salinity habitat from Cache Slough Complex to the Suisun Marsh (Pg. 2 and 15, Guidance Document).

The SMSCG have the potential to provide an increase in area of low-salinity-zone habitat for endangered Delta Smelt, and to allow them to more frequently occupy Suisun Marsh, one of their most important rearing habitats (Hammock et al. 2019; Kimmerer et al. 2013; Sommer et al. 2020). To accomplish the goals listed above, Reclamation and DWR would implement SMSCG operations for up to 60 additional days (not necessarily consecutive) from June 1st through October 31st. Reclamation intends to meet Delta outflow augmentation in the fall primarily through export reductions as they are the operational control with the most flexibility in September and October
(Pg. 4, Guidance Document). Storage releases from upstream reservoirs may be used to initiate the action by pushing the salinity out further in August and early September; however, the need for this initial action will depend on the hydrologic, tidal, storage, and demand conditions at the time (Pg. 4, Guidance Document). In addition, storage releases may be made in combination with export reductions during the fall period during high storage scenarios where near-term flood releases to meet flood-control limitations are expected (Pg. 4, Guidance Document).

The Delta Smelt SFHA also includes food enhancement actions, e.g., those included in the Delta Smelt Resiliency Strategy to enhance food supply (CNRA 2016), including the SDWSC, North Delta Food Subsidies-Colusa Basin Drain Study and the Suisun Marsh and RRDS.

- **Sacramento Deep Water Ship Channel Food Study** is a federal and local partnership between Reclamation and City of West Sacramento and West Sacramento Area Flood Control Agency to determine the feasibility of repairing or replacing the West Sacramento lock system to hydraulically reconnect the ship channel with the mainstem of the Sacramento River. Combined with nutrient enhancement and other adaptive management measures, an ongoing food web study, a reconnected ship channel has the potential to boost food production for Delta Smelt and other planktivorous fish residing in the ship channel and to export surplus food resources into the North Delta.
- **North Delta Food Subsidies – Colusa Basin Drain Study** monitors and evaluates the effects of the North Delta Flow Action on the Delta food web. The North Delta Flow Action redirects agricultural drainage or Sacramento River water into Yolo Bypass for up to two to four weeks to generate a moderate flow pulse of 20-25 thousand acre-feet (i.e. a managed ‘flow action’) to restore positive net flows and move food resources downstream, thereby enhancing the quantity and quality of food for Delta Smelt in the North Delta (Frantzich et al. 2021). The North Delta region is relatively rich in food resources compared to other parts of the Estuary but negative or low flows from water diversions during summer and fall limit the distribution of these resources to downstream areas to downstream areas of Delta Smelt habitat. The action takes an adaptive management approach planning and implementing annual augmented flow pulses (or not) in summer or fall based on a combination of factors including evaluation of past results, predicted WY type, water availability and collaboration with supporting stakeholders.

- **Suisun Marsh and Roaring River Distribution System Food Subsidies Study** will coordinate managed wetland flood and drain operations and the operation of the Roaring River Distribution System, with the additional reoperation of the SMSCG. The intent of this study is to flush food rich waters of the managed wetlands and Roaring River into Grizzly Bay.

When determining whether the measures above provide similar or better protection than the 80 km salinity management action, Reclamation and DWR will consider, at minimum, the following (Pg. 4-73, BA):

(1) habitat acreages in Suisun Marsh, Grizzly Bay, and other adjacent areas available to support Delta Smelt recruitment;
(2) recruitment projections based on lifecycle modeling and/or monitoring to evaluate the expected trend in Delta Smelt with and without the 80 km salinity management action; and
(3) the presence (or absence) of Delta Smelt in both the target areas (main Delta channels and Suisun Marsh) and other areas (such as Montezuma Slough and Cache Slough), including information from monitoring, presence/absence modeling, or similar tools

One or more habitat suitability indices that include calanoid copepod biomass density are being developed, which could be used to evaluate the success of food enhancement actions. Recruitment projections using an individual-based model (e.g., Rose et al. 2013 a,b; Kimmerer and Rose 2018) could also be calculated under different food enhancement actions. Results of caged Delta Smelt studies could be used as a measure of the success of food enhancement actions. However, future cage studies would need to compare prey availability inside and outside of cages, and whether these metrics change with food enhancement actions.

In January of 2024 and 2028, Reclamation and DWR will charter an independent panel to review the Delta Smelt SFHA, among other actions. The purpose of the independent review will be to evaluate the efficacy of the Delta Smelt SFHA and its adaptive management program and the understanding of potential resulting beneficial effects on listed species, focusing on the Delta Smelt.

In all years during the summer and fall, Reclamation and DWR also will be complying with the State Water Resources Control Board's (Water Board) Water Rights Decision 1641 (D-1641). This water rights decision prescribes minimum salinity and outflow requirements for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. While the original purpose of the marsh salinity objectives was to protect habitat for waterfowl in managed wetlands, these salinity objectives provide multi-species habitat benefits (D-1641, Pg. 49, SMPA, Pg. 18). In 2021, Reclamation and DWR petitioned the Water Board to make temporary urgent changes to D-1641 to allow for modification of agricultural and fish and wildlife water quality objectives. These relaxations allowed the CVP and SWP to conserve water for winter-run Chinook salmon and meet interior Delta salinity standards that are important to health and human safety.

The 2019 USFWS BiOp requires that Reclamation and DWR provide annual reports documenting the planning, implementation, and monitoring of the Delta Smelt SFHA. In years that an action will be implemented, Reclamation and DWR shall provide a draft of the implementation plan to the Service by May 1 and a final report of the action by May 1 of the following year. Since 2021 is a critically dry year, Reclamation and DWR notified the USFWS through the Delta Coordination Group (DCG) that it was a non-action year.

Delta Coordination Group

The Guidance Document (Pg. 4 and 5) identified a Collaborative Planning Process to implement the Delta Smelt SFHA. In June 2020, Reclamation and DWR formed the DCG to coordinate planning of the Delta Smelt SFHA with USFWS, National Marine Fisheries Service, CDFW, and representatives from federal and state water contractors. Agencies and stakeholders participating in the DCG identified the PrOACT decision support tool as the structured decision-making (SDM) process to use in informing the Delta Smelt SFHA. The DCG did not engage in SDM for 2021 SFHA decision-making due to 2021 being a critically dry year. However, as part of the initial PrOACT process performance metrics identified by the DCG were presented in a consequences table and described in associated performance metric information sheets (Appendix D). Metrics were quantified using CalSim II and abiotic habitat, copepod biomass, and Delta Smelt bioenergetics modeling (see below). The table and metrics are not intended to be carried forward, but rather can serve as an example of the kind of information that can be provided for future SDM efforts. Starting in August 2021, the DCG engaged in a formal SDM process, guided by Jennie Hoffman (Adaptation Insight) and in collaboration with Compass Resource Management to allow for exchange between the DCG SDM process and the Collaborative Science and Adaptive Management Program SDM process. To assist the DCG in technical evaluation, research needs, and expert opinions related to SFHA and an annual SDM processes, two technical subteams of the DCG were created in early 2021, including the science and monitoring working group and hydrology and operations work group. As part of the first prototype for the SDM process, each DCG technical team provided expert feedback on the evaluation, selection, and scoring of performance metrics for different alternatives for an above normal water year type.

DCG and DCG technical team discussions during this first prototype revealed various aspects of the overall SDM process that should be addressed as the DCG moves into the next SDM prototype. Regarding the overall SDM process, DCG members noted that the first prototype (i.e., iteration) was useful for providing an orientation to the SDM process yet felt rushed and incomplete. They recommended that the next prototype include more time to develop a clear scope for the decision particularly as it relates to the actions and alternatives would be considered for annual versus four-year evaluation decision-making. For example, other water year types and different options for deployment of the 100 TAF should be included for annual decision-making. Longer-term decision-making could include the Sacramento Deepwater Ship Channel and Roaring River Distribution System food subsidies actions. Second, the DCG recommended conducting a sensitivity analysis to assess how the objectives or changes in performance metric scores influence decisions. Third, the flow of information between the DCG and work groups needs to be clarified. Finally, the DCG recognized the need to include scenario planning before the water year type (WYT) is determined and to decide which exceedance forecast will be used for identifying the WYT.

While scoring the performance metrics during the first prototype, the DCG and DCG technical teams made the following observations and recommendations. Overall, the performance metrics are useful as measures of food supply, habitat, and Delta Smelt growth and survival. Some metrics and scoring still need to be defined more explicitly and the analytical steps for scoring need to be determined. For example, how to weight information based on quantitative models versus expert elicitation when scoring needs to be determined. Integration of information from multiple quantitative tools for scoring population-level performance metrics (e.g., stage-structured and individual-based life cycle models) needs to be determined as well. More specific recommendations included using hydrologic models to estimate water supply cost (as volume) as opposed to CalSim. Further, the volume of water re-routed during actions is non-consumptive and should not be included in water cost. Another recommendation was to base contaminant effect scoring on toxicity to Delta Smelt instead of loading or concentration. The DCG observed that output from the abiotic and copepod biomass models were not as useful as they could be for scoring suitable habitat and food due to concerns over modeling limitations and assumptions. Performance metrics for the learning objective were not scored during the first prototype. The DCG discussed a possible scoring system based on value of information analysis of different science actions (e.g., data collection and analysis or modeling). The next SDM prototype will be aimed at revisiting the scope of the decision and alternatives and refining and scoring the performance metrics.

Decision Support Models and Tools

The Delta Smelt SFHA is informed by several conceptual models such as the Delta Smelt Management, Analysis, and Synthesis Team, the Fall Low Salinity Habitat and the Flow Alteration model (FLOAT 2019). For example, the Fall Low Salinity Habitat conceptual model suggested that Delta Smelt habitat should include salinity conditions ranging from fresh to low salinity (0-6 ppt), minimum turbidity of approximately 12 Nephelometric Turbidity Units (NTU) for adults, water temperatures below 23°C, food availability, and bathymetric complexity (Brown et al. 2014, Pg. 15-23; Komoroske et al. 2015).

Reclamation has developed a numerical model to simulate the anticipated impacts to Delta Smelt habitat suitability that would result from implementation of different action alternatives (no action; each action alone; different combinations of actions) under different WY types (wet, below normal, above normal, dry), with the exception that the SMSCG action was not simulated for dry water years. See Appendix- C RMA Report (2021a) for a detailed explanation. The model uses inflows generated with CalSim II by Reclamation, which include an X2 action of 80 km during above normal and wet water years for all action alternatives. The model simulates monthly-averaged current speed (ms^{-1}), salinity (PSU), salinity suitability (percent of time < 6 PSU); water temperature (°C), and water temperature suitability (percent of time < 25 °C); secchi depth (m) was interpolated from continuous monitoring turbidity observations for wet/above normal and dry/below normal years (2019 and 2018, respectively). Habitat suitability indices (HSI) were calculated two ways: (1) using salinity suitability, turbidity, and current speed per Bever et al. (2016); and (2) adding a modification to exclude habitat with water temperatures greater than 25 ˚C. Simulated data are reported in monthly time steps. The model does not include CalSim II inflows for critically dry years, and thus, cannot be used to simulate conditions similar to 2021. A web-based data visualization and access tool ([RMA Shiny Demo (rmanet.app)]) is now available for DCG members and the public to view different action-water year simulations interactively.

DWR has developed a parallel modeling effort to assess the area of habitat with appropriate salinity, water temperature, and turbidity for Delta Smelt using the Bay-Delta SCHISM model, which is based on the Semi-Implicit Cross-scale Hydroscience Integrated System Model (SCHISM) (Zhang et al. 2016). Prior SCHISM modeling for the Incidental Take Permit produced two metrics of Delta Smelt habitat area. First, the spatial area of habitat below 6 PSU. Second, the area below 6 PSU that also has a Secchi disk depth of 0.5 m or less (higher turbidity) and water temperature of 25 °C or lower. In the modeling, salinity and water temperature are produced by the model and turbidity is interpolated field data from continuous sondes using turbidity data. Following improvements in the continuous turbidity monitoring network close to Suisun Bay and Marsh, modelers have translated the current index from Secchi depth to turbidity (12 NTU) in order to take advantage of better temporal resolution, which has been the accuracy limiter in prior work.

Finally, Resource Management Associates (RMA) developed a model to provide an upper estimate of each food subsidy action's (NDFS and SDWSC) impact on total calanoid copepod density (biomass per unit effort, BPUE), which is the primary prey of Delta Smelt. See Appendix C (RMA 2021b) for a detailed explanation. For both the NDFS and SDWSC actions, total calanoid copepod (hence copepod) BPUE was a combination of ambient (observed) adult and juvenile copepod biomass density and source water (flow pulse) copepod biomass density and population growth. Monthly ambient (i.e., "no action") 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). The 2018 data were used to simulate dry and below normal water years and the 2019 data for above normal and wet years. For both the NDFS and SDWSC actions, augmented (i.e., "source") water is modeled to contain elevated copepod BPUE and cholorophyll a concentration. NDFS source water copepod BPUE was calculated as the 75th percentile using DWR zooplankton data collected approximately monthly in the Toe Drain from July through September, 2016-2019 (Kayfetz et al. 2021); SDWSC source water copepod BPUE was similarly calculated using the 2018 or 2019 data (see above) for the upper region of the ship channel. 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, 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. For each action, mean monthly total calanoid copepod BPUE and the difference in mean monthly total copepod BPUE (action –no action) were calculated for regional strata per Rose et al. (2013a). Copepod BPUE increased the most in the Yolo strata, within which each of the actions occurs, and gradually decreases downstream with minimal detectable effects beyond the confluence. This model includes a number of assumptions and simplifications that could be impacting the results (e.g., passive transport of zooplankton, zooplankton population growth rate parameters). Future modeling efforts could address some of these assumptions. The Rose et al. (2013) bioenergetics model (i.e., R code provided by Will Smith, USFWS) was used to evaluate how the changes in copepod BPUE might impact Delta Smelt habitat quality, measured as growth rate potential (g Carbon mo-1). Growth rate potential (GRP) was simulated for 1,000 fish in each of the Rose et al. (2013) strata under the NDFS and SDWSC actions for each of the four water year types. Reclamation is currently working with USFWS to modify the bioenergetics model to produce a growth model index (GRI) based on the Von Bertalanffy Growth Model. The GRI represents the proportion of the expected mean weight of a fish (from the Von Bertalanffy Growth Model) that is realized, given environmental and prey conditions (W. Smith, personal communication). Key modifications include calculating Von Bertalanffy Growth Model -predicted lengths, including secchi depth (m) and its effect on consumption, and using RMA simulated temperatures for each action-water year type scenario.

Operations

The 2021 WY was classified as critically dry defined by the Sacramento Valley 40-30-30 index (see Appendix E) water year hydrologic classification. The index value for WY 2021 was 4.0 . Since it was a critically dry WY, Reclamation and DWR did not implement the Delta Smelt SFHA as described within Reclamation's 2020 ROD and analyzed in the 2019 USFWS BiOp or the 2020 CDFW ITP, see Figure 2 below. This is the second year that no action has been taken due to hydrologic conditions, since 2020 was a dry year with an index value of 6.13.

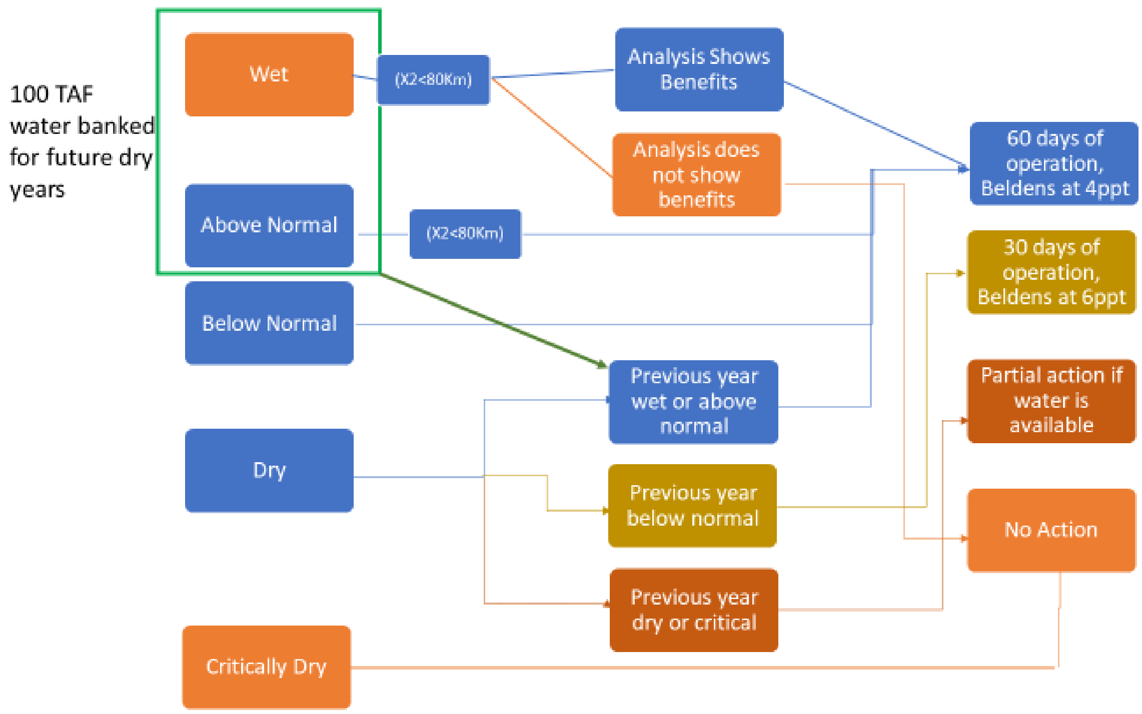

Figure 2. Flow Chart for additional Suisun Marsh Salinity Control Operations and X2 location as part of the Delta Smelt Summer Fall Habitat Action

Salinity Control Gates Operations

The SMSCG were not operated from June through August; two out of the three gates were held open, and one was closed for refurbishment. SMSCG operations began September 8th for the purposes of meeting the channel water salinity standards for the Suisun Marsh outlined in the Suisun Marsh Preservation Agreement (SMPA 2015), see Table 1 below.

Flashboard Status indicates if they are installed or removed. Boat Lock Status indicates if it is closed or in operation.

Table 1. 2021 Suisun Marsh Salinity Controls Gate Operations

Date	Gate Status	Flashboard Status	Boat Lock Status	Notes
9/1/20 – 9/7/20	Closed	Removed	Closed	
9/8/20 – 9/23/20	Operational	Installed	Operational	
9/24/20 – 9/30/20	Closed	Installed	Operational	
10/1/20 – 10/8/20	Open	Installed	Operational	
10/9/20 – 11/17/20	Operational	Installed	Operational	
11/18/20 – 11/22/20	Closed	Installed	Closed	Gate 3 closed for refurbishment
11/23/20 – 2/14/21	2 Operational 1 Closed	Installed	Operational	
2/15/21	Open	Installed	Operational	
2/16/21 – 5/6/21	2 Operational 1 Closed	Installed	Operational	
5/7/21 – 5/14/21	1 Operational 2 Closed	Installed	Operational	Gate 1 gearbox failure 5/7-5/14
5/15/21 – 5/31/21	2 Operational 1 Closed	Installed	Operational	
6/1/21 – 6/2/21	2 Open 1 Closed	Installed	Operational	
6/3/21 – 8/22/21	2 Open 1 Closed	Removed	Closed	
8/23/21 – 8/31/21	2 Open 1 Closed	Installed	Operational	
9/1/21 – 9/2/21	2 Operational 1 Closed	Installed	Operational	
9/3/21 – 9/12/21	Closed	Installed	Operational	Mechanical problem
9/13/21 – 9/30/21	2 Operational 1 Closed	Installed	Operational	

The SMSCG tidal operations are reflected in the salinity measurements at Belden's Landing. There was a noticeable decrease in salinity following implementations of operations, see Figure 3 below.

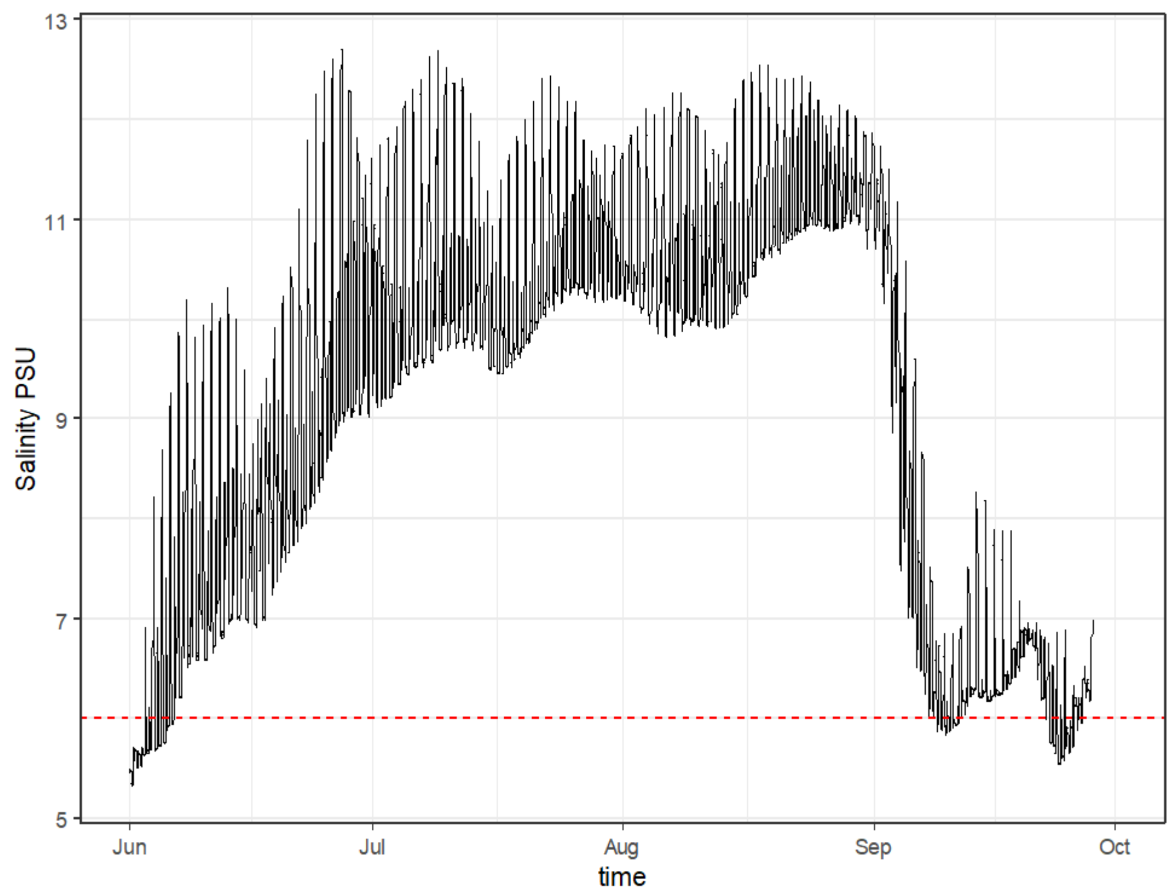

Figure 3 Salinity at Belden's Landing from June through October (Station BDL at CDEC).

Delta Outflow

Delta operations during the Summer-Fall of 2021 were controlled by a combination of D-1641 Delta water quality and Delta outflow requirements, including those that were modified due to the Water Board's Temporary Urgent Change Order (2021 TUCO). The 2021 TUCO modified the minimum Net Delta Outflow Index (NDOI) standard in June and July from 4,000 cfs to 3,000 cfs. As seen in the Figure 5, generally Delta outflow was near target when management of salinity in the Delta required additional outflow. During the summer and fall the CVP maintained exports at below 1,000 cubic feet per second (cfs) until September when it increased to 2,000-3,000 cfs. Meanwhile the SWP exports during this period were generally less than 1,000 cfs throughout the season (Figure 4).

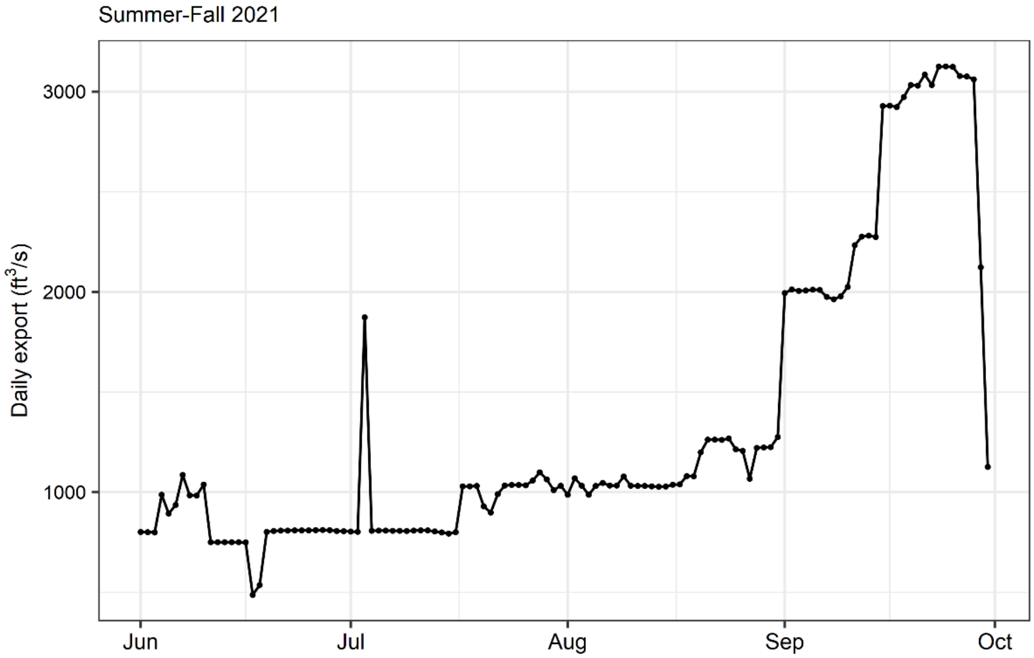

Figure 4 Delta Exports at SWP and CVP pumping facilities.

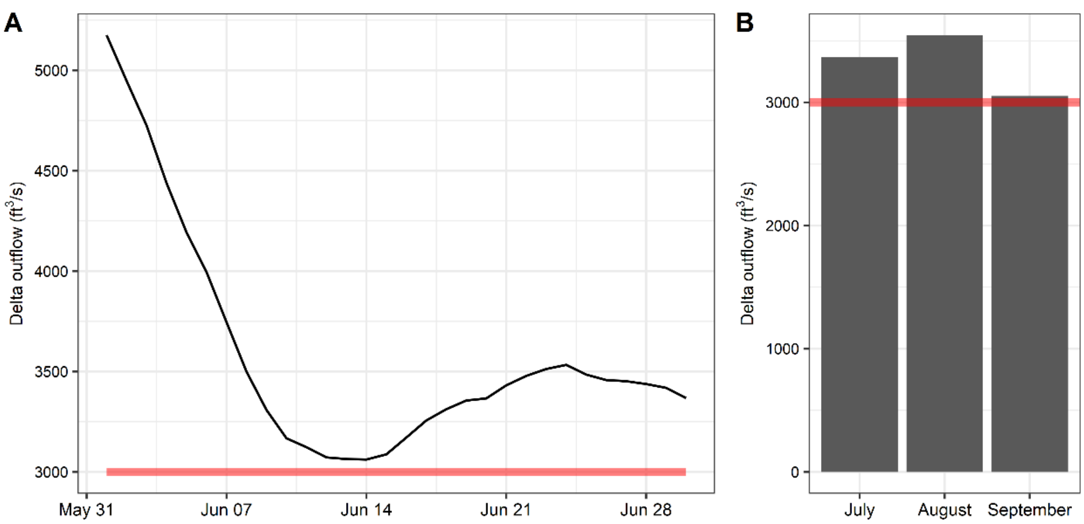

Figure 5 Delta Outflow (Black line and black bars) and SWRCB's D-1641 Outflow Standards for a critically dry year including 2021 TUCOs (Red Line). For June (A), Delta Outflow was calculated as a 14-day rolling average, while monthly average values were used for July to September (B).

The summer and fall periods of 2021 saw the consistently low Delta outflow and highest X2 (distance from Golden Gate Bridge at which water salinity measures at roughly 2 parts per thousand) towards late September (Figure 6). The average position of X2 during Summer and Fall of WY 2021 was 89 km. Water year 2021 was exceptionally dry, with X2 being further inland than in recent critically dry year (Figure 7). Outflow in summer and fall of 2021 was generally lower than previous critically dry years.

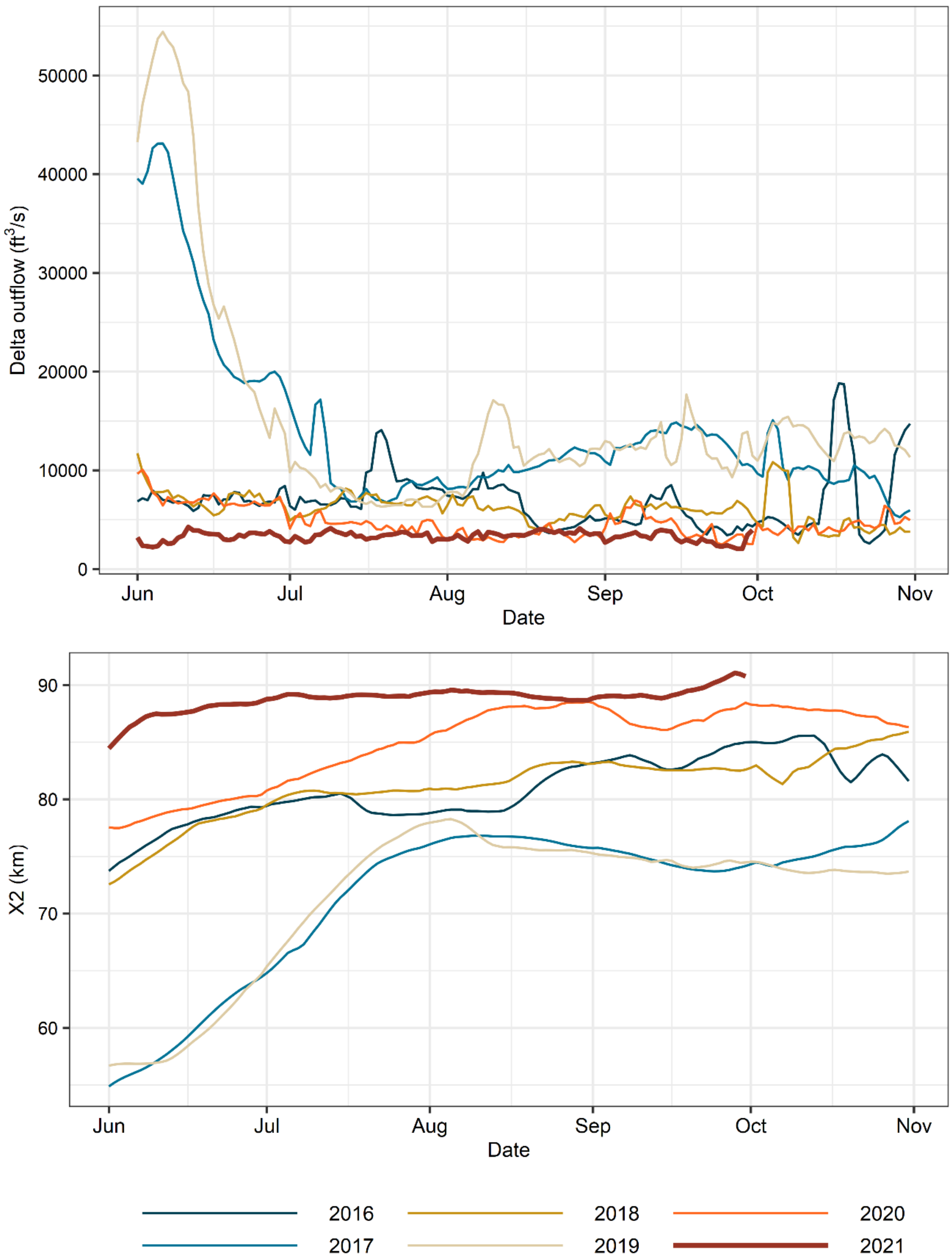

Figure 6 Top: Modeled daily Delta outflow from DWR Dayflow model from 2016 to 2020, plotted alongside 2021 Net Delta Outflow Index (NDOI) from DWR. Bottom: Modeled daily X2 from DWR Dayflow model (with the exception of 2021), plotted alongside calculated X2 for 2021 using X2 equation used in Dayflow and NDOI data (bottom). Dark red bold line indicates the year 2021.

