Addendum to the State Water Project and Central Valley Project Drought Contingency Plan

April 30, 2021

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This addendum to the Drought Contingency Plan (Drought Plan) has been prepared by the California Department of Water Resources (DWR) and US Bureau of Reclamation (Reclamation).

Hydrology and April 1 Forecast Updates

Conditions to date have been extraordinarily dry. Based upon the April 1 B120 runoff forecast, the Sacramento Valley and San Joaquin River indices remain classified as critical water year types. Following an exceptionally dry Water Year (WY) 2020, the State's April 1, 2021, snow survey found a Sierra Nevada snowpack that is still well below average in terms of the amount and water content for this time of year. Furthermore, the October through March precipitation for the Northern Sierra 8-Station Index for WY 2021 was the third driest on record, while the San Joaquin Basin and the Tulare Basin are ranked as the fifth and second, respectively. Observed October through March Runoff for the Sacramento Valley, San Joaquin Valley, and Tulare Lake Basin were the third, sixth, and eighth driest in historical record, respectively. Lastly, the peak snowpack throughout the Sierra Basins was observed around the third week of March and is quickly diminishing with dismal runoff due to the very dry soils. Because of the continued dry conditions in April, it is anticipated that the May 1 runoff forecast will be reduced substantially for all exceedance levels. This anticipated May 1 reduction is informed by the weekly B120 forecast updates that have been steadily decreasing throughout this month. Given these drier conditions, the eight-station index for water years 2020 through 2021 are now the second driest on record, behind the drought of 1976 through 1977.

State Water Project (SWP) and Central Valley Project (CVP) April Operations

Due to the critically dry conditions in the state, the SWP and CVP (Projects) have been struggling to meet the Delta outflow requirements as required by the State Water Resources Control Board's (SWRCB) water rights permit Decision 1641 (D-1641) in both March and April. As such, on April 20, 2021, the Projects notified the SWRCB of an exceedance, beginning April 17, 2021, of the 3-day average Delta outflow standard of 7,100 cfs and possibly continuing throughout the remainder of the month. This was not anticipated; however, there was a significant decrease of inflow into the Delta, likely caused by increased diversions due to very warm temperatures in mid-April, coupled with well below average seasonal rainfall and no measurable rainfall for nearly a month. In addition, the higher outflow requirement in April of three days of 11,400 cfs (3-day average) outflow will not be met. In order to meet the outflow objectives for the remainder of April, significant upstream storage releases would have been necessary. Shasta, Trinity, Oroville and Folsom all have well below average storage and inflows are currently tracking at or below the 90% April 1 forecast, with much of the northern Sierra snowpack diminishing. Storage is a serious concern for all of these reservoirs, and additional releases for the April outflow standard would compromise storage for both water supply and temperature management for aquatic species. Since April 17, 2021, DWR has sustained minimum exports from the Delta of 400 cfs and expects minimum exports to continue to meet deliveries to those SWP contractors not directly connected to San Luis Reservoir. Releases from Lake Oroville have been at 1,100 cfs, slightly above minimums. DWR plans to further reduce to 800 cfs by the end of April to conserve storage. Reclamation has also sustained minimum exports from the Delta of 800 cfs (one pump) and expects minimum exports to continue to meet required deliveries primarily to wildlife refuges and senior water right holders. Releases from Folsom Lake were decreased from 2,000 cfs to 1,000 cfs on April 24 to further conserve storage with the decreasing inflow.

During this period of non-compliance, DWR has not triggered any actions set forth in the 2020 Incidental Take Permit (ITP) for DWR's long-term operation of the SWP or the 2019 Biological Opinions issued by National Marine Fisheries Service and US Fish and Wildlife Service for the long-term operations of the CVP and SWP. In addition, since April 17, 2021, daily calculated Old and Middle River (OMR) flow averaged approximately -700 cfs, well below any threshold outlined in the ITP. OMR restrictions under 8.4.2 for the protection of larval Longfin Smelt were not triggered by 20mm surveys in April. Similarly, no larval Delta Smelt were detected in the south Delta or at station 716 (which would trigger Barker Slough Pumping Plant restrictions) in April. Due to less negative OMR flows this month, the Smelt Monitoring Team did not provide any OMR recommendations for the protection of either smelt species. Salvage of larval Longfin Smelt has continued at both facilities in April, but generally only a few fish per day without an increasing trend.

Very little salmon loss has occurred at the south Delta facilities, well below annual and daily thresholds for both the State ITP and the NMFS Biological Opinion. Daily loss thresholds were never triggered for winter-run, and there is extremely low probability that any annual cumulative loss thresholds for salmon will be triggered. Natural winter-run cumulative annual loss is currently at 8.2 (0.4% of the annual allowance), and only one spring-run hatchery surrogate group has seen loss, putting it at 2% of the annual allowance. All other protected salmon groups are currently at 0% of annual allowances, with very little further take expected. The Salmon Monitoring Team interpretation of current monitoring data and historic migration patterns is that smaller than expected numbers of salmon entered the Delta this year due to extended rearing in the Sacramento River, and associated high mortality there.

