Drought Ecosystem Monitoring and Synthesis Plan

2021-2023

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CALIFORNIA DEPARTMENT OF
WATER RESOURCES

And the Interagency Ecological Program

Interagency Ecological Program

COOPERATIVE ECOLOGICAL INVESTIGATIONS SINCE 1970

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Abbreviations and Acronyms

CDFW – California Department of Fish and Wildlife
CVP – Central Valley Project
Delta – Sacramento San Joaquin Delta
DJFMP – Delta Juvenile Fish Monitoring Program
DRY – Drought Response Year Team
DSP – Delta Science Program
DWR – Department of Water Resources
EDSM – Enhanced Delta Smelt Monitoring Survey
EMP – Environmental Monitoring Program
IEP – Interagency Ecological Program
JPE – Juvenile Production Estimate
FMWT – Fall Midwater Trawl
FWS – United States Fish and Wildlife Service
MAST – Management Analysis and Synthesis Team

Reclamation – United States Bureau of Reclamation
SWP – State Water Project
SWRCB – State Water Resources Control Board
STN – Summer Townet Survey
TUCP – Temporary Urgency Change Petition

Abstract

The 2021 Drought Contingency Plan includes the commitment to ecosystem monitoring to assess the impact of drought and drought actions. To that end, DWR and Reclamation are leading a team of scientists to develop a monitoring and synthesis plan for the environmental impacts of the drought and DWR and Reclamation drought actions on the Delta and Suisun Marsh. The execution and reporting of this plan will be coordinated through the Drought Response Year (DRY) Team, which will provide guidance to several partners that will assist with field collections and synthesis. This monitoring plan outlines the data collection and analysis we will undertake to evaluate ecosystem responses to the current drought in the Sacramento-San Joaquin Delta and Suisun Marsh, with special emphasis on the Temporary Urgency Change Petition (TUCP) and the Emergency Drought Barrier. Data collection will rely primarily on existing monitoring, with the addition of some special studies of aquatic vegetation, predation rates, and harmful algal blooms. Data will be integrated and compared to previous droughts and previous wet periods to detect ecosystem changes. This study on the impacts of drought on the Delta will be conducted in collaboration with other actions included in the Drought Toolkit, such as management actions and studies conducted in tributaries not covered by this plan.

Introduction

California's Mediterranean climate is characterized by hot, dry summers, and cool, wet winters. There is typically little to no rainfall for six to nine months out of the year in the central and southern regions of the state. There is also high inter-annual variability, with average rainfall varying from a low of 23.8 cm in 1924 to a high of 105.8 cm in 2017, usually depending on just a few massive storms each year (Dettinger 2011). This high variability leads to frequent floods and multi-year droughts that result in massive year-to-year changes in both the aquatic community and the ability of managers to provide water for consumptive use.

California's inter-annual variation in precipitation is great enough that a single dry year does not necessarily produce a drought. While there is no single agreed-upon definition for "drought", droughts in California generally occur when multiple dry years in a row reduce water storage to an extent that water supply operations can no longer compensate (Resources 2020). For the purposes of this document, we are defining "drought" as two or more consecutive years with a Sacramento Valley Index of Below Normal, Dry, or Critically Dry. This aligns with the requirements of the ITP which require drought contingency planning when there are consecutive Dry or Critically Dry years. We have chosen to include Below Normal years as well, to be consistent with previous drought research (Mahardja et al. 2021), and account for lack of reservoir recharge in below normal years.

Previous droughts in recent history include the dry periods of 1959-1962, 1976-1977, 1987-1992, 2001-2002, 2007-2010, and 2012-2016 (Figure 1). In pre-historical periods, tree ring analysis shows droughts lasting decades to hundreds of years (Stine 1994). Climate change could bring increased frequency of major floods and droughts, which will stress California's environment and economy (Swain et al. 2018). The current drought (2000-2021, ongoing), has resulted in record low stream flows, record low reservoir levels, extremely dry soils, low groundwater reserves, and problems providing enough water for wildlife and human uses. As of July 30th, 2021, 88% of California was in a state of either "Exceptional drought" or "Extreme Drought" (https://droughtmonitor.unl.edu/CurrentMap/StateDroughtMonitor.aspx?CA) and Governor Gavin Newsom had declared a drought emergency in 41 counties, and has called for a voluntary 15% reduction in water use (https://www.gov.ca.gov/2021/07/08/as-drought-conditions-intensify-governor-newsom-calls-on-californians-to-take-simple-actions-to-conserve-water/).

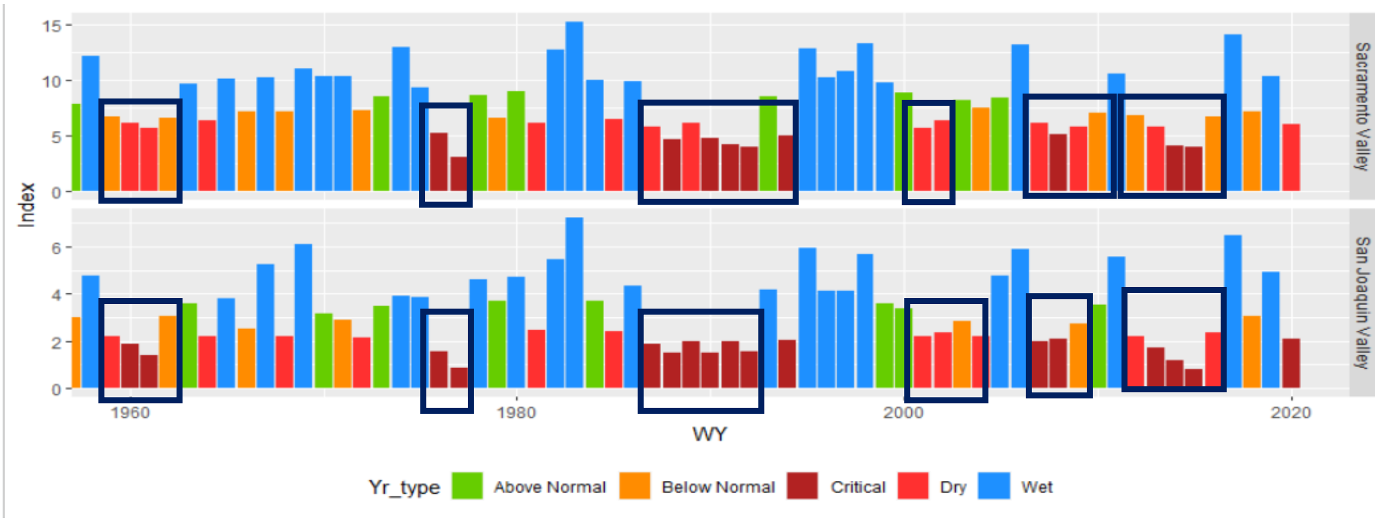

Figure 1. Plot of water year indexes for the Sacramento and San Joaquin Valleys from 1960 to the present. Data is from the California Department of Water Resources (https://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST)

Regulatory Background

The 2021 Drought Contingency Plan includes a commitment to ecosystem monitoring to assess the impact of drought and drought actions. This aligns with the requirements of the 2020 Incidental Take Permit (ITP) which require drought contingency planning in when there are consecutive Dry or Critically Dry years and actions within the Record of Decision on the coordinated Long-Term Operation of the Central Valley Project (CVP) and State Water Project (SWP) to prepare a Drought and Dry Year Toolkit. This plan describes monitoring and synthesis to evaluate impacts of drought and some of the actions included in the Drought Toolkit on the Delta and Suisun Marsh.

The 2020 Record of Decision on the Long-Term Operations of the CVP and SWP and the 2020 ITP for the SWP included a “Drought Toolkit”, containing voluntary actions which may help address the impact of drought and dry year conditions. The ITP also contains the requirement for a Drought Contingency Plan, containing specific actions to be undertaken in a drought year. These plans are developed by the California Department of Water Resources (DWR) and the US Bureau of Reclamation (Reclamation), in coordination with the US Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), the California Department of Fish and Wildlife (CDFW), the State Water Resources Control Board (SWRCB), and SWP and CVP Contractors. By February of each year following a critical year, DWR must report on the measures employed and assess their effectiveness. Reclamation has agreed to coordinate with DWR on this planning and reporting.

The Drought Toolkit is still in development (as of 5/27/2021), but both the draft toolkit and the 2021 Drought Contingency Plan include ecosystem monitoring to assess the impact of drought and drought actions. To that end, DWR is leading a team of scientists to report and synthesize the monitoring occurring for the environmental impacts of the drought and drought actions, including the Temporary Urgency Change Petition (TUCP) conditionally approved by SWRCB on June 1st, 2021, and the installation of the

Emergency Drought Barrier (EDB) in False River. This monitoring plan outlines the data collection and analysis to evaluate ecosystem responses in the Delta to the current drought and the drought actions planned for water year 2021. While the plan includes an evaluation of the overall effects of drought, we will also evaluate the effectiveness and ecosystem responses of two of the management actions in the Drought Toolkit, namely the TUCP and the Emergency Drought Barrier.

Drought Actions for 2021

Other Drought Actions included in the 2021 Drought Contingency plan include a Temporary Urgency Change Petition (TUCP) with changes to flow requirements (Table 1) and an emergency drought barrier in False River, just west of Franks Tract.

Table 1. Summary of TUCP Operations Framework.

Timeframe	Proposed Action
June 1 through July 31, 2021	Reduce outflow requirements for salinity control from 4,000 cubic feet per second (cfs) to 3,000 cfs on a 14-day running average
June 1 through July 31, 2021	Cap the combined SWP and CVP exports at 1,500 cfs when Delta outflow is between 3,000 cfs and 4,000 cfs
June 1 through August 15, 2021	Relocate the Western Delta Agriculture compliance point from Emmaton to Threemile Slough
June 1 through August 30, 2021	SWP and CVP exports may exceed 1,500 cfs when Delta outflow meets D-1641

Beginning June 1, 2021 Reclamation and DWR request modification of D-1641 outflow and the relocation of the Emmaton compliance point described in D-1641 Table 3. The requested changes would modify the minimum monthly Net Delta Outflow Index (NDOI) described in Figure 3 of D-1641 during the months of June and July to no less than 3,000 cfs on a 14-day average, to allow management of reservoir releases that will conserve storage for later fishery protection and minimum health and safety needs. In addition, the request includes relocation of the Western Delta Agricultural compliance point from Emmaton to Threemile Slough beginning June 1 and continuing through August 15. Under this proposal, the CVP and SWP would maintain reservoir releases that would sustain minimum health and safety export levels, currently estimated to be 1,500 cfs anytime NDOI is between 3,000 and 4,000 cfs.

This TUCP is similar to the TUCPs filed during 2014 and 2015. The analysis and monitoring done for these previous TUCPs, along with the emergency drought barrier in 2015, give us some background as to expected ecosystem responses to the planned drought actions. There is the potential for the TUCP to be extended into the fall, in which case effects of the second TUCP will also be analyzed as a part of this synthesis project.

Scientific Background

The influence of annual freshwater flow (or lack of flow) on water quality, productivity, and fishes of the San Francisco Bay-Delta Estuary (Estuary) is relatively well-studied, though many responses are still difficult to predict. There are well-established relationships between freshwater outflow and population levels of certain biota, most notably the Longfin Smelt (*Spirinchus thaleichthys*) which has much higher abundances and recruitment during high-flow conditions (Kimmerer et al. 2019). Other fishes, such as the Delta Smelt (*Hypomesus transpacificus*), have a more complicated relationship with flow. Temperature, rather than outflow has been the key driver of their population growth, particularly over the past ten years (Schultz et al. 2019, FLOAT-MAST 2020).

