From: Mooney, David M <dmmooney@usbr.gov>
Sent: Thursday, December 15, 2022 5:24 PM
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Subject: April 4, 2022 TUCO Condition 8

EXTERNAL:

Erik,

Please find attached the interim draft report from Reclamation and DWR on Harmful Algal Blooms required by condition 8 of the April 4, 2022, Temporary Urgency Change Order. A completed draft Report is scheduled for submittal by April 1, 2023.

Take care.
Dave

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Impact of Temporary Urgency Change Petition of 2022 and Emergency Drought Salinity Barrier on Harmful Algal Blooms and Aquatic Vegetation in the Delta: Interim Draft Report

Central Valley Project and State Water Project, California

California Great Basin, Region 10

U.S. Department of the Interior and State of California

December 15, 2022

Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

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

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

Impact of Temporary Urgency Change Petition of 2022 and Emergency Drought Salinity Barrier on Harmful Algal Blooms and Aquatic Vegetation in the Delta: Interim Draft Report

Central Valley Project and State Water Project, California

California Great Basin, Region 10

Authored by

United States Bureau of Reclamation

California Department of Water Resources

Cover Photo: Drone footage showing the presence of an algal bloom from DWR North Central Regional Office in Franks Tract at Piper and Sandmound Slough in the Sacramento-San Joaquin Delta. (Photo Credit: DWR/Jared Frantzich

Executive Summary

On April 4, 2022, the State of California Environmental Protection Agency State Water Resources Control Board (SWB) issued "Order approving temporary urgency changes to water right licenses and permit terms relating to Delta water quality objectives" to the U.S. Bureau of Reclamation (Reclamation) and the California Department of Water Resources (DWR) for the Central Valley Project and State Water Project. Condition 8 of the order requires Reclamation and DWR to submit a report the effects of the TUCO on the prevalence and extent of Harmful Algal Blooms (HABs) and expansion of invasive aquatic weeds in the Delta as follows:

> *In coordination with the State Water Board, Central Valley Water Board, IEP, Delta Science Program (DSP), the fisheries agencies, and USEPA, DWR and Reclamation shall continue and build upon the special study on the prevalence and extent of harmful algal blooms (HABs) and expansion of invasive aquatic weeds in the Delta as required by the 2021 TUCO, 2021 Emergency Drought Salinity Barrier (EDSB) Certification, and the 2022 Order on Reconsideration of the 2021 TUCO. The special study shall identify the effects of this TUCO Order, any future TUCO Orders, and any associated actions including drought barriers on the prevalence and extent of HABs and expansion of invasive weeds in the Delta. The study shall include the measurements of cyanotoxin concentrations in areas where this TUCO Order may modify hydrodynamics to Delta waterways. The cyanotoxin samples shall be collected consistent with the requirements of any approved extension of the EDSB certification, including, at a minimum, the types of cyanotoxins analyzed, locations, frequency, triggers for additional monitoring, and methods. The draft study plan shall be submitted by April 20, 2022, to the coordinating entities identified in the condition for review and comment. The final study plan incorporating the coordinating entities' comments are due to the State Water Board by May 10, 2022. Cyanotoxin monitoring shall be initiated in May 2022.The report shall summarize impacts to sub-regions of the Delta consistent with the localized nature of HABs and aquatic weeds and analyze potential for (or presence of) 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 where HABs and aquatic weeds are prevalent or where this TUCO Order may modify hydrodynamics to Delta waterways. This work shall be coordinated with IEP and DSP, and any broader watershed evaluation of HABs and aquatic weeds. An interim draft Report shall be submitted to the State Water Board by December 15, 2022, summarizing the results available at that time. A summary of the interim draft report shall be presented at a public Board meeting in January 2023, or as designated by the Deputy Director of the Division of Water Rights. A completed, draft Report shall be submitted to*

the State Water Board by April 1, 2023, released for public comment, and presented at a public Board meeting as determined in coordination with the Deputy Director of the Division of Water Rights. In coordination with the State Water Board, Central Valley Water Board, IEP, DSP, CDFW, and USEPA, DWR and Reclamation shall review and consider comments from the State Water Board, other agencies, and the public and modify the final report as appropriate based on these comments. A complete, final report shall be submitted to the State Water Board 30 days after receipt of public and State Water Board staff comments unless the Deputy Director for the Division of Water Rights grants and extension.

Harmful Algal Blooms

To be completed for next draft after all data have been received and interpreted and comments on this draft addressed.

Submerged and Floating Aquatic Vegetation

To be completed for next draft after additional all data have been received and interpreted.

Vulnerable Communities

To be completed for next draft after report from contractor has been received.

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Appendix B. Sampling Stations.

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List of Acronyms

CAWSC	California Water Science Center
CCHAB	California Cyanobacterial and Harmful Algal Bloom Network
CDFW	California Department of Fish and Wildlife
CVP	Central Valley Project
CyanoHABs	cyanobacterial harmful algal blooms
DWR	California Department of Water Resources
EDB	Emergency drought salinity barrier
EMP	Environmental Monitoring Program
FAV	floating aquatic vegetation
FHABs	freshwater harmful algal blooms
HAB	harmful algal bloom
IEP	Interagency Ecological Program
NCRO WQES	DWR North Central Region Office Water Quality Evaluation Section
NTU	nephelometric turbidity units

NWIS	National Water Information System
OMR	Old/Middle River Corridor
PWT	Project Work Team
RWQCB	Regional Water Quality Control Board
Sac	Sacramento River
SAV	submersed aquatic vegetation
SJ	San Joaquin River
SWB	State Water Resources Control Board
SWP	State Water Project
TUCO	Temporary Urgency Change Petition
TUCO	Temporary Urgency Change Order
USGS	United States Geologic Survey
YSI	Yellow Springs Instruments

Acknowledgments

Thank you to Rosemary Hartman (DWR), Dave Bosworth (DWR), Ted Flynn (DWR), Tiffany Brown (DWR), Morgan Battey (DWR), Sarah Perry (DWR), Jared Frantzich (DWR), Tyler Salman (DWR), Andrew Tran (DWR), Brianne Sakata (DWR), Elena Huynh (DWR), Nick Rasmussen (DWR), Keith Bouma-Gregson (USGS), Timothy Malinich (CDFW), Janis Cooke (CVRWQCB), Karen Atkins (State Water Board), Marisa Van Dyke (State Water Board), Carly Nilson (State Water Board), Armando Martinez (State Water Board), Hal MacLean (East Bay Regional Parks), Mui Lay (UC Davis), Ellen Preece (Robertson-Bryan, Inc), and Jeffrey Caudill (Department of Parks & Recreation) for providing data and input on the analyses and interpretations in this report. Thank you to all of the field staff in the Interagency Ecological Program long-term monitoring surveys, the California Department of Water Resources' North Central Regional Office, the United States Geological Survey's California Water Science Center, and other special studies for their efforts in collecting field data summarized in this report.

Suggested citation: Bureau of Reclamation and California Department of Water Resources. 2022. Temporary Urgency Change Petition of 2022 and Emergency Drought Salinity Barrier: Impact on Harmful Algal Blooms and Aquatic Weeds in the Delta. Sacramento (CA): Bureau of Reclamation. May 2023. ? pp. + appendix.

Section 1: Overview of the Temporary Urgency Change Petition

1.1 Introduction

Water year 2022 continued to be a dry year, extending the drought to a third year, with the 2020-2022 period being the driest three-year period on record. Precipitation in the Sacramento River Basin was at 76% of average and in the San Joaquin River was at 66% of average (California Department of Water Resources [DWR] 2022a). Large storm events in late 2021 resulted in significant increases in Oroville and Folsom reservoir storages. However, these were followed by the driest January and February on record, causing storages in these reservoirs to be insufficient to meet water right permit obligations for instream flows and water quality under D-1641. Similarly, storages in other Central Valley Project (CVP) and State Water Project (SWP) reservoirs were insufficient to meet critical water supply needs.

The U.S. Bureau of Reclamation (Reclamation) and California Department of Water Resources (DWR) jointly submitted the 2022 Temporary Urgency Change Petition (TUCO) on March 18, 2022. The TUCO requested that the State Water Resources Control Board (State Water Board) consider temporarily modifying the requirements of Reclamation's and DWR's water right permits and license included in D-1641 to enable changes in CVP and SWP operations that would allow the projects to meet health and safety needs, control saltwater intrusion into the Delta, deliver water with conservation for later instream uses and water quality requirements.

1.2 Substance of the Temporary Urgency Change Petition

Reclamation and DWR requested the following temporary changes to requirements that were imposed pursuant to D-1641 for the period of April 1 to June 30:

1. From April 1 – April 30, reduce the minimum Delta outflow requirement as measured by the NDOI from a minimum of 7,100 cfs on a 3-day running average to 4,000 cfs on a 14-day running average. For May 1 – June 30, a minimum NDOI of 4,000 cfs on a 14-day running average is requested if the May 1 forecast of the Sacramento River Index is greater than 8.1 million acre-feet (MAF) at the 90% exceedance level. If the index is less than 8.1 MAF, D-1641 already includes an offramp allowing for the lower outflow level.

2. Move the Western Delta agricultural salinity compliance point on the Sacramento River at Emmaton 2.5-3 miles upstream to Threemile Slough.

3. Limit the maximum export rate to 1,500 cfs when the unmodified D-1641 requirements are not being met.

4. Reduce the minimum monthly average flow requirement on the San Joaquin River at Airport Way Bridge, Vernalis from 710 – 1140 cfs (April 1 – 14 and May 16 – June 30) and 3,110 – 3,540 cfs (April 15 – May 15) to a minimum monthly average of 710 cfs from April 1 – June 30.

1.3 Emergency Drought Salinity Barrier

During drought conditions, reservoir water storage may not be sufficient to prevent the movement of high-salinity water upstream from San Francisco Bay. Intrusion of that water into the Central and South Delta would significantly impair the quality of exported water, impacting the ability for agriculture and millions of California residents to use the water and the maintenance of habitat quality for aquatic species. On June 22, 2021, DWR installed an emergency drought salinity barrier (EDB or barrier) in West False River to reduce the intrusion of high-salinity water into the Central and South Delta (Figure 1). The barrier is a temporary, physical rock barrier that can be removed or notched when water quality conditions improve. On January 18, 2022, DWR cut a notch in the top of the barrier to allow fish passage. On April 1, 2022, the notch was re-filled to again prevent high-salinity water from intruding into the Central and South Barrier. DWR removed the barrier in mid-Oct-Nov. of 2022, with hydrologic breaching achieved on November 1, 2022.

Figure 1. Location of the West False River emergency drought salinity barrier, placed in June 2021.

Section 2: Harmful Algal Blooms (HABs)

2.1 Introduction

General Background

The term "Harmful Algal Blooms" (HABs) is used to describe high levels of production of some types of microscopic plankton that can produce strong odors and chemicals toxic to humans, fish, and wildlife, and can deplete oxygen and release noxious gases when the bloom dies. HABs in freshwater are typically caused by cyanobacteria, photosynthetic bacteria (i.e., blue-green algae) that occur worldwide. Some species of cyanobacteria can produce a variety of toxins, collectively called cyanotoxins, including microcystin, anatoxin, and saxitoxin. HABs in brackish and saltwater are usually caused by dinoflagellates or diatoms (i.e., red tide) and can produce toxins like saxitoxins or domoic acid, among others. Genera of cyanobacteria capable of producing toxins and forming cyanobacterial HABs include *Anabaena/Dolichospermum*, *Aphanizomenon*, *Cylindrospermopsis*, *Nodularia*, *Lyngbya*, some *Oscillatoria*, *Microcystis*, and *Planktothrix*.

Cyanobacteria taxa differ in physiological capabilities, such as nitrogen fixation and vertical migration in the water column, and they differ in environmental requirements and optima, including temperature, irradiance, and nutrient forms and availability (Lehman et al. 2013; Dahm et al. 2016; Lehman et al. 2018; Wan et al. 2019; Xue et al. 2022). Most cyanobacteria responsible for HABs thrive at high light intensity and warmer water temperatures (Figure 2), conditions that support high growth rates and greater competitive success over eukaryotic algae (e.g., diatoms, green algae) that are more productive at cooler water temperatures (Berg and Sutula 2015). However, *Planktothrix* may experience greater growth leading to blooms at cooler temperatures, when microbial antagonists are less likely to be present (Rohrlack 2018). Other external factors controlling blooms include water flow, water residence time, and grazing rates by planktivorous organisms (Figure 2). Most cyanobacteria are not preferred food for planktivorous grazers, though some zooplankton and clams will consume *Microcystis* and other cyanobacteria (Kimmerer et al. 2018; Liu et al. 2009; Silva et al. 2020).

Not all cyanobacterial blooms produce toxins, and the size of a bloom is not always correlated with toxicity (Chaffin et al. 2022). Toxicity can be influenced by the genetic structure of the blooms because different genotypes within a species vary in the production of toxins (e.g., microcystin) and in relative abundance within a population over time (Yancey et al. 2022). Other factors, such as pH and the concentrations of different forms of nitrogen (e.g., ammonium and nitrate), have been shown to influence toxin production in some systems and is an area of active research (Barnard et al. 2021; Yancey et al. 2022). Humans, domestic animals, and wildlife can be exposed to different levels and types of health risk when exposed to toxin producing HABs. Microcystins are hepatotoxins that can affect the liver and cause gastroenteritis and allergic reactions (Dawson 1998). Anatoxins and saxitoxins are neurotoxins that can negatively affect the nervous system, including the heart and respiratory structures, sometimes lethally (Colas et la. 2021).

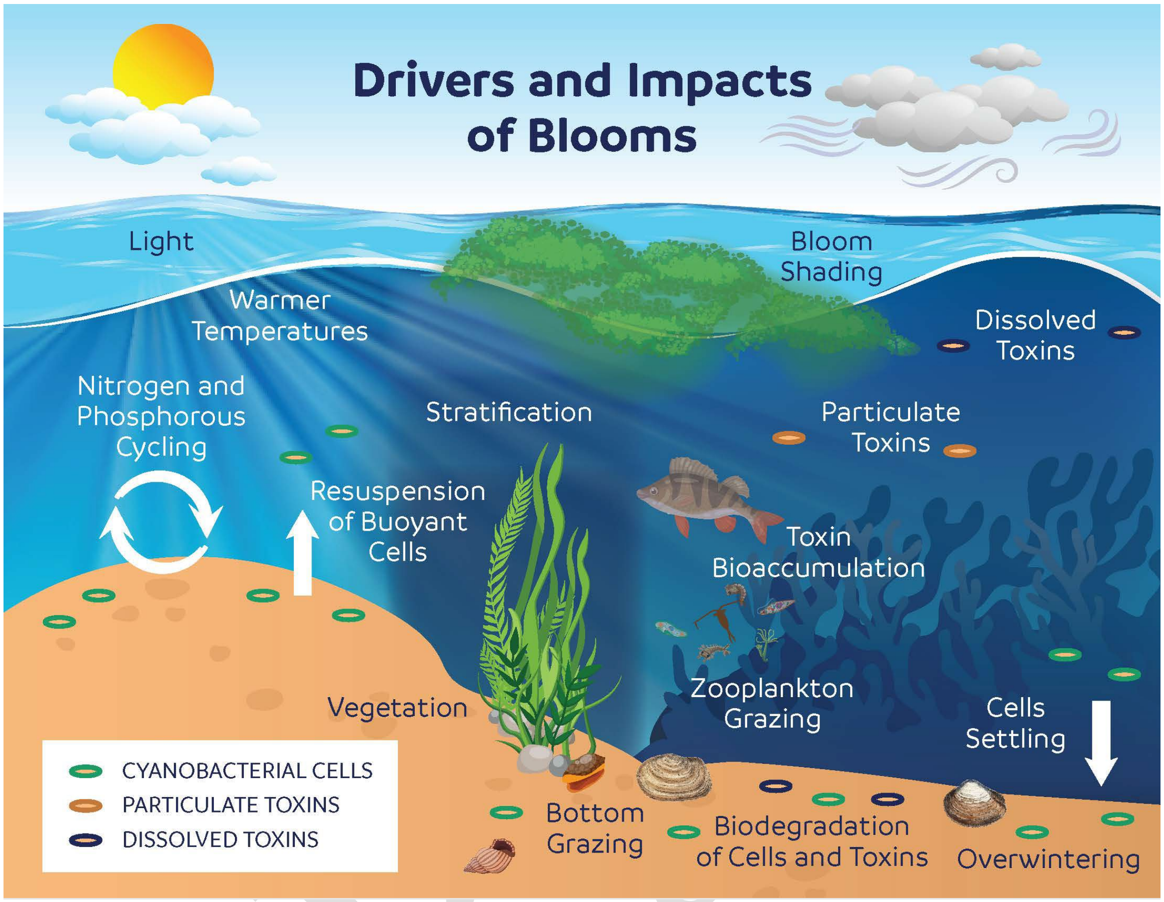

Figure 2. Conceptual model of factors contributing to freshwater Harmful Algal Blooms. Image courtesy of Delta Stewardship Council, Delta Science Program. HAB Development Conceptual Models for Delta HABs Workshop, November 2022.

HABs in the Delta

Blooms of *Microcystis aeruginosa*, a potentially HAB-forming cyanobacterium, have been observed in the Delta by researchers working at DWR and other agencies since the late 1990s. These blooms were first documented visually and appear as small lettuce-like flakes at the water's surface (Lehman and Waller 2003). Studies of these blooms demonstrated that *Microcystis* blooms can contain multiple toxins. Investigations after 2005 have found that the blooms frequently are composed of a mix of cyanobacteria: *Aphanizomenon*, *Microcystis*, *Dolichospermum* (formerly *Anabaena*), *Planktothrix* and *Pseudoanabaena*. (Lehman et al. 2010; Mioni et al. 2012), however research to date has focused primarily on *Microcystis*.

Overall, the Central and South Delta have 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 (Spier et al. 2013; Lehman et al. 2018). *Microcystis* abundance is typically much lower in Suisun Bay west of Antioch and north of Collinsville on the Sacramento River (Lehman et al. 2005; Lehman et al. 2008; Lehman et al. 2013; Lehman et al. 2018; Mioni et al. 2012).

HAB development in the Delta can be attributed to multiple natural and anthropogenic factors that operate at different spatial and temporal scales (Figure 3). 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. Water temperatures in the Delta are driven mainly by air temperatures (Vroom et al. 2017) and have increased with the general warming trend observed throughout California and globally due to climate change, leading to more favorable conditions for HABs (Diffenbaugh et al. 2015). Years with low inflow also tend to have warmer water temperatures (Bashevkin and Mahardja 2022). Temperatures vary spatially within the Delta with warmer temperatures in the South Delta and cooler temperatures along the Sacramento River and in Suisun Bay (Bashevkin et al. 2022). Turbidity controls light penetration in the Delta water column during summer and is driven by sediment concentration of the incoming water, water velocity and wind. The largest sediment inputs occur during winter storms, so summer conditions will have clearer water. Sediment inputs in the Delta have been decreasing over the past 50 years, causing a trend toward increased water clarity (Schoellhamer 2011). Residence time in the Delta is controlled by the combined interaction of tidal action, inflows, diversions, and physical characteristics of the Delta. Decreased flow typically occurs during July–September, which coincides with the occurrence of *Microcystis* blooms (Lehman et al. 2013, 2018, 2020; Spier et al. 2013). At low outflow values, changes to the physical characteristic and routing of the Delta, such as installation of barriers, operation of gates, or growth of submerged vegetation may have a greater impact on regional residence times than changes to outflow since these physical changes may alter tidal dynamics.

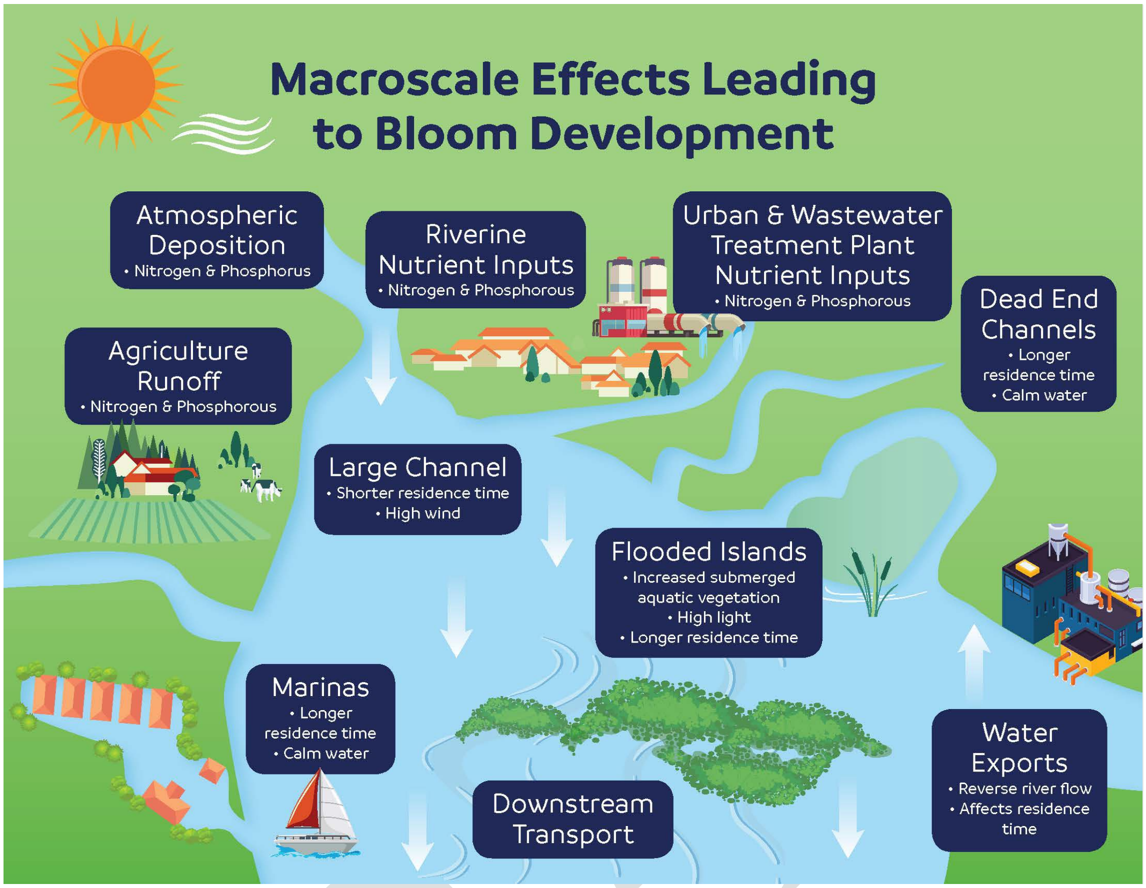

Figure 3. Conceptual model for factors in the Delta that lead to HABs development. Image courtesy of Delta Stewardship Council, Delta Science Program. HAB Development Conceptual Models for Delta HABs Workshop, November 2022.

2021 TUCO and EDB report findings

Hartman et al. (2022) concluded that the 2021 TUCO appeared to have no or a very localized effect, respectively, on HABs. Instead, HABs appear to be correlated to the more general effects of increased temperature and water residence time during drought conditions. Hartman et al. (2022) concluded that the EDB likely had a localized effect on HABs occurrence in Franks Tract during July and August, due to its effect on water residence time (Figure 4).

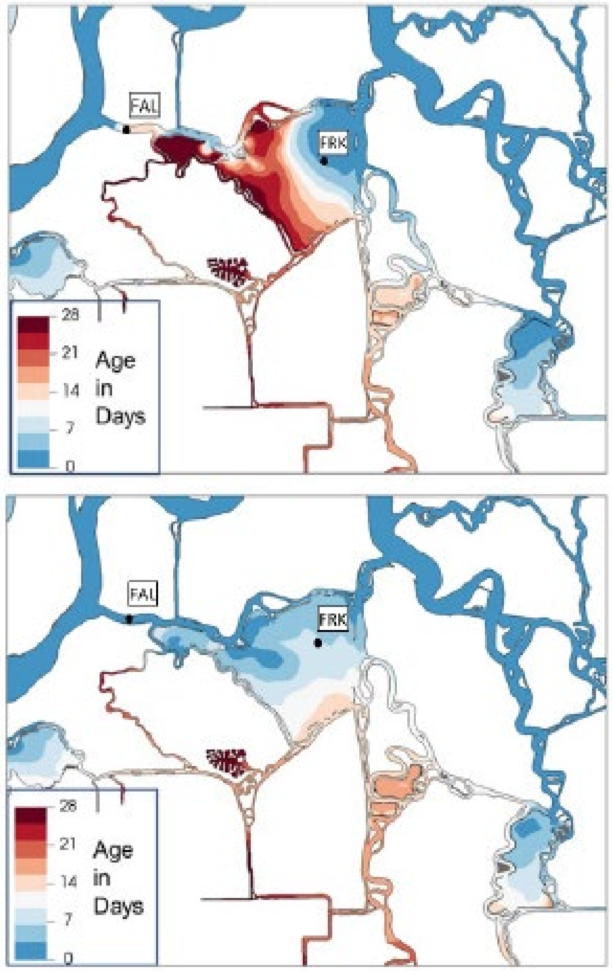

Figure 4. Modeled Daily Averaged Age of Water in Franks Tract with the Barrier (top) and without the Barrier (bottom) on August 17, 2021. Figure from Hartman et al. 2022 (Figure 2-36).

