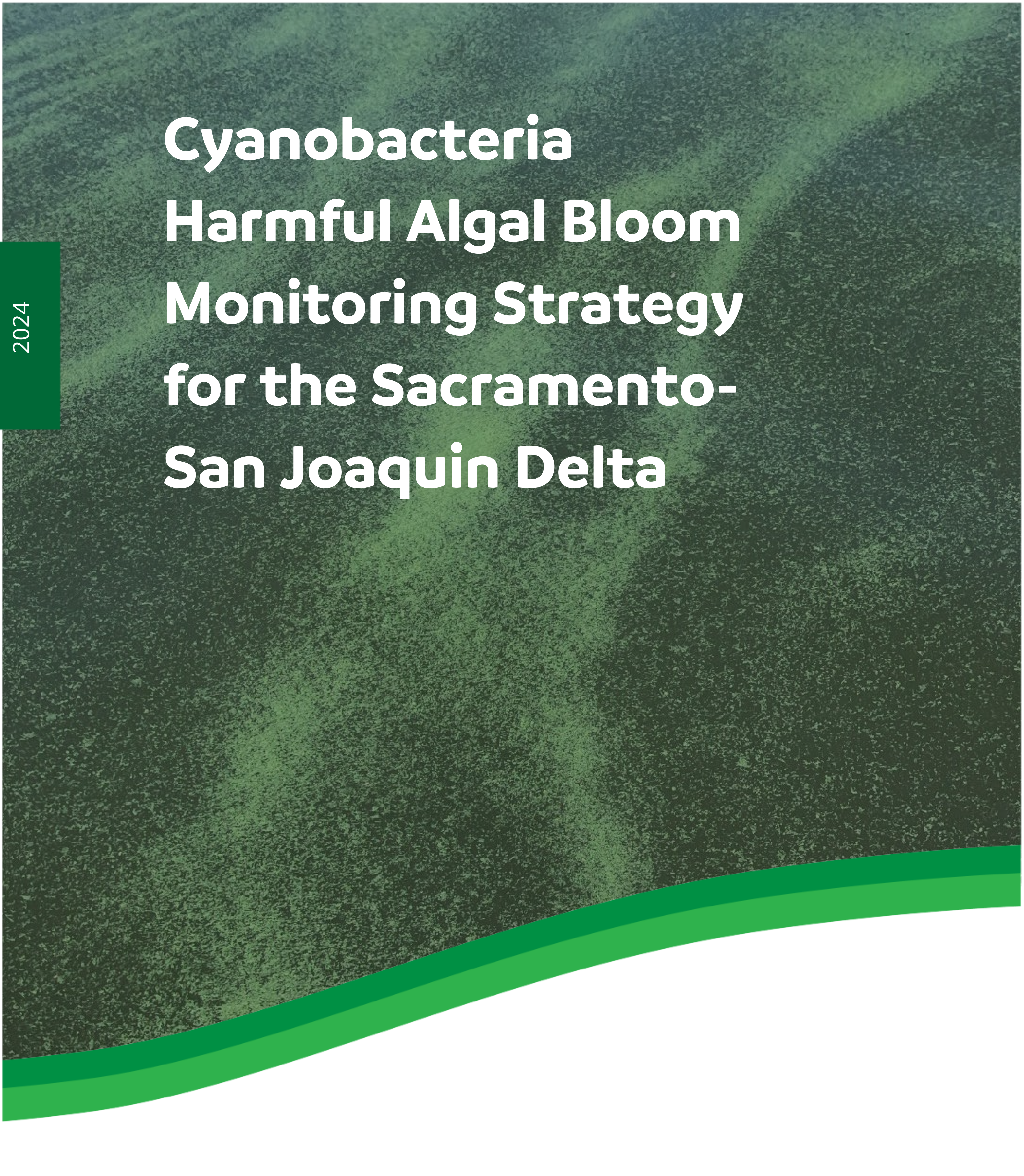
2024

Cyanobacteria Harmful Algal Bloom Monitoring Strategy for the Sacramento-San Joaquin Delta



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The views represented in this document are those of the authors and not their respective affiliations.

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Table of Contents

Figures

Tables

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Glossary

Having standardized terminology for cyanobacteria harmful algal blooms (CHABs)monitoring will improve consistency, collaboration, and ease of data sharing amongst the Delta science community. The following terms and their definitions are what we are using in this document, and we hope that these definitions can be standardized across monitoring efforts.

CCHAB Network	California Cyanobacteria and Harmful Algal Bloom Network
CDEC	California Data Exchange Center
CDFW	California Department of Fish and Wildlife
CHAB	Cyanobacteria harmful algal bloom
Delta ISB	Delta Independent Science Board
DSP	Delta Science Program
DWR	Department of Water Resources
FAIR	Findability, Accessibility, Interoperability, Reuse
FHAB	Freshwater and estuarine harmful algal bloom
HAB	Harmful algal bloom
IEP	Interagency Ecology Program
MERHAB	Monitoring and Event Response for Harmful Algal Blooms
NOAA	National Oceanic and Atmospheric Agency
NPDES	National Pollutant Discharge Elimination System
QAPrP	Quality assurance program plan
SFEI	San Francisco Estuary Institute
SOP	Standard operating procedure
SPATT	Solid phase adsorption toxin tracking
SWAMP	Surface Water Ambient Monitoring Program
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey

Executive Summary

E1. Need for a Cyanobacteria Harmful Algal Bloom Monitoring Strategy in the Delta

In winter 2021, the Central Valley Regional Water Quality Control Board and California Department of Fish and Wildlife approached the Delta Science Program (DSP) regarding the development of a strategy to address cyanobacteria harmful algal blooms (CHABs), the type of HAB that dominates waterways in the Sacramento-San Joaquin Delta[1] (Delta). Although CHABs have been a major nuisance in the Delta for decades, and many special studies have been conducted to demonstrate their impacts on the ecosystem and public health, no regulatory framework for monitoring CHABs exists in the Delta.