Multi-year droughts have received less study than outflow per se. However, the 2012-2016 drought provided the impetus for a number of studies and reports that give us a basis for predictions regarding major ecosystem changes we expect to see during a drought (Lehman et al. 2017, Jabusch et al. 2018, Singer et al. 2020, Mahardja et al. 2021)(Table 2). Based on similar information and experiences with previous drought operations (e.g. Kimmerer et al. 2019; Durand et al. 2020), we also provide a specific discussion of the expected influences of the TUCP and EDB (see text below and Table 3).

1. Hydrology and Water Quality

Reduced precipitation and the associated decrease in freshwater inputs to the estuary is the most obvious impact of a drought. In the Delta, hydrology is largely controlled through upstream dam releases, exports, gates, and barriers. With lower annual precipitation, we can expect lower instream flows in all of the major rivers entering the Delta (Durand et al. 2020). Lower flows in the rivers will reduce the activation of off-channel habitat and limit floodplain inundation. The decreased inflow will have several direct impacts on water quality. Within the Delta, the salinity gradient will move inland due to greater oceanic and tidal influence under decreased outflow conditions. Water residence times in the Delta generally increase under low flows, allowing more time for biogeochemical processes to impact water quality, as well as more time for biota (e.g., phytoplankton and zooplankton) to grow. Lower freshwater flows, combined with an increase in aquatic weeds, will reduce sediment transport and turbidity (Conrad et al. Draft manuscript; (Hestir et al. 2015)).

The draft Drought Toolkit includes a number of potential Drought Response Actions (DRAs) that are intended to conserve early seasonal storage by reducing delaying downstream demands and instream flows. These actions include accommodating water transfers outside of the authorized transfer window; modified and coordinated diversion schedules; and Shasta releases made through the river outlets (i.e. power bypass). The Drought Toolkit also includes a number of infrastructure improvement actions which are intended to provide a more efficient operation the upstream reservoirs. Ultimately the effectiveness of any of these actions, implemented as part of a coordinated drought response, will be evaluated as to their water storage conservation benefit and downstream impacts. The aspects of upstream water storage conservation and associated impacts on upstream habitat for anadromous fishes will be evaluated by the DRY team, but will not be assessed in this synthesis plan.

The TUCP and EDB will affect influential environmental drivers such as hydrology and salinity, though these effects are expected to be slight in comparison with the effect of the drought itself. In 2015, modeling completed for the EBD and TUCP showed a decrease in Sacramento River volume of approximately 200 TAF (DWR 2015) and a shift in the salinity field with slightly higher salinity in Suisun and the Sacramento River, and lower salinity in the South Delta when compared to D-1641 conditions (Figure 3). However, water was not available to achieve D-1641 conditions, so whether the modeled changes were “due to” the TUCP or to the drought itself is difficult to disentangle. Forecasting for the summer of 2021 predicts similar increases in conductivity and increases in X2 as seen in 2015. Models of the 2021 TUCP analyzed in the Biological Review currently predict an increase in conductivity of approximately 1000 uS/cm at Chipps Island and an increase in X2 of 2 km June-August (see TUCP Biological Review, (Figure 2).).

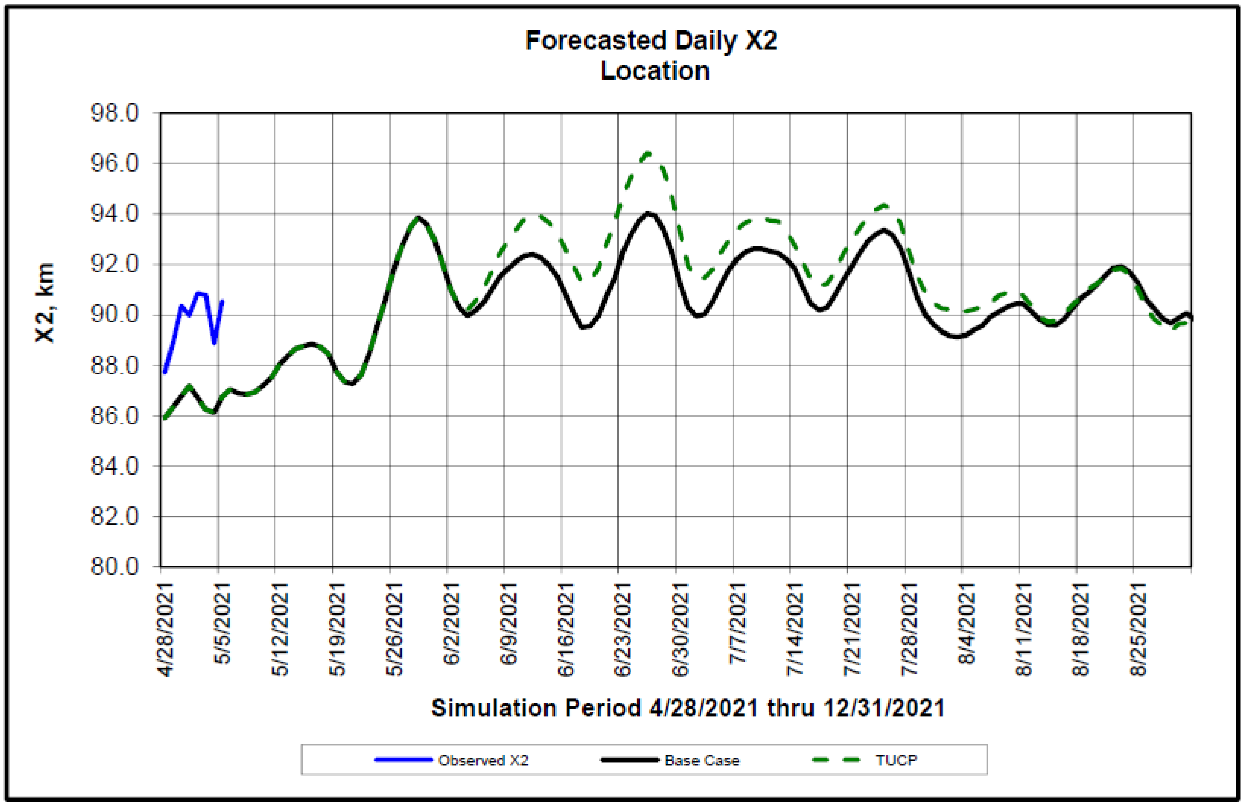

Figure 2. Figure DS2. Modeled X2 for changes in X2 location based on DSM2 modeling of Delta hydrology with D-1641 regulations versus TUCP conditions. Figure from TUCP Biological Review.

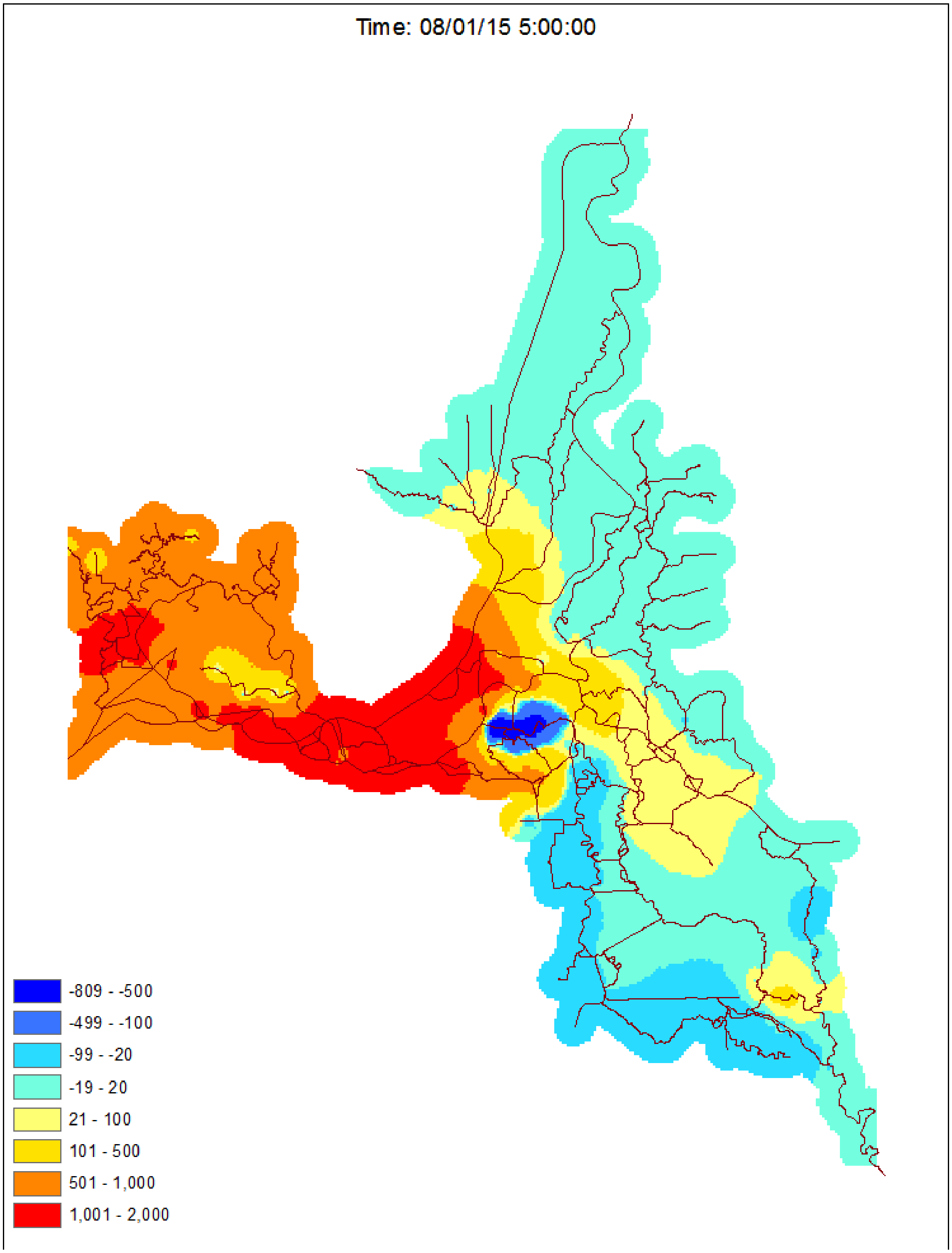

Figure 3. Difference in specific conductance caused by TUCP and barrier versus D-1641 conditions during 2015. Figure from DWR report on TUCP, 2015.

2. Nutrients and Contaminants

We predict that the transport downstream of nutrients and contaminants will decrease, but that concentrations of both may increase locally. Presence of nutrients and contaminants in the system is controlled by concentration and rate of input to the system (loading), as well as transport, transformation, and burial within the system. Reduced freshwater flow may decrease contaminant loading because most contaminants enter the waterways via runoff during storm events (Weston et al. 2015). Paradoxically, lower flow may also increase the concentration of contaminants in the system because less inflow results in less dilution and slower transport out of the system.

Discharge from wastewater treatment plants provides the bulk of the nitrogen influx into the system, though nitrogen also enters the system from agricultural and urban runoff (Wankel et al. 2006, Novick et al. 2015, Saleh and Domagalski 2015). Based on predicted changes to hydrology, drought may not significantly impact loading from wastewater treatment plants, but it will reduce dilution and increase transport times, potentially leading to increases in observed concentrations in certain areas. During the 2012-2016 drought, an increase in ammonium concentrations was one of the responses noted (Conrad et al. draft manuscript). Upgrades to the Sacramento Regional County's Wastewater Treatment Plant, which were completed in May of 2021, substantially reduced total nitrogen inputs to the Delta, and may change the response of nitrogen to the current drought (District 2021).