Flow differed an order of magnitude greater among water year types than between drought periods with and without a TUCO (Hartman et al. 2022). Drought periods also experienced higher temperatures, longer water residence times, and great water clarity, all of which are more favorable conditions for HABs development and growth. Concentrations of ammonium, nitrate, and orthophosphate have varied somewhat among years; however, variability does not appear to be related to drought or chlorophyll a, a measure of more general phytoplankton abundance.

Microcystis has been observed throughout the Delta with consistently higher rankings during periods of drought and in the Lower Sacramento River, Lower San Joaquin River, Franks Tract, OMR, and South Delta (Hartman et al. 2022). The incidence of *Microcystis*, based on visual ranking data, was most strongly correlated with temperature, turbidity, and CVP and SWP exports (Hartman et al. 2022). Cyanobacteria community composition included *Microcystis*, *Aphanizomenon*, and *Dolichospermum*. Composition varied among years, with *Aphanizomenon* most abundant in 2015 and 2020 and *Microcystis* most abundant in 2014, 2016-2018, and 2021

(Hartman et al. 2022). However, the results could be influenced by the distribution of different cyanobacteria within the water column and sampling methods that collect water 1-meter below the surface. For example, cyanobacteria that tend to float to the surface during the day, like *Microcystis*, could have been underrepresented in the water grab samples. While long-term toxicity data are lacking, recent data suggest higher levels are most frequently observed in the Lower Sacramento River, Lower San Joaquin River, OMR, and South Delta regions, with the potential for particularly high levels to occur in Big Break, Discovery Bay, and the Stockton waterfront (Hartman et al. 2022).

Goals and Hypotheses for 2022

In 2021, Condition 8 of the June 2021 Temporary Urgency Change Order (TUCO) and Section 401 certification for the 2021 EDB required a special study of cyanobacterial harmful algal blooms (HABs), based on the biological review and assessment for the 2021 TUCO and EDB, respectively. Both identified potential increases in HABs and submersed aquatic vegetation (SAV). Condition 8 of the April 2022 TUCO specified continuation of the 2021 special study and reporting on HABs occurrence and invasive SAV expansion in the Delta. This report provides an update to the 2021 special study report (Hartman et al. 2022), with data collected during spring through early fall 2022 that describes Delta environmental conditions and the distribution, intensity, and toxicity of HABs. The objective of this chapter is to evaluate the impacts of the TUCO and EDB on harmful algal blooms in the Delta. While a thorough study was conducted last year, the timing and some conditions of the TUCO differ this year. Similar to the 2021 report, data are presented regionally based on expected and observed differences in the impact of the TUCO and EDB in different areas of the Delta (Figure 5). Comparisons are also made between impacted and unimpacted locations. Temporal comparisons include 2021 and other dry TUCO years as well as other dry years not impacted by the TUCO and the EDB. The TUCO is expected to affect more of the Delta as flow restrictions span the whole system, whereas the EDB is expected to primarily affect the areas directly adjacent to the barrier, especially around Franks Tract (DWR 2022b).

2022 TUCO

The 2022 TUCO is hypothesized to impact the hydrology, water quality, and the potential for cyanobacterial blooms and toxicity incidents as follows (Table 1):

1. Increased water residence time in in the Upper and Lower Sacramento regions and Lower San Joaquin region due to reduced flows;
2. Increased water residence time in the Old and Middle River Corridor (OMR) due to reduced exports;
3. Higher nutrient concentrations and reduced transport of nutrients due to reduced outflow and consistent inputs from wastewater treatment plants.
4. Higher salinities in portions of the Lower Sacramento River and Lower San Joaquin River regions due to changes in salinity compliance points and reduced outflow;
5. Higher chlorophyll a concentrations in areas with longer water residence times;

6. Cyanobacterial blooms in areas with longer water residence times might increase in total number or frequency, duration, and intensity throughout the season; and
7. Cyanotoxin incidents might increase in number and concentration in areas with longer water residence times.

Spatial and temporal comparisons included:

1. Regional comparisons between regions expected to be more impacted by the TUCO and those regions expected to be less or not impacted by the TUCO (Hartman et al. 2022).
   a. Impacted regions: Lower Sacramento River, Lower San Joaquin River, OMR, Franks Tract;
   b. Unimpacted regions: Sacramento Deepwater Ship Channel, Cache Slough/Liberty Island, Upper Sacramento, East Delta regions.
2. Liberty Island (LIB) was used as a spatial comparison for the more highly impacted locations because residence time in the Cache Slough/Liberty Island area and the Sacramento Deep Water Ship Channel is primarily controlled by tidal forcing and therefore, not affected by the TUCO (Hartman et al. 2022).
3. Temporal comparisons were made with other drought years, both with and without a TUCO in place; which years were used depended on availability of data for different parameters of interest. Drought years were considered 2013, 2014, 2015, 2016, 2020, 2021, and 2022.
   a. TUCO drought years: 2014, 2015, 2021;
   b. Non-TUCO drought years: 2013, 2016, 2018, 2020.

2022 EDB

Impacts of the EDB were anticipated to include salinity, water residence time, and velocities as follows (Table 1):

1. Increased water residence time and altered velocities in the Franks Tract and OMR regions, with greater velocities in Fisherman's Cut and Old River near the terminus at the northeast end of Franks Tract (OSJ) and reduced velocities at Holland Cut near Bethel Island (HOL) and Old River at Quimby Island (ORQ) (see Figure *6*) associated with:
   a. Increased flows in Fisherman's Cut and decreased flows in Holland Cut near Bethel Island (DWR 2022b);
   b. Increased water age in Franks Tract on the west side and slightly decreased water age on the east side (DWR 2022b);
2. Reduced salinity in Franks Tract, OMR, and the Lower Sacramento regions; increased salinity in the Middle River and in the Lower San Joaquin River just west of the confluence with the Mokelumne River (DWR 2022b);
3. Higher chlorophyll a concentrations in areas with longer water residence times;
4. Cyanobacterial blooms in areas with longer water residence times or reduced velocities might increase in total number or frequency throughout the season, duration, and intensity;

5. Epiphytic cyanobacteria capable of producing toxins may be present; identifying and quantifying them is important for understanding potential sources of toxicity.
6. Cyanotoxin incidents might increase in number and concentration in areas with longer water residence times or reduced velocities.

Spatial and temporal comparisons included:

1. Liberty Island (LIB) and Mildred Island (MDM, HLT) and, in some cases, Clifton Court Forebay were used as spatial comparisons for Franks Tract, because they were low in salinity, have longer water residence times, and were unimpacted by the EDB (DWR 2022b; see Figure *6*).
2. Within 2022, temporal comparisons were made between before and during the period when the EDB was in place (April 1 – November 1).
3. Temporal comparisons were also made with other drought years, both with and without an EDB in place; which years were used depended on availability of data for different parameters of interest. Drought years were considered 2013, 2014, 2015, 2016, 2020, 2021, and 2022.
    a. EDB drought years: 2015, 2021, 2022;
    b. Non-EDB drought years: 2013, 2014, 2016, 2020.

Anticipated water quality responses to cyanobacterial blooms

Cyanobacterial blooms are often associated with low nitrate concentrations, due to high uptake by cells. High rates of photosynthesis during cyanobacterial blooms can cause higher pH levels and daytime DO concentrations. High biomass and thus respiration at night can cause DO concentrations to be lower; bloom senescence can result in high decomposition rates and lower DO concentrations.

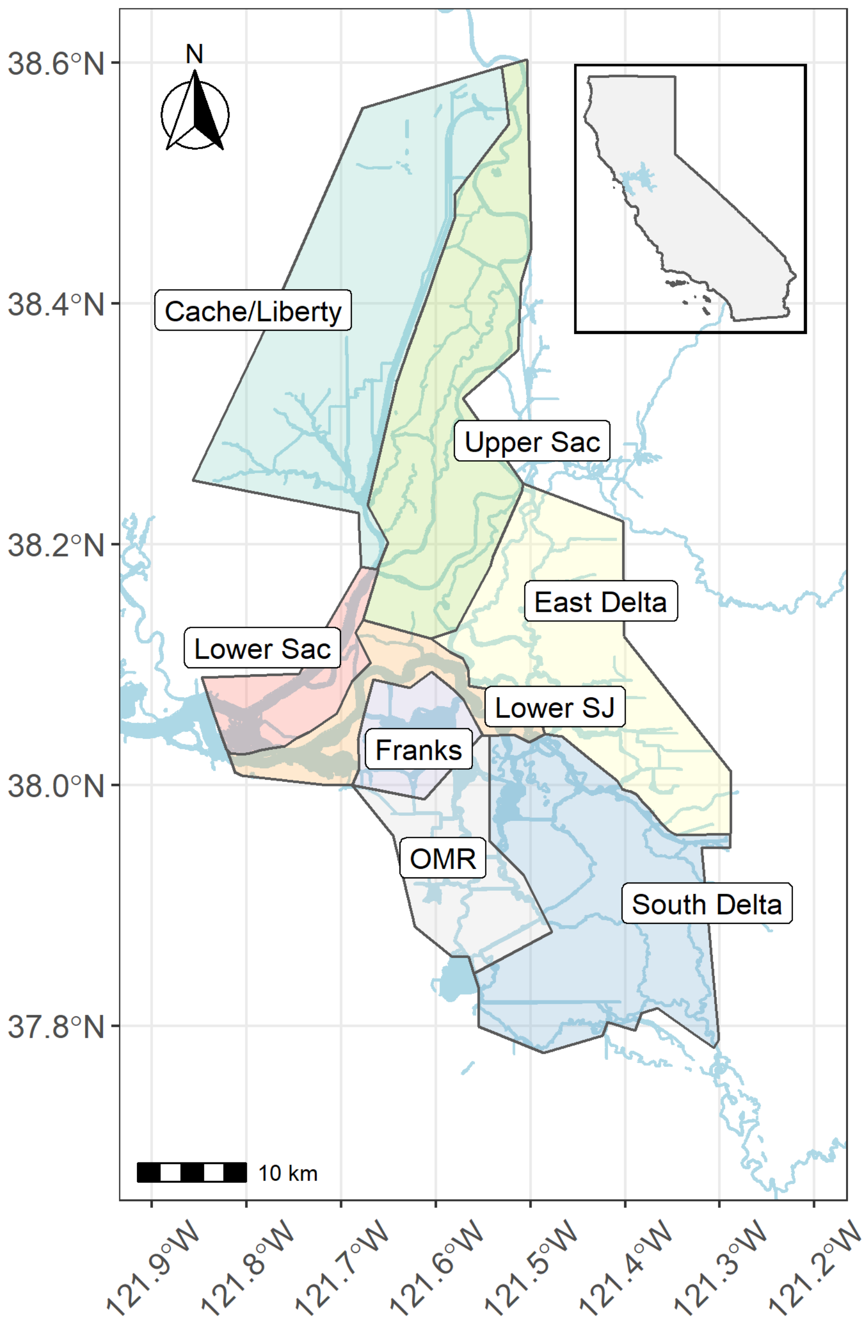

Figure 5. Regions used for analysis of the 2021 and 2022 Temporary Urgency Change Petitions and Emergency Drought Salinity Barrier.

Table 1. Hypothesized responses of water quality, cyanobacteria, and cyanotoxins to the 2022 TUCO and EDB. The years used for each comparison may differ based on data availability. Dry years include Below Normal, Dry, and Critically Dry water year types.

Action	Hydrological conditions	Water quality response	Cyanobacteria response	Spatial Comparison	Temporal Comparison
TUCO	Decreased flow Increased water residence time Regions impacted • Lower Sacramento River • Lower San Joaquin River • OMR • Franks Tract • South Delta	<u>Salinity</u> Increase in portions of Lower Sacramento and Lower San Joaquin river regions <u>Chlorophyll a</u> Increase in chlorophyll a <u>Nutrients</u> Increase	Greater number, frequency, duration, and intensity of cyanobacterial observations, blooms, incidents, and toxicity Areas with higher salinities may be less hospitable for freshwater cyanobacteria	<u>Flow</u> Delta- wide Liberty Island (unaffected by TUCO) <u>All others</u> Regional	Time series starting 2013 or more recently Non-TUCO drought years (2013, 2016, 2020) Other TUCO drought years (2014, 2015, 2021) Pre-TUCO, TUCO, Post-TUCO
EDB	Altered flow Increased water residence time in Franks Tract	<u>Salinity</u> Decrease in salinity in Franks Tract and in Old River south of Franks Tract Increase in salinity in Middle River and in the San Joaquin River west of the confluence with the Mokelumne River <u>Chlorophyll a</u> Increase in chlorophyll a	Greater number, frequency duration, and intensity of cyanobacterial observations, blooms, incidents, and toxicity Lower salinities in Franks Tract are comparable to habitats in regions with fresher water and may be more hospitable for freshwater cyanobacteria Some epiphytic cyanobacteria taxa Tract may be capable of toxin production.	Franks Tract Mildred Island Liberty Island	Non-EDB drought years (2013, 2014, 2016 , 2020) Other EDB drought years (2015, 2021) Pre-EDB versus EDB

2.2 Methods

Continuous Hydrology and Physical Water Quality

Hydrology

Dayflow was not yet reported for 2022; therefore, daily data were downloaded from the California Data Exchange Center (CDEC) stations to estimate metrics for delta outflow (station DTO) and exports (sum of stations HBP and TRP). San Joaquin River outflow data (Station VER or 11303500) were downloaded from the United States Geologic Survey (USGS) National Water National Water Information System (NWIS) (Table B-1). Averages across different subsets of years were calculated for comparison with 2022: 10-year average (2011-2021), Drought with TUCO Average (2014, 2015, 2021), and Drought with no TUCO Average (2013, 2016, 2020). Fourteen-Day Averages were used for Delta Outflow, Daily average was used for Combined Daily CVP and SWP Exports, and Monthly Rolling Averages were used for San Joaquin River Flow at Vernalis to align with stipulations in the TUCO.

Water Quality

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 are managed by the following monitoring programs: DWR's Environmental Monitoring Program (EMP), DWR's North Central Region Office (NCRO) Water Quality Evaluation Section (WQES), and the USGS California Water Science Center (CAWSC) (Figure 6). See Programs section below for more information. We selected stations near Franks Tract, where we expected EDB effects, and Mildred Island, which acted as a control. The water quality stations collect data on water temperature, specific conductance, flow, DO, chlorophyll fluorescence, turbidity, and pH (although not all stations contain all sensors; see Table B-1). For DWR stations, quality-controlled data were requested from DWR personnel when available, and provisional data were queried from the California Data Exchange Center (CDEC) using the "CDECRetrieve" package if no finalized data were available (Rodriguez & Cain 2022). For USGS stations, data were obtained from NWIS using the "dataRetrieval" package (De Cicco et al. 2022). See the "Programs" section below for a description of each of these sampling programs.

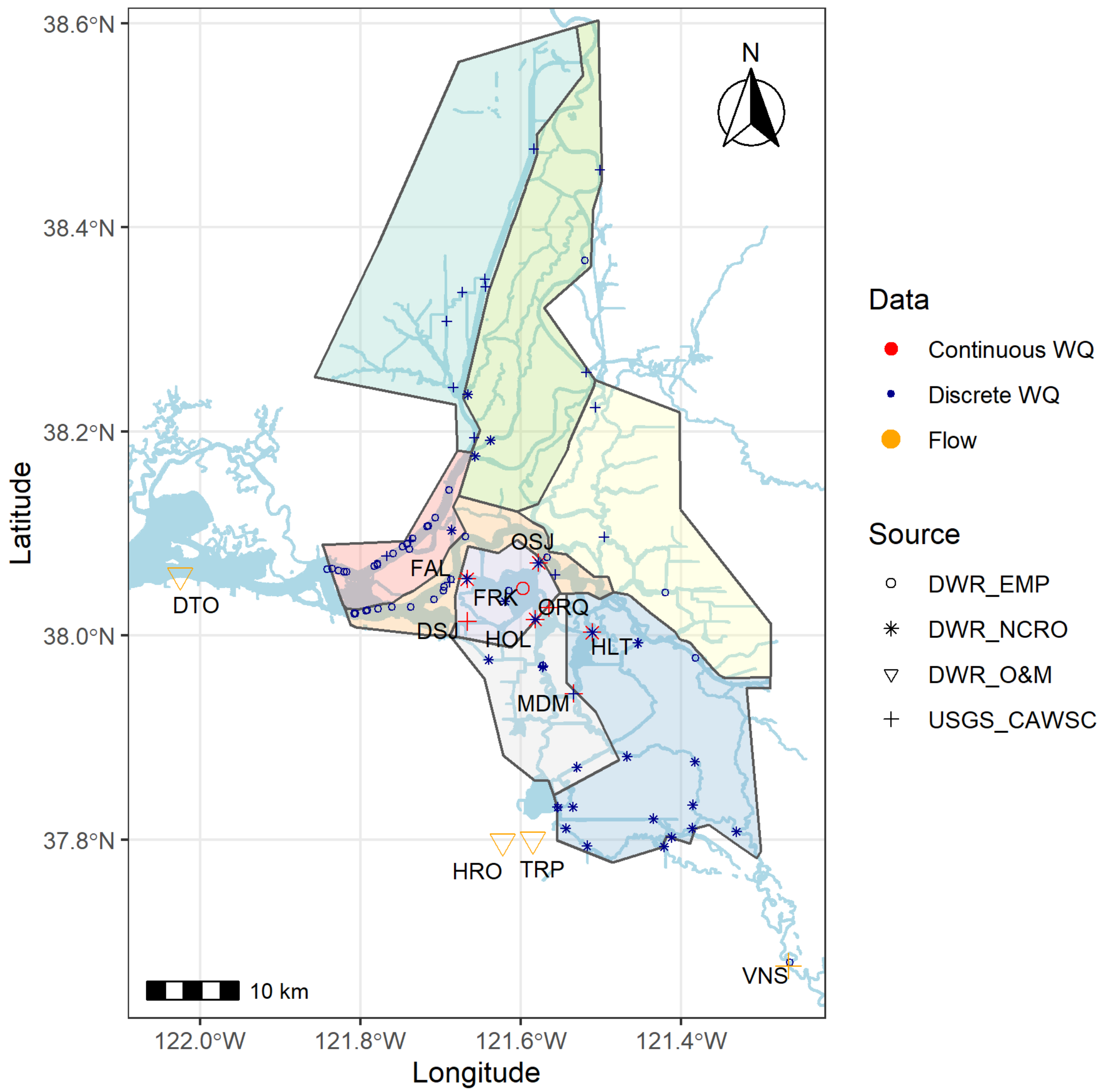

Figure 6. Locations of Continuous and Discrete Water Quality Monitoring in 2022. Red points indicate continuous water quality sampling and are labeled with station codes from CDEC. Shapes indicate monitoring source of data.

Discrete Water Quality

Nutrient concentrations were measured in discrete water grab samples that were collected monthly throughout the summer by the following monitoring programs: the DWR EMP, DWR NCRO Water Quality Evaluation Section (WQES), and USGS CAWSC (Figure 6). See the "Programs" section below for a description of each of these sampling programs. Data from 2022 were acquired through direct data requests and appended to the 2014-2021 dataset that was compiled for the 2021 TUCO and EDB report (as described in Hartman et al. 2022).

Cyanobacteria

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.

For EMP, 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” (Figure 7) (Flynn et al. 2022). In other surveys, researchers look directly into the water rather than using a bucket, but the methods are comparable. Although this method is imprecise, it is generally reliable for detecting *Microcystis* and giving a rough estimate of magnitude.

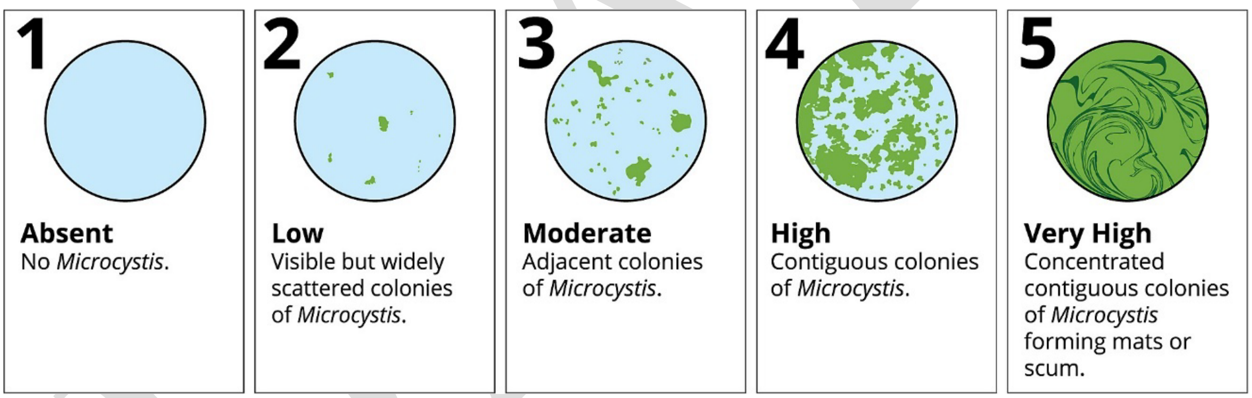

Figure 7. Visual *Microcystis* ranking system used by various monitoring programs.

Visual assessment data for this report come from five surveys (Figure 8). These data were subset to only include observations made during the summer and fall, June–October, because this is the time frame during which HABs usually occur. Data sets were also subset to only include observations in the regions outlined in Figure 5. Total observations varied by region of the Delta and year but ranged from 360 to 1,372 data points per summer.

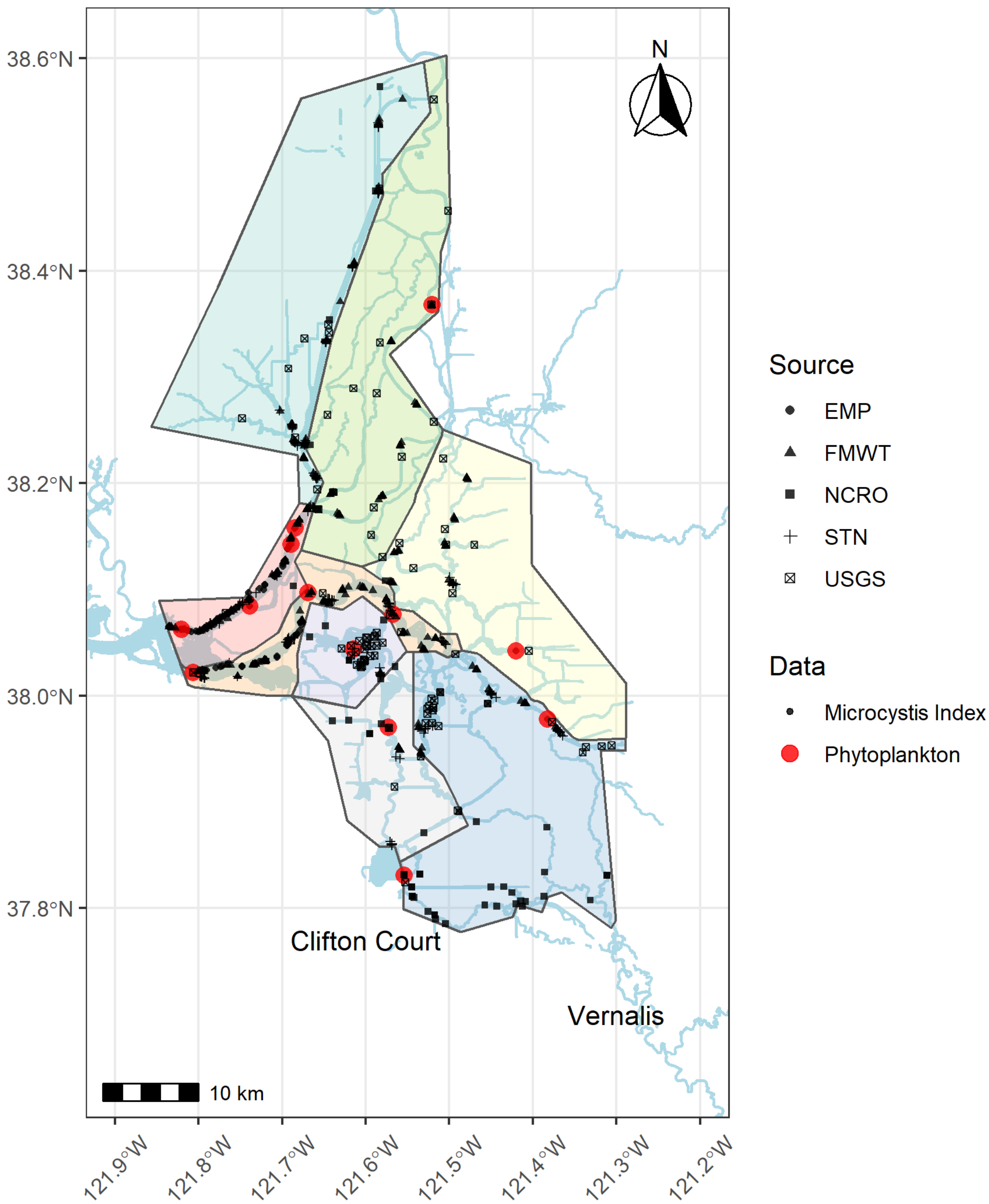

Figure 8. Map of Stations for Long-Term Monitoring Programs Contributing *Microcystis* Visual Observations (black) and Environmental Monitoring Program Phytoplankton Grab Samples (red). FMWT data from 2022 were not available in time to be included in this draft but should be available for the Dec draft.