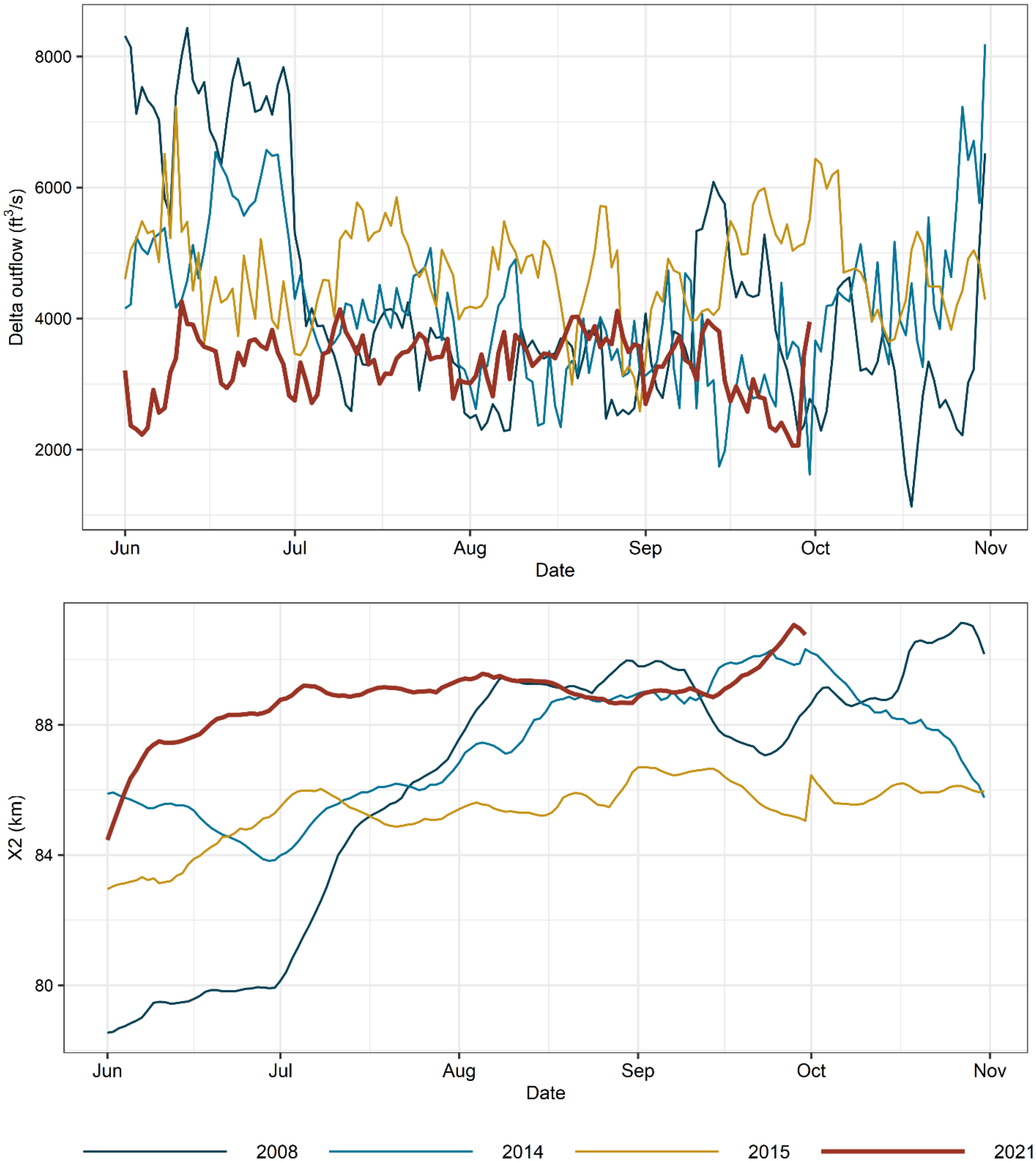

Figure 7 Top: Modeled daily Delta outflow from DWR Dayflow model for all critically dry years since 1997 (with the exception of 2021), plotted alongside 2021 NDOI from DWR. Bottom: Modeled daily X2 from DWR Dayflow model (with the exception of 2021), plotted alongside calculated X2 for 2021 using X2 equation used in Dayflow and NDOI data (bottom). Dark red bold line indicates the year 2021.

Food Enhancement Actions

The Delta Smelt SFHA included three food enhancement studies. These projects are the NDFS, Sacramento River Deepwater Ship Channel Food Study (SDWSC), and Suisun Marsh and RRDS. Food Enhancement studies are addressed within the USFWS 2019 BiOp programmatically (on Pg. 55 and 56) and are subject to future consultation and collaborative planning. Future consultations may require additional reporting specific to each action below.

North Delta Food Subsidies-Colusa Basin Drain Study

The NDFS action redirects agricultural drainage or Sacramento River water into the Yolo Bypass Toe Drain to create positive net flow during the summer and/or fall when flows are typically net negative to enhance the quantity and quality of food for Delta Smelt in the North Delta including Cache Slough Complex and potentially the lower Sacramento River. This is accomplished by generating a larger than normal flow pulse of 20-25 thousand acre-feet in the Yolo Bypass Toe Drain during the summer or fall period for up to two to four weeks, which has been shown to transport lower trophic plankton and/or potentially trigger a phytoplankton bloom downstream in some years (Frantzich et al. 2018, 2021; Twardochleb et al. 2021b).

Two types of flow actions (i.e., managed flow pulse) have been conducted to date: a Sacramento River action (MA-SR) and an agricultural action (MA-Ag). During flow actions, DWR alters the operation of the Knights Landing Outfall Gates (KLOG) and Wallace Weir (near Knights Landing, CA) to increase fall agricultural return flows (MA-Ag) or re-direct Sacramento River water (MA-SR) into the Yolo Bypass Toe Drain to create a managed flow pulse of sustained positive, daily average net flow measured at Lisbon Weir. Study operations begin in mid-to late-July for MA-SR actions and are coordinated among DWR, Reclamation, and local irrigation and reclamation districts and require increased pumping of Sacramento River water into Colusa Basin Drain and Knights Landing Ridge Cut (Ridge Cut). MA-Ag actions begin in mid- to late-August, depending on suitable water allocations and water quality within the Colusa Basin Drain, Ridge Cut, and Yolo Bypass as determined by DWR and monitoring by reclamation districts. This type of action relies on coordinated releases of rice field drainage into Colusa Basin Drain. Figure 8 below provides a potential decision diagram for conducting the two action types; however, implementation of NDFS actions will be decided by the DCG with consideration of the MA-SR, MA-Ag, and alternatives included in the SDM process.

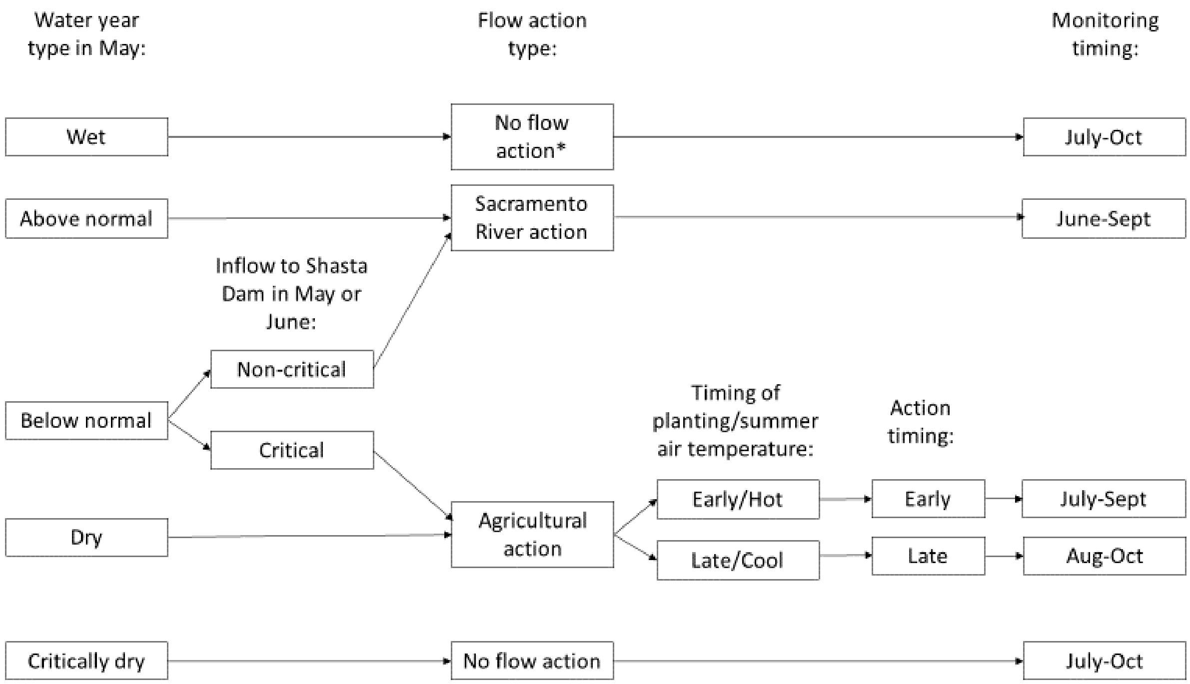

Figure 8 Decision diagram for implementing a Sacramento River (MA-SR) vs. agricultural (MA-Ag) flow action. The type of flow action in any year will depend on (left to right): Projected water year type (wet to critically dry) with the final hydrologic forecast in May, and inflow to Shasta Dam in May or June (critical or non-critical); however, implementation will be decided by the DCG. In addition, summer air temperature and the timing of agricultural planting in the north Delta region will both affect the timing of an agricultural action. Monitoring timing depends on the type and timing of the flow action. *Note that a flow action will not normally be conducted in a wet year, except under certain circumstances such as a wet winter and a dry spring. In addition to current year hydrology, DWR and BOR will consider previous year hydrology, storage capacity, available cold-water pool for salmon, and water quality in the Delta when determining which type of flow action to conduct.

This study was not implemented in 2021 since the water year was critically dry. Figure 9 reflects the water flow within the Toe Drain from June through October of 2021.

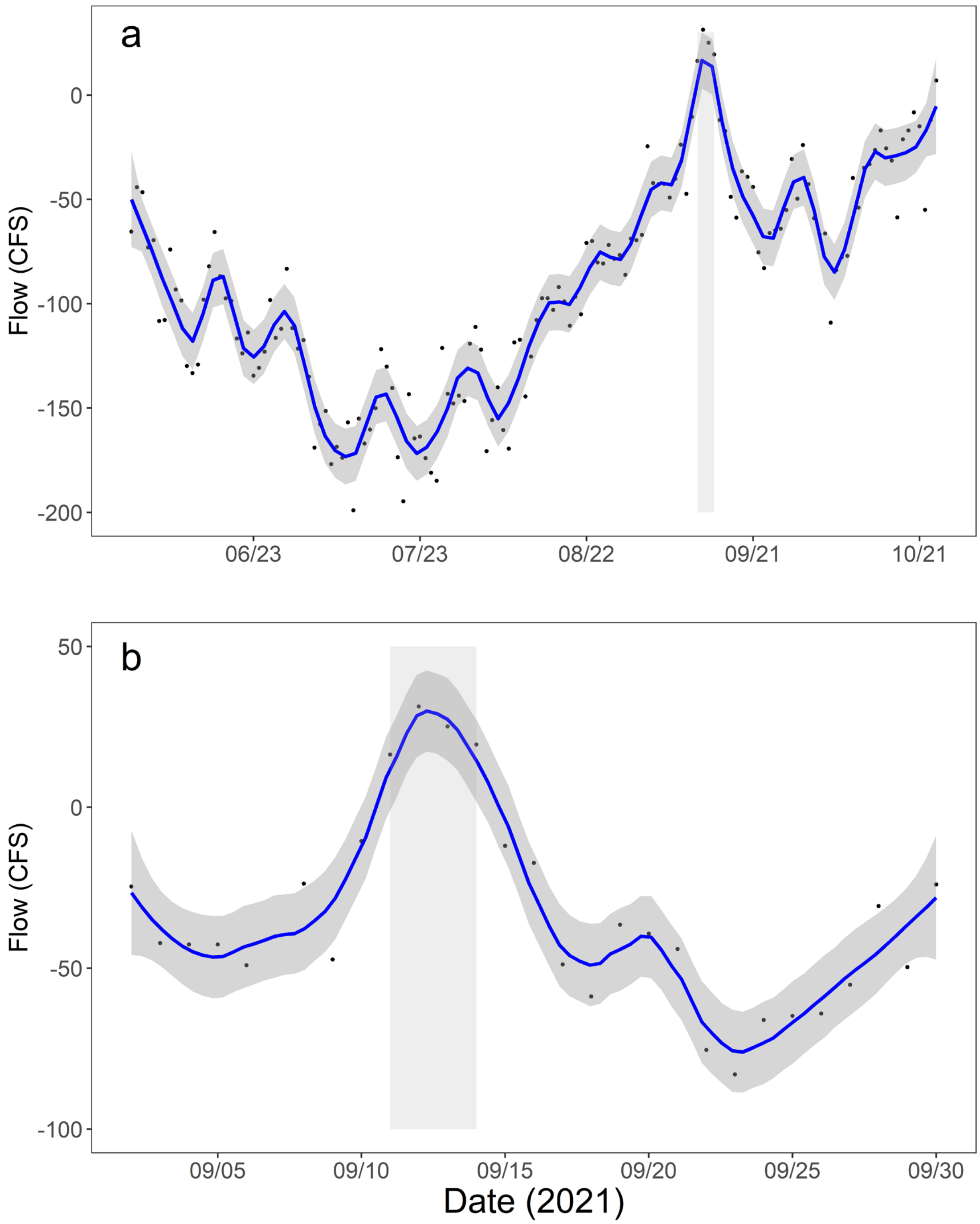

Figure 9 CDEC flow data from Lisbon Weir at the Yolo Bypass Toe Drain (station LIS) from June through October 24th of 2021, taken at 15-minute intervals. Blue line indicates LOESS smoothing line ± 1 SE of daily average flow. Points are daily average flow. Gray boxes indicated the period of the small, non-managed flow pulse. Data from CDEC are provisional, did not undergo QA/QC and are subject to change. Panel a) flow data over the entire interval from June through October; b) September flow data including the 4-day period of the non-managed flow pulse when the maximum daily average flow was 31.3 CFS.

Sacramento Deep Water Ship Channel Food Web study
The SDWSC study is investigating the feasibility of exporting phytoplankton, zooplankton and other food web resources from the upper relatively productive reaches of the ship channel to the lower reaches of the ship channel and Cache Slough. Export production would be managed adaptively in part by controlling inflow from the Sacramento River at West Sacramento. Presently, inflow is limited to the small amount of flow (~3 cfs) that leaks through the Stone Lock facility sector gates which are inoperable and locked in their closed position. Reconnecting the ship channel with the river at West Sacramento could also supply the lower Sacramento River mainstem with a 'seed source' capable of taking advantage of the higher nitrogen concentration in the lower river. This concept is thus similar to the strategy being implemented by the North Delta Food Subsidies action.

During 2012-2019, Reclamation and its University of California Davis partners conducted monthly fixed-station sampling of nutrients, suspended solids, chlorophyll concentration, phytoplankton and zooplankton density and other constituents to document baseline trophic conditions in the ship channel and how they vary longitudinally and seasonally (Figure 10). Reclamation is also funding the U.S. Geological Survey (USGS) to operate four continuous monitoring stations that record variation in tidal stage and velocity as well as EC, temperature, dissolved oxygen, turbidity and chlorophyll fluorescence. At one location in the upper ship channel (in the reach where nitrogen addition experiments were conducted by Reclamation, University of California Davis and USGS in 2018 and 2019) (Reclamation 2019; Loken et al, in review), nitrate concentration is also being monitored continuously. These data provide the basis for determining how temperature stratification, nitrogen concentration, chlorophyll concentration and other parameters vary at the tidal and finer temporal scales required to model hydrodynamics and food web dynamics (Lenoch et al. 2021).

The monthly discrete sampling effort was suspended in March 2020 due to the COVID-19 epidemic and is not slated to resume until spring 2022. Continuous monitoring, however, has continued at all four stations (Figure 11). These data are available at: https://waterdata.usgs.gov/nwis/uv?site_no=11455095, percent2011455136, percent2011455142, percent2011455335.

Table 2 Links to USGS continuous monitoring station data.

ID	USGS #	Link
CM72	11455095	https://waterdata.usgs.gov/nwis/uv/?site_no=11455095
CM66	11455136	https://waterdata.usgs.gov/nwis/uv/?site_no=11455136
CM62	11455142	https://waterdata.usgs.gov/nwis/uv/?site_no=11455142
CM54 (DWS)	11455335	https://waterdata.usgs.gov/nwis/uv/?site_no=11455335

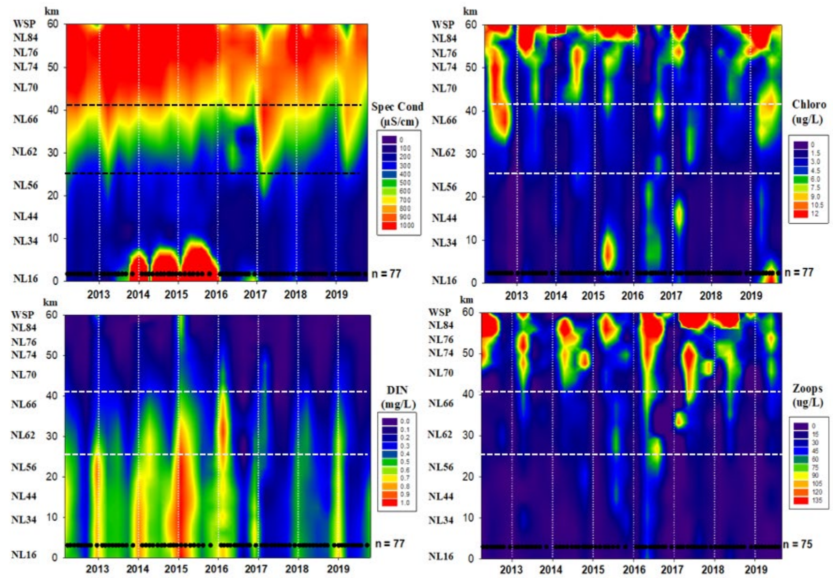

Figure 10 Longitudinal and temporal variation in specific conductance, dissolved inorganic nitrogen, chlorophyll concentration and zooplankton biomass recorded by monthly fixed-station discrete sampling 2012 – 2019.

Experimentally manipulating flow into the ship channel cannot occur until the required infrastructure is approved, constructed and permitted for operation as part of the city of West Sacramento's effort to address flood risks at the Stone Locks facility. The 2015 General Reevalution Report prepared by the US Army Corps of Engineers recommends an earthen levee and sheet pile wall to achieve 200-year flood reduction risk (USACE 2015). The authorizing legislation stipulates that the City shall achieve 200-year protection by 2025. The US Army Corps of Engineers solution would permanently isolate the ship channel from the Sacramento River. As part of its urban development planning process the City of West Sacramento evaluated multiple alternatives for achieving this level of protection. In addition to the US Army Corps of Engineers alternative, the analysis also included construction of a wall with culverts and repairing the sector gates of the Stone Lock facility (Wood Rodgers 2018). Evaluation criteria included: flood risk reduction and system resiliency, local water quality, fish passage, ecosystem enhancement (boosting plankton production and export), recreational opportunities, historical preservation (lock system) and redevelopment/urban design potential. Repairing the lock facility sector gate system achieved the highest overall rating and was one of the alternatives recommended for further consideration. If net flow can be restored to the ship channel and manipulated experimentally to adaptively manage food web productivity, it will be important to determine how much algal biomass and other forms of biologically available organic carbon it exports to the lower Sacramento River and how the magnitude of this exported material compares to organic carbon fluxes at stations up- and downstream. For this purpose, Reclamation funds USGS to maintain continuous monitoring stations in the Sacramento River at Walnut Grove and Decker Island, in Cache Slough and in the San Joaquin River at Jersey Point (Figure 11).

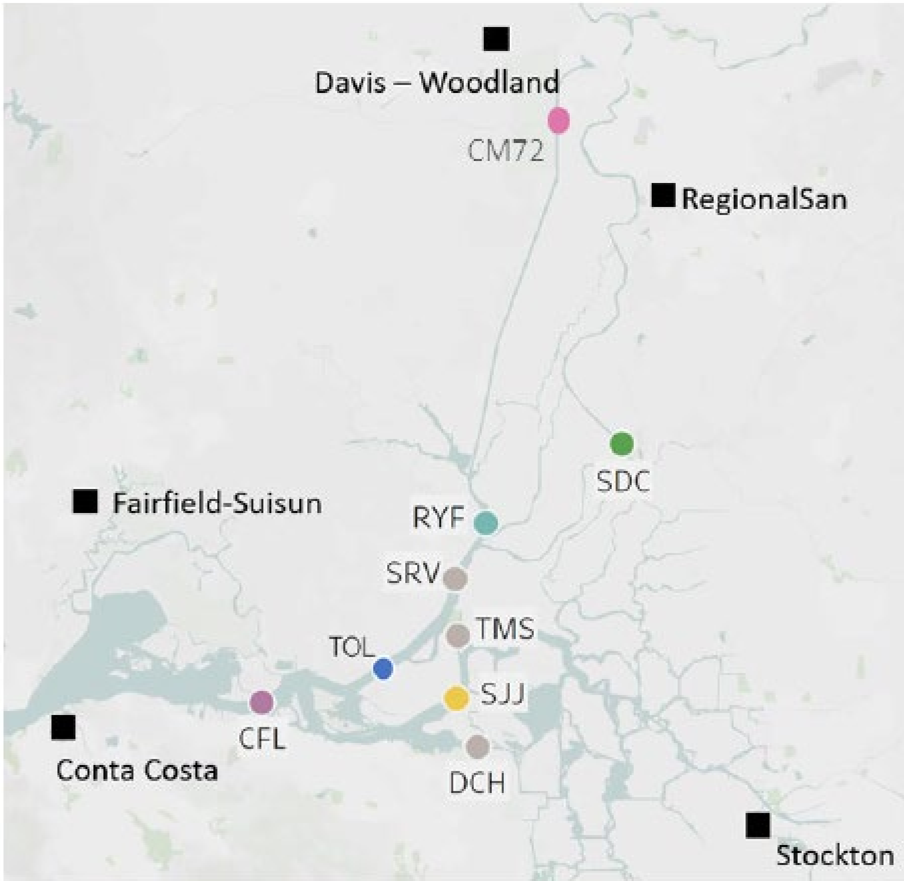

Figure 11 Continuous Monitoring Stations - with nitrate and chlorophyll fluorescence – for September 2021. Sacramento River below Toland (TOL) is new station that replaces the Decker Island station (decommissioned in April 2021). Report also includes station data collected at Walnut Grove (SDC), Cache Slough (RYF), Jersey Point (SJJ), Confluence (CFL, Sacramento Deep Water Shipping Channel Marker 72 (CM72). Flow stations used to estimate flux at CFL include SJJ, Rio Vista (SRV), Three Mile Slough (TMS), and Dutch Slough (DCH). TOL does not yet have a discharge rating – for the purpose of this report, the SRV discharge is used to estimate flux at TOL. Black boxes indicate wastewater-derived nitrogen input. Source: Brian Bergamaschi, USGS.

The stations at Toland (TOL) and Jersey Point (JPT) represent the chlorophyll fluxes from the northern and southern Delta into the low salinity zone, respectively. The station at Walnut Grove (WGA) represents flux from upper Sacramento River and the station at Cache Slough (RYFCC) represents the flux from the Cache Slough complex making it possible to separate their relative contribution to the flux into Suisun Bay via TOL.

Suisun Marsh and Roaring River Distribution System Food Subsidies Study

The RRDS Study would use the existing infrastructure to drain food-rich water from the canal into Grizzly Bay to augment Delta Smelt food supplies in that area. This management action may attract Delta Smelt into the high-quality Suisun Marsh habitat in greater numbers, reducing use of the less food-rich Suisun Bay habitat (CNRA 2016). Modified operations for the study will require extensive coordination with private landowners as the majority of managed wetlands are private property. Infrastructure repairs may also be needed. This study is still in the planning and development phase and was not implemented in 2021. Thus, it will not be addressed further in this report.

Monitoring

To assess Delta Smelt habitat conditions in 2021, a no-action year, this report evaluates regional and historical comparisons. Regional Comparisons will examine differences between geographic areas within the estuary to determine areas of quality Delta Smelt habitat. Since the estuary has been relatively well-monitored for many years, comparisons to historical years will examine conditions in relation to other critically dry years. This work serves to document conditions in the absence of the Delta Smelt Summer-Fall Habitat Action, as described in the Background section.

Fish Monitoring

Fish monitoring efforts that are utilized in this seasonal report include existing surveys conducted by IEP, specifically the CDFW's Summer Townet Survey (STN), Fall Midwater Trawl Survey (FMWT), as well as the UC Davis Suisun Marsh Survey and USFWS Enhanced Delta Smelt Monitoring Program (EDSM). Because monitoring relies entirely on existing monitoring programs, each of which has limited sampling, statistical analysis of community composition may not be possible until multiple action years are combined. Each survey is described fully in the Appendix B- Monitoring.

Water Quality Monitoring

The water quality in the low salinity zone, Suisun Marsh, and lower Sacramento River region are relatively well-monitored by routine and long-standing surveys such as the Environmental Monitoring Program (http://www.water.ca.gov/iep/activities/emp.cfm), which collects water quality, phytoplankton, zooplankton and benthic invertebrate samples on a monthly basis. DWR maintains a number of water quality stations in the low salinity zone and Suisun region. Several continuous water quality stations that cover the downstream range of Delta Smelt were selected in order to provide a general overview of the abiotic habitat conditions in the summer and fall of 2021 (Figure 12). Stations Grizzly Bay West (GZL), Grizzly Bay East (GZB), and Tule Red (TRB) were used to evaluate conditions in Grizzly Bay. Stations at the mouth of Montezuma Slough (GZM), Hunter's Cut (HUN), Belden's Landing (BDL), and National Steel (NSL) were used to describe conditions within Suisun Marsh. To evaluate conditions along the Sacramento River, data from stations at Mallard Island (MAL), Decker Island (SDI), and Rio Vista (RVB) were used.

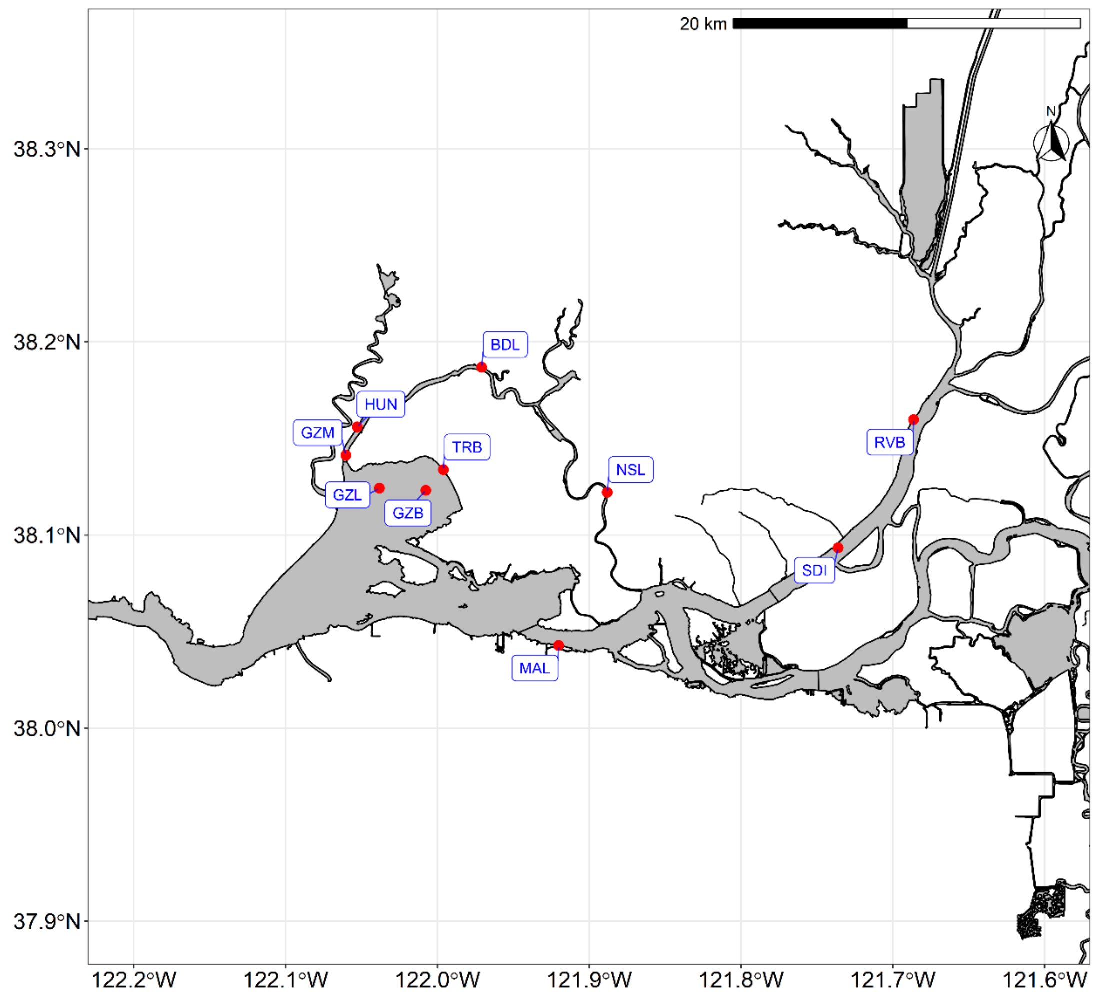

Figure 12 Map of the general low salinity zone within the San Francisco Bay-Delta and the CDEC stations used to create figures in this document. HUN = Hunter's Cut, BDL = Belden's Landing, NSL = National Steel, GZL = Grizzly Bay West, GZB = Grizzly Bay Buoy East, TRB = Tule Red, GZM = Grizzly Bay at Montezuma Slough, MAL = Sacramento River at Mallard Island, SDI = Sacramento River at Decker Island, RVB = Sacramento River at Rio Vista.

Phytoplankton and Zooplankton

Phytoplankton and zooplankton monitoring utilized in this report is produced from the Directed Outflow Project (DOP), Summer Townet Survey, Fall Midwater Trawl, and EMP. For phytoplankton, the only 2021 data available in time for this report are those for the Lower Sacramento River. The 2020 data from EMP, Summer Townet Survey, and Fall Midwater Trawl are complete and presented in this report, but the 2020 DOP data are not yet available. For zooplankton, only DOP data are available for 2021, but we present data from 2020 and previous years that include the other three zooplankton surveys.

The DOP (https://www.usbr.gov/mp/bdo/directed-outflow.html), established in 2016, collects data on water quality, phytoplankton, zooplankton, and fish (Schultz 2019). Like EDSM, DOP conducts stratified random sampling instead of sampling at fixed station. The DOP uses a generalized random-tessellation stratified sampling design (Stevens and Olsen 2004; Starcevich et al. 2016; also used by the current EDSM program) to select three sampling sites within each regional sampling stratum within the full study area per weekly sampling period. DOP habitat monitoring occurs during the majority of the Delta Smelt rearing-stage period (April – November; start date coincides with start of EDSM 20-mm sampling). The DOP study area (Figure 13) includes the North Delta Arc (Moyle et al. 2016), an area consistently occupied by a large portion of the Delta Smelt population.

Phytoplankton and Zooplankton monitoring is further detailed in Appendix B.

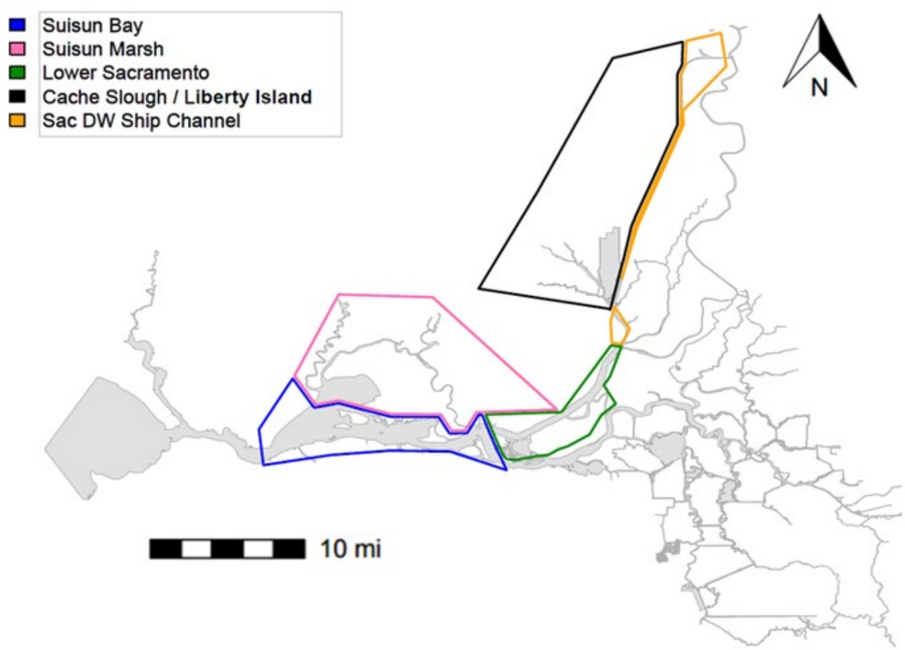

Figure 13. Map of the Directed Outflow Project Study Area depicting sampling strata

Microcystis

Microcystis is a genus of cyanobacteria often associated with harmful algal blooms in the San Francisco Bay-Delta. Microcystis is generally considered one of the most toxic cyanobacteria due to their capability of producing the toxin microcystin, which has been demonstrated to have detrimental effects to the health of humans, fish, and wildlife. Microcystis blooms have occurred annually during the summer and fall since 1999, particularly between July and September, and they often increase in magnitude with high water temperature, low streamflow and brackish water conditions associated with drought (Lehman et al. 2008, 2017, 2018, Kurobe et al. 2018). Microcystis is harmful to many fish and invertebrates (Ger et al. 2018; Acuna et al. 2012; Lehman et al. 2010);

and can impact community composition and abundance of beneficial phytoplankton. Therefore, areas high in Microcystis and other harmful algal blooms are likely to provide poor habitat for Delta Smelt.

Microcystis is surveyed in the region by visual observations conducted by CDFW's Summer Townet Survey, the Directed Outflow Project, and the Environmental Monitoring Program. Field staff rank *Microcystis* presence/absence on a scale of 1 to 5, with 1 being absent and 5 being very high. We integrated these data sets and assessed relative frequency of high *Microsystis a*bundance between regions of the estuary.

Clam Density and Biomass

The vast majority of bivalves found in Suisun Marsh belong to two non-native species, the brackish-water *Potamocorbula amurensis* (Nichols et al. 1990) or the more freshwater-adapted *Corbicula fluminea* (Brown et al. 2016). Both species have been presumed to impact Delta Smelt by reducing food availability (Mac Nally et al. 2010, Kimmerer and Thompson 2014). The density and biomass of these two clam species are important parameters to monitor for the management of Delta Smelt. Benthic invertebrate data is routinely collected by EMP, and was supplemented by a special investigation of clams in Suisun Marsh to further investigate the habitat value of this area.

DWR staff conducted bivalve surveys at twenty-eight sites in July and September of 2020, matching the survey months and sample sites of earlier years 2018 and 2019. Data from samples collected in 2021 is currently being processed and analyzed, and data from 2018-2020 is presented below. At each site, a Ponar dredge was used to collect a sample of benthic sediment, which was rinsed and preserved in ethanol. All *C. fluminea* and *P. amurensis* individuals were identified, counted, and shell measured to the closest millimeter shell length using either a micrometer or handheld calipers. Biomass and grazing rates of each clam species were estimated for all Suisun Marsh sites sampled using log-log regressions of shell biomass on shell length constructed from additional samples of clams collected at two reference sites (methodology outlined in Thompson et al. 2008).