In May, a formal joint letter will be sent by DWR and Reclamation to the SWRCB addressing the SWRCB's comments regarding this period of non-compliance.

SWP and CVP May Operations

Beginning May 1, 2021, the D-1641 Delta outflow requirement changes to 4,000 cfs due to built-in D-1641 relaxations because of the dry hydrology. DWR and Reclamation expect to meet May D-1641 outflow requirements while maintaining minimum exports.

SWP Operations Forecasts

DWR updated the operational forecasts through September 30, 2021, using the 50% and 90% exceedance forecasts from the April 1 B120 Water Supply Runoff forecast from DWR's

Hydrology and Flood Operations Office within the Division of Flood Management. The 90% exceedance forecast for April 1 differed only slightly from the 90% exceedance forecast for March 1, thus there were no significant changes; the 90% exceedance forecast continues to show critically dry conditions for WY 2021. Each Project reservoir exhibits extremely low carryover storage at the end of WY 2021.

DWR's objective is to hold at least 900 TAF of storage in Oroville through August. The purpose of maintaining storage at this level is to delay dropping below power pool. Once the lake elevation drops below power pool, the outflow capability from the lake is limited, it inhibits some of our temperature management capabilities and needed power resources are no longer available to support power grid operations.

CVP Operations Forecasts

As noted above, the small changes to the 90% exceedance forecast between March 1 and April 1 led to minor changes in the operational outlook. Shasta, Trinity, and Folsom reservoirs each continue to exhibit low carryover storage at the end of WY 2021.

2021 Drought Actions

Feather River Settlement Contractor Delivery Reduction

Based upon the April 1 Bulletin 120 Feather River runoff forecast, the shortage criteria were triggered for the Feather River Settlement Contractors (FRSC). On April 9, 2021, DWR notified the FRSC that the full 50% delivery reduction of their contractual amounts will be implemented this year.

Sacramento River Temperature Management

Forecasted conditions have not improved at Shasta Reservoir since the last drought contingency plan update. In an effort to support better temperature management in the summer and fall months, Reclamation began a significant warm water power bypass on April 18 to release warmer water through the higher river outlet gates and preserve the colder water for later use in the summer. This bypass may include flows up to 100% of the releases from Shasta up to the point where the Sacramento River does not exceed temperature metrics determined appropriate by the State and Federal fishery agencies. Initially, the fishery agencies have determined 60°F at the Clear Creek confluence gauge is an appropriate maximum temperature and will revisit weekly to revise if needed. The additional drought actions from the previous update are currently being considered and evaluated for improving temperature management.

Delta Cross Channel Gates

There is no immediate plan to open the Delta Cross Channel gates to manage salinity. However, salinity conditions are continuously being monitored, and if conditions do warrant opening the gates in the first half of May, the Projects will coordinate with the SWRCB, and State and federal fishery agencies through the relevant technical teams and the Water Operations Management Team.

Temporary Urgency Change Petition (TUCP)

To date, a TUCP has not been submitted to the SWRCB to modify standards required in D-1641. Because of the recent drastic decline in runoff forecasts for the major SWP and CVP reservoirs, DWR and Reclamation will be having discussions in early May with the SWRCB and State and federal fisheries agencies about a potential TUCP, drought barrier, and other type(s) of actions that can be taken this year.

Facilitating Transfers

DWR and Reclamation are currently working with various water agencies across the state to facilitate water transfers to meet minimal water needs throughout the basin. At times, these transfers may require elevated reservoir releases and elevated exports during the transfer window of July 1 through November 30.

Drought Monitoring

DWR is providing the attached draft Drought Ecosystem Monitoring and Synthesis Plan currently in development.

Next Steps

DWR and Reclamation continue to coordinate real-time and anticipated summer and fall operations with the SWRCB, CDFW, NMFS, USFWS, and other stakeholders through various weekly and monthly meetings. This plan will be updated in May to include potential and expected actions that the Projects will take this summer and fall.

Drought Ecosystem Monitoring and Synthesis Plan

2021-2023

Date: 4/27/2021

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Division of Environmental Services

California Department of Water Resources

And the Interagency Ecological Program

Contents

Figures and Tables

Abstract

The 2021 Drought Contingency Plan includes ecosystem monitoring to assess the impact of drought and drought actions. To that end, DWR is leading a team of IEP scientists to develop a monitoring and synthesis plan for the environmental impacts of the drought and drought actions. 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. Data collection will rely primarily on existing monitoring, with the addition of a few special studies. Data will be integrated and compared to previous droughts and previous wet periods to detect ecosystem changes. These changes will be compared to actions in the Drought Toolkit to inform future dry year actions.