We do not expect the TUCP to significantly impact loading or concentation of nutrients and contaminants above any changes due to the drought itself. Increased treatment for aquatic vegetation control within Franks Tract due to the Barrier may increase local concentration of herbicides in the vicinity of the barrier, but we do not predict any larger-scale effects of the Barrier on nutrients or contaminants.

3. Phytoplankton and Harmful Algal Blooms

We predict the drought will produce an increase in both duration and severity of blooms of *Microcystis* and other harmful algae, with the potential for localized increases in other phytoplankton. Reduction in nutrient influx can reduce phytoplankton growth (Wetz and Yoskowitz 2013). However, because nutrients in the estuary are not generally considered limiting, longer residence times and increased water clarity associated with drought may result in some local increases in biomass or productivity (Wetz and Yoskowitz 2013, Glibert et al. 2014b). On the landscape scale, no clear relationship has been identified between estuary-wide phytoplankton biomass (as indexed by chlorophyll) and outflow (Kimmerer 2002). Several examples of localized blooms, however, have been tied to particular outflow conditions. In Suisun Bay, high chlorophyll can only occur when there are relatively long residence times, but also high freshwater inputs (Hammock et al. 2019). The drought years of 2014 and 2016 saw major diatom blooms when the combination of high nutrients and long residence times allowed diatom growth (Glibert et al. 2014a, Jungbluth et al. 2020). However, the most consistent change in phytoplankton seen during droughts over the past 20 years is the increase in

Microcystis and other harmful algal blooms, resulting from high temperatures and long residence times (Lehman et al. 2017).

The installation of the Barrier will reduce flow through Frank's Tract, so and therefore may increase harmful algal blooms in the central Delta. Separating the impact of the Barrier from increases due to the droughtdrought itself, however, will likely be difficult. We do not predict any change in Micrycystis due to the TUCP above the impact of the drought itself.

4. Zooplankton

We predict an overall decline in zooplankton abundance during the drought, decreasing the availability of this critical source of food for fishes. The effect of drought on zooplankton communities, however, is difficult to predict. The drought will likely impact specific taxa differently and impacts will also vary by location. High outflow years have been shown to transport freshwater zooplankton into Suisun Bay, increasing abundance of certain taxa (particularly the calanoid copepod *Pseudodiaptomus forbesi*) in this region (Kimmerer et al. 2018b). Such events are unlikely during a drought, and we can therefore predict freshwater zooplankton like *P. forbesi* will likely decrease in the Low Salinity Zone and that many taxa will shift their center of distribution upstream. Analysis of the distribution of zooplankton communities during the previous drought found copepod density decreased during the driest summers, as did cladocerans (Conrad et al. Draft manuscript). Other analyses, however, have not detected a trend between copepod densities and X2 over longer time frames (Hobbs et al. report).

The drought-induced change in phytoplankton communities discussed earlier may also have bottom-up effects on the zooplankton community. *Microcystis* and other toxigenic cyanobacteria may directly harm copepods in the estuary (Ger et al. 2009). Other cyanobacteria, usually considered "poor-quality" food for zooplankton, may comprise a larger proportion of zooplankton diet than previously thought (Kimmerer et al. 2018a). In contrast, diatoms are generally thought to be nutritious for zooplankton. Jungbluth et al. (2020), however, found that blooms of the diatom *Aulacoseira* seen during the 2012-2016 drought did not aid in zooplankton growth (Jungbluth et al. 2020).

Floodplains may be highly productive sources of zooplankton with appropriate timing and duration of inundation. Flow pulses during the fall on the Yolo Bypass have been linked to several phytoplankton blooms and associated increases in zooplankton (Frantzich et al. 2018), though other pulses failed to provide the same magnitude of response (Twardochleb et al. 2021). Other studies of zooplankton have noted their abundance can be order of magnitude greater in flooded rice fields and managed floodplains compared to adjacent rivers (Sommer et al. 2001, Grosholz and Gallo 2006, Corline et al. 2017, Jeffres et al. 2020). Lack of floodplain inundation and low summer-fall flows, as predicted under drought may limit subsidies of this supply of zooplankton to downstream habitats.

We do not expect the TUCP or Barrier to significantly impact abundance of zooplankton above any changes due to the drought itself, though it may decrease import of freshwater zooplankton from the Delta into Suisun Bay (As seen in Kimmerer et al. 2019).

5. Aquatic Weeds

We predict drought conditions will cause an increase in invasive floating aquatic vegetation (FAV) and submerged aquatic vegetation (SAV). FAV and SAV have increased in coverage over the past 20 years (Ta et al. 2017), with particular increases seen in the last drought (Kimmerer et al. 2019). From 2008 to 2019, aquatic vegetation increased in coverage by 2.4× (7,100 acres to 17,300 acres) to occupy nearly one-third of the area of waterways in the Delta (Ta et al. 2017, Ustin et al. 2020). Both types of vegetation establish more readily in slower-moving water, so low flow conditions that occur during droughts have been linked to increases in coverage of invasive vegetation. Increases to nutrients, such as seen during 2013-2014, may also facilitate expansion of aquatic vegetation, though this effect is less conclusive (Boyer and Sutula 2015, Dahm et al. 2016). Changes to flow patterns caused by the 2015 emergency drought barrier were implicated in the expansion of submerged vegetation in Franks Tract (Kimmerer et al. 2019).

The increase in aquatic vegetation may be mitigated by control methods. The Aquatic Invasive Plant Control Program of the CA State Parks Division of Boating and Waterways (DBW) is chiefly responsible for aquatic vegetation control in the Delta and primarily employs chemical control tools. DBW is permitted to treat up to 15,000 acres per year of aquatic vegetation, though typically they treat only about 40% of that limit (DBW 2020). For FAV control, DBW most commonly uses glyphosate but also uses some imazamox and 2,4-D. For SAV control, fluridone is by far the most commonly applied herbicide in the Delta. However, recent studies have shown use of fluridone on submerged vegetation in tidal environments, such as the Delta, are generally ineffective (Rasmussen et al. in review, Khanna et al. In review). Therefore, this treatment program may increase loading of herbicides into the system and may or may not reduce weed abundance. Treatment of floating aquatic vegetation with herbicides is thought to be somewhat more effective.

We predict an increase in aquatic vegetation in Franks Tract after installation of the EDB, due to the decrease in water velocity in the tract. While Durand et al. (2016) failed to detect a relationship between establishment of aquatic vegetation and velocity, in 2015, weed coverage in Frank's tract increased significantly, while nearby reference sites did not increase to the same degree (Kimmerer et al. 2019). This was attributed to the decrease in water velocity through the center of the tract. We can expect a similar response to the 2021 EDB.

6. Fish

It is relatively well-understood that recent droughts have resulted in major effects on the fish assemblage (Mahardja et al. (2021). We therefore predict the general effects of the drought will be an increase in invasive fishes, particularly those associated with vegetation, and a decrease in floodplain spawners and pelagic fishes. The decline in pelagic fishes includes a decline in abundance and recruitment of Delta Smelt and Longfin Smelt. We also predict a decrease in survival of out-migrating juvenile salmonids, a decrease in survival in oversummering juvenile steelhead, and a decrease in spawning success of winter-run, spring-run, and fall-run Chinook salmon. Decreased survival in oversummering juvenile steelhead is expected when water temperatures reach unsuitable levels, as is expected, for example, in the American River below Folsom and Nimbus Dams. Decreased spawning success is expected to be due to unsuitably warm water temperatures, exacerbated by drought, increasing pre-spawn mortality of adults or mortality of incubating eggs and pre-emergent fry.

The native fish community of California evolved in response to regular cycles of floods and droughts. However, water management in today’s system have altered the historic floods and droughts dynamics. With lower spring outflow and higher summer base flows than historic conditions, today’s Delta is more like the hydrology of southeastern US streams and rivers than historic California rivers. Introduced fishes from the Southeast thrive in these more stable conditions (Moyle et al. 2012). During droughts, stream flows are slower and water is warmer, making habitat more suitable for these invaders. Salinity intrusion during low flow periods would be predicted to reduce abundance of invasive freshwater centrarchids (such as Largemouth Bass *Micropterus salmoides*), but there was no decline detected during the 2012-2016 drought (Conrad et al. draft manuscript).

The increase in invasive vegetation that occurred during the drought may partially account for this surprising results. Increased vegetation may also contribute to the reduction in abundance of the pelagic fish community. Mahardja et al (2021) found that pelagic fish tended to decline during drought conditions. Pelagic fish often recovered quickly, but they did not always fully recover in wet years following a drought. In contrast, littoral fishes were more resistant to drought. In particular, the invasive Mississippi Silverside (*Menidia audens*) experienced a marked increase in abundance during the drought (Mahardja et al. 2016).

Obligate floodplain spawners, such as the Sacramento Splittail (*Pogonichthys macrolepidotus*), may have the clearest response to the drought. Without floodplain inundation, we predict much lower recruitment of Splittail during the drought (Sommer et al. 2002). Other fishes that seasonally use floodplains, such as Chinook Salmon (*Oncorhynchus tshawytscha*), may also experience declines in growth and survival when cut off from this productive habitat, though they have been found to use perennially wet channels within floodplains even during dry years (Sommer et al. 2001, Takata et al. 2017, Goertler et al. 2018, Johnston et al. 2018).

Delta Smelt abundance is affected by habitat availability and quality, as defined by temperature, turbidity, and salinity. High-outflow years put the majority of fall low salinity zone habitat (0.5 to 6 PSU) in Suisun Marsh and Suisun Bay which results in greater habitat area (Sommer and Mejia 2013). However, this relationship only holds true during cool years. Warm, high-outflow years do not benefit smelt to the same degree (as seen during the hot, high-outflow year of 2017) (FLOAT MAST 2020). While dry years may be either warm or cool, droughts tend to be warmer, on average, than wet periods (Jeffries et al. 2016). Delta Smelt population numbers are critically low, with only two adult and eight larval smelt detected by the Enhanced Delta Smelt Monitoring Program in the first five months of 2021 (USFWS data). An extended drought, particularly if temperatures are warm, could push wild Delta Smelt to extirpation, leaving only a hatchery refuge population.

Longfin Smelt abundance is strongly tied to freshwater outflow, with large increases in population during high-outflow years (Kimmerer 2002, Nobriga and Rosenfield 2016). This may be tied to increased access to spawning/rearing habitat in San Pablo Bay and South San Francisco Bay during high-outflow periods(Grimaldo et al. 2017, Parker et al. 2017), but the precise mechanism remains elusive. Regardless of the mechanism, low outflow will decrease Longfin Smelt recruitment, and an extended drought may have major impacts on the population's ability to rebound after the drought. Longfin Smelt experienced record low population numbers during the 2012-2016 drought, and their population has yet to fully recover, so their population resilience may be substantially reduced (Mahardja et al. 2021).

The TUCP and EDB will cause a slight decrease in Delta outflow and a slight increase in X2, however this is not expected to have a significant impact on fish distribution or abundance beyond the impact of the drought itself. The increase in X2 will not cause a change in habitat area. However, the installation of the EDB may cause local increases in predatory fishes (Striped Bass and Black Bass) immediately around the barrier since predatory fishes are known to congregate around artificial structures and eddies (Sabel et al. 2016(Sabal et al. 2016, Lehman et al. 2019)). We also predict an increase in centrarchids and other vegetation-specialists in the area around Franks Tract.

