TEMPORARY URGENCY CHANGE PETITION OF 2021 AND EMERGENCY DROUGHT SALINITY BARRIER

Impact on Harmful Algal Blooms and Aquatic Weeds in the Delta

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Prepared by

California Department of Water Resources

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EXECUTIVE SUMMARY

Temporary Urgency Change Petition of 2021 and Emergency Drought Salinity Barrier: Impact on Harmful Algal Blooms and Aquatic Weeds in the Delta

Condition 8 of the June 2021 Temporary Urgency Change Order for the Central Valley Project (CVP) and State Water Project (SWP) requires a special study of harmful algal blooms (HABs) in the Sacramento–San Joaquin Delta (Delta) and the spread of submersed aquatic vegetation (SAV), also referred to as "aquatic weeds" (State Water Resources Control Board 2021).

In the Delta, HABs are chiefly caused by cyanobacteria (i.e., cyanobacterial harmful algal blooms or cyanoHABs). The February 15, 2022, order on petitions for reconsideration of the Temporary Urgency Change Petition (TUCP) expanded upon this condition, requiring an updated report that includes regional analysis, provides additional data, and identifies impacts on vulnerable communities (State Water Resources Control Board 2022a).

This report describes the study, presents preliminary results regarding potential drivers of the occurrence of cyanoHABs and spread of SAV, and identifies possible mitigation strategies. This report is a draft that is being made available for public comment and review by the State Water Resources Control Board. A final version will be published after all review comments have been addressed.

ES.1 Harmful Algal Blooms

HABs were monitored using visual assessments from existing surveys, satellite data, continuous water quality cruises, grab samples for taxonomy, and cyanotoxin data. Major findings were as follows:

- More HABs occurred in drought years than in wet years, most likely because of the higher temperatures, higher residence time, and greater water clarity in drought years.

- *Microcystis* occurred Delta-wide during the summers of 2020 and 2021. These two years exhibited a similar frequency and severity of *Microcystis* observations; and in both years, the frequency of observations was similar to, if slightly higher than, that in other dry years.
- During summer 2021, phytoplankton grab samples contained *Microcystis, Aphanizomenon*, and *Dolichospermum*.
- Temperature, turbidity, and CVP and SWP exports were the most statistically correlated to *Microcystis* observations in the South Delta. Blooms tend to be the most severe when temperatures are above 19 degrees Celsius, water is clear, and exports are low. Reductions in CVP and SWP exports that resulted from the TUCP may have increased the probability of observing *Microcystis*, but export levels likely would have been low without the TUCP.
- A large cyanobacterial bloom occurred in the eastern side of Franks Tract and surrounding waterways in July and August 2021. This bloom may have been exacerbated by change in flows resulting from the West False River Emergency Drought Salinity Barrier (EDB or barrier), coupled with high water temperatures attributable to local weather patterns. Other regions of the Delta did not show a higher incidence of *Microcystis* observations than in previous years.
- Concentrations of cyanobacterial toxins in Franks Tract and several other locations in the South Delta, Lower San Joaquin River, Lower Sacramento River, and Old/Middle River regions exceeded "Caution" levels for recreational use,[1] although they were below the "Warning" level. The potential also exists for these toxins to cause sublethal effects on fish and wildlife.
- Several other areas experienced high levels of cyanotoxins, some above the "Danger" level: Big Break, Discovery Bay, and the Stockton Waterfront. These areas have experienced high cyanotoxin levels annually for the past several years, so these occurrences are unlikely to have been caused by the 2021 drought actions.

Taken together, these findings suggest that increased residence time caused by drought and increased water temperatures were major factors leading to the development of cyanoHABs across the estuary, and that the 2021 TUCP was unlikely to have caused increases in the occurrence of *Microcystis*. A local increase in residence time caused by the EDB most likely contributed to the cyanobacterial bloom in Franks

1 Office of Environmental Health Hazards Assessment Levels (OEHHA 2022).

Tract during July and August 2021. Elsewhere in the Delta, areas that had experienced cyanoHABs in previous years experienced cyanoHABs in 2021 at similar levels. Conditions in areas with low or no previous cyanoHABs remained unchanged.

Because toxins in the bloom exacerbated by the barrier remained low, there was no disproportionate impact on vulnerable communities from recreational exposure pathways.

Managing cyanoHABs in the Delta is rapidly becoming a priority for State, federal, and local water agencies, and this condition will only increase in a warming climate. Mitigation methods for reducing residence time locally near the barrier are still under development; however, ideas include notching the barrier temporarily if blooms develop (if feasible while maintaining water quality protections), using mixing methods, or potentially using algicide. However, most of these control methods may become infeasible at the scale of the entire Franks Tract, may be cost prohibitive, or both. Future research should explore the targeted use of these methods, or the use of methods that can be implemented on a larger scale. Also, increased monitoring to identify recurring problem areas for aquatic weeds and cyanoHABs will provide important baseline information to develop in support of the identification of mitigation measures.

ES.2 Aquatic Weeds

Aquatic vegetation was monitored across the Delta using hyperspectral imagery. Imagery has been collected over all or most of the Delta annually since 2014, with additional surveys conducted in 2004 to 2008. SAV within Franks Tract has also been monitored annually using rake surveys conducted by the California Department of Parks and Recreation, Division of Boating and Waterways (DBW), in collaboration with SePRO Corporation, Carmel, Indiana. Major findings are as follows:

- The total area of aquatic weeds has been increasing over the past 15 years, with an apparent step change in 2015 that was seen at both Big Break and Franks Tract.
- Wet years (2017 and 2019) did not produce a significant decrease in the total coverage of aquatic weeds in the Delta.
- The 2021 EDB shifted the distribution of SAV within Franks Tract, with greater density on the western side of the tract, where the barrier decreased flow, and reduced density on the eastern side of the tract, where velocities increased.

- SAV may have interacted with cyanobacteria, competing with them for light and nutrients, limiting the development of blooms on the western side of Franks Tract.
- Big Break, Franks Tract, and Clifton Court Forebay all experienced similar changes to vegetation coverage by year, which indicates that Delta-wide drivers such as water quality may be better predictors of total vegetation coverage than the barrier or TUCP.
- The relative composition of native and invasive SAV species in Franks Tract has changed over time; however, complex interactions between DBW's herbicide applications, drought, barrier installations, and temperature may all play a role in these dynamics.
- Coverage by floating aquatic vegetation in 2021 was similar to that found in other recent years.

Taken together, these patterns indicate no evidence for an impact of the TUCP on aquatic vegetation, although the barrier caused changes in the distribution of weeds within Franks Tract. Weed distribution appears to be partially controlled by water velocity, but other drivers remain elusive. Weed density increased dramatically during the 2014–2016 drought but did not decrease during subsequent wet years, so it is difficult to determine whether the drought was the cause of these increases.

Because aquatic weeds chiefly affect boaters, and they affect all other users of the Delta equally, there was no disproportionate impact on vulnerable communities.

Multiple strategies for controlling aquatic weeds are in development or in use, to varying levels of success. Aquatic herbicides have low efficacy in tidal waters; however, the long residence times in Franks Tract caused by the EDB may provide an opportunity for increased efficacy. In particular, if the center of Franks Tract can be cleared by herbicide while the barrier is in place, increases in velocities that occur when the barrier is removed may be able to prevent weeds from reestablishing. Other methods, such as the use of new herbicides, benthic mats, booms, and biocontrol, are also an area of active investigation.

Control of weeds throughout Franks Tract may be best addressed by a more comprehensive ecosystem restoration program, such as the one proposed by the Franks Tract Futures project. This project would restrict salinity intrusion, reduce aquatic weeds, and result in fewer effects on residence time than the emergency drought barrier. It would therefore be a more sustainable solution than repeatedly installing drought barriers.

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Acronyms and Other Abbreviations

Acronym or Abbreviation	Definition
°C	degrees Celsius
µg/g	micrograms per gram
µg/L	micrograms per liter
µS/cm	microSiemens per centimeter
Banks Pumping Plant	Harvey O. Banks Pumping Plant
barrier	West False River Emergency Drought Salinity Barrier
Bay-Delta	San Francisco Bay/Sacramento–San Joaquin Delta
BMAA	β-methylamino-l-alanine
Cache/Liberty	Cache Slough/Liberty Island area and Sacramento Deep Water Ship Channel
CAWSC	California Water Science Center
CCHAB	California Cyanobacteria and Harmful Algal Bloom Network
CDEC	California Data Exchange Center
CDFW	California Department of Fish and Wildlife
cfs	cubic feet per second
CI	Cyanobacteria Index
corr	correlation coefficient
CSTARS	Center for Spatial Technologies and Remote Sensing (University of California, Davis)
CVP	Central Valley Project
cyanoHAB	cyanobacterial harmful algal bloom
D-1641	Water Rights Decision 1641
DBW	California Department of Parks and Recreation, Division of Boating and Waterways
DCP EJ Survey Report	California Department of Water Resources Delta Conveyance Project's *Your Delta, Your Voice* environmental justice community survey
Delta	Sacramento–San Joaquin Delta
DO	dissolved oxygen
DWR	California Department of Water Resources
East Bay Regional Parks	East Bay Regional Park District
EAV	emergent aquatic vegetation
EDB	West False River Emergency Drought Salinity Barrier
ELISA	Enzyme-Linked Immunosorbent Assay
EMP	Environmental Monitoring Program
EPA	U.S. Environmental Protection Agency
FAV	floating aquatic vegetation
FMWT	Fall Midwater Trawl

Acronym or Abbreviation	Definition
Franks	Franks Tract
ha	hectare(s)
HAB	harmful algal bloom
LC-MS	liquid chromatography–mass spectrometry
LC-MS/MS	liquid chromatography with tandem mass spectrometry
LD_{50}	median lethal dose
Lower Sac	Lower Sacramento River region
Lower SJ	Lower San Joaquin River region
MHI	median household income
mL	milliliter(s)
N:P ratio	ratio of nitrogen to phosphorus
NCRO	North Central Region Office
NEPA	National Environmental Policy Act
nitrate	dissolved nitrate + nitrite
NTU	nephelometric turbidity unitsw
OEHHA	Office of Environmental Health Hazard Assessment
OMR	Old/Middle River Corridor
qPCR	quantitative polymerase chain reaction
Reclamation	U.S. Bureau of Reclamation
RWQCB	Regional Water Quality Control Board
SAV	submersed aquatic vegetation
SePRO	SePRO Corporation
SFBS	San Francisco Bay Water Quality Survey
SPATT	Solid Phase Adsorption Toxin Tracking
State Water Board	State Water Resources Control Board
STN	Summer Townet
SWP	State Water Project
TUCO	Temporary Urgency Change Order
TUCP	Temporary Urgency Change Petition
Upper Sac	Upper Sacramento River region
USGS	U.S. Geological Survey
WAIC	Widely Applicable Information Criterion
WHO	World Health Organization

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SECTION 1

Overview of the Temporary Urgency Change Petition and Barrier and Need for This Report

1.1 Introduction

Water Year 2021 was the driest water year recorded in California since 1977. Although rainfall was well below average, the snowpack in March 2021 indicated that sufficient reservoir inflow would be available to meet water quality requirements. Conditions changed significantly at the end of April 2021, when it became clear that expected reservoir inflow from snowmelt had failed to materialize. The May forecast for the water year in the Sacramento Valley Four Rivers Index identified a reduction of expected runoff of 685 thousand acre-feet from the forecast generated only a month earlier, in April.

A combination of factors—the May 2021 forecast of inflow that was far less than predicted, parched watershed soils and extremely low rainfall, continued dry and warm conditions, and limited available water supplies in the San Francisco Bay/Sacramento–San Joaquin Delta (Bay-Delta)—created an urgent need to act. Governor Gavin Newsom acknowledged this need in his May 10, 2021, Emergency Proclamation, which declared a state of emergency for the Bay-Delta and other watersheds due to drought conditions. The continuation of extremely dry conditions in the Delta watershed meant that there was not an adequate water supply to meet water right permit obligations for instream flows and water quality under Water Rights Decision 1641 (D-1641).

The U.S. Bureau of Reclamation (Reclamation) and California Department of Water Resources (DWR) jointly submitted the 2021 Temporary Urgency Change Petition (TUCP). The TUCP requested that the State Water Resources Control Board (State Water Board) consider modifying the requirements of Reclamation's and DWR's water right permits to enable changes in Central Valley Project (CVP) and State Water Project (SWP) operations that would allow the projects to deliver water with conservation for later instream uses and water quality requirements. On June 1, 2021, the State Water Board issued an order, the Temporary Urgency Change Order (TUCO), conditionally approving the petition and conditions requiring compliance with Delta water quality objectives in response to drought conditions (State Water Resources Control Board 2021).

The TUCP's modification to some D-1641 requirements preserves water quality in the Delta while maintaining some carryover storage in upstream reservoirs, including Shasta and Oroville. On February 15, 2022, the State Water Board issued an order denying in part and granting in part petitions for reconsideration of the June 2021 TUCO (State Water Resources Control Board 2022a). This order included additional reporting requirements, among them an updated draft of this report.

1.2 Substance of the Temporary Urgency Change Petition

DWR and Reclamation requested the following temporary changes to requirements that were imposed pursuant to D-1641 for the period June 1 through August 15:

- For June 1 through June 30, reduce the required minimum 14-day running-average Delta outflow from 4,000 cubic feet per second (cfs) to 3,000 cfs.
- For July 1 through July 31, reduce the required minimum monthly average Delta outflow from 4,000 cfs to 3,000 cfs, with a seven-day running average of no less than 2,000 cfs.
- For June 1 through July 31, limit the combined maximum export rate to no greater than 1,500 cfs when Delta outflow is below 4,000 cfs; allow the 1,500 cfs limit to be exceeded when the Petitioners are meeting Delta outflow requirements pursuant to D-1641, or for moving transfer water.
- From June 1 through August 15, move the compliance point for the western Delta agricultural salinity requirement from Emmaton on the Sacramento River to Threemile Slough on the Sacramento River.

1.3 Emergency Drought Barrier

Along with the TUCP, DWR requested emergency authorizations in May 2021 for installation of the 2021 West False River Emergency Drought Salinity Barrier (EDB or barrier). The 2021 EDB is a temporary physical rock fill barrier that reduces the intrusion of high-salinity water into the Central and South Delta. **Figure 1-1** shows the location of the barrier.

Figure 1-1 Emergency Drought Barrier Location

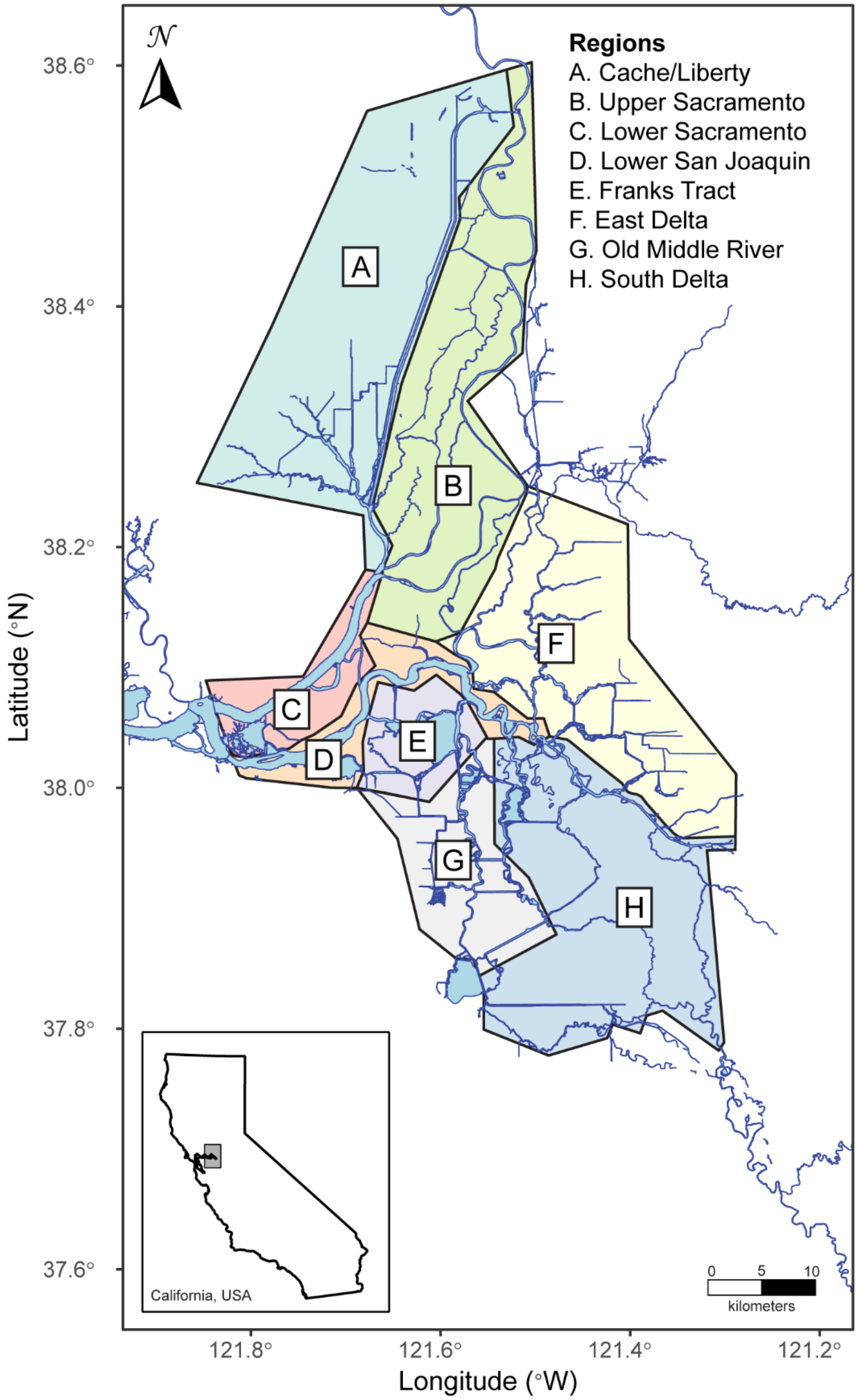
Installation of a drought salinity barrier at West False River was shown to be an effective tool for reducing the intrusion of salt water into the Central and South Delta in 2015 (California Department of Water Resources 2019). During drought conditions, water stored in upstream reservoirs may be insufficient to repel salinity moving upstream from San Francisco Bay. Without the protection of the drought salinity barrier, saltwater intrusions could render Delta water unusable for agricultural needs, reduce habitat value for aquatic species, and affect roughly 25 million Californians who rely on the export of this water for personal use. In terms of location, size, and design, the 2021 EDB is very similar to the drought salinity barrier that was permitted and installed during the 2015 drought. However, the 2021 EDB was not removed in November of the year in which it was installed. Instead, a notch was cut into the top of the barrier in January 2022 to allow fish passage, then the notch was re-filled in April 2022 to restore the barrier’s effectiveness as a salinity barrier.

Both the biological assessment for the 2021 EDB and the biological review for the TUCP identified the potential for an increase in cyanobacterial harmful algal blooms (cyanoHABs) and an increase in submersed aquatic vegetation (SAV), also referred to as “aquatic weeds.” Therefore, the Section 401 certification for the 2021 EDB and Condition 8 of the June 2021 TUCO for the CVP and SWP require a special study of cyanoHABs and SAV in the Delta. This report describes the study, presents preliminary results regarding drivers of the occurrence of cyanoHABs and spread of SAV, and identifies possible mitigation strategies.

1.4 Regional Analysis

The impacts of the TUCP and 2021 EDB will not be uniform across the area of the Delta; therefore, many of the analyses in this report are divided into regions based on the projected changes to flow caused by the TUCP and barrier (**Figure 1-2**):

- In the Upper Sacramento River region (Upper Sac), reduced inflows will cause increased residence time, although maximum and minimum velocities, which are controlled primarily by tides, are expected to be minimal.
- In the Cache Slough/Liberty Island area and Sacramento Deep Water Ship Channel (Cache/Liberty), residence time and velocities are controlled primarily by tidal forcing, so no impacts from the TUCP are expected.



NOTE: The largest impacts of the TUCP and barrier are expected to be in the Lower San Joaquin (D), Franks Tract (E), and OMR (G) regions.

Figure 1-2 Regions Used for the Impacts Analysis of the Temporary Urgency Change Petition and 2021 Emergency Drought Salinity Barrier

- In the Lower Sacramento River region (Lower Sac), the barrier will cause salinity to increase, and reduced inflows will cause increased residence time, although changes to maximum and minimum velocities are expected to be minimal.
- In the Lower San Joaquin River region (Lower SJ), the barrier will cause salinity to increase. There will be local increases to flows and current speed on the San Andreas Reach.
- In Franks Tract (Franks), the barrier will cause a significant increase in residence time, particularly on the western side of the tract. Maximum current speed and tidal flows will decrease through False River and increase through Fisherman's Cut and Old River.
- In the Old/Middle River Corridor (OMR), south of Franks Tract, the barrier will cause salinity to decrease and residence time to increase in Old River, with a smaller effect in Middle River. Residence time in this area is controlled mainly by exports; therefore, low, health-and-safety export levels will result in lower residence time than during wetter years.
- Impacts on flows or salinity in the South Delta or East Delta will be minimal. Data from these regions are shown for context only.
- Suisun Marsh and Suisun Bay will have slight increases in salinity; however, such conditions are not expected to influence cyanoHABs or weeds in these regions, so data from these regions are not shown in this report.

In its study of drought impacts on the Delta, the Interagency Ecological Program synthesis team predicted that the drought would cause increases in the incidence and severity of cyanoHABs and the coverage and density of SAV. The team predicted that the TUCP would not cause detectable changes in either of these parameters beyond the level of the drought, but that the 2021 EDB may cause local increases in cyanoHABs and SAV in the vicinity of Franks Tract or the Central Delta (**Table 1-1**).

TABLE 1-1
PREDICTED ECOSYSTEM IMPACTS OF THE 2021 EMERGENCY DROUGHT SALINITY BARRIER AND TEMPORARY URGENCY CHANGE PETITION RELEVANT TO SUBMERSED AQUATIC VEGETATION AND HARMFUL ALGAL BLOOMS IN THE DELTA

Category	Expected Conditions and Impacts	Monitoring
Hydrology/ water quality	Higher salinity in the Sacramento River Higher residence time in Franks Tract and the Old/Middle River Corridor Lower salinity in Franks Tract and the Old/Middle River Corridor	DWR/USGS flow and water quality stations Modeling
cyanoHABs	Increase in Franks Tract, the Old/Middle River Corridor, and the Lower San Joaquin River region	Visual assessment from monitoring surveys State Water Board cyanotoxin samples DWR/USGS SPATT study DWR pumping plant cyanotoxin samples EMP microscopy samples FluoroProbe data USGS high-speed mapping surveys Satellite data
SAV	Increased weeds in Franks Tract	DBW/SePRO Franks Tract survey UC Davis imagery UC Davis grab samples to ground-truth imagery

NOTES: cyanoHABs = cyanobacterial harmful algal blooms; DBW = California Department of Parks and Recreation, Division of Boating and Waterways; Delta = Sacramento–San Joaquin Delta; DWR = California Department of Water Resources; EMP = Environmental Monitoring Program; km = kilometers; SAV = submersed aquatic vegetation; SePRO = SePRO Corporation; SPATT = Solid Phase Adsorption Toxin Tracking; State Water Board = State Water Resources Control Board; TUCP = Temporary Urgency Change Petition; UC Davis = University of California, Davis; USGS = U.S. Geological Survey

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SECTION 2
Harmful Algal Blooms

2.1 Introduction

2.1.1 Biology, Ecology, and Impacts

Cyanobacteria are photosynthetic bacteria that occur as components of phytoplankton communities in all the world's waterbodies. Many taxa are harmless, but some species may produce harmful chemicals (cyanotoxins), and some can form toxic blooms in freshwater and brackish ecosystems. Many cyanobacteria genera can form cyanoHABs, including the nitrogen-fixing genera *Anabaena/ Dolichospermum*, *Aphanizomenon*, *Cylindrospermopsis*, and *Nodularia*; the benthic nitrogen-fixing genera *Lyngbya* and some *Oscillatoria*; and the non-nitrogen-fixing genera *Microcystis* and *Planktothrix.*

Although these genera frequently co-occur, they are distinguished by different physiological capabilities and environmental optima. *Microcystis* has one of the highest optimum temperature ranges (25–28 degrees Celsius [°C]) and increases its growth rate fastest with every 10°C increase in temperature (i.e., Q_{10}), but it requires high light availability because of its low photosynthetic efficiency (Lehman et al. 2022; Reynolds 2006; Wu et al. 2009). *Microcystis* migrates to the surface to maximize the availability of light (Wilhelm et al. 2020). Other taxa, such as *Aphanizomenon, Pseudoanabaena*, and *Dolichospermum*, have lower temperature and light requirements and can fix nitrogen gas, but they have lower growth rates (Li et al. 2016; Reynolds 2006; Stal et al. 2003). Therefore, *Microcystis* generally dominates later in the summer when temperatures are warmest and the water is clearest, and other taxa dominate earlier in the year in conditions of higher turbidity and cooler temperatures.

Blooms of *Microcystis* in the Delta are associated with the release of cyanotoxins such as microcystins in the water and potential impacts on both human and aquatic health. For example, embryonic and larval stages of fish appear to be very sensitive to the toxin microcystin, with chronic exposures as low as 0.25 micrograms per liter (µg/L) leading to oxidative stress, reduced growth, developmental defects, and lethality (Acuña et al. 2020; Kurobe et al. 2018; Office of Environmental Health Hazard Assessment Ecotoxicology et al. 2009).

Consumption of prey items with body burdens of cyanotoxins can also be a potential pathway of impact (Banerjee et al. 2021). Lehman et al. (2010) traced concentrations of microcystins from the water (0.05 μg/L) to zooplankton (0.4 to 3.9 micrograms per gram [μg/g] dry weight) to the muscle tissue of Striped Bass (1.6 to 2.9 μg/g dry weight). These values are similar to the sublethal level of microcystin doses to fish (2.5 μg/g dry weight), as determined by the California Environmental Protection Agency's Office of Environmental Health Hazard Assessment (OEHHA) (Office of Environmental Health Hazard Assessment Ecotoxicology et al. 2009). Tumor lesions in the liver tissue of juvenile Striped Bass and Mississippi Silversides caught in the San Joaquin and Sacramento rivers are consistent with sublethal effects caused by the microcystin toxin (Lehman et al. 2010; Office of Environmental Health Hazard Assessment Ecotoxicology et al. 2009). Similarly, fish feeding studies have demonstrated that diets containing microcystin result in lesions of the liver (Acuña et al. 2012a; Acuña et al. 2012b; Deng et al. 2010). Recent research has indicated that wild fish are continually exposed to dietary toxins through the accumulation of microcystins in the gut and liver tissue (Acuña et al. 2020).

Microcystin concentrations around 3.5 μg/g dry weight fish tissue found in Striped Bass in the Delta also pose a risk to human health (**Table 2-1**). Microcystin concentrations of 0.05 to 2 μg/L measured in the Central Delta before 2020 (i.e., Lehman et al. 2008; Lehman et al. 2018; Spier et al. 2013) were usually lower than exposure guidelines issued by the World Health Organization (WHO) and U.S. Environmental Protection Agency (EPA) for human health in recreational waters (U.S. Environmental Protection Agency 2019). However, such concentrations are within the "caution" tier of the California Cyanobacteria and Harmful Algal Bloom Network's (CCHAB's) three-tiered warning system, identified in Table 2-1. Concentrations of microcystins in drinking water may be harmful at lower levels (Table 2-1) (U.S. Environmental Protection Agency 2015a, 2015b; World Health Organization 2021).

TABLE 2-1
OEHHA AND CCHAB ACTION LEVELS FOR HUMAN RECREATIONAL EXPOSURE TO CYANOTOXINS, COMPARED TO WORLD HEALTH ORGANIZATION AND U.S. ENVIRONMENTAL PROTECTION AGENCY MICROCYSTIN GUIDANCE LEVELS

Toxin	Source	Advisory Type	Concentration
Microcystins	OEHHA	Fish Consumption	10 ng/g fish wet weight
Microcystins	WHO	Provisional Tolerable Daily Intake for chronic exposure	0.04 µg/kg body weight/day
Microcystins	OEHHA	Recreation—Caution	0.8 µg/L
Microcystins	OEHHA	Recreation—Warning	6 µg/L
Microcystins	OEHHA	Recreation—Danger	20 µg/L
Microcystins	EPA	Drinking Water—adults[1]	1.6 µg/L
Microcystins	EPA	Drinking Water—children[1]	0.3 µg/L
Microcystins	EPA	Recreation	8 µg/L
Microcystins	WHO	Recreation	24 µg/L
Microcystins	WHO	Drinking Water	1 µg/L
Cylindrospermopsin	OEHHA	Fish Consumption	70 ng/g fish wet weight
Cylindrospermopsin	OEHHA	Recreation—Caution	1 µg/L
Cylindrospermopsin	OEHHA	Recreation—Warning	4 µg/L
Cylindrospermopsin	OEHHA	Recreation—Danger	17 µg/L
Cylindrospermopsin	EPA	Recreation	15 µg/L
Cylindrospermopsin	EPA	Drinking Water—adults[1]	3 µg/L
Cylindrospermopsin	EPA	Drinking Water—children[1]	0.7 µg/L
Anatoxin-a	OEHHA	Recreation—Caution	Detection
Anatoxin-a	OEHHA	Recreation—Warning	20 µg/L
Anatoxin-a	OEHHA	Recreation—Danger	90 µg/L

NOTES: µg/kg = micrograms per kilogram; µg/L = micrograms per liter; CCHAB = California Cyanobacteria and Harmful Algal Bloom Network; EPA = U.S. Environmental Protection Agency; ng/g = nanograms per gram; OEHHA = Office of Environmental Health Hazard Assessment (California Environmental Protection Agency); WHO = World Health Organization

1 Drinking water advisories are for 10-day exposures, assuming adults drink two liters of water per day.

SOURCES: Office of Environmental Health Hazard Assessment 2022; World Health Organization 2021; U.S. Environmental Protection Agency 2015a, 2015b, 2019

Critically, not all cyanobacteria capable of producing toxins will be producing those toxins at any given time. Furthermore, many strains of cyanobacteria from genera known to produce cyanotoxins, including *Microcystis*, may or may not carry the gene to produce toxins, nor are they necessarily producing the toxin in the environment (Chorus and Welker 2021), including those found in the Delta (Baxa et al. 2010; Moisander et al. 2009; Moisander et al. 2020). Toxicity to animals in the ecosystem depends on whether they are exposed to toxins bound within the cyanobacterial cells or to toxins free in the environment, and the toxins may become bound by suspended sediment or taken up by benthic filter feeders (Bolotaolo et al. 2020). Toxin concentrations in the water may be relatively low during a bloom, but increase as cells lyse and release stored toxins into the water column (Zastepa et al. 2014).

2.1.2 Harmful Algal Blooms in the Delta

Blooms of the toxin-producing cyanobacteria *Microcystis* sp. have been observed in the Delta since the late 1990s by researchers from DWR and other agencies. These blooms were first documented visually appearing as little lettuce-like flakes in the water (Lehman and Waller 2003). The blooms were initially classified as *Micyrocystis aeruginosa*; however, this morphospecies has since been found to comprise multiple strains, so it is referred to here by genus, rather than by species (Otten et al. 2017; Pérez-Carrascal et al. 2019). Studies of these blooms demonstrated that the blooms contain multiple variants of microcystin, which act as liver toxins (Lehman et al. 2005), and the presence of low concentrations in the Delta is cause for concern. Investigations have found that the blooms frequently are composed of a mix of *Aphanizomenon* sp., *Microcystis* sp., *Dolichospermum* (formerly *Anabaena)* sp., *Planktothrix* sp., and *Pseudoanabaena* sp. (Lehman et al. 2010; Mioni et al. 2012); however, research to date has focused primarily on *Microcystis*.

Regionally, the Central and South Delta have historically had the highest surface concentrations of *Microcystis* and *Aphanizomenon* (Berg and Sutula 2015; Lehman et al. 2013; Lehman et al. 2008; Lehman et al. 2018; Mioni et al. 2012). Starting in 2012, very high abundances of *Microcystis* colonies were observed in the South-East Delta region in the Turning Basin of the Stockton Shipping Channel, in Discovery Bay, and at Rough and Ready Island (Lehman et al. 2018; Spier et al. 2013). *Microcystis* abundance is typically much lower in Suisun Bay west of Antioch and north of Collinsville on the Sacramento River (Lehman et al. 2013; Lehman et al. 2005; Lehman et al. 2008; Lehman et al. 2018; Mioni et al. 2012).

2.1.3 Drivers

A worldwide increase in the incidence of cyanoHABs has prompted a great deal of research into the conditions that favor the growth of these species (Carmichael 2008; Chorus and Welker 2021; Hudnell 2008; Hudnell 2010; O'Neil et al. 2012; Paerl and Paul 2012). Environmental conditions favoring the formation of cyanoHABs typically include calm and stratified water, warm water temperatures, high availability of light, and an ample supply of nutrients (Berg and Sutula 2015; Huber et al. 2012; Lehman et al. 2013; Lehman et al. 2018; Paerl et al. 2011). The most successful strategies for mitigating cyanoHABs have focused on these environmental factors, including increasing the flow of water, promoting mixing of the water column, and reducing the supply of nutrients (Paerl et al. 2011).

A conceptual model has been developed showing how the TUCP, the EDB, and other drought-related actions may influence bloom formation (**Figure 2-1**). Cyanobacterial blooms are controlled by limitations on their photosynthetic rate or by external factors that remove them from the system. Limitations on their photosynthetic rate include nutrient supply, water temperature, and light availability (Lehman et al. 2013; Lehman et al. 2018).

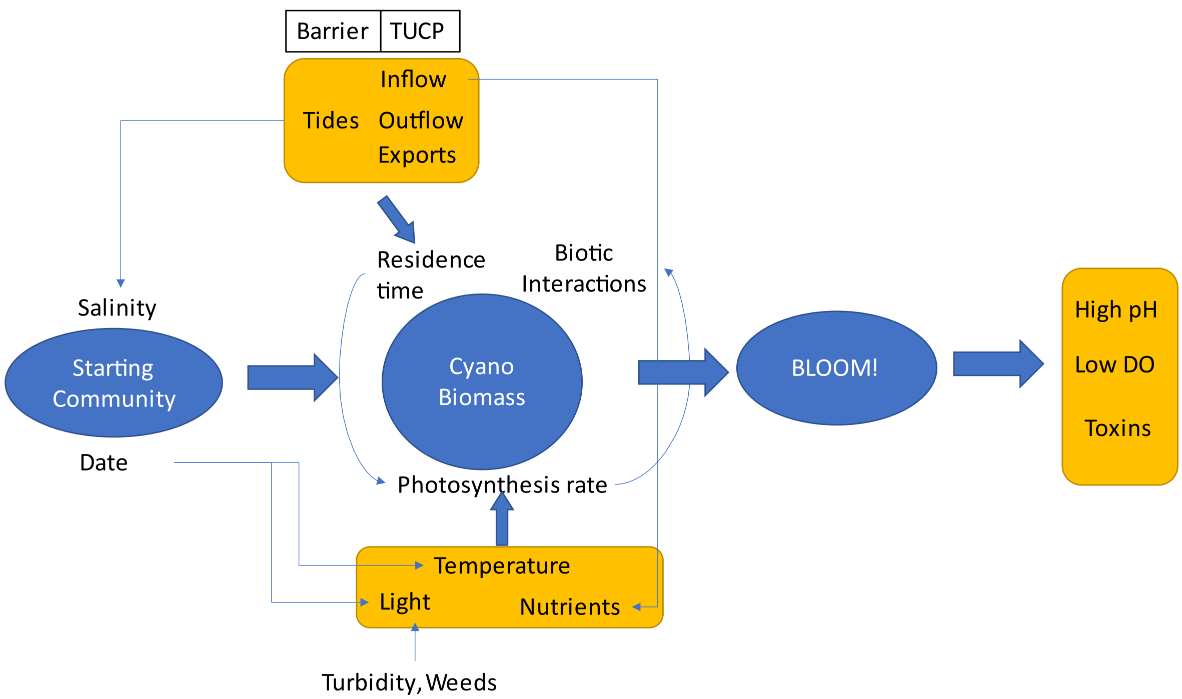


Figure 2-1 Conceptual Model of the Influence of Hydrology and Other Factors on Harmful Algal Blooms

Nutrients in the system are controlled by both nonpoint sources (runoff from agriculture) and point sources (chiefly wastewater treatment plants within the Delta) (Senn et al. 2020). Some cyanobacteria can also fix nitrogen gas dissolved in the water, although *Microcystis* (the dominant toxigenic cyanobacterium in the Delta) cannot. Nutrient concentrations peak in the winter and spring, when high flows increase the loading of nutrients from the watershed; concentrations decrease during the summer, when there is less runoff and when primary productivity and nutrient uptake by phytoplankton is at its peak. In the Delta, summertime chlorophyll concentrations are typically relatively low (2.5 to 3.5 µg/L), and nutrients are generally not considered limiting to phytoplankton growth and biomass accumulation (Jassby 2008). However, sporadically large phytoplankton blooms occur that completely deplete the available nitrogen supply. Nitrogen, rather than phosphorus, is usually the limiting nutrient in the system (Cloern and Jassby 2012; Gowen et al. 1992), so phosphorus is generally not considered an important factor in predicting phytoplankton or cyanobacterial blooms. That said, a reduction in phosphorus has been correlated with a reduction in chlorophyll in the estuary (Van Nieuwenhuyse 2007).

Water temperatures in this region have increased over the period of record (Bashevkin et al. 2022), with substantial increases starting in 1999 (Brooks et al. 2011). Water temperatures in the Delta are driven mainly by air temperatures (Vroom et al. 2017), and periods of low inflow also tend to be warmer (Bashevkin and Mahardja 2022). Temperatures vary spatially within the Delta—warmer in the South Delta and cooler along the Sacramento River and in Suisun Bay (Bashevkin et al. 2022).

The availability of light changes with solar irradiance and turbidity. Although cloud cover and smoke may block sunlight temporarily, light availability in the water column during the summer is controlled mainly by turbidity. Turbidity in the Delta is driven by the sediment concentration of the incoming water, water velocity, and wind. The largest sediment inputs in the Delta occur during winter storms, so summer conditions will have clearer water, and sediment inputs in the Delta have been decreasing over the past 50 years, causing a trend toward increased water clarity (Schoellhamer 2011). As water slows, suspended particles sink, causing the water to clear further.

During the summer, water velocity is controlled by tidal action, so (as for residence time) water velocity on the local scale is most affected by the Delta’s physical characteristics, particularly the presence of submersed vegetation. Vegetation causes the water to slow, and the trend toward increasing water clarity in the Delta has also been linked to the increase in aquatic vegetation over the past 20 years (Hestir et al. 2016). This forms a positive feedback loop in which increased vegetation leads to increased water clarity, facilitating further vegetation establishment (see Section 3, “Weeds,” for more discussion). Wind increases sediment re-suspension and turbidity in extended areas of shallow open water, such as Suisun Bay, but is less of a factor in narrow channels or areas with dense vegetation (Bever et al. 2018).

External factors controlling blooms include flow, residence time, and biological interactions. Residence time in the Delta is controlled by the combined interaction of tidal action, inflows, diversions, and physical characteristics of the Delta (Downing et al. 2016; Hammock et al. 2019). On the larger scale, inflows dominate inter-annual and intra-annual differences in residence time, with major floods greatly reducing residence time during the winter and spring months. Decreased flow typically occurs during July–September, which coincides with the occurrence of *Microcystis* blooms (Lehman et al. 2013, 2018, 2022; Spier et al. 2013). At the local scale, particularly at low-flow values, tidal action will dominate both residence time and velocity, with greater differences seen on the spring-neap tidal cycle. At low outflow values, changes to the Delta's physical characteristics, such as the installation of barriers, operation of gates, or growth of submersed vegetation, will have a greater impact on residence time than changes to outflow because physical changes will alter tidal dynamics.

Most cyanobacteria are not preferred food for planktivorous grazers, although some zooplankton and clams will consume *Microcystis* and other cyanobacteria (Kimmerer et al. 2018; Liu et al. 2009; Silva et al. 2020). Therefore, top-down control of cyanoHABs appears to be rare in the Delta, and blooms are more frequently dissipated through depletion of nutrients, decreases in temperature, or increases in flow. Other biotic interactions, such as viruses (Manage et al. 2001; Otten et al. 2017), inter-specific competition (Paerl and Otten 2016), or allelopathic chemicals from other algae (Rzymski et al. 2014), may also contribute to the death of a bloom, but these processes are understudied in the Delta.

When nutrients, turbidity, temperature, and residence time are all at the right level, a phytoplankton bloom may occur (Glibert et al. 2014a). However, the type of bloom will depend on the starting community, the nutrients available, and the time of year. Early in the season, spring blooms are more often dominated by diatoms and other "beneficial" phytoplankton that are considered good food for zooplankton and higher trophic levels. Later in the year, when temperatures are warmer, cyanobacteria are more likely to dominate (Lehman et al. 2013). Salinity will greatly affect the starting community, with most cyanoHABs taxa limited to fresher water (less than 10 parts per thousand). Although some cells may be present at higher salinities, growth drops dramatically (Preece et al. 2017). The ratio of nitrogen to phosphorus and the form of nitrogen present (ammonium versus nitrate) are also believed to favor some taxa over others (Dahm et al. 2016; Wan et al. 2019).

2.1.4 Drought Barrier and Temporary Urgency Change Petition

Because increased residence time, temperature, and water clarity increases the risk of the occurrence of blooms of *Microcystis* and other cyanobacteria (Figure 2-1), the drought is expected to increase both the duration and the severity of blooms of *Microcystis* and other potentially toxic cyanobacteria, because droughts tend to be hotter, with higher water clarity and lower outflow (Interagency Ecological Program Drought Management, Analysis, and Synthesis Team 2022). An important concern is whether the TUCP increased the effect of the drought on cyanoHABs, and whether the drought barrier in West False River promoted cyanoHABs in the Central Delta by restricting flows and increasing residence times.

The TUCP may increase residence time down the Sacramento River corridor and the Cache/Liberty area by decreasing outflow, but it is not likely to influence local-scale velocities because they are mostly driven by tidal forces in these regions, particularly at low outflows. By contrast, the barrier will significantly change tidal dynamics in the vicinity of Franks Tract and the Old/Middle River Corridor (OMR), and thus will change local velocities and increase residence time within the tract.

Both times that the emergency drought salinity barrier was in place, it was during the time of year (June–October) when cyanoHABs are most common in the Delta. Two previous analyses focused on ecosystem differences during successive drought years (2014 versus 2015) without and with the drought barrier in place. The analyses found that no impact on overall phytoplankton biomass—or on *Microcystis* biomass specifically—resulted from the barrier being in place (Kimmerer et al. 2019; Lehman et al. 2018). Biomass of *Microcystis* and concentrations of total microcystin toxins at Central Delta stations were greater in 2014, when the barrier was not in place, than in 2015, when the barrier was in place, despite warmer median water temperatures (Lehman et al. 2018) and lower water flow rates east of the barrier in 2015 (Kimmerer et al. 2019). Although impacts of the barrier on phytoplankton biomass could not be detected, the growth and extent of SAV increased in Franks Tract directly east of the barrier, potentially aided by a reduction in jet flow through the middle of the waterbody (Kimmerer et al. 2019).

This report presents information on cyanoHABs observed during the TUCP and emergency drought barrier installation of 2021. The extent of cyanoHABs in 2021 is compared to their extent during previous years with different water management conditions, to identify impacts of the TUCP and 2021 EDB on the occurrence of cyanoHABs.

The analysis is divided into three parts:

1. A description of where and when cyanoHABs were detected in 2021, across all regions of the Delta, along with the toxin levels observed during blooms, water quality conditions, and hydrologic conditions.
2. A comparison of cyanoHAB levels and water quality in each region of the Delta in 2021 versus 2014–2020, using visual assessments and phytoplankton community composition as enumerated in grab samples.
3. A model of drivers of cyanoHAB observations versus several environmental correlates, with predictions for how changes resulting from the TUCP may have affected the probability and severity of cyanoHABs.

2.2 Methods

2.2.1 Visual Assessments

Most monitoring surveys that collect data on water quality and fisheries in the Delta also collect visual observations of *Microcystis* and other visually detectable algal blooms. Because *Microcystis* colonies are relatively easy to identify visually in the field, this visual ranking gives a general idea of when and where the most common harmful cyanobacteria in the Delta occur. However, this method does not detect other cyanobacteria taxa that may be present and is subject to observer bias. This method also provides no information on the toxicity of the bloom, because *Microcystis* may or may not carry toxin-producing genes and those with toxin-producing genes may not be actively producing the toxin.

A surface water sample is brought on board a research vessel in a bucket and the *Microcystis* concentration is ranked on a scale of 1–5, 1 meaning “absent” and 5 meaning “very high” (Flynn et al. 2022). Although this method is imprecise, it is generally reliable on the whole for detecting *Microcystis* and giving a rough estimate of magnitude (**Figure 2-2**).

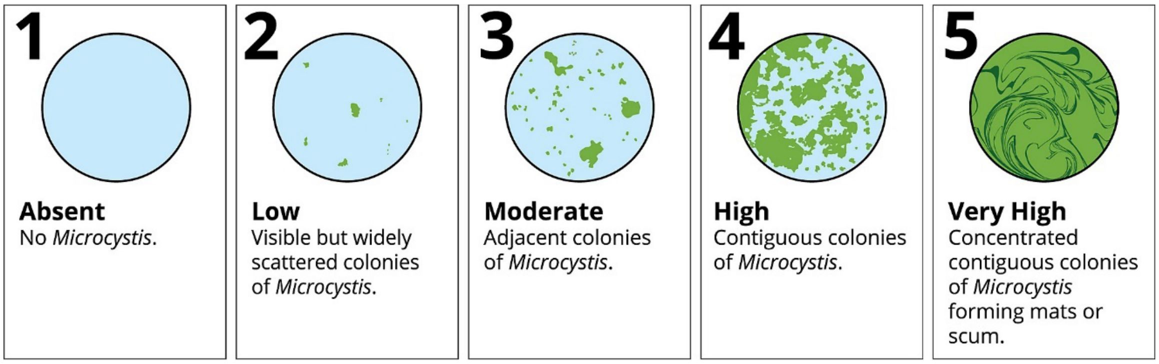


Figure 2-2 Scale for Visual *Microcystis* Index Used by Monitoring Programs in the Delta

Visual assessment data for this report come from five surveys. These data were subset to only include observations made during the summer and fall, June–October, because this is the time frame during which cyanoHABs usually occur. Data sets were also subset to only include observations in the regions outlined in Figure 1-2. Total observations varied by region of the Delta and year, but ranged from 360 to 1,372 data points per summer (**Table 2-2**):

- The Environmental Monitoring Program (EMP) is conducted jointly by DWR, the California Department of Fish and Wildlife (CDFW), and Reclamation and collects water quality, phytoplankton, zooplankton, and benthic invertebrate data throughout the Delta, Suisun Bay, and San Pablo Bay. The EMP has recorded *Microcystis* observations at each of its discrete stations since fall 2015, using the scale shown in Figure 2-2. The EMP also collects data on phytoplankton community composition via microscopic enumeration of grab samples, allowing an evaluation of which species are contributing to phytoplankton blooms. These data are collected at 24 fixed stations (**Figure 2-3**) and up to four floating stations each month throughout the year (Interagency Ecological Program et al. 2020). These data are published annually on the Environmental Data Initiative repository.
- The CDFW Summer Townet (STN) Survey samples fixed locations from eastern San Pablo Bay to Rio Vista on the Sacramento River, and to Stockton on the San Joaquin River and a single station in the lower Napa River. The STN survey runs twice per month during June, July, and August and samples at 40 stations (Figure 2-2). The survey primarily monitors young-of-the-year fishes, but also measures zooplankton and environmental variables including water

temperature (°C), water clarity (Secchi depth and nephelometric turbidity units [NTU]), and specific conductance (microSiemens per centimeter [µS/cm]). Visual observations of *Microcystis* have been collected since 2007. STN data are available via the CDFW website.

- The CDFW Fall Midwater Trawl (FMWT) survey samples at fixed locations from eastern San Pablo Bay to the Cache Slough complex and Sacramento Deep Water Ship Channel, on the Sacramento River, and to Stockton on the San Joaquin River. This survey runs once per month during September, October, and November at 122 stations (Figure 2-2). The FMWT survey primarily monitors young-of-the-year fishes, but also measures zooplankton and environmental variables including water temperature (°C), water clarity (Secchi depth and NTU), and specific conductance (µS/cm). Visual observations of *Microcystis* have been collected since 2007. FMWT data are available via the CDFW website.

- DWR's North Central Region Office (NCRO) conducts water quality and cyanoHAB sampling at stations throughout the South Delta (Figure 2-2). These samples include chlorophyll, nutrients, bromide, and organic carbon. When water samples are collected, the study also measures environmental variables including water temperature (°C), water clarity (Secchi depth and NTU), specific conductance (µS/cm), and a visual *Microcystis* index. NCRO data are available from DWR's Water Data Library platform.

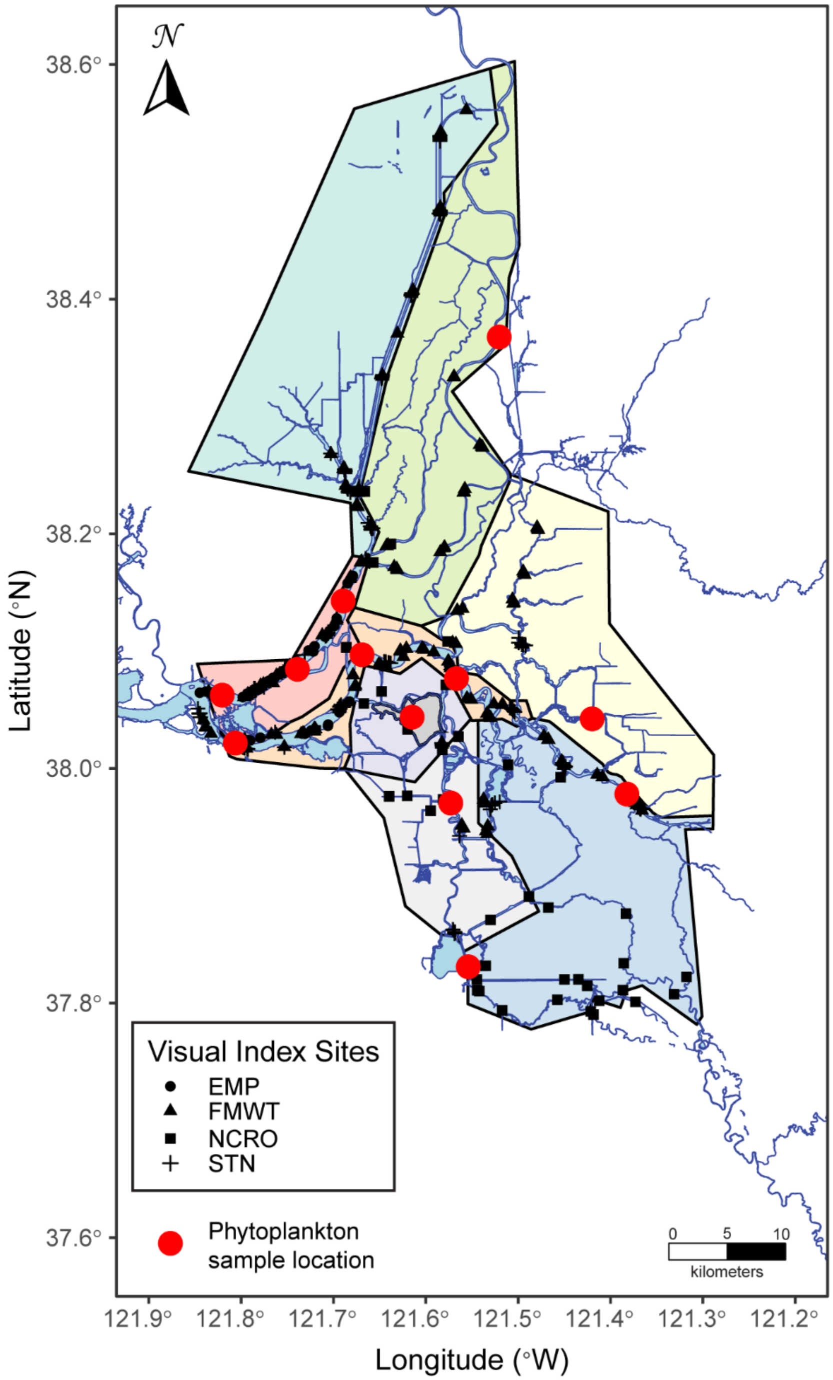
- Reclamation's Directed Outflow Project samples at randomly selected stations throughout Suisun Bay, Suisun Marsh, and the Delta in coordination with the U.S. Fish and Wildlife Service's Enhanced Delta Smelt Monitoring Program. This program primarily collects zooplankton and water quality samples, as well as environmental variables including water temperature (°C), water clarity (Secchi depth and NTU), specific conductance (µS/cm), and a visual *Microcystis* index. Data were collected by ICF International, Inc., under contract with Reclamation and obtained from the contract manager.

TABLE 2-2
SAMPLE SIZE OF VISUAL ASSESSMENT INDEX DATA, BY REGION AND YEAR

Region	2014	2015	2016	2017	2018	2019	2020	2021
Cache/Liberty	83	84	84	84	82	309	364	286
East Delta	27	35	42	44	54	52	49	45
Franks	10	15	22	37	86	79	70	68
Lower Sac	64	84	107	109	127	242	283	232
Lower SJ	90	113	134	133	151	144	139	119
Old/Middle River	20	25	32	58	128	99	103	75
South Delta	38	43	53	126	305	231	234	196
Upper Sac	28	33	38	51	89	75	75	63
Total	360	432	512	642	1,022	1,231	1,317	1,084

NOTES: Cache/Liberty = Cache Slough/Liberty Island area and Sacramento Deep Water Ship Channel; Franks = Franks Tract; Lower Sac = Lower Sacramento River region; Lower SJ = Lower San Joaquin River region; Upper Sac = Upper Sacramento River region

The visual *Microcystis* scale goes from 1 (absent) to 5 (very high). However, because the scale is somewhat subjective and varies between observers, these data were categorized for this analysis using a three-point scale. Values of 1 were re-coded as “absent,” values of 2 or 3 as “low,” and values of 4 or 5 as “high.” Plots are presented with all five categories, but statistics were run on only three categories. First, the annual difference in the incidence of *Microcystis* between years across the entire Delta was assessed for 2014–2021. These years were chosen because they include the bulk of the available data, they encompass the most recent two droughts, and they include two years with emergency drought barriers. The increased incidence of *Microcystis* in 2021 versus 2020 may indicate Delta-wide impacts of the TUCP. Then, the data were broken up into regions (as defined in Figure 1-2) to see whether any subregion had a disproportionately large change in *Microcystis* levels. Regions where *Microcystis* levels were particularly high received additional analysis.



NOTES: Stations sampled by DOP are chosen randomly each month, so are not shown on the map. Analysis to assess the impact of the 2021 Emergency Drought Barrier will focus on the Lower Sacramento, Lower San Joaquin, and Southern Delta. Analysis to assess the impact of the TUCP will encompass the entire area.

Figure 2-3 Stations for Long-Term Monitoring Programs Contributing *Microcystis* Visual Observations (black) and Environmental Monitoring Program Phytoplankton Grab Samples (red)

An ordered logistic regression (the 'polr' function from the MASS R package in R (Ripley et al. 2021) was then used to test for differences between regions and between years. This regression was followed by a pairwise post-hoc test using the function ‘emmeans’ in the emmeans R package (Lenth et al. 2021) to evaluate whether drought years had an increased probability of presence or increased probability of high *Microcystis* presence compared to wet years, and whether there were significant differences between years with a drought barrier (2015, 2021) and drought years without a barrier (2014, 2016, 2020). This same analysis was then repeated for each region individually to determine whether regions with greater changes in flow/residence time due to the TUCP or barrier had a greater presence of Microcystis in 2021.

To assess the impact of change in Delta outflow, SWP and CVP exports, Secchi depth, and temperature on the probability of detection of *Microcystis* in visual index surveys, the data were subset to the Lower Sacramento, Lower San Joaquin, Franks Tract, Old/Middle River, and South Delta, because these regions regularly have the highest incidence of cyanoHABs. Daily Delta outflow, San Joaquin River flow, and SWP and CVP export data were compiled from DWR’s Dayflow model from 2014–2021 (California Department of Water Resources 2002). San Joaquin flow and Delta outflow were too highly correlated to include in the model, so only outflow was used because changes to outflow were included in the TUCP. The analysis ran Bayesian ordinal regressions on the probability of observing “absent,” “low,” or “high” *Microcystis* as a function of Delta outflow, exports, Secchi depth, and water temperature (at time of observation). Year (as a factor) and day of year were included as a random effect. All predictors were tested for collinearity before the model was run, and all predictors were normalized by subtracting the mean and dividing by the standard deviation.

The regression was run using the ‘brm’ function in the ‘brms’ R package with 2,000 iterations per chain on two chains, with the first 1,000 iterations discarded as warmup (Bürkner 2018). All combinations of these four predictors were run, and the best model was chosen as the model with the fewest predictors that had a Widely Applicable Information Criterion (WAIC) score within delta-WAIC of 3 from the lowest score. The best model was checked for model fit by using posterior predictive checks and examining diagnostic plots. This model was used to predict the difference in the probability of *Microcystis* observations at varying levels for each predictor in the top-ranked model.

2.2.2 Community Composition

The EMP also provides data on phytoplankton community composition via microscopy from subsurface grab samples, allowing a determination of which species are contributing to phytoplankton blooms. These data are collected at 24 fixed stations and two stations that track the location of the salinity field each month throughout the year (Figure 2-3). Phytoplankton samples are collected with a submersible pump from a water depth of 1 meter below the water surface. Samples are stored in 50-milliliter (mL) glass bottles with 2 mL of Lugol's iodine solution to act as a stain and preservative. Samples are analyzed by BSA Environmental Services, Inc. (Beachwood, Ohio). Phytoplankton are identified to the lowest taxonomic level possible, using the Utermöhl method and American Public Health Association Standard Method 10200 F (American Public Health Association 2017; Utermöhl 1958).

These data were subset to show only cyanoHABs species, defined as species in the genera *Anabaeopsis, Aphanizomenon, Cylindrospermopsis, Dolichospermum*, and *Microcystis*. Although *Microcystis* is occasionally collected by these grab samples at a depth of 1 meter, particularly when the water column is well-mixed, it is better assessed by surface tows. These data are included to provide an idea of which taxa were present in the community, but the data should not be taken as a quantitative assessment of *Microcystis* abundance.

2.2.3 Nutrients and Discrete Chlorophyll

Discrete nutrient (ammonium, nitrate + nitrite, and orthophosphate) and chlorophyll-a data were collected from four sources:

1. The EMP collects discrete water quality grab samples at all stations where samples for phytoplankton community composition are collected. Water is collected using a flow-through system in which it is pumped into the shipboard laboratory either from a fixed intake 1 meter below the water's surface, or from a Van Dorn water sampler, or via a submersible pump (Interagency Ecological Program et al. 2020). DWR's Bryte Laboratory performed analyses for dissolved ammonium, dissolved nitrate + nitrite (hereafter referred to as "nitrate"), total Kjeldahl nitrogen, total phosphorus, dissolved orthophosphate, and chlorophyll-a, using EPA methods, American Public Health Association Standard Methods, or DWR-approved modifications of these methods (Interagency Ecological Program et al. 2020).