Incident reports

The State Water Board maintains the freshwater HABs Incidents Report Map. This map and corresponding table only show the locations where HABs have been voluntarily reported. Incidents reported in 2022 were obtained from staff at the State Water Board. Advisories were classified as "No advisory," "Caution," "Warning." Or "Danger." "No advisory" samples were filtered out and remaining advisories were mapped to identify "HAB hot spots" that may have been missed in other visual sampling.

USGS and DWR FluoroProbe mapping

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 AlgaeTM sensor), dissolved oxygen (DO), and water temperature. Both surveys monitor the phytoplankton community 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 and July 2022, 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 (https://tableau.usgs.gov/views/SFBD_Data_Portal/Mapping2018and2020?%3Aiid=1&%3AisGuestRedirectFromVizportal=y&%3Aembed=y). For this report, raw Fluoroprobe data were filtered to cyanobacteria and plotted by location.

EMP cyanobacteria community composition

The EMP collects samples of the phytoplankton community composition monthly at stations marked in Figure 8. The community composition is enumerated and identified via microscopy by BSA Environmental Services, Inc (Beechwood, OH), allowing a determination of which species are contributing to phytoplankton blooms. Phytoplankton samples are collected with a submersible pump from a water depth of one 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. Phytoplankton are identified to the lowest taxonomic level possible, using the Utermöhl method and American Public Health Association Standard Method 10200 F (Utermöhl 1958, American Public Health Association 2017).

Data were subset to show only cyanobacterial HABs 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.

While pelagic cyanobacteria have been relatively well studied in the estuary, the extent to which toxic epiphytic cyanobacteria are an issue in the Delta remains unknown. Therefore, DWR conducted a pilot study on epiphytic algae to see how frequently toxic cyanobacteria occurred on vegetation in the Franks Tract region. A subset of the four stations were sampled to detect potential cyanobacterial HABS on submerged aquatic vegetation (SAV). SAV samples were collected within a two-meter radius of the water quality station. A section of SAV approximately between 5-10 cm in length, depending on species, was scraped of algae to sample a similar surface area from each. Scrapings were collected in deionized water. Samples were transported back to the West Sacramento DWR office on ice and subsequently shipped to GreenWater Laboratories (Palatka, FL). Algae were identified to the lowest feasible level of taxonomic resolution. These data were compared to pelagic phytoplankton samples collected by EMP at station D19 within Franks tract.

SFEI satellite images

Satellite data, available from the San Francisco Estuary Institute's HAB Satellite Analysis Tool (San Francisco Estuary Institute 2022), 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 x 10-05 is near natural background levels of cyanobacteria) or very high (CI of 6.327 x 10-02 in extremely dense scums). This means the satellite cannot detect as low a level of cyanobacteria that grab samples or fluoroprobes can detect. It also cannot differentiate between differences between high and very high levels of cyanobateria.

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 ≤ 6.310 x 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.

Cyanotoxins

Delta-wide

While cyanotoxin data were obtained from throughout the Delta, data requests were focused on the Central and South Delta, as Hartman et al. 2022 indicated this was the main area influenced by the TUCO and EDB.

The cyanotoxin data collected in 2022 and presented here came were collected from several different investigations (Figure 9). These studies all used either enzyme-linked immunosorbent assay (ELISA), liquid chromatography–mass spectrometry (LC-MS), or liquid chromatography with tandem mass spectrometry (LC-MS/MS) to analyze toxin concentrations (Table 2). Agreement is generally very high between these methods, although ELISA may produce higher concentration values than LC-MS/MS (Preece et al. 2021). 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.

- The State Water Board's freshwater HAB program collects samples as a response to severe blooms, or for pre-holiday monitoring and is not a comprehensive monitoring program (https://www.waterboards.ca.gov/water_issues/programs/swamp/freshwater_cyanobacteria.html). The Central Valley RWQCB collected cyanotoxin samples during pre-Labor Day sampling in the Stockton area on August 24, 2022. Samples were lysed and analyzed by Bend Genetics, LLC (Sacramento, CA) for microcystins/nodularins, anatoxins, cylindrospermopsins, and saxitoxins using the ELISA method.

- DWR State Water Project Division of Operations and Maintenance collects water 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 (*Microcystis, Aphanizomenon, Cylindrospermum, Dolichospermum, Planktothrix*, and others). If potentially toxic algae are detected, cells are lysed and samples are then tested for probable toxins using either ADDA-ELISA or LCMS/ MS, as appropriate (Foss and Aubel 2015).

- DWR North Central Regional Office collects water samples at Franks Tract for Emergency Drought Barrier Monitoring. Samples are collected monthly in May–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 (*Microcystis, Aphanizomenon, Cylindrospermum, Dolichospermum, Planktothrix*, and others). If potentially toxic algae are detected, cells are lysed and samples are then tested for probable toxins using either ADDA-ELISA or LCMS/ MS, as appropriate (Foss and Aubel 2015).

- 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/nodularins by Bend Genetics using Eurofins Abraxis ADDA ELISA. The Proposition 1 Senn/Preece/Cooke/Otten studies were designed as special studies to better understand toxin dynamics, rather than to establish a baseline. 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. 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. Data were requested from staff at the East Bay Regional Park District.

- 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/nodularins, anatoxins and saxitoxins using ADDA ELISA as appropriate. Data were requested from staff at the Central Valley Water Board.

- USGS and DWR are conducting a special study collaboratively with funding from the Delta Regional Monitoring Program and the Delta Science Program. Samples are collected at several stations throughout the Delta. For these efforts, cyanotoxins are measured in whole water discrete samples and using Solid Phase Adsorption Toxin Tracking (SPATT) samplers every two to four weeks, though SPATT data are still being evaluated and are not currently included in this report. The cyanotoxin samples are analyzed using LC-MS/MS. All laboratory analyses are conducted by Lumigen

Instruments, Wayne State University, Detroit, Michigan. Data from this study have not been approved by USGS and are considered preliminary.

Combining these data sets provides a relatively wide spatial and temporal scope of cyanotoxin monitoring for evaluating TUCO effects related to the EDB and HABs. These data sets may miss small-scale or short-lived toxin events, particularly in smaller, backwater sloughs in the Delta; however, these locations are not expected to be affected by the TUCO. 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.

Table 2. Description of Cyanotoxin Analyses Conducted by Various Programs and Studies.

Program	Analyzed by	Method	Toxins tested	Sample frequency and Data Availability
FHAB	Bend Genetics, LLC	ELISA	Anatoxins, Cylindrospermospin, Microcystin/Nodularins, Saxitoxin	8/24/2022 (1 time)
DWR SWP	GreenWater Laboratories	ELISA: ADDA ELISA for MC/Nod, Saxitoxin-specific ELISA, LC-MS/MS for ANTX-a and CYN	Microcystins/Nodularins, Cylindrospermopsins, Saxitoxins, Anatoxins; PTOX	2-5 times per month, through end of August
EB Parks	Bend Genetics	ADDA ELISA	Microcystins	2-4 samples per month at launch, through 9/19/2022
NCRO EDB	GreenWater Laboratories	ELISA: ADDA ELISA for MC/Nod, Saxitoxin-specific ELISA, LC-MS/MS for	Microcystins/Nodularins, Cylindrospermopsins, Saxitoxins, Anatoxins; PTOX	Monthly, June through August

		ANTX-a and CYN		
Prop 1	Bend Genetics, LLC	ADDA ELISA – DM (Direct monoclonal) ELISA kits	Microcystins/Nodularins	1-2 times per month, through end of July
USGS	Lumigen	Liquid chromatography tandem mass spectrometry (LC-MS/MS)	Microcystins, Anabaenopeptins, Nodularins, Anatoxins, Cylindrospermopsins	1-3 times per month, not all sites sampled every month, through July
Nautilus Data Technologies	Bend Genetics	ELISA	Saxitoxin, Anatoxins, Microcystins/Nodularins	2 times per month, through August
Restore the Delta	UCSC	Abraxis Test strip/ LC-MS (UCSC)	Microcystin, Nodularins, Anatoxins, Cylindrospermospins	Monthly, through September

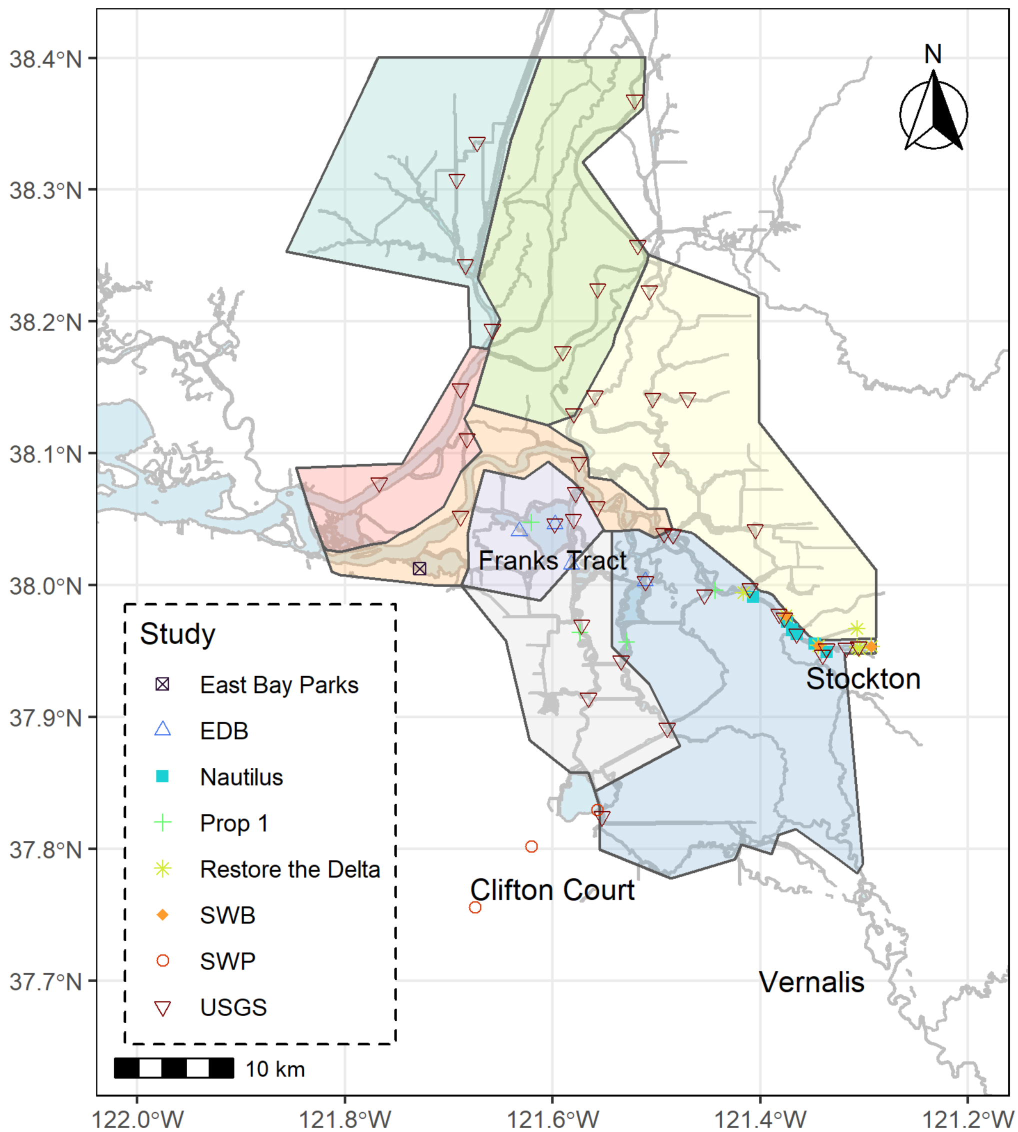

Figure 9. Locations of Cyanotoxin Sampling During 2022. Shapes and colors denote the programs that collected cyanotoxin sample data.

For cyanotoxin visualizations, we standardized naming conventions of the toxins, and summed cyanotoxins for each toxin type within a particular sample. We labeled non-detects as having a concentration of 0 to be able to visualize all samples that were tested. In order to compare toxin levels with health risks, we classified toxin levels corresponding to OEHHA trigger levels for human and animal health by grouping them into advisory levels (Table 3). For PTOX visualizations, we classified species into genera, and used descriptions of the numbers of colonies or filaments to provide a rough estimate of abundance of different genera of cyanobacteria.

Table 3. OEHHA (Office of Environmental Health Hazard Assessment) Trigger Levels For Human and Animal Health. From https://mywaterquality.ca.gov/habs/resources/habs_response.html.

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

Programs

Environmental Monitoring Program

The Environmental Monitoring Program (EMP) is conducted collaboratively by DWR, Reclamation, and the California Department of Fish and Wildlife (CDFW) in compliance with D-1641. This program has been collecting data since 1971, although stations and parameters have shifted somewhat over time. The EMP includes 15 continuous water quality stations, at which Yellow Springs Incorporated (YSI) sondes collect data every 15 minutes on the following water quality parameters: specific conductance, pH, water temperature, dissolved oxygen, turbidity and chlorophyll fluorescence measured using a YSI Total Algae sensor. Discrete water quality and phytoplankton sampling occurs monthly at 24 fixed stations and between 2-4 floating stations, where the bottom specific conductance is 2000 µS/cm and 6000 µS/cm. Water is collected using a flow-through system in which it is pumped into the shipboard laboratory either from a fixed intake one meter below the water's surface, or from a Van Dorn water sampler, or via a submersible pump (Interagency Ecology Program [IEP] 2020). Water quality parameters measured either in the field or laboratory include water temperature, turbidity, Secchi depth, pH, chlorophyll a concentration, organic and inorganic species of nitrogen and phosphorus, silica, dissolved organic carbon, specific conductance, and dissolved oxygen. 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 (IEP 2020). Phytoplankton samples are also collected for enumeration to document species composition and calculating biovolume for different taxonomic groups. Starting in 2015, visual estimates of *Microcystis* have been collected at each discrete water quality station (Flynn et al. 2022). Standard operating procedures (SOPs) for equipment maintenance and calibration QAQC, sample collection and analysis, and data management and QAQC are described in the following documents:

- DWR Division of Integrated Science and Engineering. 2022. Quality Assurance Project Plan for the Continuous Environmental Monitoring Program (CEMP). Document number: DES-3-QAP-001, Version 1.0. 49 pp. (Appendix D in U.S Bureau of Reclamation [USBR] and DWR 2022).

- DWR Division of Integrated Science and Engineering. 2022. Discrete Environmental Monitoring Program field and laboratory manual. Version 6. 83 pp. (Appendix E in USBR and DWR 2022).

Department of Water Resources North Central Region Office

The Department of Water Resources conducts HAB monitoring in the south and central Delta as required by the South Delta Temporary Barriers Project Section 401 Water Quality Certification. In brief, DWR's NCRO WQES 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. DWR's Bryte Laboratory analyzed the samples using EPA methods or DWR-approved modifications of these methods (IEP 2020). EMP's Visual Index scale is recorded to monitor HAB formation in the South and Central Delta year-round at all continuous monitoring stations. Tow nets and Van Dorn samplers are used to sample for *Microcystis* and phytoplankton during the months of known peak *Microcystis* presence (July-October) and coincide with Temporary Agricultural Barrier installation which is typically May-October. Sampling can occur outside of that window, however, if the barrier installation timeline is altered and or visual index scores indicate earlier detection of FHABs. Water samples for toxin analysis will be collected only during peak Visual Index periods (Visual Index >4). Additional FHAB sampling for cyanotoxins also occurs in areas adjacent to the West False River drought barrier in years where the barrier is in place. Standard operating procedures (SOPs) for equipment maintenance and calibration QAQC, sample collection and analysis, and data management and QAQC are described in the following documents:

- DWR Division of Regional Assistance North Central Region Office. 2022. NCRO WQES Proposed HAB monitoring workplan 2022. 6 pp. (Appendix A in USBR and DWR 2022).
- DWR Division of Integrated Science and Engineering. 2022. Quality assurance project plan for discrete water quality sampling emergency drought barrier and TUCO Cyanotoxin monitoring. Document number: DES-10-QAP-001, Revision 1.0. 6 pp. (Appendix B in USBR and DWR 2022).

- DWR Division of Regional Assistance North Central Region Office. 2022. Quality assurance project plan Central Delta and emergency drought barrier water quality monitoring program. Document number: DRA-2-QAP-005, Revision 2. 66 pp. (Appendix C in USBR and DWR 2022).

United States Geologic Survey monitoring

The USGS CAWSC, under an agreement with Reclamation, maintains approximately 53 continuous monitoring stations throughout the Delta. Most stations measure water flow or, in some cases, velocity and core water quality parameters including water temperature, specific conductance, and turbidity. At some stations, an expanded set of water quality parameters is collected, including dissolved oxygen, pH, and chlorophyll a. Discrete nutrient samples are collected approximately monthly from 14 stations. Starting in 2020, visual index scores of *Microcystis* colony prevalence are also recorded approximately weekly during spring through fall at a subset of stations. Standard operating procedures (SOPs) for equipment maintenance and calibration QAQC, sample collection and analysis, and data management and QAQC are described in the following documents:

- Wagner, R.J., Boulger, W.R., and Smith, B.A., 2006, Revised Guidelines and standard procedures for continuous water-quality monitors: site selection, field operation, calibration, record computation, and reporting: U.S. Geological Survey Techniques and Methods, Book 9, Chapter B. http://pubs.usgs.gov/tm/2006/tm1D3/

- Pellerin, B.A., Bergamaschi, B.A., Downing, B.D., Saraceno, J.F., Garrett, J.A., and Olsen, L.D., 2013, Optical techniques for the determination of nitrate in environmental waters: Guidelines for instrument selection, operation, deployment, maintenance, quality assurance, and data reporting: U.S. Geological Survey Techniques and Methods 1–D5, 37 pp. https://pubs.er.usgs.gov/publication/tm1D5

- U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9.

2.3 Results

2022 Delta-wide conditions

Hydrology

Hypotheses:

- Reduced flows in the Sacramento and lower San Joaquin rivers and reduced exports due to the TUCO, beyond drought impacts.
- Lower flows in the San Joaquin River compared with both non-TUCO and TUCO years, due to San Joaquin River stipulations in the 2022 TUCO

Comparison: across long-term average, and drought conditions with and without a TUCO

- TUCO Drought years: 2014, 2015, 2021
- Non-TUCO Drought years: 2013, 2016, 2020

Figure 10. TUCO Hydrology. Fourteen-Day Average Delta Outflow (green), Combined Daily CVP and SWP Exports (orange), and Monthly Rolling Average San Joaquin River Flow at Vernalis (dark blue) for 2022 (solid line) Compared to the 10-year Average (2011-2021; dashed line), Drought with TUCO Average (2014, 2015, 2021; dot-dash line), and Drought with no TUCO Average (2013, 2016, 2020; dotted line). Delta outflow was obtained from DTO station on CDEC, CVP and SWP exports were obtained from TRP and HRO stations on CDEC and were summed, and San Joaquin River Flow was obtained from Station 11303500 (VER) on

NWIS. Shaded boxes indicate the period and modified flow/export values specified by the 2022 TUCO. Green shading indicates values should be within the limits of the box while orange shading indicates values should be greater than the upper limit of the box.

- Delta outflow, exports, and San Joaquin River Outflow were lower in 2022 across months compared with the 10-year average,
- Flows tracked closely to TUCO specifications and were very similar to other TUCO drought years, especially for Delta outflow and San Joaquin River outflow.
- Starting at the beginning of June, exports in 2022 were approximately 100% lower than exports in non-TUCO drought years. Meanwhile, between July and September (after the end of the 2022 TUCO period), exports in 2022 were approximately 100% higher than exports in other TUCO drought year.
- During the TUCO period, San Joaquin River outflow was lower than outflow during other non-TUCO drought years, and similar to other TUCO drought years.

Water Quality

Hypothesis: Salinity was expected to increase in 2022 compared with non-TUCO years due to changes in the salinity compliance point.

Comparison: non-TUCO drought years (2013, 2016, 2020)

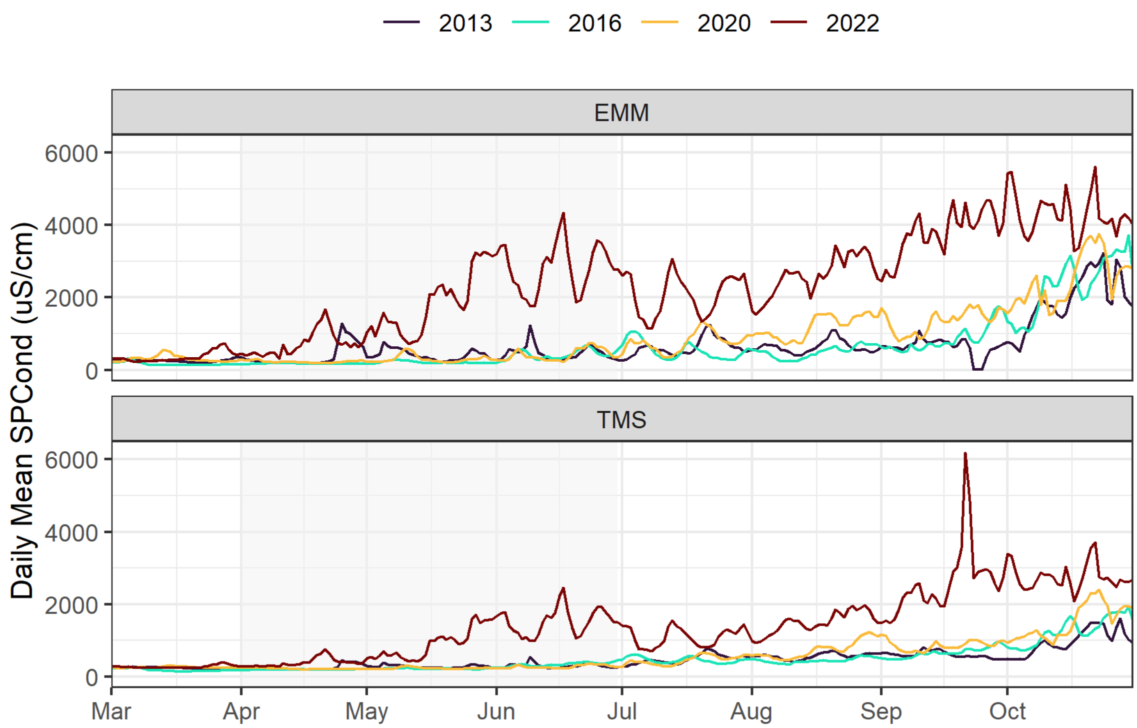

Figure 11. Specific Conductance at Emmaton (EMM) and Threemile Slough (TMS). Salinity compliance point was moved from EMM to TMS (more upstream) as part of the 2022 TUCO. Salinity in 2022 is compared with salinity in non-TUCO dry years. Shaded box indicates period of TUCO.

- Higher salinity was observed in 2022 at both EMM and TMS compared with non-TUCO drought years.

- In 2022, TMS (the specified salinity compliance point) had a mean daily salinity of 1806 – 2832 µS/cm between May and July while in other years average daily salinity was 242-465 µS/cm.

Nutrients and Chlorophyll a

Hypotheses:

- Nutrient concentrations were expected to be higher due to reduced dilution and transport as a consequence of reduced outflow and consistent inputs from wastewater treatment plants.