The DSP hosted a public workshop on CHABs in November 2022 that brought together interested parties from federal, state, and local governments, Tribal governments, community-based organizations, academia, nonprofits, nongovernmental organizations, and general members of the public. This workshop was developed to facilitate discussions for developing a CHAB monitoring strategy to fit the needs of the many varied interests on CHABs in the Delta. The workshop included presentations and panels by experts working on CHABs as well as breakout sessions and surveys to hear from all attendees. More information can be found in the HABs Workshop Summary[2]. After the workshop, the authors of this document worked to create a strategy that would address the expressed needs of workshop attendees to establish a pathway for developing a monitoring program to address HABs in the Delta. This document seeks to bring together community desires, synergistic efforts, and to build on the work conducted by many dedicated individuals throughout the system that led to this strategy being possible.

Although there is no funding affiliated with this strategy or to develop and implement a monitoring program, the community has made it clear that this monitoring strategy is needed to provide a framework to better monitor and manage Delta CHABs as resources become available in the coming years. Additionally, there are many established monitoring programs that collect water

[1] California Water Code section 85058

[2]https://www.researchgate.net/publication/368841409_Delta_Harmful_Algal_Blooms_Monitoring_Workshop_Summary_-_November_2022

quality data that might support data collection for CHABs. This strategy provides an approach to move the needle forward on managing Delta CHABs by 1) coordinating the collection of priority data, 2) working on collaborative approaches to sharing data, and 3) eventually implementing CHAB mitigation techniques.

E2. Goals and Objectives of the Delta CHABs Monitoring Strategy

The overall goal of this document is to develop a collaborative and cohesive CHAB monitoring strategy for the Delta. Building upon the data and collaboration gaps, five primary goals were identified, and within each goal are two to four objectives that can help accomplish the goal (Table 1). Detailed recommendations (Section 5. Goals and Objectives and Recommendations) are provided to expand on the goals and objectives.

This Strategy is focused on informing water quality management decisions in a 3- to 5-year horizon, however, recommendations in this Strategy may also fall under long-term implementation of >5 years and are included for consideration as this Strategy is implemented. There are multiple conceptual and technical recommendations identified throughout this CHAB Strategy. Some recommendations have previously been implemented but have not included a collective agreement or 'buy-in' from all Delta interested parties and are therefore still included. The implementation of the CHAB Strategy will provide the mechanism for this collective agreement to occur.

Given general funding uncertainties and the lack of an overall CHAB management framework for the Delta, an adaptive management approach is necessary to ensure implementation of this Strategy is effective for all interested parties (Delta ISB 2022) (Figure 1).

Table 1. Delta CHABs Monitoring Strategy Goals and Objectives

Goal 1: Enhance Delta CHAB collaboration	• Objective 1-1 Organize collaborative approach to implement Delta CHAB Strategy • Objective 1-2 Promote coordination, collaboration, and communication among agency and community partners • Objective 1-3 Identify mechanisms to ensure sustainability of long-term Delta CHAB monitoring and collaboration.
Goal 2: Identify management questions, monitoring goals, and objectives	• Objective 2-1 Identify how monitoring results will be used by decision makers • Objective 2-2 Consider data and monitoring gaps needed to answer management priorities • Objective 2-3 Determine how to prioritize questions and goals
Goal 3: Develop a CHAB monitoring program	• Objective 3-1 Identify specific monitoring program(s) needed to achieve the management questions and goals • Objective 3-2 Identify priority monitoring parameters, locations, sampling period/frequency, and methods for the monitoring program(s) • Objective 3-3 Create implementation guidance for Delta CHAB monitoring • Objective 3-4 Synergize Delta CHAB monitoring with ongoing HAB efforts
Goal 4: Develop collaborative reporting protocols	• Objective 4-1 Validate and standardize current methods used for monitoring CHABs • Objective 4-2 Develop protocols for accurate and timely reporting
Goal 5: Utilize a data sharing platform	• Objective 5-1 Identify existing CHAB and HAB data repository platforms • Objective 5-2 Explore how to integrate Delta CHAB monitoring data with existing data repositories • Objective 5-3 Develop protocols to make CHAB data accessible and available to all

E3. Proposed use of the Delta CHABs Monitoring Strategy

Throughout the development of this document, the authors worked with various technical experts, Tribes, environmental justice experts, and resource managers to establish a strategy that is detailed enough to kickstart specific actions but lenient enough for individual parties to continue to share their needs throughout the implementation of the document. Given that there are broad interests in Delta CHABs and there is no ongoing, dedicated funding for CHAB monitoring, the success of the implementation of this Strategy falls to the ongoing coordination and collaboration of the Delta science community. This Strategy focuses on building capacity for improving coordination and collaboration through goals, objectives, and recommendations that can be implemented in a "phased" or adaptive approach (Figure 1) depending on community needs and available resources.