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 results in massive year-to-year changes in both the aquatic community and the ability of managers to provide water for consumptive use.

Inter-annual variation is great enough that "drought" is not defined by a single dry year. Droughts in California only occur when multiple dry years in a row reduce water storage to an extent that water supply operations can no longer compensate. For the purposes of this document, we are defining "drought" as two consecutive years with a Sacramento Valley Index of Dry or Critically Dry. 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).

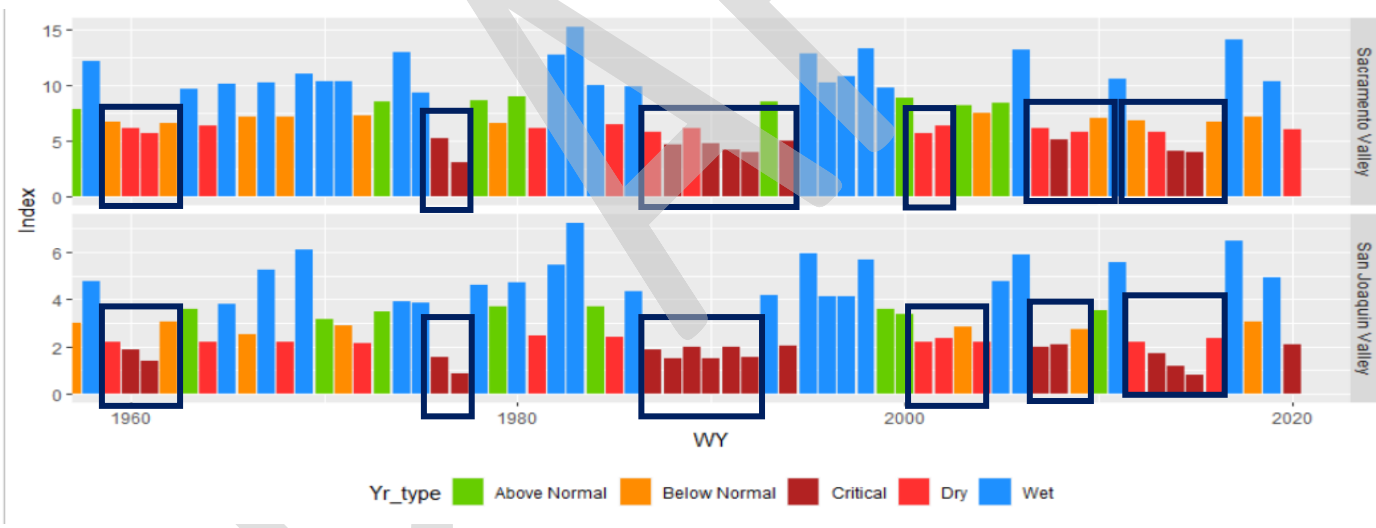

Figure 1. Plot of water year indexes for the Sacramento and San Joaquin Valleys from 1960 to the present. Data is from the California Department of Water Resources (https://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST)

Regulatory Background

The major drought of 2012-2016 prompted water managers to increase efforts to plan for future droughts. Environmental regulations regarding the operation of the State Water Project (SWP) and Central Valley Project (CVP) are chiefly dictated by Water Rights Decision D-1641, the California Endangered Species Act Incidental Take Permit of 2020, and the US Endangered Species Act Biological

Opinions of 2019. All of these regulations include a framework for adapting management during dry conditions.

Water Rights Decision D-1641 regulates water quality and flow standards for the Water Project, but complying with the terms of D-1641 becomes more challenging during a drought. During the 2013-2016 drought, a Temporary Urgency Change Petition (TUPC) was used to request certain changes to the terms of D-1641. This included changes to the minimum monthly average net delta outflow, a change in the minimum San Joaquin flow at Vernalis, modification of operations to the Delta Cross Chanel Gates, and a change to combined export rates (DWR and USBR 2015). These changes were accompanied by ESA consultations and monitoring to ensure protection of endangered species. Operational flexibility within D-1641 allows some drought responses without a TUCP, and as of February 24th, 2021, no TUCP is being considered, however future drought years may require changes. Using data from the monitoring completed in compliance with the TUCP will help guide our monitoring in response to this new drought.