- Nutrients were expected to decrease over HAB season as the result of uptake by cyanobacteria and other primary producers.

- Chlorophyll a values were expected to be higher in regions that experienced longer water residence times due to the TUCO and EDB (e.g. parts of Franks, OMR, South Delta, Lower Sac, and Lower SJ).

Comparison: regional comparison of 2022 to the previous eight years

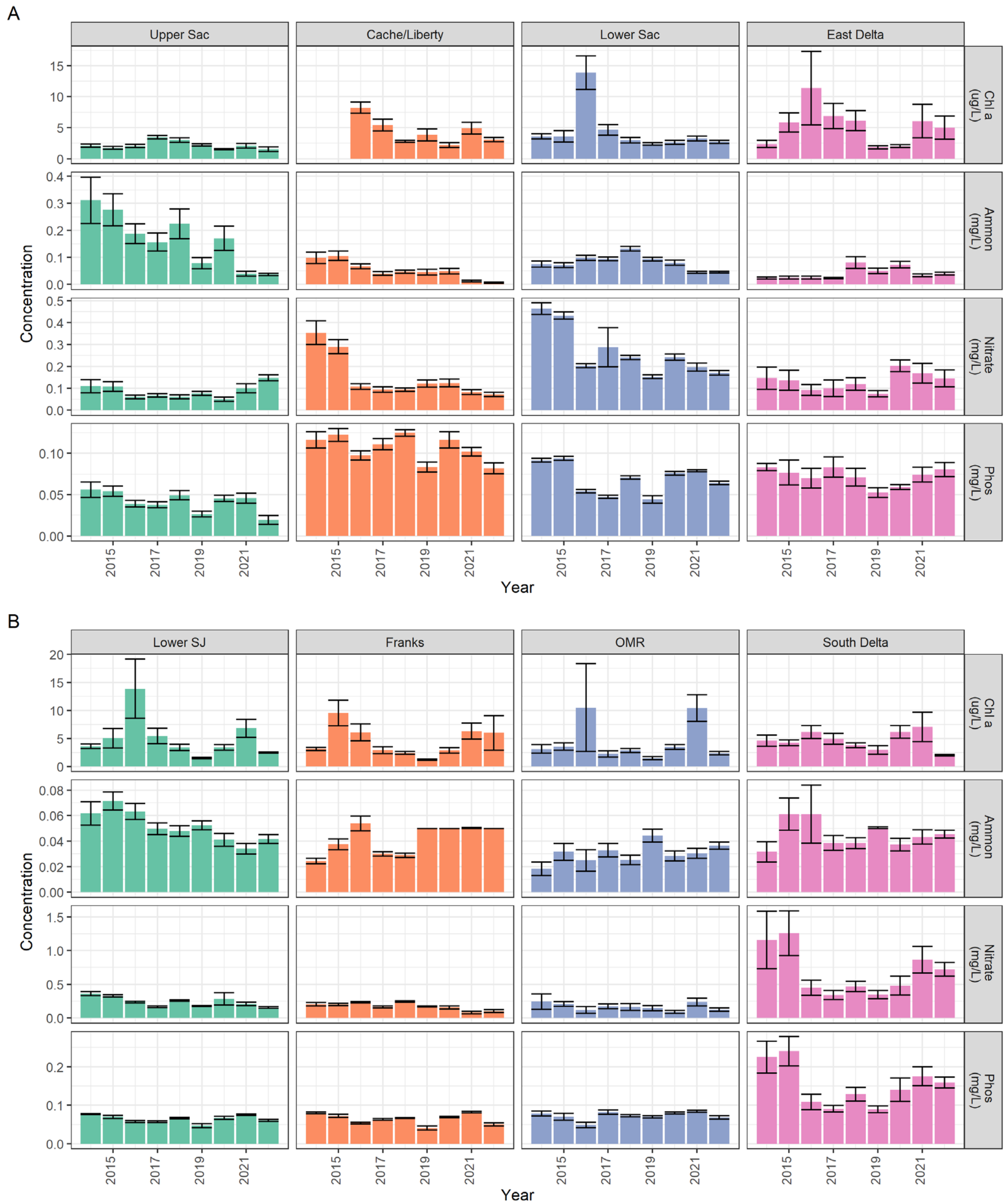

Figure 12. Mean monthly chlorophyll a and nutrient concentrations by region from 2014 – 2022, calculated from monthly, discrete water samples for February through September (September data for 2022 will be added in the final draft). Panel A shows data for the North Delta and Lower Sacramento River regions and panel B shows data for the Central and South Delta Regions.

- In 2022, chlorophyll a concentrations were similar and in some regions notably lower compared to 2021 and 2016, which both had relatively high chlorophyll a concentrations.

- In 2022, ammonium concentrations were consistently and noticeably lower in the North Delta and Lower Sacramento River similar to 2021. This is likely due to improvements to the Sacramento Regional Wastewater Treatment Plant in 2021.

- In 2022, nitrate and orthophosphate concentrations were slightly higher in the East and South Delta regions, but similar to previous years' concentrations in the other regions.

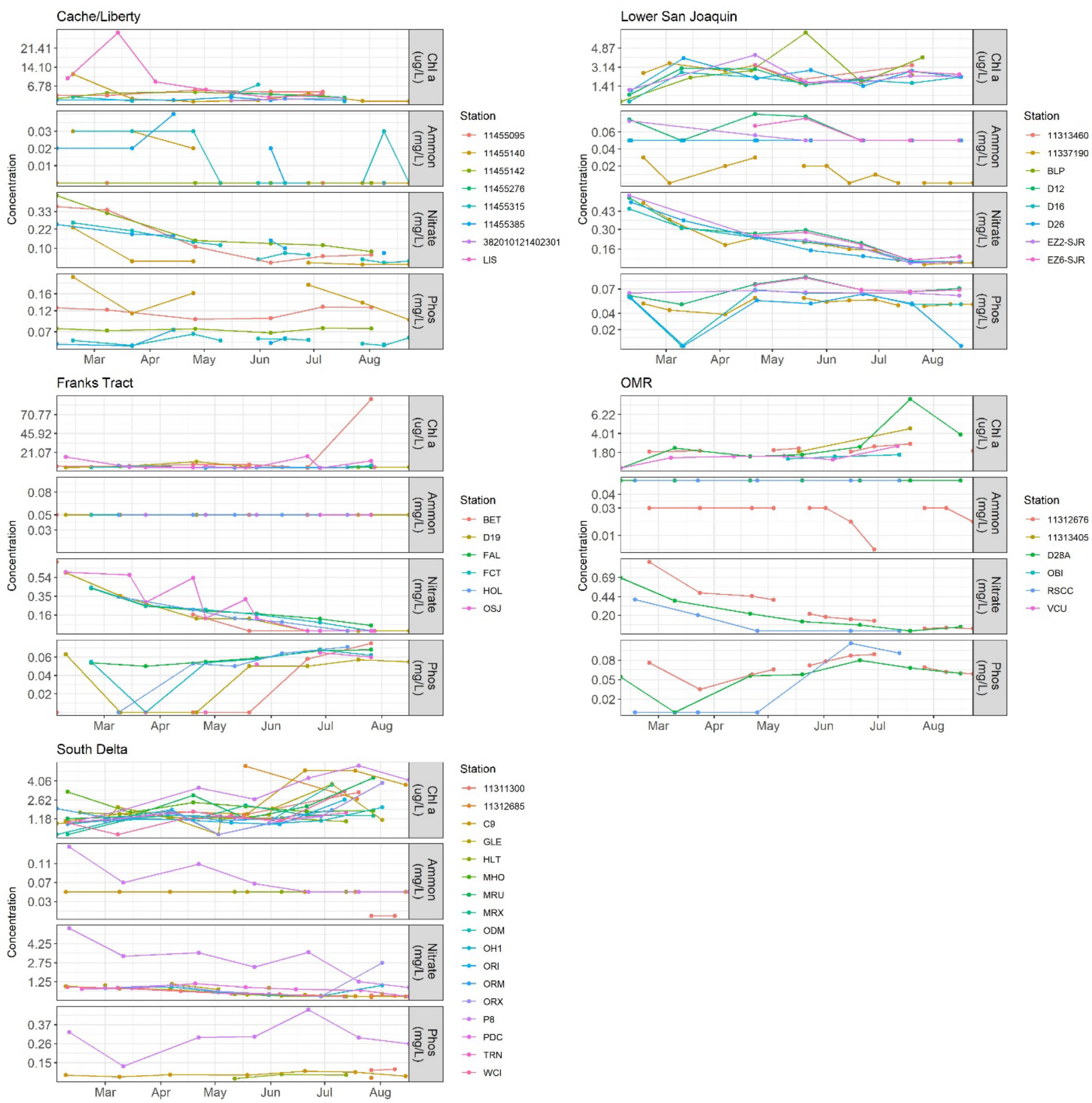

Figure 13. Monthly discrete chlorophyll a (Chl a) and nutrient concentrations from January-August, 2022. Values in the Cache Slough/Liberty Island region are less likely to be impacted by the Temporary Urgency Change Petition (TUCO), compared to regions in the South and Central Delta, which are more likely to be affected by the TUCO, and in some cases the Emergency Drought Barrier. The minimum detection limit for chlorophyll a is 0.5 µg/L, for ammonium and orthophosphate is 0.05 mg/L, and for nitrate/nitrite is 0.04 mg/L. See Appendix, Table A-2 for a list of sample stations for each region.

- High levels of chlorophyll a in the Cache Slough/Liberty Island region were observed by NCRO at the Lisbon site before the TUCO period began, followed by a decrease over time. In the South and Central Delta, chlorophyll a generally increased over time with most blooms occurring during summer. In Franks Tract, chlorophyll a was higher and fairly consistent over time, except for a noticeably high reading at Bethel Island (BET; on the northwest side of Franks Tract in August.
- Nitrate decreased over time across all sites, as would be expected based on seasonal patterns due to biological uptake; ammonium was often at or below the minimum detection limits, obscuring the detection of any trends over time. No pattern was observed related to the 2022 TUCO.

Cyanobacteria

Visual assessments.

Hypotheses:

- At the annual scale, visual assessments of *Microcystis* might increase in frequency and intensity due to the effects of the TUCO on water residence time in some regions.
- At the regional scale, visual assessments of *Microcystis* would be higher in frequency and intensity in regions most impacted by the TUCO, particularly during June through August.

Comparison: annual and regional comparisons; drought years with and without a TUCO.

- TUCO years: 2014, 2015, 2021
- Non-TUCO years: 2013, 2016, 2018, 2020
- Regions with increased water residence times: Lower Sacramento River, Lower San Joaquin River, OMR, Franks Tract

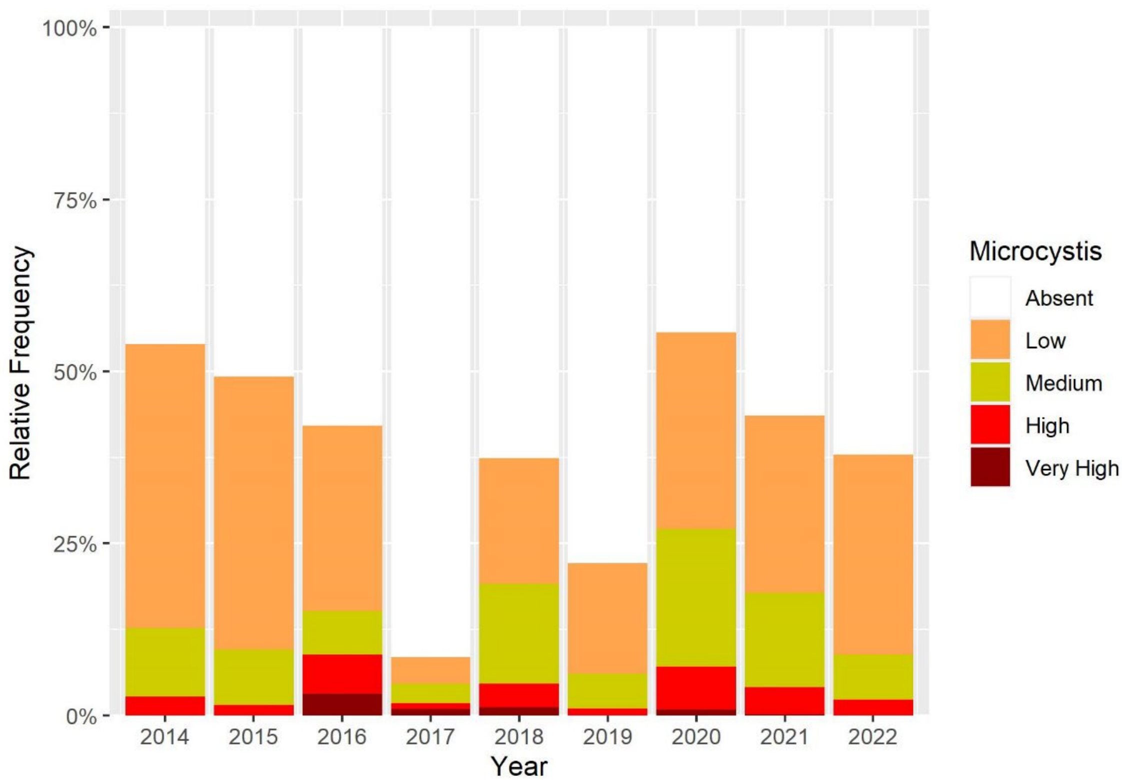

Figure 14. The relative frequency of *Microcystis* observations by year, from 2014 – 2022, across full spatial range of observations (Figure 7).

- In 2022, *Microcystis* observations occurred at relatively lower frequency than in nearly all other drought years (2014, 2015, 2016, 2020, 2021); intensities (i.e., ranking levels) were comparable or lower than all other drought years.

- Very high levels of *Microcystis* were not observed during TUCO drought years but were observed during non-TUCO drought/drier years (2016, 2018, 2020).

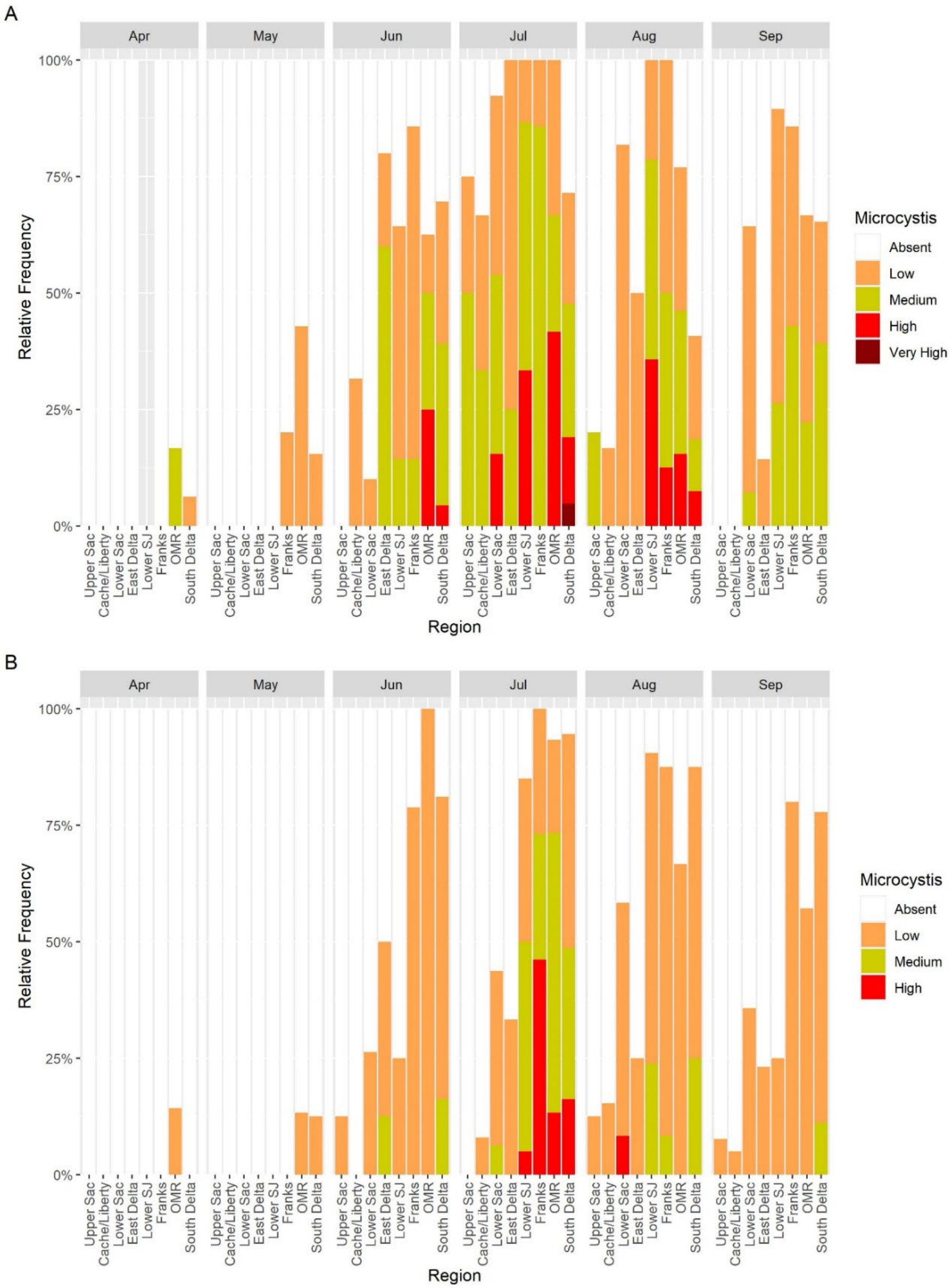

Figure 15. The relative frequency of *Microcystis* observations by month from April – September of 2021 (A) and 2022 (B).

- In 2022, the relative frequencies and rankings were lower throughout the Delta compared to 2021, with the exception of Franks Tract in July (to be statistically tested in final report).
- In 2022, *Microcystis* observations occurred more frequently and were ranked higher in the Lower Sacramento River, Lower San Joaquin River, and the South Delta, OMR, and Franks Tract, with July having the highest frequency of occurrence, which is similar to 2021.

HABs incident reports.
Hypotheses:

- Cyanobacterial blooms and toxin incidents in 2022 might increase in total number or frequency, duration, and intensity throughout the season due to the TUCO and EDB.
- Across regions in 2022, reported incidents of cyanobacterial blooms in regions with increased water residence times might increase in total number or frequency, duration, and intensity throughout the season in response to the TUCO and the EDB.

Comparisons: annual, monthly, and regional; drought years with and without a TUCO.

- TUCO years: 2014, 2015, 2021
- Non-TUCO years: 2013, 2016, 2018, 2020
- Regions with increased water residence times (Lower Sacramento River, Lower Sacramento River, Lower San Joaquin River, OMR, and Franks Tract) compared with regions without increased water residence times (Cache/Liberty, East Delta)

Note: data were not available for all years for every data source.

Note: community composition of cyanobacteria is shown; however, the TUCO and EDB were not expected to affect community composition.

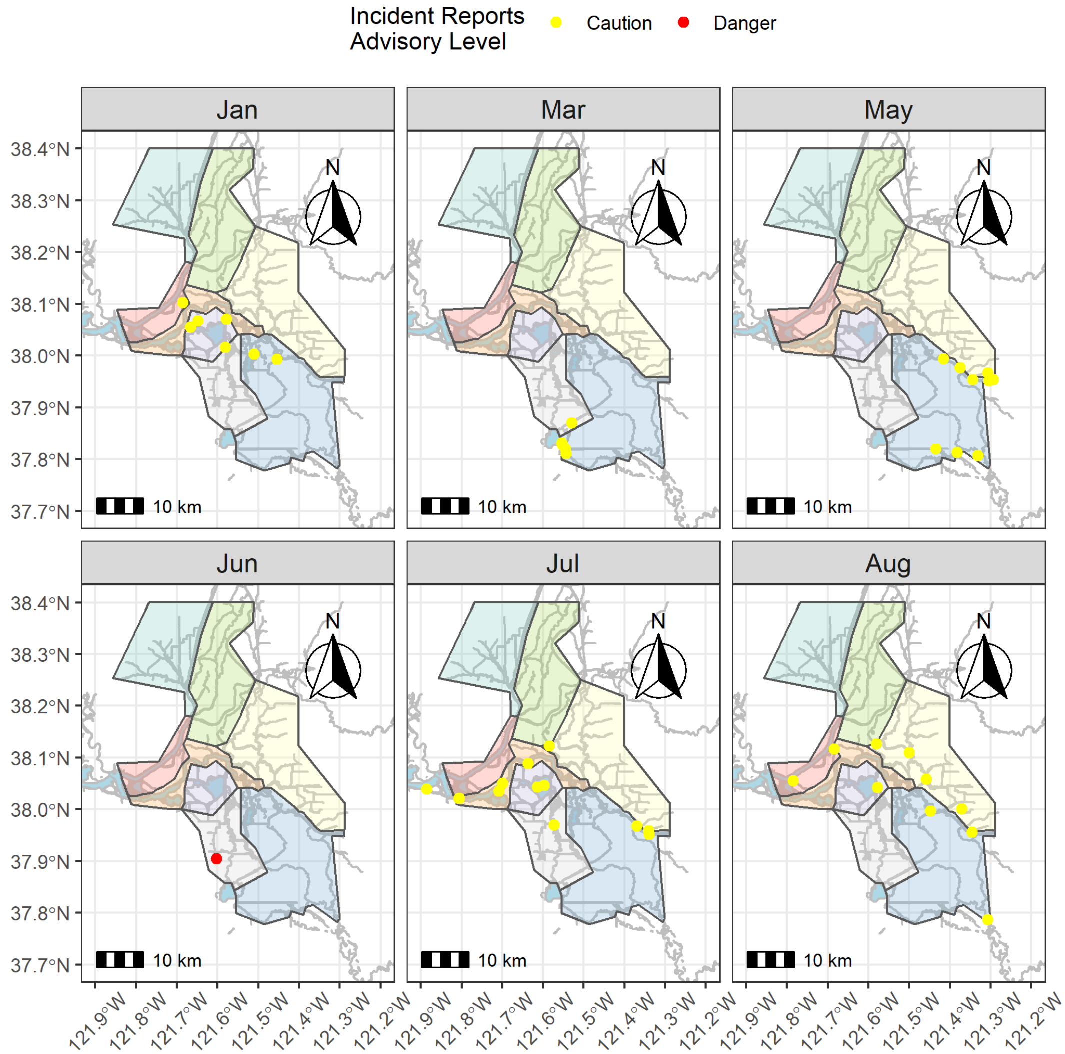

Figure 16. Cyanobacteria incidents from 2022, as reported from State Water Board's HAB Portal. Colors indicate different advisory levels. Data were downloaded through October 2022.

- One "Danger" advisory was posted in Discovery Bay in June. No "Warning" advisories were posted.

- Incidents were reported in most months, with greater numbers of incidents in June and July.

- Incidents were distributed throughout the Lower Sacramento, Lower San Joaquin, Franks, OMR, South Delta and East Delta regions. No incidents were reported in Cache/Liberty or the Upper Sacramento River.

- Incident reports do not always reflect the highest toxicity reached at a particular location since not all programs test for toxicity. "Caution" advisories can be based on visual cues (e.g., discoloration, algal mats, paint-like appearance) or lab testing, while “Warning” and “Danger” advisories both require lab testing.