Clam Density and Biomass monitoring is further detailed in Appendix B.

Results

Modeling results

Resource Management Associates – Habitat Suitability

Monthly habitat data were averaged to provide seasonal conditions for each WY type and action combination. The SMSCG action resulted in a substantial decrease in salinity, consistent with previous implementation of this action (Sommer et al. 2020). Salinity at Beldon Landing met salinity thresholds of < 4 ppt and < 6 ppt a greater percentage of the time during below normal, above normal, and wet water year types for scenarios with the SMSCG action versus without (Figure 14). In general, differences in habitat suitability index values between simulations with and without the SMSCG action showed increased habitat suitability in Suisun Marsh (Montezuma and Suisun

Sloughs) but decreased habitat suitability in Honker Bay and the confluence (Figure 15). August and September habitat suitability increased with changes in current speed. A July DWSC flow augmentation action resulted in shifts in temperature distribution in the ship channel. The North NDFS flow augmentation actions had negligible effects on relevant abiotic metrics.

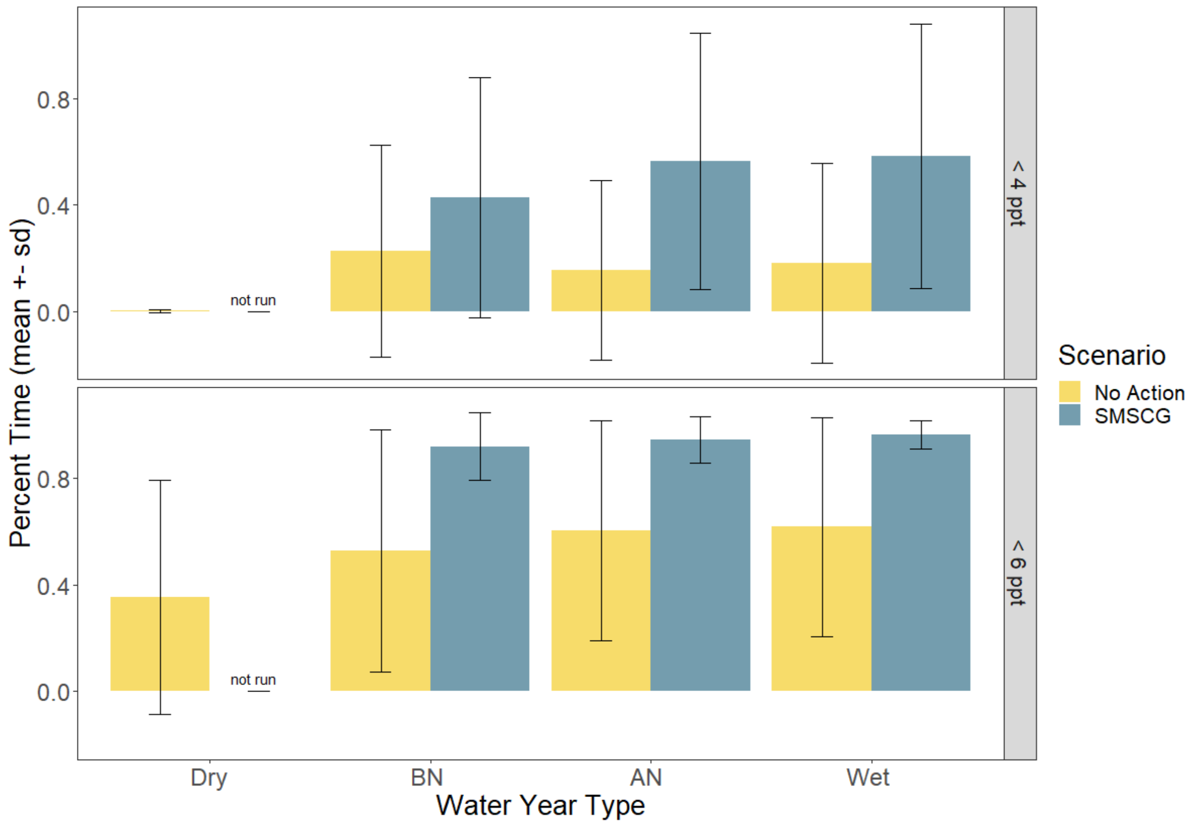

Figure 14 The percent of time the < 4 ppt (upper panel) and < 6 ppt (lower panel) salinity thresholds were met at Beldon Landing with and without the SMSCG action for each water year type. Simulations were not run for the SMSCG action for dry water year types.

Figure 15. Example HSI difference from 2D model output in Suisun Marsh: difference between NDFS+SMSCG+DWSC and No Action August, Below Normal (1979 CS) monthly-averaged HSI.

Resource Management Associates – Copepods

The effect of the NDFS and SDWSC food subsidy actions on calanoid copepod BPUE was simulated for each action, independently, for each water year type in 12 different regions stretching from the Yolo Bypass to the South Delta and lower San Joaquin River. In general, calanoid BPUE increased in response to each action within the region and month in which the action was simulated to have occurred (NDFS: September; DWSC: July), with the NDFS action resulting in higher calanoid BPUE than the DWSC action (Figure 16). Simulated calanoid BPUE increased by approximately 200 percent (compared to no action simulations) in response to the NDFS action in the Yolo Bypass region across water year types, quickly declining to less than a 50 percent increase in the downstream regions. The change in simulated calanoid BPUE in response to the SDWSC action ranged from less than a 50 percent increase in the Yolo Basin to approximately a 10 percent increase further downstream.

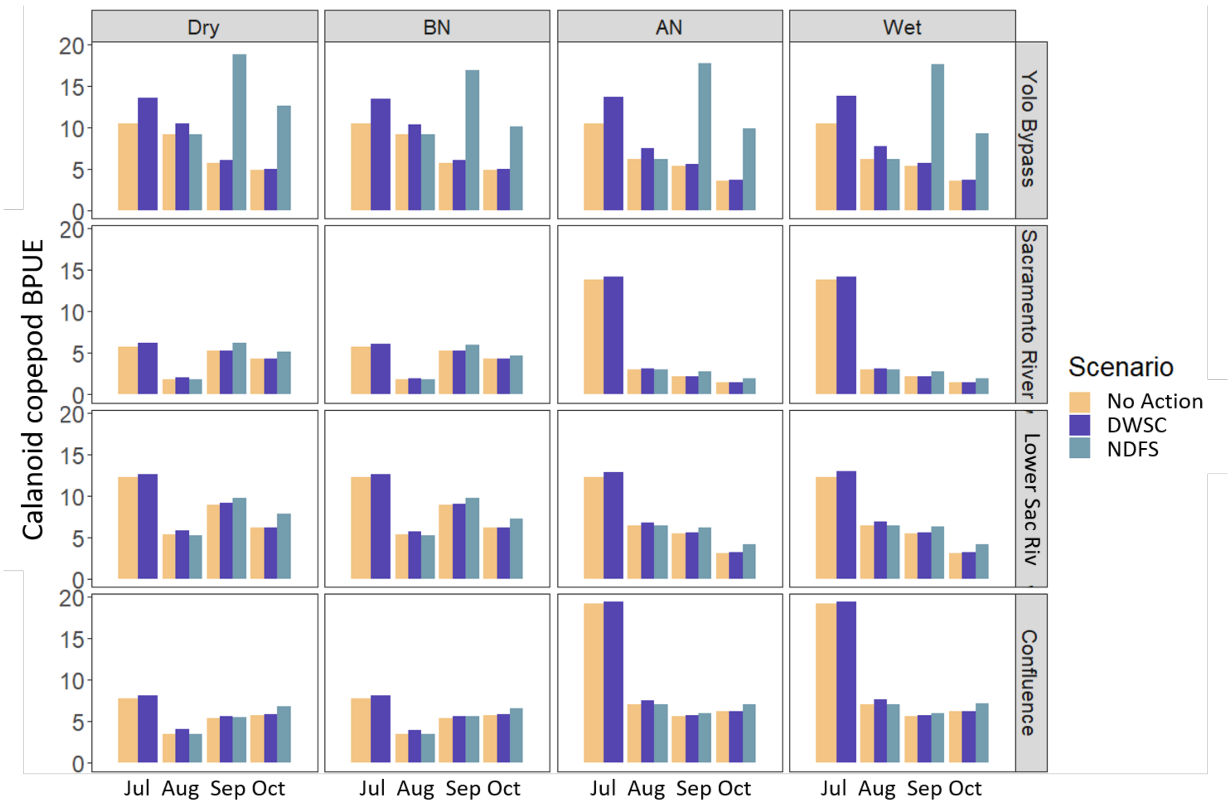

Figure 16. Simulated calanoid copepod biomass per unit effort (BPUE) for no action (tan), the DWSC action (blue), and NDFS action (teal) for the upper regions in the Delta.

Rose et al. (2013) bioenergetics model

Delta Smelt GRP increased only slightly in response to higher copepod BPUE across action-water year type combinations (Figure 17). However, each month is simulated independently (i.e., growth does not carry over from one month to the next) and fish do not move among regions. These daily growth rate potentials result in less than 0.1 mm growth in fork length per month.

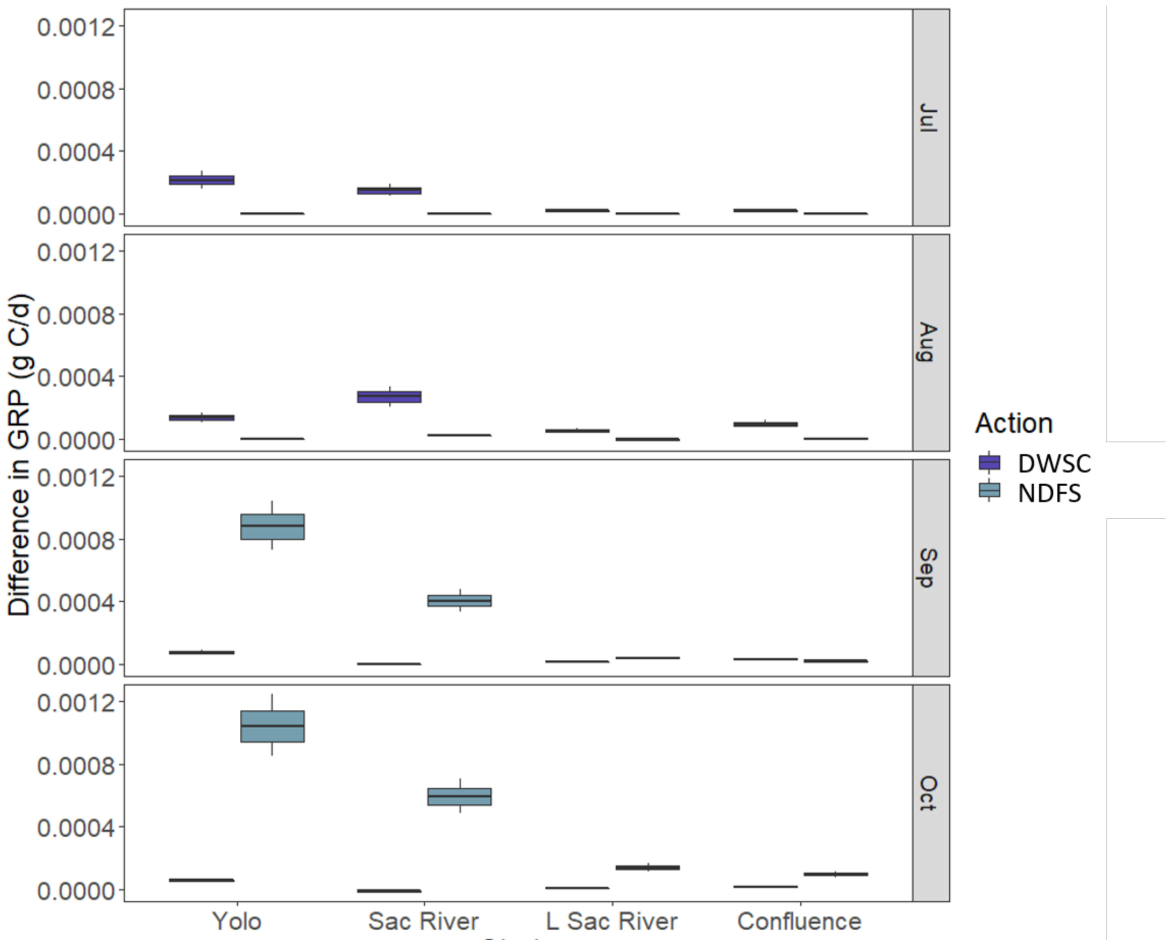

Figure 17. The difference in daily growth rate potential (GRP) between each action and the non-action scenario. The DWSC action is shown in blue and the NDFS action in teal. Boxplots show the median (horizontal line), minimum and maximum (bottom and top of shaded box), and first and third quartiles (vertical lines) across months.

SCHISM

Bay-Delta SCHISM 3D hindcast simulations were performed by DWR (for 2021) and Reclamation (for 2020) to assess habitat acreage availability in the marsh over the summer-fall periods of 2021 and 2022. Habitat area was quantified using both Low Salinity Zone (Salinity < 6.0 PSU) and three-factor Suitable Habitat Indices (Salinity<6.0 PSU, Turbidity > 12 NTU, Temperature < 23.9°C). In the production of these indices, salinity and temperature are based on 30-minute instantaneous model outputs, while turbidity is interpolated over the irregular domain from the field stations shown in Figure 18 using the methods of Sangalli (2013), which is a regularized interpolation method over irregular domains. Because of its noisy nature, the turbidity data are prefiltered with a 25-hour median filter and the interpolation was carried out on log transformed values before back-transformation to NTU. Compatibility with NTU units was assumed for stations reported in FNU.

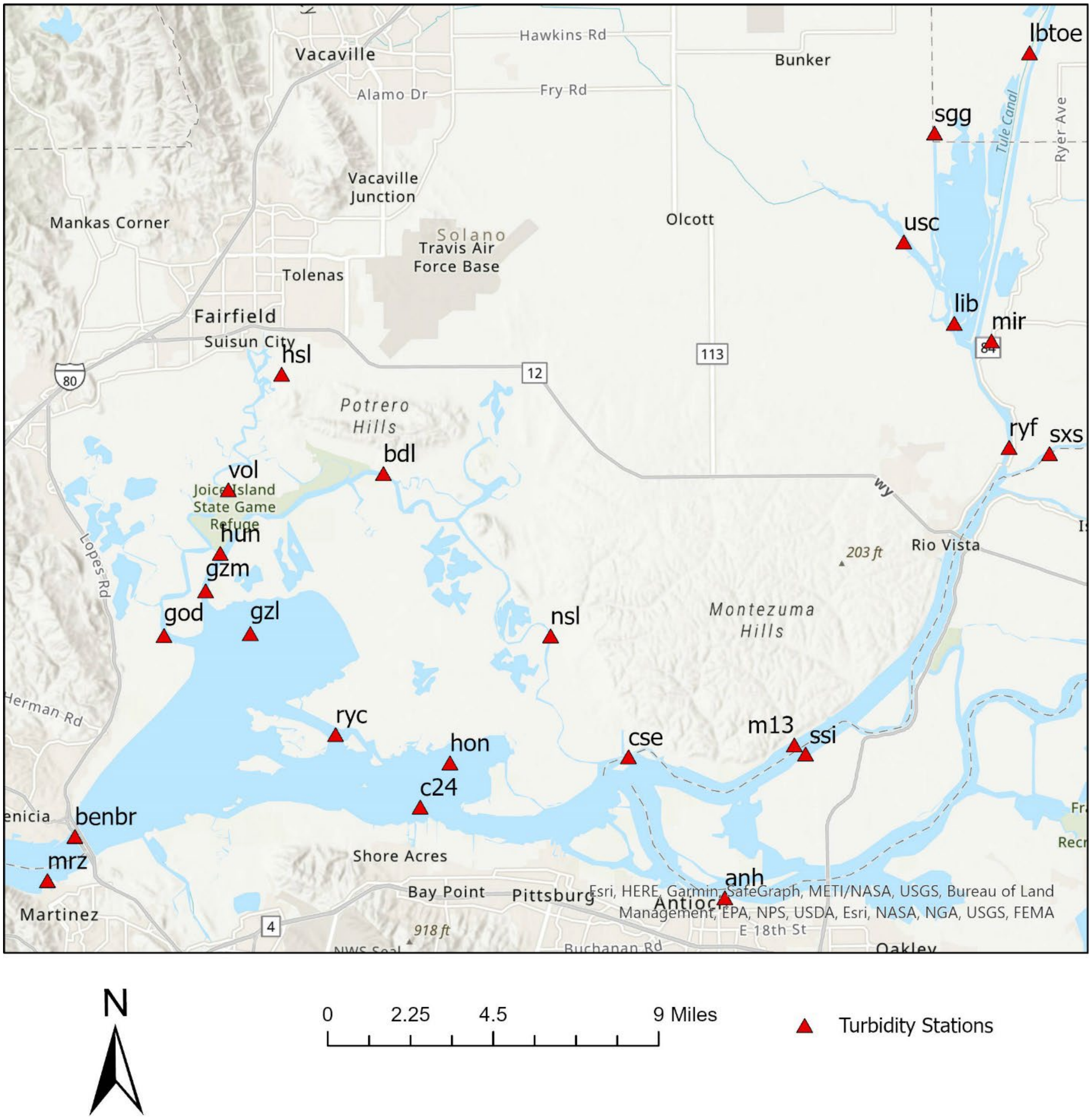

Figure 18. Stations used to interpolate turbidity (full station names are provided in Table 3)

Table 3. List of turbidity station names

Station ID	Turbidity Station Name
anh	San Joaquin at Antioch
bdl	Montezuma Slough near Beldons Landing
cse	Sacramento River at Collinsville
god	Godfather II on Suisun Slough
gzl	Grizzly Bay
hon	Honker Bay
hun	Hunter Cut at Montezuma Slough
mrz	Sacramento River at Martinez
nsl	Montezuma Slough at National Steel
ryc	Suisun Bay Cutoff Near Ryer
srh	Sacramento River at Hood
ssi	Sacramento River near Sherman Island
vol	Suisun Slough 300 south of Volanti Slough
gzm	Grizzly Bay at Head of Montezuma Slough Buoy
hsl	Hill Slough
mir	Miner Slough
sxs	Steamboat Slough near Sacramento River
benbr	Suisun Bay at Benicia Bridge
c24	Suisun Bay at Channel Marker 24A near Bay Point
lbtoe	Toe Drain at Liberty Island near Courtland
lib	Cache Slough at Liberty Island
m13	Sacramento River below Toland Landing near Rio Vista
ryf	Cache Slough Above Ryer Island Ferry
sgg	Shag Slough at Liberty Island near Courtland
usc	Cache Slough near Hastings Tract Near Rio Vista

Figures 19 and 20 show 14-day averages of the interpolated turbidity in August 15-28, 2020 and September 12-24, 2020, and August 15-28, 2021 and September 12-24 2021, respectively. The region of highest turbidity is often west of Nurse Slough.

The observed general turbidity pattern with a break point between Beldon's Landing and Nurse Slough is also seen in many NOAA remote sensing images based on the methods described by Lee (2021), an example of which is given in Figure 21. The remote sensing maps have a root mean squared error that is significant compared to the 12 NTU threshold for habitat but the regional picture rendered by the maps should still be indicative of general trends in field values. Also, although the accuracy of the remote sensing images may be affected by the combination of the remote sensing resolution and channel width in Montezuma Slough, the trends should still be indicative.

Taken together, the improved continuous station coverage of turbidity and the remote sensing images provide an order-of-magnitude increase in time resolution of information about turbidity relative to trawl data used in prior assessments. Based on these data, turbidity seldom limits habitat acreage, but there are instances where it can be limiting (for example, in September 2020 as shown in Figure 23). Reduction of habitat due to turbidity may be even more rare during a summer operation which would occur more in the heart of the windy season than the fall actions considered here. To the extent that turbidity limits habitat, turbidity is usually higher west of Nurse Slough. Because salinity is lowest to the east, the regions of favorable salinity and turbidity would then run contrary to one another, with overlap in the middle of Montezuma Slough near Nurse Slough. Monitoring closer to Nurse Slough would help quantify habitat success in these cases.

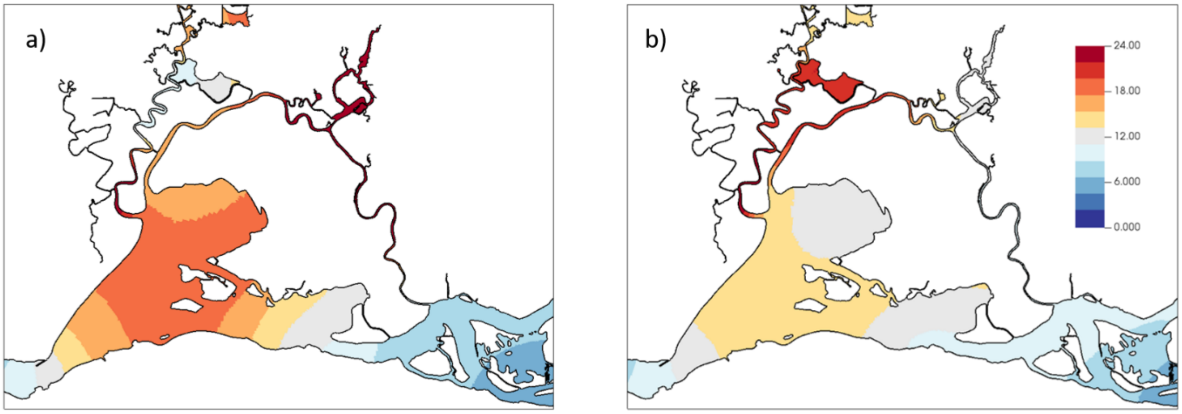

Figure 19. Interpolated turbidity in units of NTU for a) two-week average starting 2020-08-15 and b) two-week average starting 2020-09-12

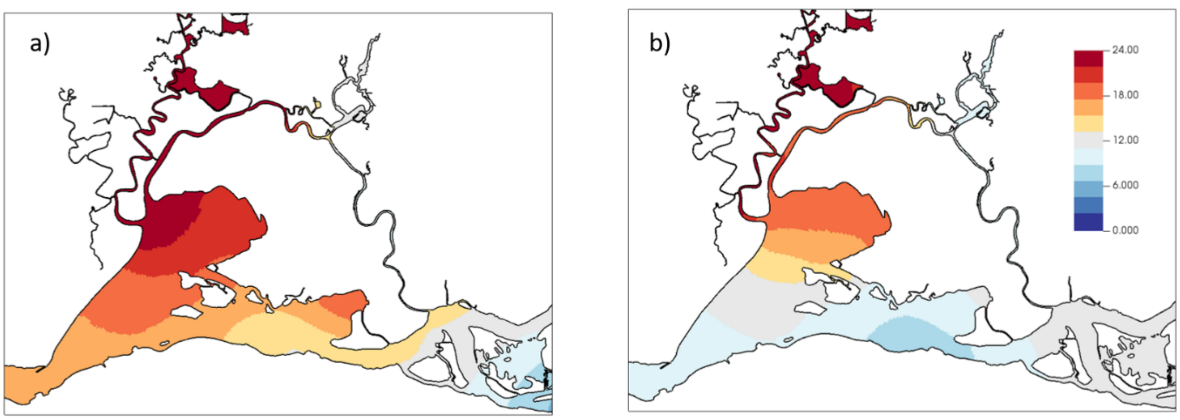

Figure 20. Interpolated turbidity in units of NTU for a) two-week average starting 2021-08-15 and b) two-week average starting 2021-09-12

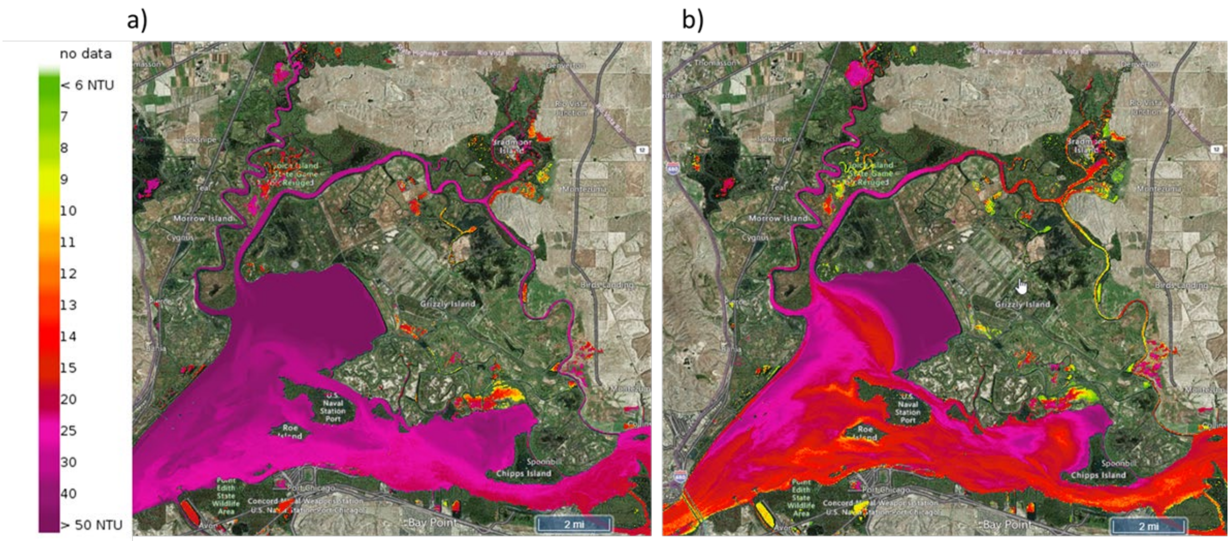

Figure 21. Processed remote sensing images of turbidity [source: https://nasa.baydeltalive.com/research/map-story].

Figures 22 shows modeled 14-day averaged salinity in August 1-14 2020, September 12-24, 2020, August 15-28, 2021 and September 12-24 2021. These are paired periods before and after gate operations for each year, timed in relatively steady flow periods so that salinity in the confluence area and Suisun Marsh is near equilibrium. In 2020, modeled (and observed) salinity hovered around the 6PSU LSZ threshold in the couple of weeks leading up to the tidal gate operations, with a noticeable increase in LSZ zone after the operations commenced. In 2021, salinity was above the 6PSU LSZ threshold the weeks leading up to gate operations in much of the marsh and even after tidal operations After tidal gate operations began, more habitat was generated in 2020 than in 2021. However, considerable acreage in 2021 was improved to levels falling between 6PSU and 7PSU, which might be important in light of the dearth of alternative favorable habitat.

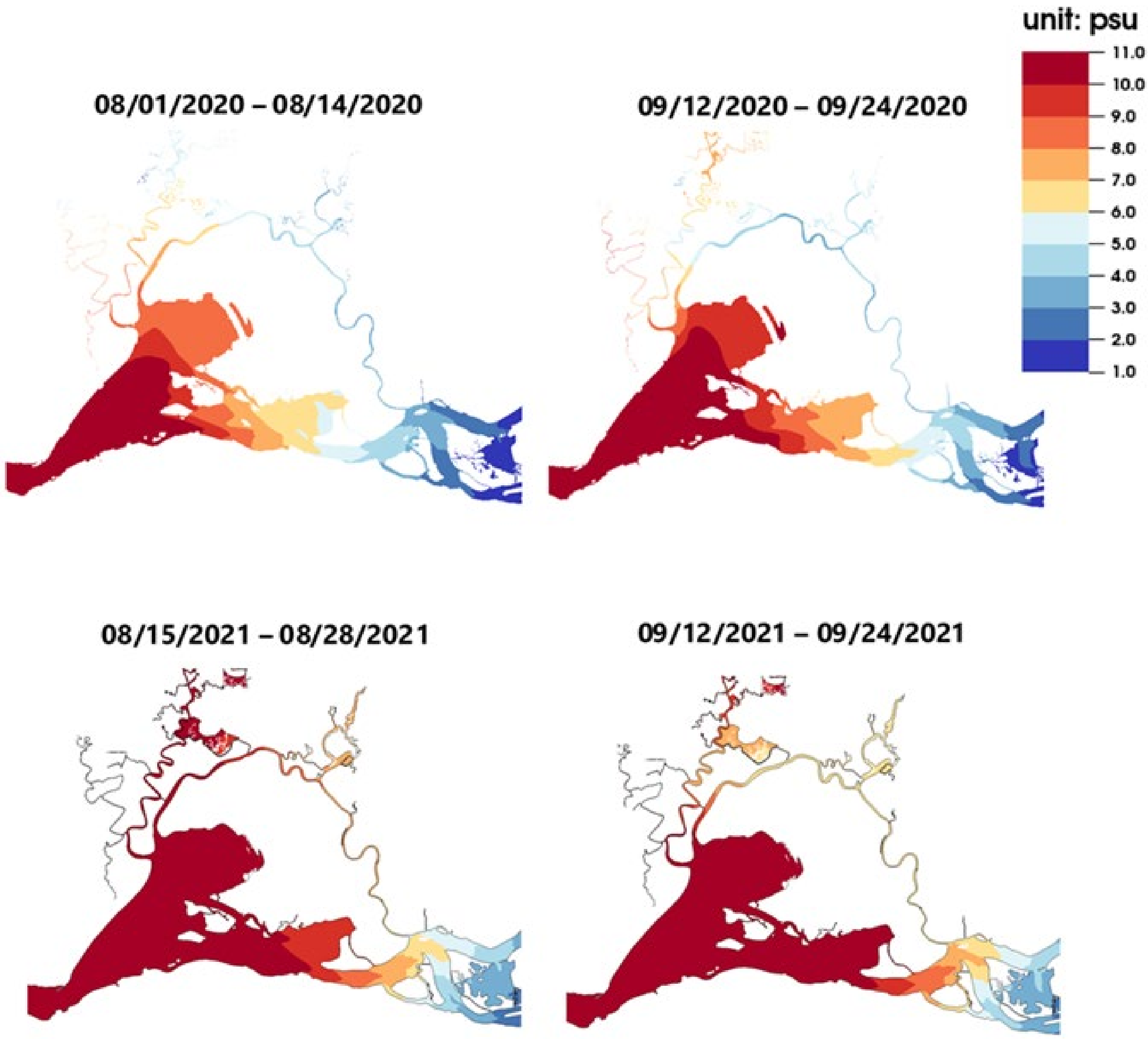

Figure 22. Modeled average salinity for paired periods before and after gate operations in 2020 (top) and 2021 (bottom)

Time evolution of habitat for Suisun Marsh is shown in Figures 23-25 for both LSZ and suitable habitat acreage. Figure 23 shows 2020, in which an intermediate acreage of habitat was available compared to the potential acreage of habitat measured by the model which is approximately 4,000 acres. The plot is annotated within time windows to describe evolution in the limiting habitat components: salinity, temperature and turbidity. In 2021, the modeled Suisun Marsh LSZ acreage vacillates near zero during mid-summer and a modest habitat area becomes available in September when the salinity control structure is operated tidally. The acreage is low – considerably lower than the 4000 acres of potential habitat; however as noted in the discussion of spatial plots, much of the difference between years has to do with habitat that falls between 6 and 7 PSU. Suisun Bay habitat is not shown and is essentially zero throughout the period of study for both years.

It is evident from the three figures (Figures 23-25) that the 3-factor habitat index acreage can, in instances, be markedly lower in acreage than that of the low salinity zone habitat alone. This happens because the regions with acceptable turbidity may sometimes not coincide with regions with the low salinity. Also, although water temperatures are suitable most of the time in the Marsh, they can be limiting during very warm periods, for example, during the last two weeks of August 2020. Temperature did not limit habitat acreage at all in 2021.