2. The DWR NCRO collects discrete nutrient and chlorophyll-a data at six locations in the Central Delta surrounding Franks Tract. Chlorophyll-a samples were collected routinely from 2014 through 2021, while nutrient samples were collected only in 2014–2016 and 2021. Water is collected from a Van Dorn water sampler at a depth

of 1 meter (California Department of Water Resources 2022). DWR's Bryte Laboratory analyzed the samples using EPA methods or DWR-approved modifications of these methods (IEP et al. 2020).

3. The U.S. Geological Survey (USGS) has two programs that routinely collect discrete nutrient and chlorophyll-a data in the Delta: the California Water Science Center (CAWSC) and the San Francisco Bay Water Quality Survey (SFBS). The CAWSC collects samples at numerous locations throughout the Delta; the SFBS collects most of its samples downstream of the Delta, with a few locations extending into the Delta. The SFBS has been collecting discrete water quality samples from 1969 to present, while the CAWSC began collecting samples more recently.

Data collected in 2014–2021 from the four surveys listed above were acquired through direct data requests or downloaded from either the discretewq data package (Bashevkin 2022), DWR's Water Data Library, or the National Water Quality Monitoring Council's Water Quality Portal. Data were integrated into one data set, limiting the stations to only those where all three nutrient parameters (ammonium, nitrate, and orthophosphate) and chlorophyll-a were collected. Some of the data collected in 2021 were considered provisional at the time of acquisition.

Outliers were identified as any value with a modified Z-score greater than 15, with the data grouped by the regions shown in Figure 1-2. All identified nitrate and orthophosphate outliers were excluded from the data set. The detected ammonia and chlorophyll-a outliers were not removed because they appeared to be representative based on best professional judgment. Nutrient values that were below the reporting limit but had high reporting limits compared to the range of the overall data (greater than the 75th quantile) were excluded from the data set. In addition, the most common reporting limit for the laboratory method was used to estimate the reporting limit values for the nutrient data with missing reporting limit values. Additional details on data integration and processing can be found in the EDBdata GitHub package: https://github.com/mountaindboz/EDBdata.

Data from 2021 were plotted across the Delta, separated by region to show trends across the summer. Data were then subset to include stations in the Lower Sacramento, Lower San Joaquin, Franks Tract, Old/Middle River, and South Delta (where cyanoHABs are most frequent) and were summarized by month and year. A generalized linear mixed model on each constituent was run using the Ime4 package (Bates et al. 2020). The formula *Concentration ~ Year + Season +*

Error(Month) + Error(Station) was used to determine whether nutrients or chlorophyll in 2021 were different from previous years. Values that were below the reporting limit were replaced with 0's. A Tukey post-hoc test was performed on all pairwise comparisons and significant differences between years were visualized using the estimated marginal means for the 'emmeans' package (Lenth et al. 2021).

Nutrients are frequently identified as a driver for cyanoHABs, but nutrients are seldom limiting for phytoplankton production in the Delta. It is instructive to compare actual measured chlorophyll concentrations with chlorophyll-a concentrations that could be expected if all available nitrogen in the water (i.e., the residual nitrogen) were converted to chlorophyll biomass, to assess a particular region's potential for accumulation of phytoplankton biomass (i.e., bloom development). Performing this comparison first involved determining which major nutrient (nitrogen or phosphorus) was limiting phytoplankton development. The molar N:P ratio was calculated by converting total inorganic nitrogen (nitrate + nitrite + ammonium) to molar mass N and total inorganic phosphorus to molar mass P. The average N:P ratio was calculated for all samples in each region per month to the Redfield Ratio of 16:1, which is the ratio that most photosynthetic organisms need. A ratio greater than 16:1 indicates that phosphorus is the limiting nutrient. A ratio less than 16:1 indicates that nitrogen is the limiting nutrient.

To calculate residual chlorophyll, residual nitrogen concentration was converted to chlorophyll using the ratio 1 micromole N: 1 microgram chlorophyll-a (Cloern and Jassby 2012; Gowen et al. 1992). Residual nitrogen was calculated by summing all the dissolved inorganic nitrogen species (nitrate + nitrite + ammonium) in units of molar mass N. Potential chlorophyll-a was compared with measured chlorophyll-a for each region of the Delta for the summers of 2014–2020, and for summer 2021.

2.2.4 Incident Reports

The State Water Board maintains the freshwater cyanoHABs Incidents Report Map. This map and corresponding table only show the locations where cyanoHABs have been voluntarily reported. All incidents reported in 2021 were obtained from Karin Atkins of the State Water Board's fHAB program. The maximum advisory level from each incident was combined with the maximum advisory level from the cyanotoxin data (see below) and mapped to identify "cyanoHAB hot spots" that may have been missed in other sampling.

2.2.5 Cyanotoxin Data

The cyanotoxin data collected in 2021 and presented here came from six different sources (**Figure 2-4**). Some of these sources had data available from previous years, but the majority of the data was from 2021, so only 2021 data are presented here. These studies all used either enzyme-linked immunosorbent assay (ELISA), liquid chromatography–mass spectrometry (LC-MS), or liquid chromotography with tandem mass spectrometry (LC-MS/MS) to analyze toxin concentrations. There is generally very high agreement between these two methods, although ELISA may produce higher concentration values than LC-MS/MS (Preece et al. 2021) (**Table 2-4**). Across most of the national harmful algal bloom (HAB) research community, data from either method are compared to thresholds, and no conversion factor is applied, nor is one method disregarded.

Additional data collected by the Central Valley Regional Water Quality Control Board (RWQCB) also included quantitative polymerase chain reaction (qPCR) analysis identifying the frequency of toxin-producing genes in the phytoplankton community. These data are fundamentally different than toxin concentrations, so they are not directly compared.

- The State Water Board's freshwater HAB program collects samples for cyanotoxins when large blooms are reported (https://www.waterboards.ca.gov/water_issues/programs/swamp/freshwater_cyanobacteria.html). The Central Valley RWQCB collected cyanotoxin samples from Franks Tract and Mildred Island on July 2 and August 6, 2021. Samples were lysed and analyzed by Bend Genetics, LLC (Sacramento, California) for total microcystins/nodularins, using the ADDA ELISA method and using qPCR to detect the number of microcystin-producing genes present in the environment.

- DWR collects cyanotoxin samples at Clifton Court Forebay and the Harvey O. Banks Pumping Plant (Banks Pumping Plant) to ensure that the water exported from the Delta is safe for use. Samples are collected every two weeks in April–October and analyzed by GreenWater Laboratories (Palatka, Florida), using a tiered approach. Samples are first assessed via microscopy to identify whether potentially toxic algae or cyanobacteria are present. If potentially toxic algae are detected, cells are lysed and samples are then tested for probable toxins using either ADDA-ELISA or LC-MS/MS, as appropriate (Foss and Aubel 2015).

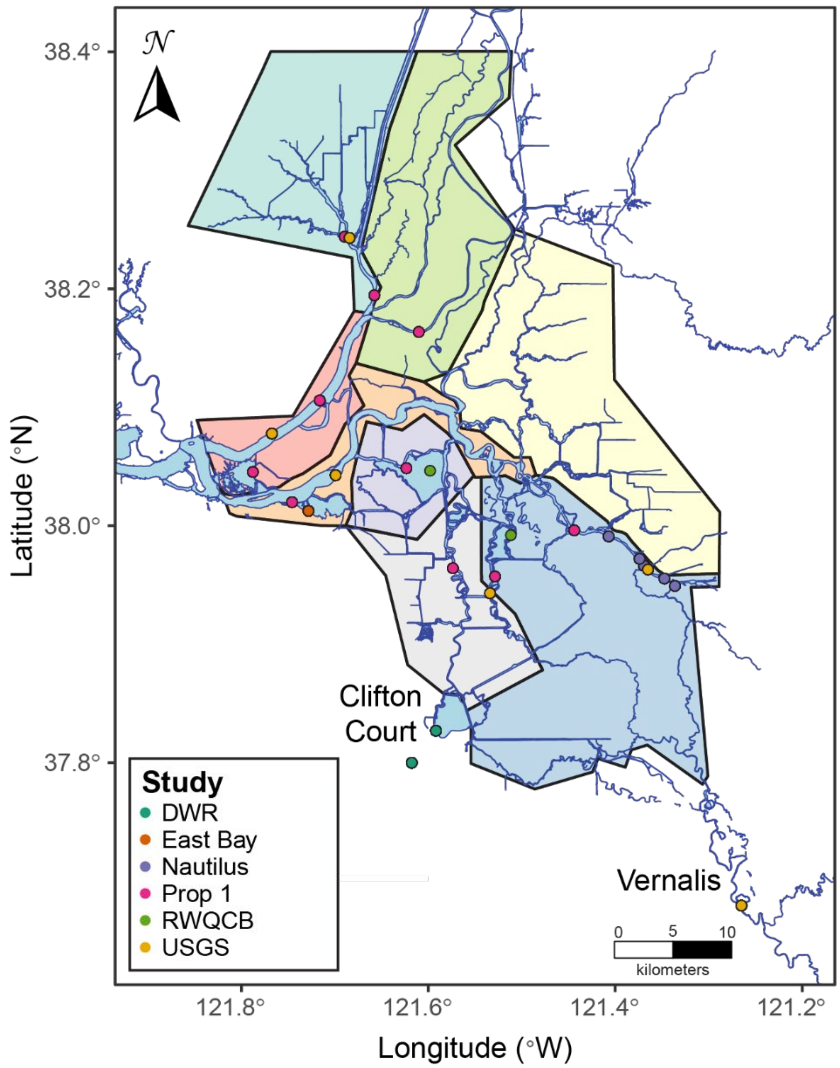


Figure 2-4 Locations of Cyanotoxin Sampling during Summer 2021

TABLE 2-3
LOCATIONS OF CYANOTOXIN MONITORING DATA

Study	Station	Latitude	Longitude	Region
Prop. 1	DHAB001	38.0454	-121.7876	Lower Sacramento
Prop. 1	DHAB002	38.1058	-121.7161	Lower Sacramento
Prop. 1	DHAB003	38.0199	-121.7458	Lower San Joaquin
Prop. 1	DHAB004	38.1636	-121.6101	Upper Sacramento
Prop. 1	DHAB005	38.1946	-121.6577	Cache Slough/Liberty Island
Prop. 1	DHAB006	38.2440	-121.6894	Cache Slough/Liberty Island
Prop. 1	DHAB007	38.0486	-121.6234	Franks Tract
Prop. 1	DHAB008	37.9641	-121.5737	Old and Middle River
Prop. 1	DHAB009	37.9962	-121.4438	Southern Delta

TABLE 2-3
LOCATIONS OF CYANOTOXIN MONITORING DATA

Study	Station	Latitude	Longitude	Region
Prop. 1	DHAB010	37.9571	-121.5286	Southern Delta
USGS	LIB	38.2430	-121.6843	Cache Slough/Liberty Island
USGS	DEC/TOL	38.0778	-121.7673	Lower Sacramento
USGS	JPT	38.0426	-121.6991	Lower San Joaquin
USGS	MDM	37.9430	-121.5340	Old and Middle River
USGS	RRI	37.9630	-121.3650	Southern Delta
USGS	VER	37.6794	-121.2650	Vernalis
DWR	BPP	37.7999	-121.6177	Clifton Court
DWR	CCF	37.8269	-121.5918	Clifton Court
RWQCB	FRK	38.0464	-121.5981	Franks Tract
RWQCB	MI	37.9920	-121.5117	Southern Delta
Nautilus	ALG-001	37.9491	-121.3362	Southern Delta
Nautilus	ALG-002	37.9554	-121.3475	Southern Delta
Nautilus	ALG-003	37.9630	-121.3650	Southern Delta
Nautilus	ALG-004	37.9661	-121.3692	Southern Delta
Nautilus	ALG-005	37.9720	-121.3740	Southern Delta
Nautilus	ALG-006	37.9910	-121.4070	Southern Delta
East Bay	BigBreak	38.0125	-121.7282	Lower San Joaquin

TABLE 2-4
METHODS USED FOR CYANOTOXIN ANALYSIS BY EACH STUDY

Study	Method	Class	Toxins
USGS/EMP	LC-MS/MS	Microcystins	(Asp3)MC-LR, D-Asp3-Dhb7-RR, (Leu)MC-LR, Leu1 LR, MC- RR, MC-HilR, MC-HtyR, MC-LA, MC-LF, MC-LR, MC-LW, MC-LY, MC-LY/E, MC-WR, MC-YR, Dha-LR, dMC-HtyR, dMC-RR
USGS/EMP	LC-MS/MS	Cylindrospermopsins	7-deoxy-Cylindrospermopsin, 7-epi-Cylindrospermopsin, Cylindrospermopsin
USGS/EMP	LC-MS/MS	Anabaenopeptins	Anabaenopeptins A, B, F, Oscillamide Y
USGS/EMP	LC-MS/MS	Anatoxins	Anatoxin-a, Homoanatoxin-a, Dihydroanatoxin
USGS/EMP	LC-MS/MS	BMAA	BMAA
USGS/EMP	LC-MS/MS	Saxitoxins	Desamidoylneosaxitoxin, Neosaxitoxin, Saxitoxin
USGS/EMP	LC-MS/MS	Nodularin	Nodularin
DWR SWP	ADDA-ELISA	Microcystins/Nodularins	Total

TABLE 2-4
METHODS USED FOR CYANOTOXIN ANALYSIS BY EACH STUDY

Study	Method	Class	Toxins
DWR SWP	Saxitoxin-specific ELISA	Saxitoxins	Total
DWR SWP	LC-MS/MS	Anatoxins	Anatoxin-a
DWR SWP	LC-MS/MS	Cylindrospermopsins	Cylindrospermopsin
RWQCB	ADDA-ELISA	Microcystins/Nodularins	Total
RWQCB	qPCR	Microcystin genes	Total
RWQCB	qPCR	Anatoxin genes	Anatoxin-a
RWQCB	qPCR	Cylindrospermopsin genes	Cylindrospermopsin
Prop. 1	ADDA-ELISA	Microcystins/Nodularins	Total
East Bay Parks	ADDA-ELISA	Microcystins/Nodularins	Total
Nautilus	LC-MS	Anatoxins	Anatoxin-a
Nautilus	LC-MS	Cylindrospermopsins	Cylindrospermopsin
Nautilus	ADDA-ELISA	Microcystins/Nodularins	Total
Nautilus	Saxitoxin-specific ELISA	Saxitoxins	Total

- A special study was conducted collaboratively by USGS and DWR with funding from the Delta Regional Monitoring Program. Samples were collected at several stations throughout the Delta: Jersey Point (JPT), Decker (DEC), Middle River (MDM), Liberty Island (LIB), Rough and Ready Island (P8, DWR-EMP), and Vernalis (C10, DWR-EMP). For these efforts, cyanotoxins were measured in whole water discrete samples and using Solid Phase Adsorption Toxin Tracking (SPATT) samplers every two to four weeks. SPATTs are synthetic resin plates deployed in the water for an extended time to determine whether toxins are present over the entire time period. All (100 percent) of these cyanotoxin samples were to be analyzed using LC-MS/MS, and—upon review of LC-MS/MS data—a subset (approximately 20 percent) would be selected for analysis using ELISA. All laboratory analyses were conducted by Lumigen Instruments, Wayne State University, Detroit, Michigan. Data from this study have not been approved by USGS and are considered preliminary.

- Under a Proposition 1 grant, principal investigators David Senn (San Francisco Estuary Institute), Janis Cooke (RWQCB), Ellen Preece (Robertson-Bryan, Inc.), and Timothy Otten (Bend

Genetics), are conducting a study of the bioaccumulation of cyanotoxins in invertebrates at 10 stations throughout the Delta. The study, "Identifying Cyanobacterial Harmful Algal Bloom Toxins in Delta Invertebrates: Implications for Native Species and Human Health," includes an analysis of Asian clams (*Corbicula fluminea*), crayfish, and whole water samples. Samples are collected monthly in the winter and every two weeks during the summer and analyzed for microcystins by Bend Genetics using Eurofins Abraxis ADDA ELISA. Preliminary data from water quality samples were shared by the principal investigators and are presented here.

- The East Bay Regional Park District (East Bay Regional Parks) conducts sampling at Big Break Regional Shoreline, visually inspecting the water for signs of cyanobacteria twice per month. If signs of cyanobacteria are detected, microscopy and toxin analysis are conducted at Bend Genetics using ADDA ELISA. Staff at East Bay Regional Parks requested data. Because Big Break has a longer monitoring history than most of these programs, all data for 2015–2021 were requested to get a better sense of how droughts and drought actions affect this cyanoHAB "hot spot."

- Nautilus Data Technologies is required to monitor for cyanotoxins near its data center at the Port of Stockton. Nautilus Data Technologies monitors at six sites on the San Joaquin River and in the Stockton Deep Water Ship channel twice per month. All water samples are sent to Bend Genetics, where the samples are analyzed for microcystins, anatoxins and saxitoxins using ADDA ELISA as appropriate. Data were requested from staff at the State Water Board's cyanoHABs portal.

None of the sources of cyanotoxin data presented here are part of a comprehensive monitoring program.

- The USGS/DWR SPATT study and the Proposition 1 Senn/Preece/Cooke/Otten studies were designed as special studies to better understand toxin dynamics, rather than to establish a baseline. The RWQCB data are designed as a response to severe blooms, not a comprehensive monitoring program.

- The DWR Banks Pumping Plant/Clifton Court Forebay monitoring is designed specifically to assess water quality for water export, so it is not necessarily applicable to the rest of the Delta.

- Nautilus data are limited to the San Joaquin River, so they are unlikely to be influenced by the TUCP.

Combining these data sets does provide a relatively wide spatial and temporal scope of cyanotoxin monitoring, although it may miss small-scale or short-lived toxin events, particularly in smaller, backwater sloughs in the Delta. Different labs and field collection crews may result in slight biases in the resulting data sets, but all these data can be compared to the health advisory levels in the same way.

2.2.6 Fluoroprobe Data

The EMP and USGS both employ vessels equipped with high-resolution sensors that collect data continuously on both water quality and phytoplankton community composition while underway. During these surveys, the EMP monitors water quality using a YSI EXO2 water quality sonde (Xylem, Inc.) to measure pH, turbidity, specific conductance, chlorophyll-a (with the Total Algae™ sensor), dissolved oxygen (DO), and water temperature. Both surveys monitor the phytoplankton community's composition using a FluoroProbe instrument (bbe moldaenke GmbH, Schwentinental, Germany) that differentiates between cyanobacteria, diatoms, green algae, and chlorophytes, based on the wavelength of the fluorescence given off by each taxonomic group's characteristic photopigments. USGS conducted mapping surveys in May, July, and October 2021, while EMP surveys are collected monthly throughout the year. Each month, these agencies covered approximately 350 miles of channels in the Delta over three to four consecutive days. USGS boat-based survey data can be visualized on USGS's online data portal.

FluoroProbe data collected by both the EMP and USGS were processed following the methodology described in the Methods PDF of the USGS data (Bergamaschi et al. 2020). Briefly, data were spatially aligned to equally spaced polygons spaced at approximately 150 meters. Interpolated values were calculated in ArcGIS using the Spline with Barriers tool (Terzopoulos and Witkin 1988) and used to create a continuous map of values (e.g., the concentration of pigments from blue-green algae) across the mapped domain.

2.2.7 Satellite Data

Satellite data, available from the San Francisco Estuary Institute's HAB Satellite Analysis Tool (San Francisco Estuary Institute 2021), can provide estimates of cyanoHAB abundance with higher spatial and temporal resolution than grab samples and visual observations. Satellite imagery is collected by the Ocean Land Color Instrument on the Copernicus Sentinel-3 mission. The cyanobacterial index algorithm (Wynne et al. 2018) is applied to the Ocean Land Color Instrument data to estimate cyanoHAB abundance in the upper portion of the water column by analyzing wavelengths of light that interact strongly with chlorophyll-a and phycocyanin, an accessory pigment in photosynthesis specific to cyanobacteria. Estimates of cyanoHAB abundance are reported in an exponential, satellite-specific, unitless metric called the Cyanobacteria Index (CI) for pixels with dimensions of 300 meters by 300 meters, each an area of approximately 22 acres.

Because of the limitations of the satellite-based sensor in distinguishing subtle differences in reflectance from cyanobacteria at levels that are very low (a CI of 6.310×10^{-05} is near natural background levels of cyanobacteria) or very high (CI of 6.327×10^{-02} in extremely dense scums), the minimum and maximum detectable levels have a smaller range than are possible using traditional water grab samples. Because the smallest pixel available is 22 acres, only larger areas of open water, such as Franks Tract, can be analyzed. Smaller sloughs are not large enough for accurate classification. Further information on these methods are detailed on the National Ocean Service website: https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/hab-monitoring-system/more-information/

Satellite mosaics of rasterized CI data across the Central Delta for June–October in 2020 and 2021 were downloaded from the San Francisco Estuary Institute’s HAB Satellite Analysis Tool (San Francisco Estuary Institute 2021). Raster pixels for four open-water regions in the Delta (Franks Tract, Clifton Court Forebay, Liberty Island, and Mildred Island) were extracted from each file using the ‘exact_extract’ function in the ‘exactextractr’ R package, version 0.7.1 (Baston 2021). The four open-water regions were defined using polygons derived from CDFW’s shapefile of Delta waterways and expanded by 200 meters around their perimeters to account for the large raster pixels.

Pixels were categorized into four CI categories (Low, Moderate, High, and Very High) based on WHO’s recreational guidance level thresholds (World Health Organization 2021). Additionally, pixels that were below the detection limit for the imagery processing method ($CI \leq 6.310 \times 10^{-05}$) were categorized as “Non Detect,” and pixels that were either invalid or missing were categorized as such. Including only pixels that were completely within one of the polygons of the four regions, the numbers of pixels within the “Non Detect,” “Invalid,” and four CI categories were counted for each region and raster image. Using only days when there were greater than 25 percent valid pixels within a region, the time series of pixel counts were visualized using area plots for each region and year.

2.2.8 Continuous Water Quality Data

DWR and USGS maintain a network of water quality sondes and flow stations that collect data continuously (i.e., every 15 minutes) across the Delta. These stations collect data on water temperature, specific conductance, flow, DO, chlorophyll fluorescence, turbidity, and pH (although not all stations contain all sensors; see **Table 2-5**). Quality-controlled data were requested from DWR personnel when available, and provisional data were queried from the California Data Exchange Center (CDEC) if no finalized data were available. To assess how cyanoHABs affect water quality parameters, this report's authors plotted the daily mean of data collected at stations in the South and Central Delta that experienced cyanobacteria blooms in 2021 versus day of the year for the past seven years (2015–2021) (**Figure 2-5**).

TABLE 2-5
STATIONS USED FOR CONTINUOUS WATER QUALITY AND AIR TEMPERATURE ANALYSES

DWR Station Code	Operator	USGS Station ID	Station Name	Latitude	Longitude	Sensors
FAL	USGS/ DWR[1]	11313440	False River near Oakley	38.05547	-121.667	Chl, DO, SC, Turbidity, Water Temp
HOL	USGS/ DWR[1]	11313431	Holland Cut Near Bethel Island	38.01582	-121.582	DO, SC, Turbidity, Water Temp
HLT	USGS/ DWR[1]	11312685	Middle River near Holt	38.00308	-121.511	Chl, SC, Turbidity, Water Temp
ORQ	USGS/ DWR[1]	11313434	Old River at Quimbly	38.02712	-121.565	SC, Turbidity, Water Temp
OSJ	USGS/ DWR[1]	11313452	Old River at Franks Tract near Terminous	38.07125	-121.578	Chl, DO, SC, Turbidity, Water Temp
FRK	DWR	NA	Franks Tract Mid Tract	38.04642	-121.598	Chl, DO, pH, SC, Turbidity, Water Temp
MDM	USGS	11312676	Middle River at Middle River	37.943	-121.534	Chl, DO, SC, Turbidity, Water Temp
SJR	DWR	NA	San Joaquin R McCune Station	37.6789	-121.265	Air Temp
HBP	DWR	NA	Harvey O Banks Pumping Plant	37.8019	-121.620	Air Temp
MSD	DWR	NA	San Joaquin River at Mossdale	37.786	-121.306	Air Temp

NOTES: Chl = Chlorophyll fluorescence; DO = dissolved oxygen; SC = specific conductance; Temp = temperature.

1 Flow, river discharge, river stage, and water velocity are maintained by the U.S. Geological Survey (USGS). Water quality parameters are maintained by the California Department of Water Resources. Data is telemetered via USGS equipment.

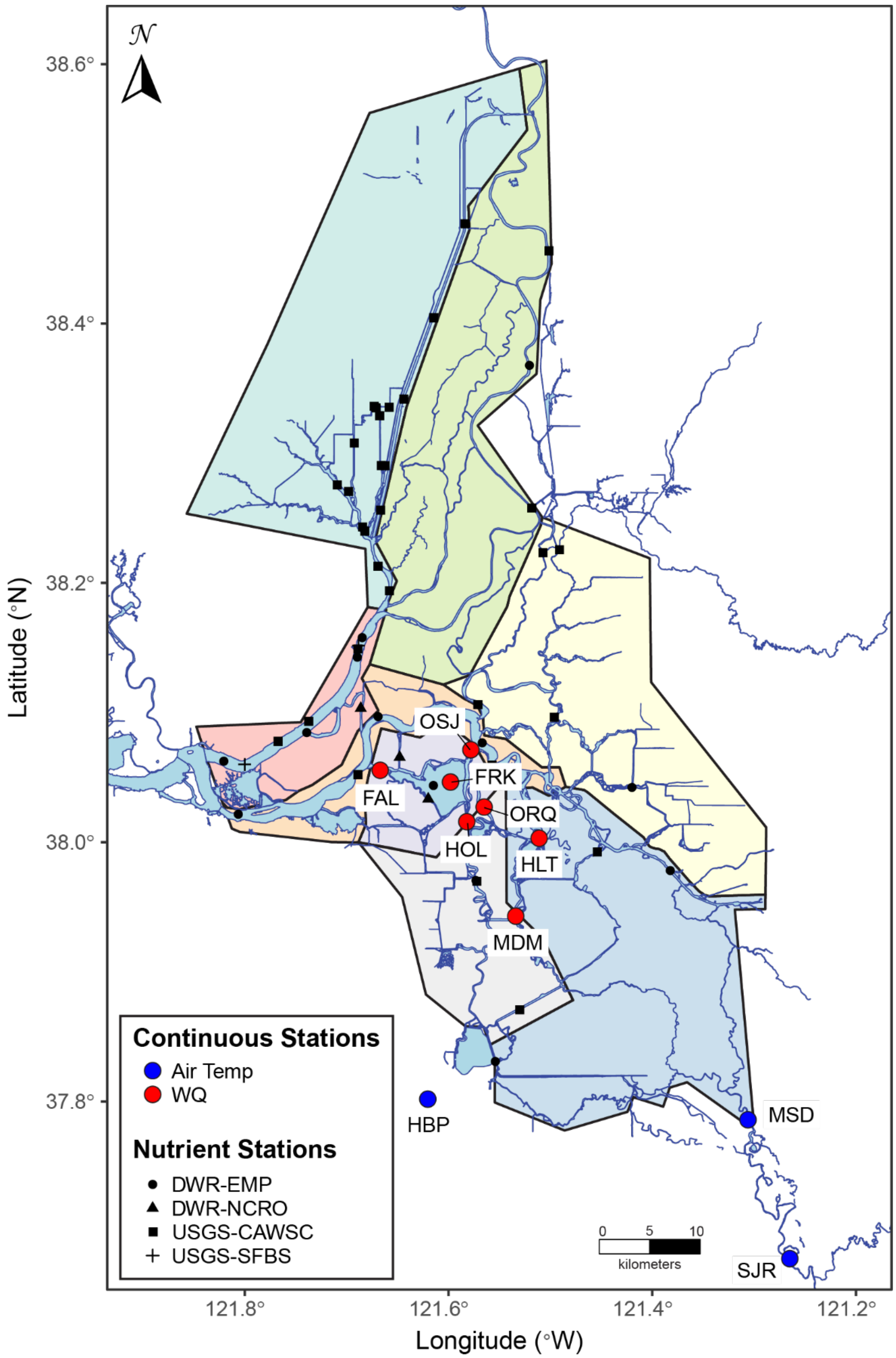


Figure 2-5 Stations Used for Continuous Water Quality or Air Temperature and Discrete Nutrients

To see how extended periods of high temperatures may drive *Microcystis* blooms, the number of degree-days over 19°C was calculated by averaging the daily maximum and minimum water temperature at seven stations in the South Delta. This was converted to degree-days using the formula:

Degree Days = (Daily Max Temp – Daily Min Temp)/2 – 19

The same analysis was then conducted on air temperature, to see whether air temperature patterns were similar to water temperature patterns. Air temperature was not available for most stations in the Delta, but the nearest stations to the study region were chosen (Figure 2-5, Table 2-5).

2.2.9 Hydrodynamic Modeling and Flow

To assess changes in residence time and temperature, three-dimensional simulations were carried out using the Bay-Delta SCHISM three-dimensional circulation model (Ateljevich et al. 2014), which is an application of the Semi-implicit Cross-scale Hydroscience Integrated System Model (Zhang et al. 2016).

Mean water age was used as a surrogate for residence time, evaluated using the Constituent oriented Age and Residence Time theory or CART (Deleersnijder et al. 2001) and the formulation described by Delhez et al. (2014). This method uses pairs of supplementary tracer transport equations to evolve the mean age of water at each point in the domain; the method naturally incorporates multiple pathways of travel and dispersion and is an economical tool for evaluating spatial patterns. “Age” in this case is defined as the time of last contact with the San Joaquin River.

Quantitative results within Franks Tract are sensitive to assumptions concerning the vegetation field. Vegetation was included using the method of Zhang et al. (2020b), which was originally tested in Franks Tract using spatial patterns of vegetation inferred from hyperspectral imagery from 2015 (Ustin et al. 2016).

2.2.10 Data Limitations

The data sets assembled in this report provide a comprehensive picture of HABs in the Delta during 2021 by virtue of the wide range of different data sets. However, each data set has certain limitations, and cyanoHABs monitoring would be better served by a Delta-wide, coordinated program designed specifically to monitor cyanoHABs rather than a synthesis of cyanoHAB-adjacent data sets. A framework for this type of program is currently being designed by an interagency team led by the Delta Science Program.

Uses and limitations of each data set are as follows:

- Visual index data provide a spatial and temporal scope, and a good indicator of *Microcystis* presence, but cannot provide a quantitative measure of *Microcystis* concentration and is not appropriate for other cyanoHAB taxa.
- Chlorophyll fluorescence data collected with a sonde provides continuous data on the relative amounts of chlorophyll in the water column, but it cannot distinguish between cyanobacteria and other phytoplankton. These data also need to be calibrated to extracted chlorophyll-a to form a strong relationship between fluorescence and actual chlorophyll concentration. It also does not accurately quantify chlorophyll in surface films or cyanobacteria that form colonies or clumps.
- Chlorophyll-a data collected with grab samples and analyzed in a laboratory are more accurate than sonde data, but may also miss surface-oriented cyanobacteria and cannot distinguish between cyanobacteria and other phytoplankton. Grab samples may also miss the peak of the bloom.
- Grab samples collected and analyzed with microscopy provide the best taxonomic resolution. However, samples collected by EMP are collected at a 1-meter depth, so they may miss surface-oriented cyanobacteria, such as *Microcystis*. Although these samples identify taxa that are present, they do not indicate whether the taxa present are made of strains capable of producing toxins, or whether they were producing toxins at the time of collection.
- Chlorophyll and phycocyanin data collected during high-speed mapping cruises using the FluoroProbe provide data on a broad spatial scale and can distinguish between cyanobacteria and other algae, but the data are limited in temporal scope. These data also cannot distinguish between types of cyanobacteria (not all cyanobacteria are harmful).
- Satellite data provide broad spatial scope but cannot quantify low concentrations of cyanobacteria, nor can they distinguish between types of cyanobacteria (not all cyanobacteria are harmful). These data also cannot quantify cyanobacteria in small channels.
- The incident data reported to the State Water Board’s HAB portal relies on agencies and members of the public submitting reports,

which may not be consistent over space and time. Many of these reports are based on visual observations rather than cyanotoxin data. However, these reports provide better coverage of marinas, boat ramps, and other places where the public regularly comes into contact with the water, than of other areas.

- Toxin data provide the most accurate assessment of potential harm caused by an algal bloom. However, unless sampling occurs on a daily basis, it may not characterize the toxicity over the entire time period. Furthermore, the ecological and human health impacts of some cyanobacterial metabolites (such as anabaenopeptins) are still unknown.

2.3 Results

2.3.1 Conditions in 2021

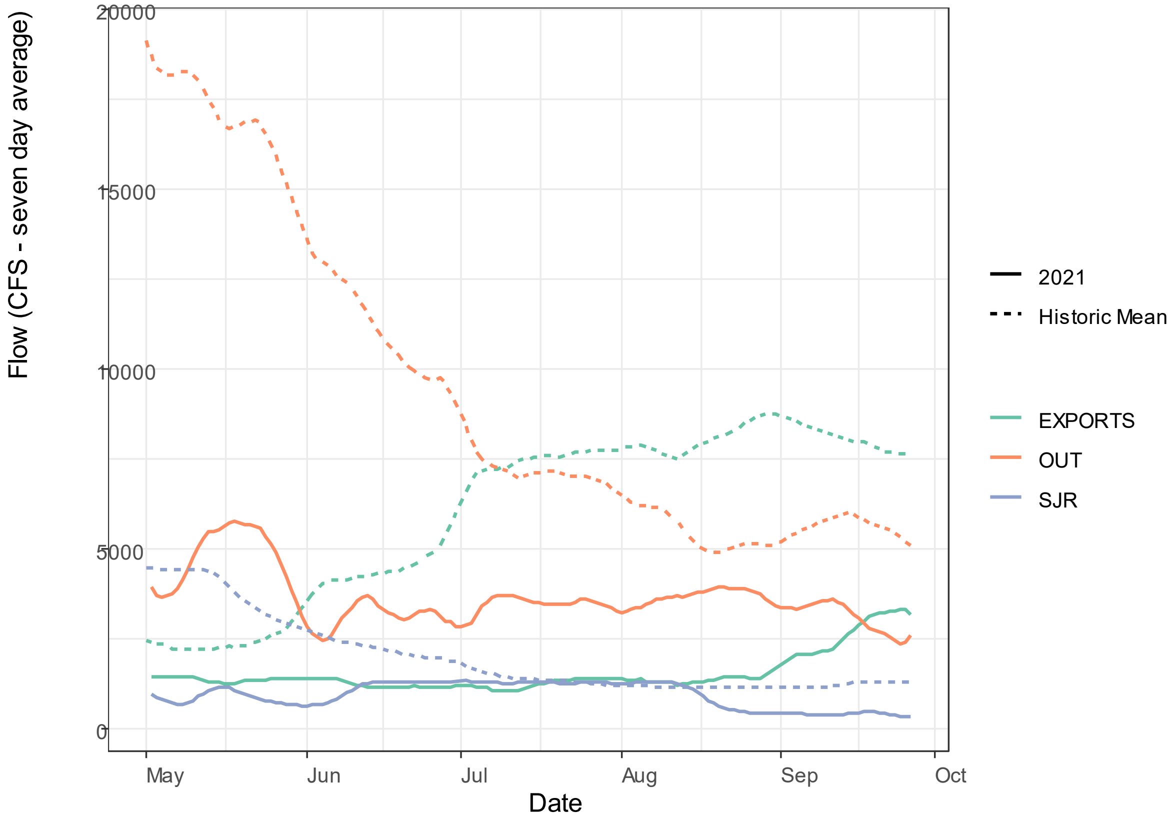
Flow

Delta outflow, exports, and San Joaquin River flow were all significantly lower than the historical averages (1997–2021; **Table 2-6**, **Figure 2-6**). The TUCP reduced minimum Delta outflow in June and July from 4,000 cfs to 3,000 cfs, and actual outflow (as calculated by Dayflow) varied from a minimum daily mean of 2,100 cfs to a maximum daily mean of 4,046 cfs (Table 2-6). Exports were also much lower than average, with a maximum below 1,500 cfs in June and July, increasing slightly in August and increasing significantly starting in September. San Joaquin River flow was lower than average in May, but releases from New Melones Dam in July and August increased flows to around average for the late summer.

TABLE 2-6
DAILY AVERAGE FLOW STATISTICS FOR SUMMER 2021 (CFS)
AS CALCULATED BY THE DAYFLOW MODEL

Month	Outflow (Min)	Outflow (Max)	Outflow (Mean)	Exports (Min)	Exports (Max)	Exports (Mean)	SJR (Min)	SJR (Max)	SJR (Mean)
May	2,986	6,160	4,785	1,069	1,512	1,372	573	1,320	856
Jun.	2,122	3,815	3,077	1,063	1,420	1,221	617	1,380	1,109
Jul.	2,249	4,046	3,452	1,032	1,492	1,252	1,210	1,410	1,278
Aug.	3,168	4,147	3,676	951	1,680	1,343	411	1,360	906
Sep.	2,260	4,197	3,087	1,737	3,330	2,635	278	519	388

NOTES: cfs = cubic feet per second; Max = maximum; Min = minimum; SJR = San Joaquin River

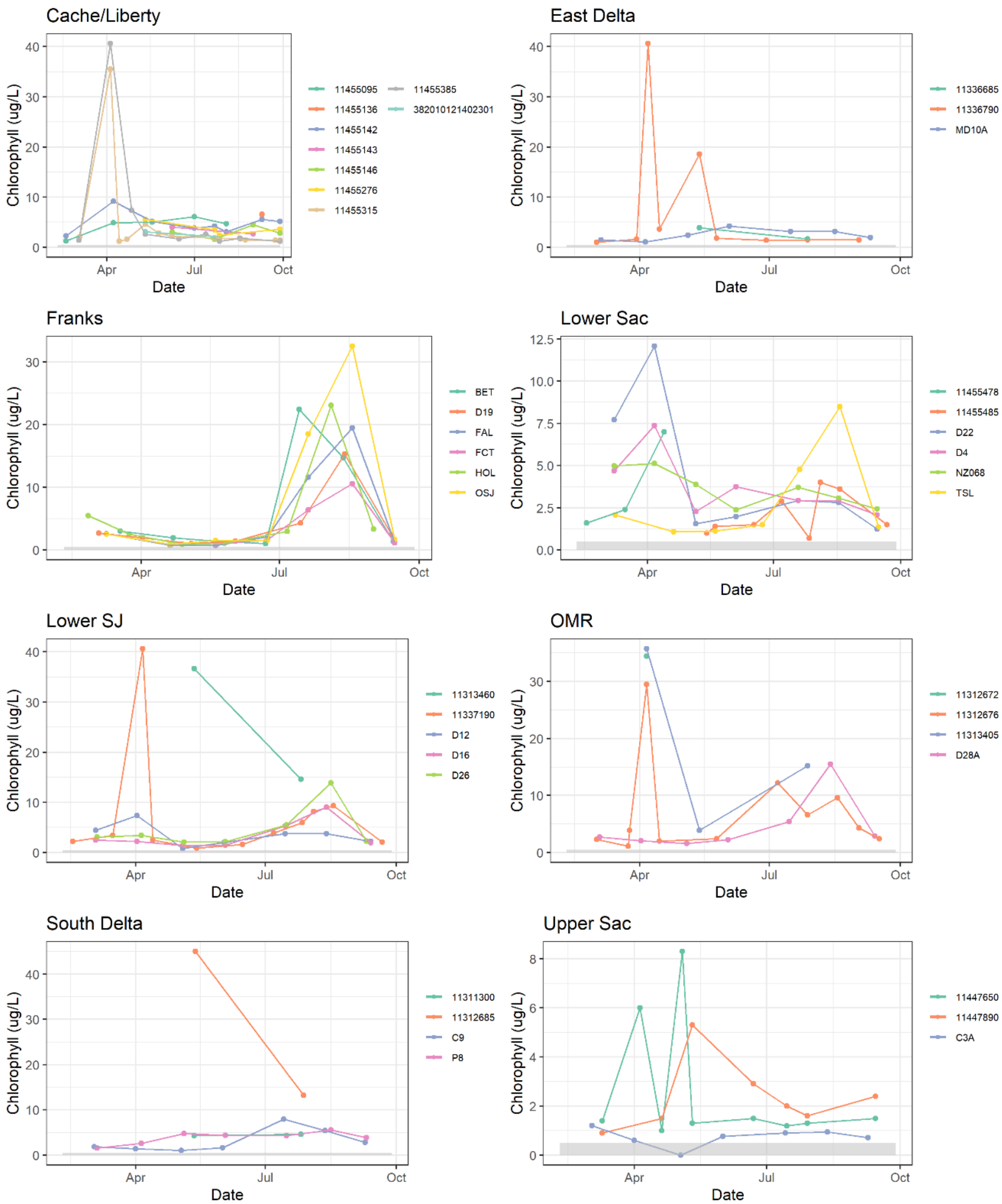


NOTE: Solid lines indicate the 2021 values; dotted lines indicate historical mean. All flow values were calculated using the DWR Dayflow model.

Figure 2-6 Seven-Day Average Delta Outflow (OUT—Orange), Combined CVP and SWP Exports (EXPORTS—cyan), and San Joaquin River Flow at Vernalis (SJR—dark blue) for Summer 2021 Compared to the Historical Mean (1997–2021)

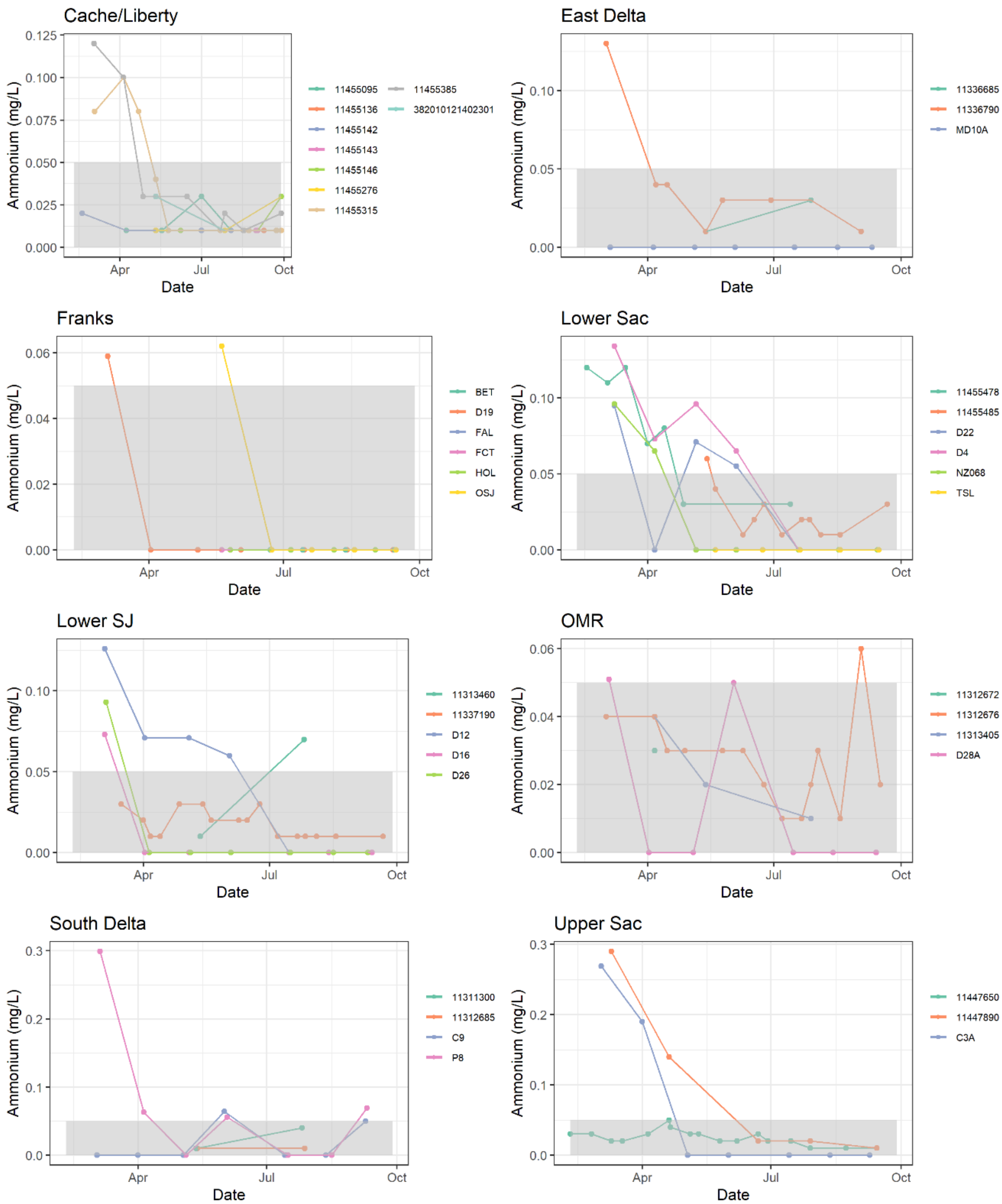
Nutrients + Discrete Chlorophyll

During summer 2021, chlorophyll-a concentrations as measured by discrete grab samples analyzed in the lab by USGS and DWR peaked in April in most areas of the Delta (**Figure 2-7**). A second peak in late July/early August occurred in Franks Tract, the Old/Middle River Corridor, and the Lower San Joaquin River and Lower Sacramento River regions (Figure 2-7). Nitrate and ammonium were highest in the spring, declining during the summer (**Figure 2-8**, **Figure 2-9**). Orthophosphate was generally low, without clear trends over the course of the season (**Figure 2-10**). During the summer, chlorophyll-a peak values and concentrations of ammonium and nitrate dropped to below the reporting limit in regions with high chlorophyll-a (Figure 2-8, Figure 2-9).



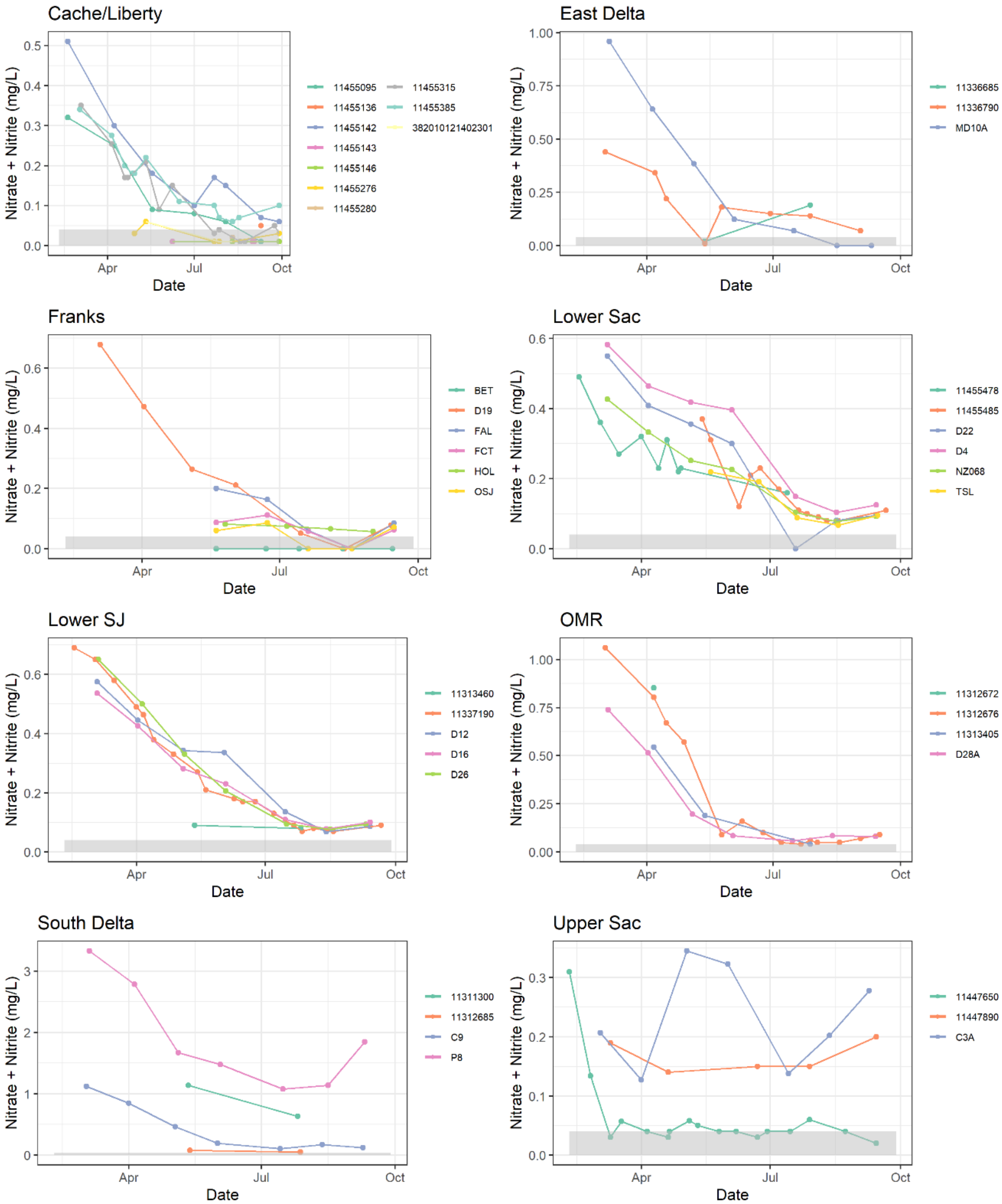
NOTE: DWR uses a reporting limit of limit is 0.5 µg/L (grey box).

Figure 2-7 Chlorophyll-a (µg/L) collected by the U.S. Geological Survey, North Central Regional Office, and Environmental Monitoring Program at Stations throughout the Delta in Spring and Summer 2021



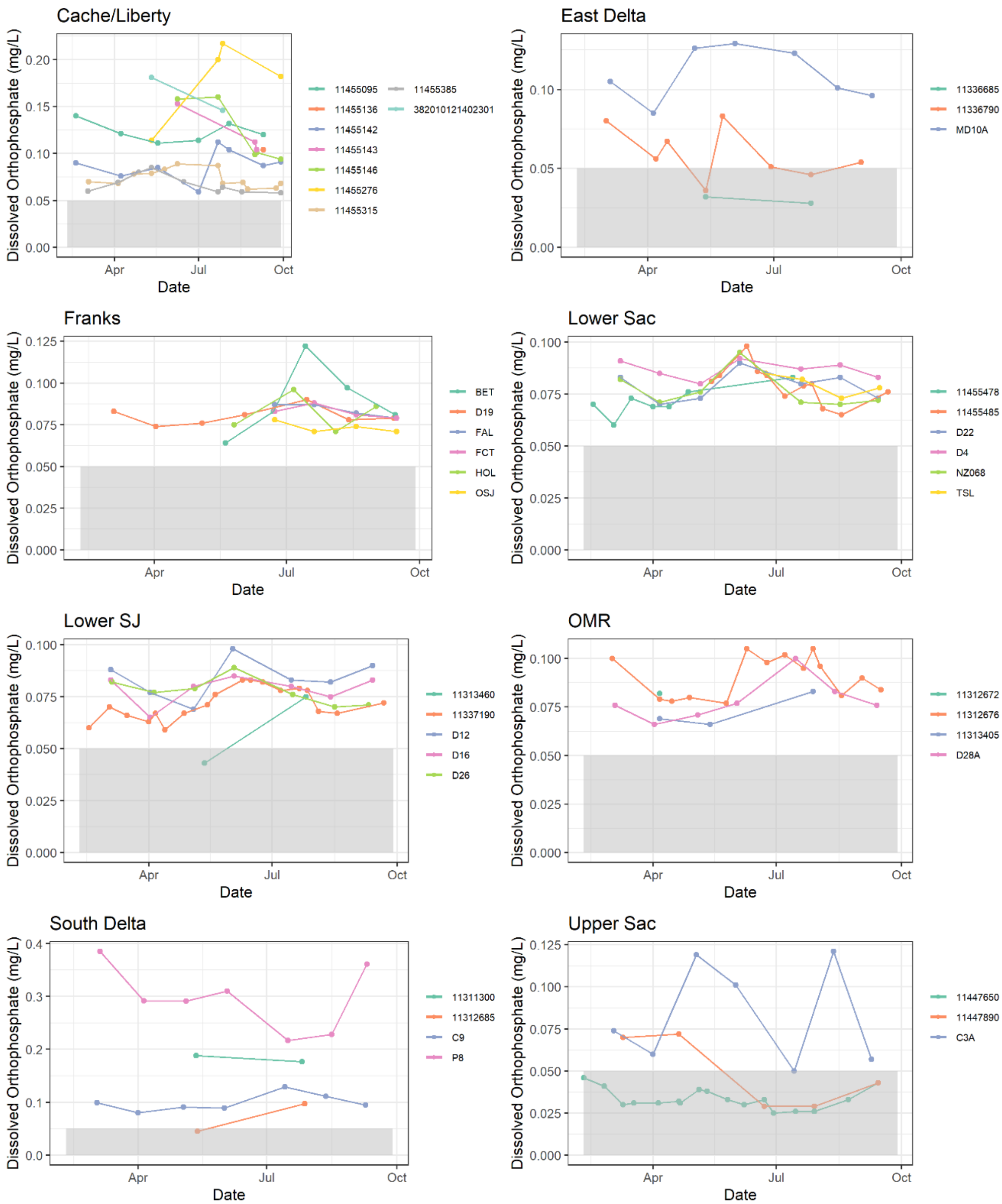
NOTE: DWR uses a reporting limit of 0.05 mg/L, so values lower than this may not be comparable (grey box).

Figure 2-8 Dissolved Ammonium Collected by the North Central Regional Office, Environmental Monitoring Program, and U.S. Geological Survey at Stations throughout the Delta in Summer 2021



NOTE: DWR uses a reporting limit of 0.04 mg/L, so values below this may not be comparable (grey box).

Figure 2-9 Dissolved Nitrate + Nitrite Collected by the Environmental Monitoring Program, North Central Regional Office, and U.S. Geological Survey at Stations throughout the Delta

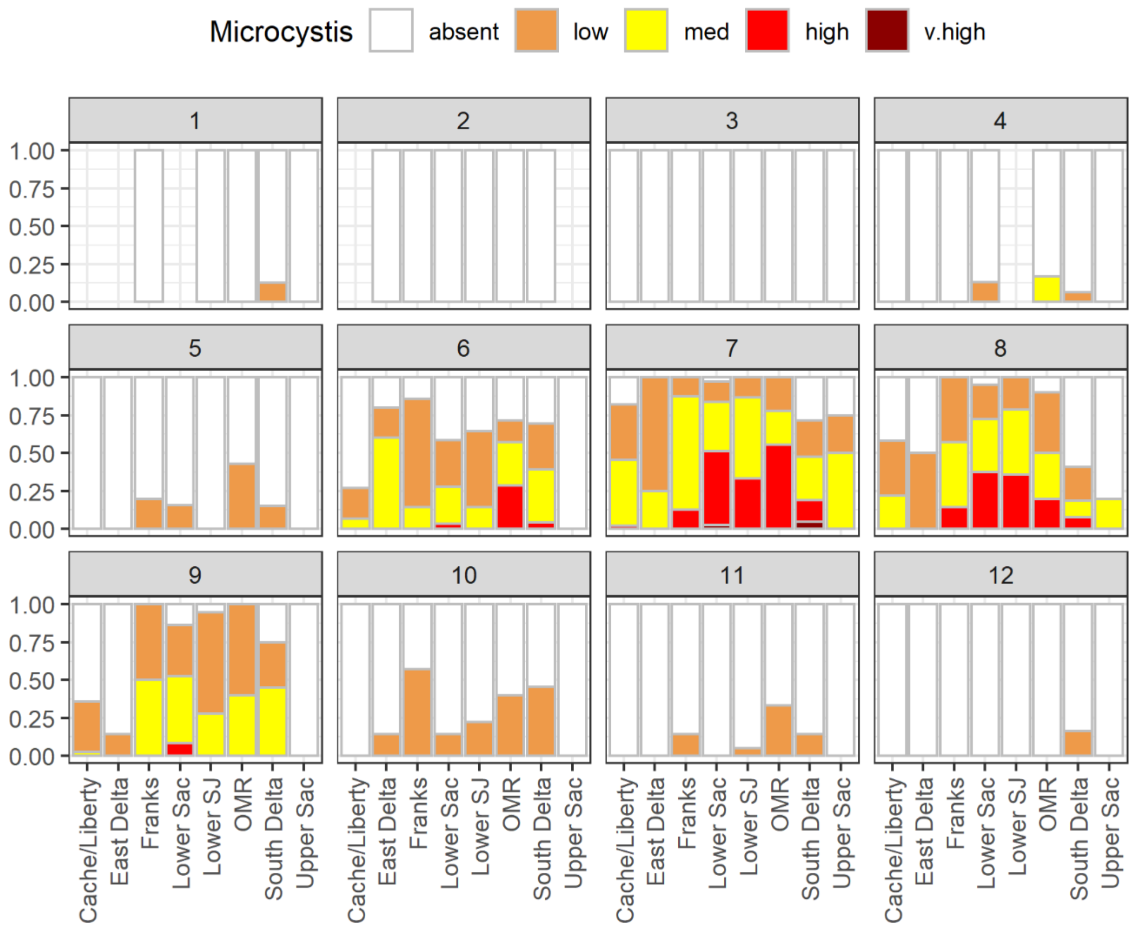


NOTE: The EMP uses a reporting limit of 0.05 mg/L, so values lower than this may not be comparable.

Figure 2-10 Dissolved Orthophosphate Collected by the Environmental Monitoring Program, North Central Regional Office, and U.S. Geological Survey at Stations throughout the Delta in Summer 2021

Visual Assessment Data

Visual assessments of *Microcystis* were infrequent during January–May 2021, but began to increase in frequency and severity during June (**Figure 2-11**). Observations were most frequent in the South Delta, Lower Sacramento River, and Lower San Joaquin River. Observations were most frequently high in the Lower Sacramento and South Delta regions. These observations peaked in July, declining slightly in September and dissipating in November and December.