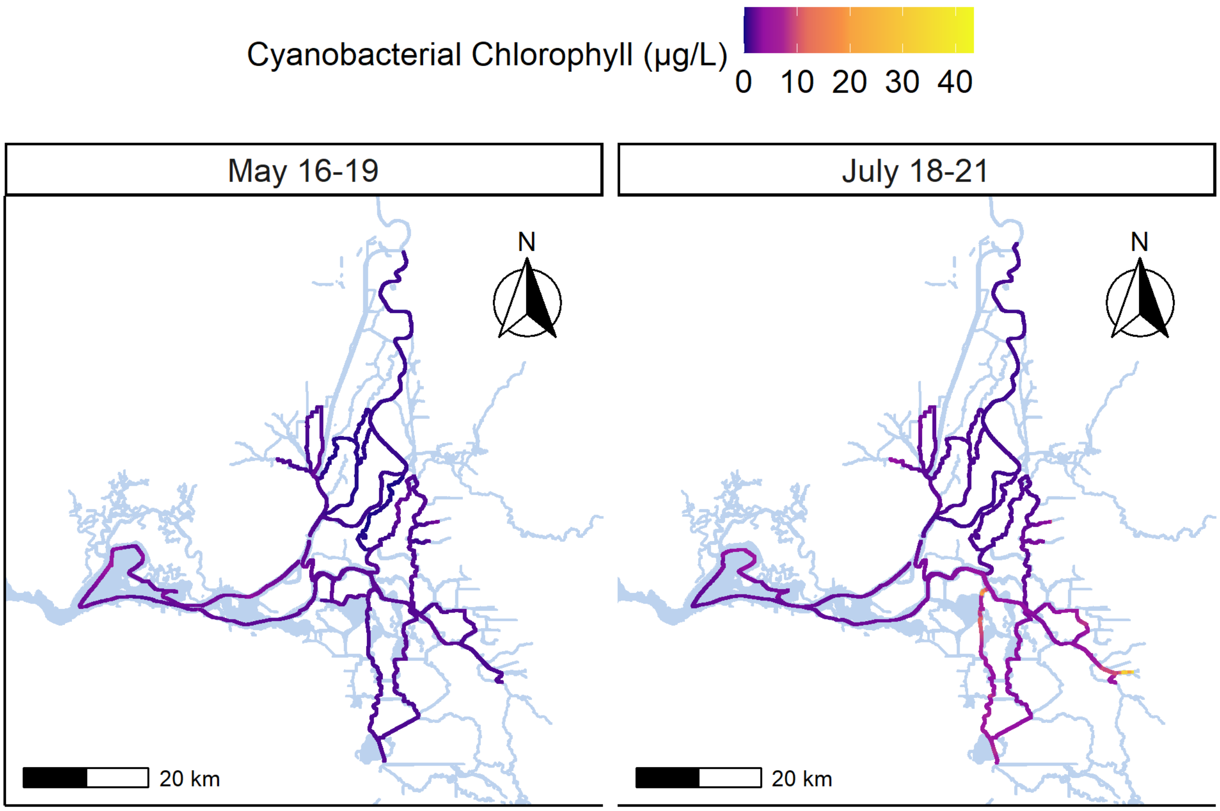

Figure 17. Monthly Cyanobacterial Chlorophyll Maps (May-July 2022) in the San Francisco Estuary. Data collected on rapid water quality cruises by the United States Geological Survey (USGS). Measurements collected using a Fluoroprobe.

- Maximum cyanobacterial chlorophyll was much higher after the TUCO period in July than in May (July maximum of 43.4µg/L compared with May maximum of 5.14µg/L).
- The bloom in July was seen in Franks Tract, Old and Middle Rivers, San Joaquin River towards Stockton.

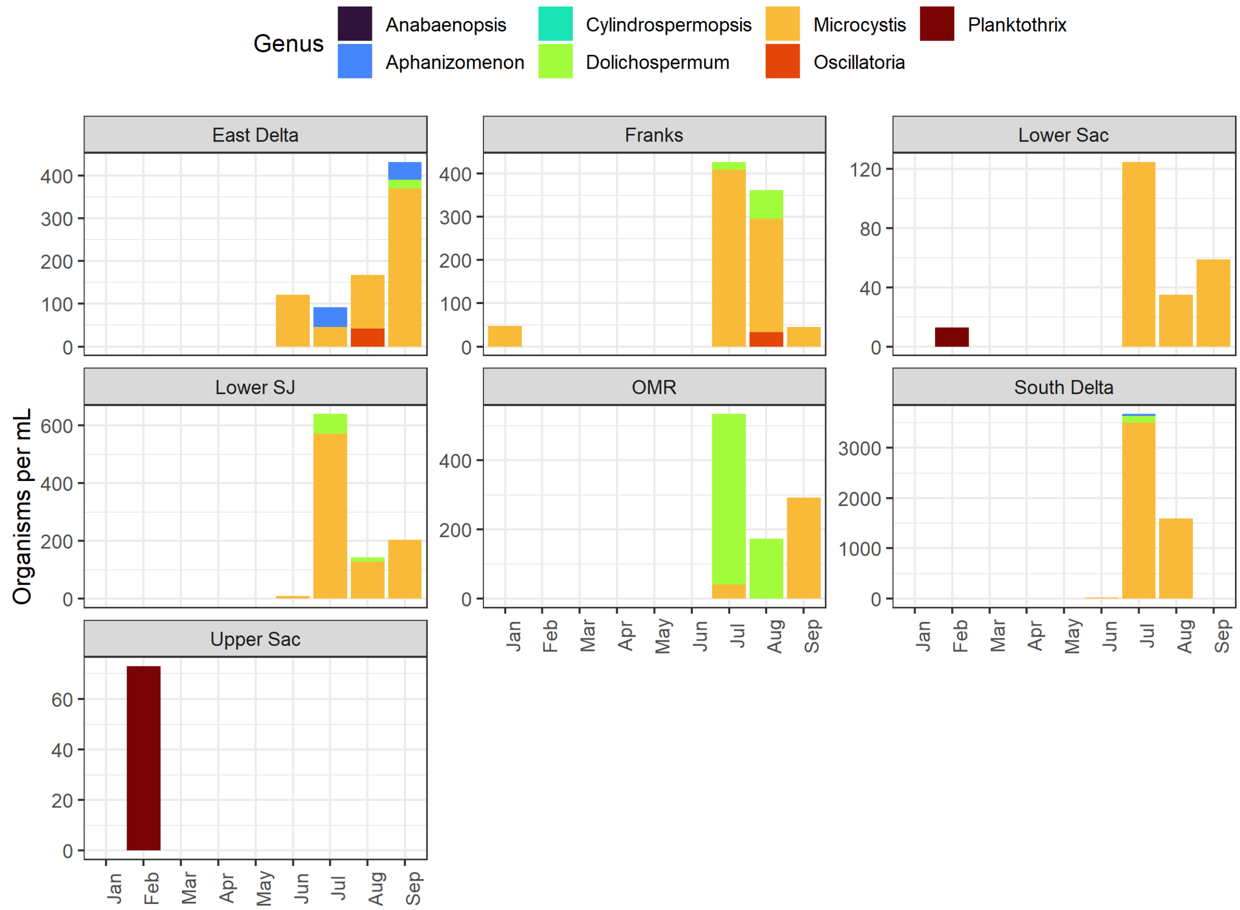

Figure 18. Cyanobacteria taxonomic composition from EMP samples collected monthly in different regions of the Delta during 2022. Note that the y-axis scales vary across regional plots.

- *Microcystis* was not present in Franks, OMR, and Lower Sac regions during the TUCO period, where influence of TUCO was expected. However, it was present in samples collected throughout the Delta during summer months, except in the Upper Sacramento River region.

- When present, *Microcystis* dominated the samples numerically except in the OMR region during July and August when *Dolichospermum* comprised the majority of the samples, and in the Upper and Lower Sac regions in February, when the only cyanobacteria collected was *Planktothrix*.

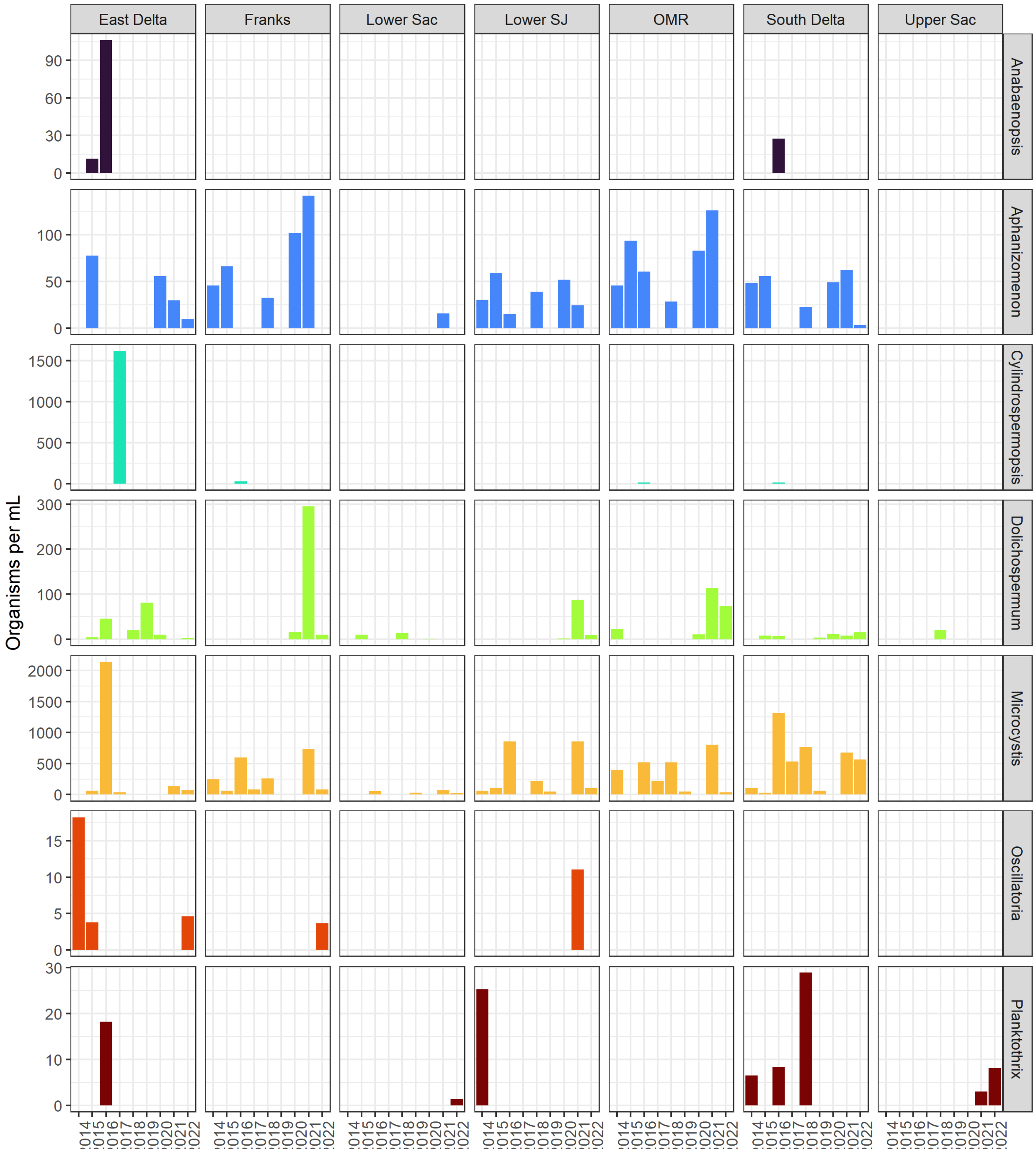

Figure 19. Cyanobacteria taxonomic composition from EMP samples collected monthly in different regions between 2014-2022. Abundances are averages of data from January-October, except for 2022, which goes through September.

- In 2022, cyanobacteria abundance was lower or similar to previous years. This was especially noticeable in Franks Tract.

- While *Microcystis* was present in most regions, abundances were generally lower across regions in 2022 compared with previous years. An exception was in the South Delta, where abundances were similar to those of 2021.

- *Planktothrix* was higher in abundance in the Upper Sac region (according to Figure 16, this occurred in February, outside of the typical HAB season).

Cyanotoxins

Toxin concentrations and toxicity-based advisories.

Hypotheses:

- Cyanotoxin incidents in 2022 may increase in number and concentration as a function of more frequent and intense cyanobacterial blooms

- Across regions in 2022, cyanotoxin concentrations will be higher in regions with increased water residence times may increase in total number or frequency, duration, and intensity throughout the season in response to the TUCO and the EDB.

Comparisons: annual, monthly, and regional; not enough historical data for drought comparisons

- Regions with increased water residence times (Lower Sacramento River, Lower Sacramento River, Lower San Joaquin River, OMR, and Franks Tract) compared with regions without increased water residence times (Cache/Liberty, East Delta, Upper Sacramento)

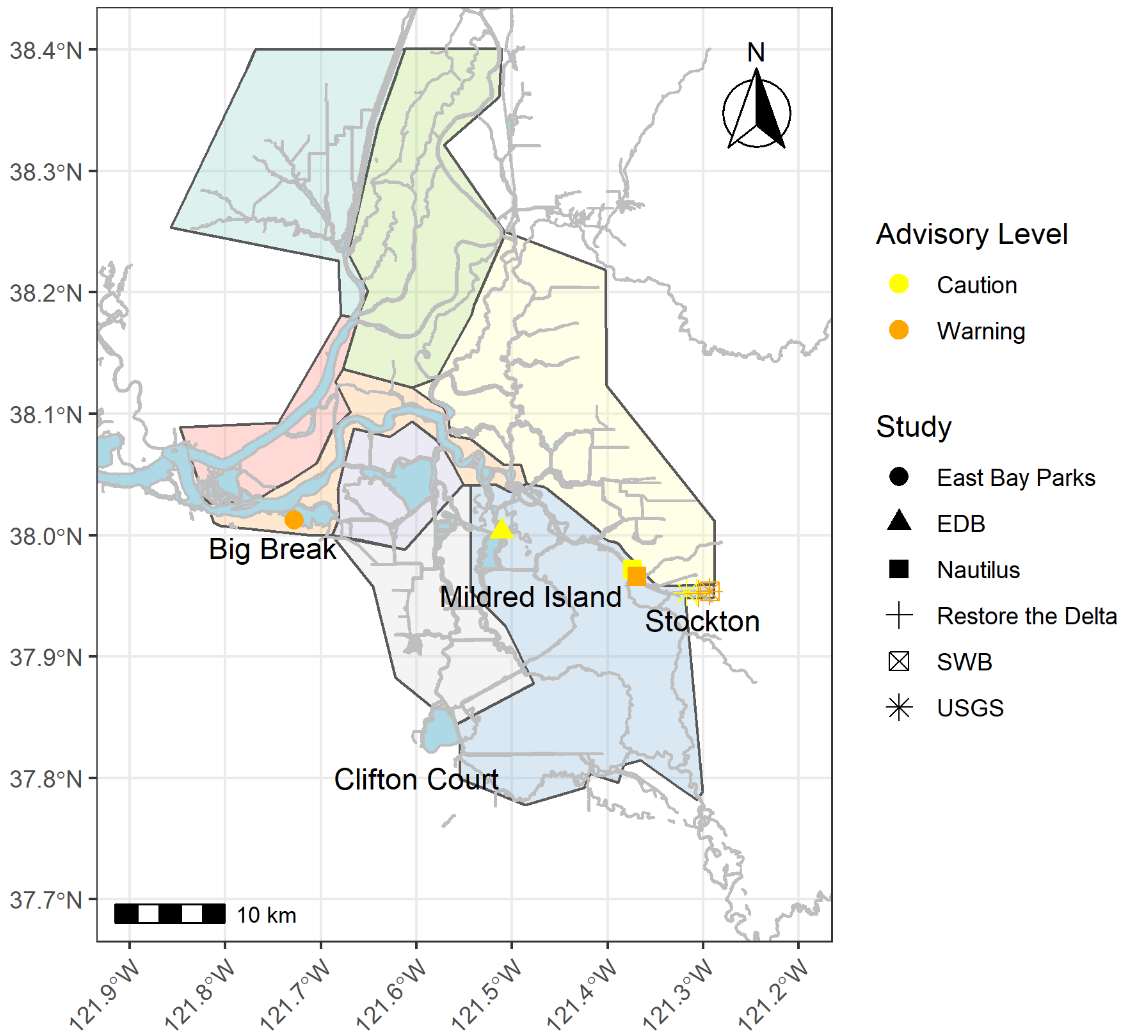

Figure 20. Map of Advisory Levels Derived from Cyanotoxin Data Sets. Dataset filters down to data that reached advisory levels, which included only Microcystins/Nodularins. Data from January – August 2022.

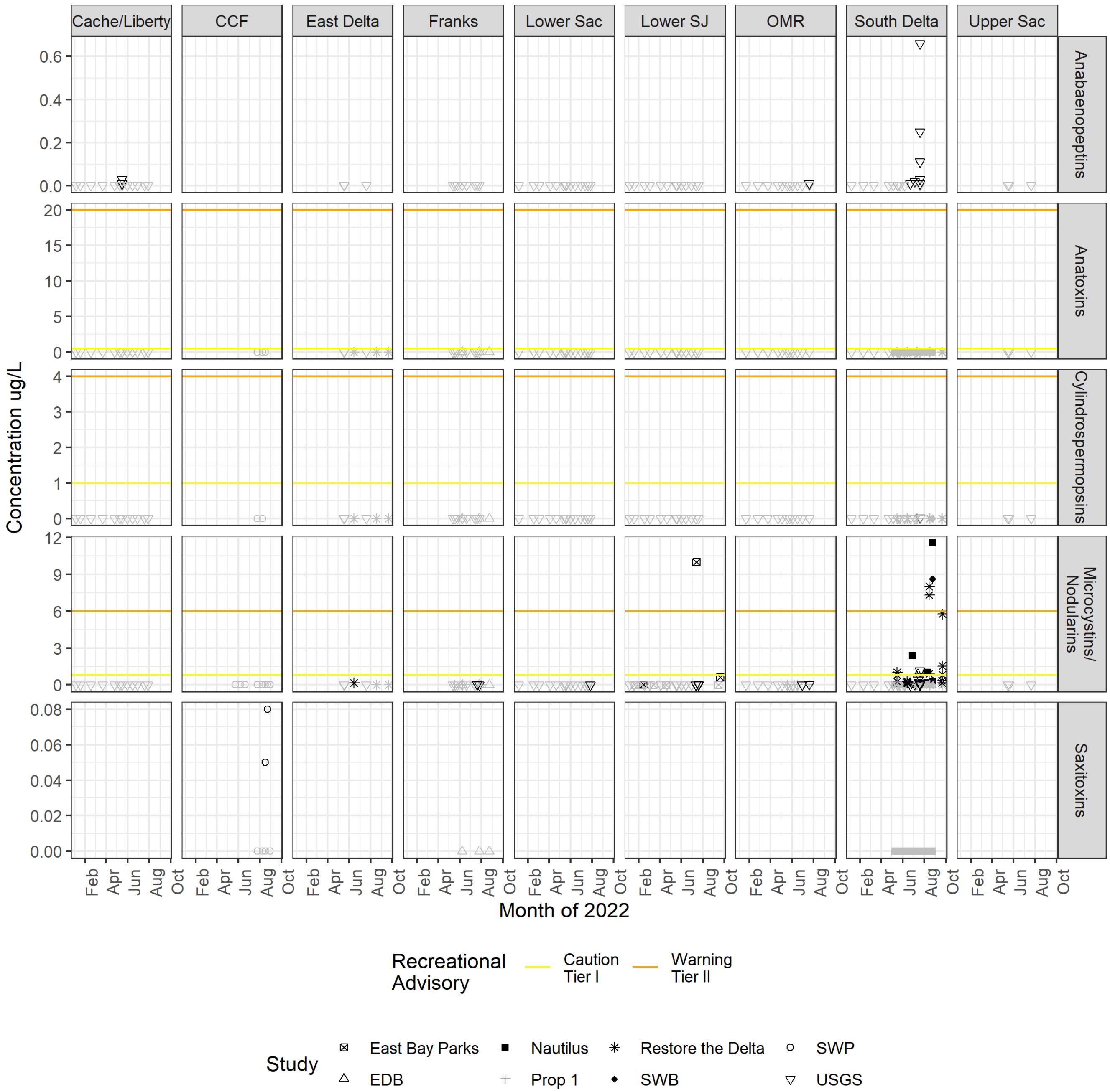

Figure 21. Results of Delta-wide Cyanotoxin Sampling by Region. Horizontal lines indicate advisory levels based on OEHHA 2022 (Caution = 0.8 µg/L, yellow; Warning = 6 µg/L, orange). Shapes indicate program that sampled cyanotoxins. Gray symbols indicate values below the detection limit, while black symbols indicate values where toxins were detected.

- In most regions, cyanotoxins were not present during the TUCO period of April and May.
- Very few samples had cyanotoxin concentrations greater than recreational advisories, and none reached danger levels. Most samples were non-detects, which are represented by 0.

- In 2022, most cyanotoxin detections occurred in the South Delta region and primarily comprised microcystins/nodularins and anabaenopeptins.

- A few instances of microcystins above the “warning” level were detected in July-September in the Lower San Joaquin and South Delta regions.

- Anabaenopeptins were also detected at low levels in the Cache Slough / Liberty Island and OMR regions.

- Saxitoxins were detected outside of Clifton Court Forebay in Dyer Reservoir in 2022.

- Anatoxins were not detected in 2022.

2022 South and Central Delta conditions

Water quality

Hypotheses:

- Salinity in Franks Tract and OMR will decrease after EDB notch is repaired, salinity in Mildred Island/Middle River will stay the same after EDB.
- Higher chlorophyll a concentrations in areas with longer water residence times.

Comparisons: location; time series, across drought years with and without an EDB; before, during, and after the TUCO and before and during the EDB.

- Locations: Franks Tract (FRK), Mildred Island (MDM, HLT), Old River at Franks Tract (OSJ), Holland Cut near Bethel Island (HOL), False River (FAL), Dutch Slough (DSJ)
- Years: drought years with an EDB (2015, 2020, 2021), drought years without an EDB (2016, 2020)

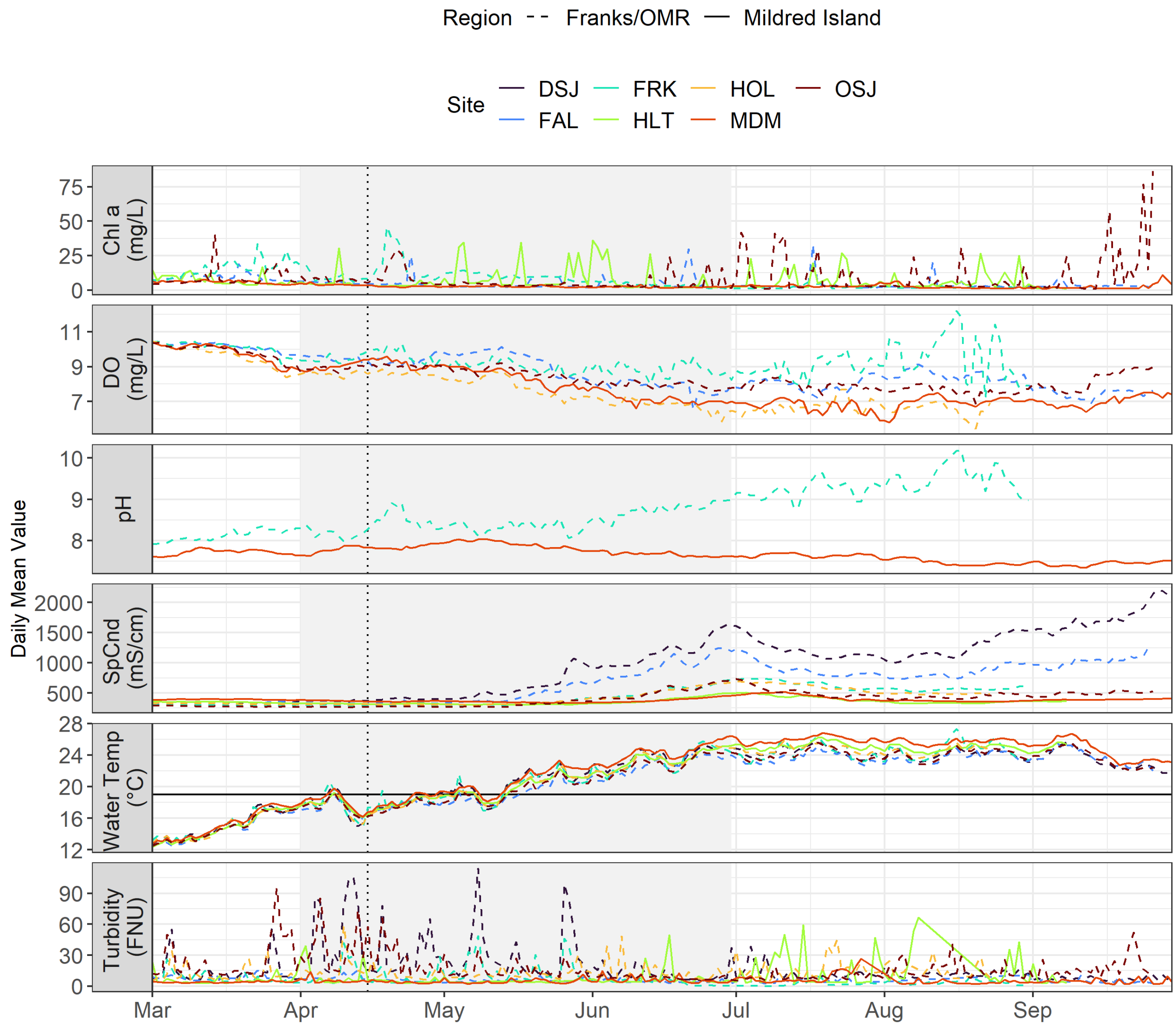

Figure 22. Continuous Water Quality from Mildred Island (MDM, HLT) and Franks Tract/OMR (FAL, FRK, HOL, OSJ, ORQ, DSJ) in 2022. Daily maximum is calculated for chlorophyll a, water temperature and turbidity, daily minimum is calculated for dissolved oxygen, and daily mean is calculated for flow, pH, and specific conductance. Not all stations have data for all parameters. Gray shaded box indicates period when TUCO was active and dotted lines indicate EDB start date (end date was in November, after the end of this plot).