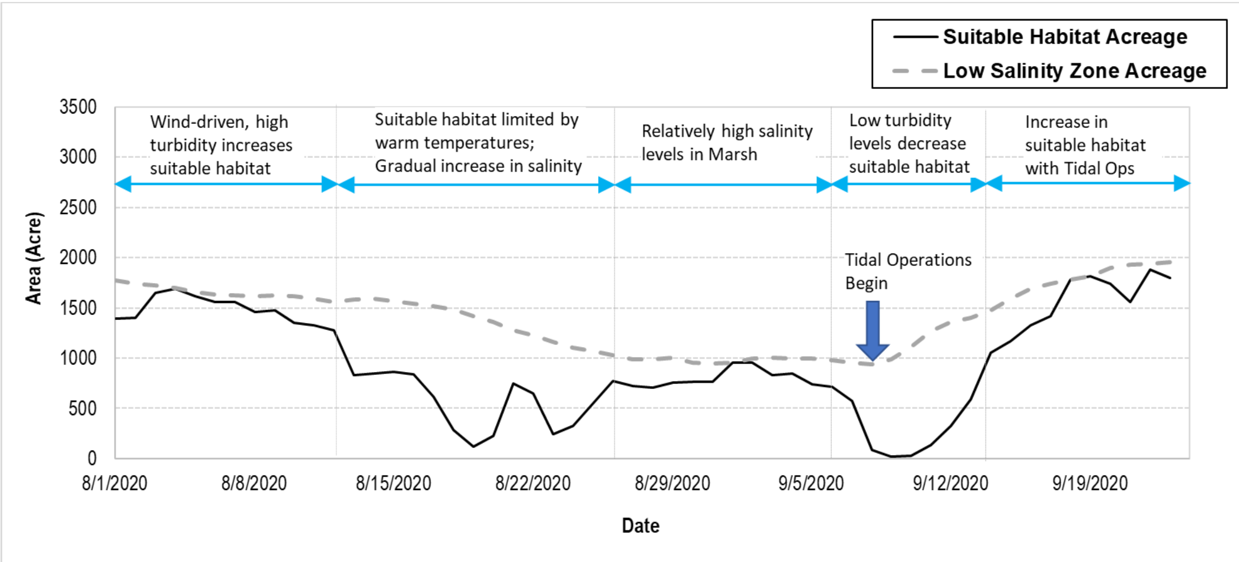

Figure 23. Time evolution of Suitable Habitat Acreage and Low Salinity Zone Acreage in Suisun Marsh from 08/01/20 to 9/24/20

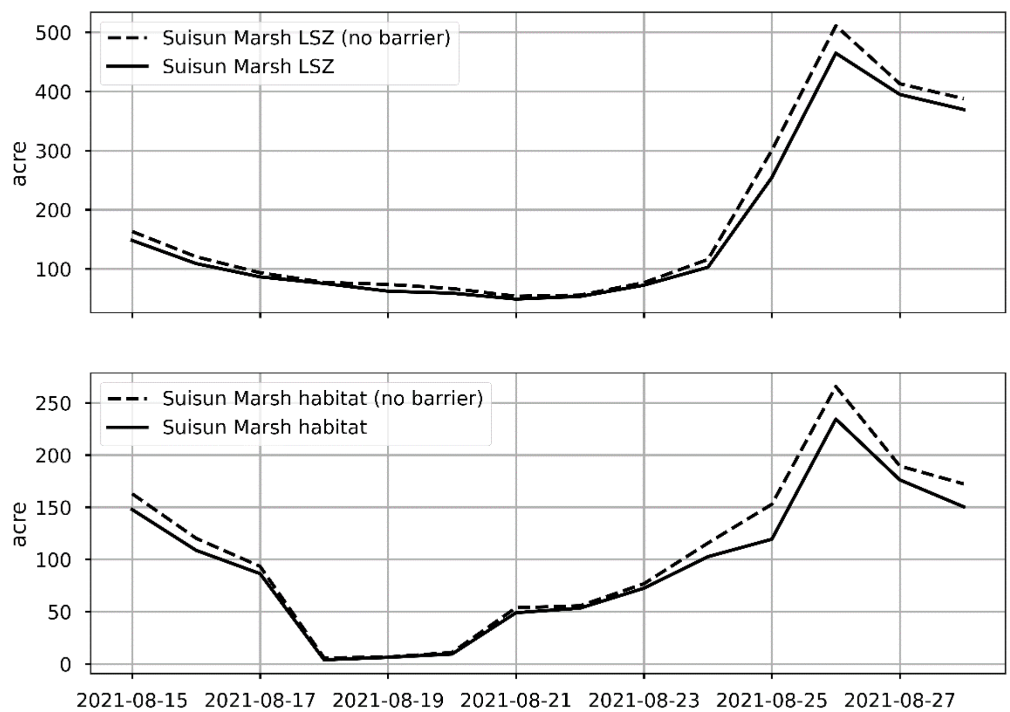

Figure 24. Time evolution of low salinity zone acreage (top) and suitable marsh habitat (bottom) from 08/15/21 to 08/28/21. A hypothetical alternative with no False River Drought Barrier is also shown.

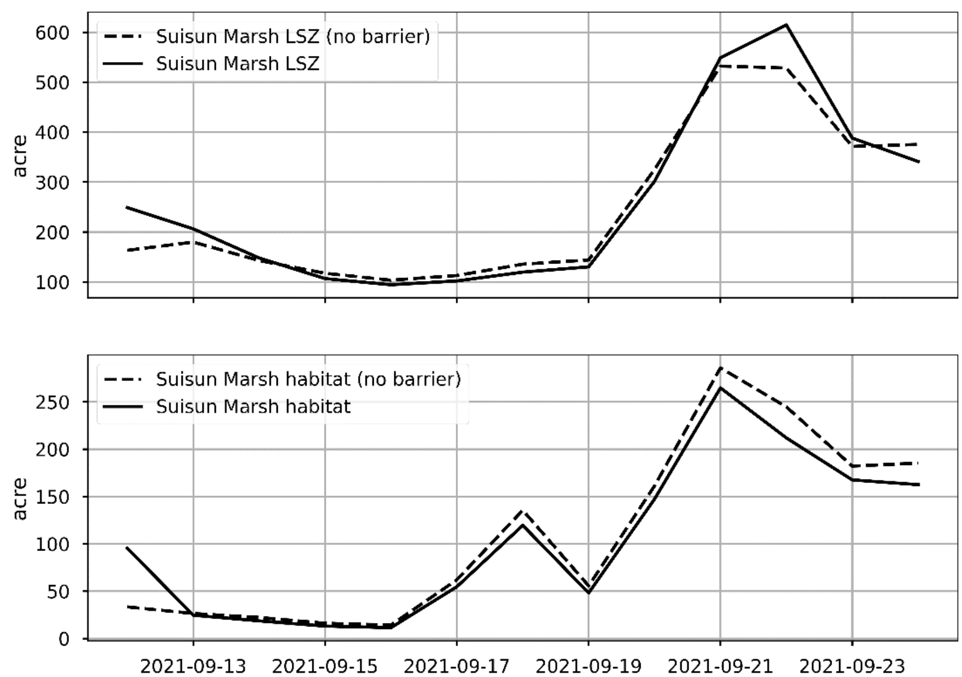

Figure 25. Time evolution of low salinity zone acreage (top) and suitable marsh habitat (bottom) from 09/12/21 to 09/24/21. A hypothetical alternative with no False River Drought Barrier is also shown.

The combined effects of turbidity and salinity on suitable habitat distribution are readily seen in spatial index plots of the region. Figure 26 shows the predicted fraction of time that LSZ conditions are met over the period September 12-24, 2021. LSZ is generally present less than 40% of the time in the marsh. This trend is dictated by the relatively high salinity in the marsh, which, on average, is slightly above the threshold of 6 PSU (Figure 22). A corresponding plot for 2020 is presented in Figure 27 for the same September 12-24 period. This figure presents the fraction of time habitat is suitable, along with the fractions of time LSZ and high turbidity conditions are met. Suitable habitat is generally present from Nurse Slough to the west over 60% of the time. The modeled LSZ extends most of the length of Montezuma Slough. However, the region of highest turbidity is primarily west of Nurse Slough. The overlap between this region and the LSZ, therefore, dictates the distribution of suitable habitat, as seen (water temperatures were always below the threshold in the period).

Figure 26. Fraction of time low salinity conditions were met from 9/12/21 to 9/24/21

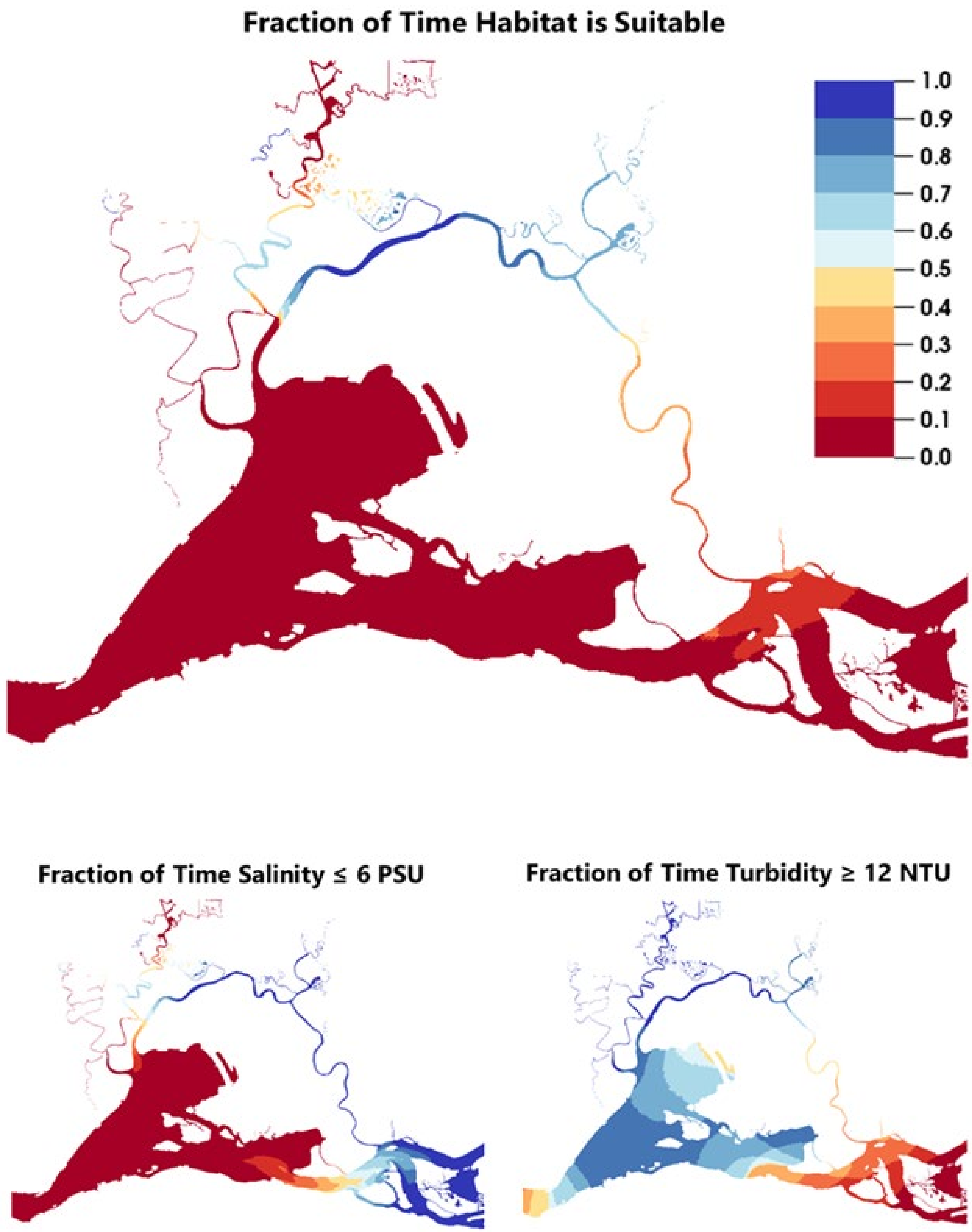

Figure 27. Fraction of time habitat suitability conditions were met from 9/12/20 to 9/24/20 with gate ops (temperature criterion was always met during the period)

Summer of 2020 was overall a very warm period. As shown in the habitat time series (Figure 23) suitable habitat acreage in the marsh dropped dramatically during the warmest period, i.e., between 08/15/20 and 08/28/20, when water temperatures were generally hovering around the suitability threshold of 23.9°C. The spatial impact of this is illustrated in Figure 28, which shows suitable habitat in the two weeks before and during the warmest period, as well as the fraction of time the temperature was suitable in each period.

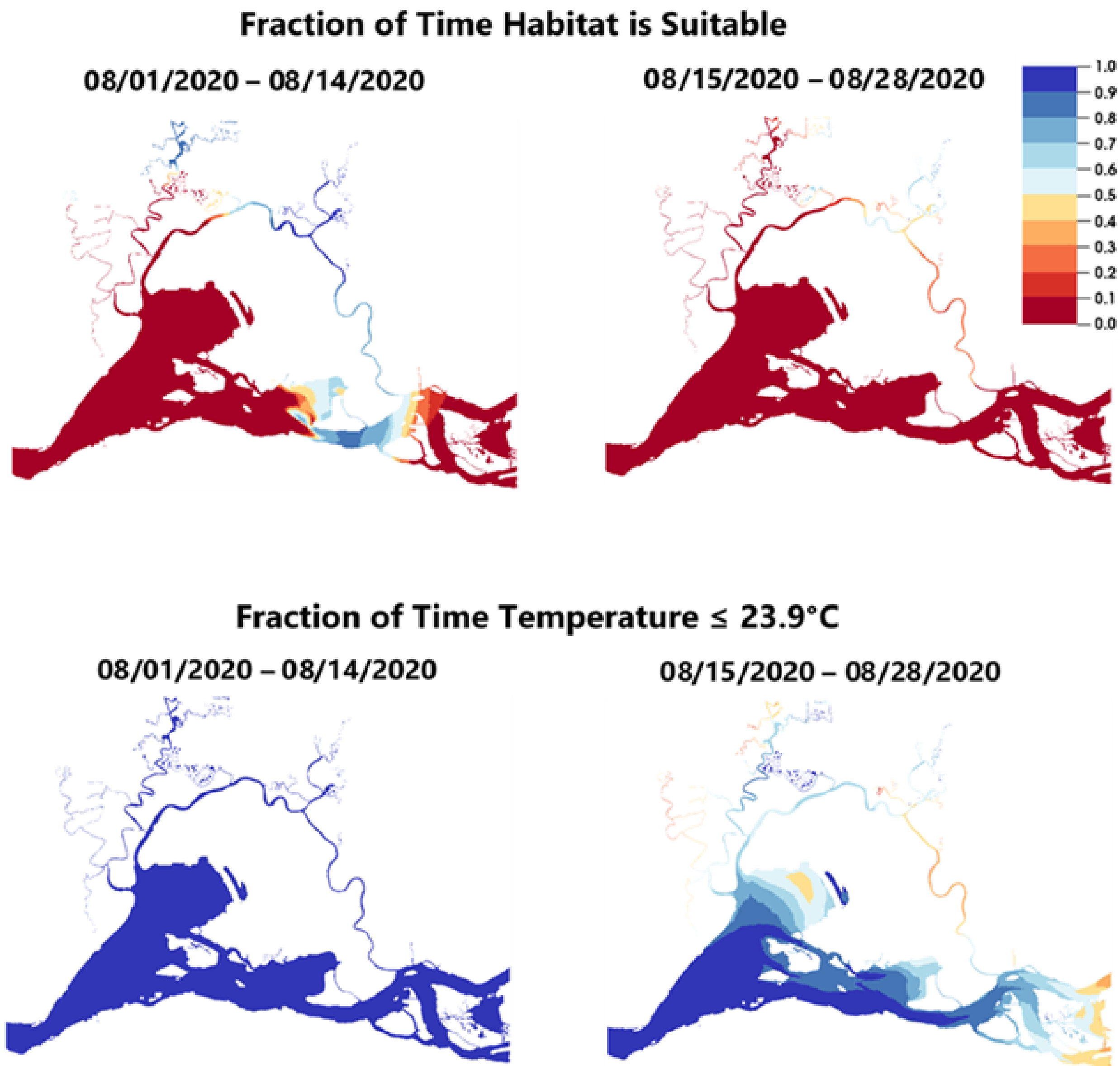

Figure 28. Fraction of time habitat suitability conditions were met for two consecutive weeks in August 2020 (top) and fraction of time the temperature was below 23.9°C in both periods (bottom).

In 2021 an emergency drought barrier was installed upstream in False River and a common question is whether the barrier plays a role this far downstream. Modeling suggests the physical effect of the emergency drought barrier on LSZ habitat is detectable but small. Figure 28 shows the change in mean salinity during the period August 15-28, 2021 given equal hydrology. Time series plots in Figures 24 and 25 indicate some changes in habitat acreage due to salinity and temperature. Besides the change induced by the presence of the barrier itself, the West False River Emergency Drought Barrier supports novel flow management and regulatory relaxation under the Water Board's 2021 Temporary Urgency Change Order which in turn allowed reduced outflow and ultimately salinity in the marsh region. Assessing the extended effects of drought policy are beyond the scope of this model investigation.

Figure 29. Change in mean salinity with and without barrier during the period August 15-28 2021, given equal hydrology

Some of the highest temperatures in 2020 were overestimated at certain locations in the bay/marsh by more than one degree during the period from 08/15/20 to 08/28/20 when temperatures hovered near the 23.9°C threshold. The average bias was 0.85 degrees. The period coincided with very heavy smoke, and the 32km NARR reanalysis inputs for radiation may not have been sufficiently resolved cloud and smoke cover. While the model skill scores are still acceptable through the season, classification errors based on a hard criterion at 23.9 degrees would be affected and required bias correction of 0.85 degrees. Neither the bias nor the classification error consequences occurred in 2021. Modelers anticipate proposing methods to "soften" the thresholding and/or correct for bias in the future.

Abiotic Habitat Attributes

The current prevailing hypothesis is that abiotic habitat conditions for Delta Smelt in the San Francisco Bay-Delta are generally better in years when the low salinity zone in the summer and fall (as indexed by X2) is located further downstream (Brown et al. 2013). Three commonly measured water quality parameters form the underlying basis for this hypothesis: salinity, water temperature, and turbidity; as demonstrated by past studies on Delta Smelt (Nobriga et al. 2008; Mac Nally et al. 2010, Feyrer et al. 2011, Bever et al. 2016).

Abiotic habitat attributes within suitable ranges for Delta Smelt are defined in this report as low salinity conditions of 6 ppt or less, turbidity higher than 12 NTU, and water temperatures below 75°F (~23.9°C) based on Brown et al. (2014). To illustrate conditions for Delta Smelt at the various stations, proportion of time in each day deemed suitable for Delta Smelt based on each water quality parameter threshold was calculated and plotted in a summary heat map (Figure 18). Based on the general understanding of Delta Smelt biology, unsuitable condition based on just a single parameter (e.g., salinity), may preclude most Delta Smelt from the area. More detailed discussion on each water quality parameter can be found below.

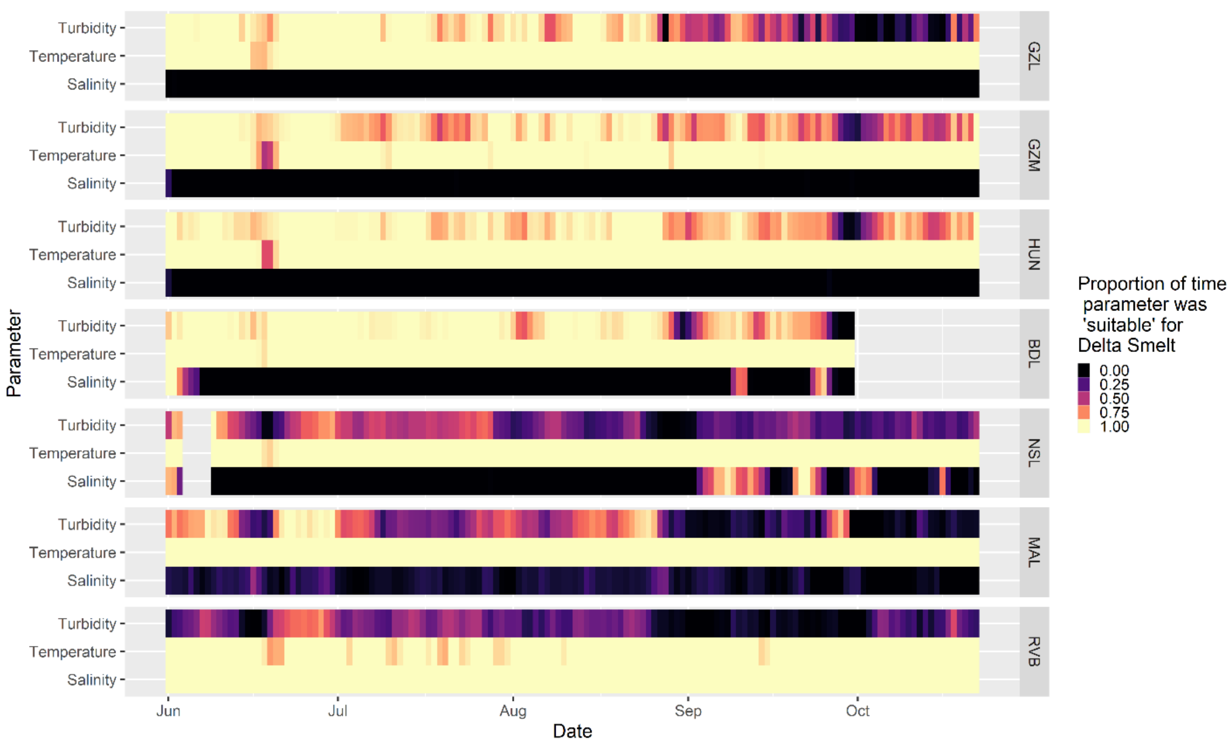

Figure 30. Heat map demonstrating proportion of time in each day that each water quality parameter was suitable for Delta Smelt at the stations shown in Figure 12 (i.e., salinity ≤ 6 ppt, turbidity ≥ 12 NTU, temperature ≤ 23.9° C). Note that data has not undergone quality control/ check and that stations may actually record formazin nephelometric units (FNU) instead; however, the general turbidity patterns observed should remain valid.

Salinity

Delta Smelt has been described as a semi-anadromous species. The species spawns in freshwater habitat and most migrate to brackish low-salinity habitat where they spend large parts of their life cycle. Although some Delta Smelt reside in freshwater year-round, they are uncommon in higher salinity waters. Delta Smelt physiological stress response to high salinity (Komoroske et al. 2016), and studies that demonstrated the species' higher occurrence in low salinity habitat based on field data (Feyrer et al. 2007, Nobriga et al. 2008) are the reasons why size and location of the low salinity zone have been described as key factors for Delta Smelt habitat.

In 2021, salinity within Suisun Marsh was generally highest downstream at Grizzly Bay (GZL) and lowest at Rio Vista upstream (Figure 30 and Appendix-A Figure 1). Sites within Suisun Marsh exhibited the general pattern of increasing salinity between June and September, followed by a decline in salinity in early- to mid-September that continued into October. It is likely that salinity was a limiting factor in Suisun Marsh for Delta Smelt for the majority of the 2021 Summer-Fall period (>6 ppt). As expected based on NDOI pattern, (Figure 6, Operations Section), the MAL station showed a pattern of increasing salinity over time from June to October of 2021. Delta Smelt were not likely to be present around the vicinity of MAL station for the entirety of summer-fall period of 2021; however, salinity upstream of the confluence between Sacramento and San Joaquin Rivers remained suitable for Delta Smelt based on the RVB station at Rio Vista.

Salinity at Belden's Landing (BDL), a monitoring station central to the additional operation of the SMSCG, was above 6 ppt from June to September based on extrapolation of existing data (Figure 3). After September, salinity at BDL declined to roughly around 6 ppt, coincident with the beginning of SMSCG operations. Overall, there was higher salinity in 2021 relative to 2020. Several days of low turbidity (<12 NTU) deemed unsuitable for Delta Smelt were observed at BDL in Summer-Fall of 2021 (Figure 30).

In 2021, mean salinity in the Suisun regions among DOP, STN, and EMP sampling sites was consistently above 6 PSU during the and fall (Appendix-A Figure 2). Salinity in Suisun Marsh dropped in September when the SMSCGs began operating. The Lower Sacramento Region was also slightly brackish, with salinities over 5 PSU on some sampling occasions.

Turbidity

Turbidity has been demonstrated to be a key determinant factor in the occurrence and abundance of Delta Smelt in the field (Feyrer et al. 2007, Nobriga et al. 2008, Mahardja et al. 2017a, Polansky et al. 2018). Under culture conditions, Tigan et al. 2020 found that both turbidity and light intensity, as well as the interaction between these factors, play an important role in the feeding activity, growth, and survival of larval Delta Smelt.

In summer and fall of 2021, western Suisun Marsh sites saw generally higher turbidity relative to eastern sites closer to the confluence (NSL, MAL, and RVB) (Figure 30 and Appendix A Figure 3). The observed low turbidity (<12 NTU) in these more upstream sites may have been a limiting factor for Delta Smelt in this region during summer and fall of 2021. Grizzly Island and Montezuma Slough (GZL, GZM, HUN, BDL) also had fairly low turbidity in the months of September and October of 2021. It should be noted that reported readings in this document are in NTU but collected data from continuous water quality stations may be in FNU instead (DWR Memorandum). Nevertheless, the relative turbidity patterns observed should remain valid as both units (FNU and NTU) are very similar (DWR's June 5, 2020 Memorandum; Morgan-King and Schoellhamer 2013).

In both the summer and fall of 2021, turbidity from discrete samples taken by long-term monitoring programs averaged 14.93 FNU and ranged from 0.34 to 117 FNU. Turbidity was highest in Suisun Marsh, followed by the SDWSC, and the Cache/Liberty complex had the clearest water. (Appendix Figure 4).

Temperature

Evidence of Delta Smelt's sensitivity to warm water temperatures has come from both laboratory and field studies. Critical thermal maxima of juvenile Delta Smelt appear to range somewhere between 25 to 29°C in a controlled laboratory setting (Swanson et al. 2000, Komoroske et al. 2014; Davis et al. 2019), a temperature range that is observed in the field at times. High summer temperature was also found to have a negative impact on juvenile Delta Smelt survival from summer to fall based on a multivariate autoregressive model work and the life cycle model (Mac Nally et al. 2010, Polansky et al. 2020). Moreover, Delta Smelt occurrence seems to be less common at higher water temperature (Nobriga et al. 2008, Sommer and Mejia 2013).

In both the summer and fall of 2021, mean water temperature measured by Summer Townet, FMWT, DOP, and EMP generally increased toward more landward freshwater areas and was generally lower than 23.9°C (Appendix-A Figure 7). However, several sampling events for the freshwater regions of Lower Sacramento, Cache Slough, and Sacramento Ship Channel had readings that approached or exceeded 23.9C, and these warm temperatures continued into September.

Water temperatures did not vary substantially between fixed stations (relative to turbidity and salinity) and generally stayed under 23.9° C for most of the summer and fall period. Nonetheless, there was a notable heatwave in mid-June that likely impacted the Delta Smelt population to some extent. Although mean water temperatures were below 23.9° C for all regions during both seasons, temperatures were warmer further inland and there were multiple sampling events when water temperature was above 23.9° C in the Lower Sacramento and SDWSC regions (Appendix Figure 6). Based on the upper thermal limit for Delta Smelt suitable habitat used in this document (23.9° C, 75° F), water temperature may have limited Delta Smelt survival or distributions in freshwater regions of the northern Delta during summer of 2021 (Figure 30 and Appendix-A Figure 5).

Extent of Contiguous Low Salinity Habitat

In years of high net Delta outflow, habitat suitable for Delta Smelt may extend contiguously from the freshwater habitat of Cache Slough Complex in the North Delta to much of Suisun Bay and Suisun Marsh. However, based on the 2021 X2 location estimates and data from continuous water quality stations, Delta Smelt may have been excluded from large parts of Suisun Bay and Suisun Marsh regions for the majority of 2021 (Figures 31 and 32 below). X2 was estimated at 85km at the start of the summer of 2021 and averaged 89 km over the course of the Summer and Fall (Figures 6, 7). MAL and BDL stations showed salinity levels generally considered too high for persistent Delta Smelt for the majority of Summer and Fall (Figure 30 and Appendix A Figure 1).

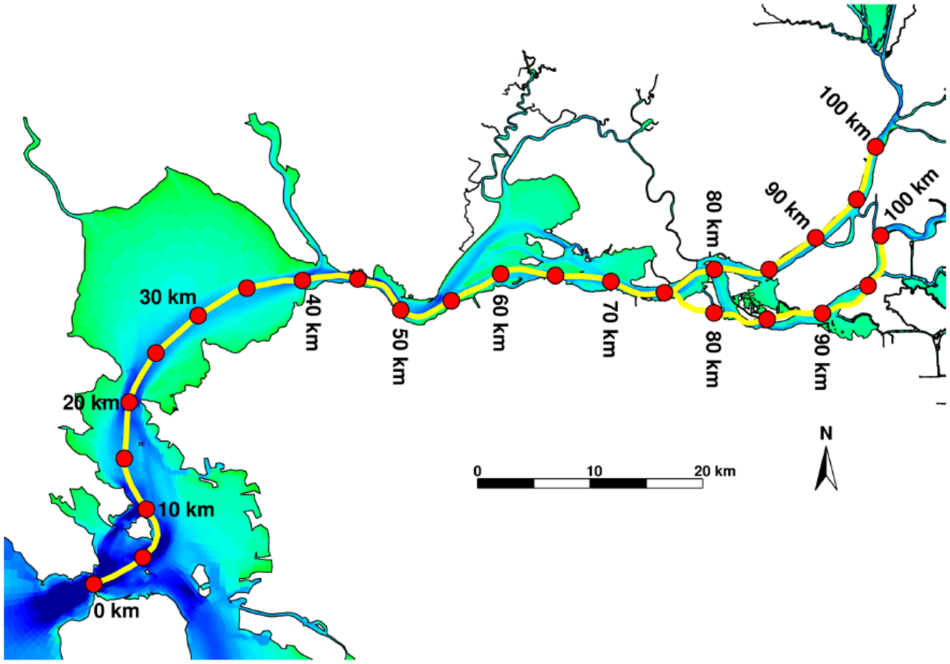

Figure 31. Map of the San Francisco Bay-Delta depicting location of X2 based on distance from the Golden Gate Bridge according to UnTRIM Bay-Delta model taken from MacWilliams et al. (2015).

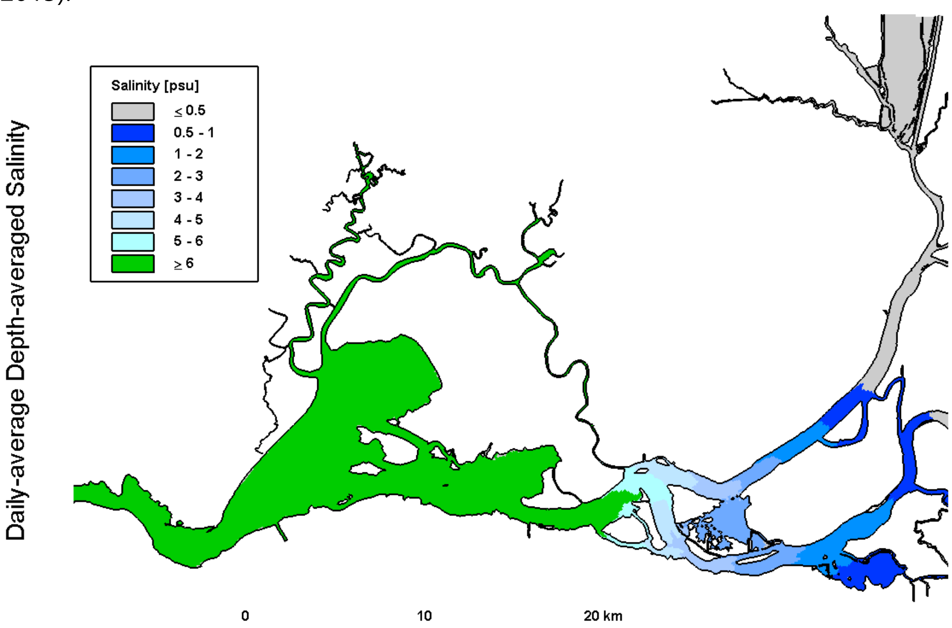

Figure 32. Daily- Average Depth-averaged Salinity when X2 is located at 89km (Delta Modeling Associates 2014), the maximum X2 value between June and October 2021 based on the X2 calculation with CDEC DTO station data.

Contiguous fresh water to low saline water conditions did not extended between Cache Slough and Suisun Bay during the summer and fall in 2021. The reduced outflow in 2021 increased salinity in

Suisun Bay, which likely isolated low salinity habitat to the northern areas of Suisun Marsh and caused contiguous low salinity habitat to contract eastward. During the summer and fall, habitat within Grizzly Bay, Honker Bay and the western part of Suisun Marsh were unsuitable for Delta Smelt. As shown in the Figure 32 above, low salinity habitat (<6 ppt) was generally located in the lower Sacramento and San Joaquin Rivers and their confluence.

Abiotic Limiting Factors

Based on abiotic habitat attributes alone, Delta Smelt distribution in Suisun Marsh was likely limited in Summer-Fall of 2021 due to encroachment of high salinity (0.5 to 6 ppt) water over time, while Delta Smelt's presence within the freshwater reaches of the Delta may have been limited by low turbidity and high-water temperatures (Figure 30).

Biotic Habitat Attributes

Food availability is an essential component of Delta Smelt habitat, but how much is needed is difficult to evaluate in the field because prey densities that are needed to sustain growth vary as a function of water temperature and the amount of time Delta Smelt can safely forage without excessive risk of predation. Food availability can also be impacted by harmful algae blooms and by competition between Delta Smelt and other fishes (Lehman et al. 2010; Whitely and Bollens 2014; Grimaldo et al. 2009). The following section describes the factors that influenced the supporting food web for Delta Smelt in WY 2021.

Chlorophyll

Although chlorophyll level and phytoplankton abundance in the summer-fall period do not directly explain summer-fall Delta Smelt abundance (Mac Nally et al. 2010), they are correlated with calanoid copepod abundance, which are known as favored prey of Delta Smelt (*Eurytemora affinis* in particular) and mysid abundance (Mac Nalley et al. 2010; Bollens et al. 2011; though see Jungbluth et al. 2021; Kimmerer et al 2018) and describing chlorophyll patterns provides a more holistic understanding of conditions in the summer-fall of 2021. Continuous water quality stations (Figure 12) varied in Chlorophyll fluorescence with several short, localized spikes during the summer and fall. (Figure 33). Average Chlorophyll fluorescence was highest at the GZM station and was generally greater for Suisun Marsh area stations than other regions. However, the highest daily mean was recorded at the MAL period in October. Chlorophyll fluorescence was lowest at the RVB stations, with the latter never ranging above three fluorescence units. Chlorophyll fluorescence was highest in Suisun Marsh, similar to patterns in previous years (Sommer et al. 2020).

In both the summer and fall of 2021, the average and upper range of Chlorophyll a (mg/l or 6.9 ug/L) measured by DOP was greatest in Suisun Marsh, followed by Suisun Bay, when compared to other regions (Figure 34), agreeing with data collected by the fixed stations. Concentrations were much lower in the Sacramento and Cache/Liberty regions than Suisun Regions and highly variable chlorophyll in the SDWSC.