Due to the multiple vested interests in CHABs, this phased approach should be conducted in coordination with the community to prioritize investment and management questions throughout the implementation of the Strategy. As recommended by the Delta ISB (2022), this adaptive approach to monitoring allows "a more rigorous system for establishing purpose, setting expectations, and conducting a review of monitoring programs, as well as fostering communication at all levels".

Figure 1. Description of the phased, or adaptive, approach to monitoring for HABs described through the goals, objectives, and recommendations of this Strategy. Map is from the San Francisco Estuary Institute.

1 Introduction

1.1 Purpose

Following years of increased drought severity and associated decreases in freshwater flows, there has been an increase in the frequency and intensity of cyanobacterial harmful algal blooms (CHABs) in the Sacramento-San Joaquin Delta. The purpose of this document is to provide a forum for agencies, non-governmental and community-based organizations, Tribes, and other parties that have a vested interest in mitigating adverse impacts from CHABs to work together toward the common goal of creating collaborative and cohesive CHAB monitoring for the Delta. While a number of state and federal agencies have legal responsibilities for water management and water quality in the Delta, there exists a “collaboration gap” among agencies for CHAB monitoring and inclusion of Delta communities and interested parties. This document provides a framework for 1) agreeing on management questions and monitoring goals and objectives for a common CHAB monitoring approach; 2) actionable steps to develop a comprehensive CHAB monitoring program specific to the Delta, including interested parties and the agencies charged with protecting ecosystems and species; and 3) informing collaborative management and mitigation decisions. **The overall goal of the framework described in this document is to promote shared responsibilities and standardized data collection and reporting protocols to improve CHAB monitoring and inform and advance water quality management decisions**. This document provides an overview of the current state of knowledge on Delta CHABs, a summary of current CHAB monitoring efforts, identifies potential collaboration and knowledge gaps, and provides goals and recommendations/action steps. This information can be used to orient discussions around improving our understanding of CHABs and their mitigation in the Delta. We recognize that this is just the first step of many to make progress toward mitigating and managing CHABs in the Delta.

The Delta CHABs Monitoring Strategy (Strategy) intends to provide a big picture structure for immediate next steps, and to lay the foundation for further planning and research recommendations as capacity grows and funding becomes available.

1.2 Background on the Delta

The Delta is a 900-square-mile region formed by the confluence of the Sacramento and San Joaquin rivers in northern California. This region is intersected by a large network of sloughs and channels connected to the northern part of San Francisco Bay via the confluence of the two rivers. The entire system is referred to as the San Francisco Estuary. (Nichols et al., 1986, Jassby and Cloern 2000, Whipple et al., 2012) (Figure 2). Freshwater from the Delta watershed provides drinking water to an estimated 27 million people and water resources for agricultural commodities. The Delta also serves as a critical habitat for fish, birds, other and wildlife. Because of the competing demands for the Delta's resources, the California legislature passed the Delta Protection Act (Section 12220 of the Water Code) in 1959 and established a legal boundary of the Delta (Figure 2). Because this legal boundary is used by many of the agencies charged with protecting Delta resources it will also be used for the purposes of this framework.

Estuaries can be challenging to monitor for CHABs due to the complexities of physical, chemical, and biological interactions along the continuum of freshwater to saltwater habitats. In addition to natural complexity, numerous jurisdictional boundaries and varying opinions on the goals and priorities for monitoring confers further challenges to monitoring in estuaries (Kudela et al., 2023). This framework will focus on freshwater cyanobacterial HABs, or CHABs, which are dominant in the Delta. To date, monitoring and assessments of CHABs in the Delta have relied on special studies, intermittent monitoring, and leveraging parts of established water quality programs (Lehman et al., 2005, 2013, 2020). Due to the short-lived nature of these studies, it has been challenging to uncover trends of CHABs over time in the Delta.

Figure 2. Map of the San Francisco Estuary. The brown line shows the area of the San Francisco Estuary that has been designated as the legal Sacramento-San Joaquin Delta (Delta).

1.3 Outreach and Engagement

In winter 2021, the Central Valley Regional Water Quality Control Board and California Department of Fish and Wildlife approached the Delta Science Program to discuss the development of a strategy to address cyanobacteria harmful algal blooms (CHABs), the type of HAB that dominates Delta waterways, in the Sacramento-San Joaquin Delta (Delta). Although CHABs have been a major nuisance in the Delta for decades, and many special studies have been conducted to demonstrate their impacts to the ecosystem and public health, no regulatory framework for monitoring CHABs exists in the Delta.

Box 1. HABs-related Science Action Agenda

> 2B: Develop a framework for monitoring, modeling, and information dissemination in support of operational forecasting and near real-time visualization of the extent, toxicity, and health impacts of HABs
> 5C: Determine how environmental drivers (e.g., nutrients, temperatures, water residence time) interact to cause HABs in the Delta, identify impacts on human and ecosystem health and well-being, and test possible mitigation strategies

The extensive input and time spent by various individuals throughout the development of this document served to improve this product and ensure that the Strategy will serve the Delta science community's needs.

1.3.1 November 2022 Workshop

In November 2022, the Delta Stewardship Council – Delta Science Program hosted a 2-day public, hybrid workshop on HABs monitoring. This workshop supports the Delta Science Program's Science Action Agenda Actions 2B and 5C (Box 1).