- Chlorophyll a spikes were observed in OSJ and HLT throughout the year.
- DO and pH increased at the center of Franks Tract (FRK) starting in June, indicating greater photosynthetic rates from vegetation or possibly cyanobacteria. Meanwhile, DO and pH stayed relatively constant or decreased slightly starting in June.

- Specific conductance at Dutch Slough (DSJ) increased after the notch in the EDB was repaired (not protected from EDB), while specific conductance in the rest of Franks tract, the OMR corridor and at Mildred's Island remained low.
- At stations in Franks Tract and Mildred Island, the first date that temperatures began reaching 19°C consistently was May 13-May 17, and these conditions lasted through September.
- Turbidity in Franks Tract (FRK) was low from June-September, and thus suitable for cyanobacteria development.

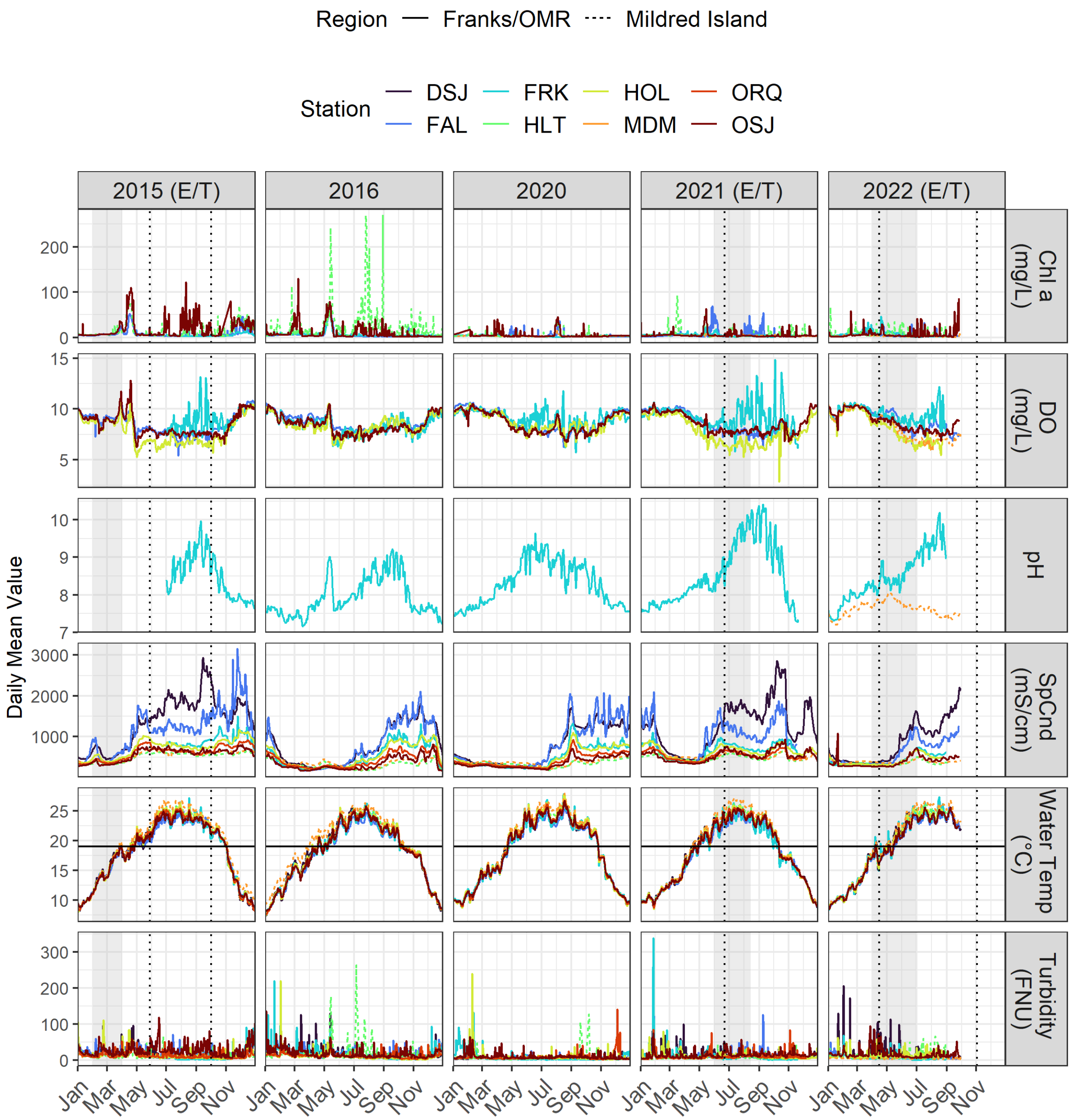

Figure 23. Comparison of Water Quality in Mildred Island(HLT, MDM) with Franks Tract and OMR Regions (FAL, FRK, HLT, HOL, MDM, ORQ, OSJ) Across Drought Years. Daily maximum is calculated for chlorophyll a, water temperature and turbidity, daily minimum is calculated for dissolved oxygen, and daily mean is calculated for pH, and specific conductance. Not all stations have data for all parameters. Data for 2022 are only displayed through October. E indicates year was an EDB year, T indicates year was a TUCO year. Gray shaded box indicates period when TUCO was active and dotted lines indicate EDB period.

- Chlorophyll a data show more and larger phytoplankton blooms occurred in 2015 compared to 2020-2022 in April. There were also large blooms in 2016 at HLT in Mildred's Island.
- Dissolved oxygen and pH spiked in the summer across all years, and had higher values during EDB/TUCO years. This could be due to higher photosynthetic rates from vegetation or cyanobacteria due to the EDB.
- Specific conductance was higher in EDB/TUCO years at Dutch Slough (DSJ), and lower in EDB/TUCO years at False River (FAL). This is likely due to the effects of the EDB, which reduces the saline water at FAL.
- Water temperature was similar across stations. Temperatures above 19°C are reached starting late April-May across years.

Cyanobacteria

Satellite Data

Hypotheses:

- Cyanobacterial blooms in areas with longer water residence times or reduced velocities may increase in total number or frequency, duration, and intensity throughout the season.

Comparisons: locations expected to be similar in salinity and water residence time to Franks Tract; drought and non-drought years with and without an EDB

- Locations: Franks Tract, Mildred Island, Clifton Court Forebay, and Liberty Island
- Years: 2019 (non-drought), 2020, 2021

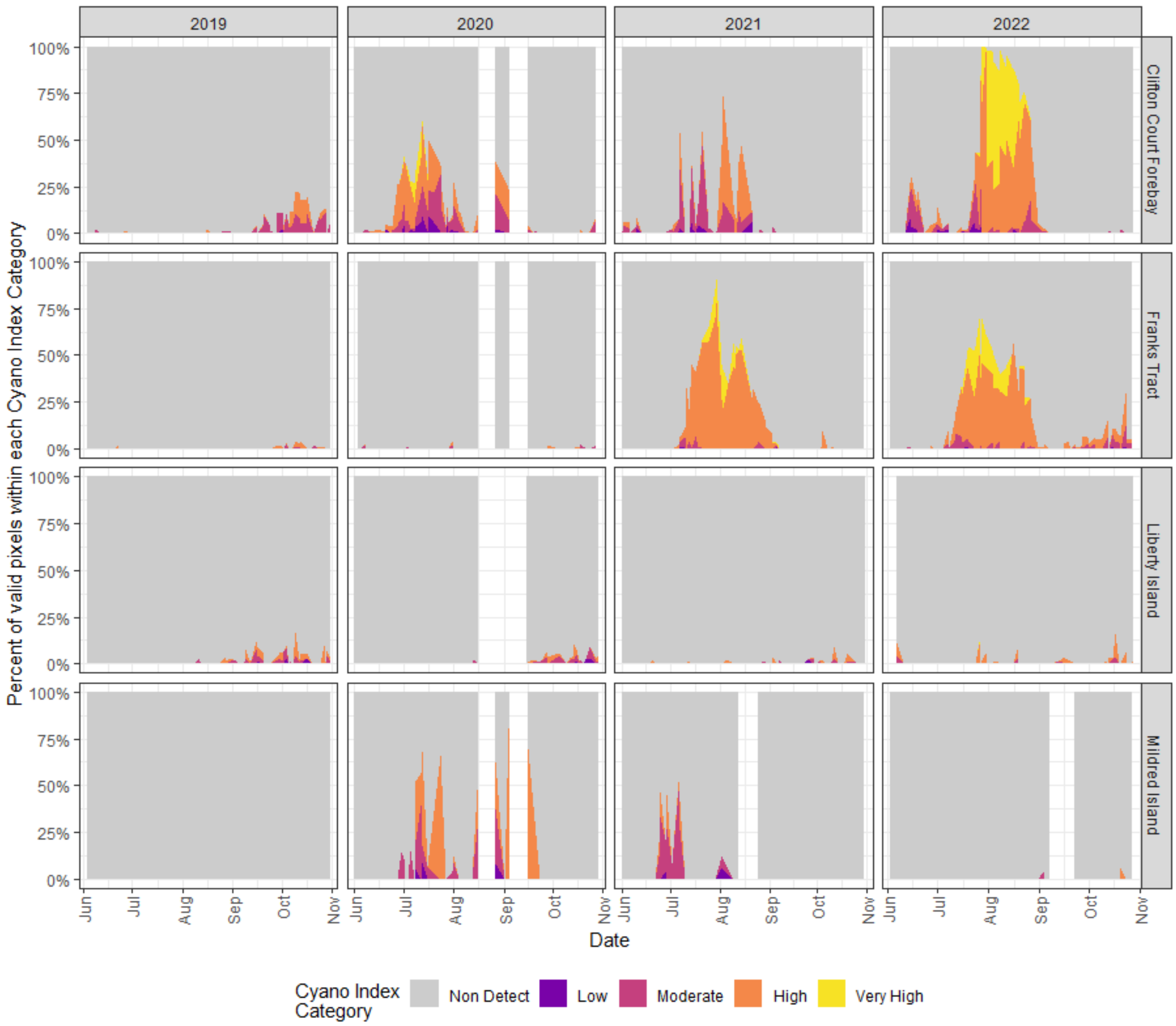

Figure 24. Percent of valid pixels within each cyanobacteria index category at four locations in the South Delta in each year from 2019-2022.

- The occurrence of cyanobacteria in 2020-2022, all Critically Dry water years, was greater than in 2019.
- Cyanobacteria blooms in Franks Tract and Clifton Court Forebay were larger ("high" and "very high" index values) and extended for a longer amount of time during the summer and early fall in 2021 and 2022 compared to other years and other locations. This is likely due to longer water residence times in these two locations.
- There were no blooms detected in Liberty Island or Mildred Island.
- The absence of cyanobacterial blooms in Franks Tract in 2019 and 2020 suggests that the effect of the EDB on water residence time could be contributing to bloom formation and persistence.

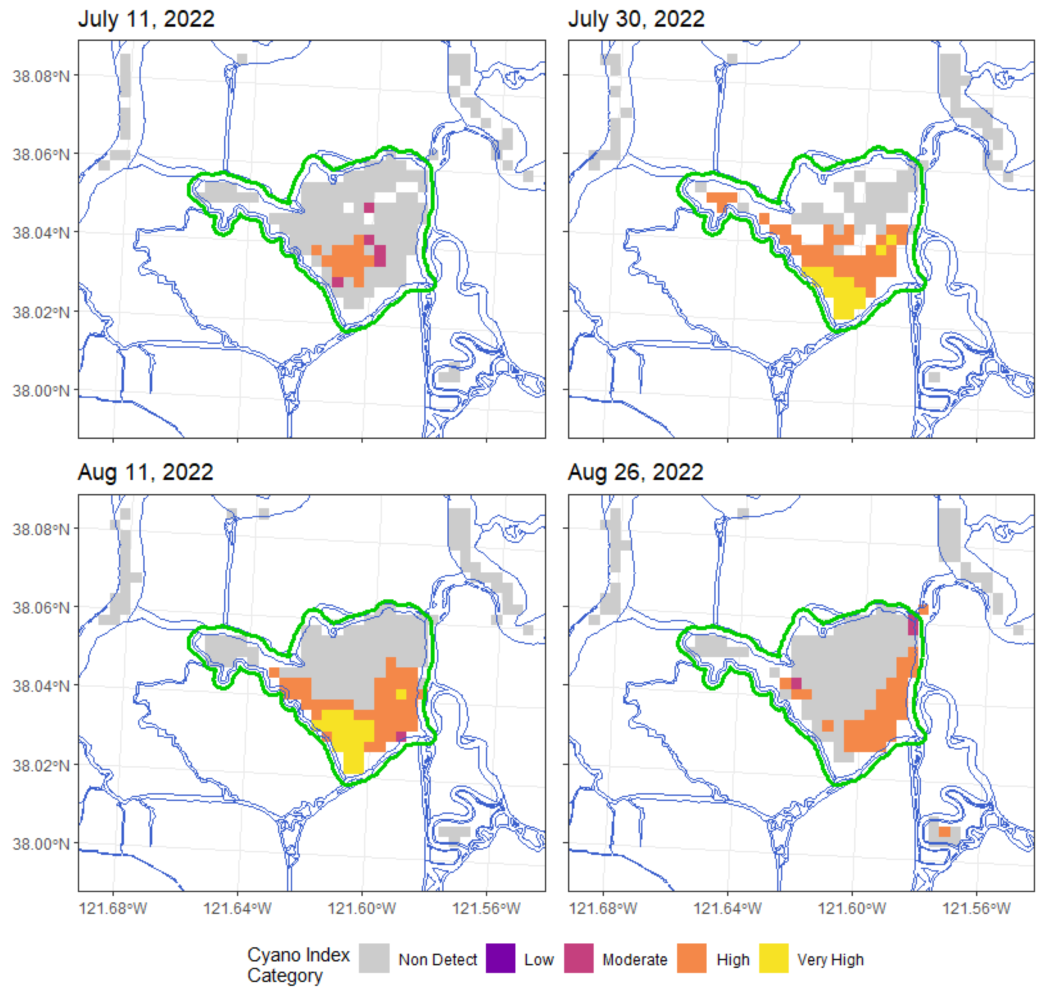

Figure 25. Maps of cyanobacteria index values in Franks Tract at the beginning (July 11), middle (July 30, August 11), and toward the end (August 26) of the 2022 bloom.

- During 2022, the July-August bloom in Franks Tract overlapped partially with areas where water age was hypothesized to be greater as a result of the Emergency Drought Barrier but was more centrally located within the southern half.

- During 2022, high levels of cyanobacteria, indicated by similar intensities (i.e., index values), occurred during the middle (late July and early August) of the blooms in Franks Tract and Clifton Court Forebay. Whereas the 2022 bloom in Franks Tract was similar to that in 2021; the 2022 bloom in Clifton Court Forebay was more intense and of longer duration than 2021. In contrast, both Mildred and Liberty islands had multiple short, low intensity blooms in 2022, with Mildred Island experience fewer than it did in 2021.

- Based on screening data for toxicity testing, the community composition of phytoplankton in both the blooms in Franks Tract was dominated by *Dolichospermum*, rather than *Microcystis*. Furthermore, cyanotoxin collections during these blooms were all below the method detection limit (see Cyanotoxins section).

<u>Boat-deployed FluoroProbe data</u>

Hypothesis:

- Cyanobacterial blooms in areas with longer water residence times or reduced velocities may increase in total number or frequency, duration, and intensity throughout the season.

Comparisons: boat transects in the Lower San Joaquin, Franks Tract, OMR, and South Delta regions on select dates during March through August

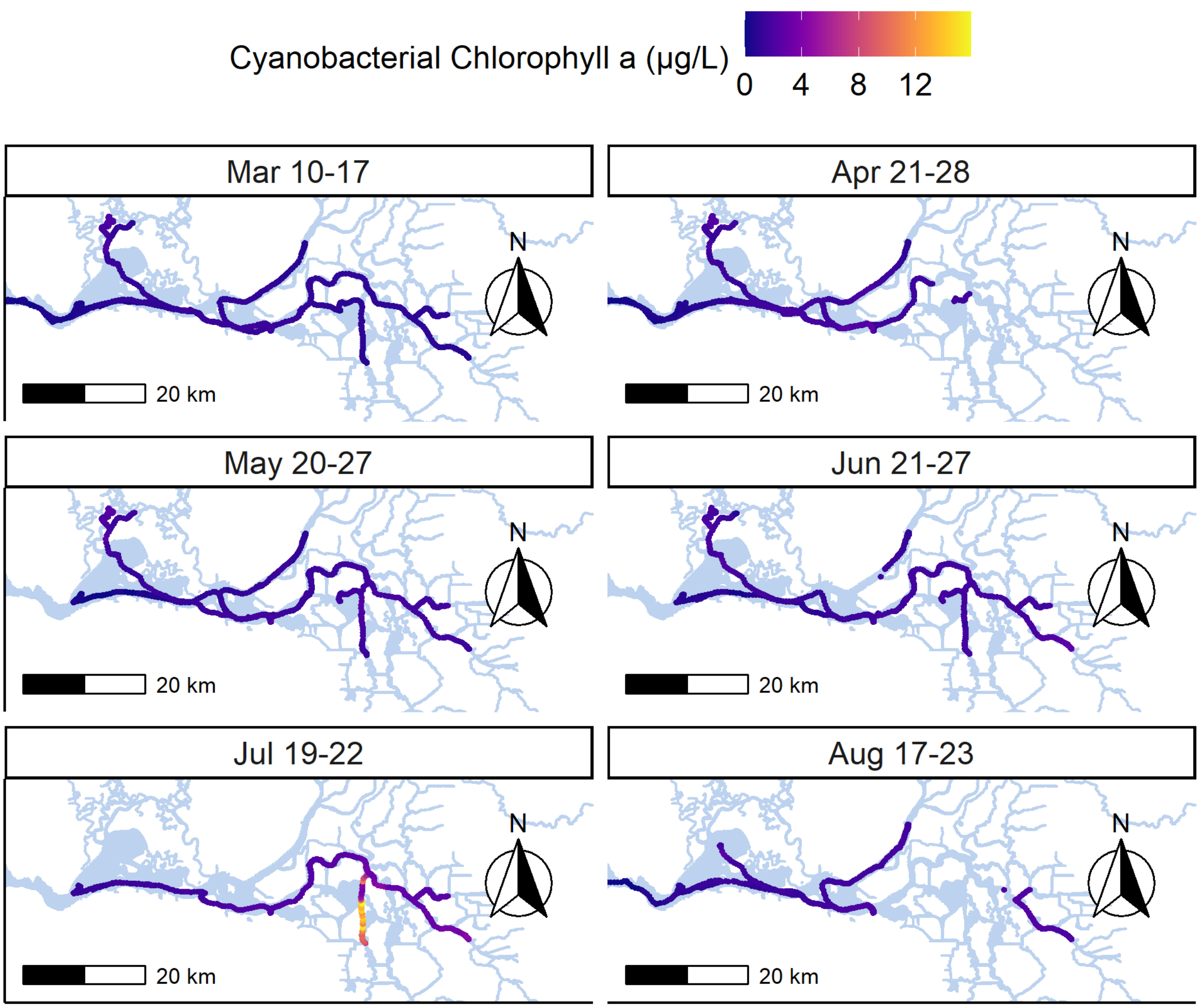

Figure 2-26. Monthly Cyanobacterial Chlorophyll Maps (March-August 2022) in the San Francisco Estuary. Data collected on monthly water quality cruises by the Environmental

Monitoring Program (EMP). Measurements collected using a Fluoroprobe. Missing data are due to sensor or sampling malfunctions.

- For the most part, there were low values of cyanobacterial chlorophyll a (less than 5µg/L).
- Higher cyanobacteria abundances were observed in mid-July near Franks Tract and Old River.
- Values returned to <5 µg/L in August, but sampling did not occur around Franks Tract and Old River.

Epiphytic versus planktonic cyanobacteria taxonomic composition

Hypothesis:

- Taxonomic composition of epiphytic cyanobacteria was expected to differ from that of planktonic cyanobacteria.

Comparisons: sample stations within Franks Tract during 2022 only; D19 is an EMP site that collects planktonic samples, whereas benthic samples were collected at the other sites.

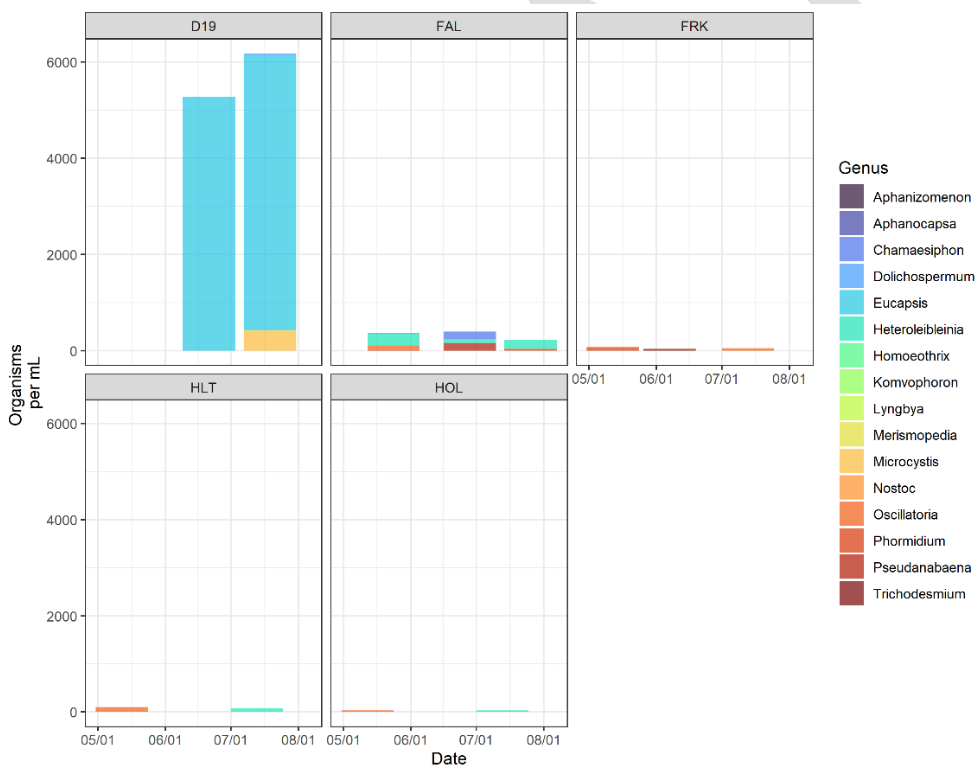

Figure 27. A comparison of cyanobacteria taxonomic composition (organisms per mL) in epiphytic algal samples collected at EMP sites in Franks Tract (FAL, FRK, HLT, HOL) and in plankton algal samples collected at EMP site D19.

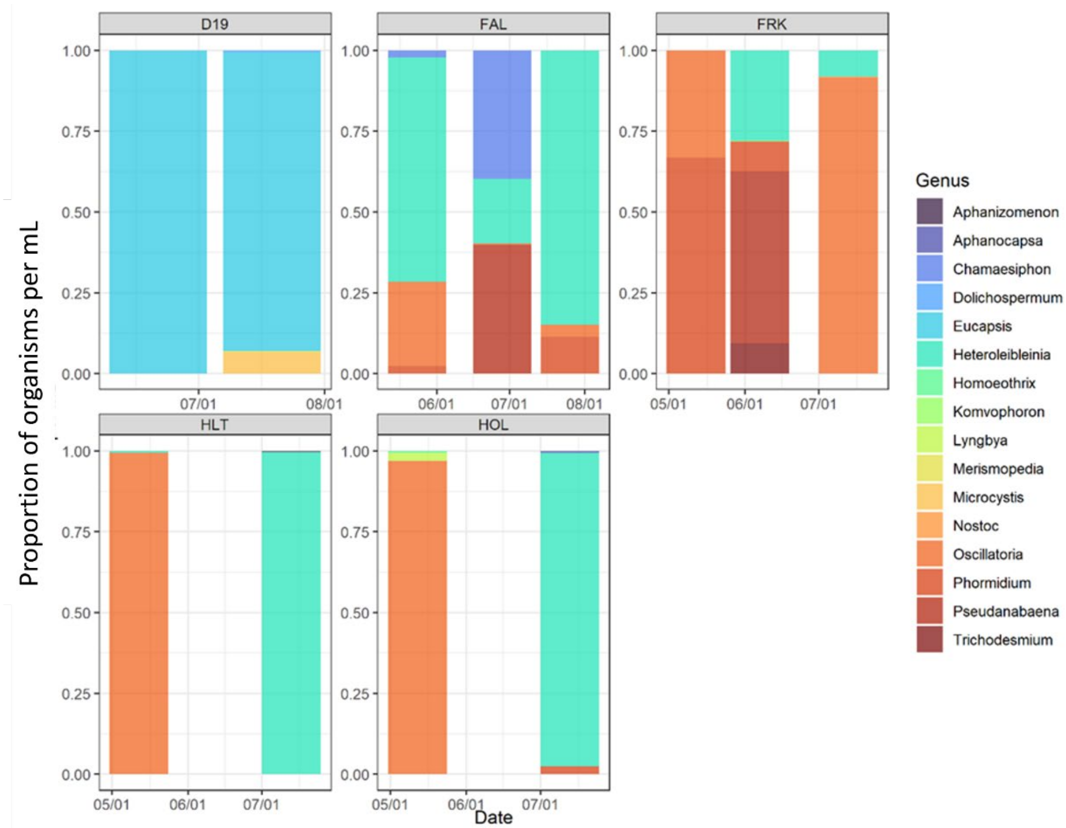

Figure 28. Proportion of cyanobacteria (organisms per mL) in epiphytic algal samples collected at EMP sites in Franks Tract (FAL, FRK, HLT, HOL) and in plankton algal samples collected at EMP site D19.