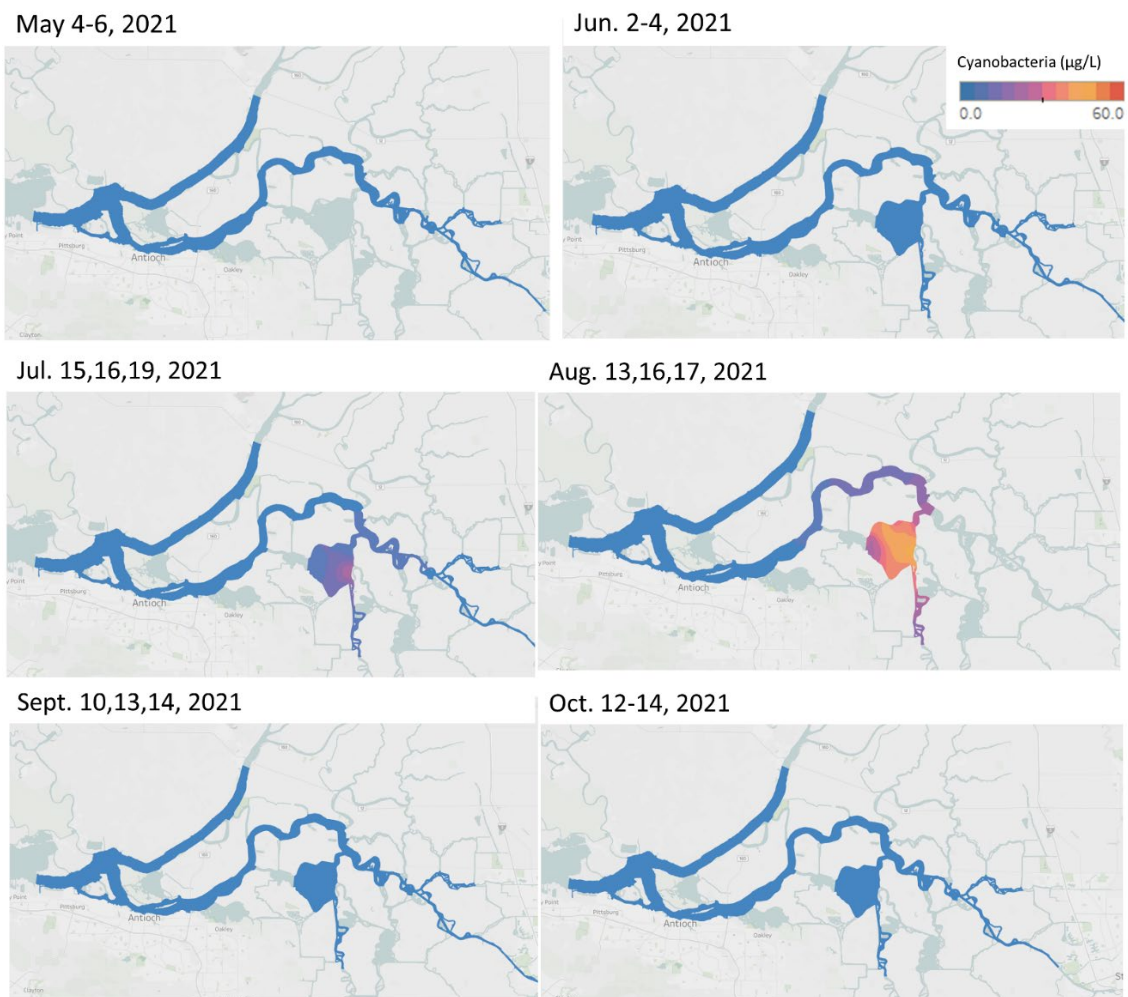


NOTE: Data were integrated across the CDFW Summer Townet Survey; the Environmental Monitoring Program survey conducted jointly by DWR, CDFW, and Reclamation; the CDFW Fall Midwater Trawl; Reclamation's Directed Outflow Project; and sampling by DWR's North Central Region Office.

Figure 2-11 Relative Frequency of *Microcystis* Observations by Month in Different Areas of the Delta in 2021

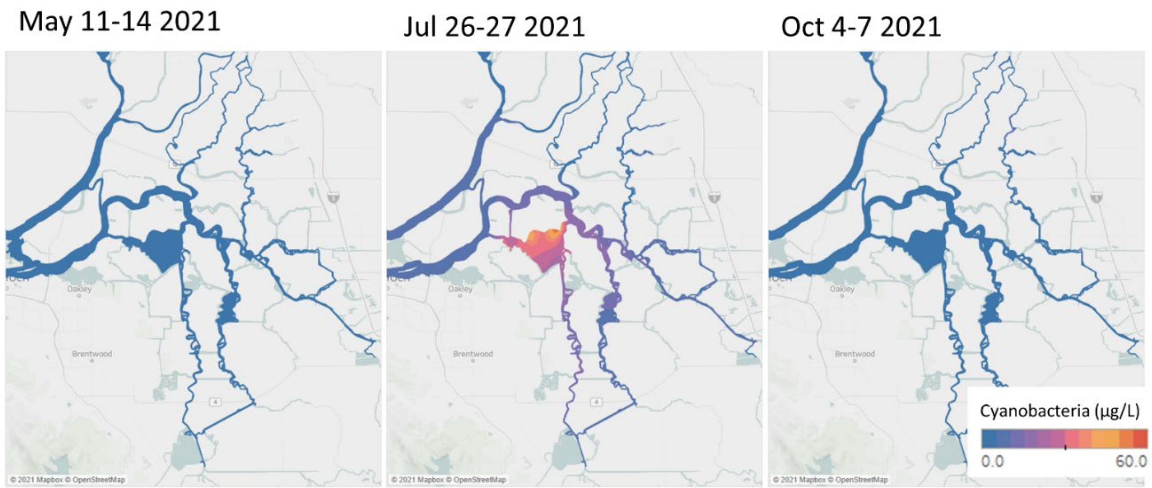
FluoroProbe Data

Spatial maps of cyanobacterial chlorophyll concentration as measured by the FluoroProbe showed low concentrations (less than 5 µg/L) of cyanobacterial chlorophyll in May and June 2021 (**Figure 2-12**, **Figure 2-13**). Measurements taken in July, however, detected increasing amounts of cyanobacterial chlorophyll in the interior Delta around Franks Tract. Notably, the concentration of cyanobacterial chlorophyll measured by the EMP in this area on July 16 was substantially lower than the concentration measured by USGS later in the month. The EMP collected data from the 15th through the 19th, while USGS mapped the 26th through the 30th. The highest concentration of cyanobacterial chlorophyll measured by the EMP occurred in August, with concentrations peaking at 60.2 µg/L in the eastern part of Franks Tract at the mouth of Old River before subsiding below 5 µg/L in September. Both data sets show the highest cyanobacterial chlorophyll around Franks Tract and south into Holland Cut. The USGS survey also measured values of cyanobacterial chlorophyll ranging from 10 to 30 µg/L in the San Joaquin River and Mildred Island in July.



NOTE: Data were collected by DWR and analyzed in ArcGIS and Tableau by USGS.

Figure 2-12 Monthly Maps (May–October 2021) Showing Concentrations of Cyanobacterial Chlorophyll in the Confluence and Interior Delta, as Measured Using a FluoroProbe during the Environmental Monitoring Program's Water Quality Cruises



NOTE: Data were collected and analyzed by USGS.

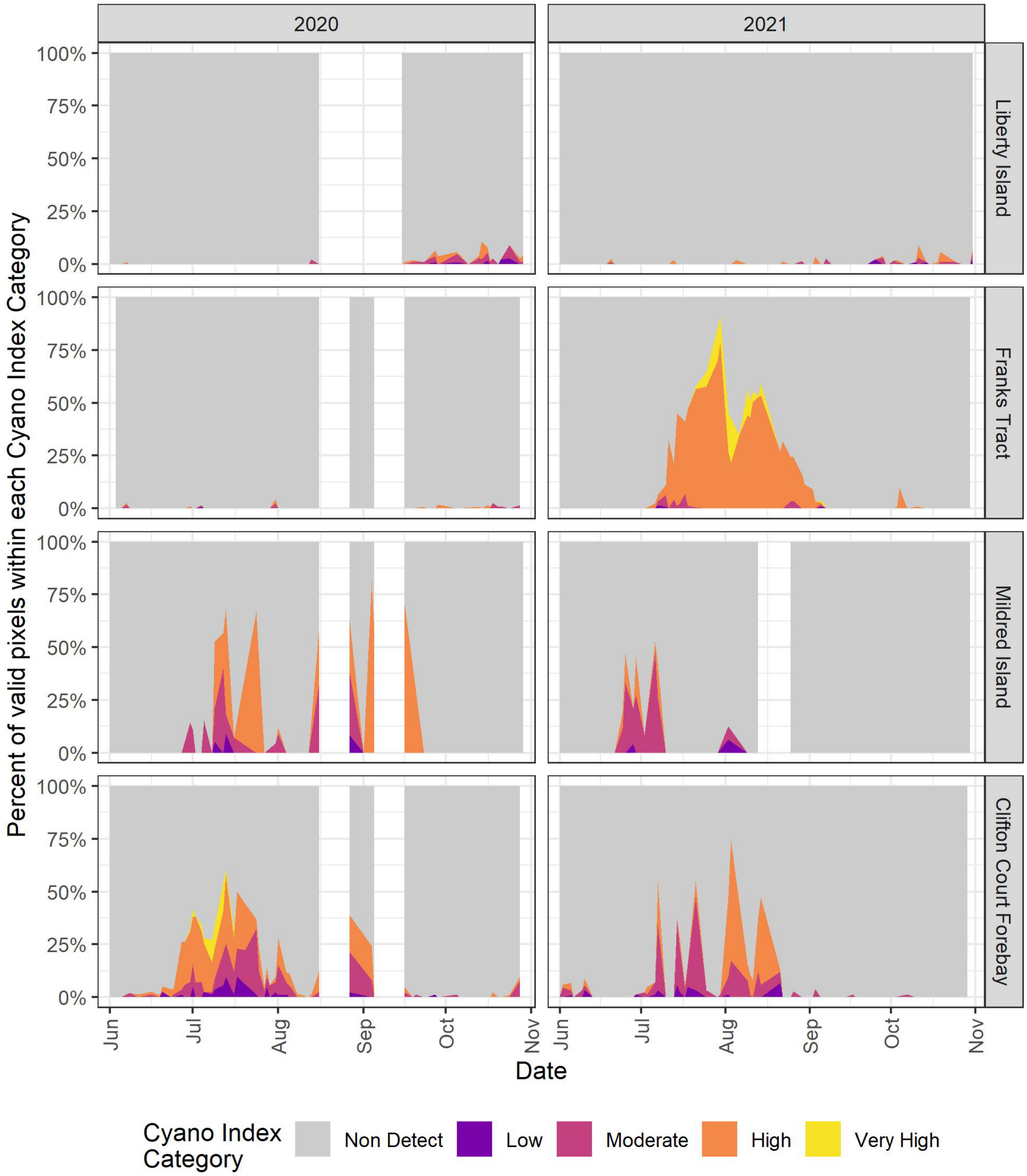
Figure 2-13 Monthly Maps (May, July, and October 2021) Showing Concentrations of Cyanobacterial Chlorophyll in the Confluence, Interior, and Southern Delta, as Measured Using a FluoroProbe on U.S. Geological Survey Rapid Water Quality Cruises

No high concentrations of cyanobacterial pigments were detected by EMP or USGS in other areas of the Delta in 2021.

Satellite Data

The July–August 2021 cyanobacteria bloom in Franks Tract documented by the EMP and USGS surveys was also apparent in the satellite data (**Figure 2-14**). Of all four open-water regions and two years examined, this 2021 bloom in Franks Tract was the largest in terms of duration, severity, and spatial extent. During the peak of this bloom from mid-July through mid-August, at least one-third of the valid pixels were in the High or Very High categories, with a maximum of 90 percent in late July 2021. It was also the only bloom observed in 2021 with pixels in the Very High CI category. Spatially, the pixels with the highest CI categories appeared to be concentrated in the southeast corner of Franks Tract throughout the bloom in 2021 (**Figure 2-15**). In contrast, almost all pixels were in the Non Detect category within Franks Tract in 2020, with no apparent cyanobacteria bloom (Figure 2-14).

Of the three other open-water regions evaluated, both Mildred Island and Clifton Court Forebay had apparent cyanobacteria blooms in 2020 and 2021, while there was no evidence of any significant blooms in Liberty Island (Figure 2-14). The blooms observed at Mildred Island and Clifton Court Forebay appeared to be more severe in 2020 than in 2021.



NOTE: Gaps in the time series are moments when data were either missing or invalid for more than a week. These could have been during times when there was dense smoke in the area from regional wildfires.

Figure 2-14 Time Series of the Percent of Valid Pixels within Each Cyanobacteria Index Category for Summer-Fall in 2020 and 2021 within Franks Tract, Clifton Court Forebay, Liberty Island, and Mildred Island

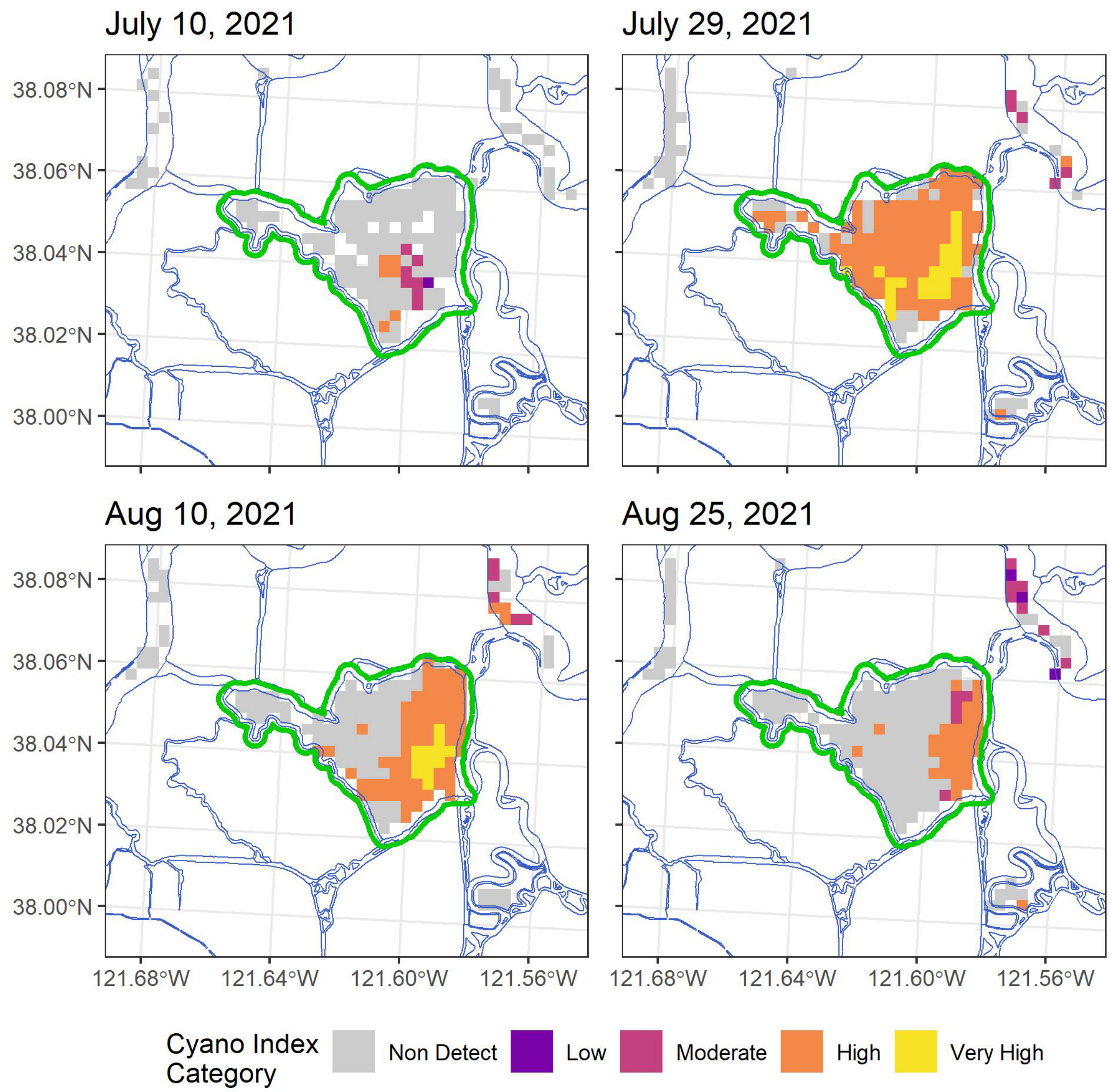


Figure 2-15 Maps of Cyanobacteria Index Categories at the Beginning (July 10), Peak (July 29 and August 10), and End (August 25) of the Cyanobacteria Bloom in Franks Tract (Highlighted in Green) during Summer 2021

Mildred Island had some instances in 2020 when at least half of the valid pixels were in the High CI category, with a maximum of 80 percent at the beginning of September, while in 2021 the percentage of pixels categorized as High remained below 20 percent.

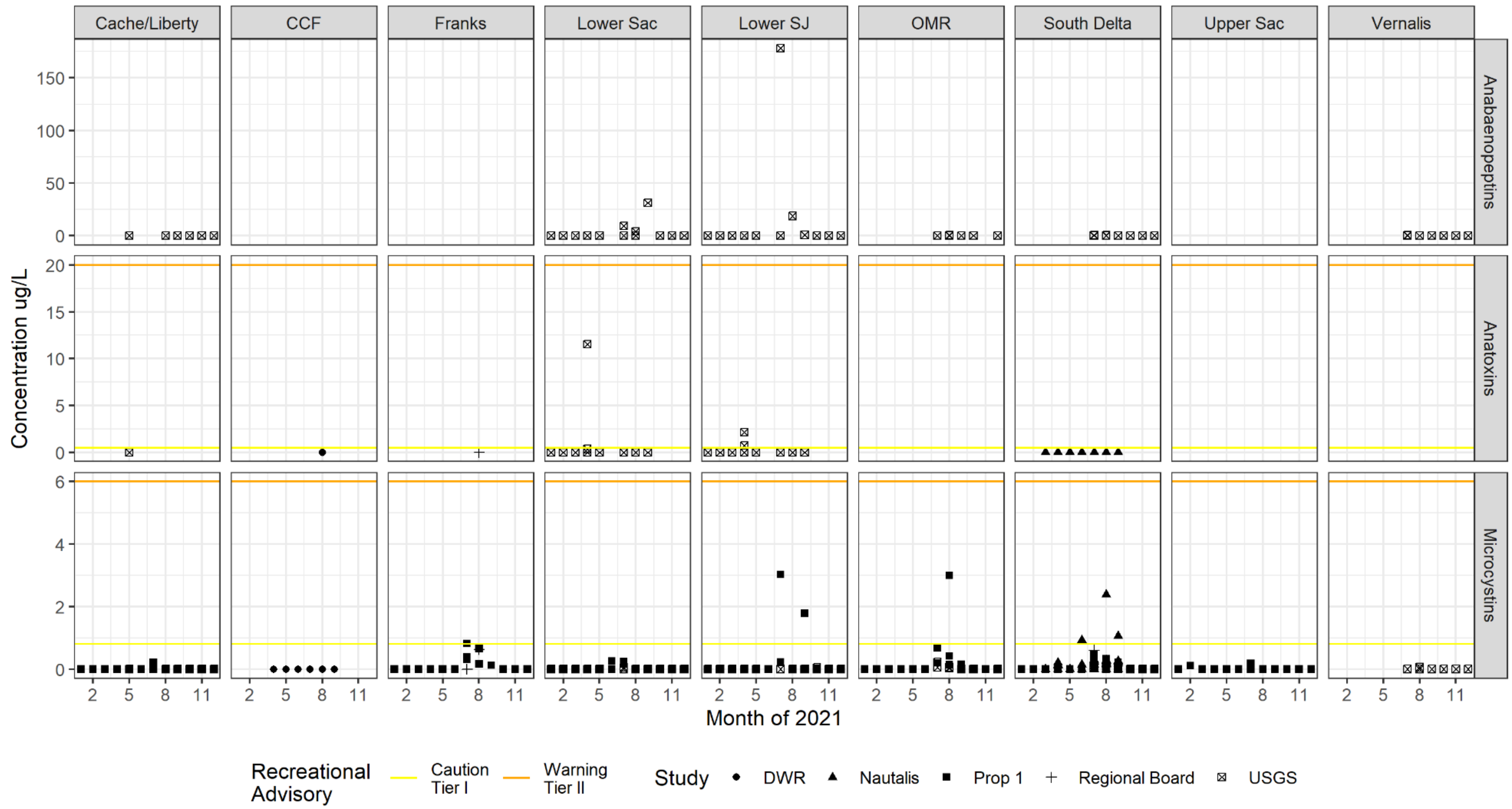
At the peak of the bloom at Clifton Court Forebay in 2020, the percentage of valid pixels in the High or Very High CI categories was consistently between 20 and 35 percent, with a maximum of 13 percent in the Very High category in mid-July. In 2021, there were a few instances in August when the percentage of pixels in the High category reached 40–56 percent at Clifton Court Forebay, but these events lasted for a few days each. In contrast, the peak of the 2020 bloom at Clifton Court Forebay spanned about 24 days, from the end of June through the third week in July.

Unfortunately, there were a few gaps in the satellite data set toward the end of August and beginning of September 2020 that may have obscured the extent of the cyanobacterial blooms in Mildred Island and Clifton Court Forebay during this time. These gaps extended for longer than a week and may have occurred during times when there was dense smoke in the area from regional wildfires.

Cyanotoxin Data

Sampling for cyanotoxins occurred every two weeks throughout the summer by the Proposition 1 team, every two weeks by the USGS/ DWR team, and twice by the RWQCB (on July 2, 2021, and August 6, 2021). The Proposition 1 team found concentrations of microcystins greater than the "Caution" level (0.8 µg/L) in three samples: at Big Break (Station DHAB003; 3.02 µg/L and 1.78 µg/L), at Middle River (Station DHAB008; 3.00 µg/L), and at Franks Tract (Station DHAB007; 0.822 µg/L) (**Figure 2-16**; Appendix A, Table A-2). These values exceed the levels of EPA's 10-day drinking water health advisory for bottle-fed infants and preschool children and WHO's preliminary guideline for safe drinking water, but the area is not a source for drinking water. Further, microcystin concentrations were not high enough to be considered unsafe for swimming (below the "Warning" level of 6 µg/L; Figure 2-16). Additional samples with concentrations between 0.3 and 0.8 µg/L were detected in Franks Tract, Mildred Island, Middle River, and the San Joaquin River (Figure 2-16).

USGS/DWR sampling found lower levels of microcystins at their sites, with the highest concentration being 0.22 µg/L at station MDM (Figure 2-16; Appendix A, Table A-2). However, the ELISA method used by the Proposition 1 method is known to have somewhat higher values than the LC-MS/MS method used by USGS. The USGS study also analyzed samples for other toxins, including anatoxin-a and anabenopeptins. Anatoxins were detected at DEC/TOL (11.6 µg/L), and JPT (2.17 µg/L and 0.73 µg/L), but these concentrations were below OEHHA's "Warning" level for recreational use. Several samples from DEC/TOL, JPT, RRI, and VER also contained anabaenopeptins, including one sample from VER with a concentration of 178 µg/L on July 7, 2021. There has been little research on the impact of anabaenopeptins on human or wildlife health, and no standards for drinking water or recreational use have been set, so it is unknown how



NOTE: The OEHHA's recreational advisories for anatoxins and microcystins are indicated with horizontal lines. No advisories have been set for anabaenopeptins.

Figure 2-16 Concentration of Cyanotoxins (in µg/L) Collected by All Sampling Programs in the Delta

these concentrations affect beneficial uses. Samples were also analyzed vis LC-MS/MS for saxitoxins, β-methylamino-l-alanine (BMAA), nodualins, and cylindrospermopsins, but none were detected.

The RWQCB sampling event in July found elevated microcystin (0.6 µg/L) at Mildred Island, but none at Franks Tract (Figure 2-16; Appendix A, Table A-2). In August, sampling at Franks Tract found a microcystin concentration of 0.63 µg/L, and also found microcystin synthase gene in the water (24,685 copies/mL), indicating that *Microcystis* was present and capable of producing toxins. Samples were also analyzed for saxitoxins and cylindrospermopsins, but none were detected.

East Bay Regional Parks detected high toxin concentrations of more than 50 µg/L at Big Break Regional Shoreline (fishing pier and kayak launch) throughout June, July, and August (**Figure 2-17**; Appendix A, Table A-2). Results of sampling by the Proposition 1 study in the center of Big Break (Station DHAB003) were significantly lower (3 µg/L), so toxin concentrations may have been elevated in the backwater area by the fishing pier and kayak launch.

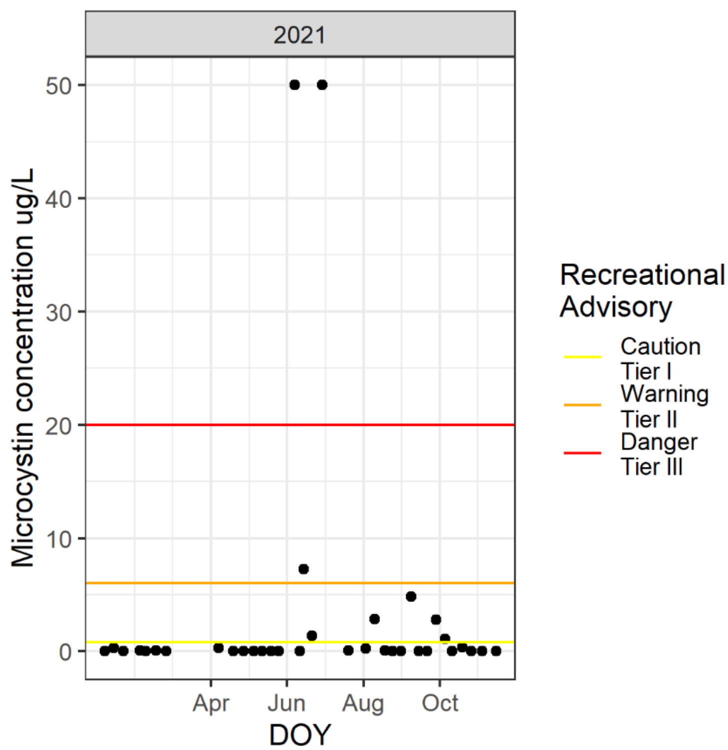


Figure 2-17 Microcystin Concentrations Detected at Big Break Regional Shoreline's Fishing Pier during 2021

The Nautilus sampling program found elevated microcystins in the San Joaquin River at Buckley Cove on August 3, 2021 (2.4 µg/L; Station ALG-005), and at Luis Park on September 7, 2021 (1.1 µg/L; Station ALG-002) (Figure 2-16; Appendix A, Table A-2). Samples were also analyzed for saxitoxins, anatoxins, and cylindrospermopsins, but none were detected. This region would not have been influenced by the EDB or TUCP, but data are included here for context.

Toxin sampling also occurred every two weeks at Clifton Court Forebay and Banks Pumping Plant. Although some harmful cyanobacteria were detected via microscopy, all toxin analysis was below the detection level (Appendix A, Table A-2).

Using the State Water Board's HAB Portal, a combination of visual observations and cyanotoxin monitoring caused "Caution" advisories throughout the Delta in 2021. A few areas of very restricted flow, including Big Break, Discovery Bay, and near the Stockton waterfront, had "Danger" advisories (**Figure 2-18**).

2.3.2 Comparisons between Years

Flow

During drought years (2015, 2016, 2020, 2021), Delta outflow and San Joaquin flow were very low (Figure 2-19). Although there were some differences between years with a TUCP (2015, 2021) and dry years without a TUCP (2016, 2018, 2020), the difference between dry years and wet years was an order of magnitude larger than the difference between dry years, especially early in the summer. For example, the mean summer (June–September) Delta outflow from 1997–2021 in wet years was 23,888 cfs, while for critically dry years it was 4,509 cfs. In contrast, the mean summer Delta outflow in 2021 was 3,626 cfs versus 5,769 cfs in 2020. Similarly, the inter-annual differences in late-summer outflow were much lower than intra-annual differences in flow, with much higher flow earlier in the year, particularly in wet years. Years with a barrier and TUCP (2015, 2021) had much lower exports throughout the summer than any other years.

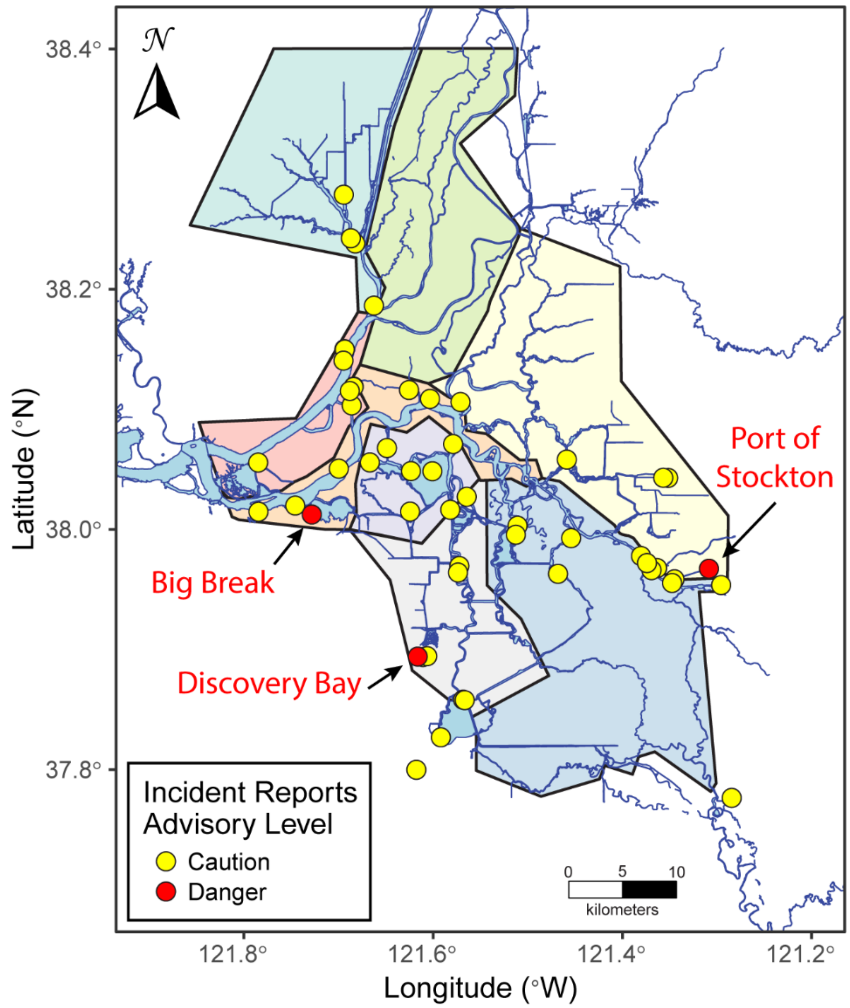


Figure 2-18 Map of Harmful Algal Bloom Incidents Reported to the State Water Board's HAB Portal, Combined with Advisory Levels Derived from other Cyanotoxin Data Sets

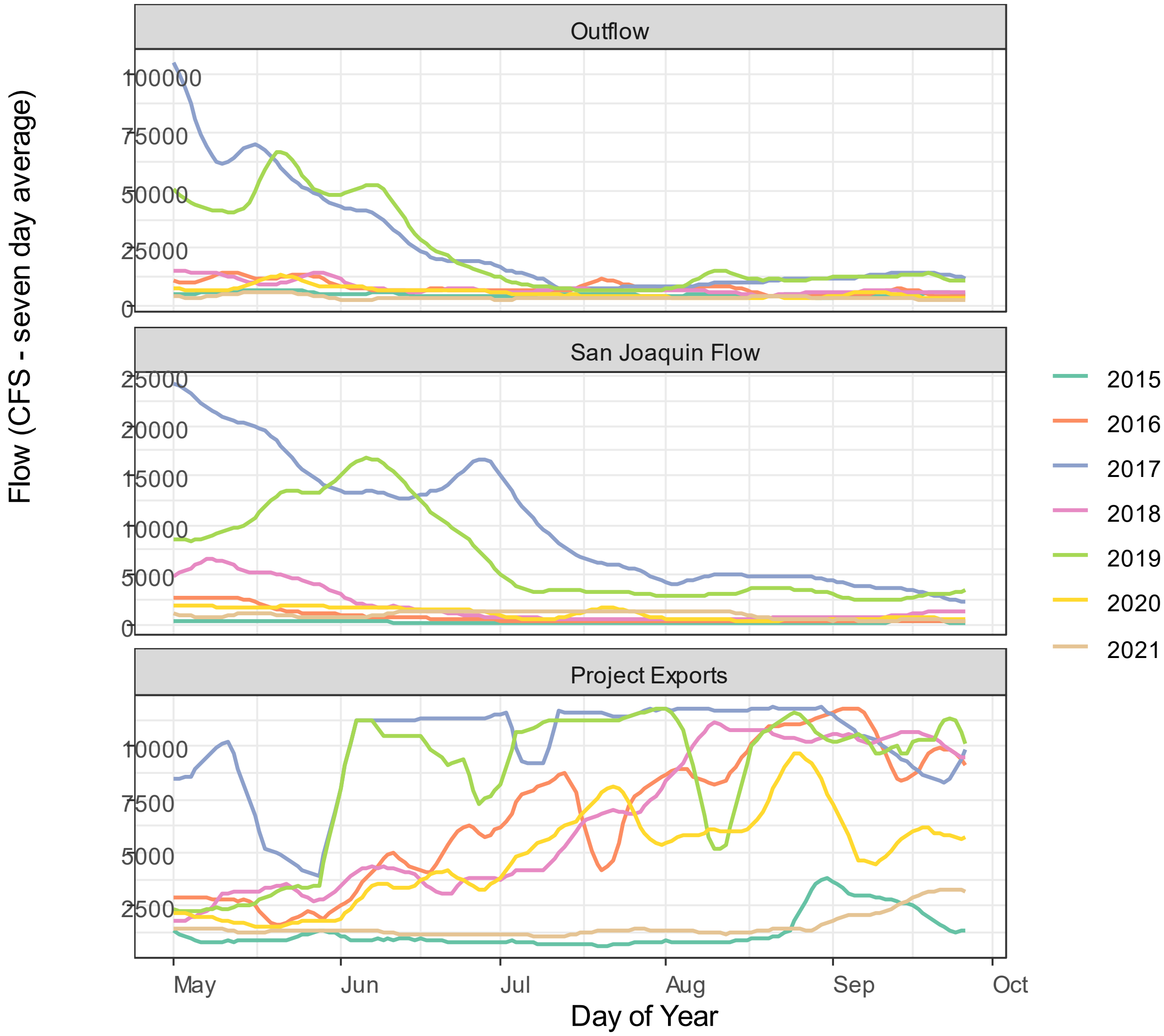
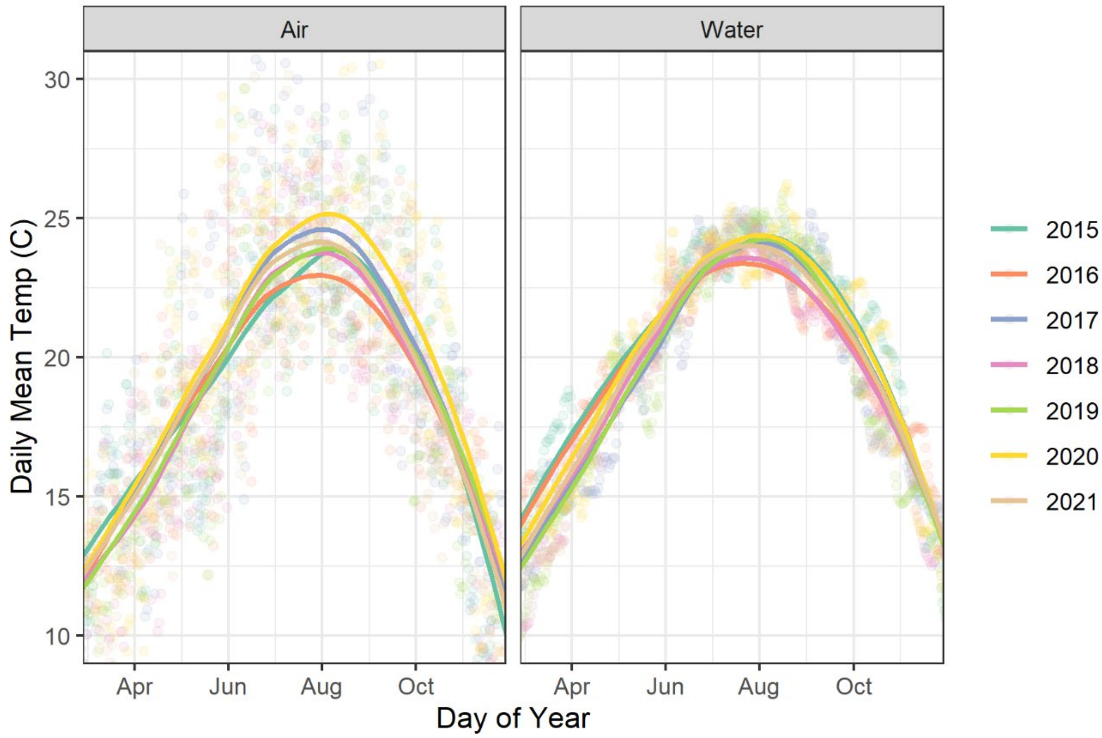


Figure 2-19 Comparison of Delta Outflow, San Joaquin River Flow, and Project Exports as Measured by DWR's Dayflow Model in 2021 versus the Past Seven Years

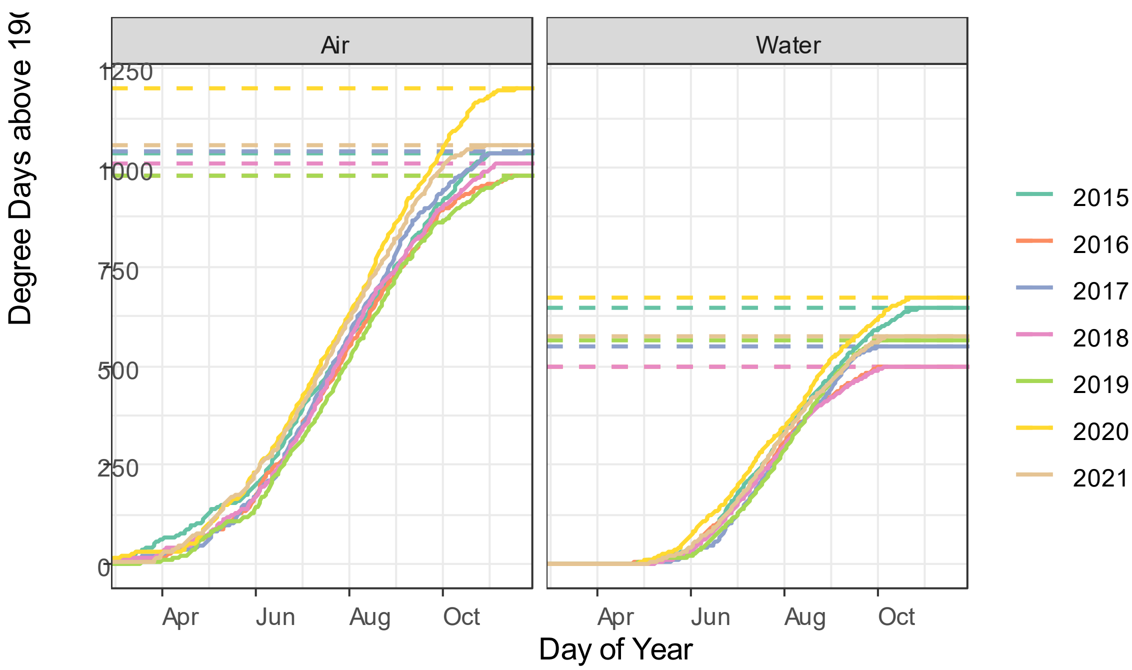
Temperature in Degree-Days

Based on number of degree-days over 19°C for the growing season, 2020 was the hottest year with the most degree-days in both water temperature and air temperature (**Figure 2-20**, **Figure 2-21**). 2020 also reached 19°C earlier than any other year, kicking off the "*Microcystis* season" earlier. In terms of water temperature, 2021 was the third warmest summer, although it was the warmest summer in terms of air temperature degree-days. Interestingly, 2015 was the second warmest in terms of water temperature degree-days, but was much cooler in terms of air temperature.



NOTE: Lines represent the LOESS smoothing curves by year.

Figure 2-20 Daily Mean Temperatures for the Delta (Average of Water Temperature for Stations FAL, FRK, HLT, HOL, MDM, ORQ, and OSJ, and Air Temperature from Stations HBP, MSD, and SJR) by Year for 2015–2021

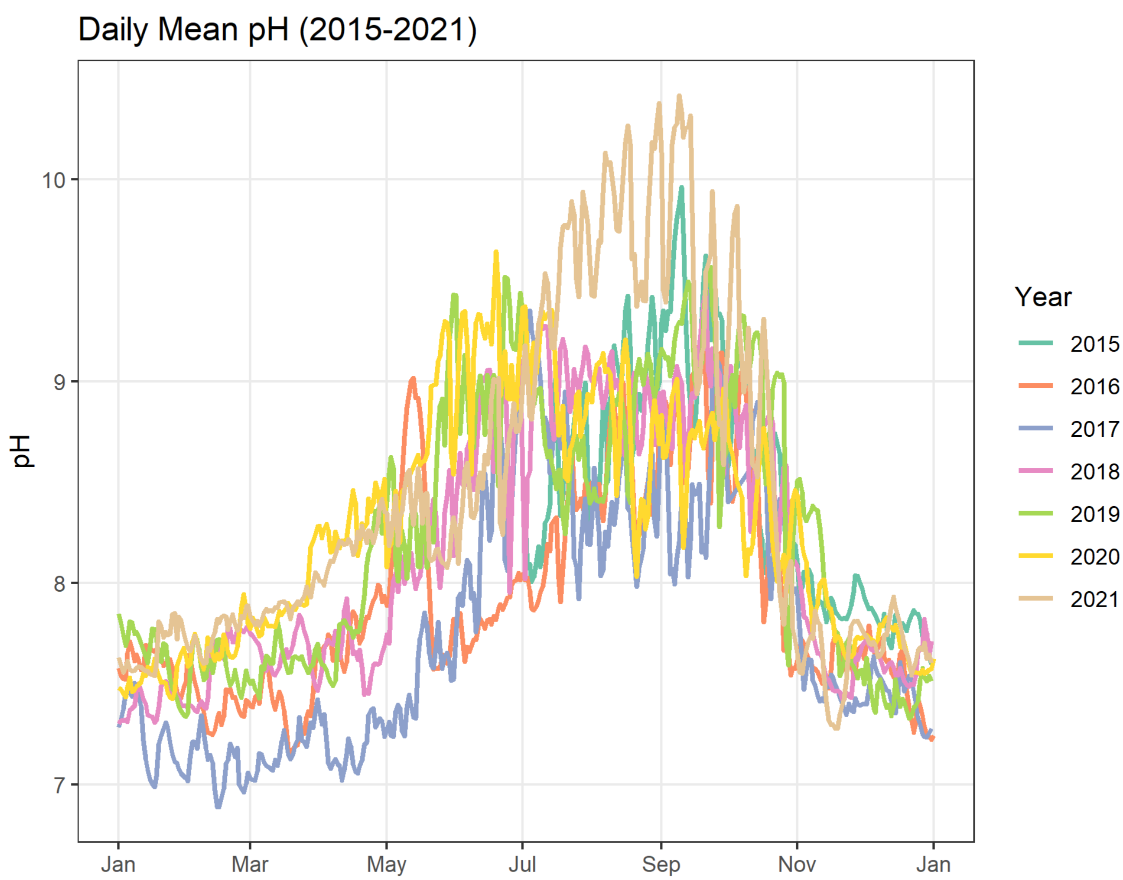


NOTE: Dashed horizontal lines represent the maximum degree days reached at the end of the season for each year.

Figure 2-21 Degree-Days above 19°C for Air Temperature and Water Temperature by Year for 2015–2021

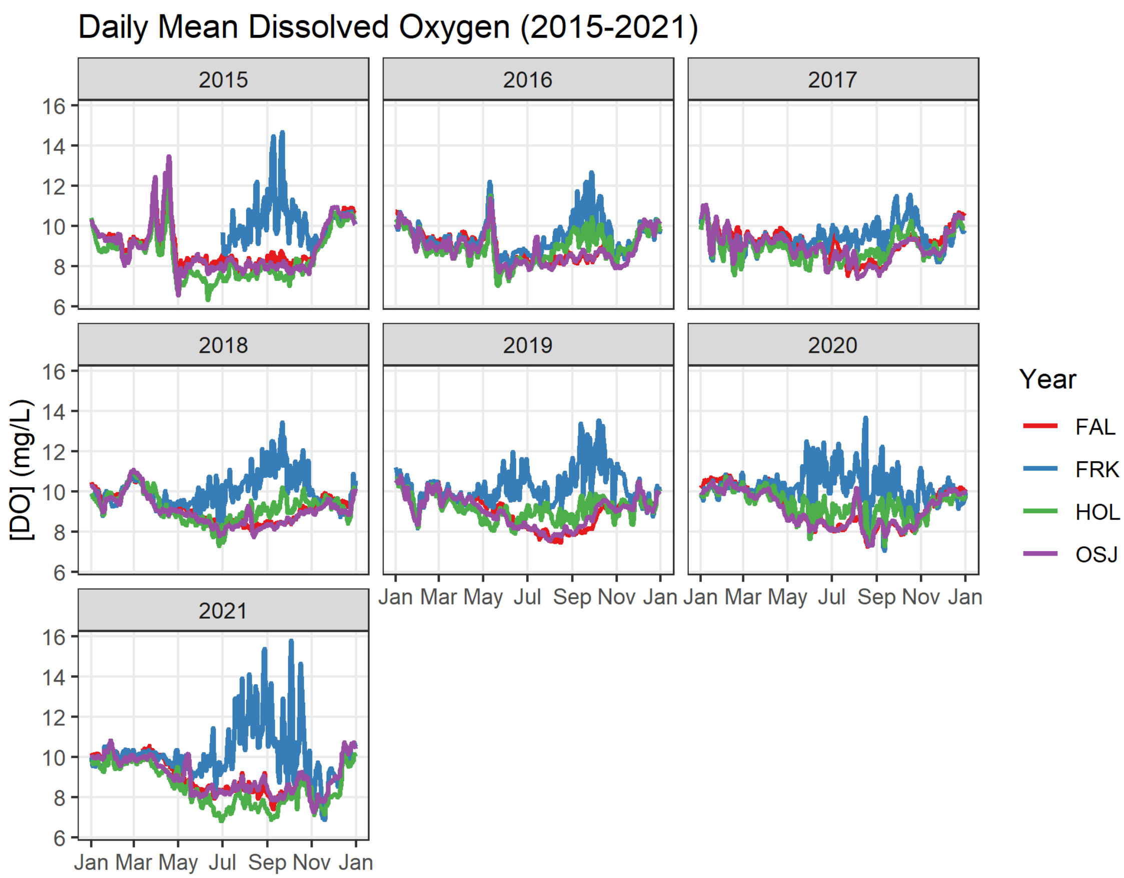
Continuous Water Quality

A focused assessment of continuous water quality collected by the EMP and NCRO at Franks Tract and adjacent sites (Figure 2-5) over the summer months of 2021 found substantial differences in parameters linked to increased levels of photosynthesis, i.e., DO and pH, from previous years. Beginning in July 2021, both the pH (**Figure 2-22**) and concentration of DO (**Figure 2-23**) in Franks Tract began to increase, and by August had reached higher levels than previously recorded at this station (collected since 2015). DO was also substantially higher in Franks Tract than at any of the adjoining continuous monitoring stations. The maximum daily pH peaked in early September before declining rapidly, while the DO peak was reached later in that month before also declining (**Table 2-7**).



NOTE: Data were collected by the Environmental Monitoring Program using a YSI EXO2 water quality sonde equipped with a pH Smart Sensor.

Figure 2-22 Daily Mean pH (2015–2021) at the Continuous Water Quality Monitoring Station in Franks Tract



NOTE: Data were collected by the Environmental Monitoring Program and North Central Regional Office using a YSI EXO2 water quality sonde equipped with an optical dissolved oxygen Smart Sensor.

Figure 2-23 Daily Mean Concentration of Dissolved Oxygen (2015–2021) at Continuous Water Quality Monitoring Stations in and around Franks Tract

TABLE 2-7
MEAN MONTHLY VALUE OF DAILY MAXIMUM PH (PH UNITS)

	2015	2016	2017	2018	2019	2020	2021
May	-	8.5	7.9	8.4	9.0	9.1	8.6
June	-	8.2	8.7	9.1	9.5	9.5	8.9
July	8.8	8.6	9.3	9.3	9.2	9.3	9.7
August	9.2	9.0	9.1	9.2	9.3	9.2	10.1
September	9.5	9.2	9.0	9.3	9.5	9.1	10.0
October	8.8	8.5	8.7	8.9	9.2	8.7	9.1

During the bloom, daily DO maxima peaked at more than 200 percent of saturation with atmospheric oxygen and averaged more than 170 percent for the months of July and August, the highest on record for this station (**Table 2-8**). Values of DO saturation greater than 100 percent indicate that photosynthesis is active in the water column. Daily chlorophyll levels, while higher than in summer 2020 (**Table 2-9**), did not match the elevated levels detected using the FluoroProbe (Figure 2-12, Figure 2-13) and were in fact lower than in previous years. While small spikes of chlorophyll-a were detected by the NCRO at nearby stations (**Figure 2-24**), these were below usual criteria for a bloom (less than 10 μg/L) and much less than observed by the FluoroProbe.

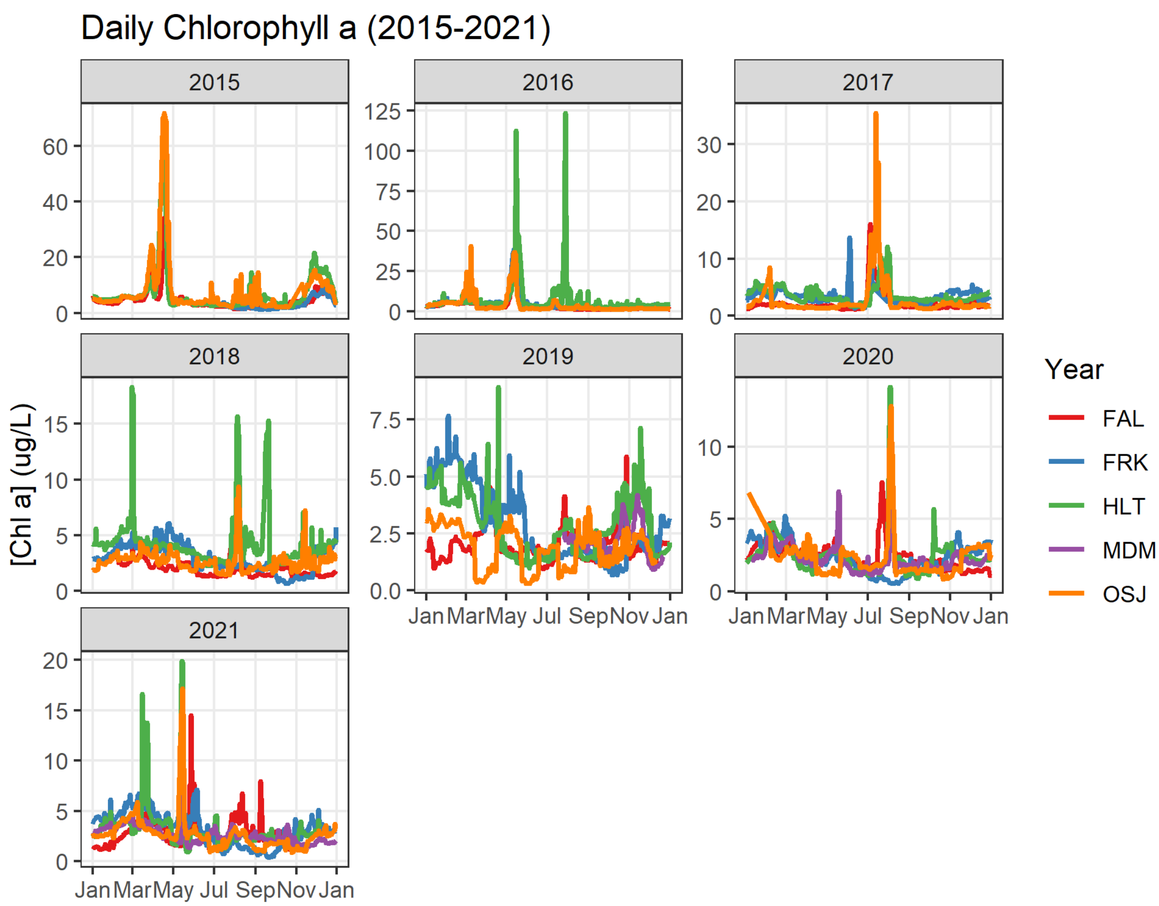
TABLE 2-8
MEAN MONTHLY VALUE OF DAILY MAXIMUM DISSOLVED OXYGEN (% SATURATION)

	2015	2016	2017	2018	2019	2020	2021
May	-	119.3	108.4	111.8	122.1	133.8	115.7
June	-	110.6	119.0	132.5	141.6	154.3	127.5
July	127.2	119.1	130.0	135.4	145.1	153.9	171.4
August	142.3	126.7	135.3	147.9	152.7	160.1	176.2
September	160.7	144.0	133.0	159.5	164.8	148.9	157.8
October	127.6	116.9	123.0	133.3	141.8	125.9	135.5

TABLE 2-9
MEAN MONTHLY VALUE OF DAILY MAXIMUM CHLOROPHYLL-A (μg/L) AT THE CONTINUOUS WATER QUALITY MONITORING STATION IN FRANKS TRACT (FRK)

	2015	2016	2017	2018	2019	2020	2021
May	-	24.0	5.3	6.3	8.0	3.5	9.2
June	-	5.2	5.7	4.4	3.4	2.1	6.6
July	4.3	4.4	11.1	5.5	2.7	1.4	2.4
August	2.9	3.9	3.7	5.5	3.2	1.4	3.4
September	2.6	4.0	3.4	4.8	5.2	2.9	2.9
October	3.2	4.0	4.8	2.1	4.4	3.0	4.4

NOTE: μg/L = micrograms per liter

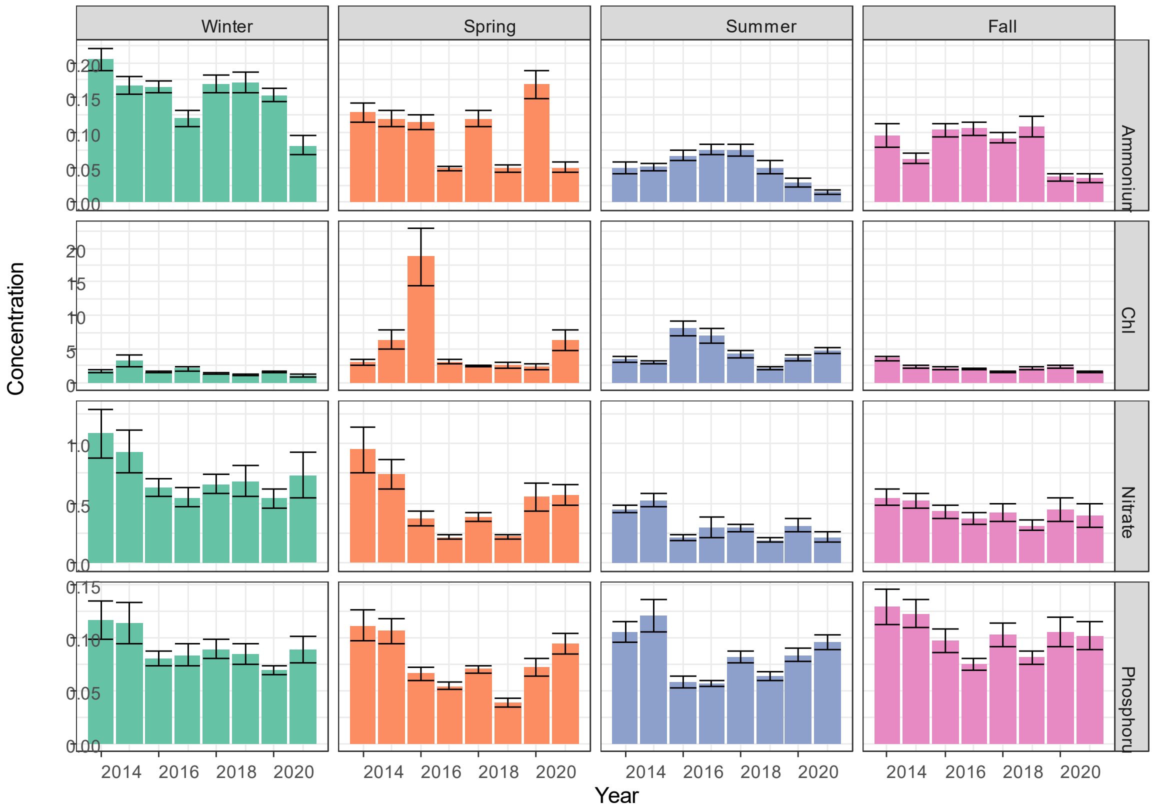


NOTE: Data were calculated based on chlorophyll fluorescence and have not been calibrated with extracted values. Data were collected by the Environmental Monitoring Program and NCRO using a YSI EXO2 water quality sonde equipped with a Total Algae sensor.

Figure 2-24 Daily Mean Estimated Concentration of Chlorophyll-a (2015–2021) at Continuous Water Quality Monitoring Stations in and around Franks Tract

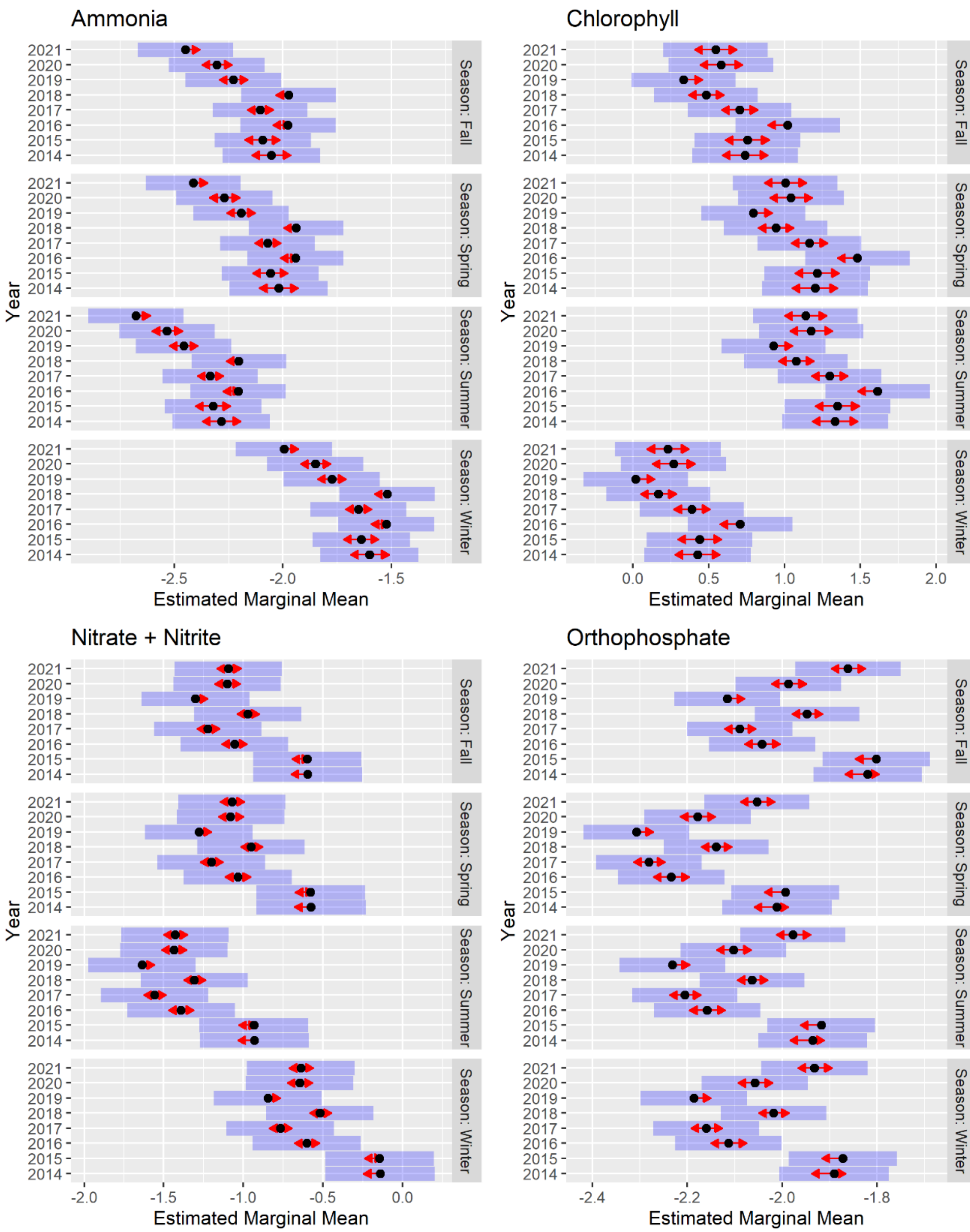
Nutrients and Discrete Chlorophyll

Nutrient samples collected in the South and Central Delta in 2021 mostly showed similar levels to the previous seven years, with a few significant differences between years and seasons (**Figure 2-25**, **Figure 2-26**). Dissolved orthophosphate was also slightly higher in the spring and summer in 2021 than in 2020, although it was similar to 2014 and 2015 levels. Chlorophyll-a was significantly higher in spring and summer 2021 than during the previous four years (Figure 2-26).