Day 1 of the workshop focused on "Creating a Coordinated Partner Monitoring Strategy" and Day 2 on "Data Sharing and Integration" topics spanning from strategic methods to approach partner monitoring to communication and data sharing methods. This workshop was an opportunity to hear from the Delta science community on preferred approaches to a CHABs monitoring program in the Delta. Major themes included information sharing, equitable and timely access to data, and building community partnerships. The authors of this document have tried to incorporate those values here to the best of their ability. More information on the

HABs Monitoring Workshop is available in the Workshop Summary[7] (Delta Science Program 2023).

1.3.2 Outreach during Strategy Development

Throughout the development of the Strategy, the authors worked to ensure that this product would reflect the desires and support the needs of the Delta science community. The authors conducted many outreach meetings throughout 2023 with interested parties, all of which is detailed in Appendix B.

1.3.3 Public Comment Period

A draft version of the Strategy was released for public comment from February 22-March 25, 2024. The major comments received and how the authors addressed them can be found in Appendix C.

1.3.4 Delta Plan Interagency Implementation Committee Endorsement

After the public comment period, the authors presented the Strategy to the Delta Plan Interagency Implementation Committee (DPIIC) on April 15, 2024 and received endorsement by this group for implementation of the Strategy.

1.4 Multi-Organization Coordinated Monitoring l

As described above, the Delta is a complex system both environmentally and jurisdictionally due to the many organizations with management responsibilities in the Delta. These organizations have different missions, legal authorities, responsibilities, interests, and expertise. To capture the different needs and contributions of these organizations, the Delta CHAB Monitoring Strategy will need to be developed and implemented in a collaborative and coordinated manner. To this end, the CHAB Strategy has leaned on several publications that provide recommendations for a holistic, integrative HAB monitoring approach (Paerl et al., 2018, Smith et al., 2021, Howard et al., 2022, Kudela et al. 2023).

Given the large number of partner organizations, one factor that is particularly relevant for the Delta is that CHAB monitoring needs to be coordinated across organizational boundaries and jurisdictions (Howard et al., 2022). An initial list of potential partner organizations with vested interests in Delta resources are as follows:

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[7]https://www.researchgate.net/publication/368841409_Delta_Harmful_Algal_Blooms_Monitoring_Workshop_Summary_-_November_2022

Government agencies:

Delta Plan Interagency Implementation Committee Member Agencies[8] are core to the intended implementation of this document. Agencies that might be most relevant to this work are:

- California Department of Fish and Wildlife (CDFW)
- California Department of Public Health
- California Department of Water Resources (DWR)
- California State Water Resources Control Board (State Water Board)
- Central Valley Regional Water Quality Control Board (Central Valley Water Board)
- San Francisco Regional Water Quality Control Board (San Francisco Water Board)
- Delta Stewardship Council (DSC) – Delta Science Program (DSP)
- United States Bureau of Reclamation (USBR)
- United States Army Corps of Engineers (USACE)
- United States Geological Survey (USGS)
- United States Environmental Protection Agency (EPA)
- Local environmental health and park departments
- Drinking water agencies
- Municipalities

Non-governmental organizations:

Some organizations have been involved throughout this project and are listed here as examples, but this is not intended to be an exclusive list.

- Restore the Delta
- San Francisco Baykeeper
- San Francisco Estuary Institute (SFEI)
- Little Manila Rising

Tribes:

Some Tribes and Tribal associations have been involved throughout this project and are listed here as examples, but this is not intended to be an exclusive list

- Shingle Springs Band of Miwok Indians
- Buena Vista Rancheria
- California Indian Environmental Alliance

[8] https://deltacouncil.ca.gov/dpiic/members; California Water Code section 85204

Universities:

Many academic groups have studied the role and impact of CHABs in the Delta and may have an interest in continued engagement for special studies and sharing information.

1.5 Strategy Scope

This framework is focused on improving collaboration, achieving consistent data collection, and monitoring Delta CHABs to address identified management questions in a 3–5-year horizon.

This Delta CHABs Monitoring Strategy builds off the recommendations and framework provided by the California Water Board's Framework and Strategy for Freshwater Harmful Algal Bloom Monitoring, which states that "*monitoring data can be broadly grouped into two categories that have similar decision support needs: 1) public health protection and response and 2) FHAB water quality management decision support*" (Smith et al., 2021). This Strategy is scoped to cover cyanobacterial harmful algal blooms in the geographic footprint of the legal Delta[9]. Given the 3–5-year horizon of this document, we believe that this approach allows CHABs monitoring practitioners, researchers, and decision-makers to focus on a very complex problem by starting with a refined scope and expanding outward in future iterations in a stepwise manner. With this scope in mind, we hope that this document will provide a starting point for approaching the development of monitoring plan(s) for the Delta in a stepwise manner. The Delta CHABs Monitoring Strategy can be utilized to address management questions for both public health and water quality decision support.

2 Existing Knowledge of Delta CHAB Dynamics

Like many freshwater systems worldwide, the Delta has been experiencing more frequent and severe CHAB events (Lehman et al., 2017). Delta CHAB events are typically dominated by the potentially toxin-producing genus *Microcystis,* which was first reported in 1920 (Allen et al., 1920) but was not observed in colonial form until 1999 (Lehman et al., 2005). Since 1999, *Microcystis* blooms have been occurring in the Delta with increasing frequency and severity (Lehman et al., 2017, Lehman et al., 2022). Other common cyanobacteria which have also been observed with increasing frequency in some portions of the Delta include genera such as

[9] California Water Code section 85058

Aphanizomenon, *Planktothrix, Dolichospermum*, *Pseudanabaena* and *Planktolyngbia* (Lehman et al., 2008, Spier et al., 2013, Lehman et al., 2017, Lehman et al., 2022, Perry et al., 2023).