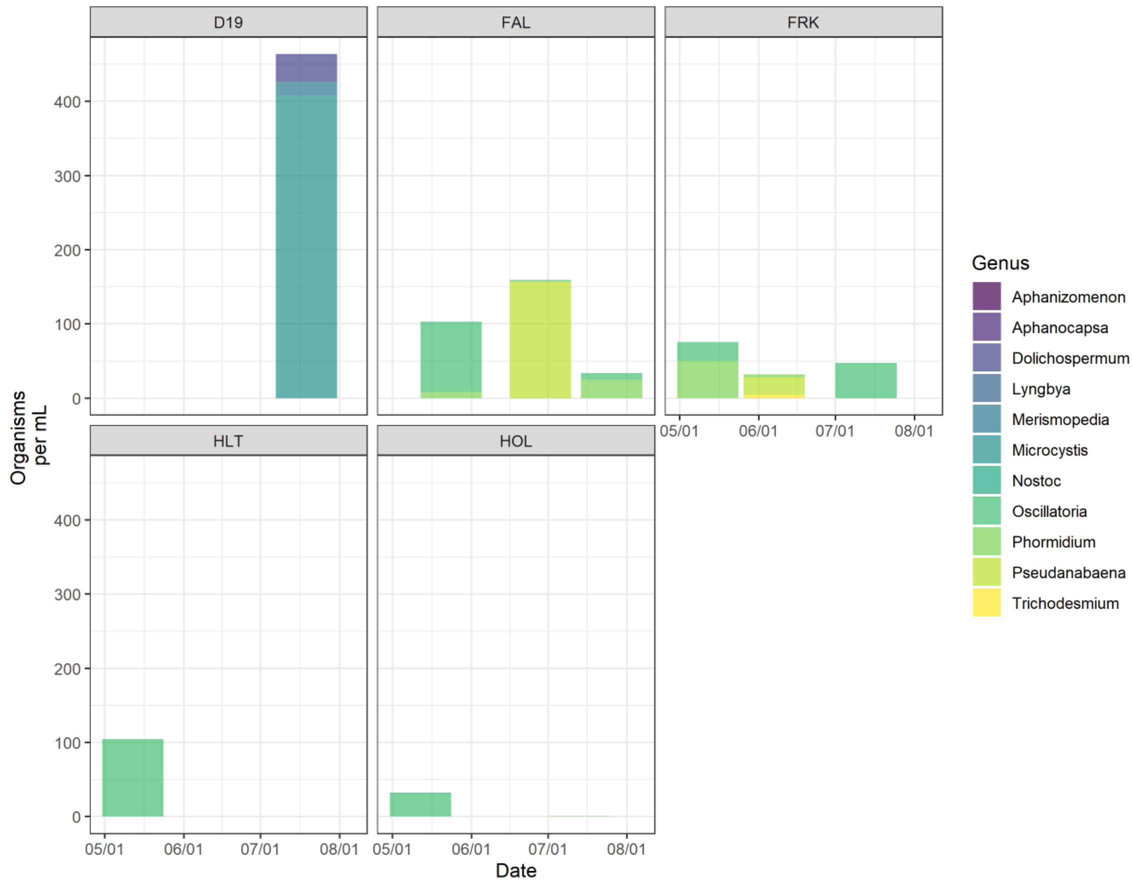

Figure 29. Taxonomic composition of toxin-producing cyanobacteria (organisms per mL) in epiphytic algal samples collected at EMP sites in Franks Tract (FAL, FRK, HLT, HOL) and in plankton algal samples collected at EMP site D19.

- Cyanobacteria taxonomic composition of epiphytic algal samples varied over time and among sample sites but were more similar to each other than to the planktonic sample.

- The relative abundance of cyanobacteria in epiphytic algal samples was much lower than in the planktonic algal sample for all cyanobacteria and for toxin-producing cyanobacteria.

Cyanotoxins

Hypothesis:

- Cyanotoxin incidents and levels in Franks Tract may be relatively high due to the EDB.

Comparisons: samples collected over time in Franks Tract; note: this was the first year this type of sampling was conducted.

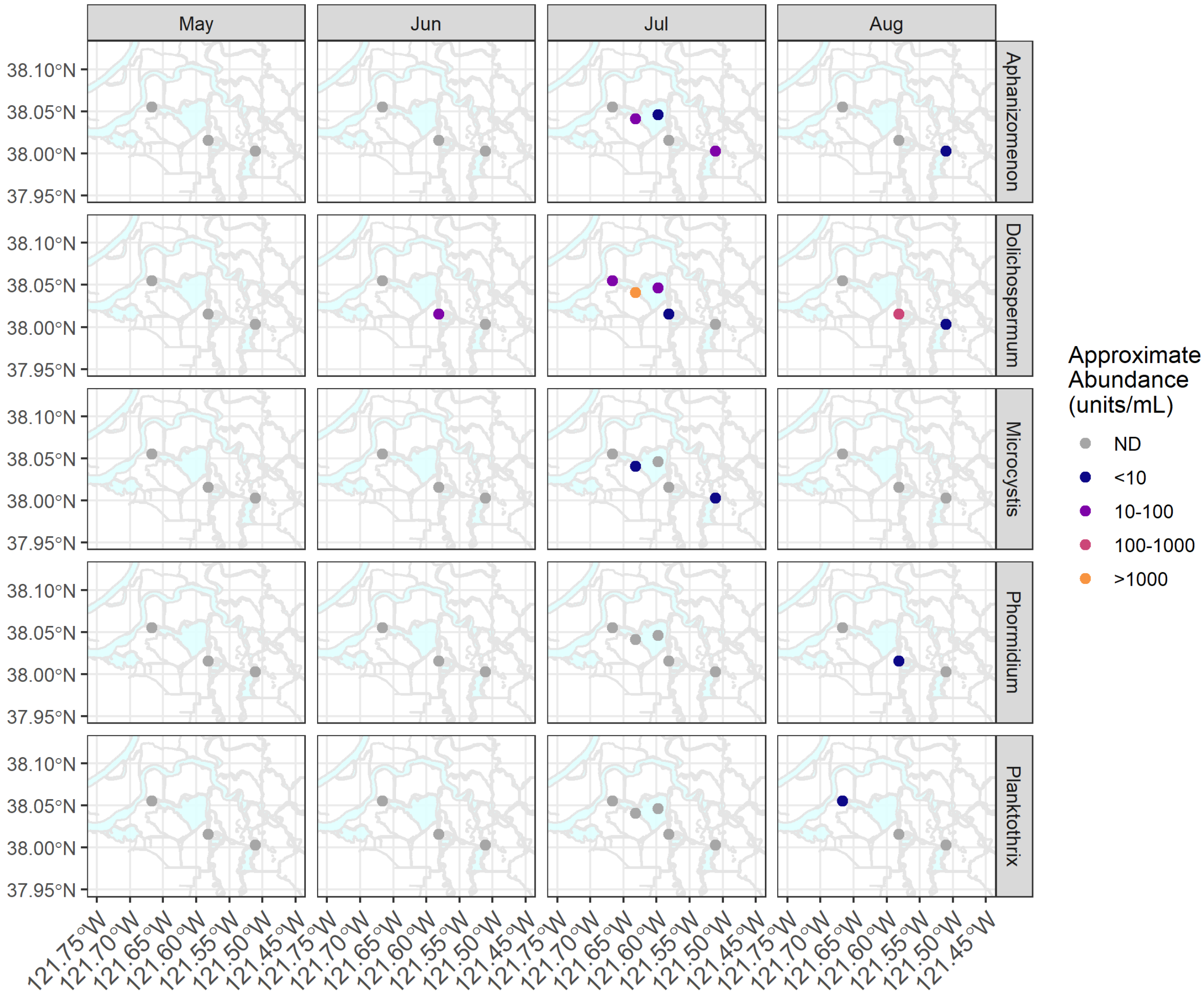

Figure 30. Map of Potentially Toxigenic (PTOX) Cyanobacteria Screen Results Near Franks Tract. Values are approximations based on numbers of filaments/colonies counted in water samples. Non-detects (ND) indicate PTOX cyanobacteria were not observed.

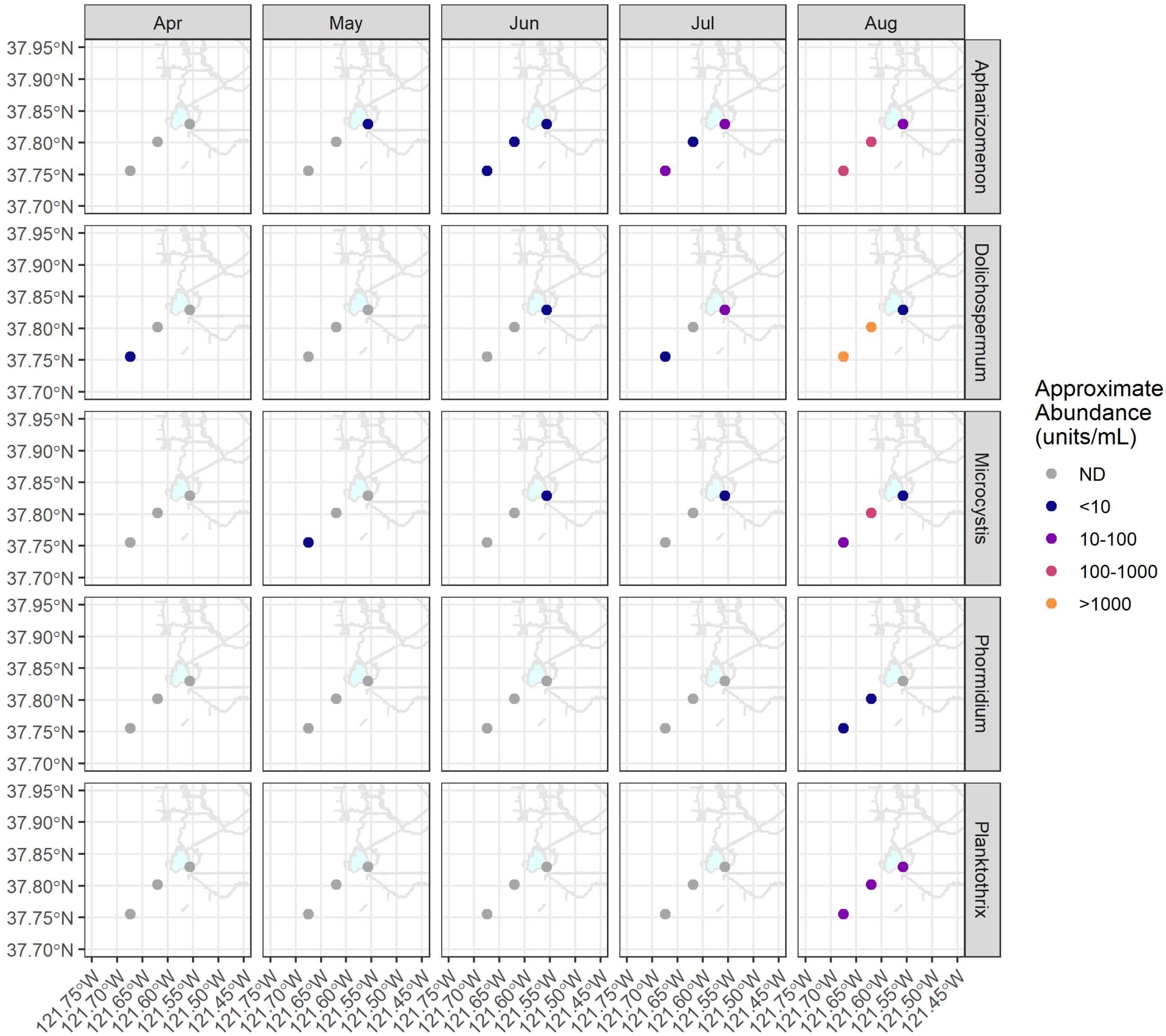

Figure 31. Map of Potentially Toxigenic (PTOX) Cyanobacteria Screen Results Near Clifton Court Forebay. Values are approximations based on numbers of filaments/colonies counted in water samples. Non-detects (ND) indicate PTOX cyanobacteria were not observed. Detections of PTOX cyanobacteria do not mean toxicity was detected.

- In Franks Tract:
    - PTOX cyanobacteria were detected between June and August, and included numerous genera.

  - The dominant genus of potentially toxigenic cyanobacteria was *Dolichospermum,* which was detected in June through August on the south side of Franks Tract. The highest detections occurred on the northwest side of Franks Tract in July.
  - The detections of *Dolichospermum* occurred more frequently and in greater abundance than those of *Microcystis*.
  - Cyanotoxicity tests indicated low frequency of toxicity despite high levels of *Dolichospermum* (see low/lack of toxin detections in Franks in Figure *20*, Figure *21*)
- In Clifton Court Forebay:
  - PTOX cyanobacteria were detected between April and August.
  - *Dolichospermum, Aphanizomenon,* and *Microcystis* were all abundant.
  - Cyanotoxicity tests indicated only two occurrences of toxin detections, which were saxitoxins in Dyer Reservoir, SW of Clifton Court Forebay.

2.4 Discussion

2022 Conditions and comparison to previous years

The objective of this chapter was to summarize the environmental conditions affected by the 2022 TUCO and EDB, and the distribution, abundance, and intensity of cyanobacteria blooms and cyanotoxins in 2022. We also compared this year's results to those of previous drought years, both those with and without EDB and TUCOs.

Delta outflow, San Joaquin River outflow, and exports were all much lower than the 10-year average, with pronounced differences during the period of the TUCO (Figure 10). Much of the difference was likely due to reduced flows associated with drought conditions, as differences in hydrology between 2022 and other drought years were much less pronounced. The TUCO did likely have an effect in decreasing flows and exports, though, since hydrology was more similar with other TUCO drought years, compared with non-TUCO drought years. The patterns in hydrology were similar with TUCO drought years despite differences in the timing of the TUCO in each year. Thus the lower outflow and exports in 2022 are likely a combined result of the TUCO, drought, and hydrology patterns in 2022.

As expected, we saw an increase in salinity in the Lower Sacramento River at compliance points due to the TUCO and the EDB (Figure 11, Figure *22*). We also saw an increase in salinity at Dutch Slough and a decrease in salinity directly east of the EDB at False River when comparing 2022 and other TUCO years with non-TUCO years (Figure *23*). These alterations in salinity could impact the freshwater cyanobacteria species composition in these areas.

We expected an increase in mean monthly chlorophyll a and nutrient concentrations during the spring and summer due to decreased flows and decreased dilution of nutrients. We found that both chlorophyll a and nutrient concentrations during spring-summer of 2022 were similar to or slightly less than concentrations in 2021 and other drought years and were similar across regions (Figure 12, Figure 13). Chlorophyll a, an indicator of overall planktonic primary production, remained mostly below the bloom-defining threshold of 10 µg/l, with the exception of Franks Tract, in which occasional blooms were observed throughout April through August.

Cyanobacterial blooms did occur in 2022 in the South and Central Delta, including in Franks Tract. Cyanobacterial taxonomic composition included *Microcystis* across most of the Delta, *Dolichospermum* in the OMR region, and some instances of *Aphanizomenon* and *Oscillatoria* (Figure 18). A small bloom of *Planktothrix* was also detected in the Upper Sacramento River region in February, which could have occurred outside of the typical HAB season due to the ability of *Planktothrix* to tolerate lower temperatures (Figure 18).

Multiple sources of information and data about the occurrence, extent, and intensity of cyanobacteria across the Delta indicate that both the frequency of occurrence and intensity of blooms, especially those involving *Microcystis*, were lower in 2022 than the previous two years. In comparison with last year, the largest bloom in the southern region of Franks tract and Clifton Court Forebay was dominated by *Dolichospermum* rather than *Microcystis* (Figure 30). These results are accompanied by numerous observations by monitoring programs of thick, green, soupy conditions in southern Franks Tract (Figure 32). These are all indicative of a Dolichospermum bloom, rather than a Microcystis bloom, which would have been dominated by flakes of algae rather than a consistent green color. There were no major blooms in comparison sites of Liberty Island or Mildred Island.

Figure 32. Images from Cyanobacteria Bloom in Franks Tract in July-August 2022. Top left: Piper and Sandmound Slough (Jared Frantzich, DWR), Bottom left: Bethel Island (BET) (Jared

Frantzich, DWR), Bottom Middle: South end of Franks Tract (Keith Bouma-Gregson, USGS), Right: Bethel Island (BET) (Jared Frantzich, DWR)

Despite the occurrence of cyanobacteria blooms, toxin grab samples collected during these blooms indicated very few detections of toxins (Figure 20, Figure 21). There were no detections of anatoxins or cylindrospermopsins, two detections of saxitoxins, and a few detections of anabaenopeptins. Microcystins/nodularins were the most frequently detected toxins, and were largely centered in the South Delta (Figure 21). The few samples in Franks Tract that had microcystin/nodularin detections were below the lowest tier of recreational advisories. While there were some advisories at recreational warning levels or above near Big Break, Discovery Bay, and the Port of Stockton (Figure 16, Figure 20, Figure 21), these are hot spots in other years as well (Hartman et al. 2022).

Conclusions

Similar to Hartman et al. (2022), we conclude that the 2022 TUCO appeared to have very little effect on HABs. While we observed reductions in outflow and exports due to the TUCO, the 2022 TUCO ended at the end of June, prior to the period during which larger blooms occurred (July-August). Cyanobacterial blooms that did occur were in Franks Tract and Old/Middle River, as well as in Big Break, Discovery Bay, and near Stockton on the San Joaquin River. The Franks Tract bloom is likely attributed to the EDB, while the Big Break, Discovery Bay, and Stockton area are prone to cyanobacterial blooms during the summer across years, even in non-TUCO years, due to the high temperatures and residence times they experience (Hartman et al. 2022). Thus, we do not believe these blooms to be attributed to the TUCO.

The EDB has been shown to have localized effects on water quality and hydrology, decreasing residence time in parts of Franks Tract (DWR 2022b). These changes, in conjunction with temperature conditions, may have impacted the formation of cyanobacteria blooms in Franks Tract and the Old and Middle River, as blooms occurred in TUCO years of 2021 and 2022, but not the non-TUCO years of 2019 and 2020. The spatial and temporal distribution of the bloom in Franks Tract differed from 2021, in that it began in the central, southern region and spread moderately to the east and west. This year’s bloom was also dominated by *Dolichospermum* rather than *Microcystis,* and was not toxic.

Section 3: Submerged and Floating Aquatic Vegetation

3.1 Introduction

General Background

Aquatic vegetation includes different growth forms that can differ in environmental requirements and ecosystem effects. Emergent aquatic vegetation (EAV) is rooted in shallow water, with most of its growth occurring above the water's surface. Submersed aquatic vegetation (SAV) grows predominantly below the water's surface in the subtidal region and may or may not be rooted in the sediment. Floating aquatic vegetation (FAV) floats on the water's surface and is not rooted in the sediment. As described in Hartman et al. (2022), aquatic vegetation provides important structure and function for aquatic organisms and waterfowl and greatly influences nutrient cycling, water quality, and the stability of sediments (Miranda et al. 2000, Caraco and Cole 2002). Fish and invertebrate species diversity tends to be greater in native aquatic plant beds, in which water quality conditions are generally more favorable for native fish and invertebrates (Toft et al. 2003; Boyer et al. 2013; Kuehne et al. 2016). Alternatively, non-native aquatic plants can have dramatic spatial and temporal effects on DO, temperature, turbidity, and pH (Frodge et al. 1990; Caraco and Cole 2002, Hestir et al. 2016) and can affect fish and macroinvertebrates (Brown 2003; Nobriga et al. 2005; Schultz and Dibble 2012).

Biomass of aquatic vegetation is influenced by multiple factors that influence establishment, growth, and persistence including water velocities, water depth, substrate, photosynthetic rate, and predation or removal (e.g., herbicides, manual removal) (*Figure 33*). Aquatic vegetation establishes more easily in lower-velocity water. Water clarity influences the depth at which photosynthesis can occur and consequently the depth at which different species of submerged aquatic vegetation can become established, depending on each species' light requirements (Chambers and Kalff 1987). Salinity influences the establishment and distribution of different species, due to difference in species-specific tolerances (Borgnis and Boyer 2015). The existing vegetative community, seed bank, and influx of propagules also influence the establishment and, in the case of propagules, spread of aquatic vegetation.

Plant growth is a function of photosynthetic rate, which is influenced by light level, temperature, and nutrient availability (Barko and Smart 1981; Chambers et al. 1991; Riis et al. 2012). Greater water clarity increases light penetration in the water column and thus photosynthetic rate. Warmer temperature also increases photosynthetic rate, based on individual species' temperature tolerances; however, high temperatures can lead to reduced growth and, if extreme, senescence (Barko et al. 1982, Ta et al. 2017). Photosynthesis also depends on the availability of nutrients, which are obtained by EAV and SAV primarily from the sediment; however, SAV can and FAV must obtain nutrients from the water column (Barko et al. 1991).

Expansion of SAV in a water body can alter both abiotic and biotic conditions by increasing water residence time and the deposition of suspended sediments, leading to greater water clarity and light penetration (Hestir et al. 2016). By reducing water velocities (Lacy et al. 2021) and increasing water clarity, aquatic vegetation promotes favorable conditions for persistence and, in some cases, expansion. Higher sedimentation rates in vegetated areas also can decrease sediment supply to tidal marshes (Drexler et al. 2020). Aquatic vegetation can affect food web dynamics by altering nutrient cycling (Boyer and Sutula 2015) and thus primary production (Cloern et al. 2016). It also influences both invertebrate and fish community composition.

Submerged and floating aquatic vegetation in the Delta

Over the past 20 years, SAV and FAV have increased in the Delta (Ta et al. 2017), particularly during the 2012-2016 drought (Kimmerer et al. 2019). Between 2008-2019, coverage of aquatic vegetation in the Delta increased over two-fold to approximately 17,300 acres, covering almost one-third of the area of Delta waterways (Ta et al. 2017; Khanna et al. 2022). Examples of EAV in the Delta include cattail (*Typha* spp.), tules (*Schoenoplectus* spp.), and common reed (*Phragmites australis*). Examples of SAV include Brazilian waterweed (*Egeria densa*), coontail (*Ceratophyllum demersum*), curlyleaf pondweed (*Potamogeton crispus*), sago pondweed (*Stukenia pectinata*), and Canadian waterweed (*Elodea canadensis*). An example of FAV in the Delta is water hyacinth (*Eichhornia crassipes*), although creeping emergents such as water primrose (*Ludwigia* spp.) and alligatorweed (*Alternanthera philoxeroides*) are also frequently categorized as FAV.

In the Delta, SAV and FAV are most likely to become established and spread in areas with lower water velocities and residence times, in areas with lower turbidity levels, and during periods of higher light intensity and warmer temperatures. During the summer, tides dictate velocity patterns such that changes in physical attributes in the Delta such as barriers or vegetation expansion will affect local velocities, as opposed to outflow (Hartman et al. 2022) (Figure 33). Areas with higher nutrient concentrations or experiencing increases in nutrient loading may also support more SAV and/or FAV. Increased water clarity since 1983 (Hestir et al. 2013), increases in nutrients as seen during 2013-2014 (Boyer and Sutula 2015; Dahm et al. 2016), and the drought conditions such as those experienced from 2012-2016 could all be contributing factors to the expansion of aquatic vegetation in the Delta (Figure 33).