Note: Spring = March–May, Summer = June–August, Fall = September–November, Winter = December–February

Figure 2-25 Average Concentration (+/- 1 Standard Error) of Nutrients (mg/L) and Chlorophyll-a (µg/L) Collected by the Environmental Monitoring Program, North Central Regional Office, and U.S. Geological Survey in the South Delta, Franks Tract, Old/Middle River, Lower San Joaquin River, and Lower Sacramento River by Season

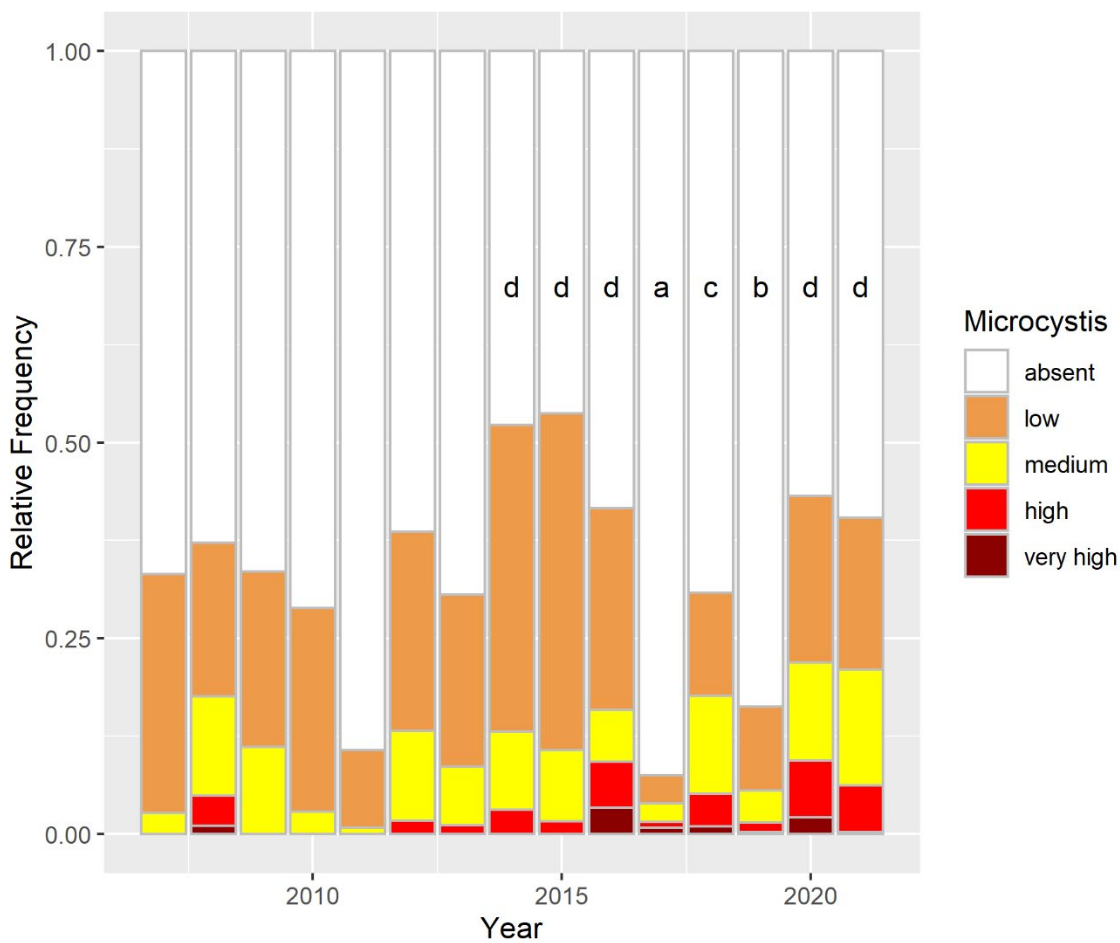


NOTE: Non-overlapping red arrows indicate significant differences; blue bars represent 95% confidence intervals.

Figure 2-26 Estimated Marginal Means from Generalized Linear Models of Nutrient Concentrations versus Season and Year

Visual Index Data

The *Microcystis* visual index data provided a broad-scale picture of harmful cyanobacteria across the Delta since 2007 (**Figure 2-27**). Data are graphed here on a 5-point scale, but are converted to a 3-point scale for statistical analysis. An ordinal regression of *Microcystis* across the entire Delta found that 2021 had an incidence of *Microcystis* observations similar to that of 2020, as well as the drought years of 2014, 2015, and 2016 (**Table 2-10**). Looking regionally, Franks Tract, OMR, the Lower Sacramento River, the Lower San Joaquin River, and the South Delta consistently have higher *Microcystis* levels than the Upper Sacramento River, Cache/Liberty area, and the East Delta (**Figure 2-28**, Table A-1). The inter-annual trends for each region mostly aligned with the Delta-wide analysis, with no significant differences between 2020 and 2021.



NOTE: Letters indicate groups of years that were not significantly different at the p = 0.05 level (results of an ordinal regression; Table 2-10, Table 2-11). The ordinal regression was only run on 2014–2021, but earlier years are shown for comparison. The regression was run on three categories (Absent, Low/Medium, High/Very High), but all five categories are shown here for reference.

Figure 2-27 Frequency of Visual *Microcystis* Observations in the Delta from Long-Term Monitoring Programs, June–October, 2007–2021

TABLE 2-10
RESULTS OF AN ORDINAL MIXED MODEL OF DELTA-WIDE *MICROCYSTIS* VISUAL INDICES

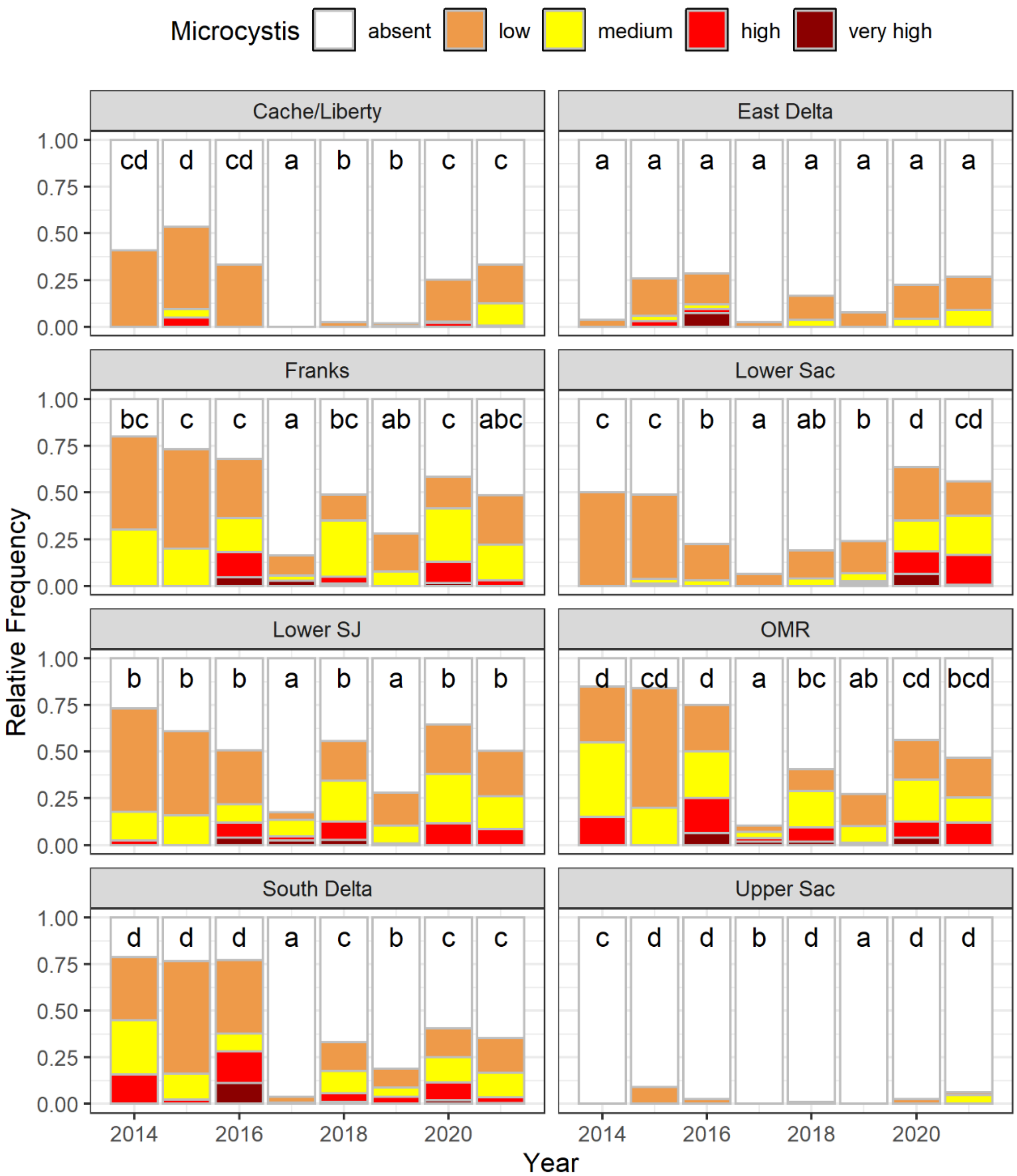
Parameter	Odds Ratio	Std. Error	t value	p value	Type
2015	-0.0212	0.1408	-0.1504	0.8804	Coef.
2016	-0.3386	0.1401	-2.4163	0.0157	Coef.
2017	-2.7227	0.1850	-14.7195	<0.0001	Coef.
2018	-0.9641	0.1277	-7.5494	<0.0001	Coef.
2019	-1.7469	0.1320	-13.2359	<0.0001	Coef.
2020	-0.1789	0.1198	-1.4939	0.1352	Coef.
2021	-0.3589	0.1230	-2.9172	0.0035	Coef.
East Delta	-0.2418	0.1618	-1.4943	0.1351	Coef.
Franks	1.3842	0.1249	11.0853	<0.0001	Coef.
Lower Sac	1.0462	0.0903	11.5818	<0.0001	Coef.
Lower SJ	1.3946	0.0945	14.7508	<0.0001	Coef.
OMR	1.3924	0.1134	12.2737	<0.0001	Coef.
South Delta	0.9247	0.0935	9.8852	<0.0001	Coef.
Upper Sac	-2.3583	0.3139	-7.5129	<0.0001	Coef.
Absent|Low	0.7129	0.1203	5.9270	<0.0001	Intercept
Low|High	3.1822	0.1303	24.4148	<0.0001	Intercept

NOTE: All odds ratios are in comparison to an intercept of the year 2014 and the region Cache/Liberty.

TABLE 2-11
ESTIMATED MARGINAL MEANS AND CONFIDENCE INTERVALS FOR DIFFERENCES BETWEEN YEARS AND REGIONS FROM THE ORDINAL REGRESSION OF *MICROCYSTIS* VISUAL INDICES

Term	Level	Marginal Mean	SE Marginal Mean	Lower CI	Upper CI	Significance Group
Year	2017	-4.227	0.160	-4.542	-3.913	a
Year	2019	-3.252	0.093	-3.435	-3.068	b
Year	2018	-2.469	0.085	-2.636	-2.302	c
Year	2021	-1.864	0.079	-2.018	-1.709	d
Year	2016	-1.843	0.104	-2.047	-1.639	d
Year	2020	-1.684	0.073	-1.827	-1.540	d
Year	2015	-1.526	0.104	-1.730	-1.322	d
Year	2014	-1.505	0.113	-1.726	-1.283	d
Region	Upper Sac	-5.097	0.309	-5.702	-4.493	a
Region	East Delta	-2.981	0.150	-3.275	-2.686	b
Region	Cache/Liberty	-2.739	0.076	-2.888	-2.589	b
Region	South Delta	-1.814	0.071	-1.953	-1.676	c
Region	Lower Sac	-1.693	0.067	-1.823	-1.562	cd
Region	Franks	-1.355	0.108	-1.566	-1.144	de
Region	OMR	-1.347	0.093	-1.530	-1.163	e
Region	Lower SJ	-1.344	0.067	-1.477	-1.212	e

NOTE: Significance Group indicates groups of years or regions that are not significant different at the $p < 0.05$ level.



NOTE: See Table A-1 for statistic test results. Data were integrated across the CDFW Summer Townet Survey; the Environmental Monitoring Program survey conducted jointly by DWR, CDFW, and Reclamation; the CDFW Fall Midwater Trawl; Reclamation's Directed Outflow Project; and sampling by DWR's North Central Region Office.

Figure 2-28 Relative Frequency of *Microcystis* Observations by Month in Different Areas of the Delta over Time

Community Composition Data

The results from phytoplankton samples collected by the EMP throughout open waters of the Central Delta showed that community composition of potentially toxic cyanobacteria varied between years. In particular, *Aphanizomenon* was the most abundant potentially toxic cyanobacterium in 2015 and 2020, while *Microcystis* was the most abundant potentially toxic cyanobacterium in 2014, 2016, 2017, 2018, and 2021 (**Figure 2-29**). *Dolichospermum* was more abundant in 2021 than in any previous year. However, concentrations of cyanobacteria were highly variable, and these types of samples do not quantitatively sample surface-oriented taxa, such as *Microcystis*. The authors of this report do not have consistent surface samples targeting *Microcystis* across these years, and do not have data on community composition for many of the cyanoHABs "hot spots" that occur in marinas and backwaters not sampled by the EMP.

Cyanotoxin Data

Much of the toxin data presented in the section on 2021, above, came from programs that were not implemented before 2021. Most data from previous years were collected at "hot spots" of HABs, such as Big Break Regional Shoreline (**Figure 2-30**).

The areas with "Danger" advisories in 2021 (Big Break, Discovery Bay, and the Stockton Waterfront) also had Danger advisories in 2020 and 2019 (see https://www.mywaterquality.ca.gov/habs/where/freshwater_events.html).

2.3.3 Drivers

Model of Visual Index Data

After running Bayesian mixed models for all possible combinations of Delta outflow, SWP and CVP exports, temperature, and Secchi depth against the probability of *Microcystis* observation in the South Delta, San Joaquin River, Lower Sacramento River, Franks Tract, and OMR regions during the summer and fall, the highest ranked model included exports, temperature, and Secchi depth (**Table 2-12**).

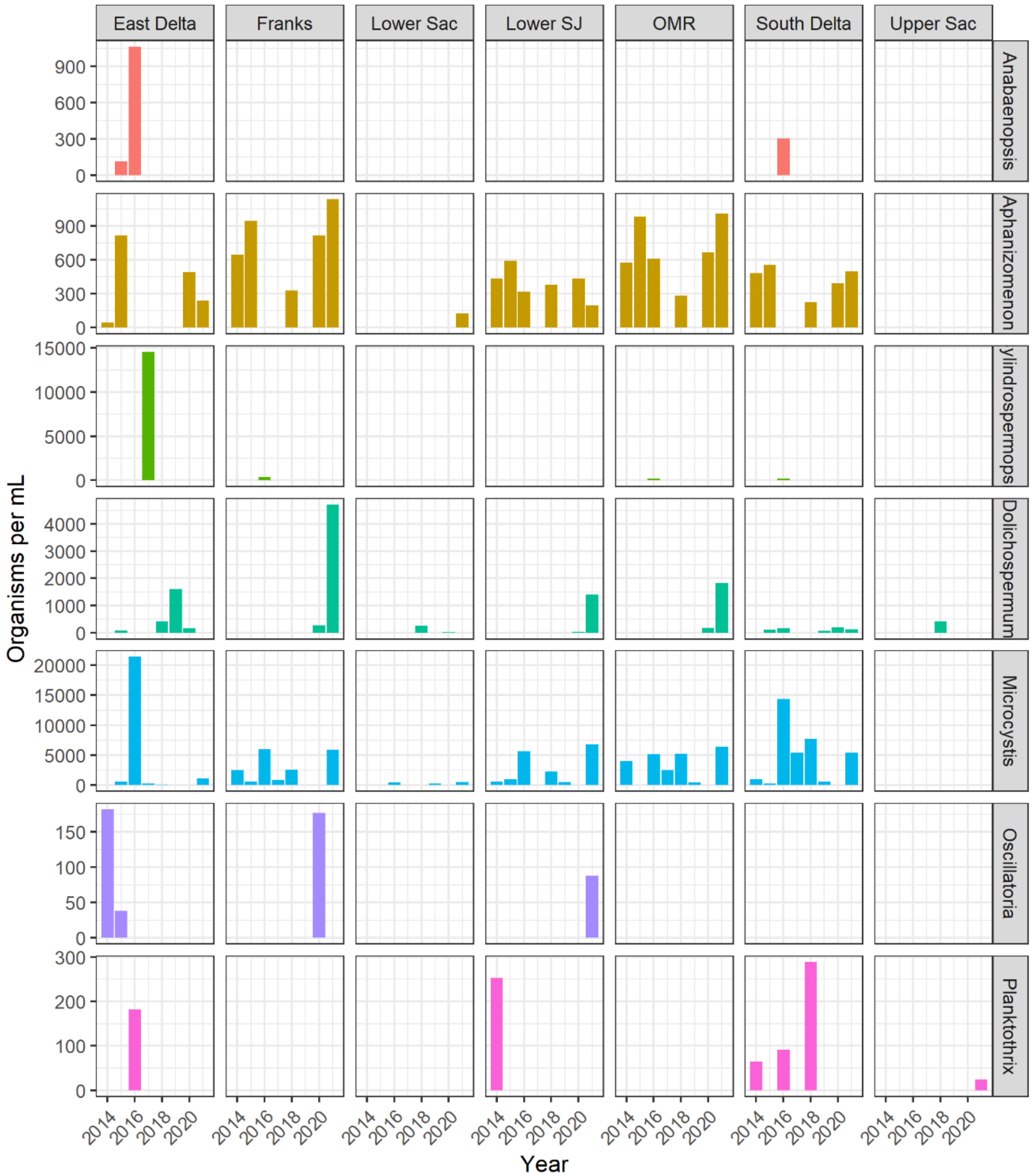
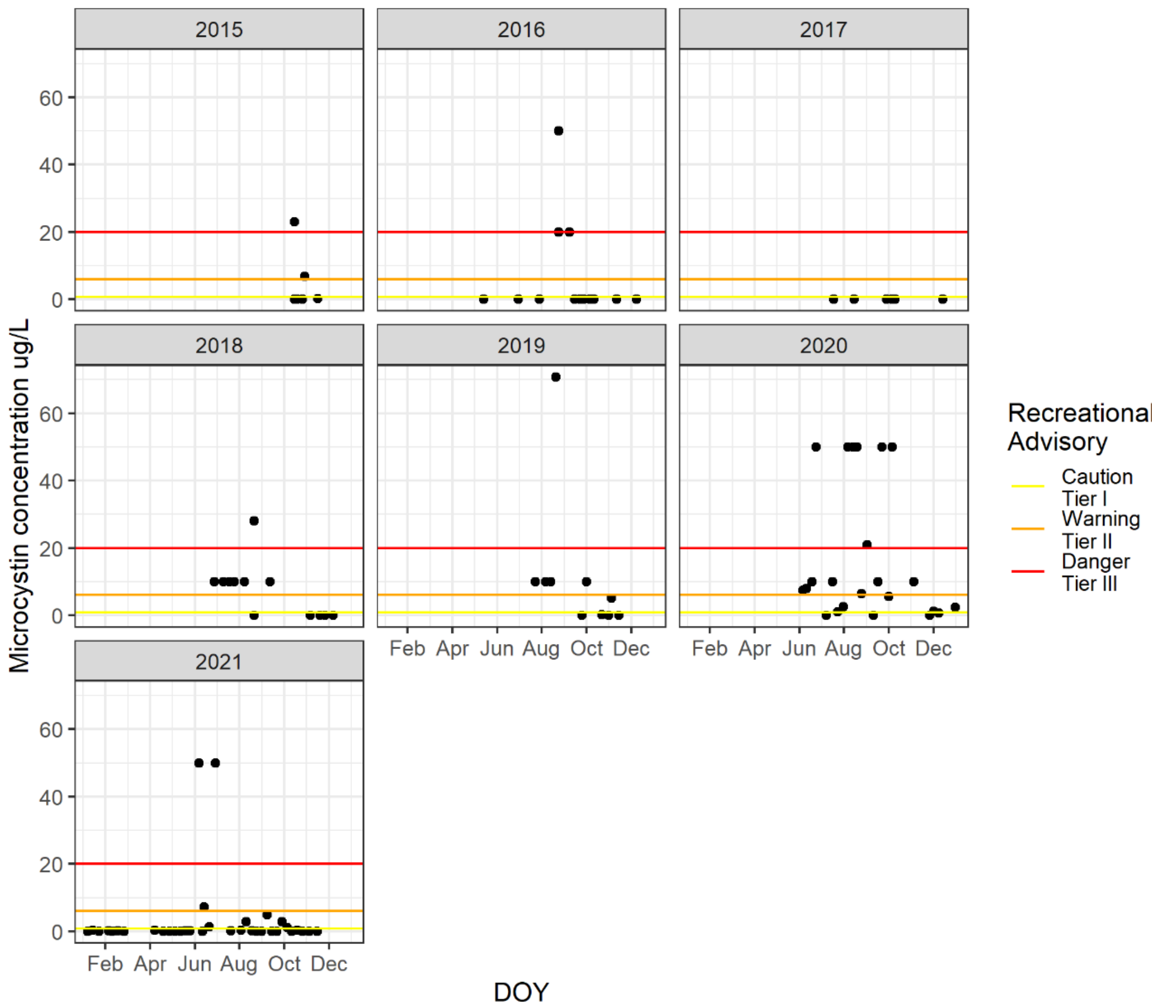


Figure 2-29 Concentration (Organisms/mL) of Potentially Toxic Cyanobacteria Collected by the Environmental Monitoring Program throughout the Delta, by Region and Year



NOTES: Concentrations above the Danger level were seen in every year except 2017. Data provided by East Bay Regional Parks.

Figure 2-30 Concentrations of Microcystins Found at Big Break Regional Shoreline, 2015–2021

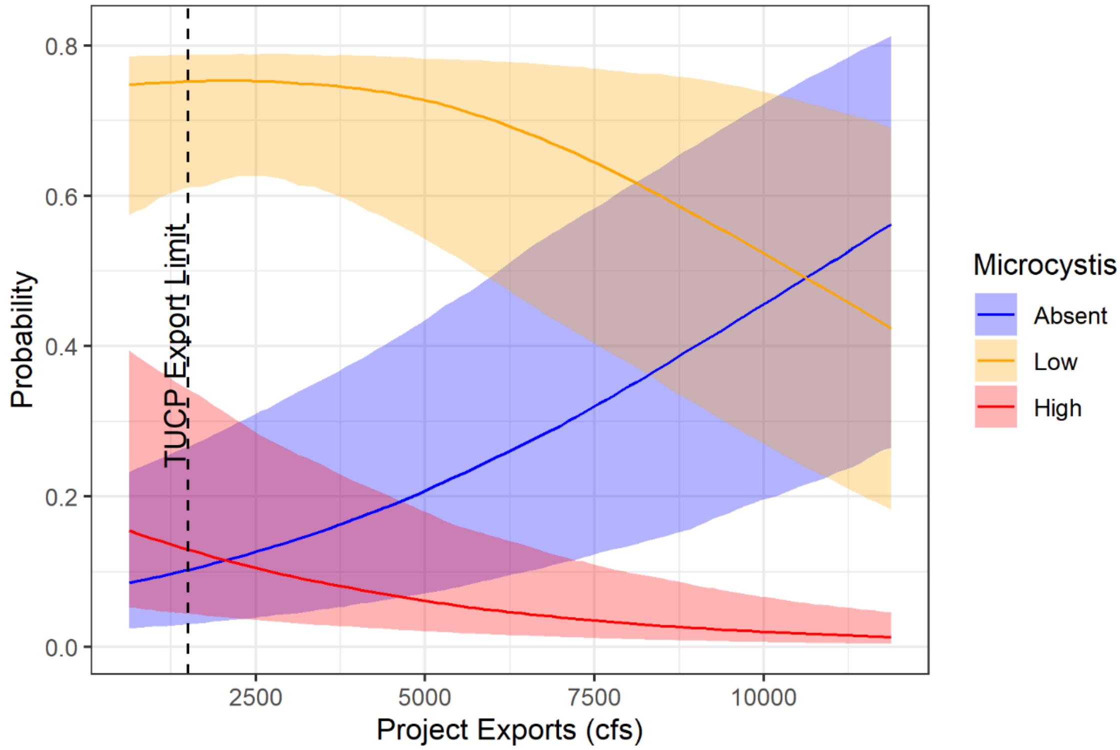
TABLE 2-12
MODEL COMPARISON OF ALL BAYESIAN MIXED MODELS PREDICTING PRESENCE OF *MICROCYSTIS* (ABSENT, LOW, OR HIGH) IN THE INTEGRATED DATA SET OF VISUAL ASSESSMENT DATA

Model Terms	WAIC	SE WAIC	Delta WAIC
Temp + Exports + Secchi	2680.9	59.2	0.0
Temp + Outflow + Exports + Secchi	2685.8	59.2	4.9
Temp + Outflow + Secchi	2724.3	60.1	43.4
Temp + Secchi	2724.6	60.0	43.7
Exports + Secchi	2760.0	58.1	79.1
Exports + Outflow + Secchi	2761.9	58.1	80.9
Temp + Outflow + Exports	2762.0	59.5	81.1
Secchi+ Outflow	2793.3	58.8	112.3
Secchi	2794.5	58.8	113.6
Temp	2798.4	59.9	117.5
Temp + Outflow	2802.2	60.1	121.3
Exports	2863.7	58.5	182.8
Exports + Outflow	2865.7	58.5	184.8
Outflow	2895.4	59.0	214.5

NOTES: WAIC = Widely Acceptable Information Criterion. SE WAIC = Standard error in WAIC. Delta WAIC = Difference in WAIC between model and best model. The model with the lowest WAIC is considered the best fit.

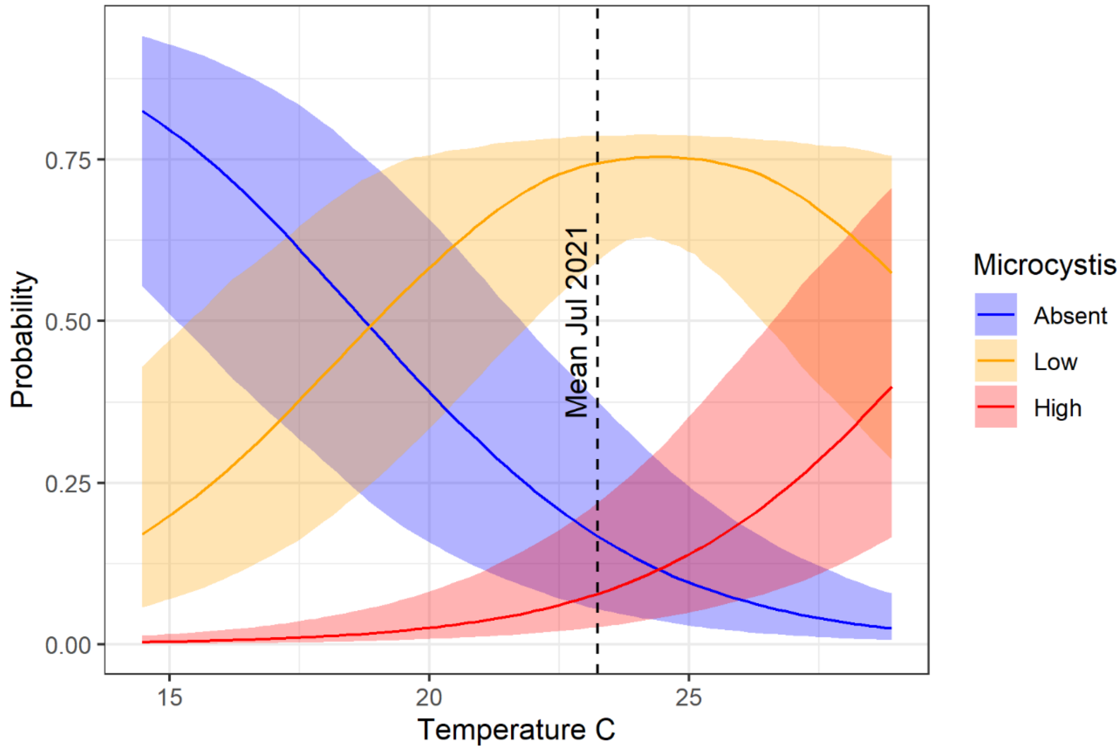
The model found that increased exports were correlated with decreased probability of low or high *Microcystis* observations, and increased probability of absence (**Figure 2-31**). However, this effect was most obvious over relatively large changes in exports. Increased temperature and increased Secchi depth also increased the probability of low or high *Microcystis* observations (**Figure 2-32**, **Figure 2-33**).

With the monthly average temperatures and Secchi depths observed in 2021, the model predicted that increasing exports by 1,000 cfs (from 1,500 to 2,500 cfs) resulted in a 1 to 8 percent change in the probability of *Microcystis* occurrence (**Figure 2-34**). However, the overlapping confidence intervals indicated that this difference is not significant.



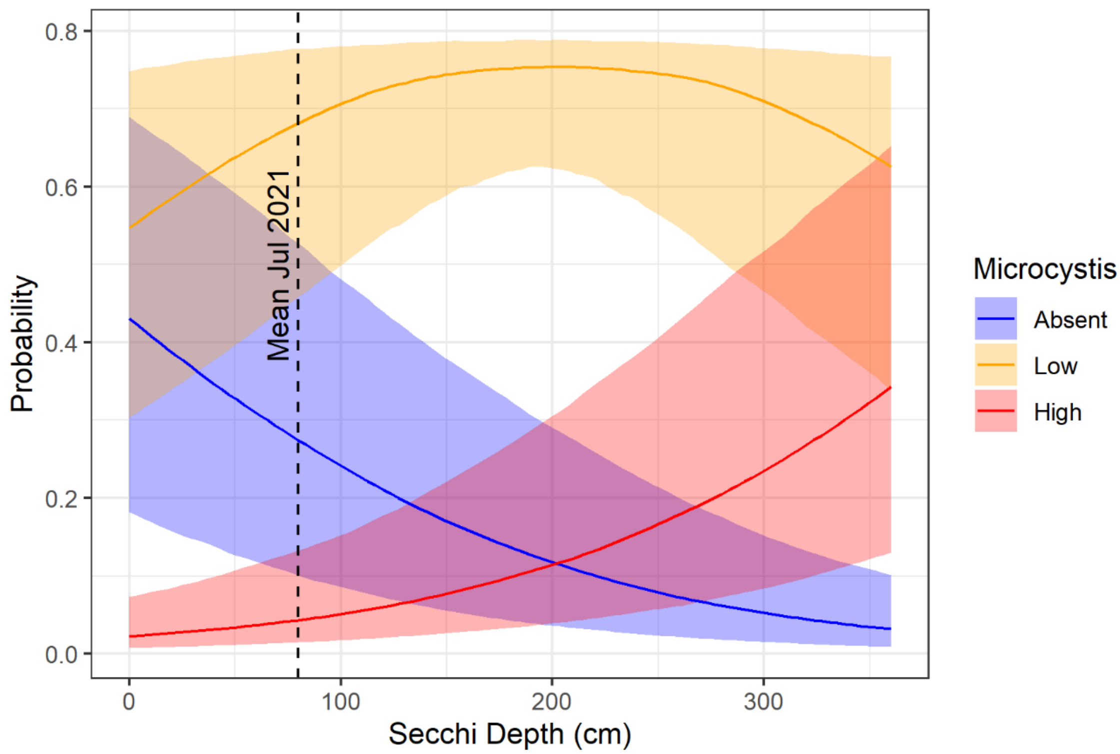
NOTE: Shaded regions represent the 95% credible interval.

Figure 2-31 Conditional Plot Showing the Predicted Value (+/- 1SE) of *Microcystis* with Varying Rates of Combined State Water Project and Central Valley Project Exports, Based on the Model of Environmental Drivers



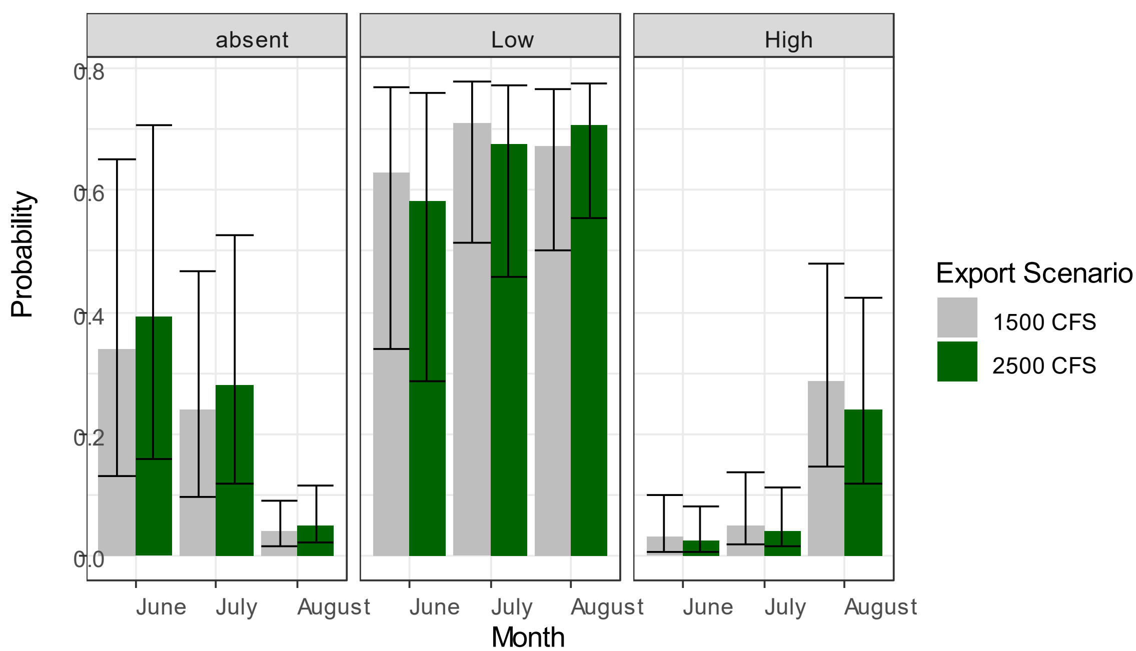
NOTE: Shaded regions represent the 95% credible interval.

Figure 2-32 Conditional Plot Showing the Predicted Value (+/- 1SE) of *Microcystis* with Varying Temperatures, Based on the Model of Environmental Drivers



NOTE: Shaded regions represent the 95% credible interval.

Figure 2-33 Conditional Plot Showing the Predicted Value (+/- 1SE) of *Microcystis* with Varying Secchi Depths, Based on the Model of Environmental Drivers



NOTE: Error bars represent the 95% credible interval.

Figure 2-34 Predicted Change in the Probability of Detecting M*icrocystis* in Visual Surveys in the South and Central Delta, Based on the Model of Turbidity, Temperature, and Exports

Nutrient Pool

During the summer months of the last eight years, nitrogen-to-phosphorus ratios have been consistently less than 16:1 across all regions (ranging from a mean of 4.8 in the Cache/Liberty region to 12.0 in the Lower Sacramento River region; Appendix A, Figure A-3). This indicates that nitrogen, and not phosphorus, was the limiting nutrient during periods of phytoplankton and cyanobacterial bloom development.

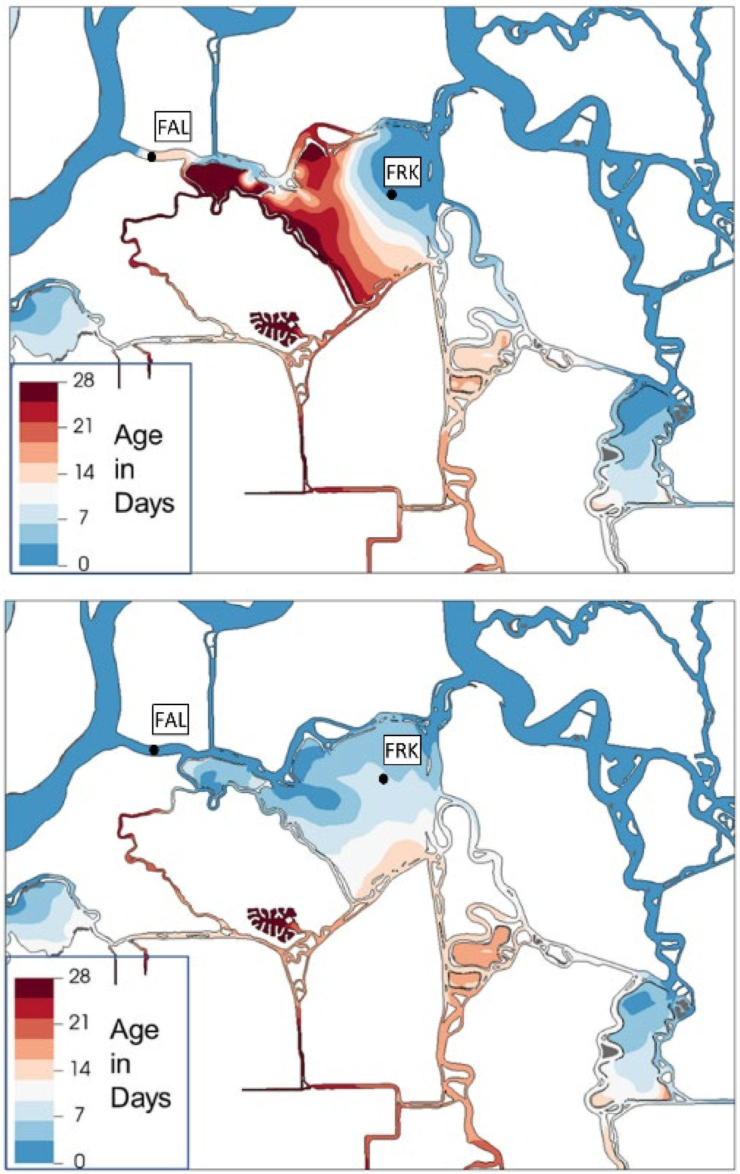
Although nitrogen is more likely to be limiting than phosphorus, nitrogen in the South and Central Delta was not found to be a limiting factor in chlorophyll-a production. Measured chlorophyll-a is typically 5–10 percent of the potential chlorophyll-a, based on nitrogen concentrations (**Figure 2-35**). Exceptions to this were the spring Aulacoseira bloom of 2016, a bloom in the Lower San Joaquin River and Franks Tract in July 2017, and the bloom observed in August 2021. In these cases, the nitrogen supply dropped to below the reporting limit in some regions, with very little excess nitrogen for further phytoplankton growth.

NOTE: Potential chlorophyll-a for 2014–2021 based on the ratio of 1 µmol nitrogen to 1 µg chlorophyll.

Figure 2-35 Potential Chlorophyll-a (Green) and Measured Chlorophyll-a (Orange)

Models of Water Age and Temperature

Figure 2-36 shows simulated mean age on August 17, 2021, with and without a barrier. The selected date coincides with a medium-strength spring tide and is timed sufficiently long after the closure of the barrier that the longest reported ages are developed entirely with the barrier in place. The images show that there is greater spatial organization of residence time within Franks Tract, with a clear gradient developing from northeast to southwest when the barrier is in place.



NOTE: “Age” is defined as time since contact with freshening flows from the San Joaquin River using the implementation described by Delhez et al. (2014). FAL and FRK are CDEC stations shown in Figure 2-5.

Figure 2-36 Modeled Daily Averaged Age of Water in Franks Tract with the Barrier (top) and without the Barrier (bottom) on August 17, 2021

The enhanced gradient in age is readily explainable in terms of changes in tidal flow on the two sides of Franks Tract. **Figure 2-37** shows time series of tidal flows for a period straddling the installation of the barrier at False River to the west (USGS 11313440, CDEC FAL) and Old River to the east (USGS 11313452, CDEC OSJ). Model flow is also shown to allow comparison with a no-barrier case and corroborate that the simulation correctly captures the very large changes that occur. Without the barrier, the tidal range of flow is generated through connections to the San Joaquin River, both on False River to the northwest and on Old River in the northeast. With two connections open, water is renewed from both sides and some net circulation is fostered. With the barrier installed, tidal flow from False River is mostly eliminated and the tidal range at Old River is nearly doubled. Because of the dominance of Old River in supplying replenishing flow, age in the With Barrier case becomes proportional to distance from that inlet. The resulting changes in age are not zero-sum; overall, age is increased in Franks Tract. However, there are significant areas of greater flushing to the east.

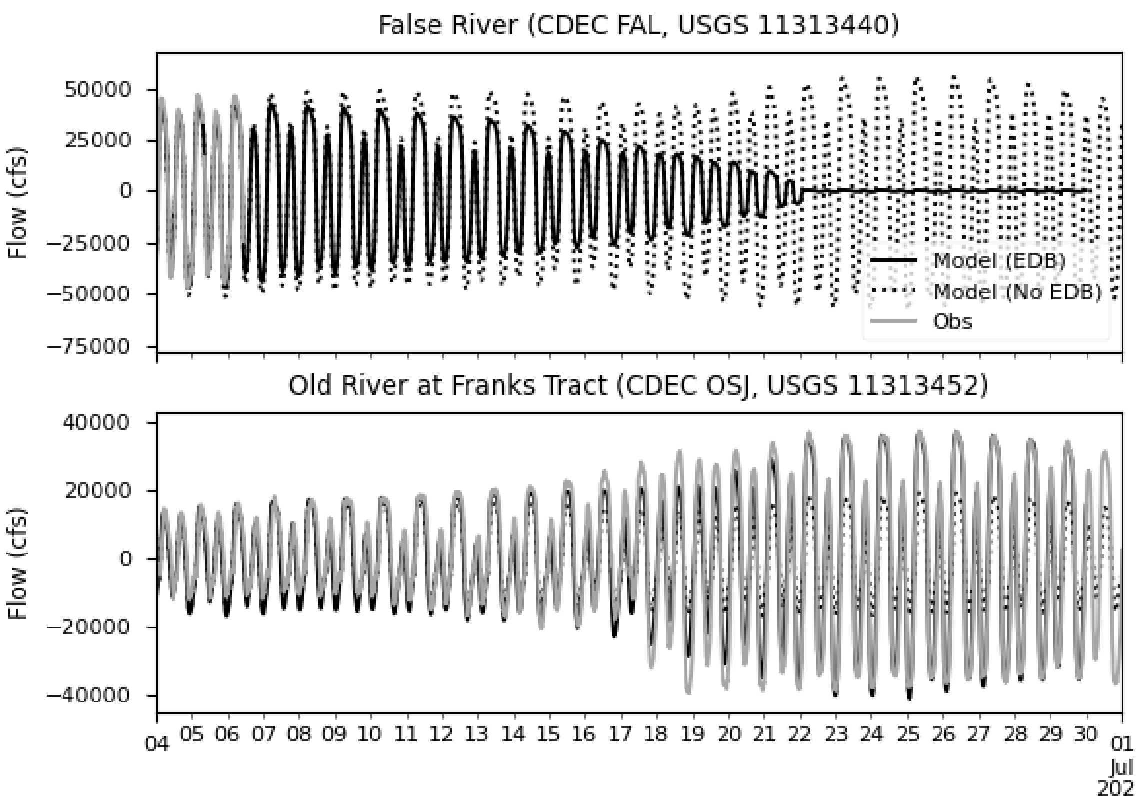


Figure 2-37 Modeled Flow with and without the Emergency Drought Barrier at False River and at Old River at Franks Tract

Differences in July mean temperature are shown in **Figure 2-38**. Mean temperature in Franks Tract is not as affected by the barrier as mean age is, with changes in the range of 0.1°C to 0.3°C. The reason for this more modest change is that water tends to reside in Franks Tract for a period that is long compared to the diel heat cycle. Local radiation and heat balance are therefore more important to temperature than advection of colder water. The exception to this generalization occurs right at the inlet of False River, where exchanges with colder San Joaquin River water have their greatest effect. There, the difference in temperature with the barrier is +0.59°C.

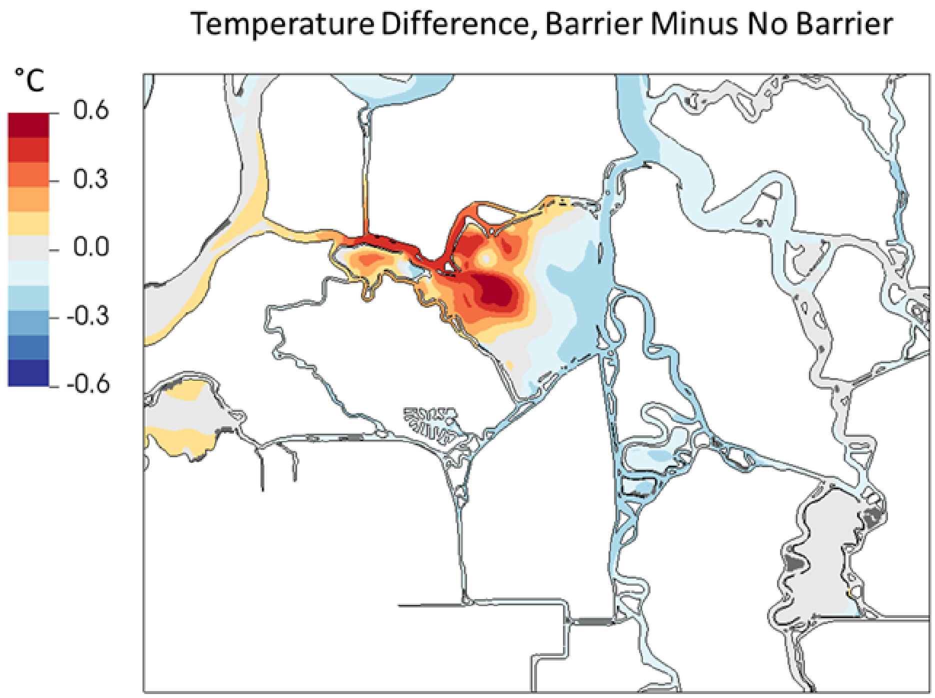


Figure 2-38 Modeled Difference in Water Temperature for Scenarios with and without the West False River Barrier

2.4 Discussion/Interpretation

2.4.1 Conditions in 2021

Microcystis was observed visually across the Delta in 2021, and cyanotoxins were detected in several sites in Franks Tract, the South Delta, and the Lower San Joaquin and Lower Sacramento rivers. A local high density of cyanobacteria was found within and around Franks Tract in late July and early August 2021. This bloom may have been exacerbated by the change in flow caused by the emergency drought barrier, but the precise mechanism remains unclear. Despite the late-July bloom, the data assembled from multiple sources for this report indicate no significant difference in the occurrence of *Microcystis* observations between 2021 and prior dry years (Figure 2-28). Outside of Franks Tract, areas with low cyanobacteria in previous years remained low, and hot spots of cyanobacteria blooms (such as Big Break and the Stockton Waterfront) remained hot spots. The highest levels of toxins occurred in areas with restricted flow and/or high residence times, such as the Stockton Waterfront, Discovery Bay, and Big Break Regional Shoreline, where they have been detected annually over the past several years.

Franks Tract Bloom

A large cyanoHAB began forming within Franks Tract in July 2021 and peaked in August before subsiding in September (Figure 2-12, Figure 2-13, Figure 2-14). This was also correlated with the higher-than-average chlorophyll-a in Franks Tract during this time period (Figure 2-7, Figure 2-25). The bloom appears to have initiated in mid-July (as seen in the satellite data as well [Figure 2-14]), before the EMP sampled; the bloom then accrued biomass through mid-August, when the EMP recorded its highest biomass values. No other blooms of similar size were seen in other regions of the Delta over the summer.

It is important to note that both the FluoroProbe data and the satellite data record concentrations of total cyanobacterial pigments; however, not all cyanobacteria are harmful. The most frequent cyanobacteria found in grab samples collected by the EMP (in terms of individuals per liter) is *Eucapsis* sp. (Brown 2021; Perry and Brown 2020), which does not produce toxins. Grab samples taken during the EMP's July and August surveys show that some of this bloom certainly contained *Microcystis, Aphanizomenon*, and *Dolichospermum* (Figure 2-29), but *Eucapsis* was also present in high abundance (data not shown).

These findings correspond to other changes in water quality as well, which indicates a large increase in photosynthesis around the end of June, as shown by increases in pH and DO above the thresholds seen in previous years before subsiding in September (Figure 2-22, Figure 2-23). Similar patterns in water quality have long been associated with cyanoHABs in water bodies worldwide (Talling 1976; Wilhelm et al. 2020), as the consumption of dissolved inorganic carbon by photosynthesis can drive pH levels near 11 (Ibelings and Maberly 1998; Verspagen et al. 2014). Research has indicated that these changes in water quality can benefit *Microcystis* and other toxin-producing taxa over other algae and cyanobacteria (Ji et al. 2020).

DO in Franks Tract is frequently supersaturated even in the absence of a bloom (Figure 2-23), a finding that is unsurprising given the amount of aquatic vegetation present. However, the levels of supersaturation seen in 2021 surpass those of previous years and correspond directly with the other observations of cyanoHAB formation shown here.

Human Health

Franks Tract experienced higher accumulation of cyanobacteria in Franks Tract during late summer 2021 than any previously seen in this location. While the magnitude of this bloom was still less than seen elsewhere in California (e.g., Clear Lake, where CI values can exceed 300 and microcystin toxin concentrations can exceed 4,000 µg/L [State Water Board HAB incidents map]), the fact that high levels of cyanobacteria occurred in an open-flow system is worrying. During the peak of the Franks Tract bloom (early August), the concentration of cyanotoxins was above the "Caution" level for recreational use, but still considered safe for swimming (Figure 2-16). While "safe to swim" for now, the trends toward higher and higher cyanobacteria blooms in the Delta is worrying.

Cyanotoxin sampling in other regions of the South Delta, OMR, and the Lower Sacramento and Lower San Joaquin rivers resulted in some samples at levels above the "Caution" guidance for posting signs in areas with contact recreation for anatoxins and microcystins (0.8 to 3 µg/L microcystins and 0.1 to 12 µg/L anatoxin-a). No toxins were detected in the Cache/Liberty region or the Upper Sacramento River region, mirroring the low frequency of visual observations of cyanoHABs in these regions. No toxins were detected at Clifton Court Forebay or Banks Pumping Plant in 2021, so SWP drinking water and irrigation water were not negatively affected.

There were also a few samples containing high anabaenopeptins in the Lower Sacramento River and Lower San Joaquin River regions (Figure 2-16). Little research has been conducted on the impacts of anabaenopeptins on human or aquatic health (Monteiro et al. 2021). They have been shown to inhibit certain proteases and have other nonlethal effects (Janssen 2019), but it is unclear whether the concentrations present in the Delta are cause for concern. The microcystins and anatoxin values are in the range of values detected in previous studies of cyanotoxins in the Delta (Lehman et al. 2022), and two of the data sets presented here were only collected in 2021, so it is unknown whether toxin concentrations in 2021 were significantly worse than normal as a result of the TUCP or EDB.

Dangerous levels of microcystins were present at Big Break Regional Shoreline, the Stockton Waterfront, and Discovery Bay (greater than 20 µg/L; Figure 2-18). However, these areas also experienced dangerous levels of microcystins in 2019 (a wet year) and 2020 (a dry year without a TUCP) (Figure 2-30, and data from https://www.mywaterquality.ca.gov/habs/where/freshwater_events.html, not shown). Concentrations of microcystins in the center of Big Break were much lower (Figure 2-16, "Lower SJ"; Appendix A, Table A-2), so it appears that the bloom was localized to the area right around the fishing pier and kayak launch.

Most of the cyanotoxin data presented in this report were collected as part of scientific special studies, so data were not available in time to make health recommendations for recreational users of the Delta. DWR is implementing enhanced monitoring for cyanotoxins in 2022 to address this problem (see the 2022 TUCO Condition 8 monitoring plan for details).

Aquatic Health Impacts

For fish and wildlife, the thresholds at which cyanoHABs may cause problems are less well understood. The microcystin concentrations detected in most of the Delta were well below the median lethal dose (LD_{50}) reported for most fish taxa (20–1,500 µg/L), but nonlethal effects have been reported at much lower levels (Office of Environmental Health Hazard Assessment Ecotoxicology et al. 2009). Microcystins can also bioaccumulate, particularly in zooplankton and mollusks; however, biodilution, rather than bioaccumulation, can also occur at higher trophic levels, and there is currently not enough research to know which process is dominant (Ferrão-Filho and Kozlowsky-Suzuki 2011; Hardy et al. 2015). Microcystins cause harmful effects on the liver, kidneys, gills, growth, and behavior (Acuña et al. 2012a; Acuña et al. 2012b; Office of Environmental Health Hazard Assessment Ecotoxicology et al. 2009). Liver lesions are frequently found in fish throughout the Delta (Fong et al. 2016; Johnson et al. 2010; Teh et al. 2020), and while these lesions may be caused by a number of toxic contaminants, microcystins may be part of the overall toxicity of the Delta, particularly in drought years.

Less research has been done on the impact of cyanotoxins on invertebrates. Studies of the dominant calanoid copepods in the estuary (*Eurytemora affinis* and *Pseudodiaptomus forbesi*) found LD_{50} levels greater than 520 µg/L of microcystins, with chronic, nonlethal effects at 140 µg/L (Ger et al. 2009), much higher than levels observed at Franks Tract in summer 2021 (3 µg/L). However, ingestion of *Microcystis* did cause significant mortality in both species, with higher mortality in the native *E. affinis* than the non-native *P. forbesi* (Ger et al. 2010b).

This is an area of active research, and recent evidence suggests that some types of cyanobacteria may actually be preferred food for copepods (Holmes and Kimmerer 2022; Kimmerer et al. 2018). Because the cyanoHABs recorded in Franks Tract were made up of multiple taxa, the full impact on invertebrates is hard to predict.

Other research has implicated *Microcystis* in broad changes to both phytoplankton and zooplankton communities in the Delta when it is present in high abundance (Lehman et al. 2010; Lehman et al. 2021). Many cyanobacteria have allelopathic effects on other phytoplankton (Chia et al. 2018; Lehman et al. 2010; Otten et al. 2017), or may affect both the phytoplankton and zooplankton communities through differential toxicity to zooplankton, which, in turn, feed on different phytoplankton. This report did not analyze potential impacts of cyanoHABs on other phytoplankton, zooplankton, or fishes, but this is an important area for future research.

Impacts of cyanoHABs go beyond the impacts of their toxins. As seen in the continuous monitoring data (Figure 2-22, Figure 2-23), cyanobacteria blooms (or any area of freshwater with large amounts of photosynthesis) can cause elevated pH and extremely variable DO (Sutula et al. 2017). Elevated pH can cause problems for fish and invertebrates, with most fish taxa experiencing negative effects at a pH above 9.5 and dying at a pH above 10 (Beklioglu and Moss 1995; Kann and Smith 1999; Scott et al. 2005).

In many cases, these negative effects on fish taxa are attributable to the shift in ion concentrations in the water with ammonium ($NH4^+$) to ammonia (NH3), which is toxic to fish. At a pH of 8, water contains almost 100 percent ammonium, while at a pH of 10.5, the water contains almost 100 percent ammonia (Salbitani and Carfagna 2021). Fish also reduce their ability to excrete ammonia and increase blood ammonia concentrations at high pH (Scott et al. 2005). Abrupt changes in pH, such as those caused by rapid changes in photosynthesis over the course of a day, may be particularly stressful for larval fishes (Mischke and Wise 2008), although most native fish have grown out of their larval stage by the summer when blooms most frequently occur. Sustained increases in pH also have negative impacts on many zooplankton taxa and some phytoplankton (Beklioglu and Moss 1995).

Large swings in DO (Figure 2-23) in Franks Tract were also seen during the bloom. Oxygen increases during the daytime when the high concentrations of phytoplankton are actively engaged in photosynthesis, and then decreases at night when photosynthesis rates drop and respiration continues to draw down oxygen supply. In many situations, the end of a bloom will result in extremely low (less than 2 mg/L) DO as dying algae increase biological oxygen demand and there is no longer adequate photosynthesis to keep up. A crash in DO was not seen at the end of the 2021 Franks Tract bloom, but this is something to watch for in the future, especially if blooms occur in areas with poor circulation, such as the Stockton Ship Channel (Jassby and Van Nieuwenhuyse 2005).

2.4.2 Differences between Years

Occurrence of Cyanobacterial Harmful Algal Blooms

Issues with cyanoHABs arose in 2021, but these issues were similar to issues experienced in other dry years. The visual index data found a significantly higher incidence and abundance of cyanoHABs in dry years (2014, 2015, 2016, 2018, 2020, 2021) than in wet years (2017, 2019) (Figure 2-27, Figure 2-28). This is consistent with previous research indicating a strong inverse relationship between *Microcystis* concentrations in the Delta and freshwater flows through the Delta (Lehman et al. 2013).

The visual *Microcystis* observations should be analyzed realizing the inherent biases in the data: There may be differences between observers, observations may change with light or turbidity, and the observations may fail to pick up taxa other than *Microcystis*. However, they provide high-frequency, broad-scale data not available with other methods (960 observations in 2021 alone; Table 2-2).

Community Composition

Interestingly, on a Delta-wide scale, there was a slightly higher incidence of high *Microcystis* observations in 2020 than in 2021 (Figure 2-27), while 2021 had a higher abundance of harmful cyanobacteria in grab samples (Figure 2-29). In addition, chlorophyll-a concentrations in the South Delta in spring and summer were higher in 2021 than in 2020 (Figure 2-25, Figure 2-26). Some of this difference may be because *Microcystis* is most common in surface scum and the EMP samples were being collected 1 meter below the surface. Also, the EMP samples a very small volume (60 mL), so it may miss *Microcystis* if it is present in large colonies. Additional surface samples targeting *Microcystis* began in August 2021 and will continue through 2022 to better capture this difference. However, without similar samples collected during 2020, it remains unknown whether surface *Microcystis* concentrations have changed.