The project description for the 2019 Reinitiation of Consultation on the long-term operations of the State Water Project and Central Valley Project, along with the 2020 Incidental Take Permit for the State and Central Valley Water Projects also include several drought provisions (United States Fish and Wildlife Service 2019, CDFW 2020). Specifically, they include a “Drought Toolkit”, containing voluntary actions which may help counteract the impact of dry conditions, and a Drought Contingency Plan, containing specific actions to be undertaken in a given year. These plans are developed by the California Department of Water Resources (DWR) and the US Bureau of Reclamation (USBR), 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. If dry conditions continue, DWR, in coordination with USBR, will regularly meet with these agencies (and potentially other agencies and organizations) to evaluate hydrologic conditions and the potential for continued dry conditions that may necessitate the need for development of a drought contingency plan (that may include actions from the toolkit) for the water year. By February of each year following a critical year, Permittee, in coordination with USBR, will report on the measures employed and assess their effectiveness.

The Drought Toolkit is still in development (as of 4/13/2021), 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 IEP scientists to develop a monitoring and synthesis plan for the environmental impacts of the drought and drought actions. This monitoring plan outlines the data collection and analysis we will undertake to evaluate responses to the current drought.

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 relationships are still difficult to predict. There are well-established relationships between freshwater outflow and population levels of certain biota, most notably the Longfin Smelt which has much higher abundances and recruitment during high-flow conditions (Kimmerer et al. 2019). Other fishes, such as the Delta Smelt, have a more complicated relationship with flow, with temperature, rather than outflow as the key driver of their population growth (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 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 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 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)).

Nutrients and Contaminants

We predict a decrease in nutrient and contaminant downstream transport, but potentially an increase in local concentration of nutrients and contaminants. Presence of nutrients and contaminants in the system is controlled by rates of input (loading) and transport within the system. Reduced freshwater flow may decrease contaminant loading, since most contaminants enter the waterways via runoff during storm events (Weston et al. 2015). However, lower flow may also increase concentration of contaminants present in the system due to less dilution and slower transport out of the system. Wastewater treatment plants provide the bulk of the total nitrogen budget for 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 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 will substantially reduce nitrogen inputs to the Delta, and may change the response of nitrogen to the current drought (District 2021); the initial phase of these upgrades came online in Fall of 2020 and are expectd to be fully online by Summer 2021.

Phytoplankton and Harmful Algal Blooms

We predict the drought will produce an increase in *Microcystis* and other harmful algal blooms (HABs), with the potential for localized increases in other phytoplankton. Reduction in nutrient import can result in reduced phytoplankton growth (Wetz and Yoskowitz 2013). However, because nutrients in the estuary are not generally considered limiting, longer residence time and increased water clarity associated with drought may result in increased primary 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), however there have been several examples of localized blooms 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 high 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 (Lehman et al. 2017).

Zooplankton

We tentatively predict an overall decline in zooplankton during the drought, decreasing food resources for fishes. However, the effect of drought on zooplankton communities may be difficult to predict, and the magnitude of the effect will be highly species-specific and location-specific. 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). We can therefor predict presence of freshwater zooplankton in the Low Salinity Zone to decrease during the drought, and many taxa will shift their center of distribution upstream. Analysis of zooplankton during the previous drought found reduction in copepod densities during the driest summers and a decrease in cladocerans during dry conditions (Conrad et al. Draft manuscript), but other analyses have not detected a trend between copepod densities and X2 when analyzing a longer time series (Hobbs et al. report).

The change in phytoplankton communities caused by drought may also have bottom-up effects on the zooplankton community. *Microcystsis* and other cyanobacteria may be harmful to the copepods of the estuary (Ger et al. 2009), however other cyanobacteria, usually considered “poor food” for zooplankton may be consumed more often than previously thought (Kimmerer et al. 2018a). In contrast, diatom blooms are generally thought of as “nutritious”. However, *Alocoseira* blooms, as 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 benefit (DWR, unpublished data). Other studies of flooded rice fields and managed floodplains have noted an order of magnitude higher zooplankton concentration than the adjacent rivers (Sommer et al. 2001, Grosholz and Gallo 2006, Corline et al. 2017, Jeffres et al. 2020). Lack of floodplain inundation, as predicted under drought conditions, may cut off this supply of zooplankton.

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 used. 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.

Fish

We predict an increase in invasive fishes, particularly those associated with vegetation, and a decrease in floodplain spawners and pelagic fishes during the drought. 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.

The native fish community of California evolved in response to regular cycles of floods and droughts. However, water management in today's system make present-day floods and droughts a different story. 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), 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 result. 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 experienced a marked increase in abundance during the drought (Mahardja et al. 2016).

Obligate floodplain spawners, such as the Sacramento Splittail, will 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, may also experience declines in recruitment and abundance when cut off from this productive habitat, however they have been found to use perennially wet channels within floodplains even during dry years (Sommer et al. 2001, Johnston et al. 2018).