7. Salmon

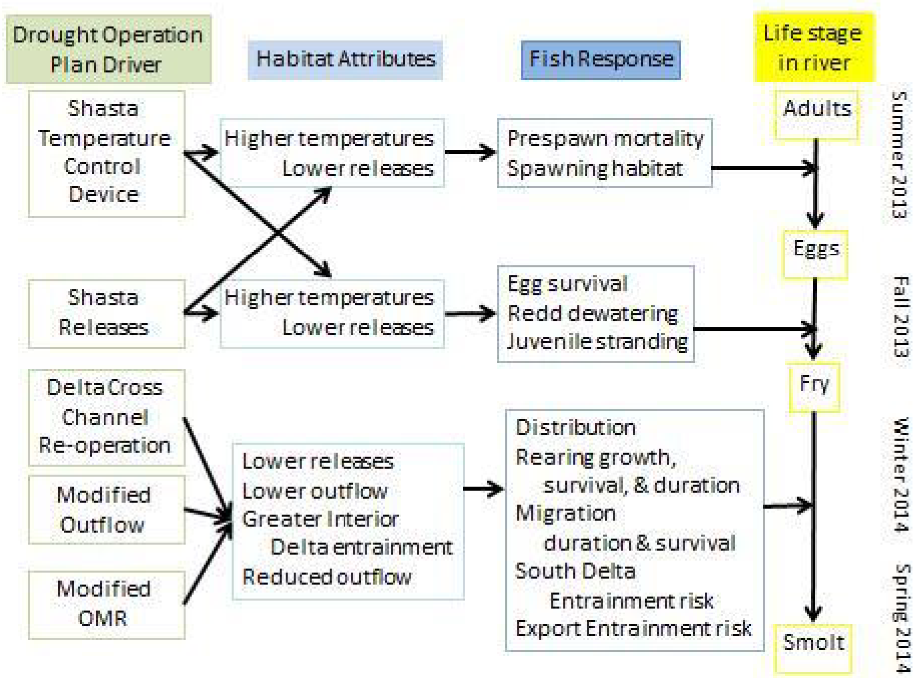

Figure 4. Conceptual model of salmon responses to drought actions from the Winter-Run Brood Year 2013 report (Israel et al. 2015).

Salmonids will be impacted by drought conditions throughout their life span, including both in-Delta impacts, upstream impacts, and ocean influences (Figure 1). This monitoring and synthesis plan will chiefly assess the impact of the drought on outmigrating juveniles as they pass through the Delta. Because of the limited geographic scope of this project, it may be difficult to assess the overall impact of the Drought on salmonids. A separate synthesis effort focused on salmon throughout their life history will be needed to assess the impact of drought on salmon populations as a whole.

Higher water temperatures in the rivers may cause lower survival of adults returning to their spawning habitats, as well as lower egg survival. While temperatures in spawning habitat in cold-water pools below the rim dams are regulated through controlled release from the reservoirs, drought conditions may limit the ability of water managers to keep temperatures within the desired range (Israel et al. 2015, Zarri et al. 2019, Sellheim et al. 2020). If water levels change quickly, redds may be dewatered or juveniles temperatures within the desired range (Israel et al. 2015, Zarri et al. 2019, Sellheim et al. 2020). To address the potential drought-induced limitations on available salmonid holding and spawning habitat the Drought Toolkit includes a number of actions intended to conserve storage in reservoirs and so that environmental and water managers are better able to provide suitable habitat conditions later in the season. When implemented, these actions will be evaluated based on their net benefit to the species of concern. For example, an action implemented to conserve spring storage for later use in the summer spawning period, would be evaluated based on the tradeoff between the biological response to decreases in spring water quality and in-river flow, compared to the biological response to increase in summer spawning habitat quality.

Once fry have left their spawning habitat to begin their outmigration, juvenile salmon are known to have low survival during low-outflow years (Michel et al. 2015). This may be due to a combination of factors, including poor connectivity between patches of suitable habitat due to low flows, a decrease in suitable habitat patches, increased pathogens, and an increase in predation. Salmon spend more time rearing in the upper water shed in low-flow years, so that salmon populations are subject to higher mortality during river residence and smaller proportions of young-of-the year make it to the Delta. Due to delayed timing of Delta entry, outmigrants that survive to the Delta experience lower Delta outflows, warmer water, and clearer water. These conditions are associated with longer migration time, higher predator activity, and higher juvenile salmon metabolic stress, culminating in elevated salmon vulnerability to predation and pathogens. Reduced outflows also influence salmon migration routing, causing higher risk of salmon migration into the Central and South Delta where survival rates are known to be low relative to Steamboat Slough and the mainstem Sacramento River (Singer et al. 2020). Although greater numbers may be entrained into the South Delta where survival rate will be lower, we do not expect increased entrainment into pumping facilities due to overall reduced numbers of salmon surviving to enter the Delta, high mortality along channels leading to the South Delta pumping facilities, and reduced pumping rates.

The TUCP is unlikely to affect juvenile salmon in the Delta because it the action will be in effect during a time of year when few, if any, juvenile salmon will be migrating through the Delta. Modeling conducted for the TUCP biological review showed a very small decrease in Delta survival and very small increase in south-Delta routing, but the 0-2% difference predicted by these models is unlikely to be detectable with monitoring. The upstream effects of operational changes made to accommodate the TUCP or as a result of a DRA are expected to provide a net benefit to salmonid species of concern relative to not taking the action. The Drought barrier will be installed through part of fall through the end of September, so it is possible that early outmigrants (e.g. winter-run) could be present in the Delta during part of the same period. However, numbers of Winter-Run and Spring-Run yearlings would be very small in the Delta during early season under very low flow conditions (del Rosario et al. 2013), and may not migrate as far downstream as the drought barrier. In general, effects of the drought barrier on juvenile salmon are not expected to be significant above the overall impact of the drought.

Research Questions

- What is the aquatic ecosystem response to multi-year droughts in the Sacramento San Joaquin Delta and Suisun Marsh?
- What are the ecosystem conditions in the Delta and Suisun during the 2020-2021 drought?
- What are the ecosystem responses in the Delta and Suisun to the 2021 TUCP and Emergency Drought Barrier?

Table 2. Predicted impacts of drought on various components of the ecosystem. The 'Impacts' listed will be the environmental parameters we will evaluate to assess the overall impact of the drought.

Category	Impacts	Monitoring
Hydrology	Lower flows Lower exports LSZ Further Inland LSZ Decreased area LSZ Decreased turbidity	CDEC/NWIS flow and water quality stations Modeling
Nutrients and Contaminants	Increased ammonium Decreased loading from agriculture Increased residence time and concentration	CDEC/NWIS water quality stations USGS Mapping Surveys Delta RMP
Microcystis and other harmful algal blooms	Blooms occur earlier in the season and extend later into the fall Increased abundance	Visual Assessment from monitoring surveys USGS Studies DWR monitoring
Weeds	Distribution shifts upstream Increased total coverage Changed Species composition Increased Herbicide applications	DBW Satellites (FAV) Hyperspectral flight (SAV)
Phytoplankton	Localized blooms Changes to community composition	CDEC/NWIS Chlorophyll sondes Fluoroprobes EMP
Zooplankton	Changes in abundance More marine species in Suisun, center of distributions shift inland Very species-specific, difficult to make generalizations.	EMP 20mm TSN FMWT DOP

Delta Smelt	Habitat – LSZ inland, lower turbidity, maybe higher temperature Earlier spawning Lower health/individual growth Low Population Growth Lower life history diversity	Smelt Larval Survey 20mm Townet FMWT EDSM Salvage
Longfin Smelt	Spawning habitat further inland Lower Health/individual growth Lower Population growth	Smelt Larval Survey 20mm Townet FMWT Bay Study Salvage
Salmonids	Increased water temperatures Decreased survival for outmigrating juveniles Decreased survival for oversummering juveniles Decreased spawning success Longer upstream holding Increased South Delta routing. Reduced alternative life history strategies Increased predation	Screw traps Trawls Beach Seines Acoustic tagging Salvage EDNA JPE (winter-run) JPE (spring-run) Carcass surveys
Other Fish	Increased littoral fishes Increased invasive centrarchids Increased Silversides Decreased Splittail (floodplain spawners) Decreased pelagic fish	All the fish surveys

Table 3. Predicted Ecosystem impacts of 2021 Drought Barrier and TUCP.

Category	Impacts	Monitoring
Hydrology	Higher salinity in Sacramento River Lower salinity in central and south Delta X2 shifts upstream up to ~2km	CDEC/NWIS flow and water quality stations Modeling
Nutrients and contaminants	Increased herbicides in Franks Tract	DBW
Microcystis	Increase in central/south Delta	Visual Assessment from monitoring surveys USGS Studies DWR MWQI monitoring
Weeds	Increased weeds in Franks Tract	DBW Satellites (FAV) Hyperspectral flight (SAV)
Phytoplankton	Localized blooms Changes to community composition	CDEC/NWIS Chlorophyll sondes Fluoroprobes EMP
Delta Smelt	Negligible impact	EDSM, FMWT, Summer Townet Survey, modeling.
Longfin Smelt	Slight decrease in recruitment	FMWT, EDSM, Summer Townet, Other potential monitoring as part of Longfin Smelt Science Plan
Salmonids	Small decrease in through-Delta survival for the small number of juvenile salmonids in the Delta.	Baseline trawling and trapping Increased monitoring starting fall as part of Spring Run JPE work.
Other Fish	Increased predators around barrier	Barrier predation study

Monitoring methods

Drought team and collaboration

The execution and reporting of this plan will be coordinated through the DRY Team. Scientific analyses may be conducted by a technical team of interagency scientists under the IEP workplan under the direction of the DRY Team. The IEP Drought Management Analysis and Synthesis Team (MAST) was originally formed in 2014 to assess the impact of the major drought of 2012-2016. This team was reformed in spring of 2021 with several of the original members as well as many new members to assess the drought of 2020-2021 and future drought impacts. The team contains members from DWR, DSP, Reclamation, CDFW, USFWS, and USGS who are all committed to synthesis and monitoring of ecosystem drought impacts. The team works closely with the Reclamation-led effort to develop a Drought Toolkit and the joint DWR/Reclamation team developing the annual Drought Contingency Plan. Additional analyses may also be conducted through contracts established as part of the project. Hence, the project team may also include university scientists, consultants, and public water agencies, depending on the topic.

Table 4. Draft list of Drought MAST members.