Another key observation was that more *Dolichospermum* was present in 2021 than in previous years (Figure 2-29). CyanoHAB research in the Delta to date has focused primarily on *Microcystis*; however, other harmful cyanobacteria, such as *Dolichospermum* and *Aphanizomenon*, are becoming increasingly prevalent (Lehman et al. 2021).

Aphanizomenon produces cylindrospermopsin, saxitoxin, and anatoxins, while *Dolichospermum* can produce microcystins and anatoxins (Chorus and Welker 2021). Anatoxins are toxic at much lower concentrations than microcystins, and act on the nervous system instead of the liver (Chorus and Welker 2021). These toxins were detected at Big Break and near Decker Island in 2021 (Figure 2-16), but were much less common than microcystins. No saxitoxins or cylindrospermopsins were detected in any of the samples during summer 2021, but low concentrations of saxitoxins have been found in the Delta in previous studies (Lehman et al. 2021). The lack of these toxins in 2021 could have been attributable to the relatively low concentrations of these cyanobacteria, strains of these genera without toxin-producing genes, or sampling during time periods of low toxin production. Increased sampling in future years may help explain this result.

Based on the physiological capabilities of these different genera, one would expect *Aphanizomenon* to dominate early in the bloom, with *Microcystis* gaining a competitive advantage as water temperature rises: The optimum temperature for *Microcystis* is 28°C, whereas for *Aphanizomenon* it is 20°C (Reynolds 2006). In other systems, *Aphanizomenon* often precedes *Microcystis* (Konopka and Brock 1978; Paerl and Otten 2016; Zhang et al. 2020a), which aligns with the decrease in *Aphanizomenon* in the Delta in August and September. This may be caused by temperature, because other studies have found that *Microcystis* dominates at warmer temperatures (higher than 17°C) and *Dolichospermum* at cooler temperatures (Zhang et al. 2020a).

Allelopathic effects by *Microcystis* on other cyanobacteria have also been posited to contribute to *Microcystis* dominance and could partially explain the subdominant abundance of *Dolichospermum* and *Aphanizomenon* during *Microcystis* dominance (Chia et al. 2018; Ma et al. 2015). The presence of all three genera during summer 2021 may be attributable to concentrations of the various species at the start of a bloom, combined with environmental factors and differences in intrinsic growth rates that may interact in unpredictable ways.

2.4.3 Drivers

Impact of the Temporary Urgency Change Petition

The TUCP affected Delta outflow and SWP and CVP exports. Flow is an important driver of cyanoHABs, and flow can also affect other drivers, including turbidity and salinity. The authors of this report found no evidence that the reduction in outflow with the TUCP caused a major change in cyanoHABs. Very low exports may have had minor effects on cyanoHABs in the South Delta (Figure 2-33, Figure 2-34), but this effect was not large enough to be statistically significant.

The underlying cause of increased *Microcystis* with decreased flow (either exports, outflow, or inflow) is the increase in residence time. It was surprising that outflow was not included in the top-ranked model of summer *Microcystis* in the South Delta, given the previous work indicating that flow is a key predictor of *Microcystis* (Lehman et al. 2013; Lehman et al. 2022). This omission may be attributed to the fact that the analysis was limited to the summer and fall months (June–October). Outflow is usually fairly low during this time period (Interagency Ecological Program Drought Management, Analysis, and Synthesis Team 2022); thus, further reduction in outflow may not be as important as temperature, turbidity, and other flow metrics, such as exports.

Export significantly changed water residence time, particularly in the South Delta and San Joaquin River Corridor (Hammock et al. 2019), so export may be a better indication of growth potential during the summer in the South Delta than Delta outflow. Furthermore, Lehman et al. (2022) developed a regression model showing that water temperature and X2 could explain a significant portion of the variation in *Microcystis* abundance in the Delta between the extreme wet year of 2017 and the extreme drought year of 2014. X2 is the position along the axis of the estuary where the bottom salinity is 2 practical salinity units (Jassby et al. 1995). It is therefore related to both Delta outflow and residence time in the Delta, but is not a direct measurement of either. X2 was not included in the models because it was less directly affected by the TUCP than exports and outflow.

In most years, exports are relatively high in the summer, but years with a TUCP and barrier have very low summer export rates (Figure 2-19). Unfortunately, there is no way to accurately model what export rates would have been "without the TUCP." If SWP and CVP operations were required to meet D-1641 conditions in these hydrologic conditions, SWP and CVP exports would have most likely been restricted to extremely low levels (health and safety export rates) to provide enough water to meet Delta outflow standards. Therefore, it is unclear whether the export rate required by the TUCO is higher or lower than it would have been otherwise.

Impact of the Emergency Drought Barrier

When comparing years with a West False River barrier (2015, 2021) to dry years without a barrier (2014, 2016, 2018, and 2020), no clear patterns were seen in visual observations of *Microcystis* or concentrations of potentially toxic cyanobacteria from grab samples. Analysis of visual observations did not find significant differences between 2020 and 2021 or 2015, 2014, and 2016 (Figure 2-27, Figure 2-28). Concentrations of harmful cyanobacteria in grab samples were higher in 2021, but 2015 had very low concentrations compared to other dry years (Figure 2-29). These observations are supported by previous studies of cyanoHABs during the 2014–2015 drought, which found that cyanobacterial concentrations were much lower in 2015 than in 2014 (Lehman et al. 2018), nor did the 2015 barrier appear to enhance blooms in September–November 2015 (Kimmerer et al. 2019).

No large blooms were detected in Franks Tract in 2020, despite the high incidence of *Microcystis* in visual assessments across the Delta (Figure 2-27). Smaller blooms occurred at Mildred Island in July of both 2020 and 2021 (Figure 2-14). The large shift in cyanobacterial abundance in Franks Tract from 2020 to 2021, and the lack of shift at Mildred Island, provide a strong indication that the barrier may have played a role in bloom development within Franks Tract. However, the lack of a bloom in 2015 makes it clear that the EDB is not the only factor important in bloom development (Kimmerer et al. 2019; Lehman et al. 2018).

The Barrier most likely played a role in the late July bloom, but the mechanism is not totally clear. The residence time of water within Franks Tract was significantly increased on the western side of the tract, based on the model shown in Figure 2-36. Decreased flow is a well-known driver of algal blooms of all kinds (Glibert et al. 2014a; Lehman et al. 2013), so the major restriction of flow within Franks Tract could have been a factor in allowing the bloom to establish. However, change in residence time differed in different regions of Franks Tract. The eastern side of the tract experienced increased flow and decreased residence time (Figure 2-36), and the largest concentration of cyanobacteria was seen in this region of increased flow (Figure 2-15). Therefore, although change in flow through the system may have exacerbated the bloom, it was not the only factor at play. It is possible that flow from Old River "seeded" Franks Tract with

Microcystis, and reduced flow stopped it from being flushed out, or changes to tidal flow reduced mixing in the system.

The complex interactions between residence time, water quality, availability of light, nutrients, SAV, and cyanoHABs may have produced these unexpected results. Franks Tract has become more and more inundated with aquatic vegetation in recent years (see Section 3, *Weeds*), which can further reduce flow and increase residence time (Boyer and Sutula 2015 and references cited therein). SAV maps from 2021 show a clearing of SAV on the eastern side of the tract, where cyanobacteria concentrations were highest (Figure 3-7 in Section 3). SAV could have been competing with cyanobacteria, blocking them from this region, or could have prevented the satellite from detecting them.

Submersed vegetation decreases turbidity (Hestir et al. 2016), potentially increasing the availability of light for cyanoHABs, but reduces light availability under the canopy. SAV may also compete with cyanobacteria for nutrients (Dahm et al. 2016), and reduction in water flow may reduce the transport of nutrients into the area, limiting the growth of phytoplankton of all types (Berg and Sutula 2015; Glibert et al. 2014a). While both nitrogen and phosphorus concentrations in the South Delta were similar to concentrations in previous years (Figure 2-25), sampling within Franks Tract was limited to a few points. There may have been spatially variable drawdown of nutrients within the weed bed. SAV may also provide a substrate for epiphytic cyanoHABs. Cyanobacteria associated with SAV have become a problem for wildlife health in other areas (Wilde et al. 2014), but remain understudied in the Delta.

Impact of Temperature

Another major driver of cyanoHABs in the Delta is water temperature. In particular, 19°C has been identified as the threshold above which *Microcystis* blooms initiate in the Delta (Lehman et al. 2013).

High temperatures throughout the Delta, particularly high temperatures in Franks Tract and the South Delta in 2020 and 2021, likely contributed to the severity of cyanoHABs seen in these years. Looking at the impact of temperature across years, years with more degree-days above 19°C over the course of the summer, particularly when the high temperatures started early in the season, most likely contributed to more blooms. In particular, 2020, 2015, and 2021 had more degree-days than other years. 2020 also warmed earlier, with a May maximum temperature of 26.2°C at Bethel Island, and temperatures stayed warm late into the fall (Appendix A, Figure A-1, Figure A-2).

However, these high temperatures are unlikely to have been caused by the TUCP or EDB, because modeling indicated temperature changes of less than 0.6°C attributable to the barrier, and these effects were very localized (Figure 2-36). Water temperatures in the Delta are driven primarily by air temperature (Vroom et al. 2017), so the relatively small impact of the barrier on temperature is not surprising.

Impact of Nutrients

Nutrients are considered one of the major causes of cyanoHABs in most systems. However, the authors of this report found that dissolved inorganic nitrogen and phosphorus were usually not limiting (Figure 2-35). This is in agreement with previous research showing that nutrient levels are not generally limiting to phytoplankton production in the Delta (Dahm et al. 2016; Jassby et al. 2002), and reductions in point-source nitrogen from the Stockton and Sacramento wastewater treatment plants have failed to prevent increases in cyanoHABs over the last 10 years (Cloern et al. 2020; Senn et al. 2020).

Some research has claimed that the form of nitrogen (ammonium versus nitrate) may drive phytoplankton community composition, with high levels of ammonium driving higher proportions of cyanobacteria (Glibert et al. 2014b), but this hypothesis is somewhat controversial (Cloern 2021). *Microcystis* has been shown to selectively uptake ammonium, rather than nitrate (Lehman et al. 2015), but the proportion of ammonium in the estuary's inorganic nitrogen supply has also decreased in recent years (Cloern et al. 2020), leaving ammonium enrichment as a poor explanatory factor in the increase of *Microcystis* blooms.

2.5 Potential Mitigation of Cyanobacterial Harmful Algal Blooms

To better predict and respond to future cyanoHABs in the Central Delta that may be related to DWR's drought actions, DWR is increasing monitoring of cyanoHABs and associated toxins in the Delta. Whole-water grab samples will be collected at several additional stations in Franks Tract, Mildred Island, and other stations in the South and Central Delta. In addition, a new SPATT station will be established in Franks Tract, which will be part of an existing study of cyanotoxins throughout the Delta currently being conducted by USGS and DWR (see the 2022 TUCO Condition 8 monitoring plan for details).

Actions that can be taken to mitigate and/or prevent cyanoHAB occurrences in months when the risk of occurrence is high, and the barrier is in place (i.e., July–October), are still being explored. Some possible avenues are to reduce nutrient inputs, investigate biological controls such as cyanophages or grazers (Pal et al. 2020), implement mechanical control methods to increase turbidity and mixing (Kibuye et al. 2021b), reduce a bloom after it has started through chemical control methods (Kibuye et al. 2021a), or reduce residence time through flow manipulations.

Preventing blooms from forming is often more effective than trying to reduce a bloom after it is initiated. The least intrusive and most effective method of preventing cyanoHABs from occurring is usually to limit nutrient availability (Kibuye et al. 2021b). However, in a region like the Delta where agricultural nonpoint-source inputs of nutrients dominate, this is an option that is challenging to implement at the source. Moreover, nutrients were not found to be limiting production in most regions and time periods in this and other analyses of the Delta (Jassby et al. 2002), so this strategy may not be as effective in the Delta as it has been elsewhere.

Top-down control of cyanoHABs may also be difficult. Most grazers (such as copepods) preferentially avoid small cyanobacteria or toxic species (Ger et al. 2010a; Lucas et al. 2016). Some research has shown that cyanophages may be able to control cyanoHABs in laboratory settings, but this has not been tried at the field scale (Pal et al. 2020). These methods are most effective in small, enclosed water bodies rather than in an open area like the Delta.

Mechanical methods for controlling cyanoHABs take advantage of the fact that, compared with eukaryotic phytoplankton such as diatoms, cyanobacteria have poor light absorption efficiencies, and thus have low rates of photosynthesis for a given light intensity (Visser et al. 2016). This is particularly the case for *Microcystis*, which has one of the lowest photosynthetic efficiencies when compared with other cyanoHABs (Wu et al. 2009).

It is important to note that mechanical control methods are particularly well-suited for the control of buoyant cyanoHAB genera, in contrast with non-buoyant cyanoHAB genera such as *Planktothrix* and *Cylindrospermopsis* (Burford and O'Donohue 2006; Reynolds et al. 1983). In addition to physically moving cyanoHABs around in the water column, mechanical/artificial mixing may increase sediment suspension and turbidity, shading the water column and lowering cyanoHAB growth rates.

Mechanical control of cyanoHABs through mixing has been proven effective on small scales, such as ponds or small lakes (Burford and O'Donohue 2006; Visser et al. 2016); however, it has not been attempted in a large, tidal environment such as Franks Tract. Mechanical mixing on the scale of Franks Tract would be cost-prohibitive, and high densities of SAV in the tract are likely to make mechanical mixing ineffective. Furthermore, the high winds and tides may already be mixing Franks Tract as much as is possible, given the high density of vegetation in the site.

If a bloom has already developed, artificial control methods for arresting the bloom include decreasing residence times, reducing the availability of nutrients, and directly killing the cyanoHAB species via an algicide. The availability of phosphorus can be reduced by adding aluminum salts or lanthanum clay (Phoslock), which form flocs that bind both phosphate and cyanobacterial cells and clear the water column (Kibuye et al. 2021a). The efficacy over time of this method is not well understood; it is likely to be most effective in a closed system, and repeated applications will most likely be necessary. Using algicide or aluminum salts in a region with special-status species may not be possible, depending on nontarget effects and permitting constraints.

With respect to Franks Tract, a decrease in the residence time of the water may be accomplished by cutting a temporary notch into the barrier, if feasible, while maintaining other water quality standards. Decreases in residence time can also be achieved by increasing SWP and CVP exports or Delta outflow. Unfortunately, all of these mechanisms require additional water supplies, which are typically not available during extremely dry years.

There is a broad need for greater monitoring and coordination on the subject of cyanoHABs beyond the effect of the 2021 drought actions. Therefore, DWR is participating in multiple efforts toward tackling harmful algal blooms on a variety of levels, including the CCHAB Network, where the results of this study were shared in January 2022; the Interagency Ecological Program’s Phytoplankton and Nutrients Project work team; and the HAB workshop being organized by the Delta Science Program in fall 2022. Participants in all of these efforts are working to increase data collection, sharing, and analysis across member agencies to elevate the issue of cyanoHABs in the Delta. Sharing methods and data in these forums and developing a framework for a long-term, integrated monitoring program will increase the collective capacity to understand and respond to cyanoHABs.

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SECTION 3
Weeds

3.1 Introduction

3.1.1 Ecology and Impacts

Aquatic vegetation provides important structure and function for aquatic organisms and waterfowl and greatly influences nutrient cycling, water quality, and the stability of sediments (Caraco and Cole 2002; Miranda et al. 2000). Diversity of fish and invertebrate species tends to be greater in native aquatic plant beds, and water quality conditions are generally more favorable for native fish and invertebrates (Boyer et al. 2013; Kuehne et al. 2016; Toft et al. 2003). Alternatively, non-native aquatic plants can have dramatic spatial and temporal effects on DO, temperature, and pH (Caraco and Cole 2002; Frodge et al. 1990) and can affect fish and macroinvertebrates (Brown 2003; Nobriga et al. 2005; Schultz and Dibble 2012).

Aquatic vegetation is commonly discussed in terms of its growth forms: submersed aquatic vegetation (SAV), emergent aquatic vegetation (EAV), and floating aquatic vegetation (FAV) (Boyer and Sutula 2015).

SAV grows predominantly below the water's surface in the subtidal region and may or may not be rooted in the sediment. Some examples of SAV found in the Delta include Brazilian waterweed (*Egeria densa*), coontail (*Ceratophyllum demersum*), curlyleaf pondweed (*Potamogeton crispus*), sago pondweed (*Stukenia pectinata*), and Canadian waterweed (*Elodea canadensis*).

EAV is rooted in shallow water, with the majority of its growth occurring above the water's surface. Examples include cattail (*Typha* sp.), tules (*Schoenoplectus sp.*), and common reed (*Phragmites australis*).

FAV floats on the water's surface and is not rooted in the sediment. An example of FAV in the Delta is water hyacinth (*Eichhornia crassipes*), although creeping emergents such as water primrose (*Ludwigia* sp.)

and alligatorweed (*Alternanthera philoxeroides*) are also frequently categorized as "FAV."

3.1.2 Weeds in the Delta

Coverage of FAV and SAV across the legal Delta has increased over the past 20 years (Ta et al. 2017), with particularly high increases seen during the last drought (Kimmerer et al. 2019). From 2008 to 2019, aquatic vegetation increased in coverage by 2.4 times (from 7,100 acres to 17,300 acres), occupying nearly one-third of the area of Delta waterways (Ta et al. 2017; Khanna et al. 2022).

This expansion of SAV has caused a suite of problems for use of the Delta, including clogging of water infrastructure, navigation hazards, and difficulty conducting scientific surveys (Caudill et al. 2021; Khanna et al. 2019). There have also been major changes to ecosystem functions: increased water clarity (Hestir et al. 2016), changes to nutrient cycling (Boyer and Sutula 2015), reduction in sediment supply for tidal marshes (Drexler et al. 2020), increased invasive fish habitat (Conrad et al. 2016), changes to primary production (Cloern et al. 2016), and changes to the composition of invertebrate communities (Young et al. 2016).

Impacts of SAV and FAV in the Delta have become severe enough that management has intervened to mitigate impacts on human use of the waterways. The Aquatic Invasive Plant Control Program of the California Department of Parks and Recreation, Division of Boating and Waterways (DBW) is chiefly responsible for control of aquatic vegetation in the Delta and employs primarily chemical control tools. DBW is permitted to treat up to 15,000 acres per year of aquatic vegetation, although typically it treats only about 40 percent of that limit, because of funding and logistical constraints (California Department of Parks and Recreation, Division of Boating and Waterways 2020).

3.1.3 Drivers

Factors contributing to the biomass of aquatic vegetation were organized into a conceptual model (**Figure 3-1**). These include parameters that affect growth and photosynthetic rate, parameters that affect establishment, and top-town effects of grazers or herbicides.

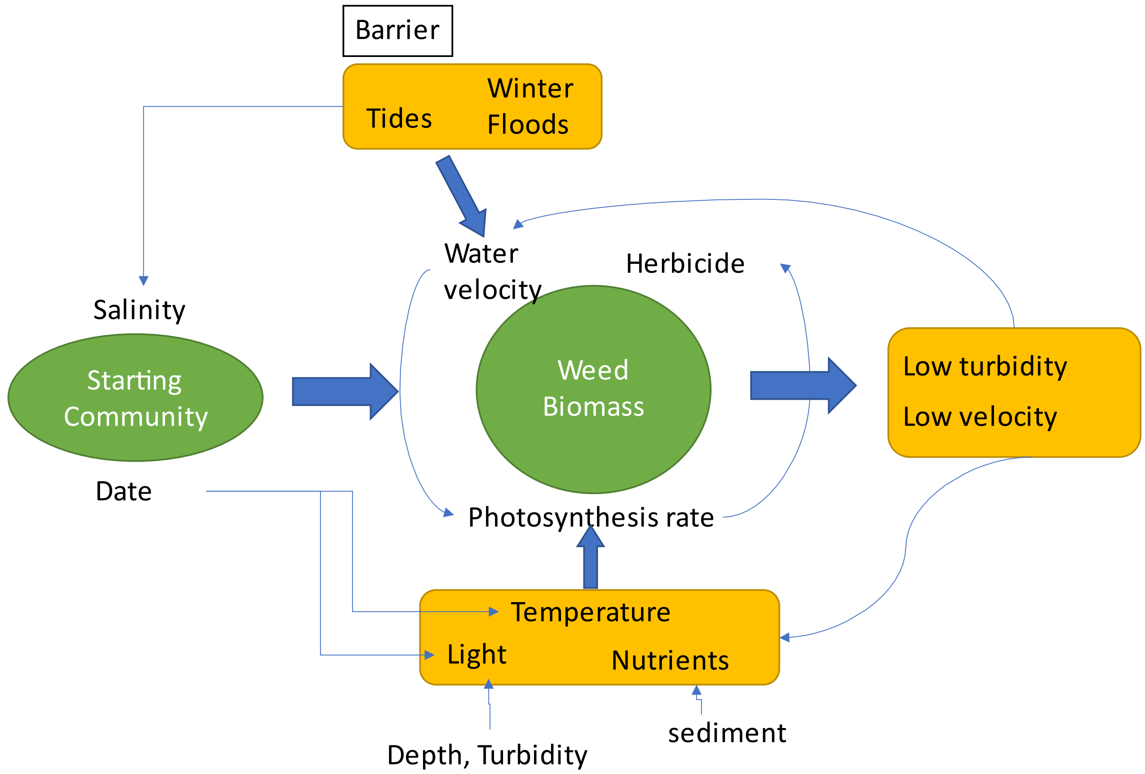


Figure 3-1 Conceptual Model of Aquatic Weed (SAV) Biomass in the Delta

Photosynthetic rate is chiefly controlled by light, nutrient availability, and water temperature (Barko and Smart 1981; Chambers et al. 1991; Riis et al. 2012). In temperate conditions, photosynthesis rates are driven primarily by light levels; they increase from sunrise, peak at midday, then slowly decline in a predictable manner. In mid-summer, very high light levels and temperatures inhibit photosynthetic rates during midday, particularly for C3 plants (Khanna et al. 2012; Santos et al. 2012). Light levels are also highest during mid-summer and decline during the fall. However, the light available to an individual plant will vary with water depth, water clarity, and the presence of other aquatic vegetation. The maximum depth of plant growth is driven by the maximum depth to which light penetrates the water column to support photosynthesis and can vary greatly between species (Chambers and Kalff 1987).

Increased water clarity allows photosynthesis to occur in deeper water. In many cases, this can cause a feedback loop whereby the presence of SAV lowers water velocity and increases sediment deposition, which increases water clarity and promotes further growth (Hestir et al. 2016; Petticrew and Kalff 1992). Increased water clarity in the Delta has been implicated in the increased spread of Brazilian waterweed

(Durand et al. 2016). The increase in Brazilian waterweed, in turn, has been implicated in increasing water clarity and the reduction in sediment transport to tidal wetlands (Drexler et al. 2020; Hestir et al. 2016).

Higher water temperatures, in general, increase photosynthetic rate and thus the vegetation growth rate (Barko et al. 1982; Ta et al. 2017). However, temperature tolerances will vary by species, and high temperatures will lead to reduced growth in the heat of the day and extremely high temperatures will cause senescence (Stuckey 1979). Although growth may be inhibited in the heat of the summer, the growing season generally stretches from spring through autumn, with peak biomass occurring in the fall (Santos et al. 2012).

Nutrients are also key drivers of photosynthetic rate, and unlike cyanoHABs, vegetation may acquire nutrients from the water or the sediment. Rooted SAV and EAV obtain the majority of their nutrients from the sediment, particularly nitrogen and phosphorus (Barko et al. 1991); however, many SAV species can also acquire nutrients directly from the water column. During plant decomposition, this interface provides a mechanism for nutrient recycling between the sediment and the overlying water column. Factors that can affect rates of decomposition, and hence nutrient cycling, include the diversity of the plant community (Banks and Frost 2017) and water temperature (Carvalho et al. 2005).

True FAV that is not rooted in the sediment must acquire all its nutrients from the water column. Coontail (*Ceratophyllum demersum*), common to the Delta, lacks true roots and similarly obtains its nutrients from the water column. Increases in nutrients, such as those seen during 2013–2014 (Figure 2-25), may facilitate the expansion of aquatic vegetation, although this effect is less conclusive (Boyer and Sutula 2015; Dahm et al. 2016).

Both SAV and FAV establish more readily in slower-moving water, so low-flow conditions that occur during droughts have been linked to increases in coverage by invasive vegetation (Chambers et al. 1991; Riis and Biggs 2003). During the winter, high velocities that occur during floods may prevent vegetation from establishing or flush established vegetation out of the system. Also, water temperatures are cooler, turbidity levels are higher, and water is deeper, limiting the regrowth of vegetation immediately after floods. During the summer, velocity patterns are dominated by tides, so changes to outflow play a smaller role in control of SAV. However, changes to the Delta’s physical structure, such as installation of barriers and growth of vegetation itself, will have a large effect on local velocity patterns. For example, changes to flow patterns caused by the 2015 emergency drought barrier were implicated in the spread of SAV into the central area of Franks Tract (Kimmerer et al. 2019).

Top-down control of vegetation occurs as grazing by invertebrates and treatment with herbicides. A variety of herbivorous insects occur on FAV and SAV (Marineau et al. 2019; Young et al. 2016), and several biocontrol agents have been released in the Delta to help control invasive vegetation (Caudill et al. 2021; Reddy et al. 2019). However, none of these herbivores appears to be limiting growth of vegetation in the Delta.

Human control efforts have had mixed success. For control of FAV, DBW most commonly uses the aquatic herbicide glyphosate but also uses some imazamox and 2,4-D. For SAV control, fluridone is the most commonly applied herbicide in the Delta. However, recent studies have shown the use of fluridone on SAV in tidal environments such as the Delta to often be ineffective (Rasmussen et al. in press). Therefore, this treatment program may increase the loading of herbicides into the system without significantly affecting weed abundance. Treatment of FAV with herbicides is thought to be somewhat more effective, although there are noticeable changes in water quality post-treatment (Portilla and Lawler 2020; Tobias et al. 2019).

When growth conditions favor SAV in general, the community composition of an SAV patch will depend on salinity, starting community, transport of propagules, and availability of light. Some invasive SAV species, such as *Egeria densa*, are adapted to low-light conditions, which enables rapid elongation of shoots and subsequent canopy formation that further blocks light to other native SAV species. Different species of SAV also have varying temperature tolerances that factor into their life history patterns. For example, curlyleaf pondweed (*Potamogeton crispus*) commonly sprouts early in the growing season and can outcompete native SAV species that are not tolerant of lower water temperatures (Stuckey 1979).

Species also vary in their salinity tolerances, with the native sago pondweed (*Stukenia pectinata*) having a higher salinity tolerance than the invasive *Egeria densa* (Borgnis and Boyer 2015). There are also species-specific sensitivities to different herbicides, leading to altered community composition in areas that receive herbicide treatment (Caudill et al. 2019).

3.1.4 Drought Barrier and Temporary Urgency Change Petition

Drought conditions may cause an increase in invasive FAV and SAV because of the lack of winter floods. The TUCP, which reduced summer outflow, was not expected to significantly affect vegetation establishment or growth because water velocity, and thus establishment of weeds, is dominated by tides during the summer months.

Although the TUCP was expected to have minimal impact on weeds, installation of the EDB was expected to cause a local increase in aquatic weeds in Franks Tract. Installation of the barrier decreased velocities on the western side of the tract and increased velocities in Fisherman's Cut and the eastern side of the tract (Figure 2-37). Durand et al. (2016) failed to detect a relationship between the establishment of aquatic vegetation and velocity; however, in 2015, weeds spread across the central region of Franks Tract, and the area was not cleared when high flows returned (Kimmerer et al. 2019). This was attributed to the decrease in water velocity through the center of the tract. A similar response to the 2021 EDB was expected, although the high coverage by weeds within Franks Tract over the past several years make detecting a response difficult.

3.2 Methods

Three sources of data were used to evaluate whether the 2021 EDB contributed to changes in the abundance and/or species composition of aquatic weeds. The first two data sets are from the Center for Spatial Technologies and Remote Sensing (CSTARS) at the University of California, Davis. These data sets consist of hyperspectral imagery that classifies the types of aquatic vegetation growing across the Bay-Delta landscape and the vegetation field surveys used to ground-truth this hyperspectral imagery.

The third data set, collected by SePRO Corporation (SePRO), consists of annual field surveys of SAV in Franks Tract and is used to assess the efficacy of herbicide treatments at this site.

3.2.1 Hyperspectral Imagery

Since 2004, hyperspectral airborne imagery has been collected by fixed-wing aircraft over the Delta in many years, although the time of year and spatial extent of these surveys have varied. Franks Tract has been included in all surveyed years (2004–2008, 2014–2021). It generally takes a year or longer from the time of imagery collection to produce finalized maps. Therefore, 2021 imagery is preliminary. Note that the area of SAV is likely underestimated in the current version of the 2021 imagery because of classification challenges caused by the wind and waves at the time of imagery collection.

It is difficult to differentiate potential impacts of the 2021 EDB and TUCP on the abundance and composition of aquatic vegetation from impacts simply caused by drought. However, it is useful to compare changes in Franks Tract to those at similar sites not influenced by the barrier (**Figure 3-2**).

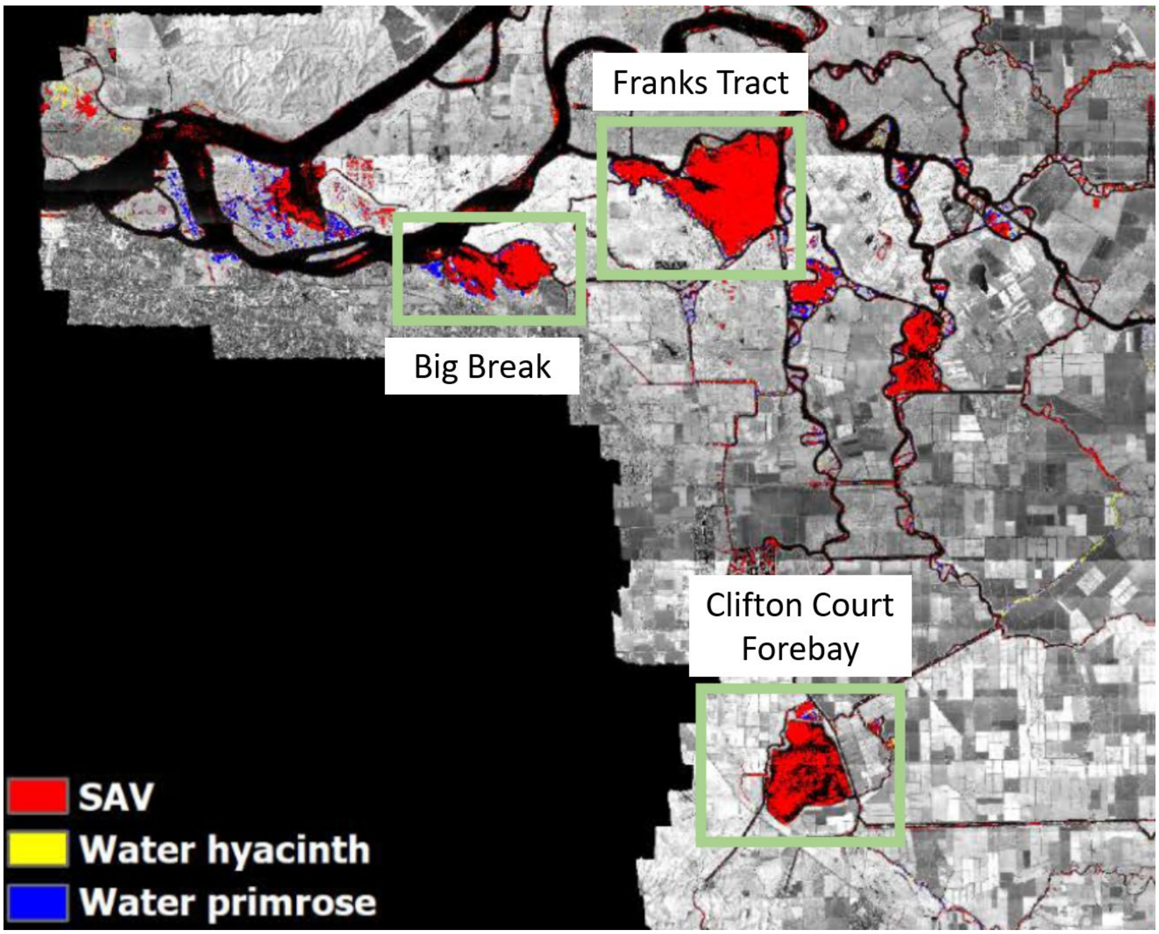


Figure 3-2 Map of the Central and South Regions of the Delta for 2019 Showing the Locations of Franks Tract and the Two Reference Sites, Big Break and Clifton Court Forebay

Previous studies have used Big Break as a reference site for Franks Tract because it is near Franks Tract but did not experience a reduction in flow as a result of the barrier (Kimmerer et al. 2019). Clifton Court Forebay was also chosen because it shares some similarities to Franks Tract in size and bathymetry, and it is far from the influence of the 2021 EDB. Imagery for this site is available for 10 of the 13 years for which there is Franks Tract imagery: 2004–2008, 2014, 2015, and 2019–2021. Mildred Island was also considered as a candidate reference site, but this location was ultimately rejected because it is too turbid to produce accurate classification maps of SAV using hyperspectral imagery.

Another challenge to isolating impacts of the 2021 EDB on aquatic vegetation is the use of herbicides for vegetation management. Herbicide treatments have been conducted more extensively at Franks Tract and Clifton Court Forebay than in most areas of the Delta, and the timing, type, and amounts of chemicals used in these treatments have varied among sites and years (**Table 3-1**, **Table 3-2**).

TABLE 3-1
AREA OF FRANKS TRACT TREATED FOR SUBMERSED AQUATIC VEGETATION BY THE DIVISION OF BOATING AND WATERWAYS WITH THE HERBICIDE FLURIDONE, BY YEAR

Year	Area Treated (hectares)
2006	57
2007	1,314
2008	1,314
2009	0
2010	202
2011	977
2012	283
2013	0
2014	758
2015	0
2016	421
2017	444
2018	456
2019	0
2020	0
2021	0

TABLE 3-2
AREA OF CLIFTON COURT FOREBAY TREATED FOR SUBMERSED AQUATIC VEGETATION BY THE CALIFORNIA DEPARTMENT OF WATER RESOURCES WITH HERBICIDES, BY YEAR

Year	Area Treated (hectares)	Active Ingredient
2002	700	Copper
2003	700	Copper
2003	500	Copper
2004	700	Copper
2004	500	Copper
2005	770	Copper
2005	770	Copper
2006	1,037	Copper
2006	1,116	Copper
2015	3,778	Copper
2015	2,530	Copper
2016	3,760	Endothall
2017	3,749	Endothall
2018	3,813	Endothall
2019	3,813	Endothall
2020	3,924	Copper
2020	3,924	Endothall
2020	6,104	Copper
2020	4,061	Copper
2020	4,061	Endothall
2021	3,998	Copper
2021	3,998	Endothall

Survey methods for the hyperspectral imagery have varied somewhat among years, but the approach generally proceeds as described here for the 2018 survey. During this survey, HyVista Corporation (Sydney, Australia) used the HyMap sensor (126 bands: 450–2,500 nanometers, bandwidth: 10–15 nanometers) to collect imagery at a resolution of 1.7 meters by 1.7 meters. A diverse suite of inputs was derived from these images to capture reflectance properties across different regions of the electromagnetic spectrum, which track biophysiological characteristics useful for distinguishing types of plants. These intermediate inputs were generated using IDL scripts (IDL 8.01, ITT Visual Information Solutions) in ENVI (ENVI 4.8, ITT Visual Information Solutions).

Concurrent with imagery collection, ground-truthing surveys were conducted to determine species composition at points across the Delta region (e.g., 2018: 950 points; see the "Hyperspectral Imagery Ground-Truthing " section for details). Field data were divided into training and validation subsets for image classification and independent validation of class maps. Training and validation polygons were overlaid on the raster images with generated inputs, and corresponding pixels within the raster images were extracted using the R statistical computing language (Version 4.0.2; R Core Team 2021) and packages 'sp' (Version 1.4.5) (Pebesma and Bivand 2021), 'rgdal' (version 0.5.5) (Bivand et al. 2021), and 'rgeos' (Version 1.5.23).

Training data were fed into a Random Forests classifier (packages 'raster': Version 3.4.5 (Hijmans 2021) and 'randomforest': Version 4.6.14 (Breiman 2001). The best-fit class type (e.g., open water, SAV, water hyacinth, water primrose) for each pixel was chosen based on consistency across tree predictions. The accuracy of the final maps was assessed using confusion matrices and Kappa coefficients. The area of SAV was calculated per year, per site, as the number of pixels classified as SAV multiplied by the area of a single pixel. FAV area was calculated in the same way, except that it is a combined category that includes water hyacinth, water primrose, and a mixed class composed of water primrose and emergent vegetation.

These area calculations were then used to make comparisons among sites and years. For additional details about the methodology of the imagery analysis, see Khanna et al. (2022).

3.2.2 Hyperspectral Imagery Ground-Truthing

Around the time that hyperspectral imagery is collected each year, the CSTARS staff collects ground-truthing field data on the community composition of aquatic vegetation across the Delta, including areas in and around Franks Tract and Big Break. They have not sampled at Clifton Court Forebay because access to that area is restricted. Efforts are ongoing to clean and integrate the SAV data from this time series, but the authors of this report were able to acquire and present the data for 2021.

In 2021, this field survey took place from late July to mid-August. In Franks Tract (**Figure 3-3**) and Big Break (**Figure 3-4**), the CSTARS staff sampled for SAV at 47 sites and 30 sites, respectively. To sample SAV, they used a weighted, double-headed, 0.33-meter-wide thatch rake that was lowered into the water and twisted before being brought back up to the surface as per the Interagency Ecological Program Aquatic Vegetation Project Work Team et al. (2018). They recorded all species collected on the rake, as well as the percentage of the sample volume each species represented, to the nearest 10 percent.

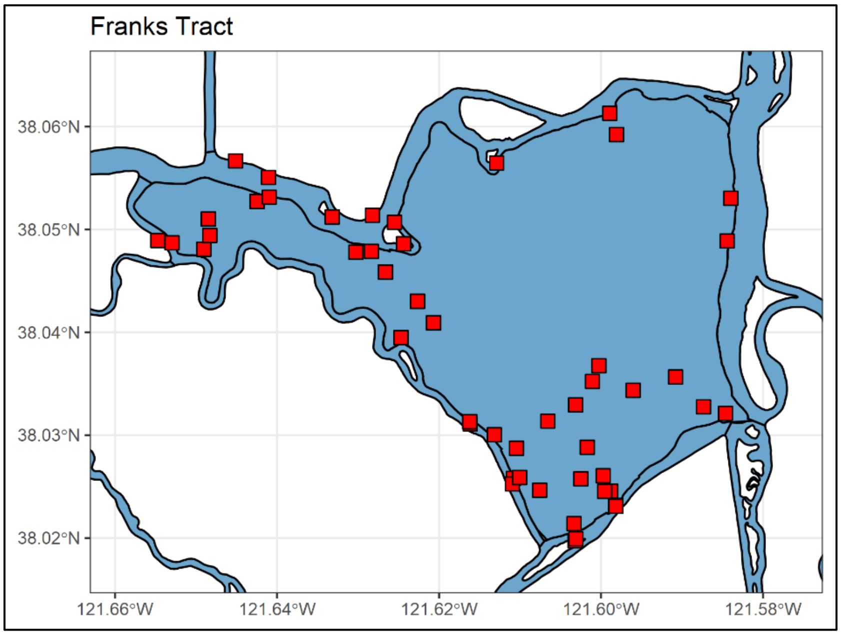


Figure 3-3 Locations in Franks Tract where CSTARS Sampled Submersed Aquatic Vegetation to Ground-Truth the Hyperspectral Imagery in 2021

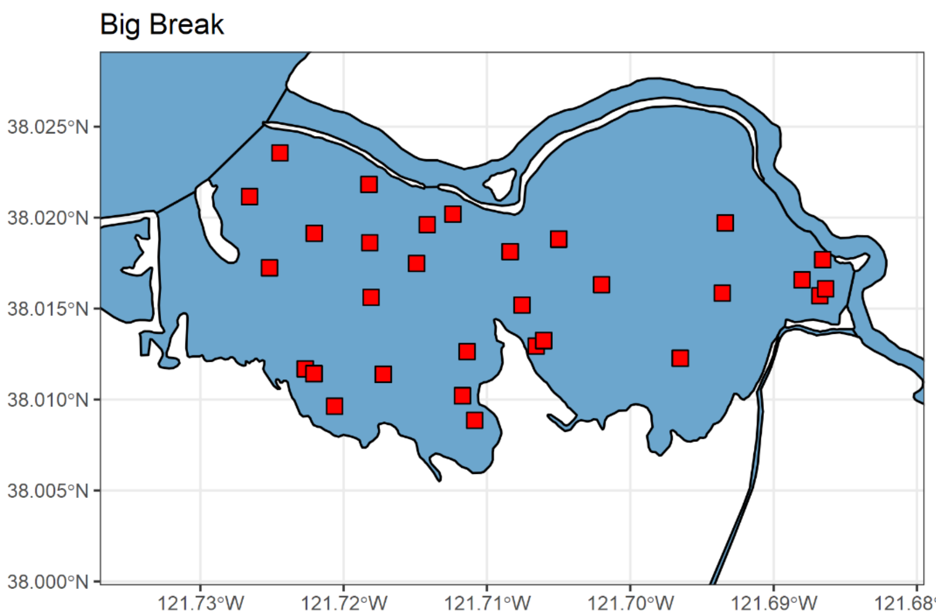


Figure 3-4 Locations in Big Break where CSTARS Sampled Submersed Aquatic Vegetation to Ground-Truth the Hyperspectral Imagery in 2021

Note that these samples are not collected randomly, which means that they provide useful information for comparing species composition between sites but not necessarily total SAV abundances.

3.2.3 SePRO Vegetation Survey

Since 2006, DBW has collaborated with SePRO Corporation to manage SAV in Franks Tract using the herbicide fluridone (Table 3-1) (Caudill et al. 2019). SePRO monitors changes in SAV community composition using point-intercept surveys (Madsen and Wersal 2018) that are conducted on one date annually in the fall.

Sampling points are chosen by generating a grid of evenly spaced points projected over the full area of Franks Tract (**Figure 3-5**). The number of sampling points varies among years but is usually 100 (range: 50–200 samples). Most surveys have been conducted in mid-October (range: October 1–October 13).

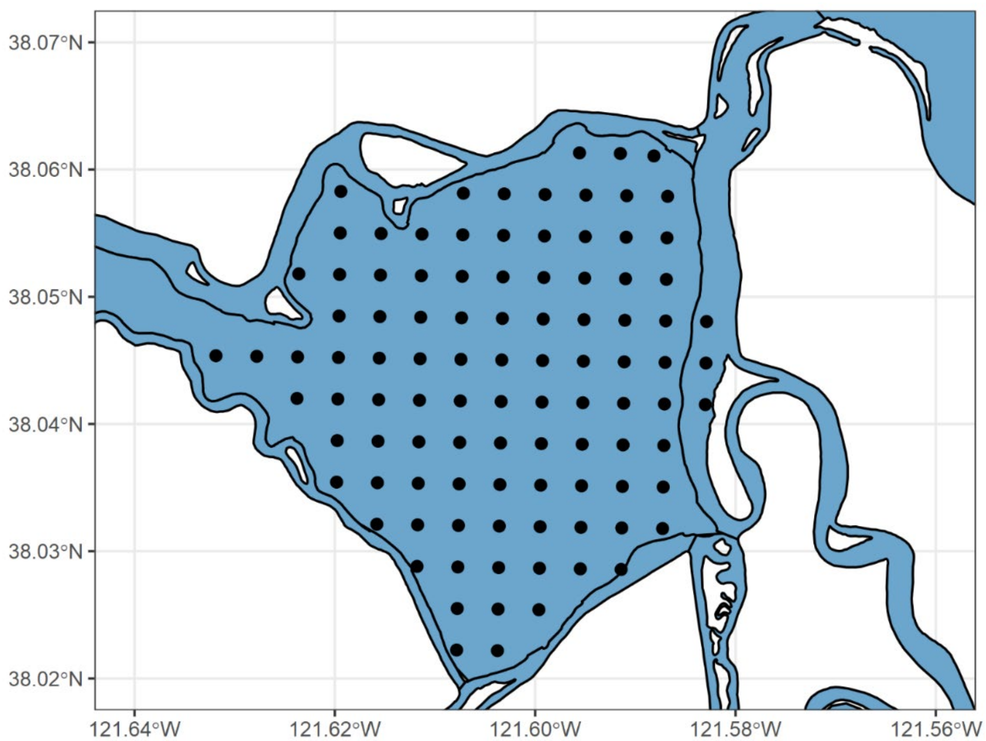


Figure 3-5 2021 Sampling Design for SePRO's Annual Long-Term Monitoring of Submersed Aquatic Vegetation in Franks Tract, Conducted in Conjunction with Herbicide Treatments

To sample each point, SePRO uses a weighted, double-headed, 0.33-meter-wide thatch rake attached to a rope, which is dragged for approximately 3 meters along the bottom and then pulled up to the boat for analysis. All SAV present on the rake is identified to species, and species-specific abundances are estimated based on the percentage of the rake each covers. Abundances are recorded using ordinal scores (1 = 1–19 percent, 2 = 20–39 percent, 3 = 40–59 percent, 4 = 60–79 percent, 5 = 80–100 percent). Monitoring data for 2014–2021 were available and used for analyses in this report.

3.2.4 Environmental Drivers and Responses

Aquatic weed data were compared with water quality, flow, and herbicide application data to determine the drivers of variation in the abundance and composition of aquatic weeds. Variables hypothesized to affect aquatic weeds included measures of flow, turbidity, salinity, temperature, and herbicide applications (Figure 3-1). The analyses also included DO and pH, variables that are hypothesized to be affected by aquatic weeds.

Net Delta outflow data were obtained from DWR's Dayflow model (California Department of Water Resources 2002). For water quality, monthly data were obtained from DWR's EMP Station D19 (Franks Tract) and DFW's Bay Study Station 853 (San Joaquin River just west of Big Break). The data for EMP Station C9 (Clifton Court) did not begin until recently (2016), so environmental drivers for this reference site were not considered. Discrete water quality stations were chosen over continuous stations for Franks Tract and Big Break because the discrete stations covered most parameters of interest for all years of aquatic vegetation monitoring (hyperspectral imagery started in 2004), whereas most continuous stations did not. As an exception, Bay Study Station 853 does not include DO or pH. For flow and water quality variables, annual means based on the main growing season for aquatic weeds (March–October) were used. Herbicide application data for Franks Tract (Table 3-1) and Clifton Court Forebay (Table 3-2) were obtained from DBW and DWR, respectively. The authors of this report are not aware of site-wide herbicide treatments in Big Break.

3.2.5 Data Analysis

Hyperspectral Imagery and Ground-Truthing

To examine changes in coverage by SAV and FAV at the focal sites, time series graphs were produced showing cover for each vegetation type for each site. To calculate the proportion of area occupied by SAV and FAV, the area of each vegetation type was divided by DBW's waterways area for each site.

In addition, Pearson correlations were conducted comparing Franks Tract with each reference site for each of the two types of vegetation. If landscape-scale environmental forces, such as droughts, are primarily driving patterns of vegetation cover through time, then Franks Tract and the reference sites should change in similar ways across years (i.e., they should be correlated). If drought barriers affect aquatic vegetation, then changes in aquatic vegetation cover in Franks Tract may differ from that of the reference sites (i.e., points for drought barrier years stray from the correlation line), although other factors can cause such deviations (e.g., differences between sites in herbicide application efforts).

For Franks Tract and the reference site Big Break, a series of Pearson correlations was conducted to determine which environmental drivers and responses (see Section 3.2.4, "Environmental Drivers and Responses") exhibited a statistically significant relationship with SAV and FAV coverage.

To examine patterns in SAV and FAV cover through time at the landscape scale, data were plotted for the largest composite Delta region that included all years of hyperspectral imagery. This region included large areas of the North and Central Delta (approximately one-third of the legal Delta), where aquatic weeds are considered most problematic (**Figure 3-6**).

For the 2021 ground-truthing data, plots were generated comparing abundances of SAV species between Franks Tract and Big Break. Franks Tract could not be compared to Clifton Court Forebay with this data set because Clifton Court Forebay was not a site sampled for ground-truthing.

SePRO Vegetation Surveys

To examine changes in SAV community composition in Franks Tract, time series of data for the 10 most common species were plotted. Annual means and standard errors were calculated from the ordinal abundance scores. A series of Spearman correlations was conducted to determine which environmental drivers and responses (see Section 3.2.4, "Environmental Drivers and Responses") exhibited a statistically significant relationship with abundances of the four most common SAV species in Franks Tract: *Ceratophyllum demersum, Egeria densa, Potamogeton richardsonii,* and *Najas guadalupensis.*

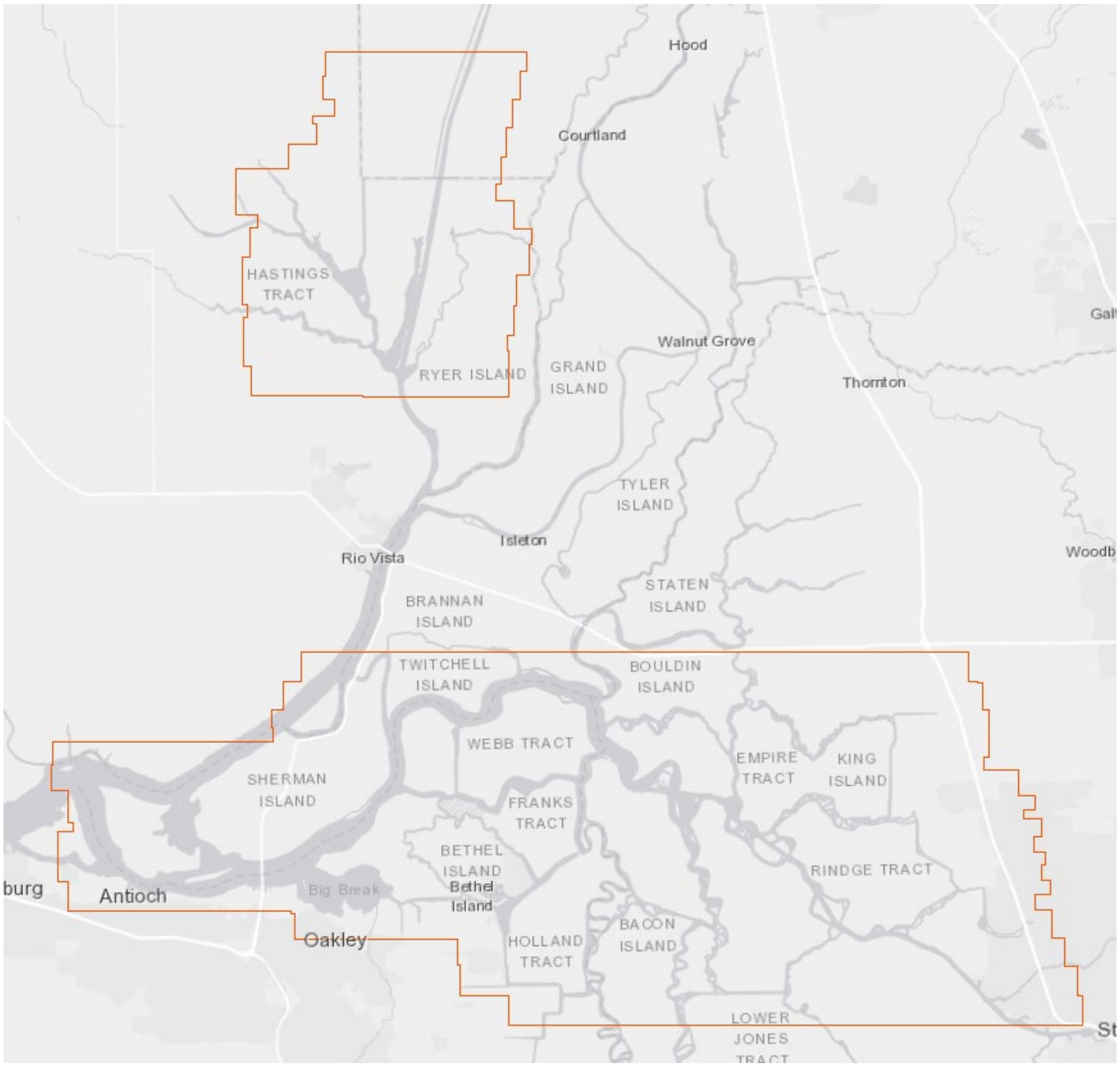


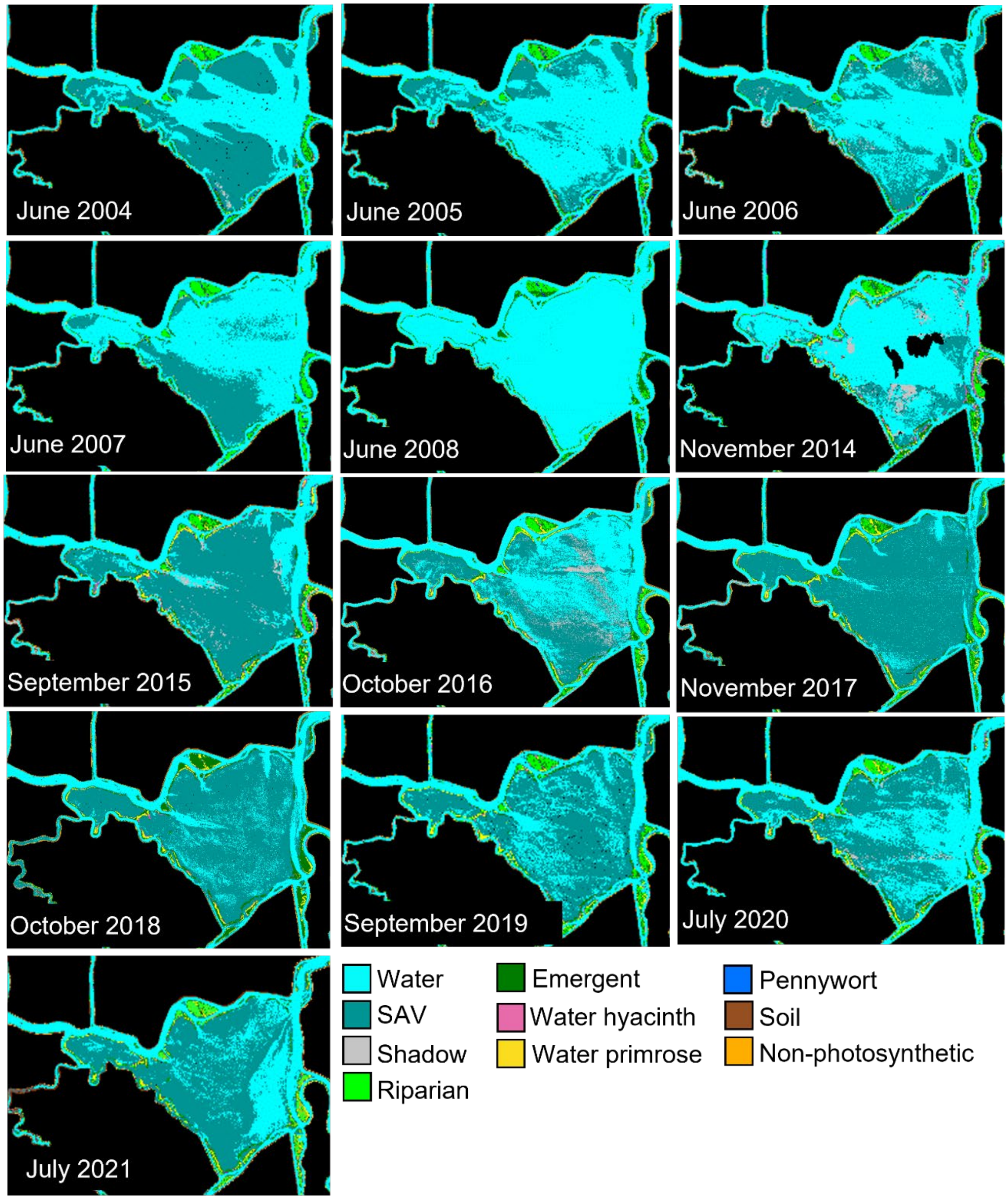
Figure 3-6 Map Showing the Spatial Extent of Regions of the North and Central Delta that Have Been Imaged during All Survey Years

3.3 Results

3.3.1 Hyperspectral Imagery

Vegetation Cover Changes in Franks Tract and Reference Sites

Based on this time series of imagery, SAV coverage in Franks Tract has changed markedly over time (**Figure 3-7**, Figure 3-10).



NOTE: The 2021 imagery is provisional.

Figure 3-7 Time Series of Hyperspectral Imagery for Franks Tract

During the first five years when monitoring was conducted (2004–2008), much of Franks Tract consisted of open water, and coverage by SAV was low to moderate (1.1 to 40.6 percent of the area). In particular, in all of these early years, the channel through the middle of the site was clear of SAV, likely because of the greater depth in and higher flows through this area than other areas. In some years, particularly 2007 and 2008, additional areas were clear of SAV, likely due in part to intensive fluridone applications by DBW (Table 3-1).

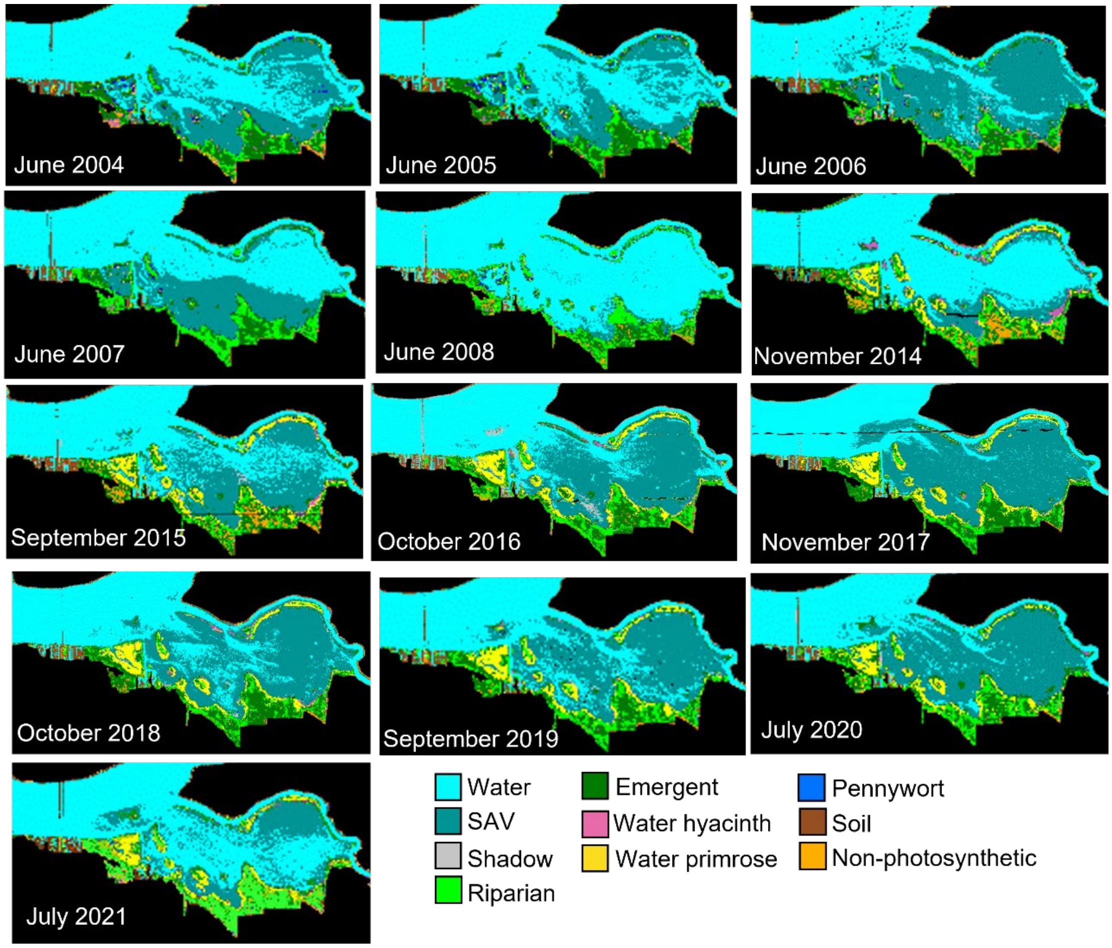
Imagery was not collected in 2009–2013, so it is unclear how SAV coverage changed during this period. In 2014, however, SAV coverage was relatively low (13.4 percent of the area), much like the earlier period of 2004–2008, although the 2014 imagery was collected late in the year when vegetation may have begun to die back.