Delta Smelt abundance is chiefly tied to habitat availability, 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 (Flow Alteration - Management 2020). While dry years may be either warm or cool, droughts tend to be warmer, on average, than wet periods (Hobbs draft; Conrad draft). Delta Smelt population numbers are critically low, with only two smelt detected by the Enhanced Delta Smelt Monitoring Program in the last six months (USFWS data). An extended drought, particularly if temperatures are warm, could push the Delta Smelt past the point of recovery.

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 is not understood. Regardless of the mechanism, low outflow will decrease longfin 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 reduced past the point of recovery (Mahardja et al. 2021).

Salmon

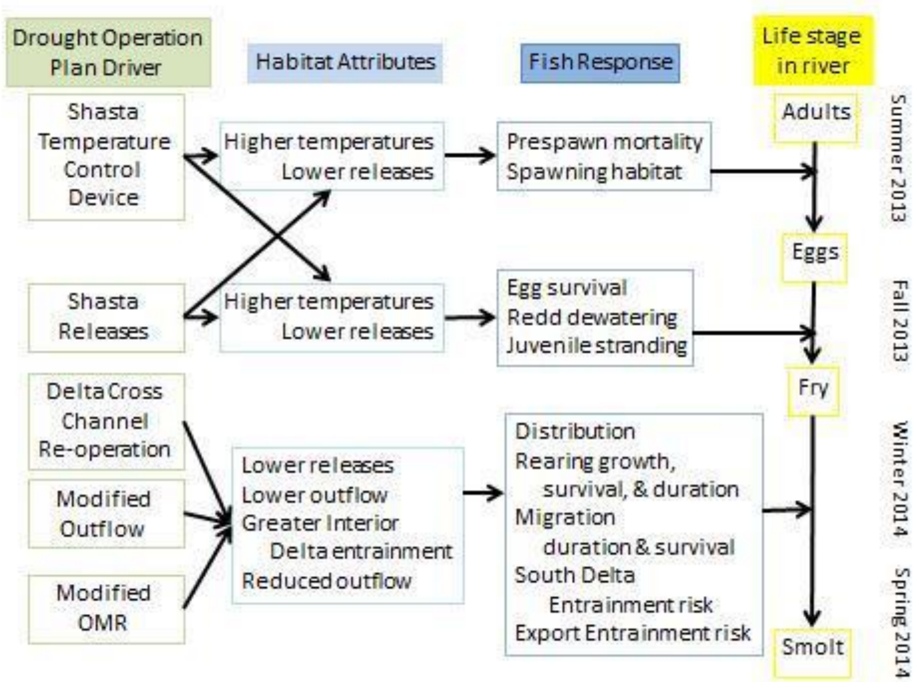

Figure 2. Conceptual model of salmon responses to drought actions from the Winter-Run Brood Year 2013 report (Israel et al. 2015)..

Salmonids will be impacted by drought conditions throughout their life span, including 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. A separate synthesis effort focused on salmon throughout their life history would be needed to assess the impact of drought on the salmon population 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 stranded (Sellheim et al. 2020).

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 watershed 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, there are several reasons why this would not lead to increased entrainment at the pumping facilities: 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.

Research Questions

- What is the ecosystem response to drought?
- What is the ecosystem response to our drought actions?
- What is the impact of these responses on listed species and water management?

Table 1. Predicted impacts of drought on various components of the ecosystem

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	Earlier in season Increased abundance Unknown toxicity	Visual Assessment from monitoring surveys USGS Studies DWR MWQI 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 Lower health/individual growth Low Population Growth Lower life history diversity Increased Entrainment?	Smelt Larval Survey 20mm Townet FMWT EDSM Salvage
Longfin Smelt	Spawning habitat further inland lower Health/individual growth Lower Population growth Life history diversity? Increased Entrainment	Smelt Larval Survey 20mm Townet FMWT Bay Study Salvage

Salmonids	Increased temperatures Longer upstream holding Higher River mortality Longer Delta migration time Increased South Delta routing. Reduced alternative life history strategies Increased predation Reduced Entrainment at pumps	Water temperature Screw traps Trawls Beach Seines Acoustic tagging Salvage EDNA JPE (winter-run) JPE (spring-run)
Other Fish	Increased littoral fishes Increased invasive centrarchids Increased Silversides Decreased Splittail (floodplain spawners) Decreased pelagic fish	All the fish surveys

Monitoring methods

Drought team and collaboration

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, USBR, CDFW, USFWS, and USGS who are all committed to synthesis and monitoring of ecosystem drought impacts. The team works closely with the USBR-led effort to develop a Drought Toolkit and the joint DWR/USBR team developing the annual Drought Contingency Plan.

Table 2. 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.
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	USBR	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
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%

Regions covered

This monitoring plan chiefly covers the legal Sacramento San-Joaquin Delta and Suisun Marsh. In some cases, it will include limited data collection outside these areas where necessary to describe habitat for anadromous species.