Because a number of natural resource agencies are responsible for protecting the Delta's resources, there are several monitoring programs already in place that collect water quality data at fixed stations throughout the Delta. These data are freely available to the larger research community, and as a result, much of the published literature on CHABs is from special studies that have leveraged data collected as part of these established water quality programs. However, the methods employed or types of data collected in these programs may not be perfectly suited for CHAB monitoring. For example, methods employed for water column sampling may not specifically target CHAB species, or sampling locations may be outside of the areas where CHABs are most severe, to mention a few. To identify monitoring gaps, needs, and future monitoring priorities, it is beneficial to have an overview of the water quality data collected to date that is particularly relevant for CHAB monitoring.

The following sections synthesize known data on phytoplankton biomass levels in the Delta (sections 2.1.1 and 2.1.2), Delta-specific CHAB community composition (section 2.1.3), cyanotoxin detections (section 2.2), and the environmental drivers (section 2.3) related to emergence and growth of cyanobacteria in the Delta. Data sources for these sections include the repositories established by agencies such as DWR[10] and CDFW[11].

2.1 Phytoplankton

2.1.1 Biomass measurements

Phytoplankton biomass is typically measured as the concentration of the light-harvesting pigment chlorophyll-*a* (chl-*a*). Chl-*a* is common to all phytoplankton, including eukaryotic phytoplankton, such as diatoms, and prokaryotic phytoplankton, such as cyanobacteria. Chl-*a* is considered a standard water quality measurement and is routinely collected throughout the San Francisco Estuary and the Delta (e.g. Jassby et al., 2002, Cloern and Jassby 2012, Sutula et al., 2017). It is also routinely used throughout most of the world to gauge whether a system is supporting unsustainably high densities of phytoplankton that can lead to water

[10] https://portal.edirepository.org/nis/mapbrowse?scope=edi&identifier=458
[11] https://iep.ca.gov/Data/IEP-Survey-Data

quality impacts including low dissolved oxygen concentrations (e.g. Nixon et al., 1995, Hagy et al., 2004, Kemp et al., 2005, Rabalais et al., 2014).

Specifically, mean summertime chl-*a* concentrations are often used to classify the trophic status of estuaries as eutrophic, mesotrophic, or oligotrophic and for establishing criteria that are protective of beneficial uses (Bricker et al., 2003, Carstensen et al., 2011, Harding et al., 2014, Sutula et al., 2017). Recent data for the past five years collected by DWR through their Environmental Monitoring Program (EMP) and North Central Regional Office (NCRO) program demonstrates that mean summertime chl-*a* concentrations typically vary between 1.5-4.0 µg/L at most locations in the central Delta (Figure 3).

In the south Delta, where the channels are less influenced by tidal exchange and have longer residence times, concentrations are typically greater and more variable than in other parts of the Delta (Figure 3). Mean summertime south Delta chl-*a* concentrations range from 2.5-8.0 µg/L, but in years with algal blooms can reach up to 40 µg/L (Perry et al., 2023).

Compared with other estuaries worldwide with similar levels of nutrient loading, mean summertime chl-*a* concentrations in the Delta are considered low. In a global comparison of chl-*a* concentrations in 12 estuaries, Jassby et al. (2002) found that the Delta ranked fourth from the bottom with a Delta-wide, mean summertime chl-*a* concentration of 5.2 ± 0.7 µg/L (Jassby et al., 2002).

Low mean concentrations of chl-*a* are reflected in relatively low thresholds for chl-*a* concentrations that constitute “bloom” conditions for the San Francisco Estuary. For example, using occurrences of total phytoplankton biomass exceeding the 99^{th} percentile of a seasonal mean described by a periodic spline function, Carstens et al. (2015) characterized a bloom threshold for the San Francisco Estuary of approximately 300 µg carbon per liter (C/L), equivalent to 12 µg chl-*a*/L (i.e. using a C:chl-*a* ratio of 25). This is close to a threshold of 13 µg chl-*a*/L characterized by Sutula et al. (2017) for the San Francisco Estuary using a different statistical approach.