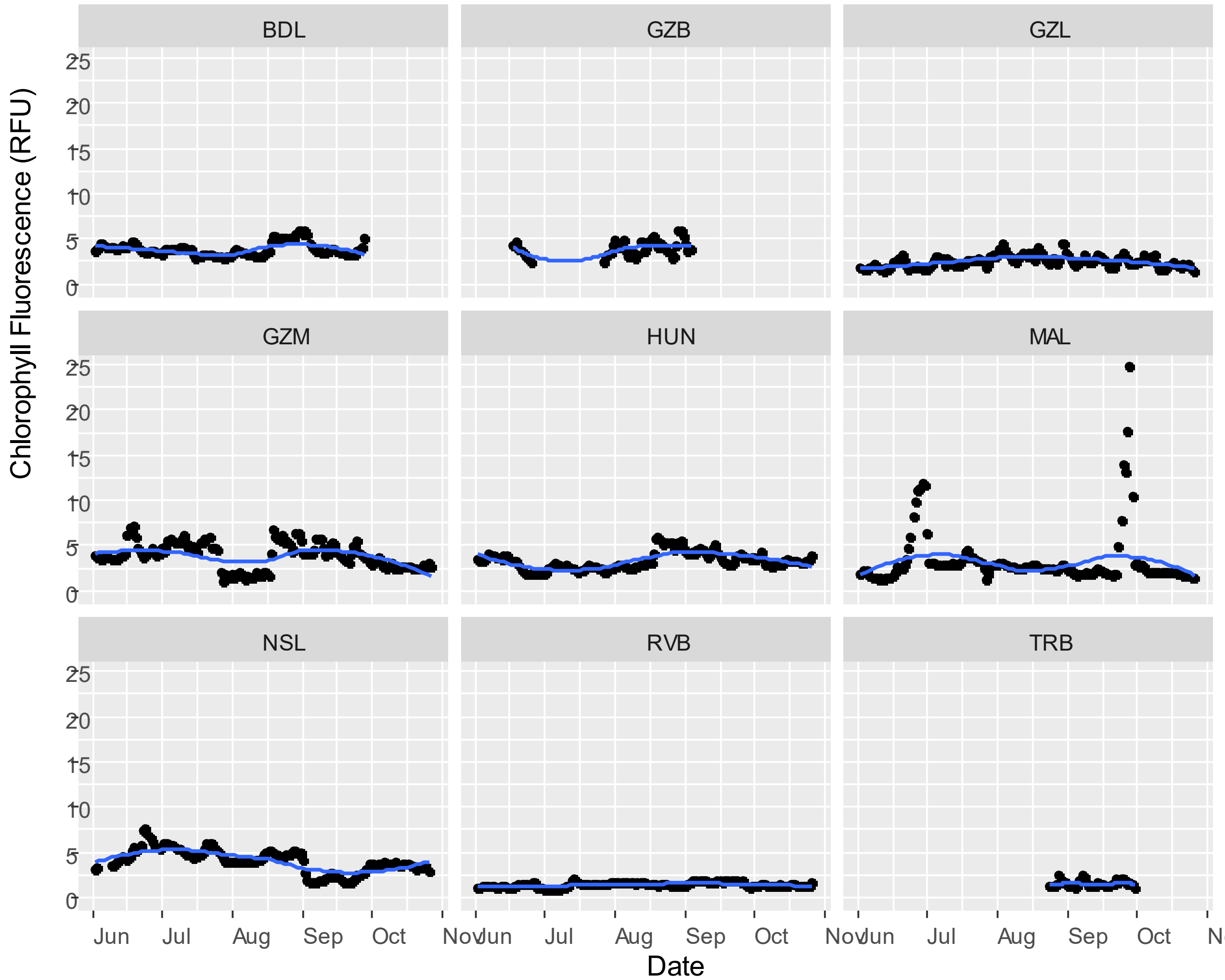

Figure 33. Daily average Chlorophyll fluorescence (in relative fluorescence units) from continuous sondes in 2021.

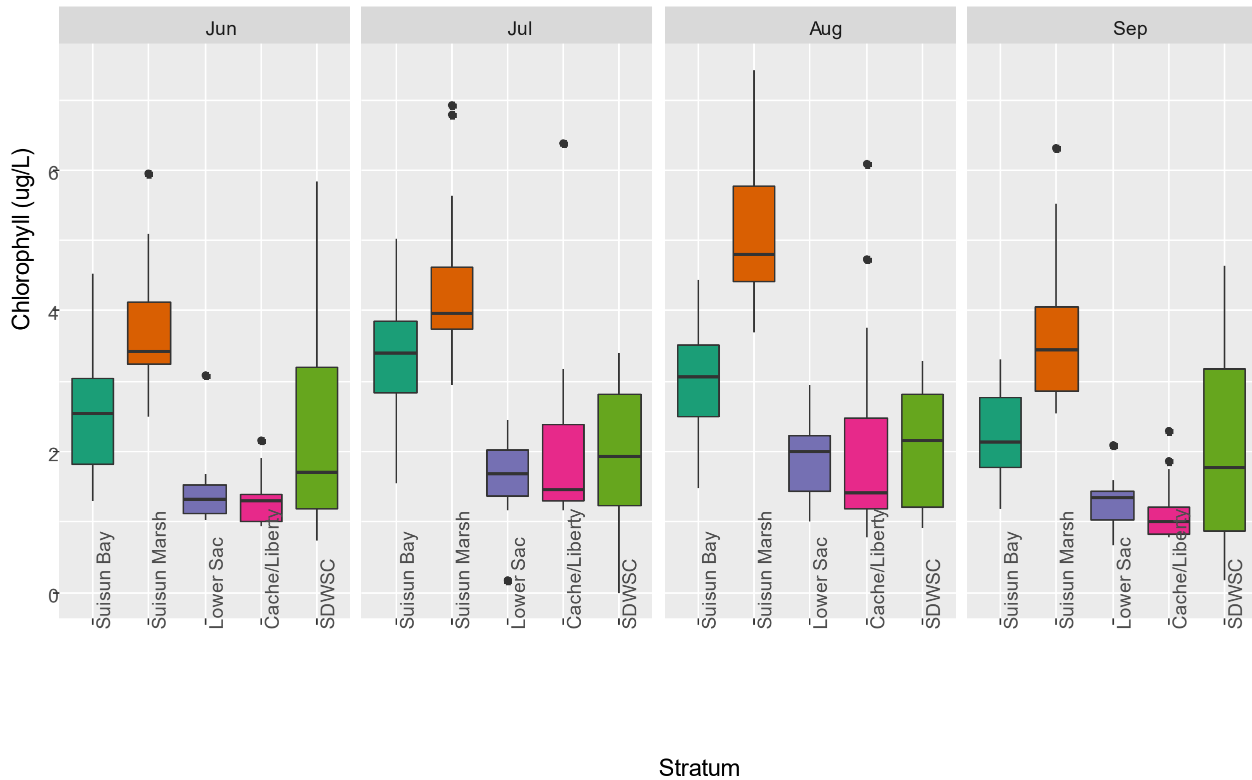

Figure 34. Variation in Chlorophyll a (µg/l) across regional strata as measured during 2021 DOP and EMP sampling.

Phytoplankton

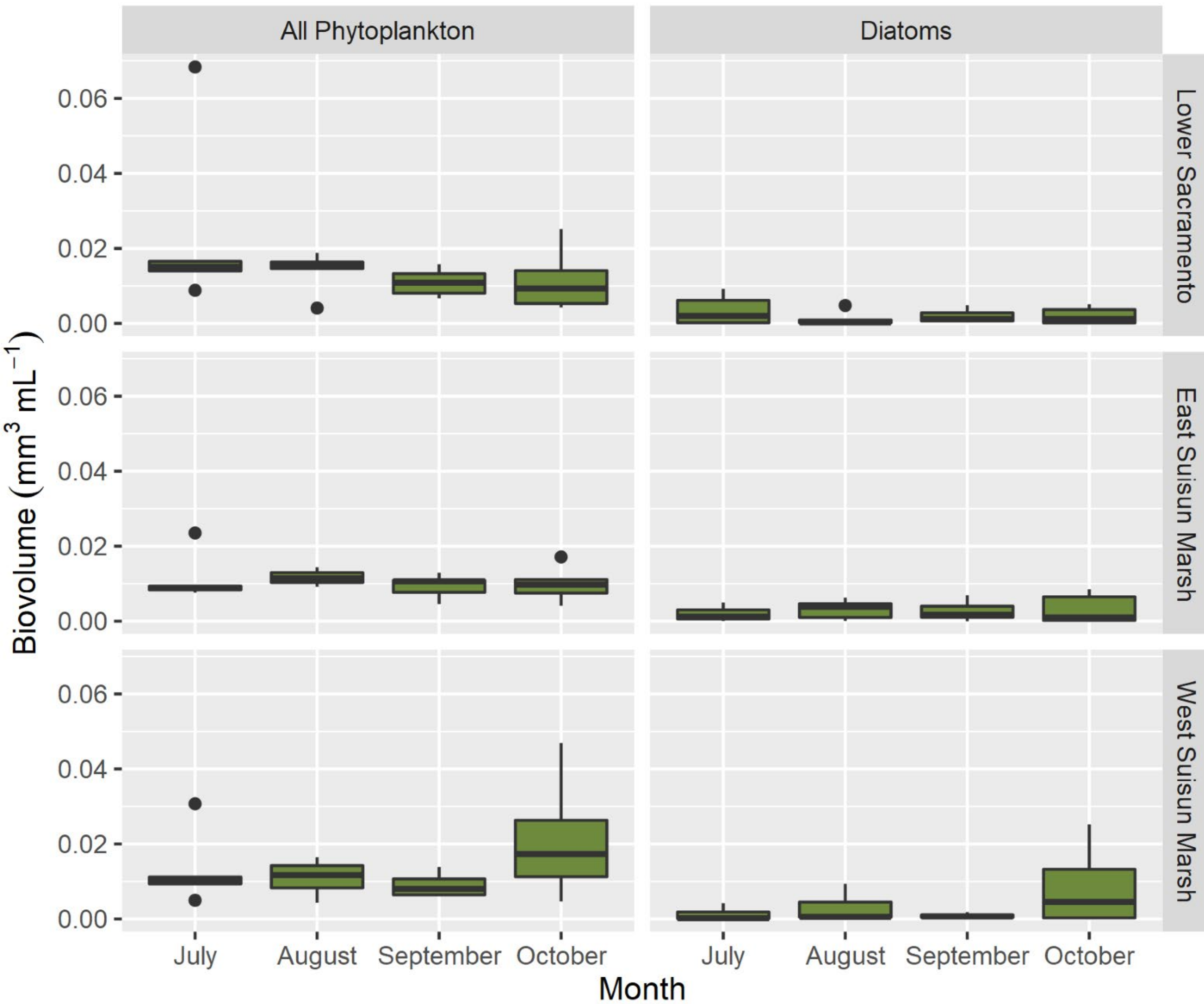

Figure 23. Biovolume of all phytoplankton (left) and diatoms (right) based on samples collected during 2020 by the Environmental Monitoring Program, Summer Townet Survey, and Fall Midwater Trawl Survey. Sample sizes range 4-7 for each month by year combination

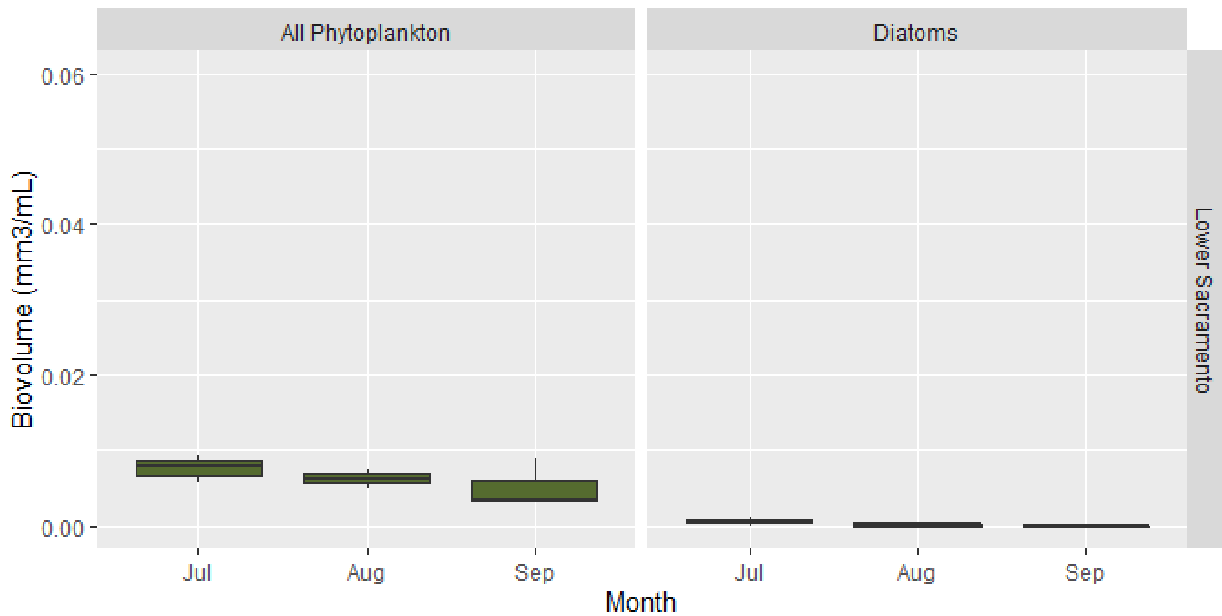

Figure 35. Biovolume of 70 samples collected by EMP, Summer Townet, and Fall Midwater Trawl - the Environmental Monitoring Program in the Lower Sacramento region. Data from the other regions was available in time of this report.

Newly available information from 2020 showed total phytoplankton biovolume did not differ among the three regions examined ($p = 0.38$; Lower Sacramento River, eastern Suisun Marsh, western Suisun Marsh) or among the four months examined ($p = 0.42$; July – October) (Figure 35). Diatom biovolume also did not differ among regions ($p = 0.73$) or months ($p = 0.50$) (Figure 36.). Mean total phytoplankton biovolume was 0.013 $mm^3\ mL^{-1} \pm 0.010\ mm^3\ mL^{-1}$ SD. Mean diatom biovolume was 0.003 $mm^3\ mL^{-1} \pm 0.004\ mm^3\ mL^{-1}$. Diatoms comprised 21.1 percent of total phytoplankton biovolume. The pattern hypothesized was that both total phytoplankton biovolume and total diatom biovolume would be highest in western Suisun Marsh and lowest in the Lower Sacramento River. The 2020 data do not match this hypothesis, but statistical power is limited with only a single year of data.

In 2021, a total of 70 samples were collected by EMP, Summer Townet, and Fall Midwater Trawl during July to October to monitor the phytoplankton community associated with the SMSCG action. These samples were distributed across the three focal regions of Delta Smelt habitat, including the Lower Sacramento River/Confluence ($n = 23$), Eastern Suisun Marsh ($n = 24$), and Western Suisun Marsh ($n = 23$). However, only data from the Lower Sacramento River was available in time for this report.

In 2021, only data from the Lower Sacramento region was processed in time for this report (Figure 36), so no statistical comparisons could be made between regions. Mean total phytoplankton biovolume was 0.013650 $mm^3\ mL^{-1} \pm 0.019\ mm^3\ mL^{-1}$ SD. Mean diatom biovolume was 0.0008 $mm^3\ mL^{-1} \pm 0.002\ mm^3\ mL^{-1}$. Diatoms comprised 5.73 percent of total phytoplankton biovolume.

Figure 36. Biovolume of all phytoplankton (left) and diatoms (right) based on samples collected during 2021

Zooplankton

To assess localized foraging conditions, a total of 90 samples were collected by CDFW's STN and FMWT surveys for monitoring of the zooplankton community during July to October of 2021. These samples were distributed across four regions, including the Lower Sacramento River/Confluence (n = 36), Eastern Suisun Marsh (n = 24), Western Suisun Marsh (n = 16), and Suisun Bay (n = 14). Currently, about 60 percent of these samples have been processed. However, the data was not available in time for this 2021 seasonal report.

Newly available information from 2020 showed zooplankton biomass was significantly (p= 0.03) lower than 2019 and significantly (p= 0.02) higher than 2018. The River region had significantly higher biomass in all years compared to the other regions (River vs Suisun Bay: p< 0.001; River vs West Marsh: p< 0.01; River vs East Marsh: p<0.0001), with the East Marsh having the lowest biomass in 2020 and 2018. In both 2018 and 2019 there was a decrease in biomass from July to August, however, the opposite trend was seen in 2020 with August having higher biomass than the other months. This was mostly due to *Tortanus* spp., a higher salinity tolerant species, increasing in the Western Marsh during this time. *Pseudodiaptomus* spp. and *Acartiella sinensis* were the dominant species from July to October in all years.

Figure 37. Mean biomass per unit effort of major zooplankton taxa contributing to Delta Smelt diets in regions surrounding the SMSCG.

To assess regional foraging conditions, preliminary data from a sub-set of meso-zooplankton tows conducted by the DOP in the summer (n = 3; June-August) and early fall (n = 2; September-October) of 2020 and 2021 is presented in figures 38 through 41 and summarized below. Data for

2020 are updated from the 2020 seasonal report to include all weekly samples; data for 2021 are from samples collected every other week during the beginning of June through end of October. This dataset only used the channel surface and channel deep tows. Channel deep tows were not conducted when sampling sites were less than 20 feet in water depth. No shoal samples were processed for this dataset. The remaining 2021 meso- and macro-zooplankton data from the DOP will not be available in time for this 2021 seasonal report.

Total meso-zooplankton biomass and abundance were greatest in the SDWSC the summer and early fall of 2020 and 2021, followed by Cache Slough in the summer and early fall of 2020 and the summer of 2021(Figures 38-41). Meso-zooplankton biomass was lowest in Suisun Bay and Suisun Marsh during the summer and early fall. This is consistent with previous studies showing lower zooplankton biomass in brackish water, and Suisun Marsh in particular (Hammock et al. 2017; Sommer et al. 2020). Zooplankton biomass and abundance were greater in 2021 than in 2020 in both summer, but similar or lower in the early fall. During 2021, meso-zooplankton abundance and biomass were lower in the SDWSC, Cache Slough, and the lower Sacramento River during early fall compared to summer.

Patterns in 2020 and 2021 zooplankton composition were roughly similar between biomass and abundance among and within regions for both seasons. The three freshwater regions sampled (Sacramento Deepwater Ship Channel, Cache Slough, and Lower Sacramento) were dominated by calanoid copepod *Pseudodiaptomus forbesi* adults and *Psuedodiaptomus* spp subadults. Other prey, which include cladocerans from the families *Daphnidae* and *Sididae*, dominated the zooplankton biomass and abundance in the Sacramento Deepwater Ship Channel, with the exception of fall 2021. In 2020, the calanoid copepod *Acartiella sinenesis* was the major species numerically in the low-salinity regions of Suisun Marsh and Suisun Bay, while the calanoid copepod genus *Tortanus* contributed to almost half of the biomass. *A. sinenesis* abundance and biomass in Suisun Marsh and Suisun Bay were lower in 2021.

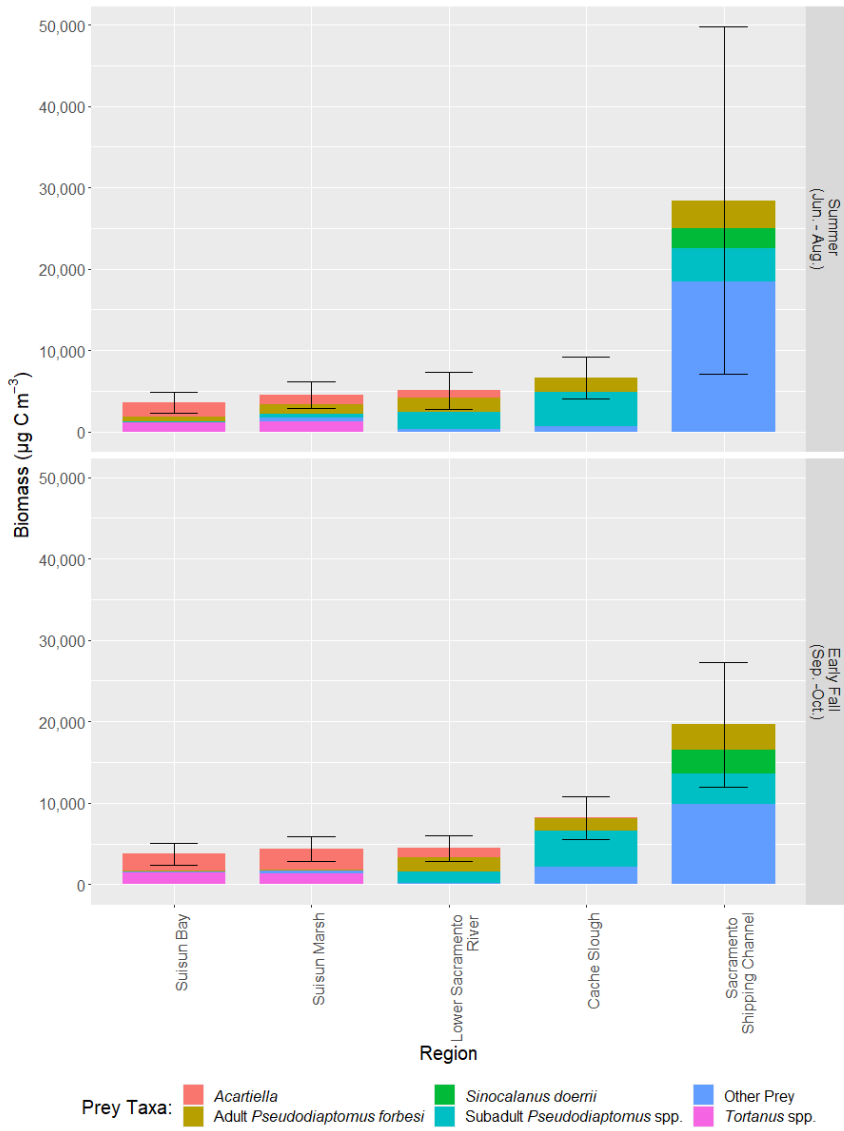

Figure 38. Variation in monthly zooplankton biomass (mean µg C/m3 + SE) across regional strata as measured during 2020 DOP sampling.

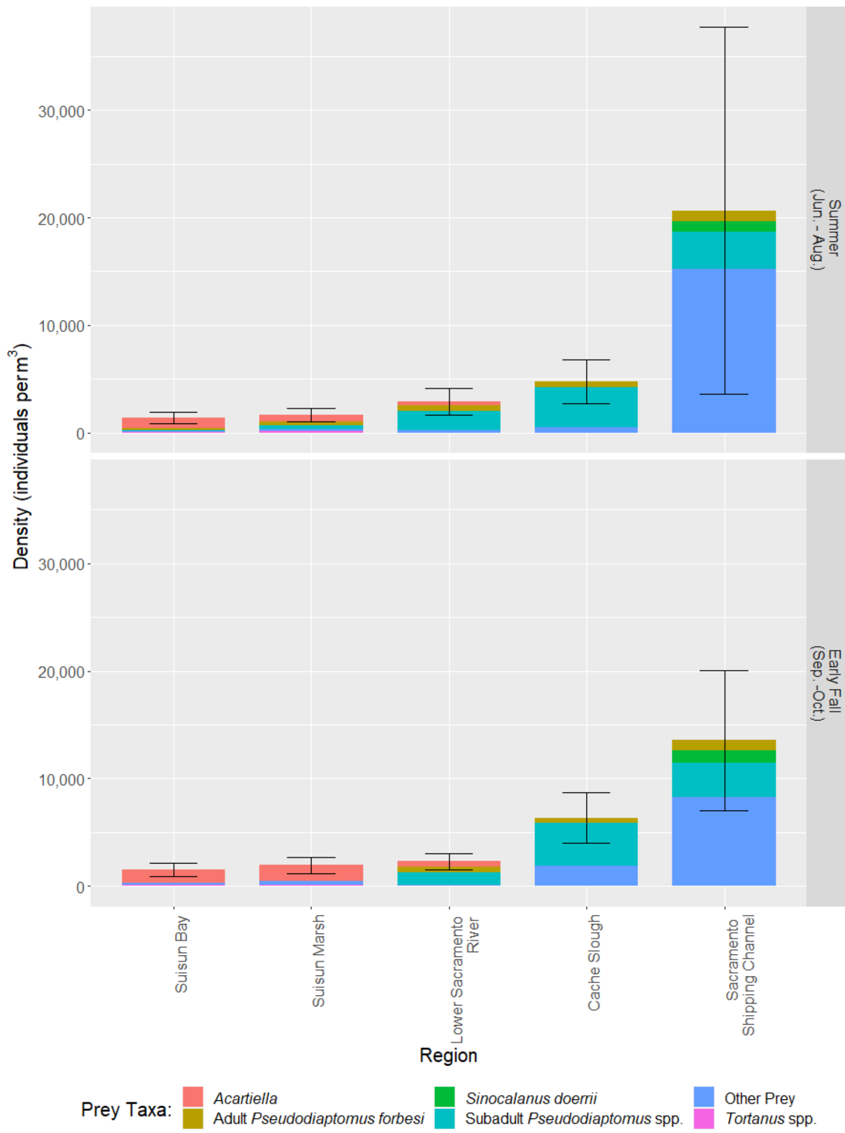

Figure 39. Variation in monthly zooplankton abundance (individuals/m3 + SE) across regional strata as measured during 2020 DOP sampling.

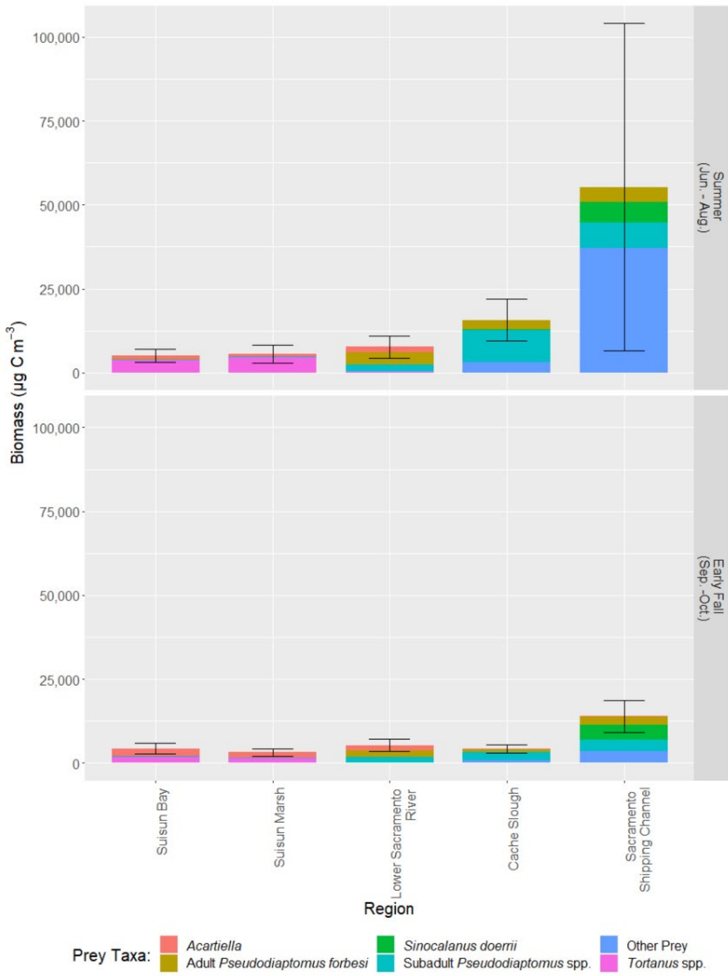

Figure 40. Variation in monthly zooplankton biomass (µg C/m3) across regional strata as measured during 2021 DOP sampling.

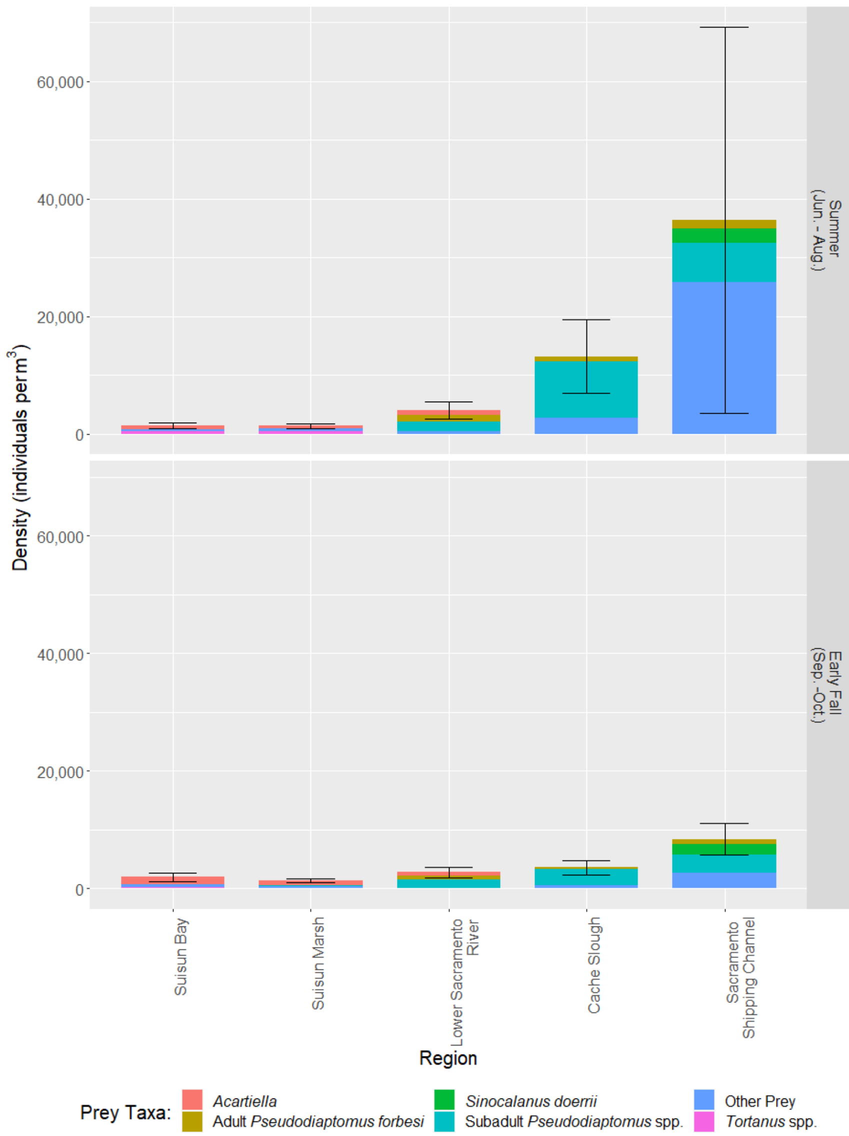

Figure 41. Variation in monthly zooplankton abundance (individuals/m3) across regional strata as measured during 2021 DOP sampling.

Microcystis

Visual assessments of *Microcystis* levels from the EMP, Summer Townet, Fall Midwater Trawl, DOP, and DWR's North Central Region Office (NCRO) indicate that 2021 had similar occurrence of *Microcystis* throughout the system as 2020, but higher than most of the preceding years, with a peak in July and August (Figure 42).

Variation in *Microcystis* among regional strata as largely followed a similar trend between seasons (Figure 43). *Microcystis* presence and overall intensity was lowest in Suisun Marsh and highest in the Lower Sacramento and Suisun Bay.

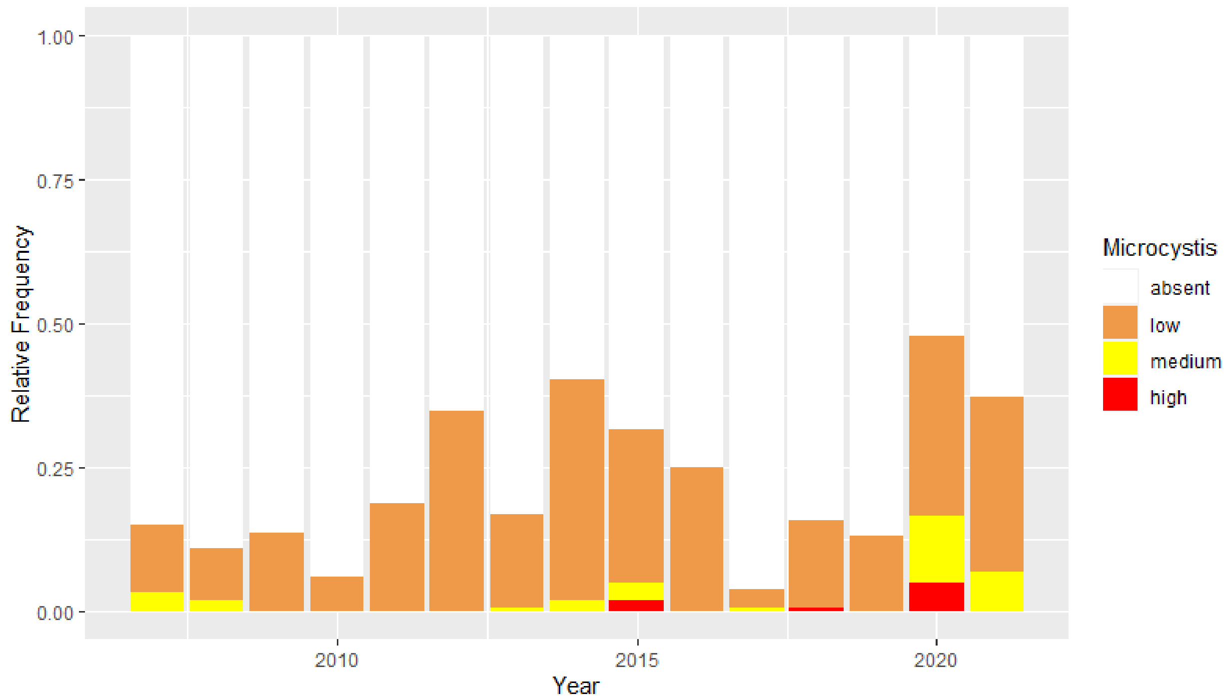

Figure 42. Summer-Fall Microcystis bloom intensity based on visual ranking data from EMP, Summer Townet, and FMWT comparing previous years to 2021. These data were only from stations within regions shown in (Figure 13). Microcystis bloom presence and intensity are measured on a qualitative scale with 5 categories: absent, low (widely scattered colonies), medium (adjacent colonies), high (contiguous colonies), and very high (concentration of contiguous colonies forming mats/scum).