Existing Monitoring/Datasets

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 and tributaries maintained by CDWR and USGS with funding from CDWR and SUGS (Who is SUGS? Or did you mean USGS?) . This will be complemented by hydrologic modeling conducted by CDWR to calculate forecasted water supply as well as hindcasted Net Delta Outflow.

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 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 IEP Environmental Monitoring Program, USGS, the Delta Regional Monitoring Program, the Fish Restoration Program, DWR's Municipal Water Quality Program, the USBR Directed Outflow Project, Regional San, and other special studies. These samples typically include all major nutrients nitrate, nitrite ammonium, phosphorus, 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, Bellvue, 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 USBR 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 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. This data will be added to our analyses where appropriate.

Phytoplankton

Phytoplankton biomass will be monitored chiefly by in-situ chlorophyll sensors, discrete chlorophyll-a grab samples, and some community composition grab samples. In addition, under funding provided by the Delta Science Program and the Delta RMP, the USGS Biogeochemistry group is testing the deployment and performance of in-situ sensors that monitor phytoplankton taxonomy (the bbe FluoroProbe at Decker, Confluence, Jersey Point, Middle River). The Environmental Monitoring Program is also piloting the use of the Fluoroprobe on their water quality surveys.

There are currently over thirty continuous water quality probes in the Delta and Suisun Marsh that are equipped with YSI total Algae sensors capable of reporting chlorophyll fluorescence. These stations are maintained by DWR and USGS, and data are made available in real-time online via the California Data Exchange Center or the National Water Information System. Periodic (approximately monthly) grab samples are collected at these stations and analyzed for chlorophyll-a, pheophytin and phytoplankton community composition at analytical laboratories. Other programs, including the IEP Environmental Monitoring Program, the Delta Regional Monitoring Program, the Fish Restoration Program, DWR's Municipal Water Quality Program, the USBR Directed Outflow Project, USGS, and other special studies also collect discrete grab samples for analysis of chlorophyll-a, pheophytin-a. A subset of these programs also analyzes samples for phytoplankton community composition – counts and biovolume by species - using microscopy.

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

Zooplankton

Zooplankton will be monitored primarily using four existing IEP surveys, including the CDFW STN and FMWT (described above), as well as the DWR/CDFW Environmental Monitoring Program (EMP) and USBR Directed Outflow Project (DOP).

Zooplankton sampling by STN and FMWT are described in the previous section. EMP conducts water quality, phytoplankton, and zooplankton sampling on a monthly basis 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 salinity reaches 2 PSU and 6 PSU, 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, 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.

Fishes

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). 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 **Error! Reference source not found.**, 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-

Bumpas 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 the Fall Midwater Trawl, (https://www.wildlife.ca.gov/Conservation/Delta/Fall-Midwater-Trawl), which operates on a monthly basis 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-Bumpas 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 United States Fish and Wildlife Service Delta Juvenile Fish Monitoring Program (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 use to to make many historical comparisons, but it provides the best information on Delta Smelt distribution and abundance from recent years.

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.

Acoustic telemetry and Coded Wire Tags

Salmon are regularly released from hatcheries with tags or transmitters. 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

Table 3. Acoustic telemetry releases planned for 2021.

Study Name	Species/Run	Fish Source	Number of Fish	Release Timing	Location of Release	Servicing Entity
Trawl efficiency study, Hatchery late fall-run	Late fall-run Chinook salmon	Coleman	601	January	Battle Creek	NMFS – Arnold Ammann
Trawl efficiency study, Hatchery winter-run	Winter-run	Livingston Stone NFH	556	January 30th	Sacramento River at Caldwell Park	NMFS – Arnold Ammann
Trawl efficiency study, Hatchery spring-run	Spring-run	Feather River Hatchery	614	March 19th – April	Feather River	NMFS – Arnold Ammann
Battle Creek Jumpstart – On Site Rearing	Winter-run Chinook salmon	Livingston Stone NFH	900	March 8 and 10 + one release March 18	Battle Creek	USFWS – Laurie Earley
Battle Creek adult winter-run pre-spawning study	Adult winter-run Chinook salmon	Coleman Complex Jumpstart Program adult returns	?	March – June	Coleman NFH & below Eagle Canyon Dam	USFWS – Laurie Earley
Paired Net Pen	Fall-run Chinook salmon	Coleman NFH	600	Last week of March for Battle Creek releases, March 27-28th for the downstream/net pen releases	300 at Coleman, 300 at Sacramento River near Scottys'	USFWS – Sarah Austings