Name	Affiliation	Email	Subteam	Time commitment	
Steve Culberson	DSP	Steve.Culberson@DeltaCouncil.ca.gov	Where ever needed	5-10%	
Ted Sommer	DWR	Ted.Sommer@water.ca.gov	NA	only until July when he disappears off into the wilderness.	
Rosemary Hartman	DWR	Rosemary.Hartman@water.ca.gov	All of them	20%	
Brett Harvey	DWR	Brett.Harvey@water.ca.gov	Fish/salmon	maybe later	
Brian Mahardja	Reclamation	Bmahardja@usbr.gov	Fish and/or water quality	2%	
Brian Schreier	DWR	Brian.Schreier@water.ca.gov	Fish/smelt	3%	
Eva Bush	DSP	Eva.Bush@DeltaCouncil.ca.gov	Fish	5%	
Gonzalo Castillo	FWS	Gonzalo_castillo@fws.gov	Fish/smelt	20%	
Jereme Gaeta	CDFW	Jereme.Gaeta@wildlife.ca.gov	Fish	5%	
Jim Hobbs	CDFW	James.Hobbs@wildlife.ca.gov	Fish/smelt	2%	
Pete Nelson	DWR	Peter.Nelson@water.ca.gov	Fish/salmon	5%	
Steve Slater	CDFW	Steve.Slater@wildlife.ca.gov	Fish	2%	
Arthur Barros	CDFW	Arthur.Barros@wildlife.ca.gov	Invertebrates	5%	
Laura Twardochleb	DWR	Laura.Twardochleb@water.ca.gov	Invertebrates	10%	
Leela Dixit	DWR	leela.dixit@water.ca.gov	Invertebrates	Depends on fieldwork	
Christina Burdi	CDFW	Christina.Burdi@wildlife.ca.gov	Invertebrates	5%	
Jan Thompson	USGS	jmchendrie@usgs.gov	Invertebrates	3%	
Nick Rasmussen	DWR	Nick.Rasmussen@water.ca.gov	Primary Producers	5%	
Peggy Lehman	DWR	Peggy.Lehman@water.ca.gov	Primary Producers	20%	
Shruti Khanna	CDFW	Shruti.Khanna@wildlife.ca.gov	Primary Producers	5%	

Ted Flynn	DWR	Theodore.Flynn@water.ca.gov	Water quality and/or Primary Producers	5%	
Jared Frantzich	DWR	Jared.Frantzich@water.ca.gov	Water Quality	TBD	
Michael McWilliams	Anchor QEA	mmacwilliams@anchorqea.com	Water Quality	TBD	
Tamara Kraus	USGS	tkraus@usgs.gov	Water Quality	5%	
Sam Bashevkin	DSP	Sam.Bashevkin@DeltaCouncil.ca.gov	Water quality and/or zooplankton	5%	
Dave Bosworth	DWR	David.Bosworth@water.ca.gov	Water quality	15%	
Sarah Perry	DWR	Sarah.Perry@water.ca.gov	Water quality	5%	
Evan Sawyer	NMFS	Evan.sawyer@noaa.gov	Salmon	5%	

Regions Covered

This monitoring plan chiefly covers the legal Sacramento-San Joaquin Delta and Suisun Marsh (figures 5-7). In some cases, it will include limited data collection outside these areas where necessary to describe habitat for anadromous species. Analysis specific to the emergency drought barrier will focus on the region surrounding the barrier.

For an interactive map of water quality stations, see: https://cdec.water.ca.gov/webgis/?appid=cdecstation

For an interactive map of fish and zooplankton surveys see: https://deltascience.shinyapps.io/monitoring/

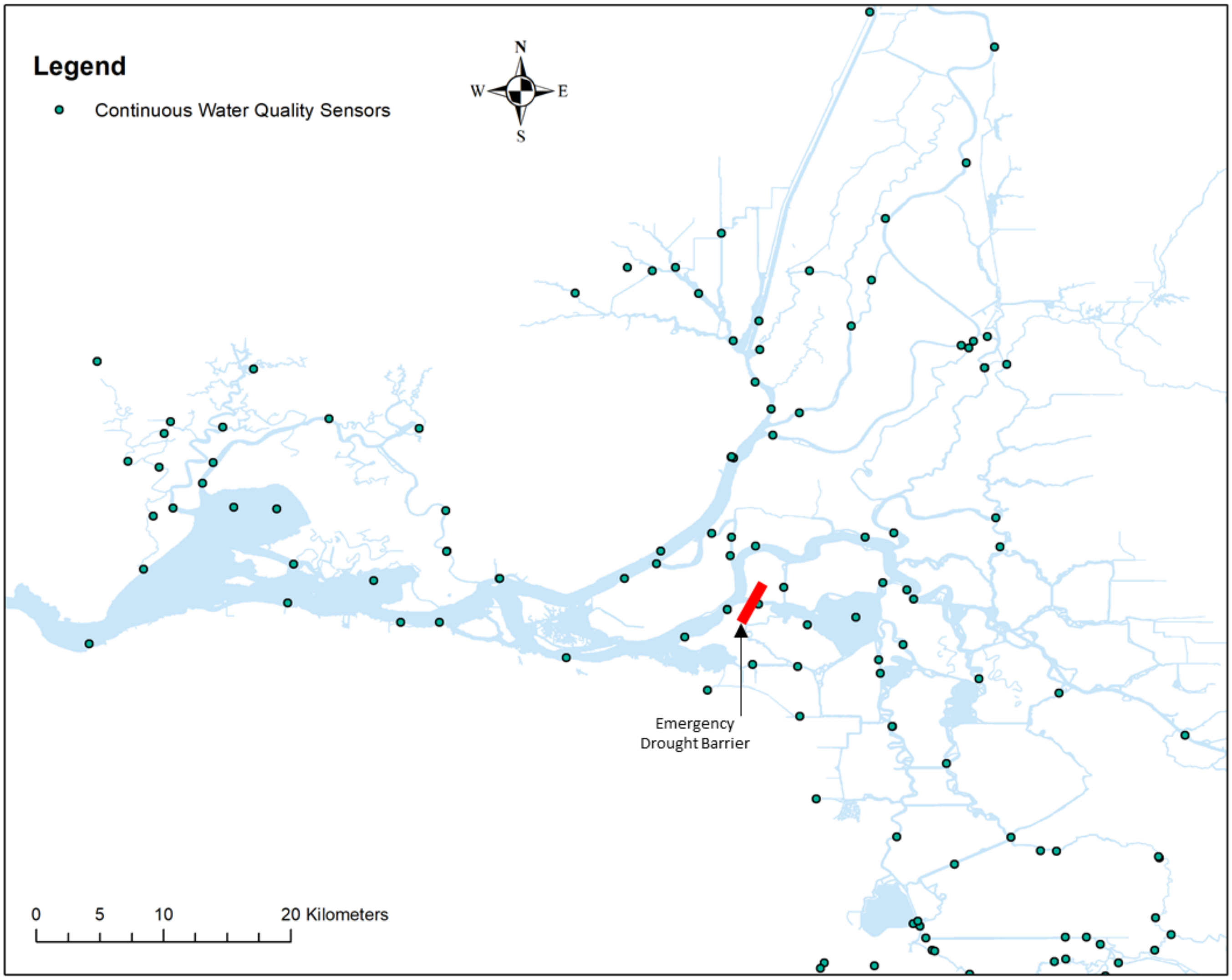

Figure 5. Continuous water quality sensors in the Delta and Suisun Marsh.

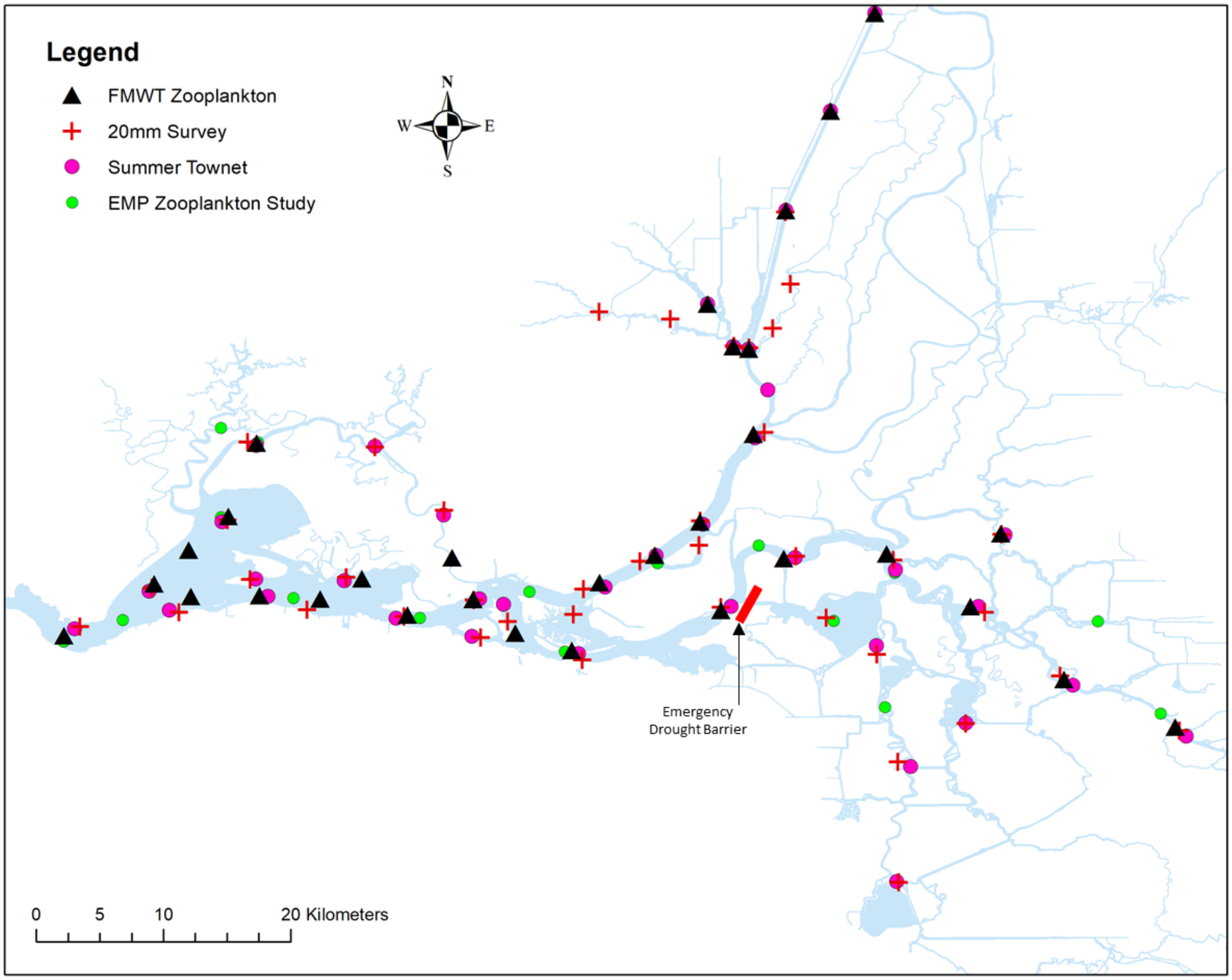

Figure 6. Stations where zooplankton samples have been historically collected by CDFW and DWR. FMWT zooplankton are collected monthly, Sept-December, 20mm area collected twice per month, March-June, Summer Townet samples are collected twice per month June-August, and EMP samples are collected once per month year-round. Additional samples are also collected by the Reclamation-funded Directed Outflow project with randomly selected stations.