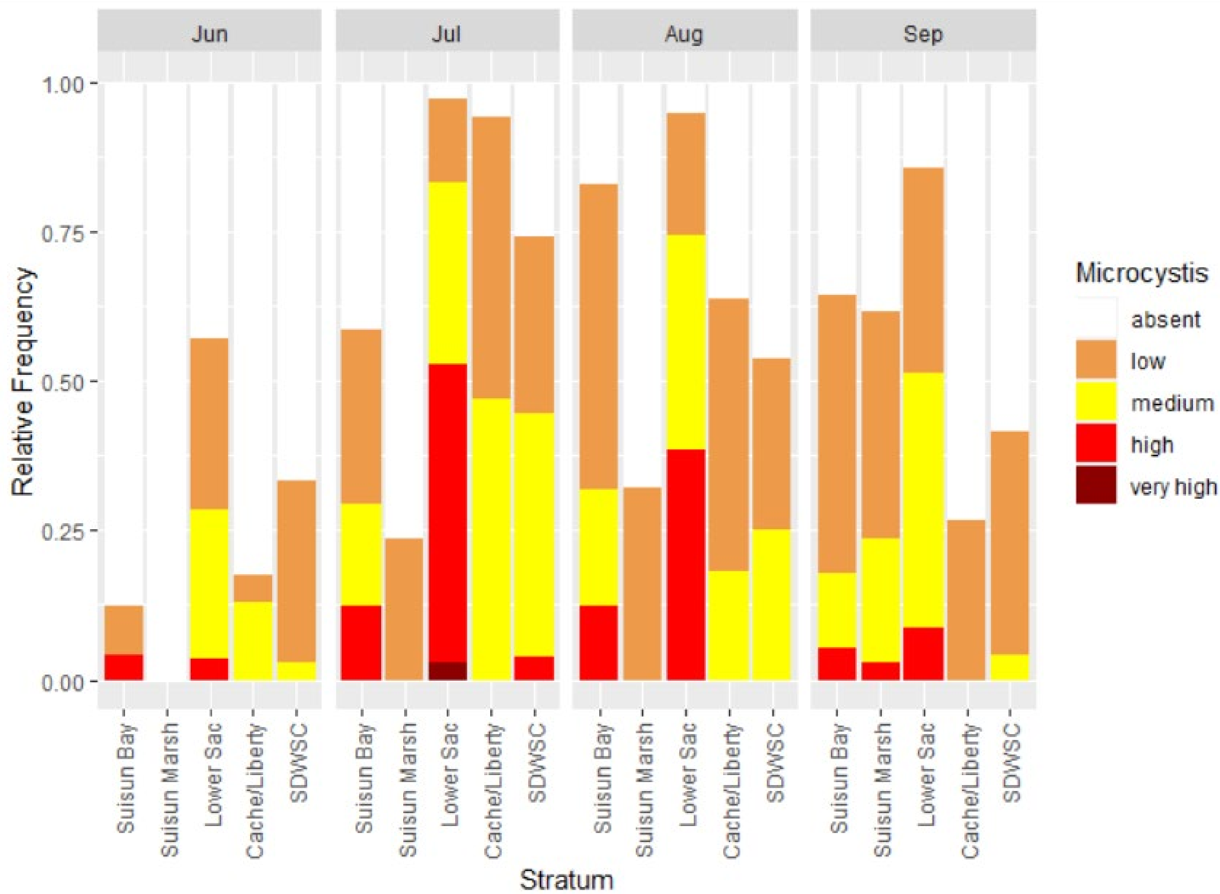

Figure 43. Variation in visually detected *Microcystis* blooms among regional strata as measured during 2021 EMP, FMWT, DOP, and STN sampling. *Microcystis* presence and intensity were measured on a qualitative scale with 5 categories: absent, low (widely scattered colonies), medium (adjacent colonies), high (contiguous colonies), and very high (concentration of contiguous colonies forming mats/scum).

Clam Density and Biomass

Analysis of clam data from 2018-2020 revealed a few predominant patterns. First the distribution of the two clam species followed the estuarine gradient in Suisun Marsh. While both species are fairly tolerant of salinity variance and were found in mixed communities through much of the marsh, there was more chance of *Corbicula fluminea* being detected at sites with lower salinity, below approximately 5 ppt (logistic model coefficient = 1.29, p<0.001), and more *Potamocorbula amurensis* biomass at higher salinities, above approximately 5 ppt (log model coefficient = 0.68, p<0.001). Second, there was a seasonal difference between summer and fall, with more sites experiencing clam grazing of any kind in September than in July (logistic model coefficient 1.55, p=0.006). Since the clam species both reproduce throughout the summer, the difference between sampling months probably reflects the arrival of new juvenile clams after summer's reproductive season. Finally, we observed that channels with shallower water had a lower chance of *C. fluminea* presence (logistic model coefficient 0.33, p=0.005), less *P. amurensis* biomass (log model coefficient 0.5, p<0.001), and less total clam grazing (logistic model coefficient 1.39, p<0.001). The pattern of fewer clams in shallower water has been noticed before in Suisun Marsh (O'Rear and Moyle 2014.).

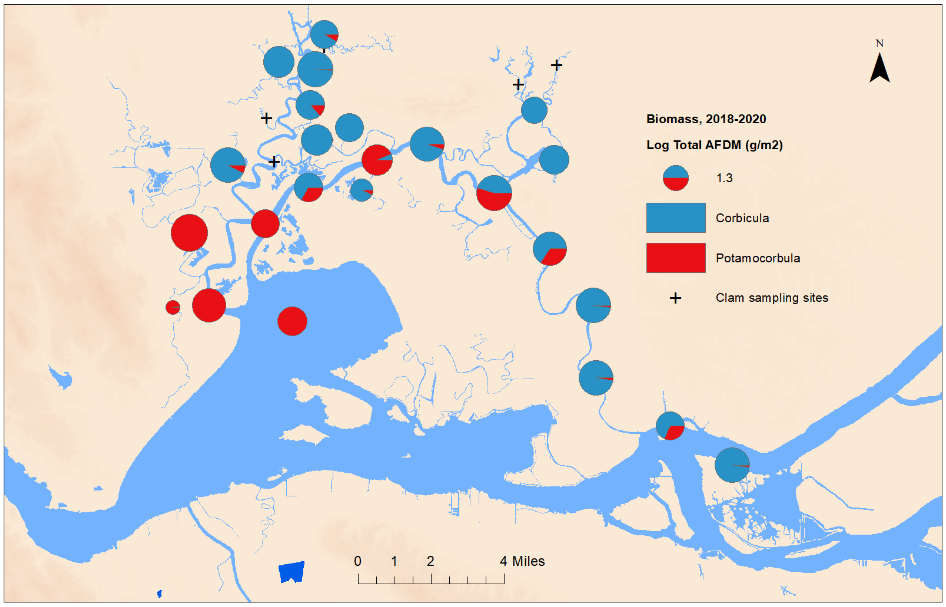

Figure 44. Map showing biomass of invasive bivalves Corbicula and Potamocorbula in Suisun Marsh from 2018-2020

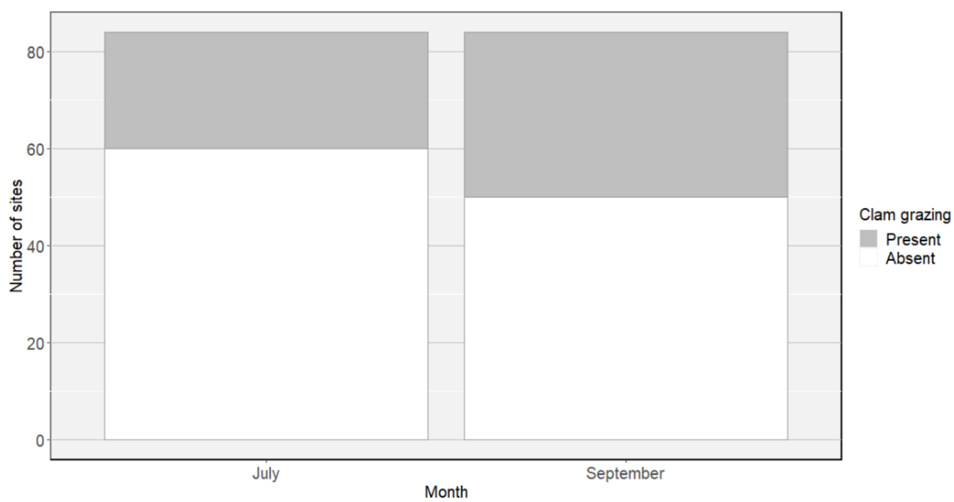

Figure 45. Number of sites in Suisun Marsh at which more than trivial amounts of clam grazing occurred in 2018-2020.

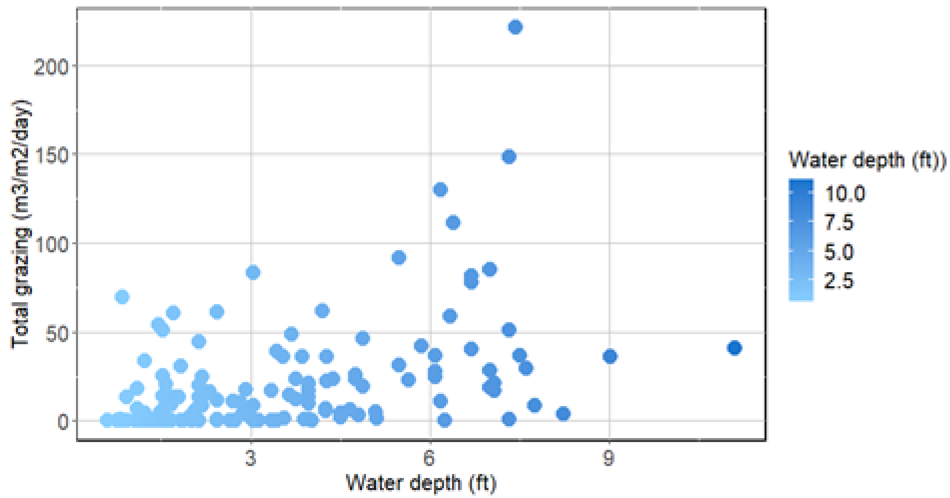

Figure 46. Total clam grazing as a function of water depth in Suisun Marsh 2018-200.

Biotic Limiting Factors

Previous studies have shown the factors that lead to decline of Delta Smelt are multifaceted and often operate simultaneously. As such, it is difficult to determine the limiting biotic factors that drive Delta Smelt abundance and distribution in 2021, especially given that the majority of biotic data remain unavailable at the time of this report's publication. Based on the available data so far, phytoplankton and zooplankton productivity were similar to other dry years in the past two decades. There was a large, concentrated harmful algal bloom in the central/south Delta in July of 2021, but toxicity was relatively low, and the bloom did not extend into the primary Delta Smelt habitat areas in the North Delta or Suisun Marsh/Suisun Bay (USGS data: https://tableau.usgs.gov/views/SFBD_Data_Portal/Mapping2018and2020). However, the effects of long-term biotic changes to the system that are detrimental to Delta Smelt (e.g., reduction of food due to invasive clams, shifts in the zooplankton community) have continued to persist.

Food Enhancement Actions

North Delta Food Subsidies-Colusa Basin Drain Study

Each year, DWR monitors continuous and discrete water quality parameters, phytoplankton, and zooplankton before, during, and after the NDFS flow pulse at sites upstream in the Colusa Basin Drain and Yolo Bypass and downstream in the Cache Slough Complex and lower Sacramento River (Figure 47). Sampling begins in July or August and continues through November in years with non-managed flow pulses or MA-Ag actions. In years with MA-SR actions, sampling occurs from June through September. Water quality parameters include temperature, dissolved oxygen (DO), conductivity, pH, turbidity, and secchi depth. Water samples for nutrients, phytoplankton, and zooplankton are collected concurrently with water quality measurements.

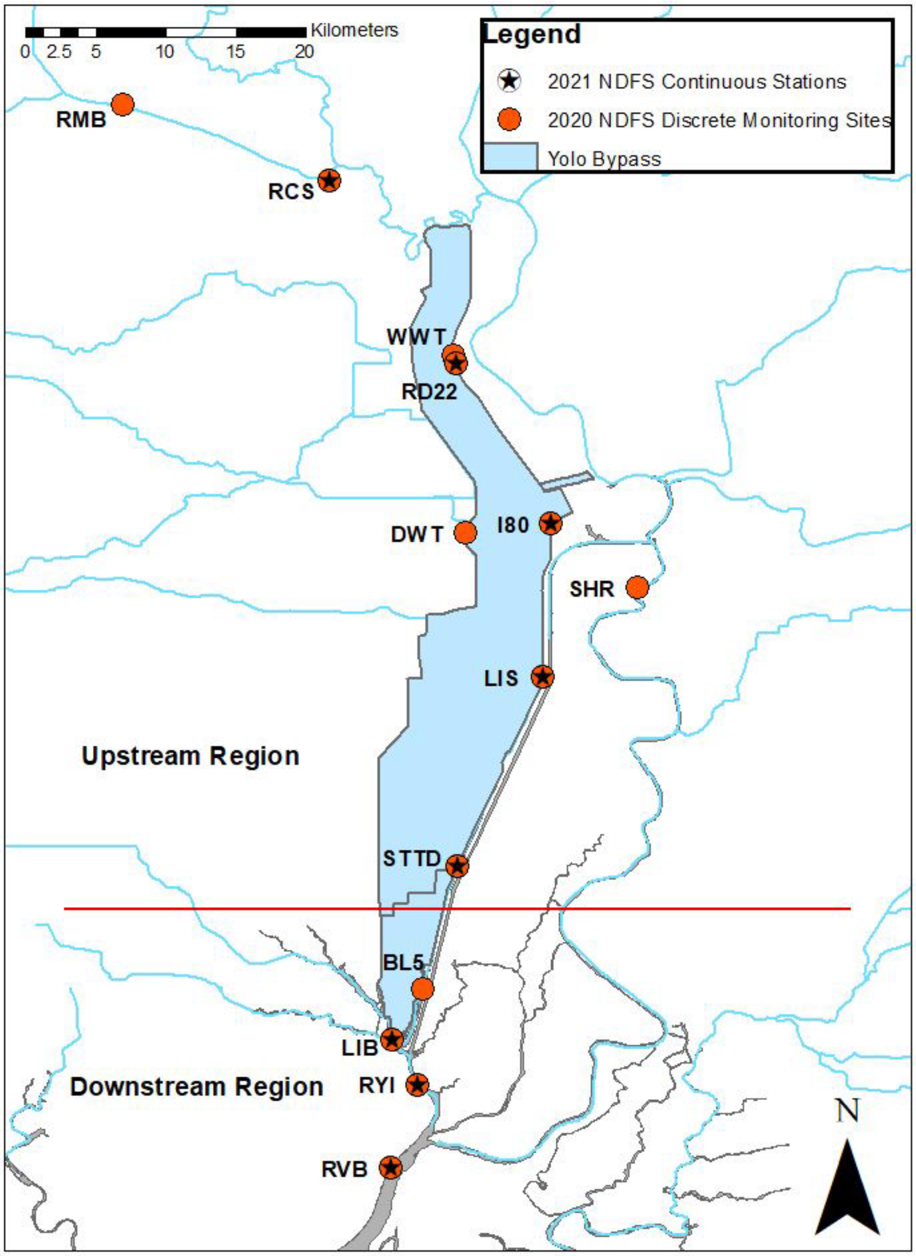

Figure *47*. Map of the NDFS study area. Red circles indicate monitoring sites for discrete water quality and biological responses to flow pulses. Circles with stars indicate sites that were monitored for continuous water quality. The red line separates monitoring sites into Upstream and Downstream regions. Upstream region sites for monitoring include Rominger Bridge (RMB), Ridge Cut Slough at Highway 113 (RCS), Woodland Wastewater Treatment (WWT), Toe Drain at Road 22 (RD22), Davis Wastewater Treatment (DWT), Toe Drain at I80 (I80), Toe Drain below Lisbon Weir (LIS), and Screw Trap at Toe Drain (STTD). Downstream region sites include Below Toe Drain in Prospect Slough (BL5), Liberty Island (LIB), Ryer Island (RYI), and Sacramento River at Rio Vista Bridge (RVB). Sacramento River at Sherwood Harbor (SHR) is a control site for biological monitoring. RMB and RCS are alternative sites for sampling the agricultural source water. RMB and RCS were sampled in 2020, but only RMB was sampled in 2021 for discrete monitoring when the channel was dry at RCS during part of the monitoring season.

Discrete monitoring data for the NDFS Study in 2020 (nutrients, phytoplankton, zooplankton) that were not available for the 2020 seasonal report are presented below. Due to unsafe sampling conditions resulting from wildfire smoke and the COVID-19 pandemic, discrete monitoring data are available only from three transects in July and August before the non-managed flow pulse. Therefore, we qualitatively compare water quality and phytoplankton and zooplankton levels between upstream and downstream regions of the study area but are unable to examine food web responses before, during, and after the small non-managed flow pulse that occurred between September 1 and 16, 2020.

In 2020, Most physical water quality parameters differed significantly between the upstream and downstream NDFS study regions according to Welch's two-sample t-tests (Figure 48). Although pH was similar between regions ($t_{8.00} = 1.45$, $p = 0.19$), other physical water quality parameters differed. Mean DO (mg/L) ($t_{5.45} = -2.80$, $p = 0.03$) and secchi depth (m) ($t_{4.24} = -7.51$, $p < 0.01$) were higher in the downstream region, whereas temperature (ºC) ($t_{5.30} = 3.69$, $p = 0.01$), turbidity (FNU) ($t_{5.06} = 3.51$, $p = 0.02$), and specific conductivity (µS/cm at 25 ºC) ($t_{5.02} = 3.84$, $p = 0.01$) were higher upstream. Nutrient levels qualitatively differed between upstream and downstream before the 2020 non-managed flow pulse (Figure 49). We were unable to run statistical tests on nutrient data due to limited sample sizes resulting from nutrient concentrations below the laboratory reporting limit. Overall nutrient levels (mg/L) were low in the study region, but ammonia concentrations were somewhat higher in the downstream region, and nitrate/nitrite and ortho-phosphate were higher in the upstream region.

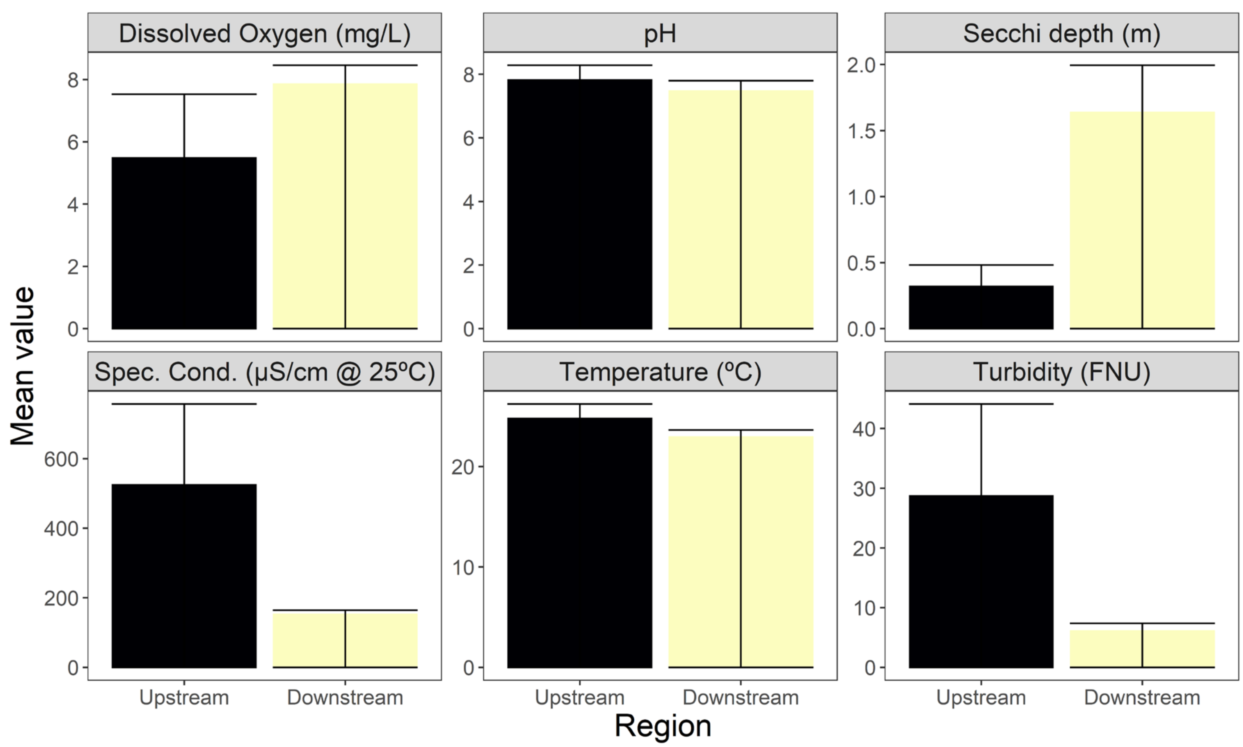

Figure 48. North Delta Food Subsidy study water quality measurements in 2020 from upstream and downstream regions and three transects in July and August, before the non-managed flow pulse. Mean (+ 1 SD) values for dissolved oxygen (mg/L), pH, secchi depth (m), specific conductivity (µS/cm at 25 ºC), temperature (ºC), and turbidity (FNU) were measured with a YSI ProDSS.

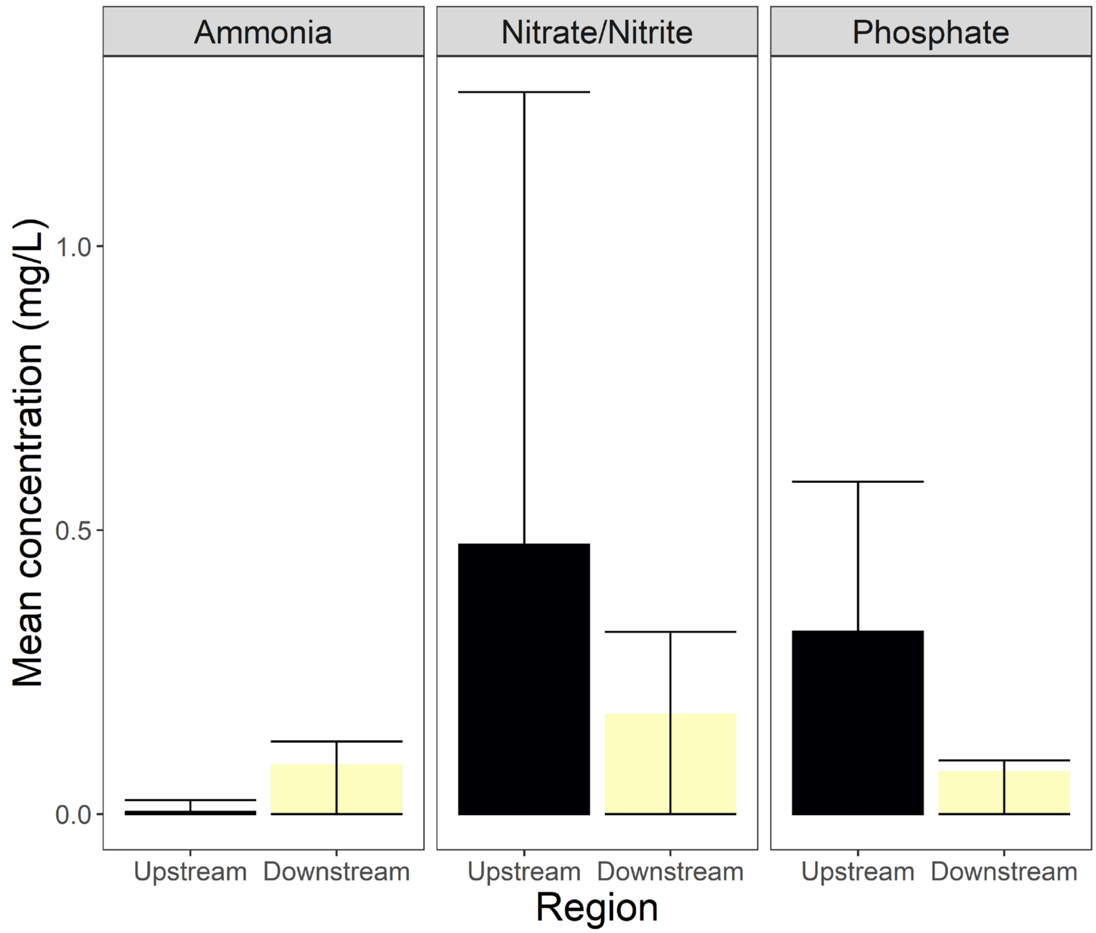

Figure 49. North Delta Food Subsidy study nutrient concentrations in water from three transects in July and August 2020, before the non-managed flow pulse. Mean concentrations (mg/L+1 SD) for dissolved ammonia, dissolved nitrate + nitrite and dissolved ortho-phosphate for sites in upstream and downstream study regions.

In 2020, an assessment of the lower trophic food web demonstrated that phytoplankton biovolume (μm³/mL) differed between upstream and downstream regions before the non-managed flow pulse. Welch's two-sample t-tests indicate that the log of the mean total phytoplankton biovolume was greater upstream ($t_{7.99} = 3.13$, $p = 0.01$; Figure 50). While the log of the mean total zooplankton CPUE (catch per unit effort, number/m³) did not differ by study region ($t_{6.12} = -0.79$, $p = 0.46$; Figure 51), the log of mean CPUE of some zooplankton taxonomic groups varied by region (Figure 52). For example, calanoid copepod mean CPUE was greater downstream ($t_{7.97} = -3.39$, $p < 0.01$), whereas cladoceran CPUE was greater upstream ($t_{6.93} = -3.63$, $p < 0.01$). Cyclopoid ($t_{7.85} = 2.18$, $p = 0.06$) and harpacticoid copepod mean CPUE ($t_{4.86} = -2.42$, $p = 0.06$), and microzooplankton and nauplii CPUE ($t_{7.22} = -0.97$, $p = 0.36$) were similar between regions.

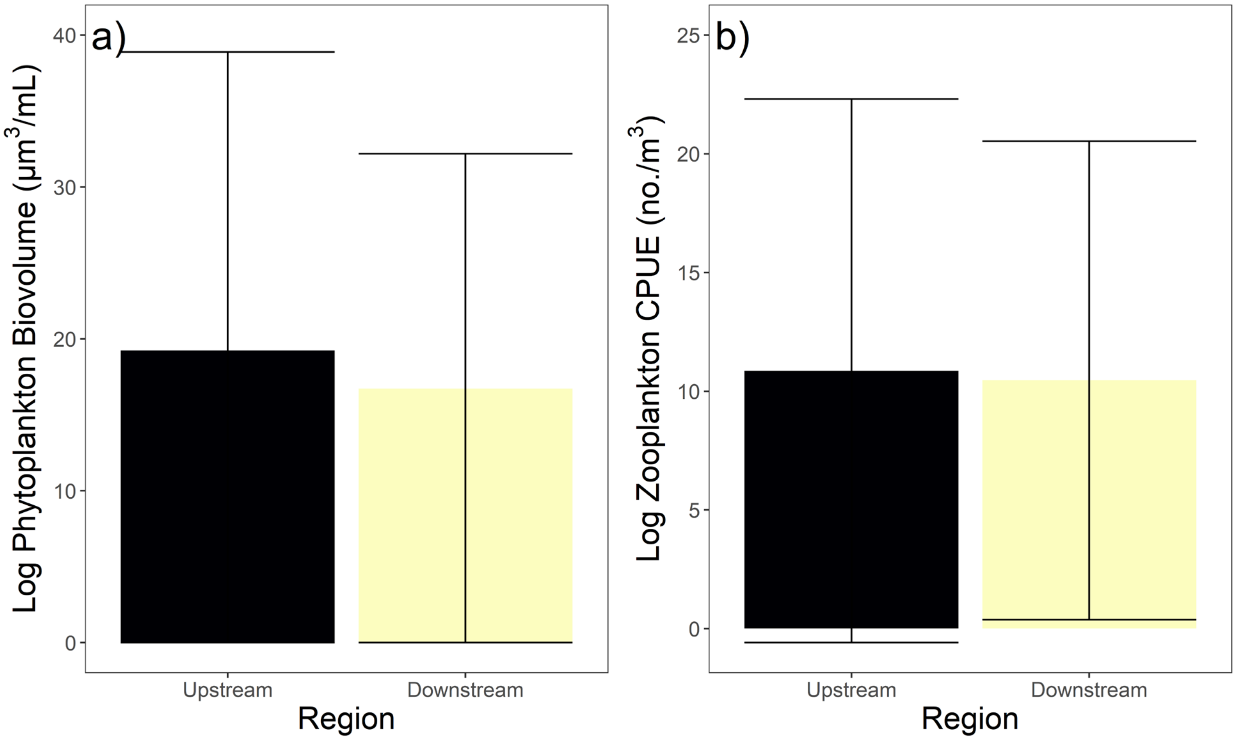

Figure 50. Mean of a) log total phytoplankton biovolume (µm^3/mL + 1 SD) and b) log total zooplankton CPUE (catch per unit effort, number/m^3 ± 1 SD) by NDFS study region for three transects in July and August before the small, 2020 non-managed flow pulse.

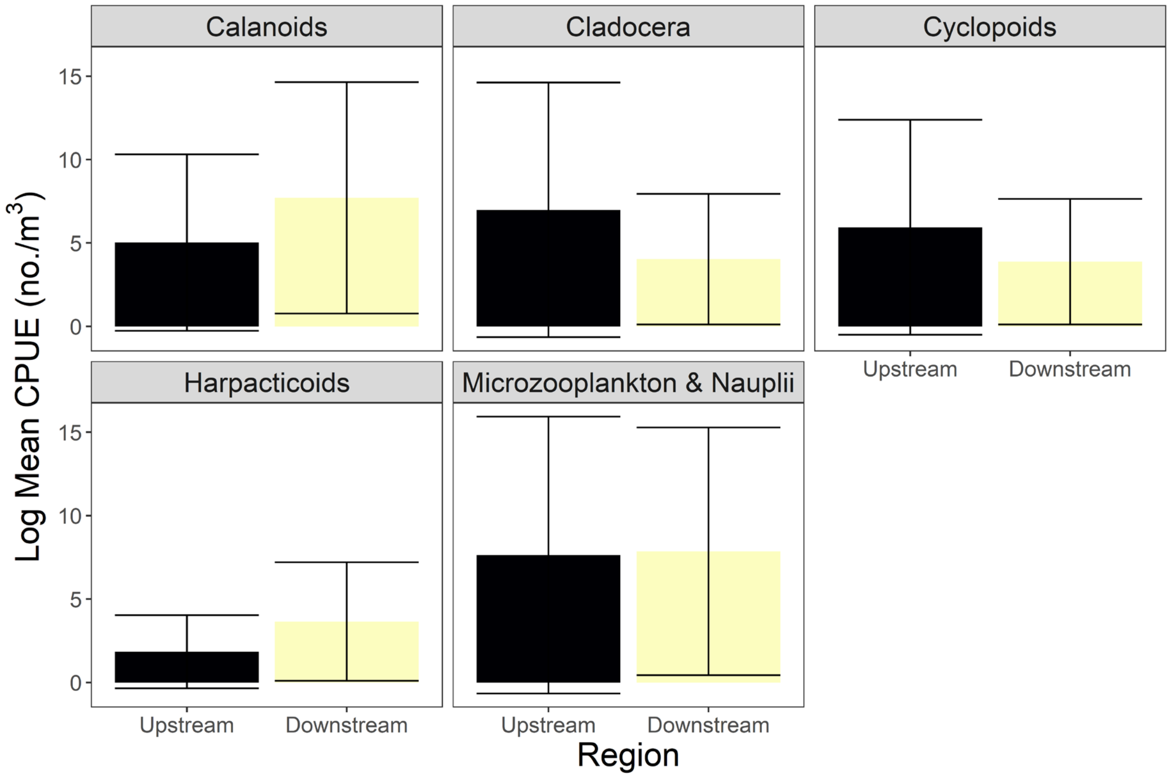

Figure 51. 2020 NDFS zooplankton CPUE (catch per unit effort, number/m^3) from three transects in July and August, before the non-managed flow pulse. Log of mean CPUE (± 1 SD) by zooplankton taxonomic group for sites in upstream and downstream study regions.

A majority of baseline information collected by the NDFS study in 2021 (e.g., nutrients, contaminants, phytoplankton, zooplankton, etc.) are not yet available for this 2021 seasonal report. Chlorophyll *a* fluorescence data from continuous water quality stations (Figure 37), suggest that that there was a subtle increase (~3-5 ug/L) in chlorophyll levels at one downstream station in the Cache Slough Complex (LIB, Figure 38) during and after the small non-managed flow pulse in the Yolo Bypass Toe Drain during September 2021 (Figure 9). No other changes in chlorophyll fluorescence were detected during or after the flow pulse relative to before.

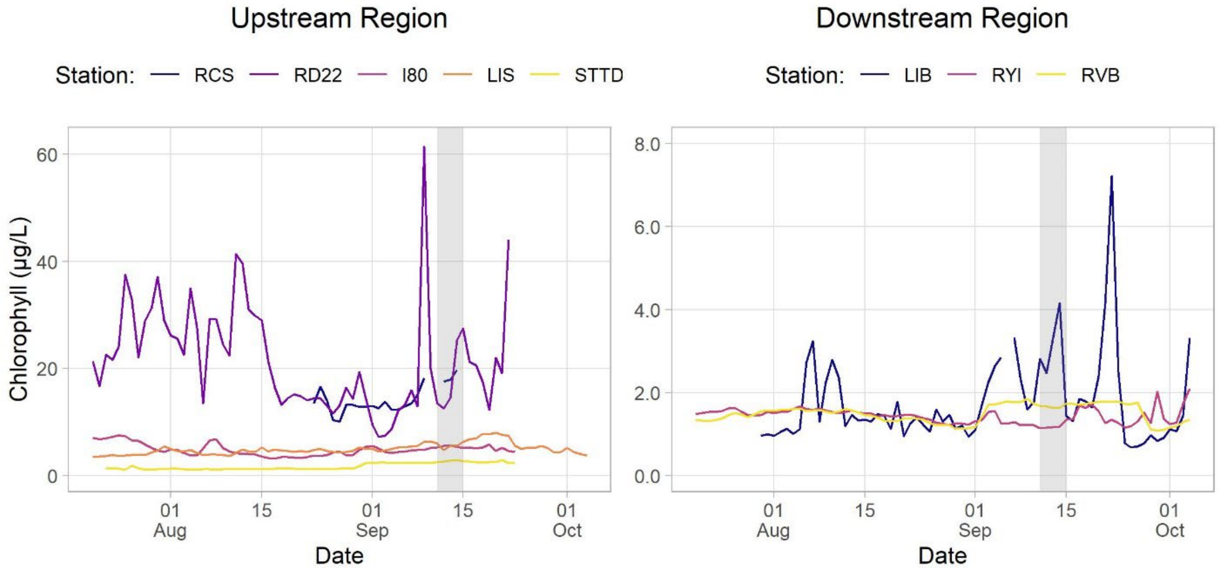

Figure 52. Chlorophyll fluorescence data from continuous water quality stations. 2021 Chlorophyll fluorescence data from continuous water quality stations in order from most upstream site to downstream: Ridge Cut Slough at Highway 113 (RCS), Toe Drain at Road 22 (RD22), Toe Drain at I80 (I80), Toe Drain below Lisbon Weir (LIS), Screw Trap at Toe Drain (STTD), Liberty Island (LIB), and Sacramento River at Rio Vista Bridge (RVB) between June and November of 2021. Chlorophyll data are daily averaged. Shaded area indicates the days of the flow action (9/11-9/14). Upstream sites were QA/QC'd using procedures from the Resources Assessment Branch WQES Field Manual (06/2020). RCS data started later than others because the site was dry until mid- August. The break in RCS data is due to Sonde battery failure. Note that LIB, RYI (downloaded from USGS NWIS) and RVB (DWR EMP) data have not undergone QC.