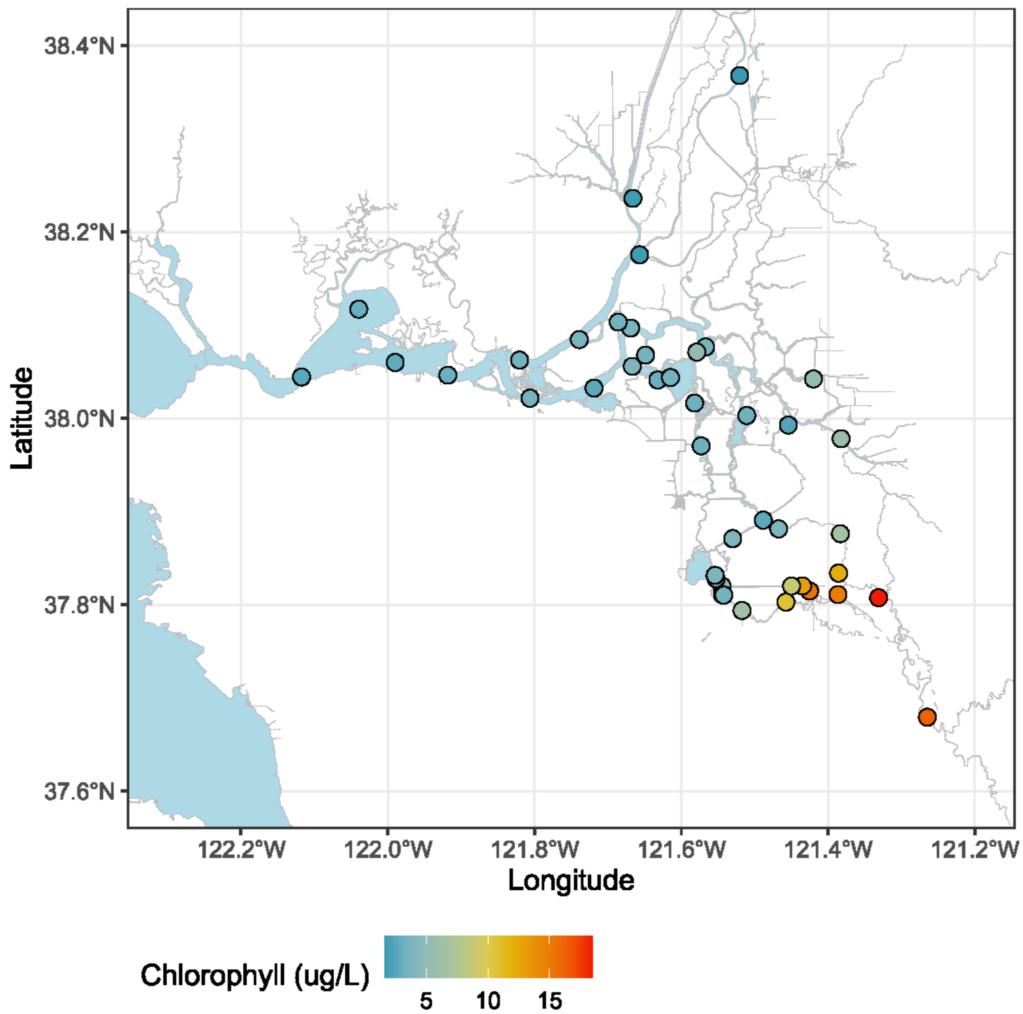

Figure 3. Chl-*a* concentrations averaged across the summer season (June-September) and recent time period (years 2017-2022) for individual stations in the Delta. Chl-*a* data from EMP and NCRO programs.

In addition to chl-*a*, phytoplankton contain accessory pigments that are useful as taxonomic markers because some are unique within broader taxonomic phytoplankton groups (Mackey et al., 1996, Jeffrey et al., 2011, Kramer and Siegel 2019). These pigments occur in specific ratios with chl-*a* in the cell (e.g. Mackey et al., 1996) and can be measured chemically (Hooker and Van Heukelem 2011) or via fluorescence (Bertone et al., 2018). This document focuses on cyanobacteria which contain a unique light-harvesting system called the phycobilisome composed of three different pigment-protein complexes, including allophycocyanin, phycocyanin, and phycoerythrin that function cooperatively with chlorophyll to increase the efficiency of light-harvesting for photosynthesis (Ting et al., 2002, Berg et al., 2011). Phycocyanin fluorescence (f-PC) is increasingly used to quantify cyanobacteria *in* *situ* and is a rapid, non-invasive technique for quantifying CHAB occurrences (Bertone et al., 2018). In the Delta, recent f-PC measurements have demonstrated relative differences in cyanobacterial biomass in specific regions such as Franks Tract and Mildred Island (Hartman et al., 2022).

Monitoring Considerations

Measurement of phycocyanin concentrations can be used as a surrogate for freshwater cyanobacteria biomass specifically, just as chl-*a* is used as a surrogate for total phytoplankton biomass. However, it can be challenging to compare f-PC with chl-*a* fluorescence because cellular PC:chl-*a* ratios in cyanobacteria are influenced by factors such as cell volume, cyanobacterial colony morphology and geometry, nutritional state, and growth phase (Kong et al., 2014, Bertone et al., 2019, Choo et al., 2019, Ma et al., 2022, Rousso et al., 2022), and therefore can be highly variable (Foy 1993). This makes it difficult to convert PC to cyanobacterial biomass estimates, and to differentiate the proportion of the total phytoplankton community biomass that is comprised of cyanobacteria (Ma et al., 2022, Rousso et al., 2022). Nevertheless, phycocyanin readings can give a general indication of cyanobacterial presence and relative changes in cyanobacterial biomass.

2.1.2 Remote Sensing

Remote sensing is another tool that can be used to estimate phytoplankton biomass. This method measures color reflected off the surface of the water via satellite and converts the color reading to pigment concentrations via algorithms. The advantage of using satellite remote sensing is the synoptic view over which data can be acquired. However, remote sensing is currently very limited in Delta waterways as the current spatial resolution restricts its use to larger water bodies (c.f., >600 m wide). This excludes many small water bodies, including narrow channels and sloughs in the Delta where CHABs most commonly occur. It also excludes areas close to shore (i.e., within 300 m) due to land contamination in the remote sensing data. Even in the broader Estuary, satellite imagery has been under-utilized for quantifying chl-*a* due to challenges posed by high turbidity, and limited research and funding available to collect the high-resolution observational data necessary for validation. Nonetheless, remote sensing is a rapidly advancing area of study with research underway to advance the tool so that it can be used for future Delta CHAB monitoring.