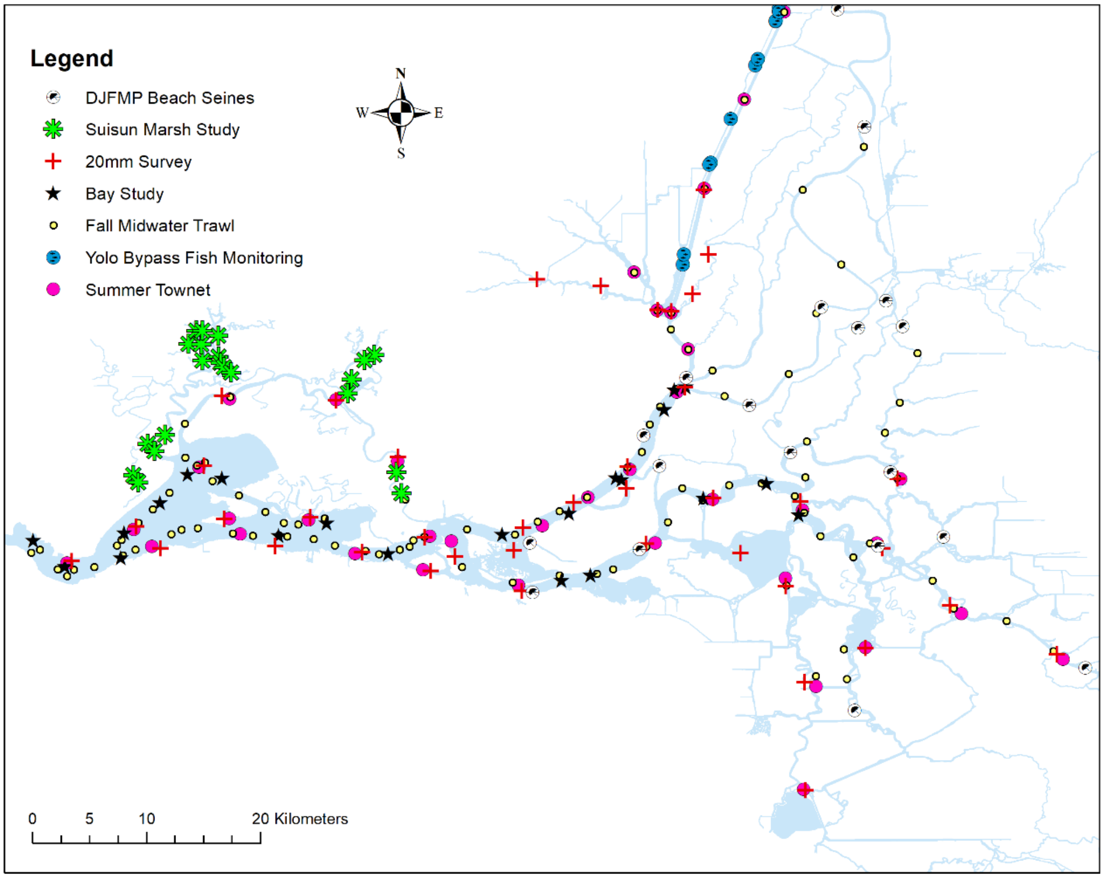

Figure 7. Sampling locations of long-term fish surveys in the Delta. DJFMP beach seines are collected weekly or twice per month, year-round. Suisun Marsh Survey sites are collected monthly, year-round. FMWT samples are collected monthly, September-December. 20mm area collected twice per month, March-June. Summer Townet samples are collected twice per month June-August, and Bay Study samples are collected once per month year-round. The Enhanced Delta Smelt Monitoring Survey does not have fixed sites, so is not shown here.

Existing Monitoring/Datasets

See Table 5 for a full list of potential monitoring data sets. The data sources we are using most frequently are described below.

8. Hydrology

Monitoring of precipitation, reservoir releases, exports, river stage, and basic water quality parameters (temperature, salinity, turbidity), will rely on the network of telemetered water quality stations throughout the Delta (Figure 5) and tributaries maintained by DWR and USGS. This will be complemented by hydrologic modeling conducted by DWR to calculate forecasted water supply as well as hindcasted Net Delta Outflow.

9. Nutrients and Contaminants

Nutrients (e.g., nitrate, nitrite, ammonium, organic nitrogen, phosphorus) are monitored using both in-situ water quality sensors (for nitrate; USGS Water Data for the Nation), discrete monthly samples taken at sites throughout the Delta by IEP's Environmental Monitoring Program (EMP), USGS, and other programs, and high resolution boat-based mapping surveys conducted by the USGS. During a synthesis of the 2012-2016 drought, lack of nutrient monitoring was identified as one of the gaps for an assessment of ecosystem-scale drought impacts – this is particularly because most nutrient monitoring occurs in main channels. Fortunately, the amount of nutrient monitoring in the Delta has increased over the past five years, with multiple types of nutrient data available.

Discrete samples are collected at multiple sites around the Delta by the EMP, USGS, the Delta Regional Monitoring Program (Delta RMP), the CDFW Fish Restoration Program, DWR's Municipal Water Quality Program, the Reclamation Directed Outflow Project, Regional San, and other special studies. These samples typically include all major nutrients: nitrate, nitrite, ammonium, ortho-phosphate, and in some cases total and/or dissolved organic nitrogen, total and/or dissolved organic carbon, and silica. Analytical methods vary slightly by survey, but most use EPA standard methods.

There are also some higher frequency data available for nitrate collected using in-situ nitrate sensors (SUNA – Seabird Scientific, Bellevue, WA); these are currently deployed at the 14 water quality stations throughout the Delta and Suisun Bay run by the USGS California Water Science Center's Biogeochemistry Group under funding provided by Reclamation and Regional San. Link to map/data. These sensors provide data every 15 minutes.

The USGS California Water Science Center's Biogeochemistry Group also conducts high-speed mapping surveys of water quality including high frequency (~1 second) data collection for nitrate, ammonium, temperature, salinity, turbidity, dissolved oxygen, pH, chlorophyll, and other parameters. During these surveys discrete samples are also collected at ~30 stations throughout the Delta and are sent in for a suite of laboratory analyses, including nutrients. In addition to conducting spatially and temporally targeted surveys, the USGS has conducted multi-day Delta-wide surveys in spring, summer and fall of 2018 and 2020 and has secured funding to do these in 2021 (Bergamaschi et al. 2020). These cruises produce a "snapshot" of conditions around the system on a particular day. Cruises are being planned for spring, summer and fall of 2021, and may continue into 2022 and beyond if funding is available.

The Delta Regional Monitoring Program (Delta RMP) also collects data on current-use pesticides, mercury, contaminants of emerging concern, and nutrients at multiple sites in the Delta. These data will be added to our analyses where appropriate.

10. Phytoplankton

Phytoplankton biomass will be monitored chiefly using in-situ chlorophyll sensors and discrete grab samples measuring chlorophyll-a and community composition. In addition, under funding provided by the Delta Science Program and the Delta RMP, the USGS Biogeochemistry group is testing the use of in-situ FluoroProbe instruments (bbe Moldaenke GmbH) to monitor the overall composition of phytoplankton communities in real-time at Decker, Confluence, Jersey Point, and Middle River. The IEP Environmental Monitoring Program is also piloting the use of this instrument during their monthly water quality cruises.

Over 30 continuous water quality probes equipped with YSI's Total Algae sensors capable of reporting chlorophyll fluorescence have been deployed in the Delta and Suisun Marsh. These stations are maintained by DWR and USGS and data from them are made available in real-time online via the California Data Exchange Center (CDEC) or the National Water Information System (NWIS). Periodic grab (approximately monthly) samples are collected at these stations and analyzed for chlorophyll-a, pheophytin and phytoplankton community composition at analytical laboratories. Other programs collect discrete grab samples for analysis of chlorophyll-a, pheophytin-a, with a subset also analyzing samples for phytoplankton community composition – counts and biovolume by species - using microscopy. These programs include the EMP, the Delta RMP, the Fish Restoration Program, DWR's Municipal Water Quality Program, the Reclamation Directed Outflow Project, USGS, and other special studies.

The Delta Science Program is also funding a study of picoplankton distribution in the Delta at 26 discrete sampling locations. This study began in Fall 2020 and is a collaboration between USGS, EMP, and BSA Environmental, Inc. and will continue into the winter of 2022.

The USGS high-speed mapping program described above also collects data on chlorophyll and other phytoplankton pigments during their high-speed mapping surveys.

11. Zooplankton

Zooplankton will be monitored primarily using four existing IEP surveys, including the CDFW 20mm Survey, STN and FMWT (described above), as well as the EMP and Reclamation's Directed Outflow Project (DOP) (Figure 6).

Zooplankton sampling by STN and FMWT are described in the previous section. EMP conducts water quality, phytoplankton, and zooplankton sampling monthly throughout the upper estuary at 17 stations. At each station, they collect a 10-minute stepped oblique trawl using the same zooplankton sled used by FMWT (see above). Additionally, they collect microzooplankton using a vertically-integrated pump sample (https://wildlife.ca.gov/Conservation/Delta/Zooplankton-Study). Two of these stations are not fixed, but instead follow the salinity field and sample where the bottom specific conductance reaches 2000 uS/cm and 6000 uS/cm, respectively.

The DOP (https://www.usbr.gov/mp/bdo/directed-outflow.html), established in 2017, collects data on water quality, phytoplankton, zooplankton, and fish (Schultz 2019). Like EDSM, DOP conducts stratified random sampling instead of sampling at fixed stations, and DOP coordinates some of its fish monitoring with EDSM. DOP collects zooplankton in three regions relevant to this action: Suisun Bay, Suisun Marsh, and Lower Sacramento River. This survey collects three zooplankton samples per week per region from April to November, paired with EDSM. Instead of the oblique tows used by the other zooplankton surveys, DOP concurrently collects pairs of samples from each location, one from near the top of the water column and one from near the bottom. Analysis suggests that this combination of top and bottom tows provides comparable results to oblique tows (Schultz 2019). Zooplankton are sampled using a 50-cm diameter bongo net frame towed for seven minutes. One of the bongo cylinders is outfitted with 500-micron mesh for macro-zooplankton, the other cylinder is outfitted with 150-micron mesh for meso-zooplankton.

All four surveys have similar zooplankton processing methods. In brief, samples are concentrated in the laboratory by pouring them through a sieve screened with 150-micron mesh wire and reconstituted to organism densities of 200-400 per milliliter. The sample is stirred to distribute the animals homogeneously and a 1-milliliter subsample is extracted with an automatic pipette and placed in a Sedgewick-Rafter cell (slide). All animals on a slide are identified and counted under a compound microscope to the lowest possible taxonomic classification. This procedure is repeated until 6% of the sample, or between 5 and 20 slides, are analyzed.

12. Fishes

13. Overall Fish Community

Fish monitoring will rely entirely on existing surveys conducted by IEP, specifically the California Department of Fish and Wildlife (CDFW) Summer Townet Survey (STN), San Francisco Bay Study, and Fall Midwater Trawl Survey (FMWT), and the USFWS Enhanced Delta Smelt Monitoring Program (EDSM) and Delta Juvenile Fish Monitoring Program (DJFMP) (Figure 7). Note that there currently is a major review of CDFW's current sampling program, so the specific programs used to analyze drought and TUCP effects may change. However, we refer to each survey by its historical reference to provide context for the general approach, as well as the seasonal and geographic coverage. Each historic survey is described in brief below. Please refer to survey web sites for full details. Each survey is described in brief below. Please refer to survey web sites for full details.

The California Department of Fish and Wildlife operates the Summer Townet Survey (https://www.wildlife.ca.gov/Conservation/Delta/Townet-Survey), which collects zooplankton and juvenile fish samples at all stations shown in Figure 7, on a biweekly basis in June, July, and August. The townet consists of a fixed D-frame sled on runners with an 18-foot net. The main net body is 11 ft. long with 1/2" stretch, knotted, nylon, mesh tapering down to a 7 ft. cod-end with a section of woven mesh with approximately 8 holes per inch. A zooplankton net (modified Clarke-Bumpus net, 160-micron mesh) is attached to the top of the net frame to sample mesozooplankton prey availability during one of the fish tows at each station. Two 10 minute stepped oblique tows are performed at each station. A third tow is conducted if any fish are captured during the first two tows. All fishes and several invertebrate species are counted and measured.

In September, the Townet Survey is replaced by FMWT, (https://www.wildlife.ca.gov/Conservation/Delta/Fall-Midwater-Trawl), which operates monthly and also collects zooplankton samples in addition to fish sampling at a subset of its fish sampling stations. The midwater trawl net has mouth dimensions of 12 ft x 12 ft. Net mesh sizes graduate in nine sections from 8-inch stretch-mesh at the mouth to 0.5-inch stretch-mesh at the cod-end. All four corners of the net mouth are connected to planing doors that hold the net mouth open when being towed through the water. At each station a 12-minute stepped-oblique tow is conducted. All fishes and several invertebrate species are counted and measured. At stations where zooplankton is collected, a mesozooplankton net (modified Clarke-Bumpus net, 160-micron mesh) and a macrozooplankton (mysid) net attached to a steel frame is sampled by a stepwise-oblique tow immediately before or after fish sampling.