Sacramento Deep Water Ship Channel Food study

The ship channel comprises three hydrodynamic zones: a zone of relatively rapid water exchange with the mainstem Sacramento River downstream of CM56: a zone of low exchange represented by long-term monthly discrete sampling stations CM62 and CM66; and a no-exchange zone represented by four stations in the uppermost reach of the channel (Figure 53). This longitudinal gradient in hydrodynamic conditions is largely responsible for the longitudinal variation in plankton production. The upper low-exchange zone supports relatively high phytoplankton and zooplankton production owing to its relatively long hydraulic residence time (months) and thermal stratification (Lenoch et al 2021). In this reach, phytoplankton uptake reduces dissolved inorganic nitrogen (nitrate + ammonium) to concentrations that constrain phytoplankton doubling rate and limit the maximum level of standing stock achievable when physical conditions (light, temperature, stratification) are ideal (Loken et al. 2021). Thus, adaptive management of the ship channel action could include operating the Lock facility gates to enhance thermal stratification and adding liquid fertilizer to boost phytoplankton production.

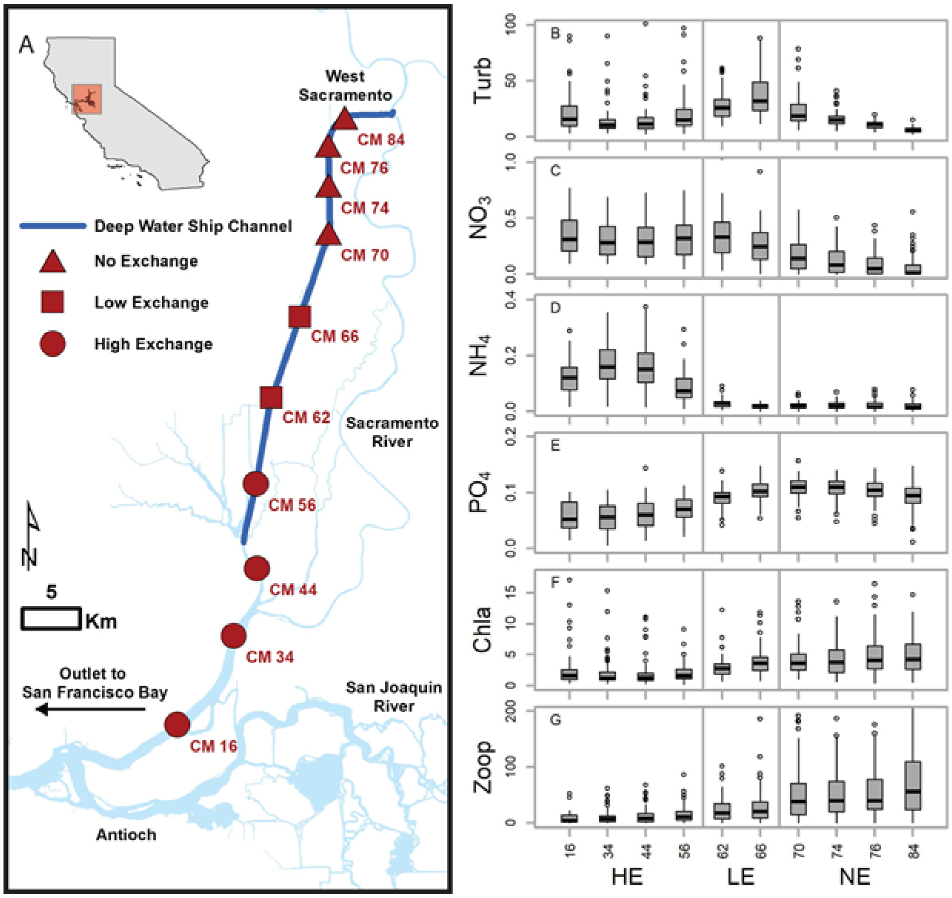

Figure 53. Location of sampling stations (designated by channel markers; CM). b-g) Turbidity (NTU), nitrate concentration (mg N L-1), ammonium (mg N L-1), phosphate (mg P L-1), chlorophyll-a (µg L-1), and total zooplankton biomass Location of sampling stations (designated by channel markers; CM). b-g) Turbidity (NTU), nitrate concentration (mg N L-1), ammonium (mg N L-1), phosphate (mg P L-1), chlorophyll-a (µg L-1 -1 g all sampling dates (2012-), and2019). Stotal amplingzooplankt stationson onbiomass the x (µg-a xesdw aLre ordered f) at each samplingrom seaward s ttation, io landward,ncludin and gray vertical lines denote site groupings based on hydrodynamic exchange zones (HE, LE, NE).

(Figure prepared by Adrianne Smits, UC Davis)

Another important habitat feature of the ship channel is its longitudinal variation in suspended solids concentration and turbidity. The length of the ship channel exceeds the maximum tidal excursion length, and its flood tides are stronger than ebb tides. These characteristics result in the formation of a Turbidity Maximum Zone (TMZ) in the low-exchange zone (Lenoch et al 2021). Here, total suspended solids concentration averages ~20 mg/L and turbidity ~30 NTU, some 3-times higher than in the upper reaches. Surveys conducted by the California Department of Fish and Wildlife Summer Tow Net Survey indicate that delta smelt catch at the TMZ station is consistently higher than at its sampling station in the no-exchange zone (Table 3).

Year	Survey	Station Code	Sample Date	Secchi	Temperature Top	Conductivity Top	TideCode	Depth Bottom	Delta Smelt
2011	5	797	8/9/2011	31	24.6	731	4	34	1
2012	5	797	8/6/2012	30	23.7	767	2	32	5
2013	1	797	6/11/2013	23	21.1	682	2	32	8
2013	2	797	6/24/2013	33	21.0	709	2	35	4
2014	1	797	6/2/2014	32	21.2	773	2	33	12
2015	2	797	6/18/2015	41	22.7	692	2	31	1
2017	2	797	6/26/2017	27	24.1	808	4	34	1
2017	3	797	7/10/2017	20	25.6	786	4	30	1
2011	1	796	6/14/2011	48	22.0	965	3	33	1
2011	2	796	6/28/2011	46	21.6	954	2	34	1
2012	1	796	6/11/2012	40	22.4	1035	2	32	2
2012	2	796	6/25/2012	38	22.1	1050	2	35	2
2012	4	796	7/24/2012	39	22.9	948	2	35	2
2011	3	795	7/12/2011	62	24.7	981	3	35	1

Table 4 Delta smelt catch at California Department of Fish and Wildlife Summer Townet Survey stations located in the TMZ (low-exchange zone) and upper no-exchange zone of the Sacramento Deep Water Ship Channel, 2009-2017.

Sampling by the US Fish and Wildlife Services' Enhanced Delta Smelt Monitoring Program also documents higher catches in the TMZ than in the clearer waters of the upper ship channel (Table 4)

Date	Reach	Lat	Long	Water temperature (°C)	Surface EC (µS/cm)	Turbidity (NTUs)	Tows	Duration (min)	Catch	FL range (mm)
2/26/2018	Upper	38.50984	-121.585	10.5	575	38.3	2	5	1	64
8/1/2018	Upper	38.48619	-121.585	24.1	832	22.2	2	10	2	46-59
7/6/2017	Lower	38.42445	-121.606	22.9	664	28.6	2	2.5	3	37-42
7/6/2017	Lower	38.38797	-121.623	22.8	603	31.9	2	5	6	33-50
7/13/2017	Lower	38.44562	-121.596	23.9	675	29.5	2	3	7	32-5
7/17/2017	Lower	38.43847	-121.6	24.8	669	33.1	1	3	40	2
7/26/2017	Lower	38.38407	-121.624	23.7	437	27.8	1	3	36	33-58
7/26/2017	Lower	38.4069	-121.614	23.9	579	45.0	1	3	26	38-52
8/1/2017	Lower	38.40133	-121.617	24.1	555	17.4	2	5	2	44-4
8/15/2017	Lower	38.38922	-121.622	22.8	434	38.6	4	5	1	5 54
8/22/2017	Lower	38.29569	-121.619	22.8	1290	51.3	2	5	1	49
1/4/2018	Lower	38.41404	-121.612	9.2	442	118.0	3	5	1	83
1/22/2018	Lower	38.42231	-121.608	10.2	356	79.2	5	5	1	75
3/14/2018	Lower	38.45014	-121.595	12.0	518	31.9	3	5	1	66
3/19/2021	Lower	38.44504	-121.597	11.0	444	42.0	5	5	1	73
7/5/2018	Lower	38.39515	-121.619	24.3	519	38.0	3	10	5	34-44
7/9/2018	Lower	38.42213	-121.607	22.8	679	36.8	3	10	2	42-5
7/18/2018	Lower	38.44809	-121.595	23.7	663	246.7	2	10	1	0
7/19/2018	Lower	38.42379	-121.606	23.5	496	45.6	6	10	1	48
7/23/2018	Lower	38.42087	-121.608	24.1	702	35.3	2	10	1	50
7/23/2018	Lower	38.42475	-121.607	24.0	710	33.0	4	10	1	44
7/24/2018	Lower	38.30199	-121.655	23.3	271	28.8	2	10	4	50
8/1/2018	Lower	38.46826	-121.586	23.9	765	28.3	2	10	2	450-45
8/8/2018	Lower	38.38556	-121.625	23.1	558	33.0	3	10	2	5846
8/14/2018	Lower	38.36973	-121.631	22.7	339	20.8	2	10	5	40-46

Table 5 Delta smelt catch by the U.S. Fish and Wildlife Service Enhanced Delta Smelt Monitoring Program in the upper and lower (TMZ) Sacramento Deep Water Ship Channel, 2017-2018. FL = fork length.

Although monthly grab sampling did not occur in 2021, continuous underway monitoring of specific conductance, temperature, turbidity, dissolved oxygen concentration, pH and chlorophyll fluorescence was conducted as an element of the fish monitoring component of the ship channel food web study that began in May 2021 (Reclamation 2021). This fish monitoring effort is being conducted using the Aquatic Habitat Sampling Platform (Platform) developed by Cramer Fish Sciences under a grant from the Reclamation. The Platform samples the fish community by guiding fish through a live well outfitted with video cameras and so does not require fish handling, an important consideration when sampling areas where Delta Smelt and other species of concern are known to reside. This effort includes near-shore and channel as well as day and night sampling. The continuous monitoring collected by the Platform during May – September 2021 documented the same longitudinal water quality patterns as the 2012-2019 record. These data also indicated, however, that turbidity was noticeably higher during 2021. This observation was confirmed by the continuous monitoring data recorded at the USGS station at CM72, which indicated generally higher turbidity in WY2021 than WY2020 (Figure 54). Further analysis will be required to determine what proportion of this increased turbidity stemmed from hydrodynamic, wind or ship traffic effects.

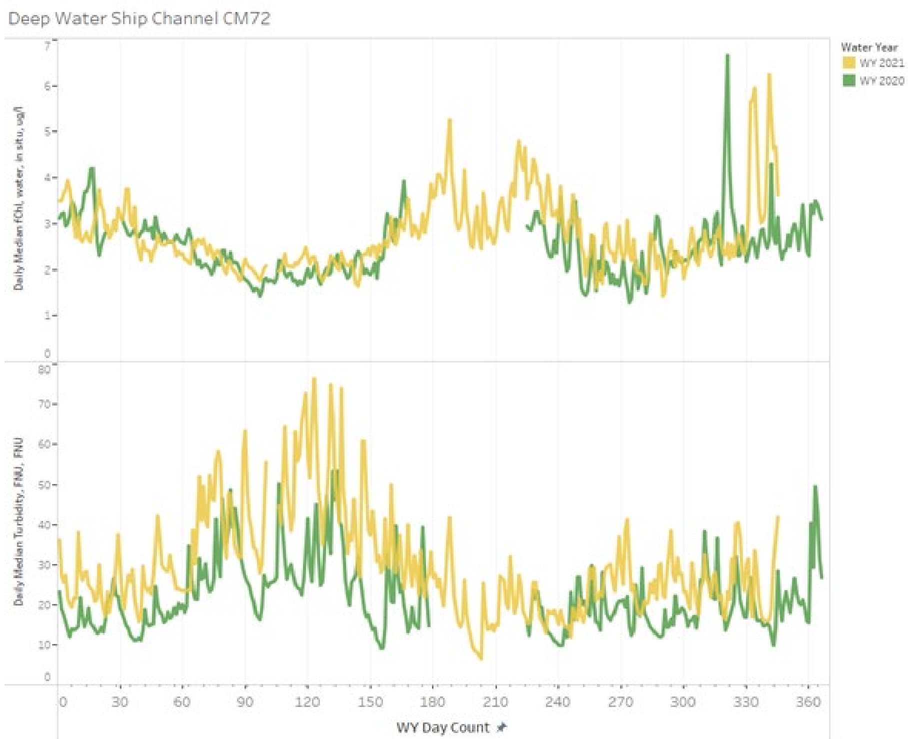

Figure 54. Comparison of chlorophyll concentration and turbidity at USGS continuous monitoring station at CM72 in the low-exchange zone of the ship channel. Missing data interval coincides with COVID-19 shut down period. Data are provisional

Chlorophyll export

Due to the isolation of its relatively productive uppermost reach and lack of net outflow, the ship channel did not function as a net exporter of chlorophyll during 2020 or 2021. On the contrary, the net chlorophyll flux in the no-exchange zone during the third and fourth quarters of both water years may have been slightly negative (landward). By comparison, the net chlorophyll flux from the Cache Slough complex during those same periods was slightly positive (Figure 55). The average chlorophyll flux conveyed into the North Delta by the Sacramento River at Walnut Grove during

July-September of 2020 and 2021 was some 3 metric tons, the equivalent of 123 tons of phytoplankton carbon. This value is comparable to the net negative chlorophyll flux at the confluence, indicating that the Delta during this period was not a net source of phytoplankton carbon to Suisun Bay.

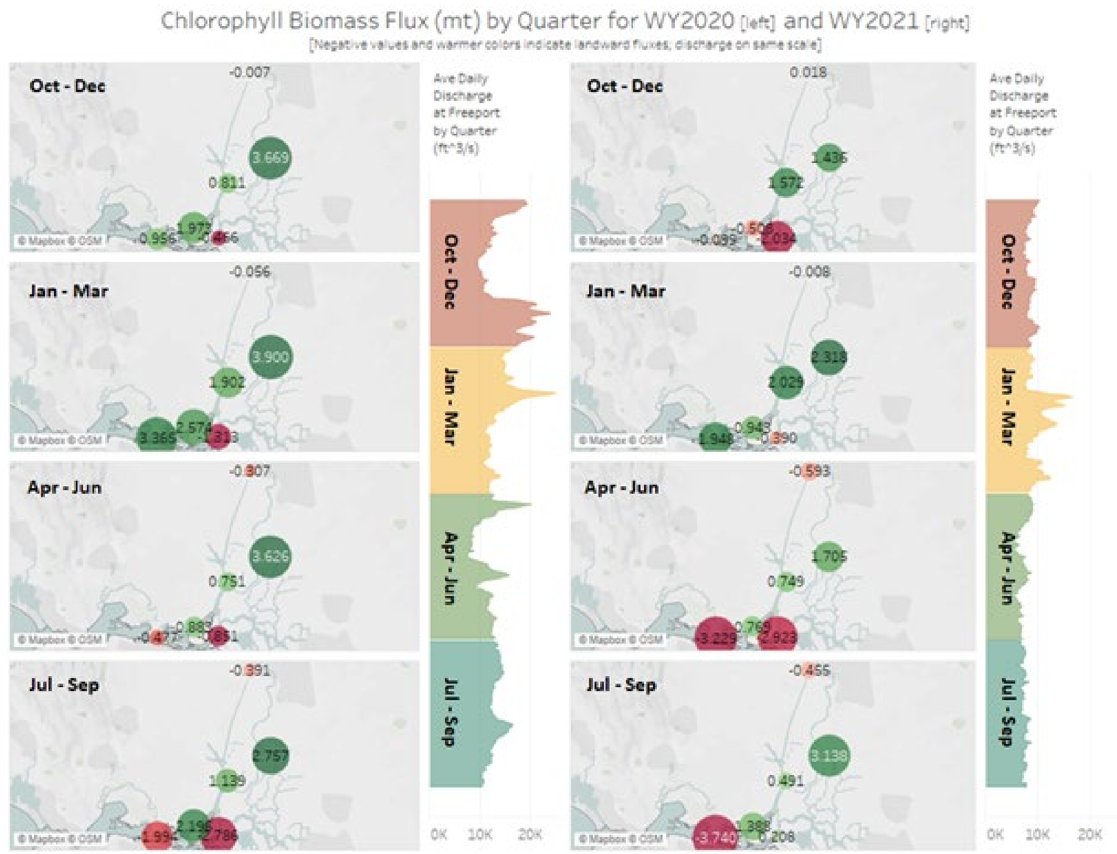

Figure 55. Comparison of seasonal chlorophyll flux at USGS continuous monitoring stations in the Sacramento-San Joaquin Delta (see Figure x for station names). Fluxes are expressed in metric tons of chlorophyll a per quarter (value within circle) with warm colors signifying landward fluxes. Multiplying chlorophyll by 41 yields an estimate of phytoplankton carbon (Source: Brian Bergamaschi, USGS). Data are provisional.

Fish Status

Delta Smelt Status

Abundance

CDFW Summer Townet Survey and Fall Midwater Trawl Survey have historically provided abundance indices for Delta Smelt in the summer and fall periods, respectively. However, Delta Smelt numbers have declined below the detection limits of both surveys. The Summer Townet Survey Delta Smelt abundance index for 2021 was 0 due to the lack of catch. Although the 2021 Fall

Midwater Trawl Survey is ongoing at the time of writing of this report, the survey has not captured any Delta Smelt at their fixed index stations thus far this season. Survey efforts were not reduced due to COVID or wildfire smoke.

EDSM sampling effort in 2021 was relatively unimpacted by COVID or wildfire smoke compared to 2020. The overall paucity of Delta Smelt catch and very few non-zero EDSM's modeled abundance estimates of Delta Smelt in 2021 indicate that the 2021 cohort of Delta Smelt is the least abundant in the history of EDSM (Figure 56).

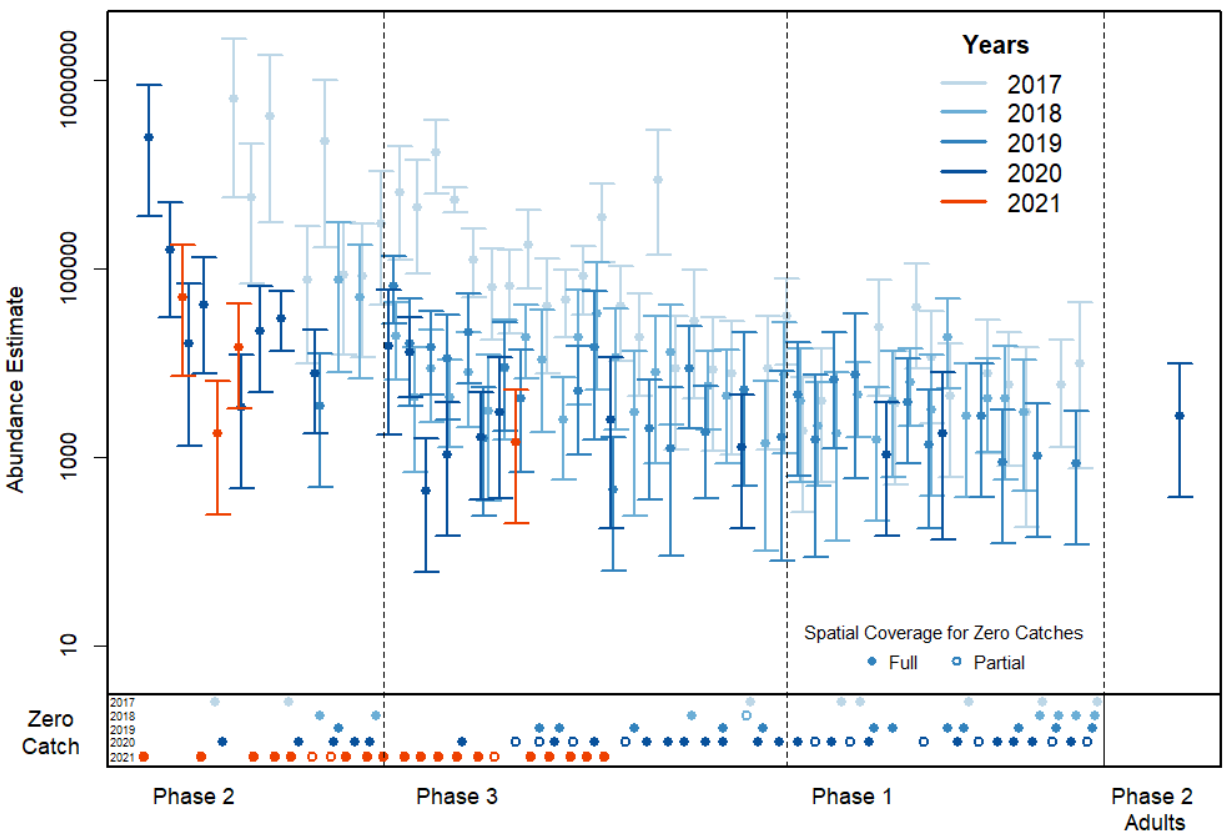

Figure 56 EDSM-ANNUAL. Weekly Delta Smelt abundance estimates from EDSM survey. Years indicates the years in which each Delta Smelt cohort was born. Phase 1 of EDSM runs from December through March and focuses on adult Delta Smelt. Phase 2 sampling takes place from April through June and targets post-larval and juvenile Delta Smelt. Phase 3 runs from July through November and targets juvenile and sub-adult Delta Smelt. Closed circles indicate normal sampling effort for the week and open circles indicate a reduced sampling effort. Figure was provided by Vanessa Tobias and Lara Mitchell (USFWS).

Distribution

Between the start of phase 3 sampling in late June and the end of September 2021, EDSM has caught only a single Delta Smelt on 530 different sampling events. The lone observation of Delta Smelt occurred on August 20th, 2021 at the Sacramento Deep Water Shipping Channel.

Delta Smelt Supplementation

Annual supplementation of Delta Smelt using cultured-reared fish from the University of California Davis, Fish Conservation and Culture Laboratory (FCCL) was proposed in Reclamation's 2019 Biological Assessment and analyzed in the 2019 BiOp (USFWS 2019). Supplementation was proposed to begin between 2022 to 2025; however, continued declines in population abundance and lack of wild Delta Smelt broodstock collections for the refuge population at FCCL the last couple years has expedited supplementation efforts. To inform future supplementation strategies, Experimental Release of hatchery Delta Smelt into the wild is planned to occur late 2021 to early 2022 that aims to provide an initial evaluation of logistical operations, techniques, science, and information needs and resources. The USFWS is leading the Experimental Release Technical Teams (ERTT) in collaboration with CEQA lead CDFW, DWR, USBR, USGS, FCCL and academic experts to plan, coordinate, and implement releases of ~40,000 hatchery Delta Smelt in the North Delta at >200 days post hatch.

The ERTT has developed a draft study plan (USFWS 2021) for experimental releases of the 40,000 fish the FCCL marked for supplementation. The plan includes objectives and procedures for high-priority areas to learn from including production, genetics, tagging, transport, release, and monitoring of Delta Smelt; many of which pertain to goals outlined in the FWS Supplementation Strategy (USFWS 2020). A brief summary of current experimental release plans (as of September 2021) is as follows:

- Production & Tagging:
  - Fish spawned in February through June 2021
  - ~17,000 fish available starting Sept-Oct, another 24,000 estimated in Nov 2021.
  - Genetic samples to be collected, a subset of fish to be VIE tagged, and the rest will have their adipose fin clipped.
  - Fish transitioned to live feed ~30 days prior to transport, and health screened.
- Transport:
  - Cultured fish transported by truck to release sites (at 200fish/20gal carboy density),
  - 32 carboys (~6,400 fish) planned for a given transport batch, will be several batches
- Release:
  - Release timing is estimated for December 2021 to February 2022.
  - Release location in the North Delta Arc this first year will be downstream of Rio Vista, in the Sacramento River across from Brannan Island.
  - Two release strategies will be tested including hard release (directly from transport carboys and boats into water) and soft-release (indirect release after enclosure-acclimation for 48-72 h).
  - Two to four release events may take place, with 9,000-12,800 Delta Smelt released each event (with 6,400 split between hard or soft release strategy).
- Monitoring:
  - Collaboration and coordination with existing monitoring programs for re-capture identification and collection of cultured fish.

- Planned ARIS cameras for visual assessments of Delta Smelt behavior, predators, and release strategy.

Fish Assemblage

Native vs Non-Native Fish Species

The Delta Plan listed percentage of native fish biomass or relative abundance as a performance measure in the Delta. This metric is based on the Delta Juvenile Fish Monitoring Program beach seine survey data that has demonstrated an increase in non-native fish numbers over the past two decades (Mahardja et al. 2017b, IEP et al. 2020b). Biomass of native fishes in the nearshore habitat continued to be considerably low relative to introduced fishes in WY2020 and WY2021 (Figure 57). Mississippi Silverside (*Menidia audens*) and centrarchid species make up a substantial portion of this introduced fish biomass. Mississippi Silverside may be a significant competitor and intraguild predator to Delta Smelt and thus their consistently high numbers in WY2020 and WY2021 are likely to be detrimental to Delta Smelt (Schreier et al. 2016). Centrarchids such as Largemouth Bass (*Micropterus salmoides*) are known to be associated with submerged aquatic vegetation, which can negatively impact Delta Smelt through reduction in turbidity and increased predation (Ferrari et al. 2014, Hestir et al. 2016). There is an apparent reduction of centrarchid biomass in WY2020 and WY2021 relative to the previous years; however, it is unclear whether this was due to the inconsistent sampling in WY2020 and lack of August data in WY2021. The heavy presence of these introduced species likely contributed to the suppression of Delta Smelt numbers to some extent, and based on the existing data, this pattern has continued into WY2020 and WY2021.

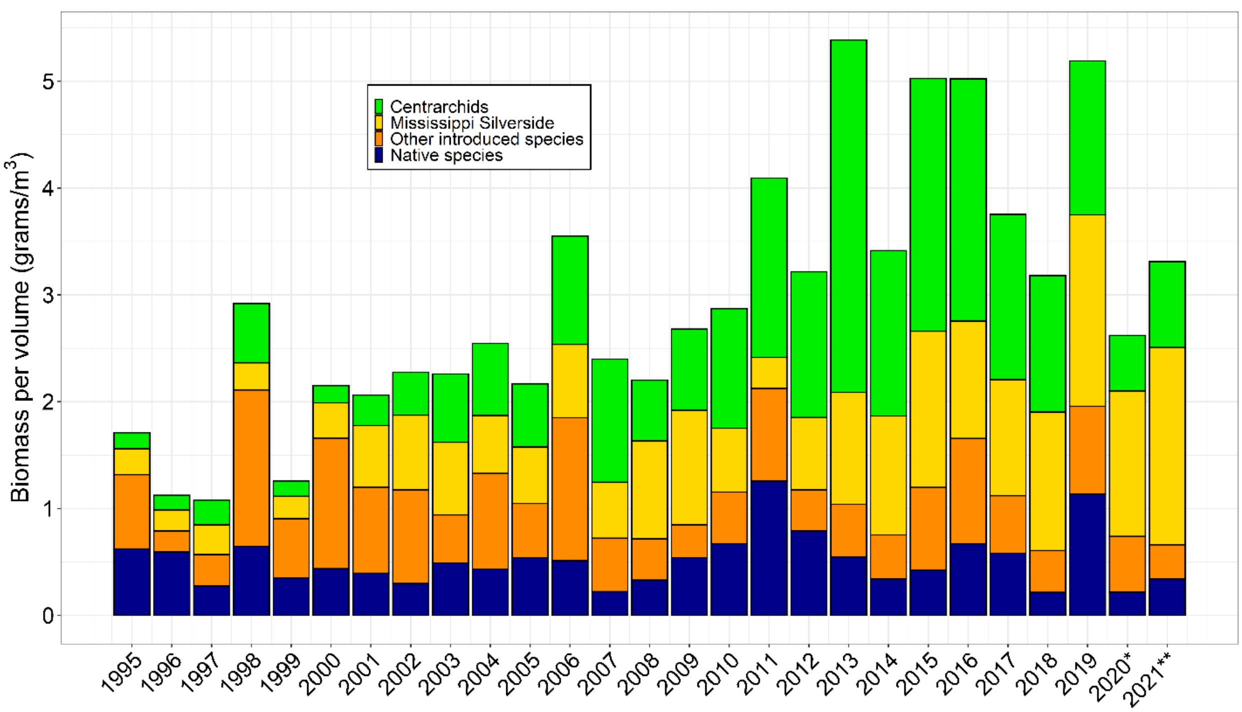

Figure 57. Estimated annual mean biomass per volume of nearshore fishes based on March-August beach seine catch data as calculated in Mahardja et al. (2017). *Reduced sampling in 2020 due to COVID-19. **No data from August of 2021.

Abundance of POD Species

The steep decline of Delta Smelt that occurred in the early 2000s was a part of the Pelagic Organism Decline (POD) event, in which four pelagic fish species experienced simultaneous, abrupt decline in abundance likely caused by common factors (Thomson et al. 2010). The 2021 status of two introduced species listed in the POD, Striped Bass (*Morone saxatilis*) and Threadfin Shad (*Dorosoma petenense*), are reviewed in this report to compare and contrast their responses to Delta Smelt under this critically dry year condition. Age-0 Striped Bass numbers in the summer and fall based on long-term surveys appear to be somewhat correlated with water years (Figure 58), with 2021 catch so far being lower than recent wet years (e.g., 2011, 2017, 2019). Unlike Delta Smelt and Striped Bass, Threadfin Shad numbers in 2021 were comparable to the past few years with no clear, discernible pattern (Figure 59).

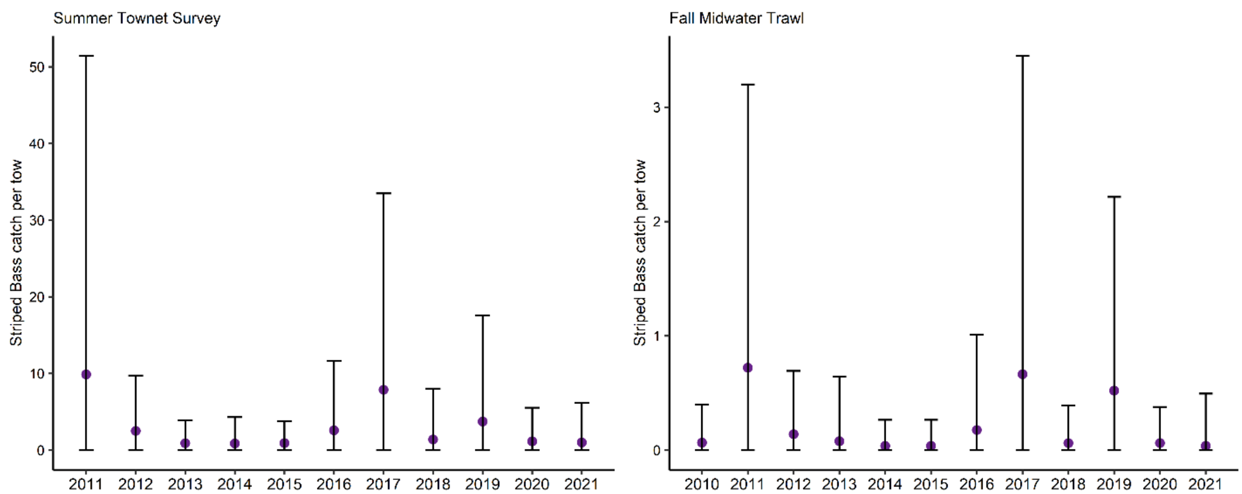

Figure 58. Mean Striped Bass catch per tow and standard deviation (error bars) from the CDFW Summer Townet Survey from all stations for each year since 2011 (left) and from the CDFW Fall Midwater Trawl Survey from all stations for each year since 2010 (right). Only data from September and October surveys were used for Fall Midwater Trawl Survey to ensure consistency with 2021 data.