In California, an ocean color visualization tool was developed as a partnership between the National Oceanic and Atmospheric Administration (NOAA), the California Surface Water Ambient Monitoring Program (SWAMP), and SFEI. SFEI stores and collates data that is acquired from ESA's Ocean Land Color Imager (OLCI) sensors onboard the Sentinel-3 satellites and post-processed by NOAA to produce a cyanobacterial index that estimates cyanobacterial concentrations (Wynne et al., 2020). The web-based tool to visualize the data, with a spatial resolution of 300 by 300 meters, is hosted by SFEI. A beta feature of the OLCI to determine chl-*a* data called the Cyano Index was released July 2023. Although this tool does not cover most of the narrow Delta waterways it is used to monitor CHABs in the western portion of the Delta including areas of the Sacramento River, San Joaquin River, and Franks Tract as well as Clifton Court Forebay.

In addition to monitoring, the National Aeronautics Space Agency (NASA) and European Space Agency (ESA) ocean color images are used by NOAA to forecast HAB events in coastal waterways and for CHAB events in the Great Lakes (https://coastalscience.noaa.gov/about/). At this time there is no HAB forecasting in place for any portion of the Estuary.

NASA and other space agencies also continue to advance remote sensing for water quality science, monitoring, and forecasting by launching new satellites. For example, NASA launched their Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) satellite in February 2024. It is anticipated that this satellite will useful for HAB monitoring in the ocean and large waterbodies since it has a spatial resolution of 1.2 km. The primary instrument for PACE is OCI (Ocean Colour Instrument) which is a color imaging spectrometer that can measure ultraviolet to infrared ocean color. As described by NASA, this measurement estimates the wavelength of light reflected by the ocean, providing information on oceanic biological and chemical ocean properties. This will provide information on phytoplankton biomass and the composition of phytoplankton communities. Other sensors that will be employed on PACE are HARP-2 (Hyper-Angular Rainbow Polarimeter-2) and SPEXone (Spectro-Polarimeter for Planetary Exploration). Since PACE has only recently been launched the information is not currently used for HAB monitoring in the Estuary, but it could be a useful tool in the future.

In addition, the use of NASA's Earth Surface Mineral Dust Source Investigation (EMIT) instrument aboard the international space station for monitoring blooms is an active area of research. There are also potential opportunities for use of private sector data, such as those from Planet Labs, which have been used for monitoring HABs. PlanetLab's Planet Scope has approximately a ~3m spatial resolution, but it is far from being ready to being an operational product for chlorophyll or CHAB monitoring.

Finally, the Australian Space Agency CSIRO is teaming with NASA's Jet Propulsion Laboratory and other partners to co-design and build the AquaWatch system of technologies to monitor water quality. The system will use an extensive network of Earth observation satellites and ground-based water sensors to monitor water quality and aquatic ecosystems in Australia and the Western United States. The goal is to launch an advanced satellite with high-resolution hyperspectral imaging, to infer concentrations of optically active water quality parameters such as chlorophyll, turbidity, and colored dissolved organic matter. Yet, even with the current capabilities the team is planning to use AquaWatch to monitor near coastal and inland waterways for HABs including CHABs.

Monitoring Considerations

In the Delta, the cyanobacterial index is a good resource for visualizing cyanobacterial blooms over larger areas given the resolution of 300 by 300 meters but is currently not available for smaller waterways which comprise much of the Delta. However, this index is useful for providing early warnings of CHABs in the western portions of the Sacramento and San Joaquin Rivers, Franks Tract, Mildred Island, Clifton Court Forebay, and Liberty Island. Although this dataset goes back to 2016, Delta satellite data has never been evaluated for status and trends of algal blooms. Efforts are underway to obtain imaging from satellite Sentinel-2 which would provide finer resolution (i.e., ~15 m spatial resolution) approximately every five days and provide more useful information for Delta waterways. Based on the rapid advancement of remote sensing capabilities it is anticipated that remote sensing will become an important tool for monitoring Delta CHABs.

2.1.3 Phytoplankton identification

Microscopy has been the most commonly employed method for analyzing cyanobacterial community composition in Delta water samples and has been used to identify 16 different cyanobacterial genera to date (Spier et al., 2013, Lehman 2022, Richardson et al., 2023, Hartman et al., 2022). In addition to enumeration of cell abundances, microscopy has been used to determine cyanobacterial biomass by measuring the volumes of individual cells or colonies.

As mentioned above, Delta CHAB events are typically dominated by blooms of *Microcystis* (Lehman et al., 2017, Lehman et al., 2022) and microscopic enumeration of *Microcystis* colony units has been incorporated into routine monitoring at certain stations throughout the Delta.