In 2015, coverage by SAV was 4.5 times greater than in 2014, which has been attributed to drought conditions and the presence of the EDB (Kimmerer et al. 2019). SAV has generally persisted at high levels since 2015 (34.2 to 68.0 percent of the area), despite wetter conditions and the absence of drought barriers in some of these years.

It is worth noting that DBW has conducted less frequent and less intensive fluridone applications in Franks Tract in recent years (Table 3-1), which may also have contributed to the high SAV levels. Total SAV coverage in Franks Tract based on preliminary 2021 imagery was similar to that of recent years (53.6 percent). However, the distribution of SAV differed somewhat from distributions in past years, with dense SAV covering much of the western and central areas of the site but little SAV present in the eastern areas.

Throughout this time series, FAV has occupied a very small area of Franks Tract (Figure 3-7, Figure 3-10). During 2004–2008, FAV covered 0.13 to 0.72 percent of the site. After the monitoring gap (2009–2013), FAV cover was an order of magnitude higher (2.4 to 3.8 percent) but remained at very low levels compared to SAV. During 2021, cover by FAV was similar to that of other recent years (2.5 percent).

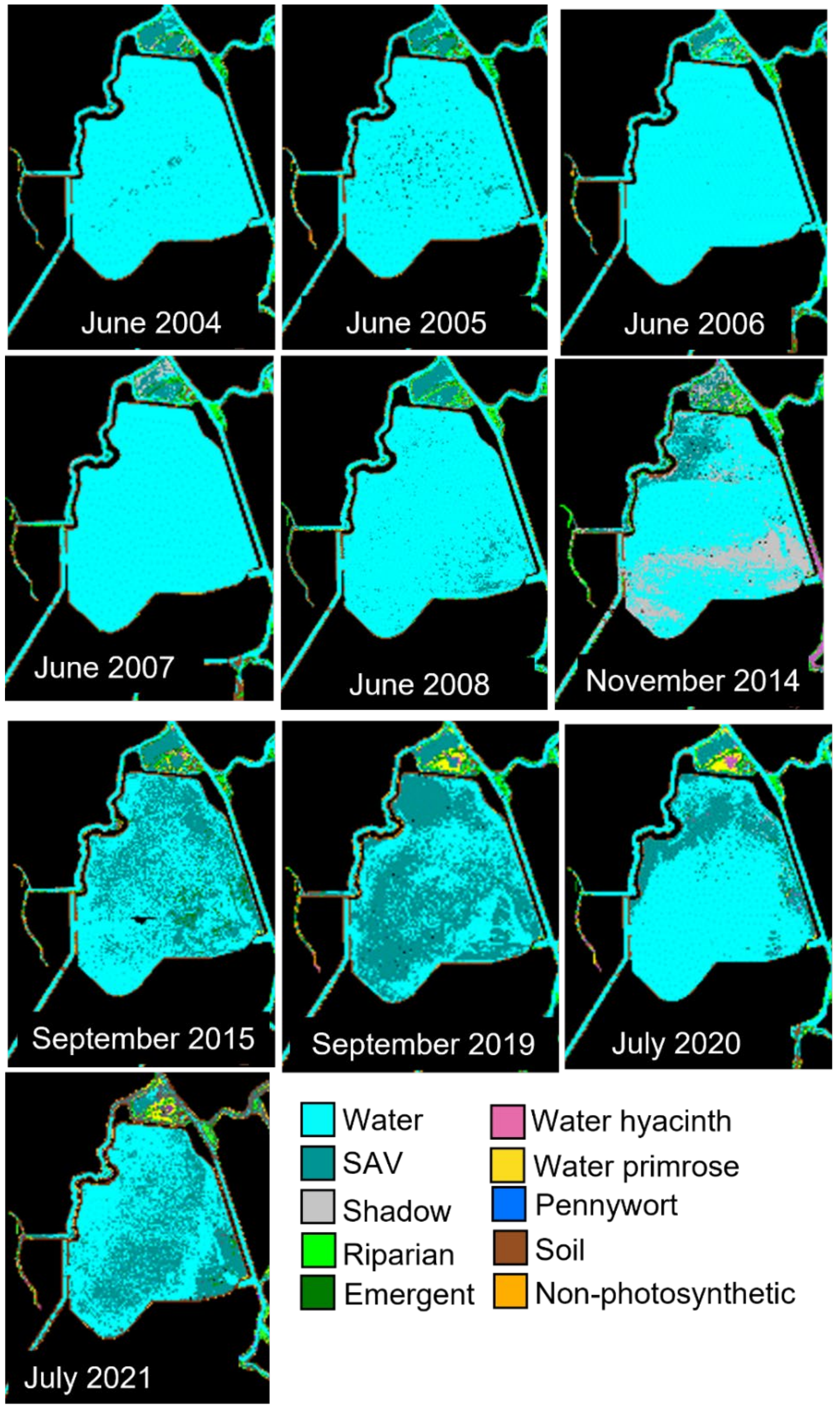
The dynamics of SAV coverage at Big Break, one of the reference sites, were similar to those of Franks Tract (**Figure 3-8**, Figure 3-10). Before 2015, SAV coverage was generally low to moderate (4.7 to 31.2 percent), except for 2006, when coverage was 48.6 percent. In 2015 and subsequent years, SAV has generally covered a higher proportion of the site (32.1 to 50.4 percent), although in 2021, SAV cover was at an eight-year low (24.5 percent). As with Franks Tract, FAV covered a small proportion of the site but increased by an order of magnitude between the earlier and later parts of the time series (Figure 3-10). During 2004–2008, FAV coverage was 0.50 to 1.8 percent, and during 2014–2021, it was 6.5 to 9.3 percent. In 2021, FAV cover in Big Break was higher than in any other year for which data were available (9.3 percent)—43.1 percent and 32.9 percent higher than in 2019 and 2020, respectively.



NOTE: The 2021 imagery is provisional.

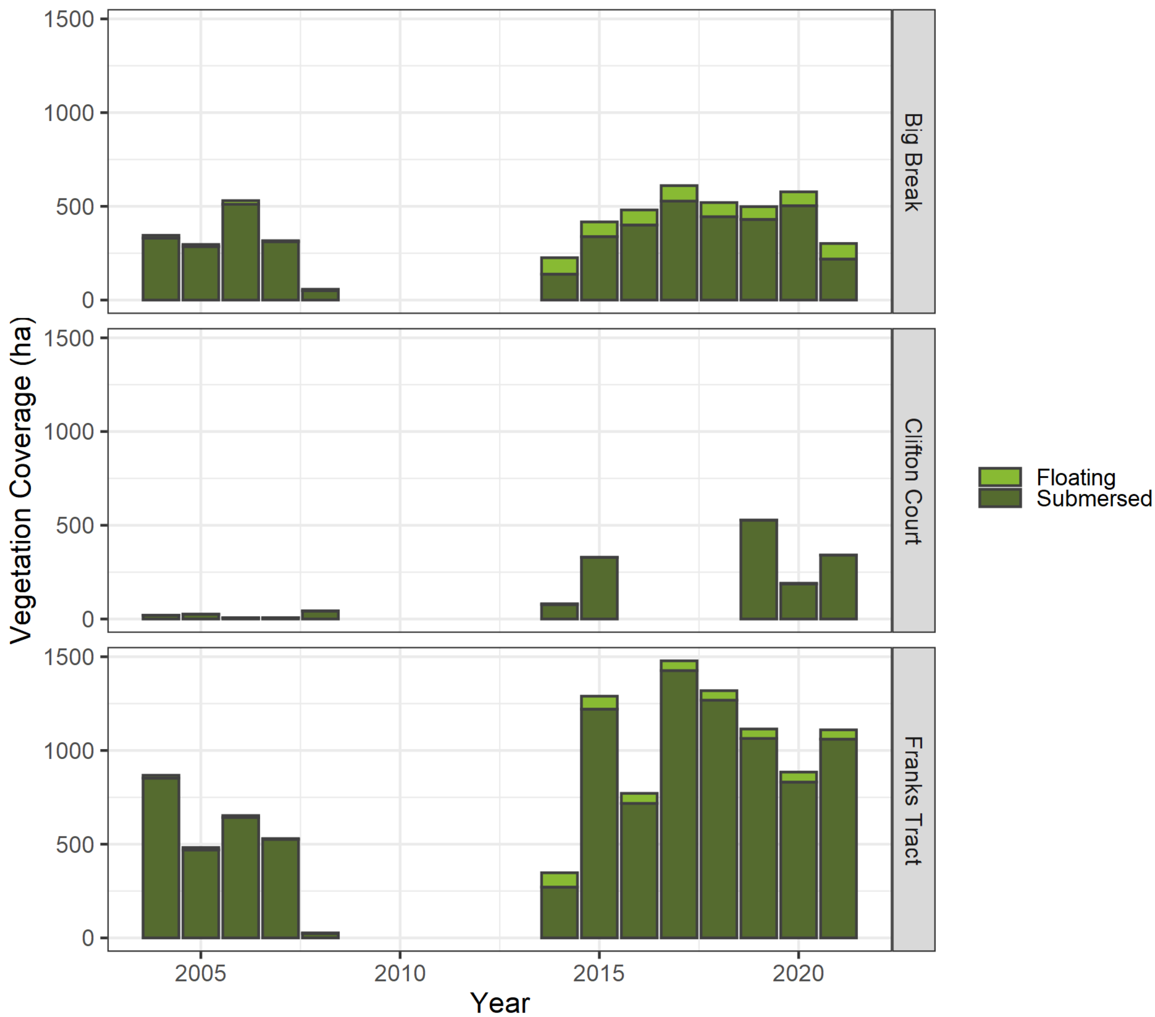
Figure 3-8 Time Series of Hyperspectral Imagery for Big Break, a Reference Site for Franks Tract

Clifton Court Forebay, the other reference site, exhibited SAV coverage patterns qualitatively similar to those of the other sites (**Figure 3-9**, **Figure 3-10**). Before 2015, the site was mostly open water (SAV area: 0.64 to 7.7 percent), and from 2015 onward, the site generally had much higher levels of SAV coverage (18.9 to 52.6 percent). Unlike conditions at the other two sites, the 2021 level of SAV cover in Clifton Court Forebay (36.9 percent) was the second highest in the time series, although this classification is still being finalized. FAV occupied an even smaller proportion of Clifton Court Forebay than it did at other two sites (0.0 to 0.50 percent), and 2021 cover by FAV was similar to that of other years (0.03 percent).



NOTES: Only 10 years of imagery were collected for this region, which represents a subset of years for which there is imagery for Franks Tract. Also, the 2021 imagery is provisional.

Figure 3-9 Time Series of Hyperspectral Imagery for Clifton Court Forebay, a Reference Site for Franks Tract

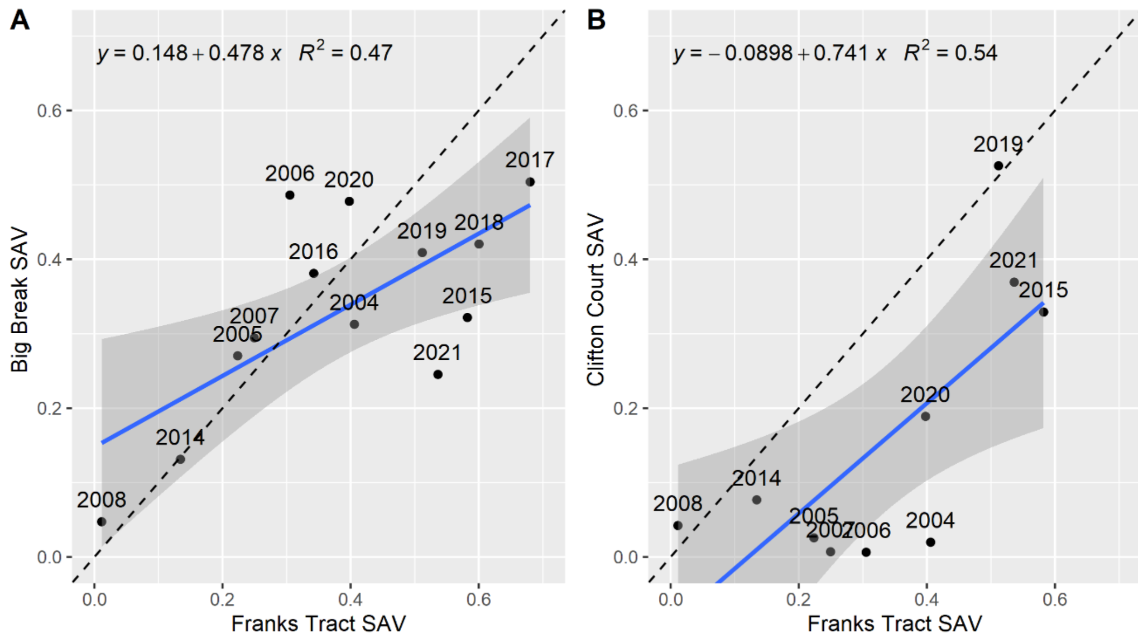


NOTE: The coverage levels shown here were calculated by analyzing the hyperspectral imagery shown in Figure 3-7, Figure 3-8, and Figure 3-9. The 2021 values are provisional. Years with no bars indicate missing data.

Figure 3-10 Coverage of Floating Aquatic Vegetation and Submersed Aquatic Vegetation in Franks Tract and Clifton Court Forebay, as Calculated by Analyzing Hyperspectral Imagery

Comparisons between Franks Tract and the two reference sites were visualized by using correlations. These correlations showed whether patterns were similar between pairs of sites and whether drought barrier years differed from other years.

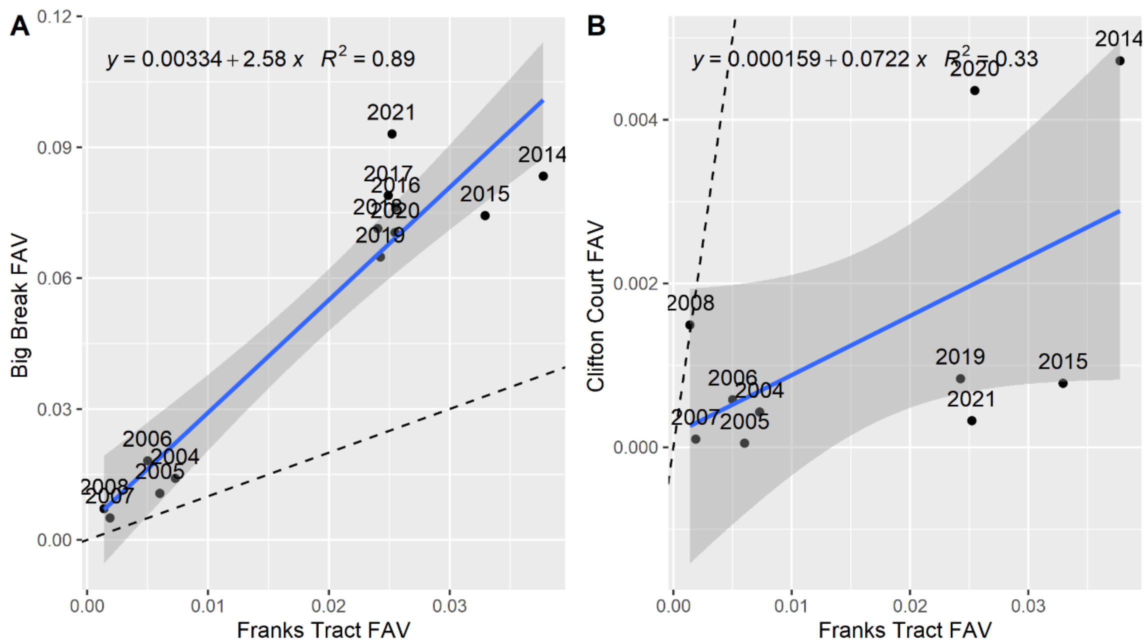
For SAV, patterns were generally similar between Franks Tract and Big Break, as indicated by the significant correlation between them (corr = 0.69, p = 0.009; **Figure 3-11**A). However, there were several points that deviated from the fitted line, including 2015 and 2021. For these two drought barrier years, the proportion of area occupied by SAV was low in Big Break relative to Franks Tract. These two years exhibited the highest salinity values in the time series for Big Break, which may explain the lower SAV there. The proportion of areas occupied by SAV was also similar between Franks Tract and Clifton Court (corr = 0.74, p = 0.02; Figure 3-11B). A few years deviated from the fitted line, but not the two drought barrier years. In particular, 2019 showed unusually high SAV in Clifton Court, although it is unclear why.



NOTES: The 2021 values are provisional. The solid line is fitted from the model, and the shaded area is the standard error. The dashed line is the 1:1 line, which would indicate that the proportion of the site covered by SAV is equal between pairs of sites. Points indicate the annual area estimates and are labeled with the year.

Figure 3-11 Comparisons of Proportion of Area Classified as Submersed Aquatic Vegetation by Hyperspectral Imagery for (A) Franks Tract versus Big Break and (B) Franks Tract versus Clifton Court

For FAV, the relationship between Franks Tract and Big Break was very strong (corr = 0.95, p < 0.0001; **Figure 3-12**A). The year 2021 deviated most from the fitted line, although this was driven by unusually high FAV cover at Big Break. Franks Tract FAV cover was similar to that of other years. The relationship was not significant for Franks Tract versus Clifton Court Forebay (corr = 0.58, p < 0.08; Figure 3-12B). This lack of relationship may be attributable in part to the intensive management of Clifton Court Forebay for aquatic vegetation across years. Also, fewer years of data are available for Clifton Court Forebay, which reduced statistical power.



NOTES: The y-axis range differs between the two panels. FAV includes water hyacinth and water primrose. The 2021 estimate is provisional. The solid line is fitted from the model, and the shaded area is the standard error. The dashed line is the 1:1 line, which would indicate that the proportion of the site covered by SAV is equal between pairs of sites. Points indicate the annual area estimates and are labeled with the year.

Figure 3-12 Comparisons of the Proportion of Area Classified as Floating Aquatic Vegetation by Hyperspectral Imagery for (A) Franks Tract versus Big Break and (B) Franks Tract versus Clifton Court Forebay

Relationships with Environmental Drivers and Responses

For Franks Tract, the correlations between SAV and the environmental responses (DO, pH) and most drivers (temperature, conductivity, Secchi depth, Delta outflow) were not significant (**Table 3-3**). As an exception, there was a significant correlation between SAV area and area treated with the herbicide fluridone (Table 3-3, **Figure 3-13**). However, this relationship was driven by the year 2008, which was the second of two consecutive years with the highest acreage of treatments (Table 3-3). For FAV, there were no significant correlations (Table 3-3). In addition, there was not a significant correlation between SAV and FAV (corr = 0.44, p = 0.13).

For Big Break, a reference site for Franks Tract, Delta outflow (**Table 3-4**, **Figure 3-14**) and conductivity (Table 3-4, **Figure 3-15**) were correlated with SAV. Note that Delta outflow and conductivity are strongly correlated with one another (corr = -0.79, p = 0.001). Only water temperature was correlated with FAV (Table 3-4, Figure 3-15).

TABLE 3-3
CORRELATION COEFFICIENT (CORR) BETWEEN ENVIRONMENTAL VARIABLES AND EACH OF THE TWO TYPES OF AQUATIC VEGETATION—SUBMERSED (SAV) AND FLOATING (FAV)—IN FRANKS TRACT

	SAV corr	SAV p-value	FAV corr	FAV p-value
Temperature	0.07	0.82	0.41	0.17
Conductivity	-0.15	0.61	0.30	0.31
Secchi Depth	0.43	0.15	0.54	0.06
Dissolved Oxygen	0.34	0.26	0.10	0.75
pH	-0.2	0.64	-0.11	0.80
Delta Outflow	0.29	0.34	-0.16	0.60
Herbicides	**-0.65**	**0.03**	NA	NA

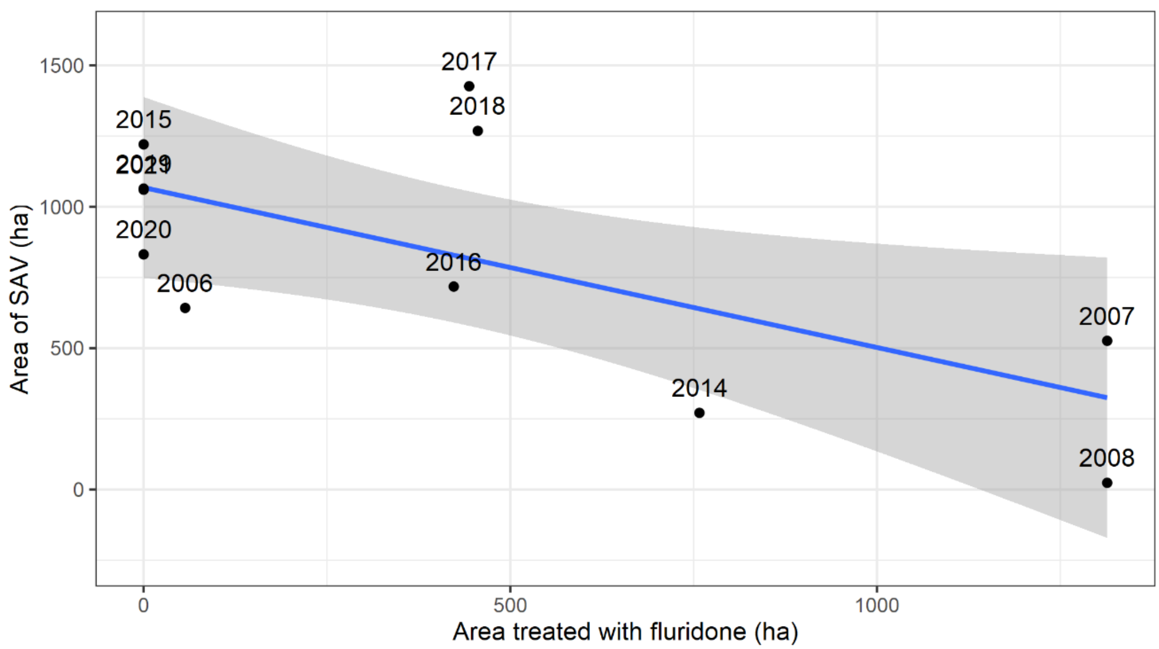


Figure 3-13 Correlation between Area Treated with the Herbicide Fluridone and Area of Submersed Aquatic Vegetation in Franks Tract

TABLE 3-4
CORRELATION COEFFICIENTS (CORR) BETWEEN ENVIRONMENTAL VARIABLES AND EACH OF THE TWO TYPES OF AQUATIC VEGETATION—SUBMERSED (SAV) AND FLOATING (FAV)—IN BIG BREAK, A REFERENCE SITE FOR FRANKS TRACT

	SAV corr	SAV p-value	FAV corr	FAV p-value
Temperature	0.13	0.67	**0.64**	**0.02**
Conductivity	**-0.57**	**0.04**	0.21	0.50
Secchi Depth	0.47	0.12	0.34	0.29
Delta Outflow	**0.62**	**0.02**	-0.08	0.80

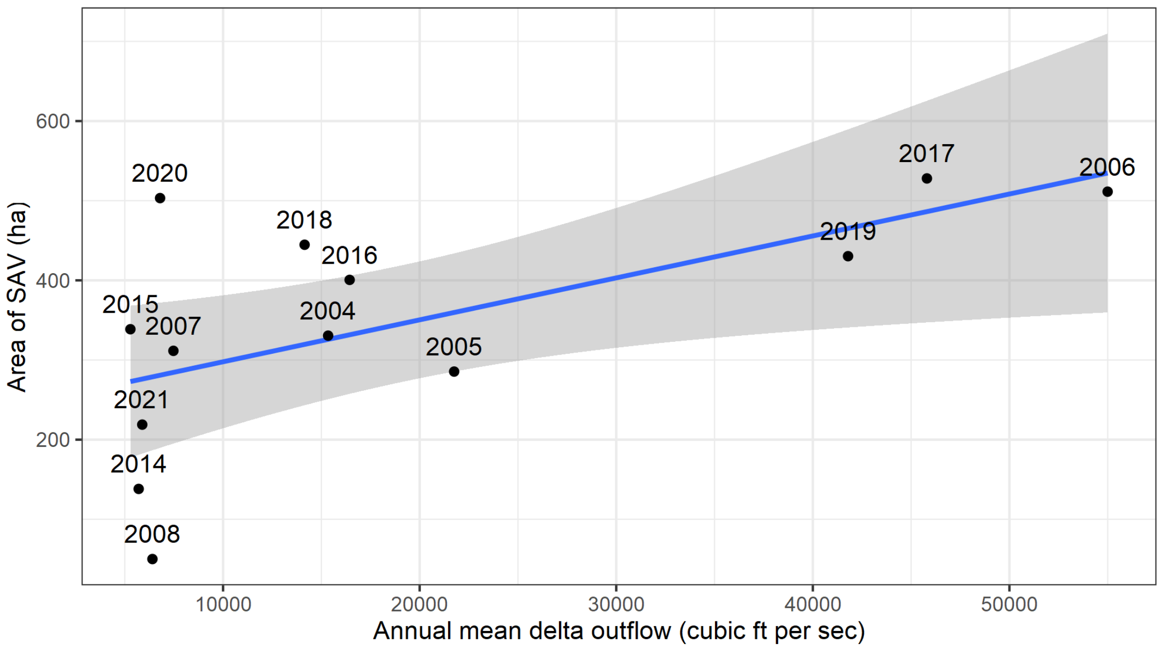


Figure 3-14 Correlation between Annual Mean Delta Outflow and Area of Submersed Aquatic Vegetation in Big Break, a Reference Site for Franks Tract

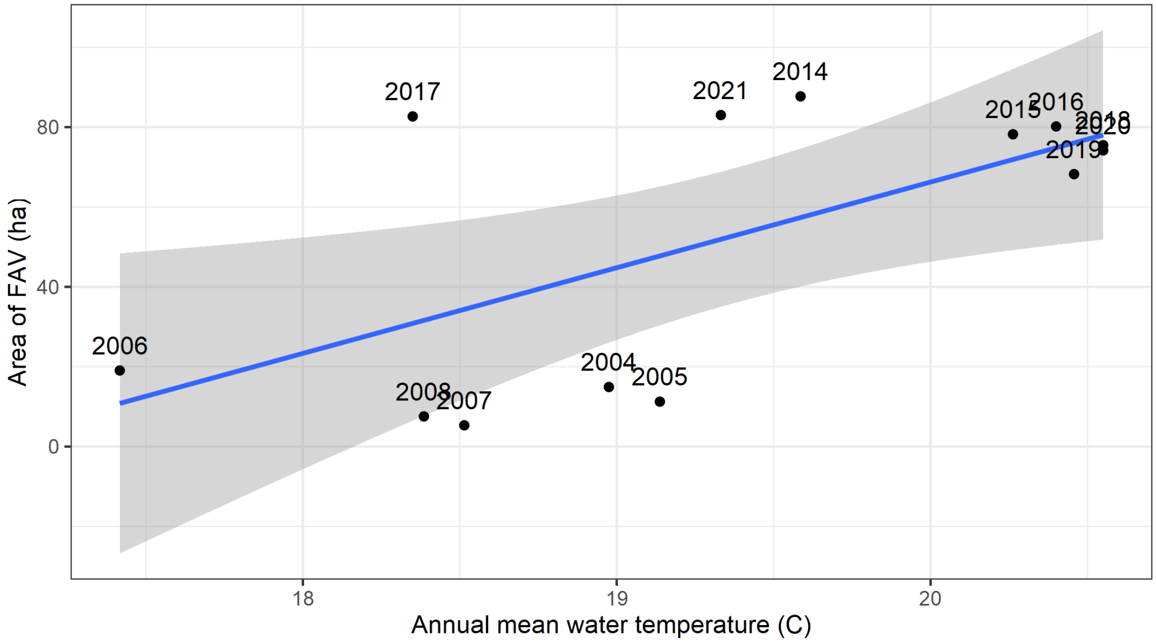


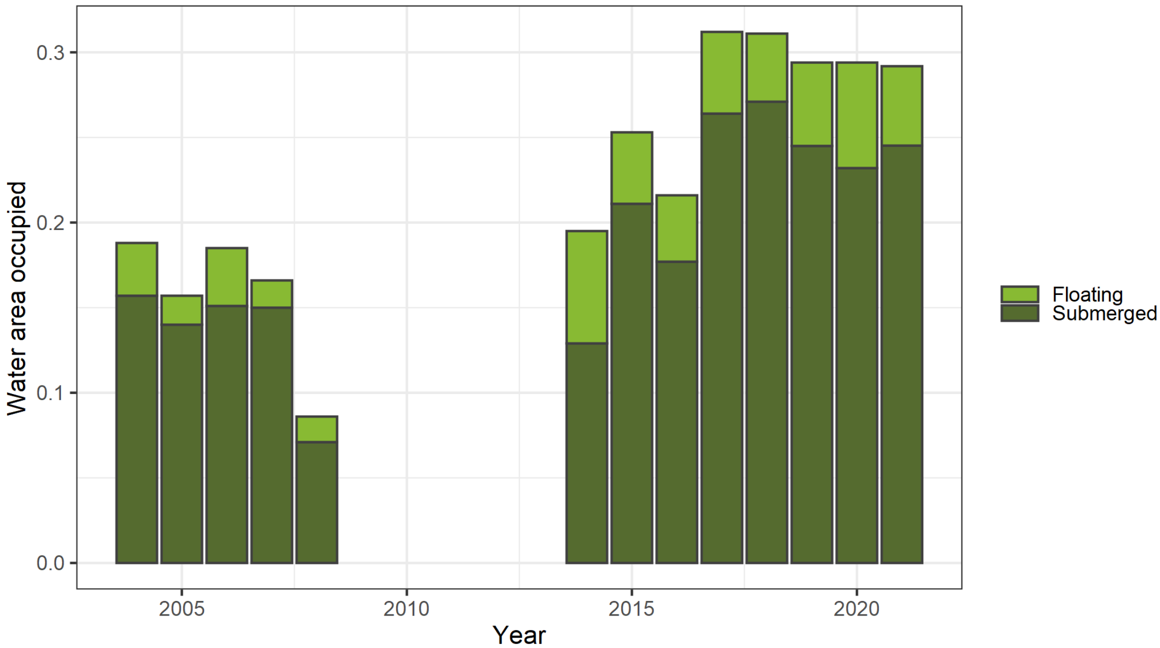
Figure 3-15 Correlation between Annual Mean Water Temperature and Area of Floating Aquatic Vegetation in Big Break, a Reference Site for Franks Tract

Vegetation Cover Changes in the Broader Delta Region

Patterns of aquatic vegetation in the region consisting of the North and Central Delta (**Figure 3-16**) generally mirrored those of Franks Tract (Figure 3-10), which was included in this broader region.

Based on the preliminary 2021 data, SAV coverage in the North and Central Delta was 3,992 hectares (ha) (24.5 percent) of the waterways. This was similar to coverage in other recent years. For example, SAV cover in 2021 was 0.0 percent and 5.6 percent higher than in 2019 and 2020, respectively. In 2021, FAV cover for this Delta region was 760 ha (4.7 percent) of the waterways, which was 4.1 percent and 24.2 percent lower than in 2019 and 2020, respectively.

The order-of-magnitude increase in FAV cover observed between the earlier years (2004–2008) and the later years (2014–2021) at all sites as well as this broader Delta region is largely driven by the spread of water primrose, rather than by that of water hyacinth.



NOTES: The estimates assume 16,282 hectares of waterways total. The 2021 estimates are provisional. Years with no bars indicate missing data.

Figure 3-16 Change in Proportion of Waterways Occupied by Aquatic Vegetation in a Region Consisting of the North and Central Delta, as Calculated by Hyperspectral Imagery

3.3.2 Hyperspectral Imagery Ground-Truthing

The 2021 survey detected eight SAV species, with some similarities and differences in species abundances between Franks Tract and Big Break (**Figure 3-17**). The two sites, for example, showed similarly high abundances of *Egeria densa* (non-native) and *Elodea canadensis* (native). However, *Najas guadalupensis* (native) was the most abundant species in Franks Tract, but it was absent from Big Break. In addition, *Ceratophyllum demersum* (native) was 2.7 times higher in Franks Tract than in Big Break. In Big Break, abundances of *Myriophyllum spicatum* (non-native) and *Potamogeton richardsonii* (native) were 5.3 times and 3.2 times higher than in Franks Tract, respectively.

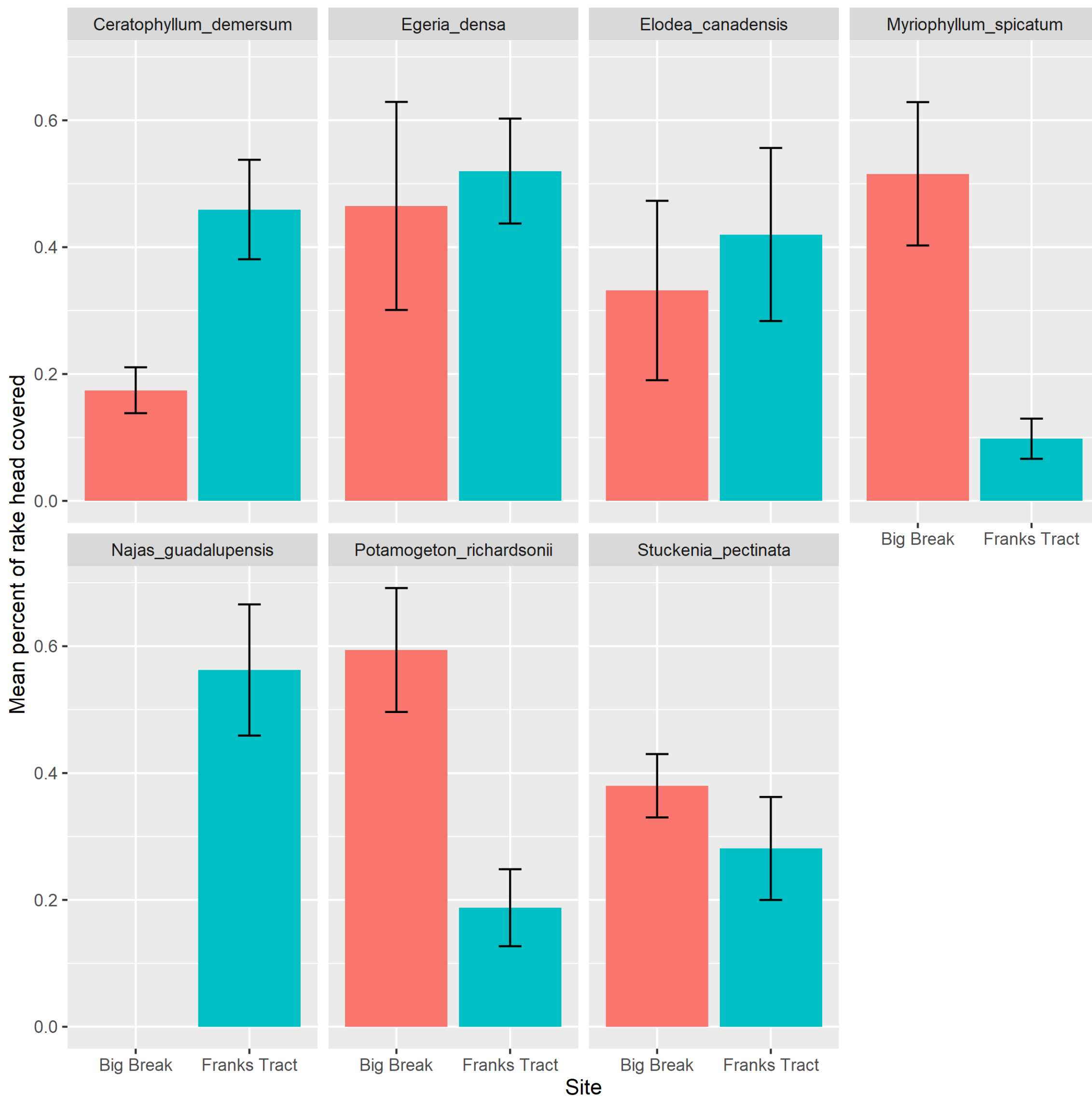


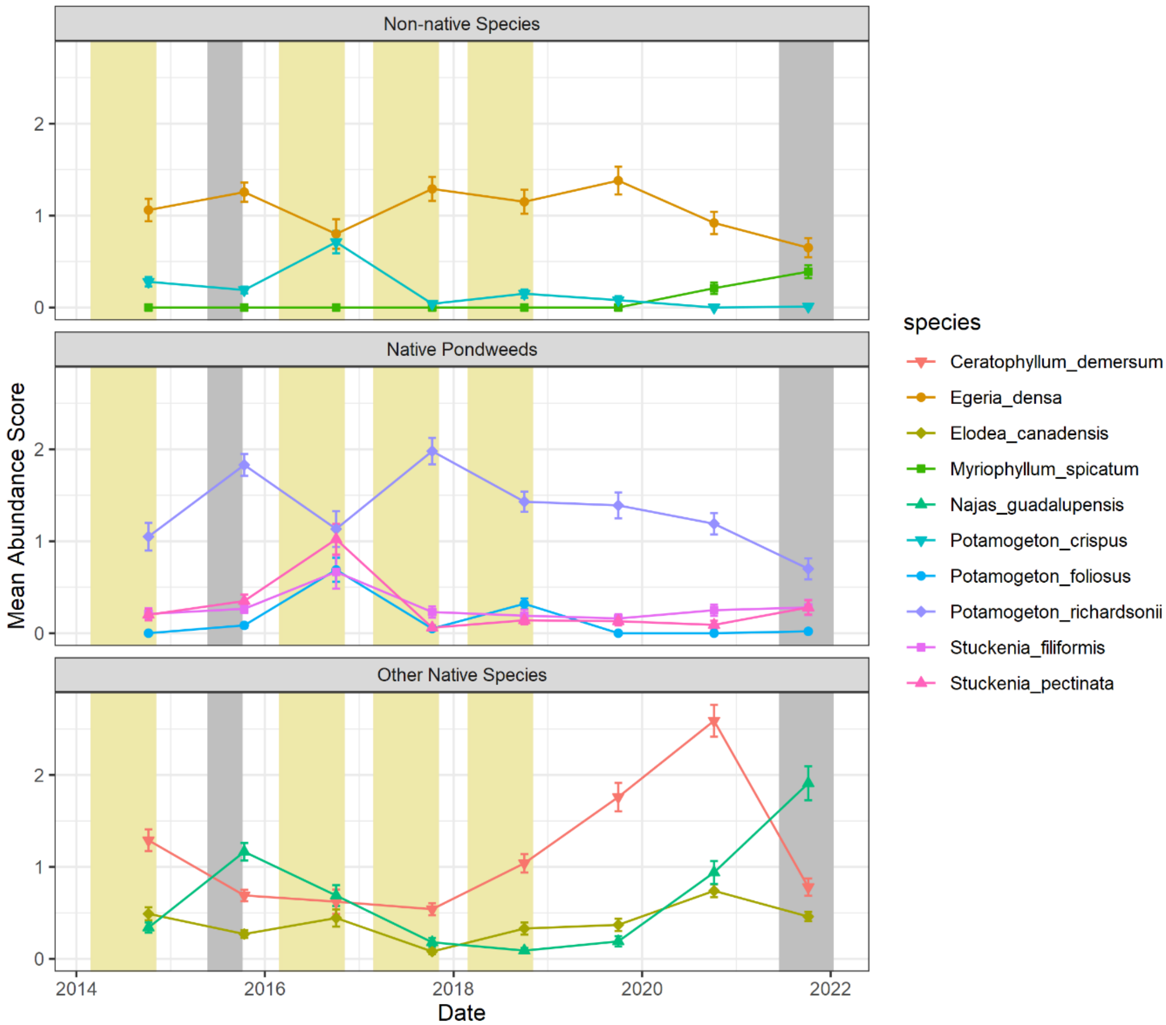
Figure 3-17 Comparison of Abundances of Submersed Aquatic Vegetation Species between Franks Tract and Big Break in 2021, as Measured by CSTARS Rake Samples

3.3.3 SePRO Vegetation Survey

Vegetation Composition Changes in Franks Tract

In total, 15 species of SAV were identified and measured in this survey, and the time series were plotted for the 10 most abundant ones (**Figure 3-18**). By far, the most dominant non-native species was *Egeria densa*, which maintained a fairly consistent abundance score over the years despite repeated herbicide applications and the presence of the barrier. The abundance of *P. crispus* was generally quite low, except in 2017, when levels were similar to those of

E. densa. *Myriophyllum spicatum*, another non-native, had been absent from all rake samples since an observation in 2006 (Caudill et al. 2019) but was found again in 2020 and 2021. Also in 2006, *Cabomba caroliniana* was observed, but the species has not been noted on rake samples since that time.



NOTE: Points are means of the ordinal abundance scores (range: 1–5) and error bars are standard errors. Five species were excluded from the plot because they were detected 10 or fewer times in total across the eight-year survey period: *Heteranthera dubia*, *Nitella* sp., *Potamogeton pusillus*, *P. zosteriformis*, and *P. nodosus*. Yellow regions indicate periods of fluridone applications and gray regions indicate periods with the emergency drought barrier installed.

Figure 3-18 Changes in Composition of Submersed Aquatic Vegetation Species during 2014–2021, Based on SePRO Corporation Rake Surveys

Figure 3-18 summarizes the results of the SePRO annual surveys as a mean abundance score (±standard error) overlain with the time frame when the barriers were in place in 2015 and 2021 (vertical gray bars) and when herbicide treatments occurred (vertical yellow bars). The dates and area of annual herbicide applications using fluridone are provided in Table 3-1.

The abundance of the native *P. richardsonii* exceeded that of *E. densa* in all years surveyed. In 2017, there was a decline in its abundance and a slight increase in the abundance of some other native species, including *Stuckenia filiformis, S. pectinata,* and *P. foliosus*. Trends in other native species include a relatively consistent abundance of *Ceratophyllum demersum, Elodea canadensis*, and *Najas guadalupensis* from 2014 to 2017. The abundance of *C. demersum* then increased greatly until the 2021 survey, when abundance dropped greatly.

Teasing out the effects of the barrier on the abundance of native and non-native SAV species is confounded by the application of aquatic herbicides in some years. Table 3-1 indicates that herbicide applications between 2006 and 2018 ranged in extent from 57 ha in 2006 to 1,314 ha in both 2007 and 2008. Treatments in more recent years have been on the order of 450 ha. The aquatic herbicide fluridone is labeled to control *C. demersum, Elodea canadensis, Egeria densa, Potamogeton* spp.*,* and *Myriophyllum* spp*.* (SePRO Corporation 2017).

Relationships with Environmental Drivers and Responses

Few of the correlations between ordinal abundances of common SAV species and the environmental responses and drivers were significant (**Table 3-5**, **Table 3-6**). For *Najas guadalupensis,* there were significant correlations for conductivity and pH (**Figure 3-19**). For *Egeria densa,* the only significant correlation was with pH (Figure 3-19). For *Ceratophyllum demersum,* the only significant correlation was with Secchi depth, and this relationship was driven by 2020 (Figure 3-19). For *Potamogeton richardsonii,* there were no significant correlations.

3.4 Discussion/Interpretation

The results of the 2021 hyperspectral imagery show that SAV continues to dominate much of the Delta. There was a step-change in 2015 in the three open-water areas focused upon in this report (Figure 3-7, Figure 3-8, Figure 3-9), and in the Delta as a whole (Figure 3-16). The 2021 EDB most likely changed the distribution, but not the abundance, of weeds within Franks Tract. There was no evidence for significant impacts of the TUCP on a Delta-wide scale, although lower flows, and associated higher salinity, were correlated with reduced SAV coverage in Big Break. In 2021, FAV was low throughout all the sites and in the broader Delta and showed abundances similar to or lower than other recent years.

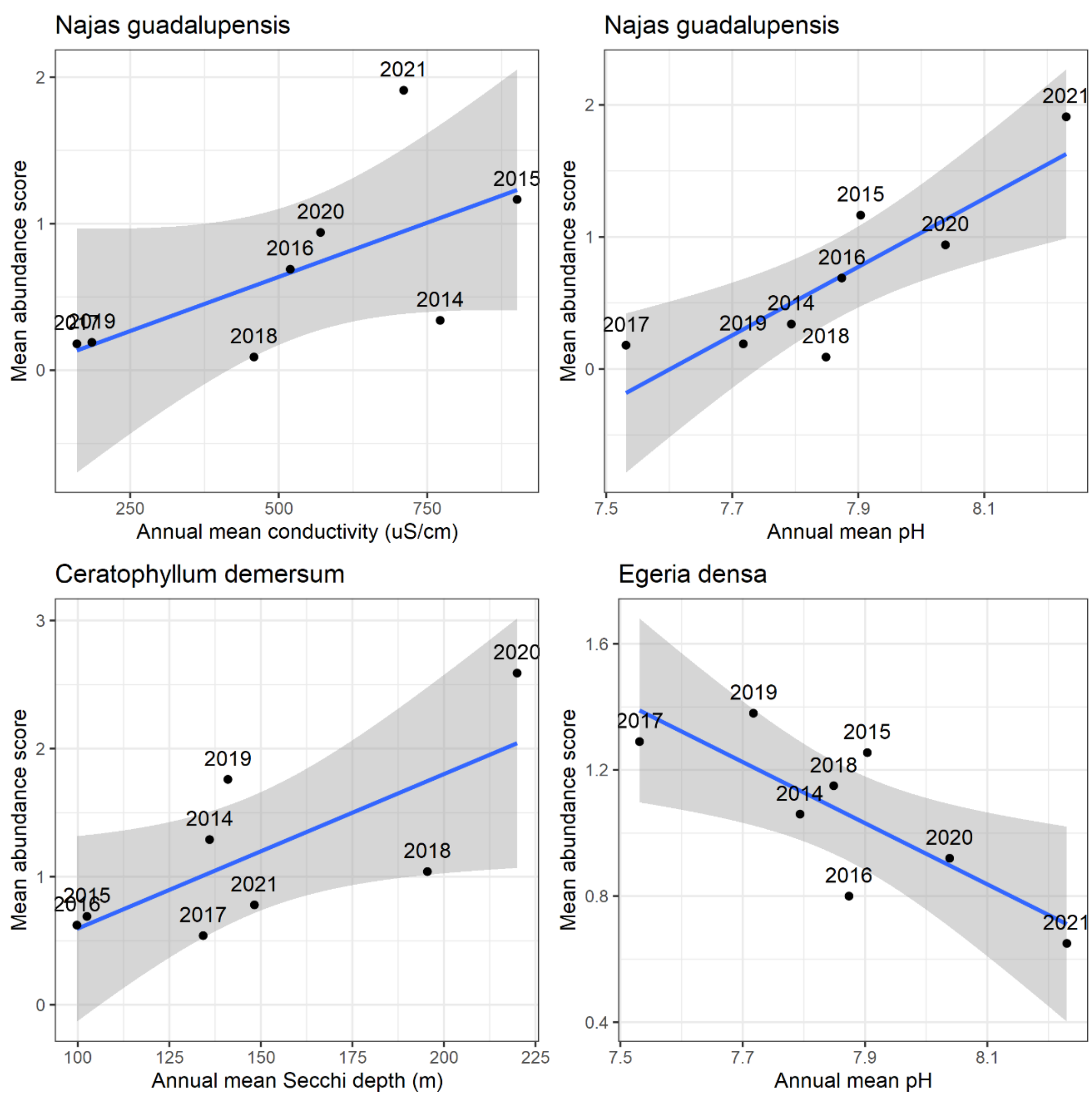
TABLE 3-5
CORRELATIONS BETWEEN ENVIRONMENTAL VARIABLES AND ABUNDANCES OF THE THREE MOST COMMON NATIVE SUBMERSED AQUATIC VEGETATION SPECIES, BASED ON THE ANNUAL SEPRO SURVEYS OF FRANKS TRACT

	CD corr	CD p-value	NG corr	NG p-value	PR corr	PR p-value
Conductivity	0.14	0.75	**0.74**	**0.05**	-0.43	0.30
DO	0.19	0.66	-0.24	0.58	-0.07	0.88
Herbicides	-0.20	0.63	-0.66	0.08	0.04	0.93
Outflow	-0.21	0.62	-0.64	0.10	0.36	0.39
pH	0.17	0.70	**0.83**	**0.02**	-0.50	0.22
Secchi Depth	**0.74**	**0.05**	-0.07	0.88	-0.19	0.66
Temperature	0.38	0.36	0.48	0.24	-0.21	0.62

NOTES: CD = *Ceratophyllum demersum* (coontail); NG = *Najas guadalupensis* (Southern naiad); PR = *Potamogeton richardsonii* (Richardson's Pondweed).

TABLE 3-6
CORRELATIONS BETWEEN ENVIRONMENTAL VARIABLES AND ABUNDANCE OF *EGERIA DENSA* (BRAZILIAN WATERWEED), THE MOST COMMON NON-NATIVE SUBMERSED AQUATIC VEGETATION SPECIES, BASED ON THE ANNUAL SEPRO SURVEYS OF FRANKS TRACT

	corr	p-value
Conductivity	-0.45	0.27
DO	-0.24	0.58
Herbicides	0.05	0.91
Outflow	0.38	0.36
pH	**-0.76**	**0.04**
Secchi Depth	-0.14	0.75
Temperature	-0.38	0.36



NOTES: Points are labeled with the year. The y-axis ranges differ among plots.

Figure 3-19 Significant Correlations between Environmental Variables and Abundances of Common Submersed Aquatic Vegetation Species, Based on Annual SePRO Surveys of Franks Tract

3.4.1 Impact of the Drought, the Barrier, and the Temporary Urgency Change Petition

Contrary to predictions, the data did not support a correlation between dry years and increased aquatic weeds. However, the lack of data from 2009–2013 makes it difficult to draw firm conclusions.

The continued dominance of weeds since 2015 has previously been attributed to drought conditions (Kimmerer et al. 2019). The authors of this report predicted that droughts would cause an increase in weeds, given the associated higher temperatures and the lack of clearing winter storms during droughts. However, 2014 was also a very dry year, yet significant changes in weeds did not occur until 2015. This finding is somewhat uncertain: Satellite imagery was not collected in 2014 until after vegetation had begun to senesce, so the weeds may have been thicker earlier in the season.

Earlier droughts (such as 2007–2008) also did not show a rapid expansion of weeds at the sites evaluated, although data are not available from the end of the drought in 2009–2010. Furthermore, the intervening high-flow years of 2017 and 2019 did not result in any clearing of weeds from either the sites focused upon in this study (Franks Tract, Big Break, Clifton Court Forebay) or the Delta as a whole (Figure 3-7, Figure 3-8, Figure 3-9, Figure 3-16).

It may be that the expansion of weeds during the 2014–2016 drought caused a regime shift in the system that cannot be reversed with a single high-flow year, and that factors other than drought alone are prompting the expansion of aquatic plants in the Delta.

The only statistically significant relationship found in this study between annual mean Delta outflow and aquatic vegetation was a significant increase in SAV at Big Break with increased outflow (Figure 3-14). This may be caused by the higher salinity seen at Big Break during low-outflow years, which may inhibit some of the freshwater species of SAV. The change in outflow and salinity caused by the TUCP may have contributed to this trend, but the relationship tested was the annual mean Delta outflow. A difference of 1,000 cfs during the driest part of the year will only have a minor impact on the annual mean.

Although a surprising lack of correlation was found between drought and SAV, the 2021 EDB did appear to change local SAV dynamics within Franks Tract. This pattern of SAV distribution in Franks Tract mirrors that of modeled water age with the barrier in place (Figure 3-7, Figure 2-36), suggesting that SAV coverage is higher where flows are lower. Conversely, significant clearing on the eastern side of Franks Tract was seen where water velocities increased. This pattern fits with previous research showing that water velocities are an important determinant of weed establishment (Chambers et al. 1991).

A similar response was seen during installation of the 2015 barrier. The open channel through the center of the island that was present in 2004–2008 had filled in by fall 2015 and did not re-form after removal of the 2015 barrier (Figure 3-7). However, expansions of aquatic weeds were also seen in other large Delta islands (such as Big Break or Clifton Court Forebay; Kimmerer et al. 2019; Figure 3-8, Figure 3-9).

The barrier may have caused changes to the distribution of weeds within Franks Tract, but did not seem to change overall coverage. This study found significant correlations between Franks Tract and the two other regions, including years with and without barriers (Figure 3-11, Figure 3-12). This suggests that landscape-level environmental patterns, rather than local changes to hydrology caused by the barrier, were controlling abundance.

3.4.2 Herbicide

The treatment of weeds with herbicides makes it difficult to identify impacts of environmental conditions versus treatment effects. The area treated annually by DBW's SAV and FAV treatment program has varied depending on funding, permits, plant community composition, and distribution of weeds (Caudill et al. 2021; Moran et al. 2021; Ta et al. 2017). Therefore, increases and decreases in weeds may be a combination of environmental parameters (e.g., water temperature, salinity, flow, water clarity) and treatment effects. Some recent research has questioned the effectiveness of fluridone in treating SAV in the Delta (Rasmussen et al. 2020); however, the authors of this report found that area of herbicide treatment was the only environmental variable that was significantly correlated with aquatic vegetation area in Franks Tract (Table 3-3).

Although herbicide-treated area was negatively correlated with aquatic vegetation coverage in Franks Tract, the application of fluridone does not appear to have been highly efficacious in controlling *E. densa,* and it is unclear whether the treatments played a role in the decline in *P. crispus* in 2017. The application of fluridone in 2017 could explain the decline in the abundance of native *S. filiformis, S. pectinata*, and *P. foliosus (*Figure 3-18*)*; however, knowing the exact dates of applications would better inform this conclusion. Because fluridone is a relatively slow-acting herbicide, the effects of treatment may not be observed for weeks, and the interacting effects of inter-specific competition and herbicide impacts are complex (Caudill et al. 2019).

Further, the exact locations of treatments are not known. Franks Tract is approximately 1,347 ha in size; thus, recent years' treatments that were less than 500 ha would have affected only a portion of the area. Of the other native species, the recovery of *C. demersum* when herbicide treatments were halted is evident. The presence of the barrier or competition with *N. guadalupensis* could have reduced the abundance of this species, as seen in the sharp decline in 2021.

3.4.3 Changes to Community Composition

Franks Tract has particularly good data on SAV community composition, thanks to the SePRO surveys and CSTARS ground-truthing (Figure 3-18).

In 2021, three species exhibited lower abundances in Franks Tract than in previous years: *Egeria densa* (non-native), *Ceratophyllum demersum* (native), and *Potamogeton richardsonii* (native). Conversely, two species exhibited higher abundances: *Najas guadalupensis* (native) and *Myriophyllum spicatum* (non-native). However, only *C. demersum* showed a strong change in the trajectory of its abundance compared to recent years. This species' abundance had increased nearly fivefold during 2017–2020, presumably as a result of release from fluridone applications, but dropped back nearly to 2017 abundance levels in 2021.

Other studies have found that fluridone is somewhat effective at reducing the abundance of *C. demersum* but generally does not completely eliminate it, and that it is more effective on *M. spicatum* (Smith and Pullman 1997; Valley et al. 2006); thus, other factors probably also contributed. The decrease in *C. demersum* in 2021 may be related to the drought barrier, but this is only a correlation and the authors of this report have not identified a mechanism. This dramatic change in 2021 could also have been caused by very high levels of *N. guadalupensis* outcompeting *C. demersum,* but their relative competitive abilities have not been explicitly tested. The salinity barrier may be favoring *N. guadalupensis* because of lower salinity and flow, but the increase in this species without fluridone applications is somewhat unexpected. Fluridone is listed as effective at treating *N. guadalupensis*, but this species is much more tolerant to the herbicide than other taxa (Koschnick et al. 2003; Netherland et al. 1997).

In 2021, SAV composition differed somewhat between Franks Tract and Big Break, possibly because Big Break had higher salinity. Specifically, there was more *C. demersum* and *N. guadalupensis* in Franks Tract and more *M. spicatum* and *S. pectinata* in Big Break (Figure 3-17, Figure 3-18). *S. pectinata* and *M. spicatum* have higher salinity tolerances than *E. densa* or *C. demersum* (Borgnis and Boyer 2015; Senavirathna et al. 2020), which may explain why they are more prevalent in Big Break. Tracking changes to community composition will be easier once additional years of data are available.

3.4.4 Impacts of Weeds on Beneficial Uses

Increases in aquatic vegetation have had multiple serious implications for both human uses and native fish habitat. SAV and FAV obstruct water diversions, with more than 30,000 cubic meters of vegetation removed from the SWP and CVP per year (Khanna et al. 2019). SAV also obstructs boat traffic, clogging propellers and jet engines, and control efforts can be extremely expensive, causing major economic impacts in the Delta (Moran et al. 2021).