The San Francisco Bay Study (Bay Study) samples with two trawl nets at each station (https://wildlife.ca.gov/Conservation/Delta/Bay-Study). The otter trawl, which has identical dimensions to the UC Davis otter trawl, samples demersal fishes, shrimp, and crabs. The otter trawl is towed against the current at a standard engine rpm for 5 minutes then retrieved. The midwater trawl, which has identical dimensions and methods to the FMWT midwater trawl, samples pelagic fishes. Fish, caridean shrimp, and brachyuran crabs are identified, measured, and counted.

The USFWS DJFMP has monitored juvenile Chinook Salmon (*Oncorhynchus tshawytscha)* and other fish species within the San Francisco Estuary since 1976 using a combination of surface trawls and beach seines. Since 2000, three trawl sites and 58 beach seine sites have been sampled weekly or biweekly within the Estuary and lower Sacramento and San Joaquin Rivers. Surface trawls at Sacramento, Mossdale, and Chipps Island (Kodiak or midwater trawls) are used to assess timing of Delta entry and exit, and survival of juvenile salmonids through the Delta. Each trawl site is sampled three days per week, ten tows per day. Throughout the year, ten 20-minute tows between approximately 7am and 1pm at all trawl sites are collected. Beach seines are used to evaluate the spatial distribution of fishes occurring in shallow near-shore habitats throughout the lower Sacramento and San Joaquin Rivers, the Sacramento-San Joaquin Delta, and the lower San Francisco Estuary. The beach seine net used by the DJFMP is a 15.2 m x 1.3 m seine net with 15.9 kg Delta 0.3 cm2 mesh and a 1.3 m x 1.3 m bag. Each net has a float line and lead line attached to 1.8 m-long wooden poles at each end. Seines are conducted weekly or once every two weeks (depending on region) year-round. Full details on methods and data are available on their Environmental Data Initiative data package {Interagency Ecological Program (IEP), 2020 #3047}.

The Enhanced Delta Smelt Monitoring Program (EDSM) was initiated by the U.S. Fish and Wildlife Service in 2016 to provide estimates of Delta Smelt distribution and abundance (https://www.fws.gov/lodi/juvenile_fish_monitoring_program/jfmp_index.htm). It also provides data on other fishes, including salmon. EDSM conducts stratified random sampling via Kodiak trawls (July-March) and larval gear (may-June). Over the course of a week, field crews sample between 18 and 37 random sites, with at least two samples in Suisun Marsh (sites are randomly selected, so not shown on sampling figure). A minimum of two tows are conducted at each site. All fish collected are identified (in the field when possible, in the lab for early life stages), measured, enumerated, and recorded. In addition to fish information, environmental data are collected for each sampling event. Full details on methods and data are available on their Environmental Data Initiative data package (United States Fish and Wildlife Service et al. 2019). Because this data set began in 2016, we will not be able to make many historical comparisons, but it provides the best information on Delta Smelt distribution and abundance from recent years.

14. Salmon-specific data sets

Salmonids in the Delta are monitored chiefly by the surveys listed above, however there are several salmon-specific studies and surveys tracking salmonids throughout their life cycle. This monitoring plan focuses on the Delta and Suisun Marsh, but a full synthesis effort of the effects of drought on salmon throughout their range would benefit conservation of the species.

15. Acoustic telemetry and Coded Wire Tags

Salmon are regularly released from hatcheries with tags or transmitters. In 2021, 5000-6000 tagged fish of various runs will be released from January-June throughout the tributaries, and their progress tracked on a network of receivers throughout the Central Valley. Real-time data for these studies can be found on the Calfish Track Central Valley Enhanced Acoustic Tagging Project Web page: https://calfishtrack.github.io/real-time/index.html

In addition, the existing Juvenile Production Estimate (JPE) for Sacramento River winter-run Chinook provides an annual forecast of the number of juvenile winter-run entering the Delta each water year. These results should reflect, in part, the effects of drought on salmon cohorts. JPEs are in the early stages of development for Central Valley spring-run Chinook and steelhead populations in the San Joaquin Basin and are expected to contribute to drought monitoring efforts for these fishes.

Beginning in fall 2021 there will be a substantial increase in overall salmonid monitoring as part of the Spring Run JPE work plan (DWR 2021). The project includes expansion of tributary sampling, addition of a pilot Delta entry rotary screw trap, and more extensive genetic monitoring of migrants. The project is likely to include an expansion of acoustic telemetry in the system, as well as expanded otolith studies to better understand life history diversion. The JPE work is timely as it may provide better insight into salmon responses to the drought.

16. Rotary Screw Traps

Rotary screw traps have been used in the Central Valley in most of the major salmon producing tributaries of the Sacramento River system, primarily to monitor outmigrating juvenile salmonids. These data are available on the SacPas website: http://www.cbr.washington.edu/sacramento/data/juv_monitoring.html

As noted above, Rotary Screw Trap sampling will be expanded in fall 2021 to support the development of a Spring-Run Chinook Salmon JPE.

Table 5. Data sets that can be used for drought monitoring.

Metric	Data set	Notes
Delta Outflow	CDEC Station DTO and/or DAYFLOW CNRA portal	
Precipitation	CDEC or CIMIS	
Water temperature	CDEC and Integrated data set	May need to use discrete data set for the long-term drought analysis.

Salinity	Sondes and/or modeling	
Turbidity	Sondes and/or modeling	
LSZ area	Modeling	DSM2 and SCHISM modeling conducted for TUCP and barrier impacts
Nutrients	EMP	
Nutrients	USGS data dashboard	Continuous mapping cruises and in-situ sensors
Contaminants	Delta RMP	
Microcystis	EMP, DWR, Water Boards, and USGS	
Phytoplankton	EMP	Contact Tiffany Brown. Tiffany.Brown@water.ca.gov
Zooplankton	EMP, 20mm. FMWT, Summer Townet	
Zooplankton	DOP	Contact Andrew Schultz
Fish - Delta Smelt	EDSM	Can also be used for salmon and longfin smelt
Fish - Salmon	DJFMP Chipps and Sac trawls	May not be as effective in clear, slow-moving water
Fish – Salmon	Coded wire tags	Marked by several programs, most monitoring surveys recover tags
Fish - Salmon	SacPas	Platform with a number of data sources
Fish – Salmon	CalFishTrack	Central Valley Enhanced Acoustic Tagging Project
Fish – Salmon	Carcass surveys and Redd surveys	In most of the upstream tributaries, used to calculate adult escapement
Fish – salmon	Acoustic telemetry	Used for routing and survival.
Fish – salmon	Rotary screw traps	In most of the upstream tributaries, used for juvenile passage and timing
Fish – salmon	Tidal Parr Trawl Survey	3-year special survey downstream of the Delta: preliminary data is available from Brett Harvey.
Fish – general	Salvage	Tracy Fish Collection Facility & Skinner Delta Fish Protective Facility
Fish - general	DJFMP beach seines	Published on EDI
Fish - general	Fall Midwater Trawl (FMWT)	CDFW ITP site
Fish - general	Summer Townet Survey (TNS)	CDW ITP site
Fish - general	Sprink Kodiak Trawl	Published on EDI
Fish – general	20 mm Survey	Published on EDI
Fish - general	Bay Study	Contact Kathy Heib
Fish – general	UC Davis	Suisun and Cache, Contact Teejay O'rear
Fish – general	Yolo Bypass Fish Monitoring Program (YBFMP)	Beach seines, screw trap, and fyke

Additional Drought Monitoring

We will not be collecting any listed species while conducting the additional monitoring associated with this project.

17. Drought Barrier Monitoring

To better understand the impact of the emergency drought barrier, DWR is planning to conduct some special studies in regions immediately around the barrier. See Drought Barrier documentation for specifics. In brief:

- Predatory fish monitoring will be conducted around the newly installed structure to see whether it serves to attract unusual numbers of piscivorous fish.
- Several new bottom water quality sondes will be installed at existing monitoring locations to better characterize the location of the salt wedge.
- An acoustic doppler current profiler will be installed in Middle River to characterize changes to water velocity.

18. Salmon eDNA

The ability of current monitoring programs to detect and characterize salmon distributions is severely reduced during drought conditions because these programs rely on net and rotary screw trap sampling, which are highly inefficient during conditions of low flow and low turbidity. However, the management need for accurate salmon distribution estimates is most critical during drought conditions when protective actions based on these distributions, such as Delta Cross Channel gate closures and reduced water extraction, must be finely balanced with other management priorities, such as water quality and water supply. To better inform water management, we are pursuing a pilot effort to see whether environmental DNA (eDNA) can be used to better detect juvenile salmon moving through the system (see eDNA study plan, separate project). If the pilot effort is successful, this may be used to monitor salmon in future drought years.

19. Weeds

Monitoring invasive aquatic weeds at the landscape scale is most efficiently achieved through remote sensing. This can be done using satellite imagery for floating vegetation, but hyperspectral imagery is required for high quality data on the extent of submerged vegetation. We propose repeating a survey for aquatic vegetation in the Delta and Suisun Marsh that has been conducted since 2014 by the UC Davis Center for Spatial Technologies and Remote Sensing (CSTARS) and CDFW personnel. This data was funded by DWR from 2016-2019 and by the Delta Science Program in 2020. Additionally, Delta imagery was also acquired from 2004 to 2008 once every summer funded by the (then) Department of Boating and Waterways and analyzed by CSTARS.

Below is a brief summary of the methods for this work. For more methodological details, see the annual reports from previous aerial surveys (Ustin et al. 2017, 2018, 2019) and Rasmussen et al 2021. Hyperspectral imagery will be collected via aircraft by SpecTIR (Reno, NV). Imagery will be trained and validated by conducting field surveys of vegetation species composition throughout the area. Vegetation across the Delta will be classified using machine learning techniques and accuracy will be assessed by comparing classifications to field-collected data. Final maps will be produced to visualize the cover of submerged and floating vegetation throughout the region. Floating vegetation will be classified down to the genus-level.

20. Harmful Algal Blooms

To date, harmful algal blooms (HABs) in the Delta are primarily associated with the growth of cyanobacteria (e.g., *Microcystis*) that can produce cyanotoxins (e.g., microcystins). There is no routine monitoring program assessing occurrence of harmful algal blooms in the Delta. Several fish and water quality surveys rank the presence of *Microcystis* (the most common harmful algae in the Delta) using a qualitative visual assessment of 1-5. However, this numerical rating method can only assess presence/absence of colonial forms of *Microcystis*, it does not provide information about toxin levels, it is often subjective and depends on current environmental conditions (e.g., wind, flow/tide, light), and it does not assess other forms of harmful algae. Fortunately, several studies are currently underway by USGS and DWR with funding from the USGS HABs Program and the Delta RMP to directly measure cyanotoxin concentrations in the Delta and Suisun Bay (Kraus, Hansen and Lehman, PIs). To provide a more comprehensive picture of the seasonal variation of HABs and their associated toxins in the Delta, these studies are collecting year-round measurements of cyanotoxins at several fixed monitoring stations in the Delta (Jersey Point (JPT; USGS), Decker (DEC; USGS), Middle River (MDM; USGS) , Liberty Island (LIB; USGS), Rough and Ready Island (P8, DWR-EMP), Vernalis (C10; DWR-EMP) that already have existing, robust monitoring programs. In addition, the USGS is collecting cyanotoxin data during their Delta-wide high-resolution boat-based mapping surveys (Bergamaschi et al. 2020), and we will be leveraging data from the Fluoroprobes referenced in the phytoplankton methods section, above.