					Landing (RM 195)	
Spring Pulse Flow	Fall-run Chinook salmon	Coleman NFH	950	April 26-30, May 10-14	Sacramento River at RBDD	UCSC – Jeremy Notch
Six Year Study Continuation	Steelhead	Mokelumne NFH	1010	Weeks of March 22, April 12, May 3, & (DWR: May 27)	Lower San Joaquin River	UCSC – Jeremy Notch
Red Bluff Diversion Dam Wild Juvenile Chinook	fall-run Chinook salmon	Wild stock	400	April	Sacramento River near RBDD	USFWS – Bill Poytress
Butte Creek spring-run (Butte Sink or Sutter Bypass)	Spring/Fall run	Wild stock	200	April 5-9, April 19-23	Butte Creek	UCSC – Jeremy Notch
Butte Creek Spring-run (PPDD)	Spring-run Chinook salmon	Wild stock	150	April-May	Butte Creek	CDFW – Chris McKibbin
GCID Fish Barrier Study	Fall-run Chinook salmon	Coleman NFH	600	March-April	Sacramento River near Hamilton City	CDFW – Chris McKibbin
Reach-specific emigration of wild spring-run Salmon in Lower Feather River to inform in-river survival studies	Spring-run Chinook salmon	Wild stock	150	April – June 15	Lower Feather River	DWR – Jason Kindopp
Lower Yuba River Juvenile Chinook salmon survivorship	Spring/Fall-run Chinook salmon	Wild stock	520	Mid-April	Lower Yuba River	CDFW- Mike Healy
San Joaquin River Natural Origin Spring-Run Chinook Survival Study	Spring-run Chinook salmon	Wild stock	100 (wild)	March 15 – no more tags	San Joaquin restoration area	UCD – Mike Thomas
San Joaquin River Hatchery Origin Spring-Run Chinook Survival Study	Spring-run Chinook salmon	San Joaquin SCARF	550	~ March 29 – early April	SJR at Fremont Ford	UCD – Mike Thomas
Putah Creek Chinook salmon	Fall-run Chinook salmon	Wild stock	100-120	April-June	Putah Creek	UCD – Mike Thomas
Mill/Deer Creek Steelhead	Steelhead	Wild stock	200	March 15th – June 15th	Mill/Deer Creek	CDFW – Ryan Revnak
South Delta Temporary Barrier Project	Steelhead	Mokelumne NFH	300?	May 27th ?	Old River	ESA – Paul Bergman
Lower Sacramento River- SFBDE	Juvenile sDPS green sturgeon;	Wild stock	Up to 100 of each	Year round	Lower Sacramento River SFBDE	CDFW Region 2 - Marc Beccio

juvenile sturgeon monitoring	juvenile white sturgeon		species annually		at point of capture	
Migration timing and civil works impacts assessment of adult green sturgeon	Adult sDPS green sturgeon	Wild stock	?	Sept - Nov	Sacramento River	USACE – Robert Chase

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.

Pathogens

Experience during the 2012-2016 drought identified salmon pathogen monitoring as a key gap in our knowledge. However, increases in both regular monitoring and special studies have greatly expanded our data set. DWR, in collaboration with NMFS, have been monitoring salmon for pathogens on the Feather River since 2013 (J. Kindopp, pers. Comm), and this will continue in the coming year. We will also use results from a study of salmon pathogens currently being conducted by Dr. Richard Connon and collaborators, funded by CDFW's prop-1 funding.

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

Table 4. 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
Salinity	Sondes and/or modeling	
Turbidity	Sondes and/or modeling	
LSZ area	modeling	Contact Eli Ateljavich
Nutrients	EMP	
Nutrients	USGS data dashboard	Continuous mapping cruises and in-situ sensors
Contaminants	Delta RMP	

Phytoplankton	EMP	Contact Tiffany Brown. Tiffany.Brown@water.ca.gov
Zooplankton	EMP, 20mm. FMWT	
Zooplankton	DOP	Contact Andrew Schultz
Fish - Delta Smelt	EDSM	Can also be used for salmon
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	Rotory 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	
Fish - general	Fall Midwater Trawl (FMWT)	
Fish - general	Summer Townet Survey (TNS)	
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

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 (DCC) 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.

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 survey 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 known as the 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 and Rasmussen et al 2021 (Ustin et al. 2017, 2018, 2019). 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.

Harmful Algal Blooms

To date, harmful algal blooms (HABs) in the Delta are primarily associated with the growth of cyanobacteria (e.g., Microcystis) that are capable of producing 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 Regional Monitoring Program 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 (P8, DWR), Vernalis (C10; DWR) 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.

Data analysis methods

Our overall research questions have been broken down into specific predictions. 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 assessing the effectiveness of some of our component drought actions, such as small water transfers or changes to outflow, may be much more difficult to differentiate. Approaches for evaluating each of our predictions are summarized below, along with example metrics that we plan to evaluate for each.