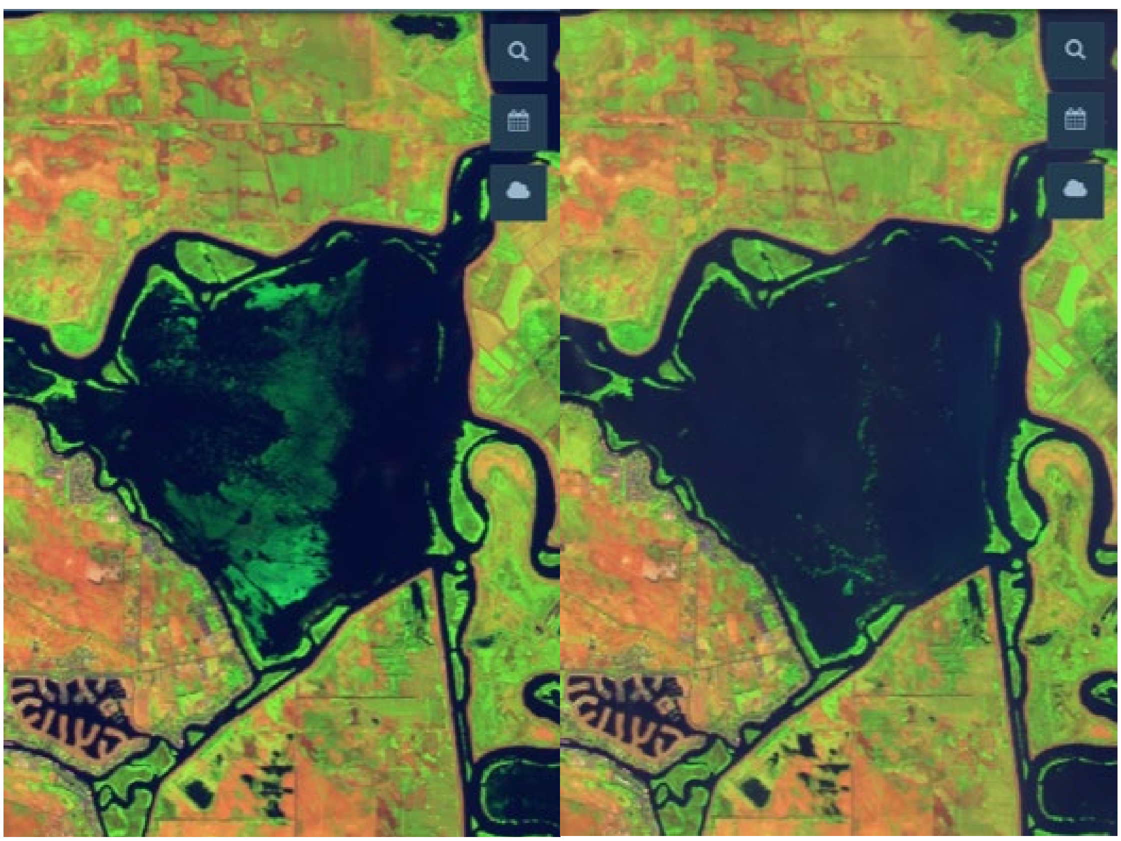
Most native fish in the Delta are adapted to an ecosystem with high turbidity and without SAV. Changes to fish communities linked to SAV have been documented as SAV has expanded (Brown and Michniuk 2007; Conrad et al. 2016). Delta Smelt preferentially seek out turbid habitat, where they have higher feeding success and lower risk of predation (Ferrari et al. 2014; Hestir et al. 2016; Tigan et al. 2020). Aquatic vegetation slows water flow, which decreases turbidity, and provides habitat for non-native predatory fish such as largemouth bass (Conrad et al. 2016). The ability of SAV to trap sediment may also reduce the transport of sediment to emergent tidal wetlands, reducing the wetlands' ability to keep pace with sea level rise (Drexler et al. 2020).

The extent to which native SAV may result in impacts differing from those of invasive SAV is not well understood. Some evidence has found that certain native species, such as *Stuckenia pectinata*, may have less of an impact on fish habitat than invasive SAV such as *Egeria densa* (Boyer et al. 2013). There is also some evidence that native floating vegetation provides better habitat for fish and native invertebrates than invasive *Eichhornia crassipes* (Toft et al. 2003). However, there has been a lack of research on the interactions between many of the native species in Franks Tract—including *N. guadalupensis*, which dominated in 2021—and the native fish community. Given the similarities in structure between many of the SAV species in Franks Tract, pelagic fish presumably will be negatively affected by both native and invasive SAV species.

These impacts of weeds on beneficial uses have been increasing over time. There is some indication of localized impacts of the 2021 EDB on weeds (Figure 3-7), but this study found no evidence of an effect of the TUCP on weeds, because vegetation coverage did not increase during summer 2021. Franks Tract and the South Delta, the areas most influenced by the barrier, are already regions with low turbidity, high temperatures, and low pelagic fish populations (CDFW data; Bashevkin et al. 2022; Moyle et al. 2012; Sommer and Mejia 2013). Therefore, any change in aquatic weeds in these regions is unlikely to have major impacts on the bulk of pelagic fish populations. The barrier may also divert migrating salmon from the Sacramento River away from Franks Tract (CDFW 2021), although this is still to be determined.

Weed treatment may also have negative effects on water quality, phytoplankton, and invertebrate populations, as well as potential fish health effects, although the extent to which this is a problem in the Delta is an area of active research (Jin et al. 2018; Marineau et al. 2019; Rasmussen et al. 2020; Tobias et al. 2019).

Along with the increased density of submerged vegetation, extensive mats of filamentous green algae were seen during field surveys and from satellite images (**Figure 3-20** and **Figure 3-21**). This type of filamentous algae in the Delta has not been extensively studied, so its potential role in the area's ecological functions remains unknown; however, it may have interacted with cyanobacteria to partially drive the observed pattern in which cyanobacteria were highest where weeds and filamentous algae were lowest.



NOTE: Large mats of filamentous green algae are visible in the early-October image, but much of this algae was washed out during the large atmospheric river that occurred October 23–25, 2021. Images courtesy of SePRO Corporation.

Figure 3-20 Satellite Images of Franks Tract in Early October 2021 (left) and Late October 2021 (right)

NOTE: Photo provided by SePRO Corporation.

Figure 3-21 Photo Showing the Amount of Vegetation and Algae Present in Franks Tract on October 6, 2021

3.4.5 Potential Mitigation Actions for the Future

Management of aquatic vegetation is an area of active research, and no clear solutions for control of weeds in the Delta have yet been identified. The existing control program run by DBW is permitted to treat a limited area with a limited number of methods. Treatment for FAV, chiefly through the use of glyphosate herbicide, is relatively effective at killing weeds; however, it requires large investments of time and money (Caudill et al. 2021), introduces toxic contaminants into waterways, and does not remove dead plant material, which will continue to alter aquatic habitats (Marineau et al. 2019; Tobias et al. 2019). The use of herbicides for SAV is much less effective in a tidal environment (Rasmussen et al. 2020). New control strategies are currently under investigation, including new herbicides (Madsen and Kyser 2020; Madsen et al. 2021), biocontrol agents (Hopper et al. 2017), and physical barriers (Moran et al. 2021).

Treatment of SAV within Franks Tract while the barrier is in place may be somewhat more effective than SAV treatment in other areas of the Delta because flows on the west side of the tract will be significantly reduced (Figure 2-36). Longer residence times may allow aquatic herbicides to remain in contact with the target species for a longer period, thus increasing their efficacy (Netherland et al. 1991; Rasmussen et al. 2020; Slade et al. 2008). Currently, the use of herbicides within Franks Tract is precluded by the presence of many species not listed in DBW’s permit (E. Hard, DBW, pers. comm.), but some investigation on reduced flow and herbicide efficiency may be an area ripe for future research. For example, increased residence time could improve the concentration and exposure time of fluridone with *Egeria densa*, improving management efforts for that species (Caudill et al. 2019). The goal of such a management strategy would be to decrease nuisance levels of *E. densa* while releasing native species from competition.

Control of weeds throughout Franks Tract may be best addressed by a more comprehensive ecosystem restoration program, such as the one proposed by the Franks Tract Futures project (California Department of Fish and Wildlife 2020). This project would serve to restrict salinity intrusion, would reduce aquatic weeds, and would have fewer effects on residence time than the emergency drought barrier. It would therefore be a more sustainable solution than repeatedly installing drought barriers.

There are several current projects that are working towards elucidating the relationship between aquatic plants and drought years. A project funded by DWR is seeking to fill the gap in SAV and FAV cover estimates from 2009 to 2013 by classifying multispectral fine spatial resolution data such as WorldView2, IKONOS and GeoEye. These satellites have very few broad bands but do collect data at a spatial resolution of 2x2m or less. Additionally, this same project is also going to classify imagery from 2014 summer and early fall (before senescence) so we can get a more accurate estimation of SAV and FAV distribution for that year. DWR is also funding two additional years of imagery acquisition over the Delta in summer of 2022 and 2023. These additional years of data will give us a continuous 20-year time series (since 2004) of SAV and FAV cover in the Delta spanning two multi-year droughts and several wet years, and two separate instances of the False River drought barrier installation with before and after imagery. This will allow more rigorous examination of the effect of the drought and the, separately, the effect of the drought barrier on SAV and FAV.

In parallel, there are a couple of studies focused on niche occupancy modeling for the SAV community and water hyacinth and water primrose. These niche models, once developed, will help understand the patterns observed as a response to drought or the drought barrier. The relationship of aquatic vegetation with hydrodynamic conditions, habitat, salinity, etc. will be explored and we know that drought conditions and the drought barrier alter these conditions in different ways in the Delta. Applying the model to these scenarios will uncover some of the mechanisms for the observed patterns.

SECTION 4
Vulnerable Communities

The February 15, 2022, Reconsideration Order (State Water Resources Control Board 2022a) requires that DWR:

> *[A]nalyze potential for (or presence of) disproportionate impacts to vulnerable communities such as low-income communities and communities of color with respect to drinking water quality, contact and non-contact recreation, impacts to tribal cultural resources, and impacts to aesthetics including odors and the visual character of Delta waterways where cyanoHABs and aquatic weeds are prevalent.*

The analysis of disproportionate environmental impacts on vulnerable communities is an analysis of environmental justice.

CyanoHABs, FAV, and SAV ("weeds") are an existing problem throughout the Delta. The focus of the environmental justice analysis will be to use the findings of the cyanoHABs study and additional research to answer the following questions related to impacts on vulnerable communities:

1. Did implementing the TUCP and/or EDB change cyanoHABS and weeds in a way that would worsen existing conditions or expected conditions (drought) without the TUCP or barrier?
2. Would effects be worse for vulnerable communities than the general population (i.e., disproportionate), and how?

Sections 2.4 and 3.4 of this report discuss the findings of effect of installing the barrier on cyanoHABs and SAV, thus answering question 1. These findings, along with U.S. Census data and other sources, inform the analysis to answer question 2.

4.1 Introduction

For the purposes of this report, "vulnerable communities" means low-income and minority communities as defined in federal Executive Order 12898, Federal Actions to Address Environmental Justice in

Minority Populations and Low-Income Populations (59 *Federal Register* 7629, February 16, 1994), and in associated guidance for environmental justice analyses for compliance with the National Environmental Policy Act (NEPA). In this section, the terms "environmental justice community," "vulnerable community," and "disadvantaged community" are used interchangeably.

As a department of the California Natural Resources Agency, DWR is subject to the agency's environmental justice policy, which directs all departments of the agency to consider environmental justice in their decision making when their actions have an impact on the environment. The California Natural Resources Agency's policy (California Natural Resources Agency, no date) reads:

> *It is the policy of the Resources Agency that the fair treatment of people of all races, cultures and income shall be fully considered during the planning, decision-making, development and implementation of all Resources Agency programs, policies and activities. The intent of this policy is to ensure that the public, including minority and low-income populations, are informed of opportunities to participate in the development and implementation of all Resources Agency programs, policies and activities, and that they are not discriminated against, treated unfairly, or caused to experience disproportionately high and adverse human health or environmental effects from environmental decisions.*

Because the TUCP is a petition to the State Water Board, this report also responds to the State Water Board's environmental justice commitment (State Water Resources Control Board 2020), to be considered in actions taken by the Water Boards that pertain to sources of drinking water:

> *The Water Boards are committed to the equitable treatment of all Californians. We seek to meaningfully involve stakeholders and other interested parties in our decision-making processes and provide open and transparent opportunities for people to participate in public meetings, hearings, and workshops that may affect their environment and health.*

The State Water Board and DWR also recognize the Human Right to Water Resolution (Assembly Bill 685), signed into law by Governor Edmund G. Brown Jr. in 2012 (State Water Board 2021), which states that "Every human being has the right to safe, clean, affordable, and accessible water adequate for human consumption, cooking, and sanitary purposes." The human right to water extends to all Californians, including disadvantaged individuals and groups and communities in rural and urban areas.

Accordingly, DWR has included this discussion of the possible effects of implementing the TUCP and the EDB on vulnerable communities.

4.2 Methods

An identification of vulnerable communities has been conducted in accordance with guidance for implementing Executive Order 12898 in NEPA analyses of environmental justice (Council on Environmental Quality 1997; Interagency Working Group on Environmental Justice & NEPA Committee 2016). Using a threshold based on the relatively high cost of living in California, "low income" is defined as households with a median household income (MHI) of 80 percent or less of the statewide MHI. The American Community Survey 2015–2019[2] reported that California's 2019 MHI was $75,235; therefore, a household within the study area with an MHI of $60,188 or less is considered low-income. A threshold of $60,000 was used, corresponding to the breakdown of the census data tables.

"Minority individuals" are defined as members of the following population groups, defined by the U.S. Census in accordance with the 1997 U.S. Office of Management and Budget standards on race and ethnicity (U.S. Census Bureau 2019):

- American Indian or Alaskan Native
- Asian or Pacific Islander
- Black, not of Hispanic origin
- Hispanic—"Hispanic or Latino" ("Hispanic or Latino" means a person of Cuban, Mexican, Puerto Rican, South or Central American, or other Spanish culture or origin, regardless of race)
- Those identifying as "some other" or "two or more"

For the purpose of this report, a "vulnerable community" is determined to be present if the study area contains total minority populations of

[2] At the time this report was prepared, 2020 U.S. Census data had not yet been posted to the U.S. Census TIGER files used for GIS analysis.

50 percent or more, or if low-income households compose 20 percent or more of all households in the study area.

An impact would be disproportionate if an adverse environmental effect exists that would affect a low-income or minority community in excess of the effect on the general population.

The definition of "disadvantaged communities" in the context of environmental justice has broadened over time to include more than just income and minority status. Tools such as CalEnviroScreen consider attributes such as health status, pollution exposure, housing cost burden, and linguistic isolation. Because of historic and ongoing social and institutional discrimination, however, income and minority status are often the primary drivers of those other characteristics and are considered here to generally capture those other disadvantages.

4.2.1 Study Area

The study area consists of the census block groups adjacent to Franks Tract and nearby water bodies, based on the extent of the last and previous cyanoHAB blooms (**Figure 4-1**) (affected area). (Census data are collected and aggregated at the tract, block group, and block level, in descending order.) This geography was selected as the most likely area from which people would be exposed to a HAB bloom. In addition to local residents, Franks Tract Recreation Area attracts visitors from all over; however, ascertaining the minority and income status of all visitors to the study area is infeasible.

4.2.2 Research and Outreach Efforts

To obtain additional information about human use of the Delta, particularly contact and non-contact recreation, and the impacts on vulnerable communities, DWR used several recently completed surveys of Delta users and residents:

- The Franks Tract Futures User Survey (California Department of Fish and Wildlife 2020), which was completed in 2018–2019 to assess the user base of Franks Tract Recreation Area and the users' opinions on different restoration scenarios. Although it did not target vulnerable communities specifically, this survey provided information about the people who travel to the Delta for recreation.

- The Delta Protection Commission's Recreation and Tourism in the Delta survey (Mickel et al. 2019), which was conducted in 2018 to assess how Delta residents and visitors recreate in the area.

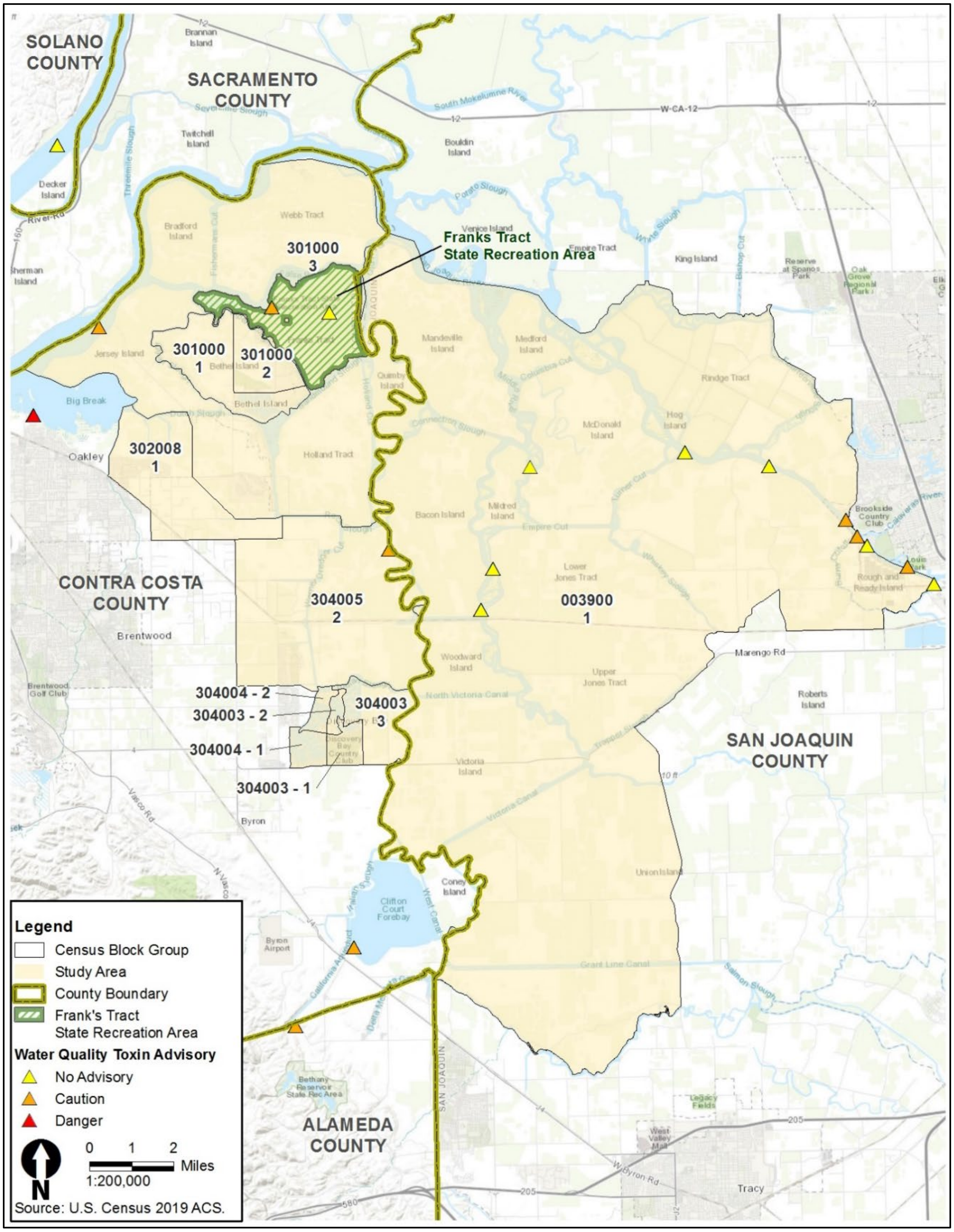


Figure 4-1 Environmental Justice Study Area for Cyanobacterial Harmful Algal Blooms and Aquatic Weeds

- DWR Delta Conveyance Project's *Your Delta, Your Voice* environmental justice community survey (DCP EJ Survey Report; California Department of Water Resources 2021b), which was completed in fall 2020. This survey had the goal of assessing how disadvantaged communities in the Delta region live, work, recreate in, and experience the Delta.

In addition, DWR met with representatives from Restore the Delta and the State Water Board on April 29, 2022, to discuss HABs and environmental justice concerns. This, and other outreach efforts are described in more detail in Appendix E.

To increase understanding of the potential impacts of cyanoHABs and weeds specifically on Tribal uses in the Delta, the DWR cyanoHABs team reached out to Tribes with known interests in the Delta and with whom DWR has had regular engagement. Tribal representatives were invited to take a short survey asking how Tribal members use the Delta (e.g., recreation, fishing, cultural or ceremonial purposes) and whether and how cyanoHABs in the Delta have affected use by Tribal members. The survey and a fact sheet were distributed to DWR's list of Tribal contacts on April 27, 2022, and to participants in EPA's Regional Tribal Operations Committee meeting on April 26 and 27, 2022 (Appendix B and Appendix C).

The following Tribes were contacted:

- California Valley Miwok Tribe (Sheep Ranch Rancheria of Me-Wuk Indians of California)
- Ione Bank of Miwok Indians
- Northern Valley Yokuts Tribe
- Shingle Springs Band of Miwok Indians
- United Auburn Indian Community
- Wilton Rancheria
- Winnemem Wintu
- Wintu Tribe of Northern California
- Yocha Dehe Wintun Nation
- Buena Vista Rancheria of Me-Wuk Indians
- Rincon Band of Luiseño Indians
- Viejas Band of Kumeyaay Indians

- Yurok Tribe

No survey responses had been received as of May 17, 2022.

Participants in the Restore the Delta listening session on April 29, 2022, shared their opinion that cyanoHABs are caused by multiple factors, including water project operation, temperature, and nutrients. They wanted appropriate mitigation measures to be enacted for any increases in cyanoHABs caused by the State's actions. They also expressed their desire for increased funding from the State Water Board for cyanotoxin monitoring.

On May 5, 2022, DWR hosted a listening session at the 2022 Quarter 2 Sustainable Groundwater Management Act Tribal Advisory Committee Meeting to hear Tribal concerns related to HABs. Meeting participants did not have specific expertise on the Delta; however, they emphasized the increasing problems that Tribes are experiencing with cyanoHABs across the state. In particular, cyanoHABs in Lake Henshaw have caused water to be shut off to several downstream Tribes. CyanoHABs have also caused water quality impairments for Tribes on the Klamath River and Russian River. They emphasized the need for a statewide, coordinated effort to monitor and mitigate the impacts of these blooms.

It should be noted that given the time frame for delivering this report, extensive direct outreach to Tribes and other community groups was not feasible. Both the new cyanoHABs survey to Tribes with subsequent listening session and the DWR DCP EJ Survey Report provide qualitative data from a self-selected sample of Delta residents and other Delta users. Other DWR reports, public comments, and ethnographic literature also inform the discussion. The results reported in these documents cannot be statistically extrapolated to the Delta community in general or environmental justice populations specifically. Based on the outreach efforts conducted on behalf of this report, there is a clear need for further robust engagement of vulnerable communities and Tribes to accurately understand their experiences with cyanoHABs across the state

4.3 Effects of the Temporary Urgency Change Petition on Cyanobacterial Harmful Algal Blooms and Vulnerable Communities

4.3.1 Census Findings for the Study Area

The population of the study area is 20,766. **Table 4-1** shows that of 7,075 households in the study area, more than 30 percent have an MHI less than $60,000; all but three census block groups meet the low-income criterion. The percentage of households in block groups that meets the low-income criterion ranges from 23.2 percent to 81.8 percent. Accordingly, a vulnerable community is present.

TABLE 4-1
DISTRIBUTION OF LOW-INCOME POPULATIONS IN THE STUDY AREA

Census Tract	Census Block Group	Median Household Income	Total Number of Households	Number of Households below $60,000	Percentage of Households below $60,000
Contra Costa County					
301000	1	$48,348	383	210	54.8
	2	$25,742	523	403	77.1
	3	$118,438	958	223	23.3
302008	1	$94,577	799	284	35.5
304003	1	$136,801	841	193	22.9
	2	$146,848	240	8	3.3
	3	$110,156	429	85	19.8
304004	1	$127,652	1,063	168	15.8
	2	$113,682	614	154	25.1
304005	2	$158,750	1,016	236	23.2
San Joaquin County					
003900	1	$47,917	209	171	81.8
Total	**–**	**–**	**7,075**	**2,135**	**30.2**

Table 4-1 displays the distribution of low-income populations in the study area.

Table 4-2 displays the distribution of minority populations in the study area, showing that 38 percent of this population identifies as minority. Census Tract 302008, Block Group 1 in Contra Costa County and Census Tract 003900, Block Group 1 in San Joaquin County have minority populations of more than 50 percent. The total population of these block groups is 4,142, of whom 2,918 are minorities.

4.3.2 Human Use of the Study Area

With Franks Tract as its locus, the study area attracts users from well beyond its boundaries. The Delta serves a wide variety of users from both within and outside the legal Delta. Users include minority and low-income people who live or work in the Delta and those who visit but do not live there. Users value the region’s landscape, natural and cultural history, and occupational and recreational opportunities (California Department of Water Resources 2021b).

TABLE 4-2
DISTRIBUTION OF MINORITY POPULATIONS IN THE STUDY AREA

Census Tract	Block Group	Total Population	White Non-Hispanic	Black Non-Hispanic	Native American Non-Hispanic	Asian Non-Hispanic	Native Hawaiian Non-Hispanic	Some Other Race Non-Hispanic	Two or More Non-Hispanic	Total Hispanic	Hispanic (% of Total)	Total Minority—Black, Hispanic, Asian/Pacific Islander, Native American, Native Hawaiian, Other, 2 or More	Minority Population (%)
Contra Costa County													
301000	1	942	609	30	0	27	0	0	0	276	29.3	333	35.4
	2	1,219	827	20	0	0	0	0	21	351	28.8	392	32.2
	3	2,989	1,769	412	0	118	0	94	76	520	17.4	1,220	40.8
302008	1	3,234	963	261	0	533	0	0	255	1,222	37.8	2,271	70.2
304003	1	2,130	1,406	85	6	216	0	0	0	417	19.6	724	34.0
	2	581	528	0	0	10	0	0	0	43	7.4	53	9.1
	3	1,082	875	10	0	8	0	10	9	170	15.7	207	19.1
304004	1	2,669	2,136	20	0	147	0	0	89	277	10.4	533	20.0
	2	1,445	1,151	0	0	64	0	0	43	187	12.9	294	20.3
304005	2	3,567	2,259	324	0	96	0	15	98	775	21.7	1,308	36.7
San Joaquin County													
003900	1	908	261	0	0	0	0	0	0	647	71.3	647	71.3
	Total	**20,766**	**12,784**	**1,162**	**6**	**1,219**	**0**	**119**	**591**	**4,885**	**24**	**7,982**	**38.4**

A 2019 study by the Delta Protection Commission found that 42.1 percent of survey respondents were visitors from outside the Delta, and 57.9 percent reported being "locals." Of survey respondents who provided income information for that study, about 60 percent reported an annual household income of $75,000 or less (Mickel et al. 2019). This is consistent with findings reported in the Delta Protection Commission's *Socioeconomic Indicators Report* and 2020 U.S. Census data that median household income in the Delta trends below the statewide median (Visser et al. 2019), as well as census data collected for this report (U.S. Census Bureau 2019).

Agriculture and related industries are the foundation of the Delta economy, but tourism and recreation are additional important sectors. Boating, fishing, and nature/wildlife were among the most commonly cited categories of recreational interests by survey respondents in the Delta Protection Commission's *Recreation and Tourism in the Delta* report (Mickel et al. 2019). DWR's *Your Delta, Your Voice* survey in 2021 similarly found that boating, fishing, and experiencing the Delta's waterways and natural areas are popular activities for survey respondents, of whom 36 percent identified as low-income or minority individuals from within and outside the Delta. Top concerns and priorities of survey respondents included drinking water quality and quality of the natural environment throughout the Delta; their comments connected habitat and water quality to their way of life, local economy, and livelihoods (California Department of Water Resources 2021b).

Fishing, boating, and the services that support water-based recreational activities are economically important in the Delta, serving vulnerable communities along with the general population. Block Groups 1 and 2 of Census Tract 30100 encompass the community of Bethel Island, located on the shore of Franks Tract. Together, nearly 68 percent of households in these block groups are considered low income, with an MHI less than $60,000. Bethel Island is a locus of significant economic activity in the Central Delta, with nearly half of its employment related to recreation, particularly fishing, boating and attendant retail, marina, hospitality, and other services (Economic & Planning Systems 2020). Fishing is a culturally important activity and a food source for some low-income and minority populations in the Delta (Shilling et al. 2010; Silver et al. 2007), as it is for minority groups, low-income communities, Tribes, and other indigenous peoples throughout the United States (U.S. Environmental Protection Agency 2002). Respondents to the *Your Delta, Your Voice* survey identified hundreds of favorite fishing spots throughout the Delta (California

Department of Water Resources 2021b). Water quality that affects this fishery is therefore a concern for both economic and public health.

CDFW convened an advisory committee representing a variety of local community stakeholders in Franks Tract for the *Franks Tract Futures Reimagined* effort, to identify a conceptual restoration project that could meet both ecological and local interests. CDFW's advisory committee was made up of residents and landowners, marina and small business owners, local government representatives, reclamation districts, hunters, fishers, boaters, and recreational advocates (California Department of Fish and Wildlife 2020; Economic & Planning Systems 2020). The income and minority status of these representatives and their constituents is unknown. Tribal stakeholders were not specifically identified, although Native American individuals or business owners may be among the stakeholders on, or represented by, the advisory committee. For this reason, DWR undertook additional research and outreach to CDFW's existing Tribal contacts to ensure that this study included a Tribal perspective.

Native Americans in the Delta

Only a few Native Americans live in the study area, but Native Americans have been present in the Delta since thousands of years before the arrival of Europeans and Euroamericans. The Delta is the ancestral land of the Nisenan, Maidu, Miwok, Costanoan, Northern Valley Yokuts, and Patwin peoples and remains an important place for their descendants today (Maven's Notebook 2020). Members of Tribes with ancestral territories both inside and outside the Delta region have provided public comments on projects in the Delta proposed by DWR and other project proponents, emphasizing that natural resources are also cultural resources. The health of the Delta is therefore a concern well beyond its legal or even geographic boundaries.

> *There is a bond that still exists with the present day descendants and their sacred places and sites, no matter how old or how small that particular cultural resource is. These cultural sites and resources continue to have religious and ceremonial significance and are still in use by Native American communities.—Anecita Agustinez, DWR Tribal Policy Advisor (Maven's Notebook 2020)*

An illustrative example is found in research that DWR conducted with the United Auburn Indian Community for a recent CEQA analysis of a barrier project in 2021. The effort identified historic themes relevant to that Tribe's culture and traditions associated with the Delta (California Department of Water Resources 2021a):

- "Delta as Provider" recognizes that the Delta is the source of vital resources—water, air, fish, and wildlife—along with "transitory resources," such as salmon runs, waterfowl migration, and periodic fogs, floods, and Delta winds, that were and remain critical to Native American survival.
- The "Delta as Home" theme "embraces concepts focused on Tribes belonging to the Delta as their place of birth and residence, with the Tribe's principal concepts of self and identity being that of Delta people and the Delta as ancestral land" (California Department of Water Resources 2021a).
- "Maidu Indigenous Beliefs" are the cultural and spiritual beliefs associated with not only material evidence of Tribal occupation and use of places in the landscape, but also hunting and fishing locations, the natural ecosystem, important waterways and landscape features, and the spiritual world.
- The "Preservation of Tribal Culture" theme captures the importance of Delta locations that provide resources for traditional craft and cultural practices, access to which allows transmission of culture across generations (California Department of Water Resources 2021a).

These themes are not unique to one tribe; ethnobotanist M. Kat Anderson cites observations by 20th-century anthropologists and travelers of the importance of place to California's indigenous peoples, and how "the flora and fauna and landforms are part of the culture. … There is no compartmentalization of nature from humans" (Anderson 2005). Heizer and Elsasser (1980) wrote that the California Indians "not only lived in nature, but considered themselves an integral part of it. … All of nature was thought to be interconnected."

Native American participants in the DCP EJ Survey noted their long-standing cultural and spiritual affiliation with Delta resources. Their comments expressed concerns about preservation and restoration of ecosystems and cultural and sacred sites, noted the traditional and sacred connection between Tribes and the Delta landscape, and prioritized indigenous stewardship of land, culture, and the environment (California Department of Water Resources 2021b).

Water quality affects both wildlife and human uses of the Delta waters. The study area is not a source of drinking water, but water quality can affect Tribal activities, such as fishing and recreational activities. The State Water Board has designated Tribal Beneficial Uses, also called "cultural uses of water," that protect water uses directly related to Native American cultures and to Native and other subsistence (non-commercial) fishing (State Water Resources Control Board 2022b). The Central Valley RWQCB has proposed adopting them into its basin plan but has not yet officially adopted Tribal Beneficial Uses or designated any water bodies as subject to Tribal Beneficial Uses.

4.3.3 Cyanobacterial Harmful Algal Blooms, Weeds, and Humans

In terms of health, the "harm" in HABs is caused by cyanotoxins produced by certain cyanobacteria that multiply to harmful levels under some conditions, although not all cyanobacteria are harmful. *Microcystis* cyanobacteria release toxins (microcystins) that can affect human and aquatic health in the Delta (Section 2.1.1). Ingestion of cyanotoxins in drinking water or exposure to water bodies containing cyanotoxins can cause skin irritation and rashes, eye irritation, vomiting, diarrhea, and cold or flu-like symptoms in humans; dogs have died from drinking infested water or eating cyanobacteria with high toxin levels; and cyanotoxins can affect livestock.

OEHHA evaluated the health risks from microcystins and other cyanotoxins commonly found in Delta waters, and with other partners, developed action levels to guide regulatory agencies in taking actions to protect public health. When toxins are found at concentrations exceeding the action levels, a public health response such as continued monitoring or issuance of public health notices is recommended (OEHHA 2022). A system has been developed for posting color-coded advisory signs (in both English and Spanish) based on levels of total microcystins. These levels are for contact recreation (swimming); advisory levels for drinking water and fish consumption are shown in Table 2-1. Criteria for action are:

- No Advisory (green): Less than 0.8 µg/L.
- Caution (yellow): 0.8 µg/L.
- Warning (orange): 6 µg/L.
- Danger (red): 20 µg/L.

1 µg/L is equal to 1 part per billion.

Figure 4-2 displays the criteria for each warning level (California Cyanobacteria and Harmful Algal Blooms Network 2022). In 2021, OEHHA issued a recommendation for an interim notification that the presence of a microcystin level of 0.03 µg/L in drinking water for a duration of three months could lead to a decline in sperm numbers in humans (OEHHA 2022); this is lower than the CCHAB Network's level of 0.8 µg/L for "No Advisory" for total microcystins. However, Franks Tract is not a source of drinking water and no toxins were detected in SWP export facilities in 2021, so drinking and irrigation water are not believed to have been contaminated with toxins.

Trigger Levels For Human and Animal Health

Criteria*	No Advisory [a]	Caution (TIER 1)	Warning (TIER 2)	Danger (TIER 3)
Total Microcystins [b]	< 0.8 µg/L	0.8 µg/L	6 µg/L	20 µg/L
Anatoxin-a	Non-detect [c]	Detected [c]	20 µg/L	90 µg/L
Cylindrospermopsin	< 1 µg/L	1 µg/L	4 µg/L	17 µg/L
Cell Density of potential toxin producers	< 4,000 cells/mL	4,000 cells/mL	______	______
Site-specific indicator(s)	No site-specific indicators present	Discoloration, scum, algal mats, soupy or paint-like appearance. Suspected illness	______	______

* Action levels are met when one or more criteria are met.
[a] For de-posting, all criteria for no advisory must be met for a minimum of 2 weeks. General awareness sign may remain posted and healthy water habits are still recommended.
[b] Microcystins refers to the sum of all measured Microcystin congeners.
[c] Must use an analytical method that detects ≤ 1µg/L Anatoxin-a.

Figure 4-2 California Cyanobacteria and Harmful Algal Blooms Network Trigger Levels for Posting Planktonic Advisory Signs

Aquatic Species

CyanoHABs may be harmful to fish and aquatic invertebrates, but generally at much higher levels than those found in this study. Harm to aquatic species can result from ingesting cyanotoxins, or indirectly from adverse changes in pH and dissolved oxygen resulting from cyanoHABs (Section 2.4.1). Toxins present in fish tissue can be passed on to human consumers, sometimes causing humans to surpass the recommended daily limit for microcystins (Poste et al. 2011). There are a large number of people who rely on fish and shellfish from the Delta for food, and many of them are people of color (Shilling et al. 2010); low levels of microcystins in fish tissue may cause problems when eaten daily. However, rates of bioaccumulation of toxins from water into fish tissue have not been studied extensively. The short-term bloom in Franks Tract in 2021 may have contributed to microcystins in fish tissues, but the magnitude of this effect is likely to be small, given the relatively low toxin levels and short time frame of the bloom.

The increased prevalence of cyanoHABs in the Delta predicted with increased temperatures and climate change will necessitate greater monitoring of cyanotoxins in fish tissue to monitor bioaccumulation and impacts to humans.

Weeds

SAV coverage in the Delta has increased substantially over the past 20 years, particularly in association with low-flow conditions during drought (Section 3.1.2). Excessive weed coverage is a nuisance for human use and alters ecosystem function. SAV can obstruct boat traffic, clog propellers and water infrastructure, and present navigation hazards, but does not directly affect human health. Chemicals used to control weeds, however, may affect water quality (Section 3.1.3).

Odors

In August 2021, Contra Costa Water District detected increased algae in Old River and the Victoria Canal, causing taste and odor problems in drinking water. To avoid the algal issues, Contra Costa Water District reduced diversions of Delta water and instead relied on previously stored high-quality water from Los Vaqueros Reservoir. On March 25, 2022, Contra Costa Water District submitted a comment letter on the draft environmental impact report on the West False River Drought Salinity Barrier Project. In the comment letter, the district asked DWR to consider incorporating culverts into future installations of the barrier to improve flow circulation and reduce the potential for algal growth in the region, and requested that DWR incorporate additional algal sensors to monitor conditions in Old River south of Franks Tract (Appendix D).

4.4 Conclusion

The study area contains low-income and minority residents at a scale that warrants an examination of the environmental justice impacts of the installation of the 2021 EDB. Low-income households compose 30.2 percent of the study area households. Two census block groups in the study area have minority populations greater than 50 percent, but overall, the study area's minority population is 38.4 percent. **Figure 4-3** shows the distribution of low-income and minority populations in the study area (U.S. Census Bureau 2019) and the maximum cyanoHAB advisory status locations during 2021, as reported to the State Water Board's HABs Incident Reports Map (https://mywaterquality.ca.gov/habs/where/freshwater_events.html).

This chapter aimed to answer the following two questions:

1. Did implementing the TUCP and/or drought barrier change cyanoHABs and weeds in a way that would worsen existing conditions or expected conditions (drought) without the TUCP or barrier?

   As reported in Section 2.4, the barrier, in combination with drought and other conditions beyond human control, may have had a role in the increase in cyanobacteria in Franks Tract in 2021, although not all the cyanobacteria found produce harmful toxins. At the peak of the Franks Tract bloom, cyanotoxins had reached the "Caution" level but remained below the "Warning" level. It is possible, however, for cyanotoxins to have had harmful effects on fish and wildlife handled or harvested by humans.

   The increase in cyanoHABs in Franks Tract with the barrier in 2021, compared to earlier years under similar climate conditions without the barrier, was likely caused by changes to flow in Franks Tract with the barrier in place. Other regions of the Delta did not show higher cyanobacteria than in prior years. As reported in Section 2.4, there was no significant difference in the occurrence of cyanoHABs between 2021 and previous dry years. Sites with low density remained low, and "hot spot" sites remained high. Accordingly, the 2021 TUCP was unlikely to have caused Delta-wide increases in *Microcystis* occurrence.

   As reported in Section 3, the barrier changed the distribution, but not the abundance, of SAV within Franks Tract. Boaters using the western half of Franks Tract may have been inconvenienced by the weeds, but boaters using the eastern half would have benefited from the clearer pathway.

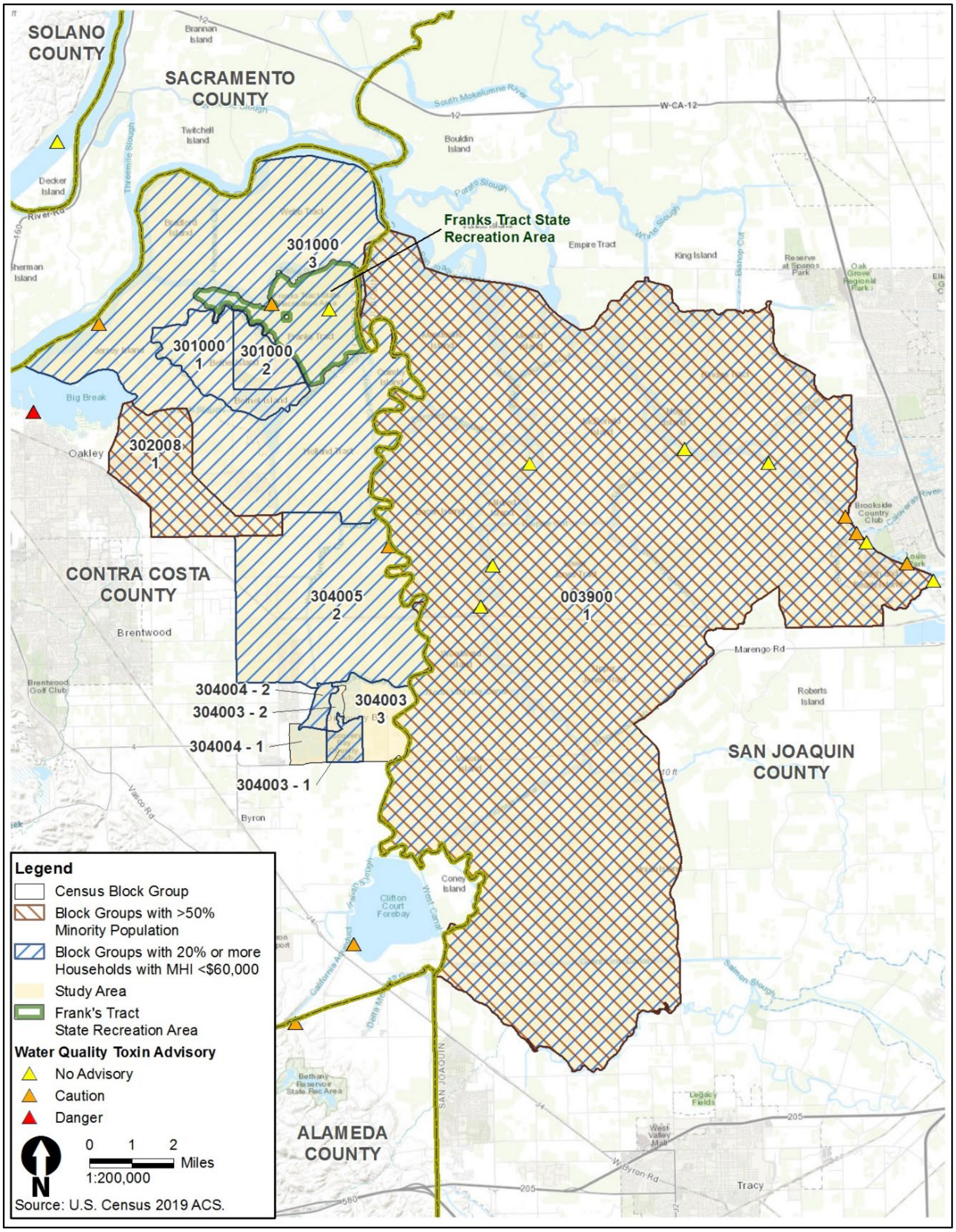


Figure 4-3 Distribution and Minority and Low-Income Populations in the Study Area and Harmful Algal Bloom Advisory Sites

2. Would effects be worse for vulnerable communities than the general population (i.e., disproportionate), and how?

   The study area includes vulnerable communities. CyanoHABs in the study area did not reach levels sufficient to affect human health in 2021 through recreational pathways. Where there is no effect, there is no disproportionate effect on vulnerable communities. SAV can interfere with beneficial uses of Franks Tract, but impacts would affect all users in the same way.

   People who engage in water-contact activities at Franks Tract would be alerted to local hazards through implementation of the cyanoHABs response plan, which includes monitoring of cyanoHABs levels in recreational waters and creates public awareness in both English and Spanish of local cyanoHABs risks. Communities with lower education and those who do not speak English or Spanish may not be able to take appropriate action based on these warnings.

   The authors of this report do not have data on how many people were fishing in the affected area in summer 2021, their ethnicity or socioeconomic status, or the toxin concentrations in fish tissue relative to baseline levels. Therefore, this study cannot evaluate disproportionate impacts on vulnerable communities through fish consumption pathways.

   Because weeds chiefly affect boaters, and affect all other users of the Delta equally, there was no disproportionate impact on vulnerable communities.

CyanoHABs in the Delta affect all people who live, recreate, and work in the Delta, as well as people who obtain their drinking water from the Delta. However, cyanoHABs may disproportionately affect vulnerable communities—low-income communities and communities of color—more than others if they live near, recreate in, or handle or consume fish in affected waters. This report is limited in its scope; it only assesses increases in cyanoHABs caused by or exacerbated by the TUCP and 2021 EDB. The ongoing and increasing cyanoHABs crisis in the Delta is beyond the scope of this report; however, in writing this report, it has become clear that a larger, multi-agency effort to fully assess the drivers, impacts, and mitigation methods of cyanoHABs is needed. This effort must specifically include the participation of low-income, minority, and Tribal communities of the Delta region to ensure that benefits and impacts are distributed equitably.

SECTION 5
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Appendix A
Additional Data and Statistical Tables

TABLE A-1
RESULTS OF ORDINAL REGRESSIONS ON VISUAL *MICROCYSTIS* INDEX FOR EACH REGION OF THE DELTA, ESTIMATED MARGINAL MEANS, AND SIGNIFICANTLY DIFFERENT GROUPS IN PAIRWISE COMPARISONS OF ESTIMATED MARGINAL MEANS

Region	term	Odds Ration	SE Odds Ratio	t-value	p-value	coef.type	Marginal Mean	SE Marginal Mean	Significance group
Cache/Liberty	2015	0.574	0.309	1.86	0.0635	coefficient	-1.608	0.248	d
Cache/Liberty	2016	-0.317	0.319	-0.99	0.3203	coefficient	-2.498	0.266	cd
Cache/Liberty	2017	-17.201	0.000	-1×10^8	<0.0001	coefficient	-19.382	0.256	a
Cache/Liberty	2018	-3.293	0.749	-4.40	<0.0001	coefficient	-5.474	0.729	b
Cache/Liberty	2019	-3.708	0.502	-7.39	<0.0001	coefficient	-5.890	0.472	b
Cache/Liberty	2020	-0.674	0.251	-2.68	0.0073	coefficient	-2.856	0.181	c
Cache/Liberty	2021	-0.317	0.253	-1.25	0.2115	coefficient	-2.498	0.183	c
Cache/Liberty	absent|Low	0.397	0.221	1.80	0.0719	intercept	NA	NA	NA
Cache/Liberty	Low|High	3.967	0.348	11.40	<0.0001	intercept	NA	NA	NA
East Delta	2015	2.206	1.088	2.03	0.0427	coefficient	-2.409	0.437	a
East Delta	2016	2.443	1.075	2.27	0.0230	coefficient	-2.172	0.399	a
East Delta	2017	-0.505	1.435	-0.35	0.7249	coefficient	-5.120	1.035	a
East Delta	2018	1.633	1.081	1.51	0.1309	coefficient	-2.982	0.422	a
East Delta	2019	0.767	1.143	0.67	0.5021	coefficient	-3.847	0.563	a
East Delta	2020	1.994	1.073	1.86	0.0631	coefficient	-2.620	0.400	a
East Delta	2021	2.215	1.071	2.07	0.0387	coefficient	-2.400	0.393	a
East Delta	absent|Low	3.258	1.018	3.20	0.0014	intercept	NA	NA	NA
East Delta	Low|High	5.971	1.108	5.39	<0.0001	intercept	NA	NA	NA
Franks	2015	-0.208	0.762	-0.27	0.7848	coefficient	-0.787	0.487	c
Franks	2016	0.102	0.735	0.14	0.8898	coefficient	-0.477	0.441	c
Franks	2017	-2.510	0.742	-3.38	0.0007	coefficient	-3.089	0.461	a
Franks	2018	-0.938	0.628	-1.49	0.1354	coefficient	-1.517	0.233	bc
Franks	2019	-1.867	0.643	-2.90	0.0037	coefficient	-2.447	0.273	ab
Franks	2020	-0.404	0.637	-0.63	0.5263	coefficient	-0.983	0.252	c

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Region	term	Odds Ration	SE Odds Ratio	t-value	p-value	coef.type	Marginal Mean	SE Marginal Mean	Significance group
Franks	2021	-0.981	0.637	-1.54	0.1237	coefficient	-1.560	0.256	abc
Franks	absent|Low	-0.888	0.593	-1.50	0.1345	intercept	NA	NA	NA
Franks	Low|High	2.047	0.614	3.33	0.0009	intercept	NA	NA	NA
Lower Sac	2015	-0.020	0.312	-0.06	0.9500	coefficient	-1.333	0.210	c
Lower Sac	2016	-1.119	0.329	-3.41	0.0007	coefficient	-2.432	0.236	b
Lower Sac	2017	-2.530	0.456	-5.55	<0.0001	coefficient	-3.843	0.394	a
Lower Sac	2018	-1.328	0.325	-4.08	<0.0001	coefficient	-2.641	0.231	ab
Lower Sac	2019	-1.005	0.278	-3.61	0.0003	coefficient	-2.318	0.158	b
Lower Sac	2020	0.800	0.262	3.06	0.0022	coefficient	-0.513	0.116	d
Lower Sac	2021	0.509	0.267	1.91	0.0566	coefficient	-0.803	0.131	cd
Lower Sac	absent|Low	0.156	0.235	0.67	0.5055	intercept	NA	NA	NA
Lower Sac	Low|High	2.470	0.253	9.75	<0.0001	intercept	NA	NA	NA
Lower SJ	2015	-0.427	0.262	-1.63	0.1028	coefficient	-1.109	0.180	b
Lower SJ	2016	-0.538	0.260	-2.07	0.0389	coefficient	-1.219	0.178	b
Lower SJ	2017	-2.207	0.303	-7.29	<0.0001	coefficient	-2.888	0.238	a
Lower SJ	2018	-0.346	0.253	-1.37	0.1713	coefficient	-1.027	0.167	b
Lower SJ	2019	-1.660	0.270	-6.15	<0.0001	coefficient	-2.342	0.194	a
Lower SJ	2020	-0.054	0.255	-0.21	0.8314	coefficient	-0.736	0.168	b
Lower SJ	2021	-0.622	0.266	-2.34	0.0192	coefficient	-1.303	0.186	b
Lower SJ	absent|Low	-0.681	0.198	-3.45	0.0006	intercept	NA	NA	NA
Lower SJ	Low|High	2.043	0.217	9.43	<0.0001	intercept	NA	NA	NA
OMR	2015	-0.364	0.531	-0.69	0.4928	coefficient	-0.364	0.345	cd
OMR	2016	0.000	0.527	0.00	0.9999	coefficient	0.000	0.339	d
OMR	2017	-3.300	0.596	-5.54	<0.0001	coefficient	-3.300	0.438	a

TABLE A-1
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Region	term	Odds Ration	SE Odds Ratio	t-value	p-value	coef.type	Marginal Mean	SE Marginal Mean	Significance group
OMR	2018	-1.494	0.445	-3.35	0.0008	coefficient	-1.494	0.189	bc
OMR	2019	-2.181	0.467	-4.68	<0.0001	coefficient	-2.181	0.235	ab
OMR	2020	-0.882	0.448	-1.97	0.0489	coefficient	-0.882	0.195	cd
OMR	2021	-1.224	0.467	-2.62	0.0087	coefficient	-1.224	0.235	bcd
OMR	absent|Low	-1.167	0.411	-2.84	0.0045	intercept	NA	NA	NA
OMR	Low|High	1.167	0.411	2.84	0.0045	intercept	NA	NA	NA
South Delta	2015	-0.347	0.396	-0.88	0.3803	coefficient	-0.476	0.266	d
South Delta	2016	0.281	0.392	0.72	0.4732	coefficient	0.152	0.260	d
South Delta	2017	-4.154	0.545	-7.62	<0.0001	coefficient	-4.283	0.460	a
South Delta	2018	-1.669	0.320	-5.21	<0.0001	coefficient	-1.798	0.131	c
South Delta	2019	-2.401	0.341	-7.04	<0.0001	coefficient	-2.530	0.176	b
South Delta	2020	-1.276	0.324	-3.94	0.0001	coefficient	-1.405	0.140	c
South Delta	2021	-1.612	0.331	-4.87	<0.0001	coefficient	-1.742	0.155	c
South Delta	absent|Low	-0.971	0.298	-3.26	0.0011	intercept	NA	NA	NA
South Delta	Low|High	1.230	0.300	4.09	<0.0001	intercept	NA	NA	NA
Upper Sac	2015	18.263	0.577	31.65	<0.0001	coefficient	-154.039	0.606	d
Upper Sac	2016	16.955	0.879	19.28	<0.0001	coefficient	-155.347	1.013	d
Upper Sac	2017	0.000	0.000	-65.14	<0.0001	coefficient	-172.302	0.297	b
Upper Sac	2018	16.089	0.873	18.42	<0.0001	coefficient	-156.213	1.006	d
Upper Sac	2019	0.000	0.000	-62.68	<0.0001	coefficient	-172.302	0.297	a
Upper Sac	2020	16.969	0.656	25.85	<0.0001	coefficient	-155.333	0.717	d
Upper Sac	2021	17.875	0.516	34.63	<0.0001	coefficient	-154.427	0.517	d
Upper Sac	absent|Low	20.566	0.297	69.14	<0.0001	intercept	NA	NA	NA
Upper Sac	Low|High	324.038	0.297	1089.29	<0.0001	intercept	NA	NA	NA

Toxins

Table A-2
Analysis of Cyanotoxins in Whole-Water Grab Samples Collected in the Study Area

Station	Date	Analyte	Concentration	Study	Region
ALG-001	3/25/2021	Anatoxins	ND	Nautilus	South Delta
ALG-001	3/25/2021	Microcystins	ND	Nautilus	South Delta
ALG-001	3/25/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-001	4/14/2021	Anatoxins	ND	Nautilus	South Delta
ALG-001	4/14/2021	Microcystins	0.1500	Nautilus	South Delta
ALG-001	4/14/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-001	4/29/2021	Anatoxins	ND	Nautilus	South Delta
ALG-001	4/29/2021	Microcystins	ND	Nautilus	South Delta
ALG-001	4/29/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-001	5/13/2021	Anatoxins	ND	Nautilus	South Delta
ALG-001	5/13/2021	Microcystins	ND	Nautilus	South Delta
ALG-001	5/13/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-001	5/27/2021	Anatoxins	ND	Nautilus	South Delta
ALG-001	5/27/2021	Microcystins	ND	Nautilus	South Delta
ALG-001	5/27/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-001	6/9/2021	Anatoxins	ND	Nautilus	South Delta
ALG-001	6/9/2021	Microcystins	ND	Nautilus	South Delta
ALG-001	6/9/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-001	6/22/2021	Anatoxins	ND	Nautilus	South Delta
ALG-001	6/22/2021	Microcystins	ND	Nautilus	South Delta
ALG-001	6/22/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-001	7/6/2021	Anatoxins	ND	Nautilus	South Delta
ALG-001	7/6/2021	Microcystins	0.2800	Nautilus	South Delta
ALG-001	7/6/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-001	7/20/2021	Anatoxins	ND	Nautilus	South Delta
ALG-001	7/20/2021	Microcystins	ND	Nautilus	South Delta
ALG-001	7/20/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-001	8/3/2021	Anatoxins	ND	Nautilus	South Delta
ALG-001	8/3/2021	Microcystins	0.1700	Nautilus	South Delta
ALG-001	8/3/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-001	8/17/2021	Anatoxins	ND	Nautilus	South Delta
ALG-001	8/17/2021	Microcystins	0.2700	Nautilus	South Delta
ALG-001	8/17/2021	Saxitoxins	ND	Nautilus	South Delta

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
ALG-001	9/7/2021	Anatoxins	ND	Nautilus	South Delta
ALG-001	9/7/2021	Microcystins	ND	Nautilus	South Delta
ALG-001	9/7/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-001	9/21/2021	Anatoxins	ND	Nautilus	South Delta
ALG-001	9/21/2021	Microcystins	0.2000	Nautilus	South Delta
ALG-001	9/21/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-002	3/25/2021	Anatoxins	ND	Nautilus	South Delta
ALG-002	3/25/2021	Microcystins	ND	Nautilus	South Delta
ALG-002	3/25/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-002	4/14/2021	Anatoxins	ND	Nautilus	South Delta
ALG-002	4/14/2021	Microcystins	0.2000	Nautilus	South Delta
ALG-002	4/14/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-002	4/29/2021	Anatoxins	ND	Nautilus	South Delta
ALG-002	4/29/2021	Microcystins	ND	Nautilus	South Delta
ALG-002	4/29/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-002	5/13/2021	Anatoxins	ND	Nautilus	South Delta
ALG-002	5/13/2021	Microcystins	ND	Nautilus	South Delta
ALG-002	5/13/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-002	5/27/2021	Anatoxins	ND	Nautilus	South Delta
ALG-002	5/27/2021	Microcystins	ND	Nautilus	South Delta
ALG-002	5/27/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-002	6/9/2021	Anatoxins	ND	Nautilus	South Delta
ALG-002	6/9/2021	Microcystins	ND	Nautilus	South Delta
ALG-002	6/9/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-002	6/22/2021	Anatoxins	ND	Nautilus	South Delta
ALG-002	6/22/2021	Microcystins	ND	Nautilus	South Delta
ALG-002	6/22/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-002	7/6/2021	Anatoxins	ND	Nautilus	South Delta
ALG-002	7/6/2021	Microcystins	ND	Nautilus	South Delta
ALG-002	7/6/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-002	7/20/2021	Anatoxins	ND	Nautilus	South Delta
ALG-002	7/20/2021	Microcystins	ND	Nautilus	South Delta
ALG-002	7/20/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-002	8/3/2021	Anatoxins	ND	Nautilus	South Delta

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
ALG-002	8/3/2021	Microcystins	0.2300	Nautilus	South Delta
ALG-002	8/3/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-002	8/17/2021	Anatoxins	ND	Nautilus	South Delta
ALG-002	8/17/2021	Microcystins	0.1900	Nautilus	South Delta
ALG-002	8/17/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-002	9/7/2021	Anatoxins	ND	Nautilus	South Delta
ALG-002	9/7/2021	Microcystins	1.0600	Nautilus	South Delta
ALG-002	9/7/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-002	9/21/2021	Anatoxins	ND	Nautilus	South Delta
ALG-002	9/21/2021	Microcystins	0.2600	Nautilus	South Delta
ALG-002	9/21/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-003	3/25/2021	Anatoxins	ND	Nautilus	South Delta
ALG-003	3/25/2021	Microcystins	ND	Nautilus	South Delta
ALG-003	3/25/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-003	4/14/2021	Anatoxins	ND	Nautilus	South Delta
ALG-003	4/14/2021	Microcystins	0.1500	Nautilus	South Delta
ALG-003	4/14/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-003	4/29/2021	Anatoxins	ND	Nautilus	South Delta
ALG-003	4/29/2021	Microcystins	ND	Nautilus	South Delta
ALG-003	4/29/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-003	5/13/2021	Anatoxins	ND	Nautilus	South Delta
ALG-003	5/13/2021	Microcystins	ND	Nautilus	South Delta
ALG-003	5/13/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-003	5/27/2021	Anatoxins	ND	Nautilus	South Delta
ALG-003	5/27/2021	Microcystins	ND	Nautilus	South Delta
ALG-003	5/27/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-003	6/9/2021	Anatoxins	ND	Nautilus	South Delta
ALG-003	6/9/2021	Microcystins	ND	Nautilus	South Delta
ALG-003	6/9/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-003	6/22/2021	Anatoxins	ND	Nautilus	South Delta
ALG-003	6/22/2021	Microcystins	ND	Nautilus	South Delta
ALG-003	6/22/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-003	7/6/2021	Anatoxins	ND	Nautilus	South Delta
ALG-003	7/6/2021	Microcystins	ND	Nautilus	South Delta