For these efforts, cyanotoxins are being measured in whole water discrete samples as well as using Solid Phase Adsorption Toxin Tracking (SPATT) samplers every 2 to 4 weeks. All (100%) of these cyanotoxin samples will be analyzed using LCMS-MS and – upon review of LCMS-MS data – a subset (~20%) will be selected for analysis using ELISA. Analysis of data from these studies using two collection methods (whole water and SPATT) and two analytical methods (LCMS/MS) allows for data and method comparability across different HAB studies and will help inform the design of future monitoring programs.

The State Water Boards' Freshwater Harmful Algal Bloom (FHAB) Program will respond to bloom notifications submitted by the public in the Delta (www.mywaterquality.ca.gov/habs). The Water Boards' FHAB Program has collected cyanotoxin data at Discovery Bay, Seven Mile Slough, and Three Mile Slough. These are not routinely collected but provide information to rapidly assess the risks associated at publicly reported bloom locations. In collaboration with the State Board, the Central Valley Regional Water Quality Control Board monitored 5 sites in the San Joaquin River and around Stockton in 2019 and 2020. Water Boards data can be visualized on the HABs incident web map (link) or the California Open Data portal (link).

Data Analysis Methods

We will take a three-pronged analysis to address our three research objectives. Evaluating the hypothesized ecosystem changes will rely on multiple types of comparisons, combined with a weight-of-evidence approach, and we will have varying ability to assess each of our research questions. Assessing the impact of the drought itself has a high likelihood of success, whereas extracting impacts of the TUCP as separate from the Drought will be slightly more difficult. Approaches for evaluating each of our predictions are summarized below, along with example metrics that we plan to evaluate for each.

1. *Historical drought analysis*: To evaluate the overall impact of multi-year droughts on the ecosystem, we will aggregate a wide variety of environmental monitoring data from 1970-2021. We will then compare annual values for each monitoring metric for drought years versus wet periods using generalized linear models, generalized additive models, cluster analysis, and ordination, as appropriate, for the variables of interest.
2. *Description of current drought:* Many ecosystem conditions have only been monitored adequately in the past ten or fifteen years. Examples include aquatic vegetation, *Microcystis*, fish health, and contaminants. For these metrics, we will compare data from the 2020-2021 drought with data from the 2012-2016 drought and the wet years of 2011, 2017, and 2019. These analyses will take the form of generalized linear models, cluster analysis, or ordination, as appropriate. We will also compare trends between regions and seasons where feasible.
3. Analysis of TUCP and Drought Barrier: To describe the impact of the drought barrier we will compare environmental metrics in areas surrounding the barrier to each other and to similar dry years without a barrier (2020, 2014). We may also compare flow and water quality conditions with and without certain management actions using hydrodynamic models.

These analyses will be combined to give an overall picture of the ecosystem response to the drought for all the attributes measured (hydrology, nutrients, phytoplankton, zooplankton, fish). We will also attempt to make specific connections between changes to water project operations and impacts on water quality and at-risk species to inform changes to future drought responses. To integrate these impacts, we will rank each metric based on its impact on beneficial uses and display them in a rose plot similar to Figure 8. This may involve defining thresholds of ecological or management significance for each metric. We will use major management tools listed in the DWR/Reclamation Drought Toolkit (currently in development) to crosswalk drought impacts with management actions to determine recommended triggers for implementing these actions. We will report annually on the results of these analyses for at least 2022 and 2023, and produce a final report describing the impact of the overall drought in the summer of 2023. If the drought continues past 2022, a separate synthesis effort will integrate the later years of the drought.

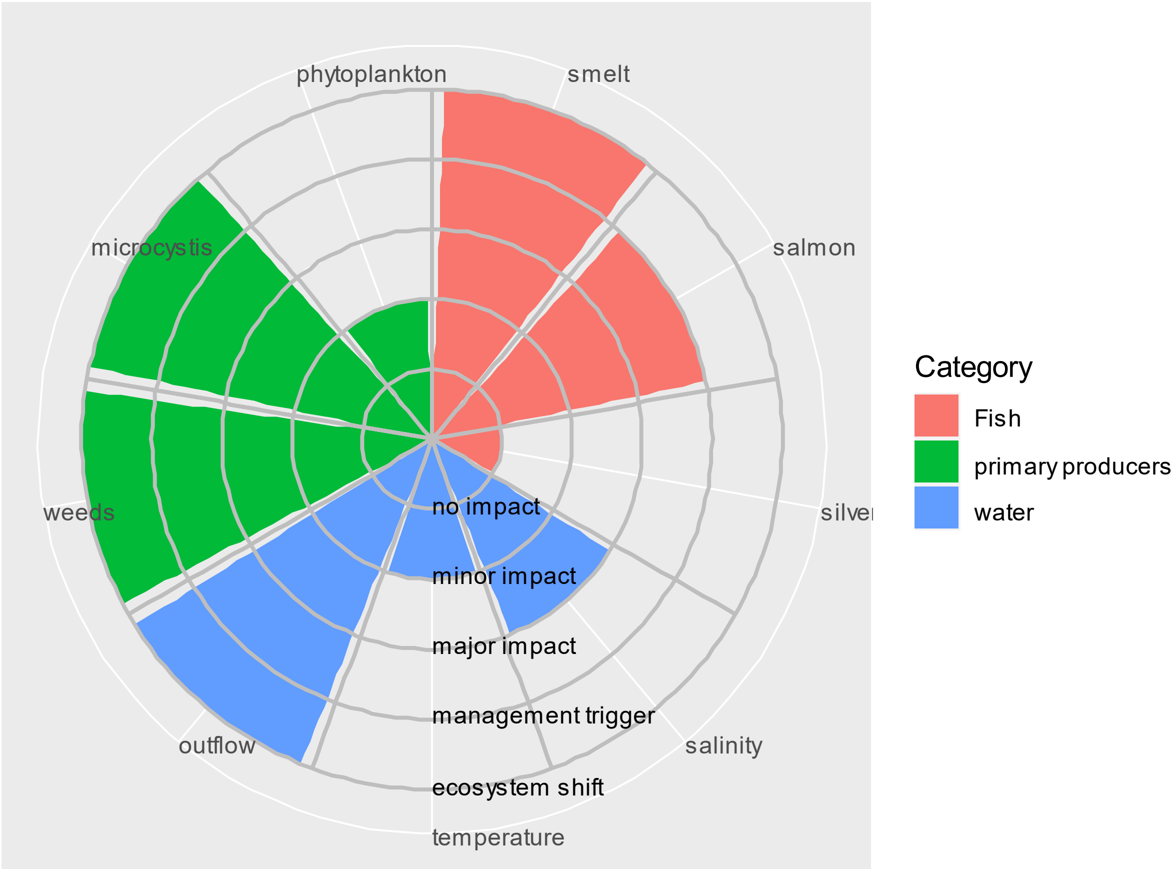

Figure 8. Example figure showing how multiple ecosystem metrics can be combined and used to determine management triggers. Size of the pie section is determined by level of drought impact, and rings will designate triggers for specific management actions.

Budget/expenditures

- Hyperspectral imagery ~$300K
- DWR Staff time - ~$250K
- Additional in-kind support will be provided in the form of staff time by CDFW, Reclamation, the Delta Science Program, USFWS, and NMFS

Timeline

- March 2021 – Development of monitoring plan and identification of team members
- May 2021 – Finalization of monitoring plan
- June-December 2021 – Data collection and processing
- February 2022 – Annual summary report and recommendations for future dry years. Draft of study plan for 2022 (if year is dry)
- May 2022 – Finalization of study plan for 2022
- June-December 2022 – Data Collection and Processing
- February 2023 – Annual summary report for 2022 and recommendations for future dry years.
- June 2023 – Final full synthesis report completed. Manuscripts for journal publications drafted.

Quality Assurance and Quality Control

The Drought Synthesis team will follow all guidelines and best practices for QAQC of synthetic data sets as recommended by the IEP Data Utilization Work Group. In brief:

- Individual data sets will be reviewed for their QA procedures and assessed to see whether quality was adequate to address the Drought Team research questions.
- Where possible, the original PIs who collected the data sets will be contacted to describe any potential problems with the data.
- Any additional data manipulations or quality control measures will be documented and any code used to "clean" data will be stored and shared along with the integrated data set.

Data management

Data will be collated from a variety of component data sets, as listed in Table 5. Data from these databases will be downloaded and organized into a single, integrated data set for the historical drought analysis. The component data sets and the integrated data set will be stored and backed up on the DWR SharePoint Site. All data manipulation and integration methods will be documented and included with the metadata. All data will be published to the Environmental Data Initiative archiving platform as soon as possible once the integrated datasets have been produced. Metadata from the original data sets is available on the project web sites and will be downloaded and stored by the PIs on a Share Point Site for future reference. Metadata for the integrated data set will be formatted per IEP's DUWG recommendations in the Ecological Metadata Language and published on the Environmental Data Initiative website. Interim metadata will be available as a word file (.docx) on the DWR SharePoint site.

Data will be shared through deliverables including IEP workshop presentations, summary reports, and reports for contractors. Interagency collaborators will also generate presentations, reports, and/or publications on data and results. All data will be open access to public upon request from project PI. The final integrated dataset will also be published to the Environmental Data Initiative website.

Deliverables

- Annual progress reports summarizing major drought-related changes seen in any of the major constituents measured.
- At least two manuscripts to be published in peer-reviewed journals
- Update to the draft 2016 drought MAST manuscript
- Impact of drought on listed fish species
- The team will plan on multiple presentations such as the following: 1) IEP Annual Meeting; 2) Bay-Delta Science Conference; 3) IEP Directors Meeting; 4) IEP Stakeholders Meeting; and potentially 5) CAMT and CSAMP meetings. If requested, team members will be available for focused presentations to regulators responsible for oversight of drought activities (e.g. SWRCB, DFW, USFWS, NMFS).
- One or more blog posts about the effort and its findings.

Note that the timing of each of these components depends largely on the duration of the current drought. In general, the team will target presentations within one year or less of the when the drought ends. However, the drought team is also committed to intermediate reports and presentations at least on an annual basis.

Coordination with IEP

The Drought Ecosystem Monitoring and Synthesis project relates to most of the major themes within the 2020-2024 IEP Science Strategy, in particular, Bay-Delta Ecosystem Resilience to Climate Change, Assessing Effects of Flow Alteration on Bay-Delta Aquatic Resources, and Aquatic Vegetation Dynamics. Droughts are expected to increase as climate change progresses, so analyzing the environmental impacts of drought will help us prepare for future climate chance scenarios. Much of the recent emphasis on “Assessing effects of Flow Alteration” have been concentrating on managed actions that increase outflow. We will take the opposite track and look at the effect of a prolonged decrease in outflow on the ecosystem. We will also be continuing the seven-year data set of annual hyperspectral imagery to track aquatic vegetation in the Delta, and specifically see how changes to flow affect submerged vegetation abundance and distribution.

This workplan has been presented to the IEP Flow Alteration PWT and the Climate Change PWT, and a summary of the workplan will be presented to the IEP Directors at their June meeting. We are drawing extensively on the work of the previous Drought MAST, and our team includes many of the same researchers. We will continue to work with the FLOAT PWT and other groups, as appropriate, to get additional feedback on our planned data integration and analyses. We will also collaborate extensively with the Climate Change MAST and PWT, because the increase in frequency of droughts projected in the future means that our analyses draw on many of the same data sets.

Most of the data synthesized in this work plan will be sourced from IEP's long-term monitoring surveys and/or special studies. We will communicate regularly with the PIs of these studies in order to ensure we understand the data and data quality. We will also share results of our analyses with the PIs of the component surveys, as well as with the broader IEP community through PWTs and the IEP Workshop.

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