1. *Historical comparisons*: Determining the ecosystem response to drought will rely primarily on comparisons to historic years. We will compare the current drought (2020-2021) to the droughts in 2012-2016, and 1987-1992, versus the wet years of 2006, 2011, and 2017. Additional historic droughts or wet periods may be added as data allows. These comparisons will be made via a variety of statistical techniques, including, but not limited to, generalized linear models, generalized additive models, cluster analysis, and ordination, as appropriate for the variable of interest.
2. *Before-During-After:* Determining the response to individual drought management actions will include comparisons of conditions before, during, and after the actions. For example, we will compare turbidity and salvage of juvenile salmonids before, during, and after changes to DCC operation. Some of these differences may be difficult to assess statistically, in which case graphical representation of results will be supported by modeling and literature review.
3. *With/Without Action*: We may also compare flow and water quality conditions with and without certain management actions using hydrodynamic models. For example, we will compare modeled location of the Low Salinity Zone with and without changes to minimum flow requirements in the Sacramento and San Joaquin Rivers.

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 1. We will use major management tools listed in the DWR/USBR 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 the length of the drought, and produce a final report describing the impact of the overall drought the year following the end of the drought.

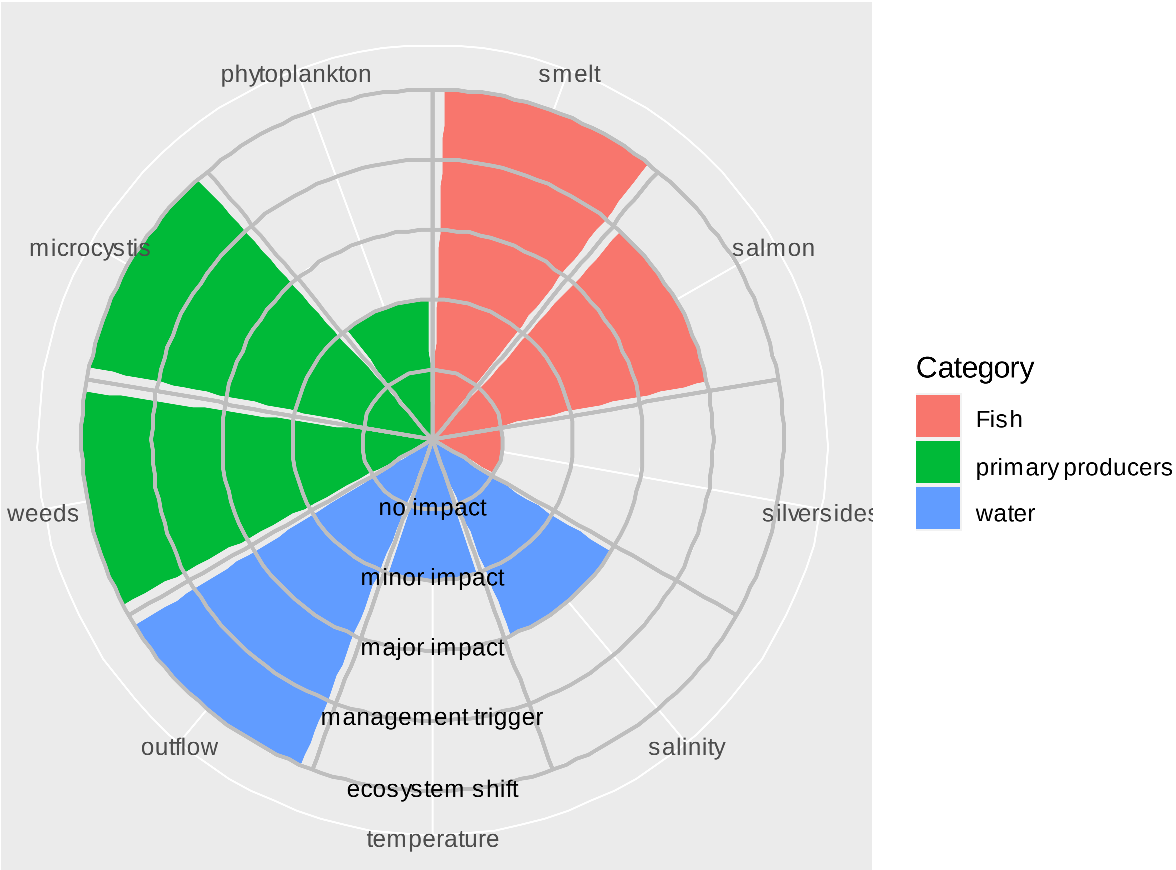

Figure 3. Example figure showing how multiple ecosystem metrics can be combined and used to determine management triggers. Size of the pie section is determined by level of drought impact, and rings will designate triggers for specific management actions.

Budget/expenditures

- Hyperspectral imagery ~$300K
- DWR Staff time - ~$400K

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

TBD

Data management

TBD

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

Works Cited/References

Works Cited

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