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
ALG-003	7/6/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-003	7/20/2021	Anatoxins	ND	Nautilus	South Delta
ALG-003	7/20/2021	Microcystins	ND	Nautilus	South Delta
ALG-003	7/20/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-003	8/3/2021	Anatoxins	ND	Nautilus	South Delta
ALG-003	8/3/2021	Microcystins	0.1600	Nautilus	South Delta
ALG-003	8/3/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-003	8/17/2021	Anatoxins	ND	Nautilus	South Delta
ALG-003	8/17/2021	Microcystins	0.1700	Nautilus	South Delta
ALG-003	8/17/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-003	9/7/2021	Anatoxins	ND	Nautilus	South Delta
ALG-003	9/7/2021	Microcystins	0.2400	Nautilus	South Delta
ALG-003	9/7/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-003	9/21/2021	Anatoxins	ND	Nautilus	South Delta
ALG-003	9/21/2021	Microcystins	0.2700	Nautilus	South Delta
ALG-003	9/21/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-004	3/25/2021	Anatoxins	ND	Nautilus	South Delta
ALG-004	3/25/2021	Microcystins	ND	Nautilus	South Delta
ALG-004	3/25/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-004	4/14/2021	Anatoxins	ND	Nautilus	South Delta
ALG-004	4/14/2021	Microcystins	0.1200	Nautilus	South Delta
ALG-004	4/14/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-004	4/29/2021	Anatoxins	ND	Nautilus	South Delta
ALG-004	4/29/2021	Microcystins	ND	Nautilus	South Delta
ALG-004	4/29/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-004	5/13/2021	Anatoxins	ND	Nautilus	South Delta
ALG-004	5/13/2021	Microcystins	ND	Nautilus	South Delta
ALG-004	5/13/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-004	5/27/2021	Anatoxins	ND	Nautilus	South Delta
ALG-004	5/27/2021	Microcystins	ND	Nautilus	South Delta
ALG-004	5/27/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-004	6/9/2021	Anatoxins	ND	Nautilus	South Delta
ALG-004	6/9/2021	Microcystins	0.9200	Nautilus	South Delta
ALG-004	6/9/2021	Saxitoxins	ND	Nautilus	South Delta

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
ALG-004	6/22/2021	Anatoxins	ND	Nautilus	South Delta
ALG-004	6/22/2021	Microcystins	0.1500	Nautilus	South Delta
ALG-004	6/22/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-004	7/6/2021	Anatoxins	ND	Nautilus	South Delta
ALG-004	7/6/2021	Microcystins	ND	Nautilus	South Delta
ALG-004	7/6/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-004	7/20/2021	Anatoxins	ND	Nautilus	South Delta
ALG-004	7/20/2021	Microcystins	ND	Nautilus	South Delta
ALG-004	7/20/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-004	8/3/2021	Anatoxins	ND	Nautilus	South Delta
ALG-004	8/3/2021	Microcystins	0.1900	Nautilus	South Delta
ALG-004	8/3/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-004	8/17/2021	Anatoxins	ND	Nautilus	South Delta
ALG-004	8/17/2021	Microcystins	0.1400	Nautilus	South Delta
ALG-004	8/17/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-004	9/7/2021	Anatoxins	ND	Nautilus	South Delta
ALG-004	9/7/2021	Microcystins	ND	Nautilus	South Delta
ALG-004	9/7/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-004	9/21/2021	Anatoxins	ND	Nautilus	South Delta
ALG-004	9/21/2021	Microcystins	0.1700	Nautilus	South Delta
ALG-004	9/21/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-005	3/25/2021	Anatoxins	ND	Nautilus	South Delta
ALG-005	3/25/2021	Microcystins	ND	Nautilus	South Delta
ALG-005	3/25/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-005	4/14/2021	Anatoxins	ND	Nautilus	South Delta
ALG-005	4/14/2021	Microcystins	0.1500	Nautilus	South Delta
ALG-005	4/14/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-005	4/29/2021	Anatoxins	ND	Nautilus	South Delta
ALG-005	4/29/2021	Microcystins	ND	Nautilus	South Delta
ALG-005	4/29/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-005	5/13/2021	Anatoxins	ND	Nautilus	South Delta
ALG-005	5/13/2021	Microcystins	ND	Nautilus	South Delta
ALG-005	5/13/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-005	5/27/2021	Anatoxins	ND	Nautilus	South Delta

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
ALG-005	5/27/2021	Microcystins	ND	Nautilus	South Delta
ALG-005	5/27/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-005	6/9/2021	Anatoxins	ND	Nautilus	South Delta
ALG-005	6/9/2021	Microcystins	ND	Nautilus	South Delta
ALG-005	6/9/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-005	6/22/2021	Anatoxins	ND	Nautilus	South Delta
ALG-005	6/22/2021	Microcystins	ND	Nautilus	South Delta
ALG-005	6/22/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-005	7/6/2021	Anatoxins	ND	Nautilus	South Delta
ALG-005	7/6/2021	Microcystins	0.1400	Nautilus	South Delta
ALG-005	7/6/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-005	7/20/2021	Anatoxins	ND	Nautilus	South Delta
ALG-005	7/20/2021	Microcystins	ND	Nautilus	South Delta
ALG-005	7/20/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-005	8/3/2021	Anatoxins	ND	Nautilus	South Delta
ALG-005	8/3/2021	Microcystins	2.3800	Nautilus	South Delta
ALG-005	8/3/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-005	8/17/2021	Anatoxins	ND	Nautilus	South Delta
ALG-005	8/17/2021	Microcystins	ND	Nautilus	South Delta
ALG-005	8/17/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-005	9/7/2021	Anatoxins	ND	Nautilus	South Delta
ALG-005	9/7/2021	Microcystins	ND	Nautilus	South Delta
ALG-005	9/7/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-005	9/21/2021	Anatoxins	ND	Nautilus	South Delta
ALG-005	9/21/2021	Microcystins	0.2000	Nautilus	South Delta
ALG-005	9/21/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-006	3/25/2021	Anatoxins	ND	Nautilus	South Delta
ALG-006	3/25/2021	Microcystins	ND	Nautilus	South Delta
ALG-006	3/25/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-006	4/14/2021	Anatoxins	ND	Nautilus	South Delta
ALG-006	4/14/2021	Microcystins	0.1500	Nautilus	South Delta
ALG-006	4/14/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-006	4/29/2021	Anatoxins	ND	Nautilus	South Delta
ALG-006	4/29/2021	Microcystins	ND	Nautilus	South Delta

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
ALG-006	4/29/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-006	5/13/2021	Anatoxins	ND	Nautilus	South Delta
ALG-006	5/13/2021	Microcystins	ND	Nautilus	South Delta
ALG-006	5/13/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-006	5/27/2021	Anatoxins	ND	Nautilus	South Delta
ALG-006	5/27/2021	Microcystins	ND	Nautilus	South Delta
ALG-006	5/27/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-006	6/9/2021	Anatoxins	ND	Nautilus	South Delta
ALG-006	6/9/2021	Microcystins	ND	Nautilus	South Delta
ALG-006	6/9/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-006	6/22/2021	Anatoxins	ND	Nautilus	South Delta
ALG-006	6/22/2021	Microcystins	ND	Nautilus	South Delta
ALG-006	6/22/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-006	7/6/2021	Anatoxins	ND	Nautilus	South Delta
ALG-006	7/6/2021	Microcystins	0.2300	Nautilus	South Delta
ALG-006	7/6/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-006	7/20/2021	Anatoxins	ND	Nautilus	South Delta
ALG-006	7/20/2021	Microcystins	0.1400	Nautilus	South Delta
ALG-006	7/20/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-006	8/3/2021	Anatoxins	ND	Nautilus	South Delta
ALG-006	8/3/2021	Microcystins	0.3000	Nautilus	South Delta
ALG-006	8/3/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-006	8/17/2021	Anatoxins	ND	Nautilus	South Delta
ALG-006	8/17/2021	Microcystins	0.1600	Nautilus	South Delta
ALG-006	8/17/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-006	9/7/2021	Anatoxins	ND	Nautilus	South Delta
ALG-006	9/7/2021	Microcystins	ND	Nautilus	South Delta
ALG-006	9/7/2021	Saxitoxins	ND	Nautilus	South Delta
ALG-006	9/21/2021	Anatoxins	ND	Nautilus	South Delta
ALG-006	9/21/2021	Microcystins	0.2300	Nautilus	South Delta
ALG-006	9/21/2021	Saxitoxins	ND	Nautilus	South Delta
BigBreak	1/6/2021	Microcystins	ND	EastBay	San Joaquin
BigBreak	1/13/2021	Microcystins	0.3200	EastBay	San Joaquin
BigBreak	1/21/2021	Microcystins	ND	EastBay	San Joaquin

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
BigBreak	2/3/2021	Microcystins	0.0700	EastBay	San Joaquin
BigBreak	2/8/2021	Microcystins	ND	EastBay	San Joaquin
BigBreak	2/16/2021	Microcystins	0.0900	EastBay	San Joaquin
BigBreak	2/24/2021	Microcystins	ND	EastBay	San Joaquin
BigBreak	4/7/2021	Microcystins	0.2900	EastBay	San Joaquin
BigBreak	4/27/2021	Microcystins	ND	EastBay	San Joaquin
BigBreak	5/5/2021	Microcystins	ND	EastBay	San Joaquin
BigBreak	5/12/2021	Microcystins	ND	EastBay	San Joaquin
BigBreak	5/19/2021	Microcystins	0.0400	EastBay	San Joaquin
BigBreak	5/25/2021	Microcystins	0.0400	EastBay	San Joaquin
BigBreak	6/7/2021	Microcystins	50.0000	EastBay	San Joaquin
BigBreak	6/14/2021	Microcystins	7.2500	EastBay	San Joaquin
BigBreak	6/21/2021	Microcystins	1.3800	EastBay	San Joaquin
BigBreak	6/29/2021	Microcystins	50.0000	EastBay	San Joaquin
BigBreak	7/20/2021	Microcystins	0.0900	EastBay	San Joaquin
BigBreak	8/3/2021	Microcystins	0.2700	EastBay	San Joaquin
BigBreak	8/10/2021	Microcystins	2.8400	EastBay	San Joaquin
BigBreak	8/18/2021	Microcystins	0.0700	EastBay	San Joaquin
BigBreak	8/24/2021	Microcystins	ND	EastBay	San Joaquin
BigBreak	8/31/2021	Microcystins	ND	EastBay	San Joaquin
BigBreak	9/8/2021	Microcystins	4.8400	EastBay	San Joaquin
BigBreak	9/14/2021	Microcystins	0.0200	EastBay	San Joaquin
BigBreak	9/21/2021	Microcystins	ND	EastBay	San Joaquin
BigBreak	9/28/2021	Microcystins	2.7900	EastBay	San Joaquin
BigBreak	10/5/2021	Microcystins	1.1200	EastBay	San Joaquin
BigBreak	10/11/2021	Microcystins	0.0200	EastBay	San Joaquin
BigBreak	10/19/2021	Microcystins	0.3700	EastBay	San Joaquin
BigBreak	10/26/2021	Microcystins	ND	EastBay	San Joaquin
BigBreak	11/4/2021	Microcystins	ND	EastBay	San Joaquin
BPP	4/26/2021	Microcystins	ND	DWR	Clifton Court
BPP	5/10/2021	Microcystins	ND	DWR	Clifton Court
BPP	5/24/2021	Microcystins	ND	DWR	Clifton Court
BPP	6/7/2021	Microcystins	ND	DWR	Clifton Court
BPP	6/21/2021	Microcystins	ND	DWR	Clifton Court

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
BPP	7/12/2021	Microcystins	ND	DWR	Clifton Court
BPP	7/26/2021	Microcystins	ND	DWR	Clifton Court
BPP	8/9/2021	Anatoxins	ND	DWR	Clifton Court
BPP	8/9/2021	Microcystins	ND	DWR	Clifton Court
BPP	8/23/2021	Microcystins	ND	DWR	Clifton Court
BPP	9/13/2021	Microcystins	ND	DWR	Clifton Court
BPP	9/27/2021	Microcystins	ND	DWR	Clifton Court
CCF	4/26/2021	Microcystins	ND	DWR	Clifton Court
CCF	6/21/2021	Microcystins	ND	DWR	Clifton Court
CCF	7/12/2021	Microcystins	ND	DWR	Clifton Court
CCF	7/26/2021	Microcystins	ND	DWR	Clifton Court
CCF	8/9/2021	Microcystins	ND	DWR	Clifton Court
CCF	8/23/2021	Microcystins	ND	DWR	Clifton Court
DEC/TOL	1/12/2021	Anabaenopeptins	ND	USGS	Lower Sacramento
DEC/TOL	1/12/2021	Anatoxins	ND	USGS	Lower Sacramento
DEC/TOL	1/12/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	2/16/2021	Anabaenopeptins	ND	USGS	Lower Sacramento
DEC/TOL	2/16/2021	Anatoxins	ND	USGS	Lower Sacramento
DEC/TOL	2/16/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	3/3/2021	Anabaenopeptins	ND	USGS	Lower Sacramento
DEC/TOL	3/3/2021	Anatoxins	ND	USGS	Lower Sacramento
DEC/TOL	3/3/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	3/16/2021	Anabaenopeptins	ND	USGS	Lower Sacramento
DEC/TOL	3/16/2021	Anatoxins	ND	USGS	Lower Sacramento
DEC/TOL	3/16/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	4/1/2021	Anabaenopeptins	ND	USGS	Lower Sacramento
DEC/TOL	4/1/2021	Anabaenopeptins	ND	USGS	Lower Sacramento
DEC/TOL	4/1/2021	Anatoxins	11.5511	USGS	Lower Sacramento
DEC/TOL	4/1/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	4/1/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	4/13/2021	Anabaenopeptins	ND	USGS	Lower Sacramento
DEC/TOL	4/13/2021	Anatoxins	ND	USGS	Lower Sacramento
DEC/TOL	4/13/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	4/27/2021	Anabaenopeptins	ND	USGS	Lower Sacramento

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
DEC/TOL	4/27/2021	Anatoxins	0.3665	USGS	Lower Sacramento
DEC/TOL	4/27/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	5/14/2021	Anabaenopeptins	ND	USGS	Lower Sacramento
DEC/TOL	5/14/2021	Anatoxins	ND	USGS	Lower Sacramento
DEC/TOL	5/14/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	7/7/2021	Anabaenopeptins	9.3300	USGS	Lower Sacramento
DEC/TOL	7/7/2021	Anatoxins	ND	USGS	Lower Sacramento
DEC/TOL	7/7/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	7/21/2021	Anabaenopeptins	ND	USGS	Lower Sacramento
DEC/TOL	7/21/2021	Anatoxins	ND	USGS	Lower Sacramento
DEC/TOL	7/21/2021	Microcystins	0.0540	USGS	Lower Sacramento
DEC/TOL	8/4/2021	Anabaenopeptins	4.1800	USGS	Lower Sacramento
DEC/TOL	8/4/2021	Anatoxins	ND	USGS	Lower Sacramento
DEC/TOL	8/4/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	8/18/2021	Anabaenopeptins	ND	USGS	Lower Sacramento
DEC/TOL	8/18/2021	Anatoxins	ND	USGS	Lower Sacramento
DEC/TOL	8/18/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	9/21/2021	Anabaenopeptins	31.2100	USGS	Lower Sacramento
DEC/TOL	9/21/2021	Anatoxins	ND	USGS	Lower Sacramento
DEC/TOL	9/21/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	10/4/2021	Anabaenopeptins	ND	USGS	Lower Sacramento
DEC/TOL	10/4/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	10/5/2021	Anabaenopeptins	ND	USGS	Lower Sacramento
DEC/TOL	10/5/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	10/21/2021	Anabaenopeptins	ND	USGS	Lower Sacramento
DEC/TOL	10/21/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	11/16/2021	Anabaenopeptins	ND	USGS	Lower Sacramento
DEC/TOL	11/16/2021	Microcystins	ND	USGS	Lower Sacramento
DEC/TOL	12/16/2021	Anabaenopeptins	ND	USGS	Lower Sacramento
DEC/TOL	12/16/2021	Microcystins	ND	USGS	Lower Sacramento
DHAB001	1/7/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB001	1/7/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB001	3/30/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB001	4/21/2021	Microcystins	ND	Preece	Lower Sacramento

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
DHAB001	5/14/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB001	6/3/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB001	6/17/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB001	7/19/2021	Microcystins	0.1752	Preece	Lower Sacramento
DHAB001	7/21/2021	Microcystins	0.1643	Preece	Lower Sacramento
DHAB001	8/11/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB001	8/31/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB001	9/4/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB001	9/22/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB001	10/20/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB001	10/28/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB001	11/12/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB001	12/27/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	1/7/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	2/8/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	2/10/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	2/10/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	3/31/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	4/19/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	5/17/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	6/3/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	6/18/2021	Microcystins	0.2620	Preece	Lower Sacramento
DHAB002	7/19/2021	Microcystins	0.2473	Preece	Lower Sacramento
DHAB002	7/21/2021	Microcystins	0.1989	Preece	Lower Sacramento
DHAB002	8/11/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	8/31/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	9/4/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	9/22/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	10/20/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	10/28/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	11/12/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB002	12/27/2021	Microcystins	ND	Preece	Lower Sacramento
DHAB003	1/7/2021	Microcystins	ND	Preece	Lower San Joaquin
DHAB003	2/8/2021	Microcystins	ND	Preece	Lower San Joaquin

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
DHAB003	3/30/2021	Microcystins	ND	Preece	Lower San Joaquin
DHAB003	3/30/2021	Microcystins	ND	Preece	Lower San Joaquin
DHAB003	4/21/2021	Microcystins	ND	Preece	Lower San Joaquin
DHAB003	5/14/2021	Microcystins	ND	Preece	Lower San Joaquin
DHAB003	6/4/2021	Microcystins	ND	Preece	Lower San Joaquin
DHAB003	6/17/2021	Microcystins	ND	Preece	Lower San Joaquin
DHAB003	7/19/2021	Microcystins	3.0285	Preece	Lower San Joaquin
DHAB003	7/21/2021	Microcystins	0.2222	Preece	Lower San Joaquin
DHAB003	8/11/2021	Microcystins	ND	Preece	Lower San Joaquin
DHAB003	8/31/2021	Microcystins	ND	Preece	Lower San Joaquin
DHAB003	9/4/2021	Microcystins	ND	Preece	Lower San Joaquin
DHAB003	9/22/2021	Microcystins	1.7845	Preece	Lower San Joaquin
DHAB003	10/20/2021	Microcystins	ND	Preece	Lower San Joaquin
DHAB003	10/28/2021	Microcystins	ND	Preece	Lower San Joaquin
DHAB003	11/12/2021	Microcystins	ND	Preece	Lower San Joaquin
DHAB003	12/27/2021	Microcystins	ND	Preece	Lower San Joaquin
DHAB004	1/8/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB004	2/10/2021	Microcystins	0.1129	Preece	Upper Sacramento
DHAB004	3/31/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB004	4/19/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB004	4/19/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB004	5/17/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB004	6/3/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB004	6/18/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB004	7/7/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB004	7/22/2021	Microcystins	0.1820	Preece	Upper Sacramento
DHAB004	8/11/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB004	8/31/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB004	9/5/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB004	9/22/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB004	9/22/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB004	10/20/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB004	10/28/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB004	11/12/2021	Microcystins	ND	Preece	Upper Sacramento

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
DHAB004	12/27/2021	Microcystins	ND	Preece	Upper Sacramento
DHAB005	1/8/2021	Microcystins	ND	Preece	SDWSC
DHAB005	2/10/2021	Microcystins	ND	Preece	SDWSC
DHAB005	3/31/2021	Microcystins	ND	Preece	SDWSC
DHAB005	4/19/2021	Microcystins	ND	Preece	SDWSC
DHAB005	5/17/2021	Microcystins	ND	Preece	SDWSC
DHAB005	5/17/2021	Microcystins	ND	Preece	SDWSC
DHAB005	6/3/2021	Microcystins	ND	Preece	SDWSC
DHAB005	6/18/2021	Microcystins	ND	Preece	SDWSC
DHAB005	7/7/2021	Microcystins	ND	Preece	SDWSC
DHAB005	7/22/2021	Microcystins	0.2154	Preece	SDWSC
DHAB005	8/11/2021	Microcystins	ND	Preece	SDWSC
DHAB005	8/31/2021	Microcystins	ND	Preece	SDWSC
DHAB005	9/5/2021	Microcystins	ND	Preece	SDWSC
DHAB005	9/22/2021	Microcystins	ND	Preece	SDWSC
DHAB005	10/20/2021	Microcystins	ND	Preece	SDWSC
DHAB005	10/28/2021	Microcystins	ND	Preece	SDWSC
DHAB005	11/12/2021	Microcystins	ND	Preece	SDWSC
DHAB005	12/27/2021	Microcystins	ND	Preece	SDWSC
DHAB006	1/8/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	2/10/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	3/31/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	4/19/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	5/17/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	6/3/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	6/3/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	6/18/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	6/18/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
DHAB006	7/7/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	7/22/2021	Microcystins	0.1525	Preece	Cache Slough/Liberty Island
DHAB006	8/11/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	8/31/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	9/5/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	9/22/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	10/20/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	10/28/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	11/12/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB006	12/27/2021	Microcystins	ND	Preece	Cache Slough/Liberty Island
DHAB007	1/7/2021	Microcystins	ND	Preece	South Delta
DHAB007	2/8/2021	Microcystins	ND	Preece	South Delta
DHAB007	3/30/2021	Microcystins	ND	Preece	South Delta
DHAB007	4/21/2021	Microcystins	ND	Preece	South Delta
DHAB007	5/14/2021	Microcystins	ND	Preece	South Delta
DHAB007	6/4/2021	Microcystins	ND	Preece	South Delta
DHAB007	6/17/2021	Microcystins	ND	Preece	South Delta
DHAB007	7/19/2021	Microcystins	0.3012	Preece	South Delta
DHAB007	7/19/2021	Microcystins	0.8220	Preece	South Delta
DHAB007	7/21/2021	Microcystins	0.3285	Preece	South Delta
DHAB007	7/21/2021	Microcystins	0.3859	Preece	South Delta
DHAB007	8/11/2021	Microcystins	0.6584	Preece	South Delta
DHAB007	8/31/2021	Microcystins	0.1606	Preece	South Delta
DHAB007	9/4/2021	Microcystins	0.1226	Preece	South Delta
DHAB007	10/20/2021	Microcystins	ND	Preece	South Delta
DHAB007	10/28/2021	Microcystins	ND	Preece	South Delta
DHAB007	11/12/2021	Microcystins	ND	Preece	South Delta
DHAB007	12/27/2021	Microcystins	ND	Preece	South Delta

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
DHAB008	1/5/2021	Microcystins	ND	Preece	South Delta
DHAB008	2/10/2021	Microcystins	ND	Preece	South Delta
DHAB008	3/30/2021	Microcystins	ND	Preece	South Delta
DHAB008	4/22/2021	Microcystins	ND	Preece	South Delta
DHAB008	5/18/2021	Microcystins	ND	Preece	South Delta
DHAB008	6/1/2021	Microcystins	ND	Preece	South Delta
DHAB008	6/16/2021	Microcystins	ND	Preece	South Delta
DHAB008	7/7/2021	Microcystins	0.6674	Preece	South Delta
DHAB008	7/22/2021	Microcystins	0.1959	Preece	South Delta
DHAB008	8/11/2021	Microcystins	0.1434	Preece	South Delta
DHAB008	8/11/2021	Microcystins	2.9965	Preece	South Delta
DHAB008	8/26/2021	Microcystins	0.4166	Preece	South Delta
DHAB008	9/5/2021	Microcystins	ND	Preece	South Delta
DHAB008	9/20/2021	Microcystins	0.1596	Preece	South Delta
DHAB008	10/20/2021	Microcystins	ND	Preece	South Delta
DHAB008	11/2/2021	Microcystins	ND	Preece	South Delta
DHAB008	11/12/2021	Microcystins	ND	Preece	South Delta
DHAB008	12/27/2021	Microcystins	ND	Preece	South Delta
DHAB009	1/5/2021	Microcystins	ND	Preece	South Delta
DHAB009	2/10/2021	Microcystins	ND	Preece	South Delta
DHAB009	3/30/2021	Microcystins	ND	Preece	South Delta
DHAB009	4/22/2021	Microcystins	ND	Preece	South Delta
DHAB009	5/18/2021	Microcystins	ND	Preece	South Delta
DHAB009	6/1/2021	Microcystins	ND	Preece	South Delta
DHAB009	6/16/2021	Microcystins	ND	Preece	South Delta
DHAB009	7/7/2021	Microcystins	0.2766	Preece	South Delta
DHAB009	7/22/2021	Microcystins	0.4150	Preece	South Delta
DHAB009	8/11/2021	Microcystins	ND	Preece	South Delta
DHAB009	8/26/2021	Microcystins	0.1588	Preece	South Delta
DHAB009	9/5/2021	Microcystins	0.1118	Preece	South Delta
DHAB009	9/5/2021	Microcystins	0.1320	Preece	South Delta
DHAB009	9/20/2021	Microcystins	0.2183	Preece	South Delta
DHAB009	10/20/2021	Microcystins	ND	Preece	South Delta
DHAB009	10/28/2021	Microcystins	ND	Preece	South Delta

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
DHAB009	11/12/2021	Microcystins	ND	Preece	South Delta
DHAB009	12/27/2021	Microcystins	ND	Preece	South Delta
DHAB010	1/5/2021	Microcystins	ND	Preece	South Delta
DHAB010	2/10/2021	Microcystins	ND	Preece	South Delta
DHAB010	3/30/2021	Microcystins	ND	Preece	South Delta
DHAB010	4/22/2021	Microcystins	ND	Preece	South Delta
DHAB010	5/18/2021	Microcystins	ND	Preece	South Delta
DHAB010	6/1/2021	Microcystins	ND	Preece	South Delta
DHAB010	6/16/2021	Microcystins	ND	Preece	South Delta
DHAB010	7/7/2021	Microcystins	0.4417	Preece	South Delta
DHAB010	7/22/2021	Microcystins	0.4603	Preece	South Delta
DHAB010	8/11/2021	Microcystins	ND	Preece	South Delta
DHAB010	8/26/2021	Microcystins	0.1859	Preece	South Delta
DHAB010	8/26/2021	Microcystins	0.3342	Preece	South Delta
DHAB010	9/5/2021	Microcystins	0.1122	Preece	South Delta
DHAB010	9/20/2021	Microcystins	0.1756	Preece	South Delta
DHAB010	10/20/2021	Microcystins	ND	Preece	South Delta
DHAB010	10/20/2021	Microcystins	ND	Preece	South Delta
DHAB010	11/2/2021	Microcystins	ND	Preece	South Delta
DHAB010	11/12/2021	Microcystins	ND	Preece	South Delta
DHAB010	12/27/2021	Microcystins	ND	Preece	South Delta
FRK	7/2/2021	Microcystins	ND	CVRWQCB	South Delta
FRK	8/6/2021	Anatoxins	ND	CVRWQCB	South Delta
FRK	8/6/2021	Microcystins	0.6300	CVRWQCB	South Delta
JPT	1/12/2021	Anabaenopeptins	ND	USGS	Lower San Joaquin
JPT	1/12/2021	Anatoxins	ND	USGS	Lower San Joaquin
JPT	1/12/2021	Microcystins	ND	USGS	Lower San Joaquin
JPT	2/16/2021	Anabaenopeptins	ND	USGS	Lower San Joaquin
JPT	2/16/2021	Anatoxins	ND	USGS	Lower San Joaquin
JPT	2/16/2021	Microcystins	ND	USGS	Lower San Joaquin
JPT	3/3/2021	Anabaenopeptins	ND	USGS	Lower San Joaquin
JPT	3/3/2021	Anatoxins	ND	USGS	Lower San Joaquin
JPT	3/3/2021	Microcystins	ND	USGS	Lower San Joaquin
JPT	3/16/2021	Anabaenopeptins	ND	USGS	Lower San Joaquin

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
JPT	3/16/2021	Anatoxins	ND	USGS	Lower San Joaquin
JPT	3/16/2021	Microcystins	ND	USGS	Lower San Joaquin
JPT	4/1/2021	Anabaenopeptins	ND	USGS	Lower San Joaquin
JPT	4/1/2021	Anatoxins	2.1684	USGS	Lower San Joaquin
JPT	4/1/2021	Microcystins	ND	USGS	Lower San Joaquin
JPT	4/13/2021	Anabaenopeptins	ND	USGS	Lower San Joaquin
JPT	4/13/2021	Anatoxins	ND	USGS	Lower San Joaquin
JPT	4/13/2021	Microcystins	ND	USGS	Lower San Joaquin
JPT	4/27/2021	Anabaenopeptins	ND	USGS	Lower San Joaquin
JPT	4/27/2021	Anatoxins	0.7305	USGS	Lower San Joaquin
JPT	4/27/2021	Microcystins	ND	USGS	Lower San Joaquin
JPT	5/14/2021	Anabaenopeptins	ND	USGS	Lower San Joaquin
JPT	5/14/2021	Anatoxins	ND	USGS	Lower San Joaquin
JPT	5/14/2021	Microcystins	ND	USGS	Lower San Joaquin
JPT	7/7/2021	Anabaenopeptins	178.0800	USGS	Lower San Joaquin
JPT	7/7/2021	Anatoxins	ND	USGS	Lower San Joaquin
JPT	7/7/2021	Microcystins	ND	USGS	Lower San Joaquin
JPT	7/21/2021	Anabaenopeptins	ND	USGS	Lower San Joaquin
JPT	7/21/2021	Anatoxins	ND	USGS	Lower San Joaquin
JPT	7/21/2021	Microcystins	ND	USGS	Lower San Joaquin
JPT	8/18/2021	Anabaenopeptins	18.6800	USGS	Lower San Joaquin
JPT	8/18/2021	Anatoxins	ND	USGS	Lower San Joaquin
JPT	8/18/2021	Microcystins	ND	USGS	Lower San Joaquin
JPT	9/21/2021	Anabaenopeptins	0.7400	USGS	Lower San Joaquin
JPT	9/21/2021	Anatoxins	ND	USGS	Lower San Joaquin
JPT	9/21/2021	Microcystins	ND	USGS	Lower San Joaquin
JPT	10/4/2021	Anabaenopeptins	ND	USGS	Lower San Joaquin
JPT	10/4/2021	Microcystins	0.0460	USGS	Lower San Joaquin
JPT	10/5/2021	Anabaenopeptins	ND	USGS	Lower San Joaquin
JPT	10/5/2021	Microcystins	ND	USGS	Lower San Joaquin
JPT	10/21/2021	Anabaenopeptins	ND	USGS	Lower San Joaquin
JPT	10/21/2021	Microcystins	ND	USGS	Lower San Joaquin
JPT	11/17/2021	Anabaenopeptins	ND	USGS	Lower San Joaquin
JPT	11/17/2021	Microcystins	ND	USGS	Lower San Joaquin

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
JPT	12/16/2021	Anabaenopeptins	ND	USGS	Lower San Joaquin
JPT	12/16/2021	Microcystins	ND	USGS	Lower San Joaquin
LIB	5/11/2021	Anabaenopeptins	ND	USGS	Cache Slough/Liberty Island
LIB	5/11/2021	Anatoxins	ND	USGS	Cache Slough/Liberty Island
LIB	5/11/2021	Microcystins	ND	USGS	Cache Slough/Liberty Island
LIB	8/18/2021	Anabaenopeptins	ND	USGS	Cache Slough/Liberty Island
LIB	8/18/2021	Microcystins	ND	USGS	Cache Slough/Liberty Island
LIB	9/23/2021	Anabaenopeptins	ND	USGS	Cache Slough/Liberty Island
LIB	9/23/2021	Microcystins	ND	USGS	Cache Slough/Liberty Island
LIB	10/4/2021	Anabaenopeptins	ND	USGS	Cache Slough/Liberty Island
LIB	10/4/2021	Microcystins	ND	USGS	Cache Slough/Liberty Island
LIB	10/5/2021	Anabaenopeptins	ND	USGS	Cache Slough/Liberty Island
LIB	10/5/2021	Microcystins	ND	USGS	Cache Slough/Liberty Island
LIB	10/21/2021	Anabaenopeptins	ND	USGS	Cache Slough/Liberty Island
LIB	10/21/2021	Microcystins	ND	USGS	Cache Slough/Liberty Island
LIB	11/16/2021	Anabaenopeptins	ND	USGS	Cache Slough/Liberty Island
LIB	11/16/2021	Microcystins	ND	USGS	Cache Slough/Liberty Island
LIB	12/9/2021	Anabaenopeptins	ND	USGS	Cache Slough/Liberty Island
LIB	12/9/2021	Microcystins	ND	USGS	Cache Slough/Liberty Island
MDM	7/7/2021	Anabaenopeptins	0.0100	USGS	South Delta
MDM	7/7/2021	Microcystins	0.2200	USGS	South Delta
MDM	7/21/2021	Anabaenopeptins	0.0300	USGS	South Delta
MDM	7/21/2021	Microcystins	0.0600	USGS	South Delta
MDM	8/2/2021	Anabaenopeptins	0.0900	USGS	South Delta

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

Station	Date	Analyte	Concentration	Study	Region
MDM	8/2/2021	Microcystins	0.0600	USGS	South Delta
MDM	8/18/2021	Anabaenopeptins	0.4700	USGS	South Delta
MDM	8/18/2021	Microcystins	0.0300	USGS	South Delta
MDM	9/2/2021	Anabaenopeptins	0.1000	USGS	South Delta
MDM	9/2/2021	Microcystins	0.0100	USGS	South Delta
MDM	9/16/2021	Anabaenopeptins	ND	USGS	South Delta
MDM	9/16/2021	Microcystins	ND	USGS	South Delta
MDM	10/6/2021	Anabaenopeptins	ND	USGS	South Delta
MDM	10/6/2021	Microcystins	ND	USGS	South Delta
MDM	10/19/2021	Anabaenopeptins	ND	USGS	South Delta
MDM	10/19/2021	Microcystins	ND	USGS	South Delta
MDM	12/8/2021	Anabaenopeptins	ND	USGS	South Delta
MDM	12/8/2021	Microcystins	ND	USGS	South Delta
MI	7/2/2021	Microcystins	0.6000	CVRWQCB	South Delta
RRI	7/16/2021	Anabaenopeptins	0.0100	USGS	South Delta
RRI	7/16/2021	Microcystins	0.1300	USGS	South Delta
RRI	7/29/2021	Anabaenopeptins	0.5300	USGS	South Delta
RRI	7/29/2021	Microcystins	0.0300	USGS	South Delta
RRI	8/16/2021	Anabaenopeptins	0.2200	USGS	South Delta
RRI	8/16/2021	Microcystins	0.0500	USGS	South Delta
RRI	8/30/2021	Anabaenopeptins	0.3000	USGS	South Delta
RRI	8/30/2021	Microcystins	0.0100	USGS	South Delta
RRI	9/10/2021	Anabaenopeptins	0.1000	USGS	South Delta
RRI	9/10/2021	Microcystins	0.0100	USGS	South Delta
RRI	9/24/2021	Anabaenopeptins	0.0400	USGS	South Delta
RRI	9/24/2021	Microcystins	0.0500	USGS	South Delta
RRI	10/13/2021	Anabaenopeptins	ND	USGS	South Delta
RRI	10/13/2021	Microcystins	0.0100	USGS	South Delta
RRI	10/26/2021	Anabaenopeptins	ND	USGS	South Delta
RRI	10/26/2021	Microcystins	ND	USGS	South Delta
RRI	11/10/2021	Anabaenopeptins	ND	USGS	South Delta
RRI	11/10/2021	Microcystins	ND	USGS	South Delta
RRI	12/10/2021	Anabaenopeptins	ND	USGS	South Delta
RRI	12/10/2021	Microcystins	ND	USGS	South Delta

TABLE A-2
ANALYSIS OF CYANOTOXINS IN WHOLE-WATER GRAB SAMPLES COLLECTED IN THE STUDY AREA

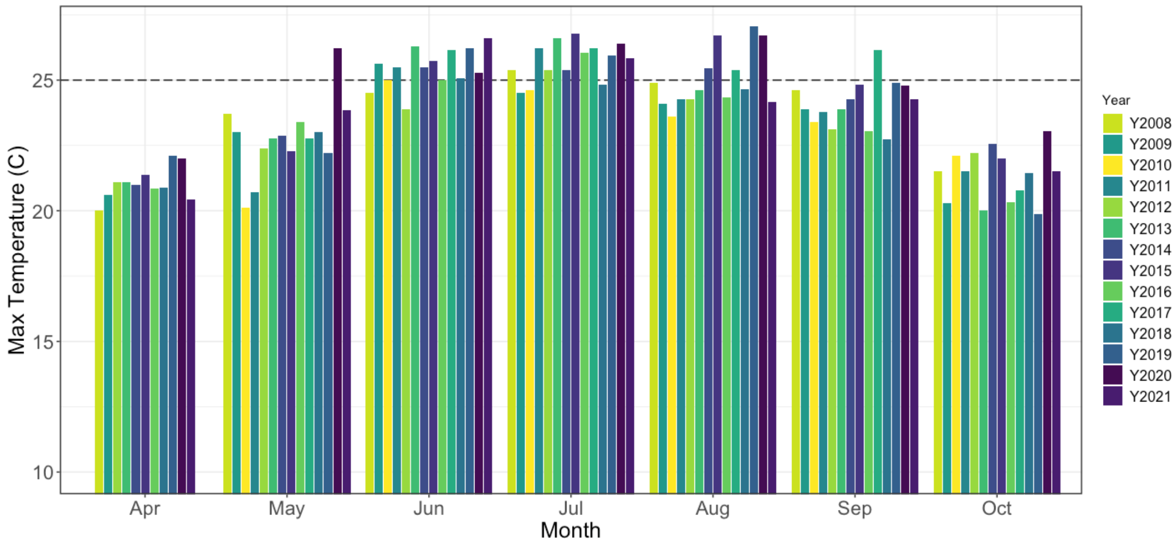
Station	Date	Analyte	Concentration	Study	Region
VER	7/14/2021	Anabaenopeptins	0.5800	USGS	Vernalis
VER	7/14/2021	Microcystins	ND	USGS	Vernalis
VER	7/29/2021	Anabaenopeptins	ND	USGS	Vernalis
VER	7/29/2021	Microcystins	ND	USGS	Vernalis
VER	8/12/2021	Anabaenopeptins	ND	USGS	Vernalis
VER	8/12/2021	Microcystins	ND	USGS	Vernalis
VER	8/27/2021	Anabaenopeptins	0.0900	USGS	Vernalis
VER	8/27/2021	Microcystins	0.0600	USGS	Vernalis
VER	9/9/2021	Anabaenopeptins	ND	USGS	Vernalis
VER	9/9/2021	Microcystins	ND	USGS	Vernalis
VER	9/24/2021	Anabaenopeptins	0.0300	USGS	Vernalis
VER	9/24/2021	Microcystins	ND	USGS	Vernalis
VER	10/11/2021	Anabaenopeptins	0.0400	USGS	Vernalis
VER	10/11/2021	Microcystins	ND	USGS	Vernalis
VER	10/26/2021	Anabaenopeptins	ND	USGS	Vernalis
VER	10/26/2021	Microcystins	ND	USGS	Vernalis
VER	11/8/2021	Anabaenopeptins	ND	USGS	Vernalis
VER	11/8/2021	Microcystins	ND	USGS	Vernalis
VER	12/8/2021	Anabaenopeptins	ND	USGS	Vernalis
VER	12/8/2021	Microcystins	ND	USGS	Vernalis

NOTE: ND = Non-Detect. Stations are defined in Table 2-3

Additional Temperature Analysis

Water temperature data recorded at the Bethel Island continuous monitoring (CDEC station BET, USGS Station 11313431) station since 2008 indicate that maximum water temperature in late spring and early summer has been increasing in the Central Delta. While water temperatures in the Central Delta typically do not exceed 25°C in May, maximum temperatures in 2020 reached above 25°C (Figure A-1). Data from 2008 to the present demonstrate a consistent increase in maximum temperatures measured in June, at the start of summer, with the highest maximum occurring in 2021 (Figure A-1). During August, when growth rates of *Microcystis* typically are highest (i.e., Lehman et al. 2018), temperatures reached maxima both in

2014–2015 and in 2020–2021 at Bethel Island near Franks Tract (Figure A-1).

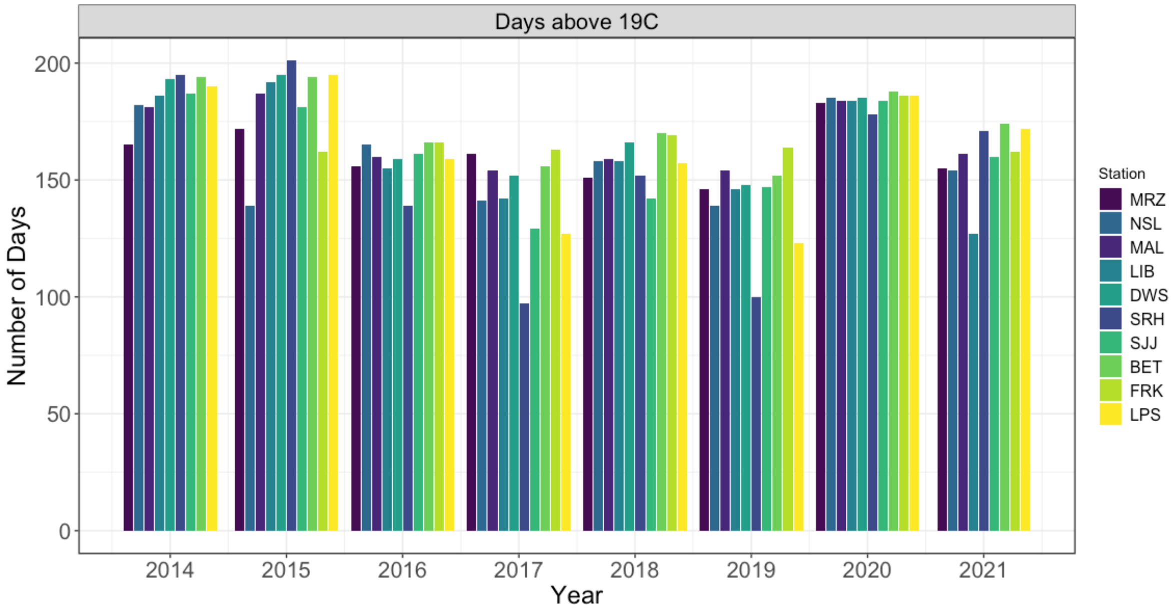


NOTE: Drought years (2014, 2015, 2020, and 2021) are indicated using darker shading.

Figure A-1 Maximum Water Temperatures by Month at Station BET, 2008–2021

Years 2014 and 2015 were both warm years, as measured by the number of days in the calendar year that water temperatures reached 19°C or warmer across most stations (Figure A-2). The same was true for 2020, while 2021, also considered a drought year, had slightly fewer 19°C days (Figure A-2).

There were differences in number of days above 19°C between years, though there were few differences between stations, with the exception of the Sacramento River (SRH), which consistently demonstrated lower temperatures and fewer days above 19°C in non-drought years (2016–2019). In contrast, the number of days with water temperatures of 25°C or above varied by stations more than between years. Only stations BET and FRK in the Franks Tract region, and station LPS in the eastern Delta, consistently reached 20 days or more of water temperatures 25°C and warmer in a calendar year (Figure A-2). During the 2014, 2015, and 2021 drought years, SRH also reached a relatively high number of days with temperatures of 25°C and warmer.



NOTE: Stations include three in Suisun Bay and the western Delta (MRZ, NSL, MAL), two within the Cache Slough/ Liberty Island complex (DWS, LIB), one in the Sacramento River at Hood (SRH), and four stations in the Central and eastern Delta (SJJ, BET, FRK, LPS). See text for station abbreviations.

Figure A-2 Number of Days in the Calendar Year that Water Temperature Reached 19°C or Above across 10 Stations in Suisun Bay, the Sacramento River, and the Delta

Limiting Nutrients

Nitrogen to phosphorus ratios were typically less than 16:1 during the summer months, indicating that nitrogen, rather than phosphorus, was the limiting nutrient, although this varied by region and year. During the winter, phosphorus was more frequently limiting, but this also varied by region and year (Figure A-3).

NOTE: Error bars display maximum and minimum value when more than one sample were available.

Figure A-3 Mean Nitrogen:Phosphorus Ratios for Each Month and Each Region of the Delta

Appendix B
HABs/Weeds Fact Sheet Distributed to Tribal Representatives

CALIFORNIA DEPARTMENT OF

WATER RESOURCES

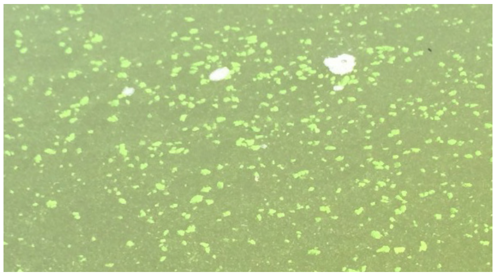
Harmful Algal Blooms of 2021

Request

The California Department of Water Resources is requesting input on any negative impacts of the harmful algal bloom in the Delta during the summer of 2021, any disproportionate impacts to vulnerable communities with respect to drinking water quality, contact and non-contact recreation, impacts to tribal cultural resources, and impacts to aesthetics including odors and the visual character of Delta waterways.

What are Harmful Algal Blooms?

Harmful Algal Blooms (HABs) are caused by toxin-producing cyanobacteria and may cause rashes or illness, depending on what type of cyanobacteria are present. HABs occur most frequently in the summer in areas with poor water circulation. They may look like bright green flakes floating in the water, green/brown discolored water, or green scum on the surface.



From left to right: **Microcystis sp. floating colonies** (Photograph: SWAMP), **Microcystis sp.** (Photograph: Jacob Kann), **Dolichospermum lemmermannii** (Photograph: Ann St. Amand; Rosen et al., 2015).
Photos from the California CyanoHAB Network identification guide.

If you have seen algal blooms in the Delta in the past year, we want to know! To provide input, please:
Fill out this survey to share how HABs impact your use of the Delta: **https://www.surveymonkey.com/r/DWR-HAB**

Join us for a listening session to learn more and share your experience.

May 5th, 2022, 2:30 p.m. as a part of the SGMA Tribal Advisory Group Meeting.
Sign up here: **https://www.signupforms.com/registrations/28387**

Contact **Rosemary Hartman** (Rosemary.Hartman@water.ca.gov)
if you cannot make the listening session or would like to share more information.

Management background

In June 2021, the State Water Board granted the CA Department of Water Resources and US Bureau of Reclamation a Temporary Urgency Change Order relaxing Delta Outflow standards in June and July. At the same time, DWR installed an emergency drought barrier in West False River to combat salinity intrusion caused by the drought. These management actions prompted concern that they would lead to an increase in harmful cyanobacterial blooms across the Delta. DWR conducted a special study of harmful cyanobacteria in the summer of 2021.

Results

Low and medium levels of Microcystis and other potentially toxic cyanobacteria were detected throughout the Delta for most of the summer of 2021, continuing the increasing trend seen over the past ten years. A large cyanobacterial bloom was detected in Franks Tract during July and August, which may have been exacerbated by the West False River Emergency Drought Barrier.

Impact of TUCP and Barrier

Drought and increased water temperatures were major factors leading to the development of HABs across the estuary in 2021, and that the 2021 Temporary Urgency Change Petition and Emergency Drought Barrier are unlikely to have caused Delta-wide increases in Microcystis abundance. An increase in residence time caused by the barrier contributed to the cyanobacterial bloom in Franks Tract during July and August 2021. All cyanotoxin levels were below warning levels for recreational use, but may have had non-lethal effects on fish and wildlife.

Future directions

- DWR will increase monitoring of cyanobacteria and cyanotoxins in 2022.
- All observations will be reported to SWRCB's My Water Quality website. **https://mywaterquality.ca.gov/habs/**

Appendix C

Survey Distributed to Tribal Representatives

EXIT

CALIFORNIA DEPARTMENT OF
WATER RESOURCES

California Department of Water Resources Harmful Algal Blooms Survey

The California Department of Water Resources (DWR) is gathering input on the potential impacts of harmful algal blooms (cyanobacteria) in the Delta during Summer 2021 and possible impacts to cultural resources important to Tribes. This survey will help DWR assess whether there was an impact of the Temporary Urgency Change Petition, Emergency Drought Barrier or other drought actions on harmful algal blooms. Participation in this survey is completely voluntary and responses are anonymous.

Signs of algal blooms include green flakes in the water, discoloration of the water, or scum on top of the water.

1. As a tribal member, how do you use the Delta?

- ◯ Boating
- ◯ Fishing
- ◯ Swimming
- ◯ Water Supply
- ◯ Cultural, Spiritual, or Ceremonial Activities
- ◯ Community Events
- ◯ Wildlife Viewing
- ◯ Hiking

Other (please specify)

2. Have harmful algal blooms impacted your use of the Delta in the past

year?

◯ Yes

◯ No

If Yes, how?

3. Have you noticed unwelcome changes in appearance related to harmful algal blooms?

◯ Yes

◯ No

4. Have you noticed unpleasant odors related to harmful algal blooms?

◯ Yes

◯ No

5. Are you concerned about harmful algal blooms in the future?

◯ Yes

◯ No

6. Do you want to continue the conversation on harmful algal blooms?

◯ Yes

◯ No

If yes, please join DWR for a Listening Session on May 5th, 2022, 2:30 PM as a part of the SGMA Tribal Advisory Group Meeting to share your ideas and concerns. Sign up here: https://www.signupforms.com/registrations/28387.

7. Are their any other comments about harmful algal blooms that you would like to add?

Done

Appendix D
Comment Letter from Contra Costa Water District on the West False River Drought Salinity Barrier Project

March 25, 2022

Robert Trang
South Delta Branch
California Department of Water Resources
1516 9th Street 2nd Floor
Sacramento, CA 95814

Submitted via email to: wfrdsb_ceqa@water.ca.gov

Subject: Scoping Comments for the West False River Drought Salinity Barrier Project

Dear Mr. Tang:

Contra Costa Water District (CCWD) appreciates the opportunity to provide comments on the scope and content of Environmental Impact Report (EIR) for the West False River Drought Salinity Barrier project (Proposed Project). CCWD solely relies on the Delta to provide water to approximately 550,000 people in Contra Costa County. CCWD's three main intakes, Rock Slough, Old River, and Middle River Intakes, are all located within a few miles of the Proposed Project. Therefore, CCWD is interested in any changes in Delta water quality resulting from the Proposed Project and potential impacts to CCWD's water quality and water supply.

CCWD recognizes the importance of controlling salinity intrusion into the Delta during extreme dry hydrological conditions, but salinity is not the sole consideration when evaluating drinking water quality. We would like to provide the following specific comments:

1. Culverts with flap gates to allow one-way flow from Franks Tract to the San Joaquin River at Jersey Point on ebb tides should be considered in the design of the drought salinity barrier. In 2021, when a temporary drought salinity barrier was installed on West False River, the altered flow and increased residence time in Franks Tract caused high algae growth that affected not only Franks Tract, but also the Old River and Middle River corridor. The algae caused taste and odor issues impacting municipal and industrial water users in central and southern Delta, including CCWD, and increased the potential for formation of disinfection byproducts. Culverts with flap gates would improve flow circulation and thus reduce the potential for algae growth in the area, while maintaining the function the salinity barrier to prevent salt intrusion on flood tides.

2. CCWD appreciates the inclusion of additional water quality monitoring in the Proposed Project. The Notice of Preparation (NOP) for the EIR did not specify what constituents would be monitored at the three new water quality stations. In order to estimate the algae flux, we suggest adding Chl-a

continuous sensors paired with flow stations at the three locations identified in the NOP on Woodward Cut and Railroad Cut. DWR's Draft Emergency Drought Salinity Barrier 2021-2023 Monitoring Plan included the new flow stations on Woodward Cut and Railroad Cut, but it is unclear if those sensors have been installed because the data do not appear to be available online. CCWD also requests that a continuous Chl-a sensor be added at the existing flow station on Old River near Bacon Island. These data would allow quantified comparison of algae growth and transport in the Old River and Middle River corridor in the years with and without the drought salinity barrier.

CCWD looks forward to reviewing the details of the Proposed Project. Please do not hesitate to contact me at (925) 688-8168 or lshih@ccwater.com if you have any questions or would like to discuss these issues further.

Sincerely,

Lucinda Shih

Lucinda Shih
Water Resources Manager

YL

Appendix E
Outreach Efforts Undertaken by DWR in Preparing This Report

HABs/Weeds report outreach

6/1/2022
Department of Water Resources

The February 15th Temporary Urgency Change Order requires that "DWR and Reclamation shall coordinate with local watershed groups to determine if additional data are available that should be incorporated into the analysis and report." To that end, DWR has conducted extensive outreach with the broader scientific, water management, and environmental community to assess whether additional data are available. The outreach was conducted via email, coordination meetings and listening sessions, and led to significant additional data being added to this report.

Email campaign

DWR obtained the contact information of several researchers investigating harmful algal blooms from Janis Cooke of the Central Valley Regional Water Control Board. We were also given names of several local water agencies, reclamation districts, and community organizations by the Regional Board and by Michael George of the State Board. We emailed everyone on this list requesting any information regarding harmful algal blooms (cyanoHABs) or aquatic weeds within the Legal Delta from 2021 or previous years. Several of these contacts provided data or recommendations for other contacts (see Table 1 for list of people and organizations contacted).

The State Board also maintains a database of cyanoHABs data. DWR requested all incident reports and cyanotoxin data from the legal delta from 2021 from Karen Atkins of the State Board to add to the report.

To obtain additional information about human use of the Delta, particularly contact and non-contact recreation, and the impacts to vulnerable communities, DWR utilized several recently completed surveys of Delta users and residents. These were:

a. The Franks Tract Futures User Survey, completed in 2018-2019 to assess the user base of the Franks Tract Recreation Area and their opinions on different restoration scenarios. While not targeting vulnerable communities specifically, this survey provided information on the people who travel to the Delta for recreation.

b. The Delta Conveyance Project Environmental Justice Community Survey, completed in fall of 2020, which had the goal of assessing how disadvantaged communities in the Delta region live, work, recreate, and experience the Delta.

c. The Delta Protection Commission's Recreation and Tourism in the Delta survey. This survey was conducted in 2018 with the goal of assessing how residents of the Delta and visitors to the Delta recreate in the area.

To increase understanding of potential impacts of HABs and weeds on tribal uses for the Delta, DWR prepared a brief survey asking how tribal members use the Delta (recreation, fishing, ceremonial purposes, etc.). The survey and a fact sheet was distributed to DWR's list of tribal contacts and to participants in the April 26-27 US EPA's Regional Tribal Operations Committee meeting.

External Review

To ensure the robustness of the scientific process, DWR distributed the draft report to several experts in the field who were not associated with preparing the report. External reviews were received from:

- Dr. Ellen Preece, Robertson-Bryan, Inc
- Dr. Peggy Lehman, Department of Water Resources
- Dr. Tamara Kraus, USGS, California Water Sciences Center
- Joshua Rosen, USGS New York Water Science Center
- Jenna Rinde, California Department of Fish and Wildlife, Harmful Algal Bloom Coordinator
- Ivan Senock, Tribal Historic Preservation Officer, Buena Vista Rancheria of Me-Wuk Indians

Comments and edits suggested by these reviewers were incorporated in the public draft report when feasible given the scope of the report and constraints in the data sets.

Meetings

To increase coordination with other agencies, community organizations, and tribal organizations, DWR participated in several meetings and workshops.

- On January 19^{th},2022, DWR provided a presentation to the CCHAB network on the bloom that occurred at Franks Tract last summer. Meeting participants discussed potential future mitigation methods.

- On March 11th, 2022, DWR met with members of the State Water Board and Central Valley Board to discuss the previous HABs/Weeds report and get clarification on the scope of the June 1 report.
- On April 21st, 2022, DWR presented draft analyses for the report to the Interagency Ecological Program Estuarine Ecology Project Work Team for feedback.
- On April 29th, 2022 DWR met with representatives from Restore the Delta and the State Board to discuss harmful algal bloom concerns.
- On May 5th, 2022, DWR hosted a listening session at the 2022 Quarter 2 SGMA TAC Meeting to hear Tribal concerns related to harmful algal blooms.

Coordination with other groups

Activities for monitoring and assessing the impact of DWR and Reclamation's drought actions are being done in coordination with larger, multi-agency efforts to address Harmful Algal Blooms. DWR is participating in a workshop being planned by the Delta Science Program on HABs in the Delta. The workshop, planned for fall of 2022, will discuss the major issues in monitoring and managing HABs, with the goal of producing a framework for monitoring HABs in the Delta as a multi-agency effort.

DWR is also participating in the Interagency Ecological Program's Water Quality and Phytoplankton and Project Work Team, which will provide a forum for discussion of HABs and other phytoplankton topics. The goals of this team are to encourage sharing of data and methods to benefit development of formal synthesis and strategy documents, discuss changes to monitoring to inform management priorities, share new research on water quality and phytoplankton, and coordinate phytoplankton sampling.

TABLE 1
NAMES OF PEOPLE AND ORGANIZATIONS CONTACTED FOR POTENTIAL DATA TO ADD TO THE REPORT.

Organization	Contact name	Date contacted	Reply?	Response
Contra Costa Water District	Deanna Sereno	3/2, 3/7	3/17	CCWD is concerned about taste and odor issues caused by cyanoHABs but is reluctant to share data from their treatment plant. Rosemary Hartman had a phone conversation with Deanna Sereno from CC Water and agreed on language to include in the report.
Restore the Delta	Barbara Barrigan-Parilla	3/9	3/9	RTD has been working with Janice Cooke and the CV board on setting up citizen science HAB monitoring. Data will be available in 2022

Organization	Contact name	Date contacted	Reply?	Response
Prop 1 grant team	Tim Otten, Ellen Preece	3/9	3/16	They are conducting a special study of microcystins in shellfish and water samples, DWR received microcystin data, 4/3
CDFW	Carl Wilcox	--	3/15	Provide survey of human use in Franks tract.
UCD	Brett Mulligan	--	3/15	Provided survey on use of Franks Tract. Appendix A, https://franks-tract-futures-ucdavis.hub.arcgis.com/
Delta Stewardship Council	Jessica Rudnick	2/24, 3/7	3/8	Call to discuss potential EJ outreach. Suggested contacting Delta Protection Commission for contacts of local marina owners. Shared resources on online tools for environmental justice screening.
South Delta Water Agency	John Herrick	3/17	3/23	No data.
CDWA	Edward Zuckerman	3/17, 4/1		No Response.
Pescadero RD	Richard Pellegri	3/17, 4/1	4/3	No data. Yes, there are SD algae/weeds issues.
Delta Island for Metropolitan	Russ Ryan	3/17, 4/1		No Response
South Delta Water Agency	Mary Hildebrand	3/22	4/1	No data.
South Delta Water Agency	Jerry Robinson	3/22, 4/1		No Response.
East Bay Regional Parks	Hal MacLean	4/8	4/8	Received microcystin data for Big Break for 2016-2021 as well as data collection methods.
Nautilus Data	Raghav Narayanan	4/8, 4/14	4/14	Happy to share data, answered questions on methods.
State Board	Karin Atkins	5-Apr	5-Apr	Provided data and contacts for East Bay Parks and Nautilus, as well as incident data

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