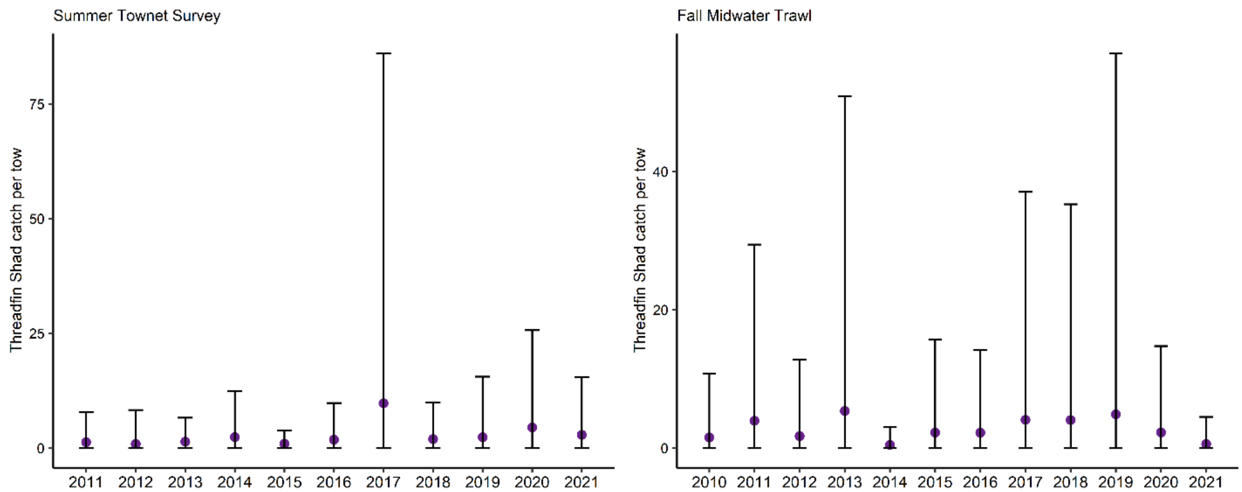

Figure 59. Mean Threadfin Shad catch per tow and standard deviation (error bars) from the CDFW Summer Townet Survey from all stations for each year since 2011 (left) and from the CDFW Fall Midwater Trawl Survey from all stations for each year since 2010 (right). Only data from September and October surveys were used for Fall Midwater Trawl Survey to ensure consistency with 2021 data.

Discussion

Abiotic Habitat Attributes

The overall abiotic habitat conditions in summer and fall of 2021 for Delta Smelt were similar to what can be expected based on a critically dry, non-action year, i.e., stressful at times throughout much of the species' typical range. Outflow and X2 in summer and fall of 2021 fell within the range of other critically dry years from the past two decades (Figure 6). Based on outflow and X2 calculations for summer and fall of 2021, salinity levels within the Suisun Marsh and Suisun Bay are somewhat higher compared to previous critically dry years (Figure 7). Salinity at Belden's Landing and within the western portion of Montezuma Slough was likely to contribute to constraining the western distribution of Delta Smelt for large parts of the season. Salinity at the BDL station largely stayed above 6 ppt starting in June. Brief periods of low turbidity were also observed at the BDL station (Figure 30); this combination of factors likely imposed additional stress for any Delta Smelt in this area.

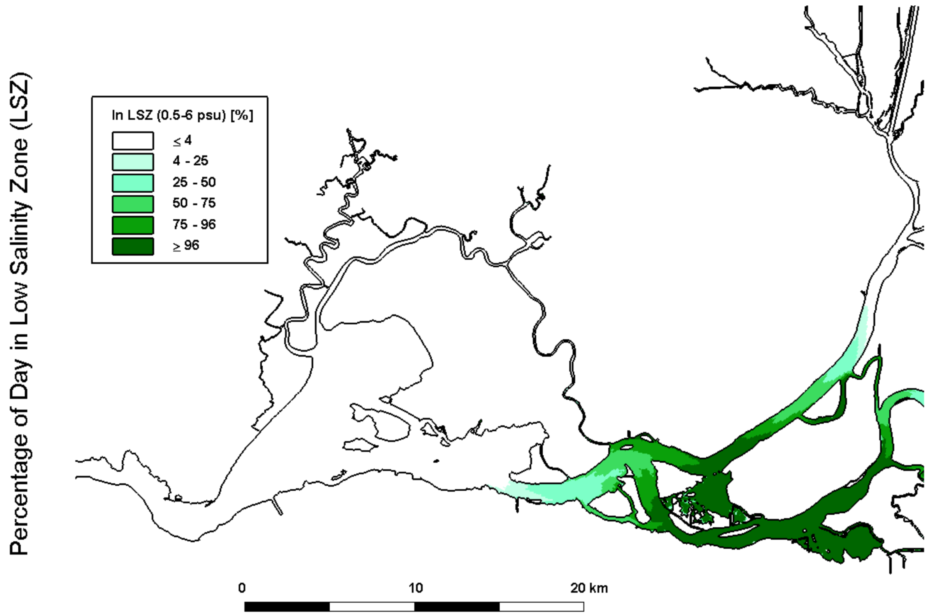

Figure 60. Percentage of Day in the low salinity zone when X2 is located at 89km (Delta Modeling Associates 2014)

Delta Smelt low salinity habitat in late summer and fall 2021 was most likely similar to Figure 60 above.

The San Francisco Bay-Delta system has seen a long-term reduction in turbidity over the past several decades (Schoellhamer et al. 2011, Hestir et al. 2013, Bever et al. 2018); however, some regional differences persist. Within the range of Delta Smelt, the Suisun region and the North Delta have generally seen the highest turbidity, along with the general area of low salinity zone where X2 is located. Turbidity in 2021 appeared to be similar to other dry years where the Lower Sacramento River and upstream sites remained less turbid than shallower downstream areas. The SDWSC had highly variable turbidity. Summer and fall water temperature in 2021 were generally under the 23.9 C threshold, but temperatures exceeded 23.9 several times in the Lower Sacramento and SDWSC, which may have been detrimental to Delta Smelt population.

Extent of Contiguous Low Salinity Habitat

One of the goals of the Delta Smelt SFHA is to establish contiguous low salinity habitat from Cache Slough Complex to the Suisun Marsh. However, dry conditions in the non-action year of 2021 meant that X2 was located far upstream, and the low salinity zone was restricted to the narrow habitat of the channelized Sacramento River throughout the summer and fall. This would isolate any fish that remained in Suisun Bay or Marsh from the lower Sacramento River through the North Delta/Cache Slough Complex. Because the location of X2 in WY 2021 was similar to previous critically dry years, it can be assumed that the temporal and spatial extent of contiguous low salinity habitat between regions was also similar to previous critically dry years.

Biotic Habitat

The extent to which Delta Smelt abundance and distribution was driven by biotic habitat factors in WY2021 is still not clear, as the majority of biotic data remain unavailable at the time of this report's publication. However, we note that chlorophyll levels remain much lower than historic (pre-1986) levels throughout both the Delta and Suisun, with the highest chlorophyll in areas of lower flow and greater hydrodynamic complexity, such as Suisun Marsh and the Sacramento Deep water Ship Channel (Figure 34). Cyanobacteria has been increasing in the Delta over the past 20 years, and 2021 and 2020 both had high incidences of Microcystis in visual assessments, especially in the Lower Sacramento (Figure 43). Microcystis thrives in high water temperatures and low flows (Lehman et al. 2018), and the combination of high temperatures and harmful algae may have been detrimental to smelt.

The data from 2020 and other previous years indicate that food for Delta Smelt, particularly the calanoid copepod *Pseudodiaptomus*, is highest in Suisun Marsh during higher outflow years (Figure 37). Few *Pseudodiaptomus* were found in Suisun Marsh during 2020, probably due to lower exports of these freshwater taxa from upstream (Kimmerer et al. 2018). Clam biomass and grazing rate tended to be lower within the small sloughs of Suisun Marsh (Figure 44), supporting this as a region of beneficial food production in the future.

North Delta Food Subsidies-Colusa Basin Drain Study

The NDFS Study results from previous years indicate that phytoplankton blooms downstream require certain water volume and maximum daily net flow through the Yolo Bypass (Davis et al. 2021). Seasonal agricultural return flow from Colusa Basin occurred in September of 2021 resulting in a very small, non-managed flow pulse lasting four days with maximum daily average flow of 31.3 cfs (Figure 9) and was followed by a slight increase of chlorophyll fluorescence at Liberty Island in the Cache Slough Complex, which may have been unrelated to the flow pulse (Figure 50). Chlorophyll fluorescence did not increase at any other sites following the flow pulse. The small flow pulse in September at Yolo Bypass Toe Drain did not seem to trigger a phytoplankton bloom downstream in Sacramento River based on the limited available information to date. Monitoring for this study will be completed in November 2021, and most of the data from 2021, including discrete water quality, phytoplankton, and zooplankton data were not yet available at the completion of this report. Reclamation and DWR intend to re-evaluate the remaining 2021 data when they become available and present in future Summer-Fall Habitat Seasonal Reports.

In 2021, chlorophyll levels were higher at RCS and RD22 in the upstream study region than at any of the sites downstream. In general, chlorophyll levels before the small, non-managed flow pulse were similar between 2021 and previous years. The lack of response in chlorophyll levels from the 2021 flow pulse contrasts with previous years with larger, managed flow actions. In 2018 and 2019 large agricultural flow actions caused noticeable changes in chlorophyll fluorescence in the upstream study region (Frantzich et al. 2019, Twardochleb et al. 2021a). In both 2018 and 2019, during the flow action, chlorophyll levels decreased at the upstream stations RCS, RD22, I80 and LIS, while stations downstream (LIB, RVB) remain relatively constant. In both 2018 and 2019, STTD saw a small increase in chlorophyll levels during the flow action. Following these 2018 and 2019 flow actions, chlorophyll levels increased at the upstream stations (Frantzich et al. 2019, Twardochleb et al. 2021a). During the 2016 Sacramento River action, chlorophyll levels in the upstream region generally dropped during the flow action while levels rose at downstream sites after the action (Frantzich et al. 2021). The magnitude of the increase downstream was greater during the 2016 flow action than in 2018 or 2019 (Davis et al. 2021). The lack of a noticeable response in chlorophyll levels in 2021 is likely due to the low flow year; very little water was released to flush phytoplankton from upstream to downstream sites (Figure 9). The chlorophyll responses in 2021 were even lower than in 2020, another non managed flow year in which chlorophyll levels increased in the Yolo Bypass but not downstream in the Cache Slough Complex following the small, non-managed flow pulse (2020 Delta Smelt Summer-Fall Habitat Seasonal Report).

Sacramento Deep Water Ship Channel Food study

The SDWSC food study has so far yielded a 7-year data set that documents spatial and temporal variation in baseline water quality and plankton standing stock throughout the entire length of the ship. It has performed bioassay-scale experiments documenting nitrogen-limitation in the low and no-exchange zones during late spring, summer and fall and it has conducted whole-reach-scale experiments to provide information on the processes that regulate phytoplankton production. It has also documented how air temperature, winds and tidal flows affect key physical processes such as longitudinal, vertical and lateral dispersion. In the next three years, the SDWSC will continue its focus on improving understanding of physical and ecological processes including measurement of plankton growth rates, nutrient dynamics (including bottom sediment processes) and ecosystem metabolism and how the fish community varies between open channel and littoral habitat and varies with water quality and plankton standing stock. These data will be used to develop enhance models for use in comparing the performance of multiple flow-nutrient management scenarios as they affect environmental conditions, food supply and Delta Smelt.

Fish Status

Delta Smelt Status

Delta Smelt catch was at an all-time low throughout the San Francisco-Bay Delta in 2021, reflecting the very low adult spawning stock and the stress of critically dry year conditions including those reviewed here. Evaluating the impacts of the 2021 non-action year on Delta Smelt is difficult because only a single Delta Smelt were caught throughout the system between June and October by all the fish monitoring programs.

Based on the existing literature and monitoring information for Delta Smelt, we expect 2021 environmental conditions to be mostly detrimental to the species due to the combination of high salinity, low turbidity, high temperatures, and high incidence of HABs. However, over 1,000 Wakasagi (*Hypomesus nipponensis*) were caught in Summer-Fall period of 2021, with the majority of catch coming from the Sacramento Deep Water Shipping Channel (same location where the only Delta Smelt was observed in Summer-Fall of 2021). Wakasagi is an introduced fish species within the same genus as Delta Smelt with similar life history and habitat requirements (Davis et al. 2021). Although additional studies are clearly needed, the high numbers of Wakasagi in 2021 offers some hope that there may be remnant suitable habitat for Delta Smelt in the Cache Slough Complex during a critically dry year. It may be beneficial to focus Summer-Fall management actions and supplementation at Cache Slough Complex, especially the Sacramento Deep Water Ship Channel, for future critically dry years.

Management Summary

We were unable to attain any of the goals for the summer-fall actions due to critically dry conditions and lack of action implementation. The average outflow and the location of X2 during WY 2021 was similar to other critically dry years as defined by D-1641. Delta Smelt abundance was likely lower the last few years. It is likely that salinity was a limiting factor in Suisun Marsh and Suisun Bay for Delta Smelt for the majority of the 2021 Summer-Fall period (>6 ppt), precluding the species from access the majority of the habitat. Abiotic habitat was available in the Sacramento River and north delta, but productivity (as measured by chlorophyll) in these regions was very low, temperatures occasionally exceeded Delta Smelt's thermal limits, and harmful algal blooms were widespread.

References

Acuna S, Baxa D, Teh S. 2012. Sublethal dietary effects of microcystin producing *Microcystis* on threadfin shad, *Dorosoma petenense*. Toxicon. 60:1191-1202.

Bashevkin SM, Hartman R, Thomas M, Barros A, Burdi C, Hennessy A, Tempel T, Kayfetz K. 2020. Interagency Ecological Program: Zooplankton abundance in the Upper San Francisco Estuary from 1972-2018, an integration of 5 long-term monitoring programs. Environmental Data Initiative. doi:10.6073/PASTA/0C400C670830E4C8F7FD45C187EFDCB9.

Berg N, Hall A. 2017. Anthropogenic warming impacts on California snowpack during drought. Geophys Res Lett. [accessed 2019 Sep 14];44(5):2511–2518. https://doi.org/10.1002/2016gl072104

Bever, A. J., MacWilliams, M. L., Herbold, B., Brown, L. R., & Feyrer, F. V. (2016). Linking Hydrodynamic Complexity to Delta Smelt (*Hypomesus transpacificus*) Distribution in the San Francisco Estuary, USA. San Francisco Estuary and Watershed Science, 14(1). https://doi.org/10.15447/sfews.2016v14iss1art3

Bever, A. J., MacWilliams, M. L., & Fullerton, D. K. (2018). Influence of an Observed Decadal Decline in Wind Speed on Turbidity in the San Francisco Estuary. Estuaries and Coasts, 41(7), 1943–1967. https://doi.org/10.1007/s12237-018-0403-x

Bollens, S. M., et al. (2011). "Mesozooplankton of the lower San Francisco Estuary: spatio-temporal patterns, ENSO effects and the prevalence of non-indigenous species." Journal of Plankton Research **33**(9): 1358-1377.

Brown LR, Baxter R, Castillo G, Conrad L, Culberson S, Erickson G, Feyrer F, Fong S, Gehrts K, Grimaldo L, et al. 2014. Synthesis of studies in the fall low-salinity zone of the San Francisco Estuary, September-December 2011. http://pubs.er.usgs.gov/publication/sir20145041.

Brown, L.R., Kimmerer, W., Conrad, J.L., Lesmeister, S. and Mueller–Solger, A., 2016. Food webs of the Delta, Suisun Bay, and Suisun Marsh: an update on current understanding and possibilities for management. San Francisco Estuary and Watershed Science, 14(3).

California Natural Resources Agency (CNRA). 2016. Delta Smelt Resiliency Strategy. California Natural Resources Agency, Sacramento, CA. http://resources.ca.gov/delta-smelt-resiliency-strategy/

City of West Sacramento 2020. Stone Lock Water Quality and Ecosystem Enhancement Project. Alternatives Analysis Technical Memorandum. Prepared by Jacobs for the City of West Sacramento, February 28, 2020. 81 pp.

Davis et al. 2021. North Delta Food Subsidy Synthesis: Evaluating Flow Pulses from 2011-2019. Department of Water Resources, Division of Integrated Science and Engineering.

Davis, B.E., Cocherell, D.E., Sommer, T., Baxter, R.D., Hung, T.C., Todgham, A.E. and Fangue, N.A., 2019. Sensitivities of an endemic, endangered California smelt and two non-native fishes to serial increases in temperature and salinity: implications for shifting community structure with climate change. Conservation physiology, 7(1), p.coy076.

Davis B.E., Adams J. B., Lewis L.S., Hobbs J.A., Ikemiyagi, N., Johnston C., Mitchell L., Shakya A., Schreier B.M., Mahardja B. 2021. Wakasagi in the San Francisco Bay Delta Watershed: Comparative trends in distribution and life-history traits with native Delta Smelt. In review.

Delta Modeling Associates, 2014. Low Salinity Zone Flip Book, Version 2.0, December 31, 2014.

Department of Water Resources, June 5, 2020, Memorandum: DWR YSI Turbidity Sensor Measurement Units (DWR Memorandum)

FLOAT-MAST. 2019. Synthesis of data and studies relating to Delta Smelt biology in the San Francisco Estuary, emphasizing water year 2017. IEP Technical Report Draft. Interagency Ecological Program, Sacramento, CA

Ferrari MCO, Ranåker L, Weinersmith KL, Young MJ, Sih A, Conrad JL. 2014. Effects of turbidity and an invasive waterweed on predation by introduced largemouth bass. Environ Biol Fishes. 97(1):79–90. doi:10.1007/s10641-013-0125-7.

Feyrer, F., Nobriga, M. L., & Sommer, T. R. (2007). Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. Canadian Journal of Fisheries and Aquatic Sciences, 64, 723–734. https://doi.org/10.1139/F07-048

Feyrer, F., Newman, K., Nobriga, M., & Sommer, T. (2011). Modeling the Effects of Future Outflow on the Abiotic Habitat of an Imperiled Estuarine Fish. Estuaries and Coasts, 34(1), 120–128. https://doi.org/10.1007/s12237-010-9343-9

Frantzich J, Sommer T, Schreier B. 2018. Physical and Biological Responses to Flow in a Tidal Freshwater Slough Complex. San Francisco Estuary and Watershed Science, 16(1).

Frantzich et al. 2019. Investigation Yolo Bypass as a Fall Food Web Subsidy for the Delta. CDFW Contract Agreement Report (no. D168300100). Department of Water Resources.

Frantzich J, Davis BE, MacWilliams M, Bever A, Sommer T. 2021. Use of a Managed Flow Pulse as Food Web Support for Estuarine Habitat. San Francisco Estuary and Watershed Science. 19(3):art3. https://doi.org/10.15447/sfews.2021v19iss3art3.

Ger KA, Otten TG, DuMais R, Ignoffo T, Kimmerer W. 2018. In situ ingestion of Microcystis is negatively related to copepod abundance in the upper San Francisco Estuary. Limnology and Oceanography. 63(6):2394-2410.doi:https://doi.org/10.1002/lno.10946.

Grimaldo, L.F., T. Sommer, N. Van Ark, G. Jones, E. Holland, P. Moyle, B. Herbold, and P. Smith. 2009. Factors affecting fish entrainment into massive water diversions in a tidal freshwater estuary: Can fish losses be managed? North American Journal of Fisheries Management 29:1253–1270.

Hammock, B. G., S. B. Slater, R. D. Baxter, N. A. Fangue, D. Cocherell, A. Hennessy, T. Kurobe, C. Y. Tai, and S. J. Teh. 2017. Foraging and metabolic consequences of semi-anadromy for an endangered estuarine fish. Plos ONE 12(3):e0173497. 10.1371/journal.pone.0173497

Hammock BG, Hartman R, Slater SB, Hennessy A, Teh SJ. 2019. Tidal Wetlands Associated with Foraging Success of Delta Smelt. Estuaries and Coasts. https://doi.org/10.1007/s12237-019-00521-5.

Hestir, E.L., D.H. Schoellhamer, T. Morgan-King, S.L. Ustin. 2013. A step decrease in sediment concentration in a highly modified tidal river delta following the 1983 El Niño floods. Marine Geology 345:304–313.

Hestir EL, Schoellhamer DH, Greenberg J, Morgan-King T, Ustin SL. 2016. The Effect of Submerged Aquatic Vegetation Expansion on a Declining Turbidity Trend in the Sacramento-San Joaquin River Delta. Estuaries and Coasts. 39(4):1100–1112. doi:10.1007/s12237-015-0055-z.

Interagency Ecological Program (IEP), M. Martinez, J. Rinde, T.M. Flynn, and S. Lesmeister. 2020a. Interagency Ecological Program: Discrete water quality monitoring in the Sacramento-San Joaquin Bay-Delta, collected by the Environmental Monitoring Program, 1975-2019. ver 3. Environmental Data Initiative. https://doi.org/10.6073/pasta/dc1fd386c098c6b71132150eee7ee86c (Accessed 2020-10-29).

Interagency Ecological Program (IEP), R. McKenzie, J. Speegle, A. Nanninga, J.R. Cook, J. Hagen, and B. Mahardja. 2020b. Interagency Ecological Program: Over four decades of juvenile fish monitoring data from the San Francisco Estuary, collected by the Delta Juvenile Fish Monitoring Program, 1976-2019 ver 4. Environmental Data Initiative. https://doi.org/10.6073/pasta/41b9eebed270c0463b41c5795537ca7c (Accessed 2020-11-06).

Jungbluth M, Lee C, Patel C, Ignoffo T, Bergamaschi B, Kimmerer W. 2021. Production of the Copepod *Pseudodiaptomus forbesi* Is Not Enhanced by Ingestion of the Diatom Aulacoseira granulata During a Bloom. Estuaries and Coasts. 44(4):1083–1099. doi:10.1007/s12237-020-00843-9.

Kayfetz, K., S. M. Bashevkin, M. Thomas, R. Hartman, C. E. Burdi, A. Hennessy, T. Tempel, and A. Barros. 2021. Zooplankton Integrated Dataset Metadata Report. IEP Technical Report 93. California Department of Water Resources, Sacramento, California.

Kimmerer WJ, MacWilliams ML, Gross ES. 2013. Variation of fish habitat and extent of the low-salinity zone with freshwater flow in the San Francisco Estuary. San Francisco Estuary and Watershed Science. 11(4):16.

Kimmerer, W. J. and J. K. Thompson (2014). "Phytoplankton Growth Balanced by Clam and Zooplankton Grazing and Net Transport into the Low-Salinity Zone of the San Francisco Estuary." Estuaries and Coasts 37(5): 1202-1218.

Kimmerer WJ, Ignoffo TR, Kayfetz KR, Slaughter AM. 2018. Effects of freshwater flow and phytoplankton biomass on growth, reproduction, and spatial subsidies of the estuarine copepod *Pseudodiaptomus forbesi*. Hydrobiologia. 807(1):113-130. https://doi.org/10.1007/s10750-017-3385-y.

Kimmerer, W.J. and Rose, K.A., 2018. Individual-Based Modeling of Delta Smelt Population Dynamics in the Upper San Francisco Estuary III. Effects of Entrainment Mortality and Changes in Prey. Transactions of the American Fisheries Society 147: 223-243.

Komoroske, L.M., R.E. Connon, J. Lindberg, B.S. Cheng, G. Castillo, M. Hasenbein, N.A. Fangue. 2014. Ontogeny influences sensitivity to climate change stressors in an endangered fish. Conservation Physiology 2: doi:10.1093/conphys/cou008.

Komoroske, L. M., Jeffries, K. M., Connon, R. E., Dexter, J., Hasenbein, M., Verhille, C., & Fangue, N. A. (2016). Sublethal salinity stress contributes to habitat limitation in an endangered estuarine fish. Evolutionary Applications, 9(8), 963–981. https://doi.org/10.1111/eva.12385

Kurobe T, Lehman P W, Haque Md E I, Tiziana S, Lesmeister S, Teh S (2018) Evaluation of water quality during successive severe drought years within Microcystis blooms using fish embryo toxicity tests for the San Francisco Estuary. Science of the Total Environment 610-611: 1029-1037.

Lee, C. M., Hestir, E. L., Tufillaro, N., Palmieri, B., Acuña, S., Osti, A., ... & Sommer, T. (2021). Monitoring Turbidity in San Francisco Estuary and Sacramento–San Joaquin Delta Using Satellite Remote Sensing. JAWRA Journal of the American Water Resources Association.

Lehman, P. W., Kurobe, T., Lesmeister, S., Baxa, D, Tung, A.., Teh, S. J. 2017. Impacts of the 2014 severe drought on the Microcystis bloom in San Francisco Estuary. Harmful Algae 63:94-108.

Lehman P, Teh S, Boyer G, Nobriga M, Bass E, Hogle C. 2010. Initial impacts of *Microcystis aeruginosa* blooms on the aquatic food web in the San Francisco Estuary. Hydrobiologia. 637(1):229-248.

Lenoch, L. E. K., Stumpner, P. R., Burau, J. R., Loken, L. C., & Sadro, S. (2021). Dispersion and Stratification Dynamics in the Upper Sacramento Deep Water Ship Channel. *San Francisco Estuary and Watershed Science*.

Loken, L.C., Sadro, S., Lenoch, L.E.K., Stumpner, P.S., Dahlgren, R.A., Burau, J.R., Van Nieuwenhuyse, E.E. (in review). Whole ecosystem nutrient-enrichment experiment disentangles effects of nutrients, light, and hydrodynamics on productivity in the Sacramento River Deep Water Ship Channel.

Lindberg, J. C., Tigan, G., Ellison, L., Rettinghouse, T., Nagel, M. M., & Fisch, K. M. (2013). Aquaculture methods for a genetically managed population of endangered Delta Dmelt. North American Journal of Aquaculture, 75(2), 186–196. https://doi.org/10.1080/15222055.2012.751942

Mac Nally R, Thomson J, Kimmerer W, Feyrer F, Newman K, Sih A, Bennett W, Brown L, Fleishman E, Culberson S, Castillo G. 2010. An analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modelling (MAR). Ecol Appl 20(5):1417–1430. doi: http://dx.doi.org/10.1890/09-1724.1

Mahardja B, Young MJ, Schreier B, Sommer T. 2017a. Understanding imperfect detection in a San Francisco Estuary long-term larval and juvenile fish monitoring program. Fisheries Manag Ecol 24:488–503. https://doi.org/10.1111/fme.12257

Mahardja B, Farruggia MJ, Schreier B, Sommer T. 2017b. Evidence of a shift in the littoral fish community of the Sacramento–San Joaquin Delta. PLoS One; 12(1):e0170683. https://doi.org/10.1371/journal.pone.0170683

Merz JE, Hamilton S, Bergman PS, Cavallo B. 2011. Spatial perspective for delta smelt: a summary of contemporary survey data. California Fish & Game. 97(4):164-189.

Morgan-King and Schoellhamer 2013. DOI: 10.1007/s12237-012-9574-z

Nichols FH, Thompson JK, Schemel LE. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis* 2. Displacement of a former community. Mar Ecol Prog Ser 66(1–2):95–101. doi: http://dx.doi.org/10.3354/meps066095

Nobriga, M.L., Sommer, T.R., Feyrer, Frederick, and Flem-ing, Kevin, 2008, Long-term trends in summertime habitat suitability for delta smelt, *Hypomesus transpacificus*: San Francisco Estuary and Watershed Science, v. 6, no. 1, http://escholarship.org/uc/item/5xd3q8tx.

O'Rear, T. and P. Moyle (2014). "Suisun Marsh Fish Study: Trends in Fish and Invertebrate Populations of Suisun Marsh January 2012–December 2012." California, California Department of Water Resources.

O'Rear, T. and P. Moyle (2017). Suisun Marsh Fish Study: Trends in Fish and Invertebrate Populations of Suisun Marsh, January 2015-December 2015. Annual Report for the California Department of Water Resources. Sacramento, California, University of California, Davis.

Owens, S., T.R. Ignoffo, J. Frantzich, A. Slaughter, and W. Kimmerer. 2019. High growth rates of a dominant calanoid copepod in the northern San Francisco Estuary. Journal of Plankton Research. doi:10.1093/plankt/fbz064.

Polansky, L., Newman, K. B., Nobriga, M. L., & Mitchell, L. (2018). Spatiotemporal Models of an Estuarine Fish Species to Identify Patterns and Factors Impacting Their Distribution and Abundance. Estuaries and Coasts, 41, 572–581. https://doi.org/10.1007/s12237-017-0277-3

Polansky, L., Newman, K. B., & Mitchell, L. (2020). Improving inference for nonlinear state-space models of animal population dynamics given biased sequential life stage data. Biometrics. https://doi.org/10.1111/biom.13267

Reclamation 2019. Biological Assessment, Sacramento Deepwater Ship Channel Nutrient Enrichment Project: Phase 2. 28 pp.

Reclamation 2021. Biological Assessment, Sacramento Deepwater Ship Channel Food Web Study Pre-Project Monitoring. 20 pp.

Resources Assessment Branch. 2020. Water Quality Evaluation Section (WQES) Field Manual

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

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

Rose, K.A., Kimmerer, W.J., Edwards, K.P. and Bennett, W.A., 2013a. Individual-based modeling of Delta Smelt population dynamics in the upper San Francisco Estuary: I. Model description and baseline results. Transactions of the American Fisheries Society 142:1238-1259.

Rose, K.A., Kimmerer, W.J., Edwards, K.P. and Bennett, W.A., 2013b. Individual-based modeling of Delta Smelt population dynamics in the upper San Francisco Estuary: II. Alternative baselines and good versus bad years. Transactions of the American Fisheries Society 142:1260-1272.

California Department of Water Resources. 2020. Sacramento Valley Salmon Resiliency Strategy: 2020 Progress Update.

Sangalli, L. M., Ramsay, J. O., & Ramsay, T. O. (2013). Spatial spline regression models. Journal of the Royal Statistical Society. Series B (Statistical Methodology), 75(4), 681–703. http://www.jstor.org/stable/24772451

Schoellhamer, D.H. 2011. Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. Estuaries and Coasts 34:885–899.

Schreier BM, Baerwald MR, Conrad JL, Schumer G, May B. 2016. Examination of Predation on Early Life Stage Delta Smelt in the San Francisco Estuary Using DNA Diet Analysis. Trans Am Fish Soc. 145(4):723–733. doi:10.1080/00028487.2016.1152299.

Sommer, T., and F. Mejia. 2013. A place to call home: a synthesis of delta smelt habitat in the upper San Francisco Estuary. San Francisco Estuary and Watershed Science 11(2). Available at: http://www.escholarship.org/uc/item/32c8t244.

Sommer, T., R. Hartman, M. Koller, M. Koohafkan, J.L. Conrad, M. MacWilliams, A. Bever, C. Burdi, A. Hennessy, and M. Beakes. 2020. Evaluation of a large-scale flow manipulation to the upper San Francisco Estuary: Response of habitat conditions for an endangered native fish. PLoS ONE 15: e0234673. https://doi.org/10.1371/journal.pone.0234673

State Water Resources Control Board. 2000. Revised Water Right Decision 1641

Suisun Marsh Preservation Agreement. 2015. United States Bureau of Reclamation

Swanson, C., T. Reid, P.S. Young, and J.J. Cech, Jr. 2000. Comparative environmental tolerances of threatened delta smelt (*Hypomesus transpacificus*) and introduced wakasagi (*H. nipponensis*) in an altered California estuary. Oecologia 123:384–390.

Thompson, J., J. R. Koseff, S. G. Monismith and L. Lucas (2008). "Shallow water processes govern system-wide phytoplankton bloom dynamics: A field study." Journal of Marine Systems 74(1-2): 153-166.

Thomson, J. R., Kimmerer, W. J., Brown, L. R., Newman, K. B., Mac Nally, R., Bennett, W. A., Feyrer, F., & Fleishman, E. (2010). Bayesian change point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. Ecological Applications, 20(5), 1431–1448. https://doi.org/10.1890/09-0998.1

Tigan G., W. Mulvaney, L. Ellison, A. Schultz, T. Hung., Effects of light and turbidity on feeding, growth, and survival of larval Delta Smelt (*Hypomesus transpacificus*, *Actinopterygii*, *Osmeridae*). 2020. Hydrobiologia (2020). https://doi.org/10.1007/s10750-020-04280-4

Twardochleb L., Maguire A., Dixit L., Bedwell M., Orlando J., MacWilliams M., Bever A., and B. Davis. 2021a. North Delta Food Subsidies Study: Monitoring Food Web Responses to the North Delta Flow Action, 2019 Report. Department of Water Resources, Division of Environmental Services.

Twardochleb L., Martinez, J., Bedwell, M., Frantzich, J., Sommer, T., and B. Davis. 2021b. North Delta Food Subsidies 2021-2023 Operations and Monitoring Plan. Department of Water Resources, Division of Environmental Services.

US Army Corps of Engineers, Sacramento District, West Sacramento Project General Reevaluation Report, December 2015.

United States Fish and Wildlife Service (USFWS). 2015. Suisun Marsh Habitat Management, Preservation, and Restoration Plan. California Department of Fish and Game, US Fish and Wildlife Service, and US Bureau of Reclemation Sacramento, CA.

United States Fish and Wildlife Service (USFWS), C. Johnston, S. Durkacz, R. Mckenzie, J. Speegle, B. Mahardja, B. Perales, D. Bridgman, and K. Erly. 2020. Interagency Ecological Program and US Fish and Wildlife Service: San Francisco Estuary Enhanced Delta Smelt Monitoring Program data, 2016-2020 ver 3. Environmental Data Initiative. https://doi.org/10.6073/pasta/764f27ff6b0a7b11a487a71c90397084 (Accessed 2020-10-28).

United States Fish and Wildlife Service (USFWS), California Department of Water Resources, United State Bureau of Reclamation, California Department of Fish and Wildlife, and University of California Davis. 2020. Delta Smelt Supplementation Strategy.

United States Fish and Wildlife Service (USFWS), California Department of Fish and Wildlife, California Department of Water Resources, United State Bureau of Reclamation, United States Geologic Survey and University of California Davis. 2021. Delta Smelt Experimental Release Study Plan, Draft 5; Sept 2021.

Wang, Z., H. Wang, J. Shen, F. Ye, Y. Zhang, F. Chai, Z. Liu, J. Du. 2019. An analytical phytoplankton model and its application in the tidal freshwater James River. Estuarine, Coastal and Shelf Science, 224(31).

Wood Rodgers. 2018. Bulkhead Alternatives Analysis Report. Prepared for City of West Sacramento, April 2018.

Personal Communications

May 19, 2020 – Microsoft Team’s Meeting between USFWS staff Will Smith and Matt Nobriga, and USBR staff Kristin Arend, Brian Mahardja, Josh Israel, and Mike Beakes.

Attachments

Appendix A- Abiotic Habitat Figures

Appendix B- Monitoring

Appendix C- RMA Report

Appendix D- Performance Metric Information Sheets