The expansion of SAV and FAV in the Delta has altered the ecology as well as human use of the Delta. Impacts include increased water clarity, changes in nutrient cycling, and impairments to boat navigation, scientific research, and water infrastructure (Hartman et al. 2022). Support of invasive fish species populations has also been attributed to the type of habitat and prey provided by SAV in the Delta (Conrad et al. 2016, Young et al. 2018).

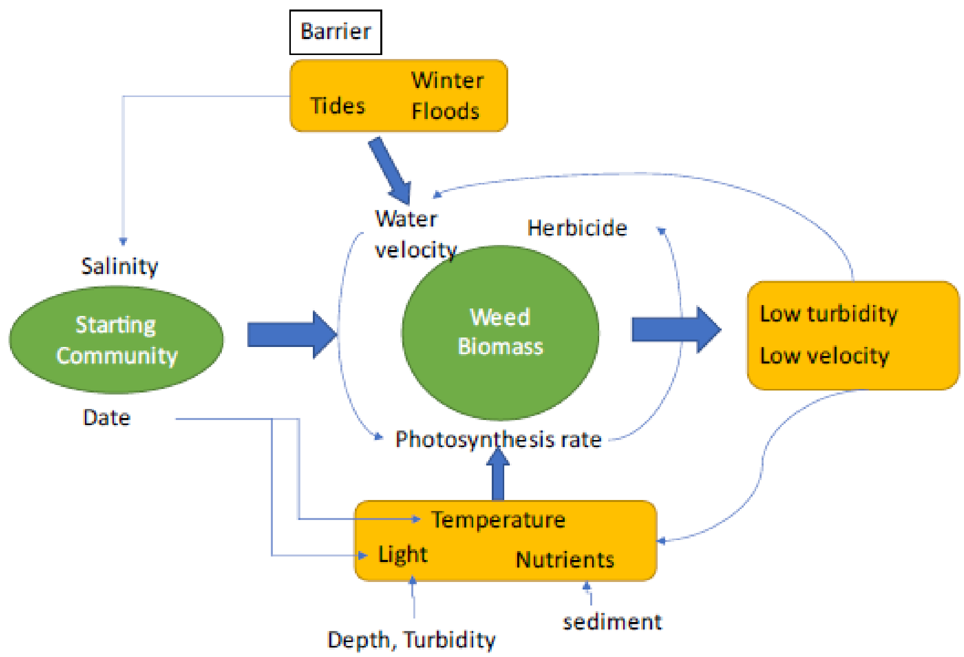

Figure 33. Conceptual model of SAV biomass in the Delta (Figure 3-1 in Hartman et al. 2022).

2021 TUCO and EDB report findings

Hartman et al. (2022) were unable to identify strong, consistent correlations between the SAV abundance and environmental drivers or dry years. They also did not find evidence that the 2021 TUCO significantly impacted SAV or FAV in the Delta, aside from a localized reduction in SAV in Big Break likely due to higher salinity caused by reduced flows. The EDB did alter SAV distribution in Franks Tract, due to its effect on water velocities within the tract. Areas with higher velocities had less SAV coverage, whereas areas with reduced velocities had higher SAV coverage (Hartman et al. 2022). These findings are consistent with a previous evaluation of the effects of the 2015 EDB on aquatic vegetation, where the barrier was associated with an increase in SAV, which persisted after the barrier was removed (Kimmerer et al. 2019).

Goals and Hypotheses for 2022

This chapter provides an update to the 2021 special study report on SAV and FAV response to the TUCO and EDB (Hartman et al. 2022) using data from hyperspectral images and field samples that were collected during the summer of 2022. The objective of this chapter is to evaluate the impacts of the TUCO and EDB on SAV and FAV in the Delta. While a thorough study was conducted last year, the timing and some conditions of the TUCO differed this year. Water velocity is an important driver of establishment and is dominated by tides during the summer months. Similar to the 2021 report, the TUCO was expected to minimally impact SAV and FAV establishment and growth (Hartman et al. 2022). In contrast, the EDB does impact velocities within and immediately around Franks Tract, so localized impacts to SAV and FAV were anticipated.

2022 TUCO

The 2022 TUCO is not anticipated to impact the potential for SAV and FAV establishment and growth, because it has minimal to no effect on summer water velocities (Table 4):

1. The proportion of waterways occupied by SAV and FAV by region is not expected to change as a result of the TUCO.

Comparison: 2004-2022 time series of North and Central Delta

2022 EDB

The EDB was anticipated to impact local water velocities and SAV and FAV as follows (Table 4):

1. Altered velocities in the Franks Tract and OMR regions, with greater velocities in Fisherman's Cut and Old River near the terminus at the northeast end of Franks Tract (OSJ) and reduced velocities at Holland Cut near Bethel Island (HOL) and Old River at Quimby Island (ORQ) (see Figure *6*) (DWR 2022b);
2. Increased water age in Franks Tract on the west side and slightly decreased water age on the east side (DWR 2022b; Hartman et al. 2022);
3. Reduced salinity in Franks Tract and increased salinity in Big Break (Hartman et al. 2022);
4. Altered distribution of SAV and FAV in and surrounding Franks Tract as follows:
    a. Relatively more SAV and FAV on the west side of Franks Tracts where velocities and flows are reduced and water age is increased.
5. Based on 2021 findings, higher salinities in Big Break may result in relatively more *Myriophyllum spicatum* and *Stuckenia pectinata* compared to Franks Tract; Franks Tract is anticipated to have more *Ceratophyllum demersum* and *Najas guadalupensis* (Hartman et al. 2022). However, data interpretation will be complicated by the use of herbicides to control aquatic vegetation.

Spatial and temporal comparisons included:

1. Franks Tract was compared to Big Break and Clifton Court Forebay, because the EDB does not reduce flow in Big Break and Clifton Court Forebay is similar in bathymetry and size (Hartman 2022).
2. Temporal comparisons were made across a 2004-2022 time series of data collected annually, based on data availability.
    a. EDB years: 2015, 2021, 2022;
    b. Non-EDB years: 2014, 2016, 2018, 2020.

Anticipated water quality responses to aquatic vegetation

Submerged and floating aquatic vegetation can slow water movement and allow suspended sediments to settle, causing reduced turbidity. Aquatic vegetation can also lead to lower nutrient concentrations due to uptake. Times of high photosynthetic activity and growth, such as occur in mid- to late summer will cause higher pH levels and higher daytime DO concentrations. High biomass and thus rates of respiration during this time can cause lower DO concentrations at night.

Table 4. Hypothesized responses of salinity and submerged (SAV) and floating (FAV) aquatic vegetation to the 2022 TUCO and EDB.

Action	Hydrological conditions	Water quality response	Aquatic Vegetation response	Spatial Comparison	Temporal Comparison
TUCO	Not anticipated to impact SAV and FAV	n/a	No differences in the proportion of waterways occupied by SAV and FAV in the North and Central Delta (calculated using hyperspectral imagery)	n/a; combined across the North and Central Delta	Time series starting 2004 but missing 2009-2013 due to lack of imagery.
EDB	Altered velocities in the Franks Tract and OMR regions • Greater velocities in Fisherman's Cut and Old River near the terminus of Franks Tract • Reduced velocities at Holland Cut near Bethel Island and Old River at Quimby Island Increased water age in Franks Tract on the west side and slightly decreased water age on the east side	Salinity Decrease in salinity in Franks Tract Increase in salinity in Big Break	Vegetation coverage of SAV and FAV in Franks Tract and Clifton Court Forebay (used as a reference site) are not expected to differ. Distribution of SAV and FAV within Franks Tract is expected to be relatively higher in the west, where water age is greater. Vegetation coverage in Big Break may decrease due to higher salinity. Species composition in Franks Tract may reflect more freshwater species, whereas that in Big Break may reflect more brackish-tolerant species.	Franks Tract Big Break Clifton Court Forebay	Time series starting 2004 but missing 2009-2013 due to lack of imagery.

3.2 Methods

Hyperspectral imagery

Similar to Hartman et al. (2022), SAV and, when available, FAV coverage in Franks Tract was compared to that of other, similar, areas like Big Break and Clifton Court Forebay, which were expected to be less directly impacted by either the TUCO or the EDB (Figure 34). This was done to try to tease apart more general drought or other environmental effects from any TUCO and EDB effects. Hartman et al. (2022) also noted that determining if the TUCO or EDB had any effects on species composition is complicated by annual herbicide treatment of SAV and FAV.

University of California Davis, Center for Spatial Technologies and Remote Sensing (CSTARS)

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). The production of finalized maps after imagery collection can require a year or longer. Therefore, 2022 imagery is not available yet. Survey methods for the hyperspectral imagery have varied somewhat among years, but the approach generally proceeds as described 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).

Ground truthing surveys were conducted concurrent to imagery collection 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).

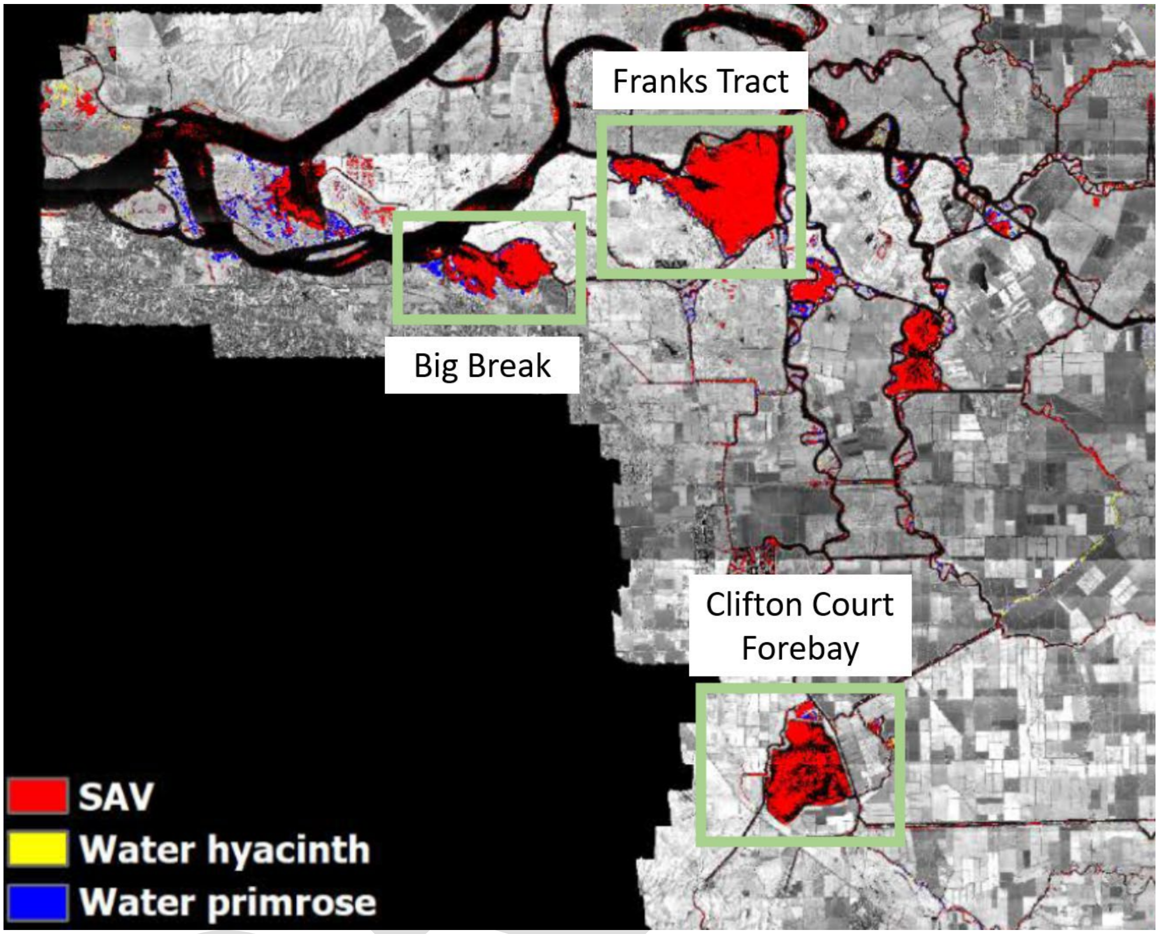

Figure 34. Map from 2021 showing the focal areas for SAV and FAV hyperspectral data: Franks Tract, Big Break, and Clifton Court Forebay (Figure 3-2 in Hartman et al. 2022).

California Division of Boating and Waterways (DBW) / SePRO Corporation (SePRO)

Working to get maps and data in January 2023.

Ground-truthing data

CSTARS

Around the time that hyperspectral imagery is collected each year in late July to mid-August, 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 2022.

CSTARS staff sampled multiple sites SAV in Franks Tract, Big Break, and the lower San Joaquin (Figure 35). A weighted, double-headed, 0.33-meter-wide thatch rake was lowered into the water and twisted before being brought back up to the surface as per the (IEP Aquatic Vegetation PWT et al. 2018). All species collected on the rake were recorded, as well as the percentage of the sample volume each species represented, to the nearest 10 percent. These sites are not selected randomly and therefore are best suited for comparing species composition among sites (Hartman et al. 2022) rather than vegetation density.

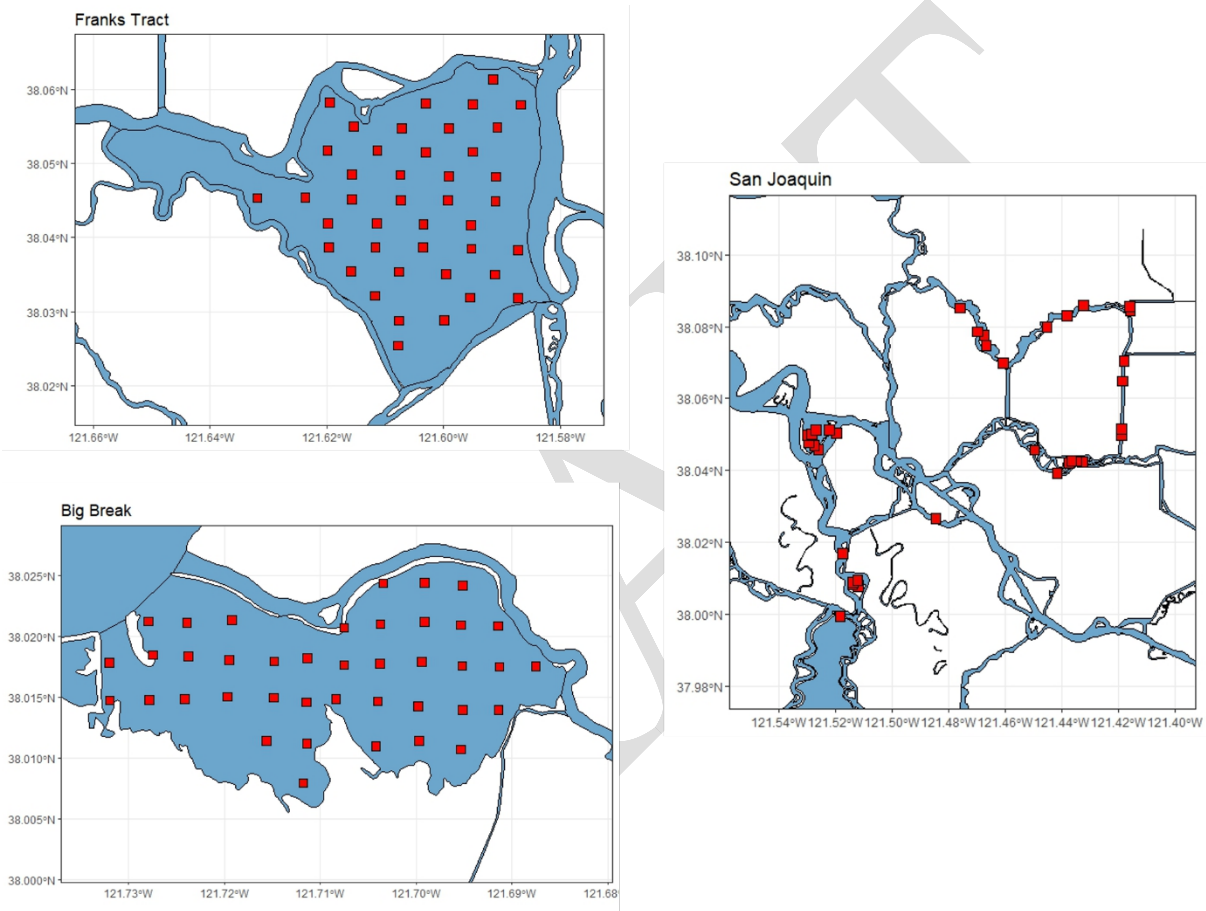

Figure 35. CSTARS ground-truthing sample sites in Franks Tract, Big Break, and the lower San Joaquin in 2022.

DBW / SePRO

Since 2006, DBW has collaborated with SePRO Corporation to manage SAV in Franks Tract using the herbicide fluridone (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. 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).

To sample each point, a weighted, double-headed, 0.33-meter-wide thatch rake attached to a rope 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.

3.3 Results

2022 Conditions

CSTARS

(Possibly: DBW / SePRO)

Hyperspectral Imagery Ground-truthing

CSTARS

Table 5. Aquatic vegetation species collected during 2022 CSTARS ground-truthing sampling.

Latin Name	Common Name	Native
Egeria densa	Brazilian waterweed	N
Myriophyllum spicatum	Eurasian watermilfoil	N
Cabomba caroliniana	Carolina fanwort	N
Ceratophyllum demersum	Coontail	Y
Potamogeton crispus	Curlyleaf pondweed	N
Potamogeton richardsonii	Richardsons pondweed	Y
Stuckenia pectinata	Sago pondweed	Y
Najas guadalupensis	Southern naiad	Y
Elodea canadensis	Common waterweed	Y
Heteranthera dubia	n/a	Y

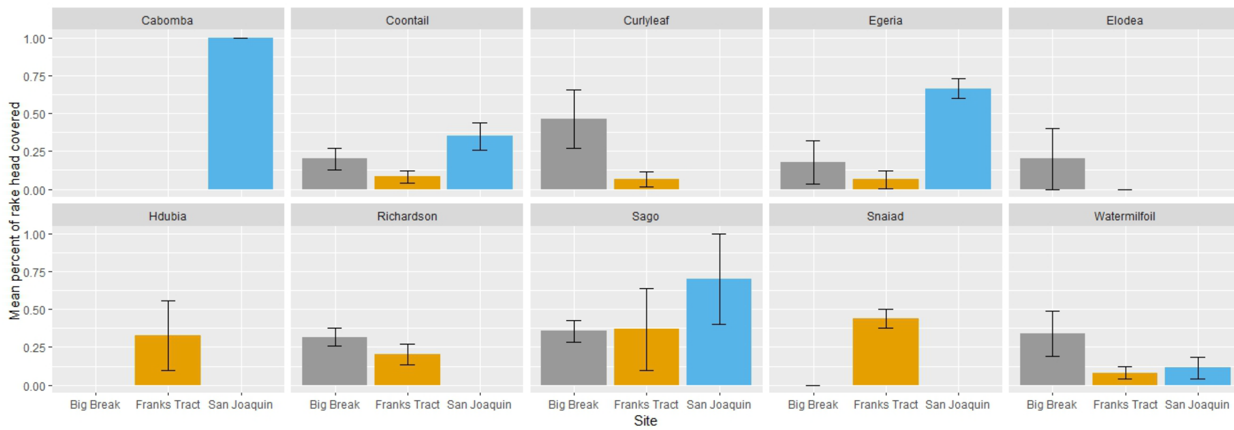

Figure 36. Mean percent of rake head covered for the ten most common species collected by the CSTARS surveys across all three locations.

- In the lower San Joaquin River, *Cabomba caroliniana* and *E. densa*, both non-native, and the native *S. pectinata* were the most common species, followed by the native *Potamogeton richardsonii* and non-native *Myriophyllum spicatum*.

- Species composition was fairly similar and more uniform in Franks Tract and Big Break. Each had eight species detected, with *Potamogeton crispus*, *E. canadensis*, and *Najas guadalupensis* occurring in both but not in the lower San Joaquin River, and *Heteranthera dubia* present in Franks Tract only. *C. caroliniana* was not detected.

DBW / SePRO

Data will be available in January 2023.

3.4 Discussion

Will be completed when additional data are available.

Section 4: Vulnerable Communities

Section will be provided by contractor in January

4.1 Introduction

4.2 Methods

4.3 Results

4.4 Discussion

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Appendices

Appendix A. DWR Division of Regional Assistance North Central Region Office. 2022. NCRO WQES Proposed HAB monitoring workplan 2022. 6 pp. (to be added in next draft).

Appendix B. Sampling Stations.

Table B-1. Stations Used for Continuous Water Quality and Hydrology Analyses.

Station Code	Operator	Station ID	Station Name	Latitude	Longitude	Data Source	Sensors
DSJ	USGS	11313433	Dutch Slough below Jersey Island Rd at Jersey Island	38.01300	-121.6710	NWIS	Water temp, SpCond, turbidity
FAL	USGS/DWR	11313440	False River near Oakley	38.05547	-121.667	NCRO	Water temp, turbidity, SpCond, DO, chl
FRK	DWR		Franks Tract Mid Tract	38.04642	-121.5981	EMP	Water temp, turbidity, SpCond, DO, chl, pH
HLT	USGS/DWR	11312685	Middle River near Holt	38.00310	-121.5108	NCRO	Water temp, turbidity, SC, chl, pH
HOL	USGS/DWR	11313431	Holland Cut Near	38.01640	-121.5819	NCRO	Water temp, turbidity,

			Bethel Island				SpCond, DO
MDM	USGS	11312676	Middle River at Middle River	37.94300	-121.5340	NWIS	Water temp, SpCond, DO, pH, turbidity, chl
OSJ	USGS/DWR	11313452	Old River at Franks Tract near Terminous	38.0711	-121.5789	NCRO	Water temp, turbidity, SpCond, DO, chl
DTO	DWR		Delta Outflow	38.059	-122.025	CDEC	Delta outflow
HBP	DWR		Harvey O Banks Pumping Plant (KA000331)	37.80194	-121.6203	CDEC	Pumping
TRP	DWR		Tracy Pumping Plant	37.800	-121.585	CDEC	Pumping
SJR	USGS	11303500	San Joaquin River McCune Station near Vernalis	37.67929	-121.2651	NWIS	Flow

Table B-2. 2022 Discrete nutrient stations for the Cache/Liberty, Franks Tract, Lower San Joaquin River, OMR, and South Delta regions.

Source	Station	Stratum2
DWR_NCRO	LIS	Cache/Liberty
USGS_CAWSC	11455385	Cache/Liberty

USGS_CAWSC	11455142	Cache/Liberty
USGS_CAWSC	11455140	Cache/Liberty
USGS_CAWSC	11455315	Cache/Liberty
USGS_CAWSC	11455095	Cache/Liberty
USGS_CAWSC	382010121402301	Cache/Liberty
USGS_CAWSC	11455276	Cache/Liberty
DWR_EMP	D19	Franks
DWR_NCRO	BET	Franks
DWR_NCRO	FAL	Franks
DWR_NCRO	FCT	Franks
DWR_NCRO	HOL	Franks
DWR_NCRO	OSJ	Franks
DWR_EMP	D12	Lower SJ
DWR_EMP	D16	Lower SJ
DWR_EMP	D26	Lower SJ
DWR_EMP	EZ2-SJR	Lower SJ
DWR_EMP	EZ6-SJR	Lower SJ
DWR_NCRO	BLP	Lower SJ
USGS_CAWSC	11337190	Lower SJ
USGS_CAWSC	11313460	Lower SJ
DWR_EMP	D28A	OMR
DWR_NCRO	OBI	OMR
DWR_NCRO	RSCC	OMR
DWR_NCRO	VCU	OMR
USGS_CAWSC	11312676	OMR
USGS_CAWSC	11313405	OMR
DWR_EMP	C9	South Delta
DWR_EMP	P8	South Delta
DWR_NCRO	GLE	South Delta
DWR_NCRO	MHO	South Delta
DWR_NCRO	MRU	South Delta
DWR_NCRO	HLT	South Delta
DWR_NCRO	MRX	South Delta
DWR_NCRO	ORI	South Delta
DWR_NCRO	OH1	South Delta
DWR_NCRO	ODM	South Delta
DWR_NCRO	ORX	South Delta
DWR_NCRO	ORM	South Delta
DWR_NCRO	PDC	South Delta
DWR_NCRO	TRN	South Delta
DWR_NCRO	WCI	South Delta
USGS_CAWSC	11311300	South Delta

USGS_CAWSC	11312685	South Delta