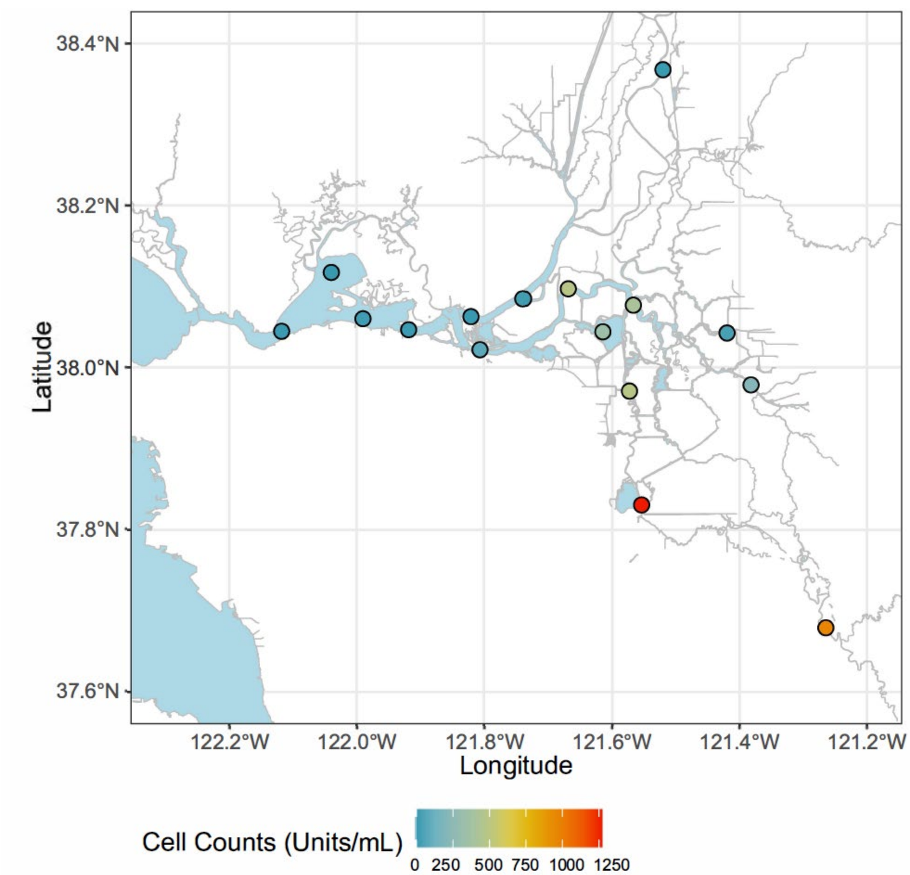

Figure 4. Abundance of *Microcystis* units (Units/ml) analyzed microscopically averaged across the summer season (June–September) and recent time period (years 2017–2022) for individual stations in the Delta. *Microcystis* colony abundance data from EMP program courtesy of Tiffany Brown and DWR.

Recent data collected by the EMP shows that the abundances of *Microcystis* colonies tend to be the greatest in Clifton Court in the south Delta and in the San Joaquin River near Vernalis (Figure 4). Colony abundances decrease from the middle of the San Joaquin River towards the confluence; the lower Sacramento River has abundances an order of magnitude, or more, lower. In the Sacramento River proper, and in Suisun Bay, *Microcystis* colonies are typically not detected (Figure 4).

Monitoring Considerations

Manual microscopy is a time-consuming process with highly variable results depending on the complexity of the target species, the training of the taxonomist, and the existence of inter- and intra-expert agreements in species identification. As such, microscopy results may not be useful for evaluating statuses and trends if utilizing data sets generated in different laboratories.

Microscopic identification requires a skill set that may not be readily available for all Delta monitoring groups. Although this may be a cost-effective method when implemented, it requires training and a standardized approach to collection for enumeration and biomass to be properly estimated. There may also be limitations to the use of microscopy including poor resolution of community composition when abundances are low. Nevertheless, long-term microscopy data sets have proved useful for monitoring phytoplankton across the Delta. Continuing to collect this type of data will provide a valuable contribution to the long-term data set. Growing advancements in automizing different aspects of phytoplankton analyses, including deep learning techniques, offer promising approaches to improving imaging of phytoplankton species (e.g., Figueroa et al., 2024). Future monitoring will likely need to incorporate these improved technologies for imaging.

2.1.4 Molecular Methods

A growing number of studies in the Delta are using molecular methods to monitor cyanobacteria. The most widespread technique to identify the presence of specific cyanobacteria genera is to amplify the gene encoding the small subunit (16S) of ribosomal RNA using quantitative polymerase chain reaction (qPCR) (i.e., 16S rRNA amplification). Portions of the 16S rRNA gene sequence are highly conserved among all bacteria, including cyanobacteria, and this method can generally be used to enumerate total cyanobacteria or a specific genus of cyanobacteria (Janse et al., 2003). To evaluate species of cyanobacteria present in the community that are potentially toxigenic (i.e., produce cyanotoxins), qPCR of 16S rRNA sequences can be combined with qPCR of DNA sequences encoding toxin production genes. For example, a commonly used gene to detect potential microcystin toxin production is the microcystin synthase B (*mcyB*) gene. Quantitative amplification of a region of the *mcyB* gene combined with amplification of 16S rRNA can give insight into toxigenic *Microcystis* strain composition (Otten et al., 2017). RNA-based qPCR is useful for determining the relative abundances of single cells and small colonies that are too small to enumerate quantitatively by microscopy.

RNA-based qPCR has been used to measure total cyanobacteria and the percent abundance of the most common Delta cyanobacteria genera such as *Microcystis*, *Aphanizomenon*, and *Dolichospermum* (Lehman et al., 2017). RNA-based qPCR have confirmed that the abundance of cyanobacteria is likely dominated by genera that are less than 10 μm (Lehman et al., 2017, Preece et al. 2024a). For example, small single-celled cyanobacteria such as *Synechococcus* are often present in background populations (Lehman et al., 2017, Kimmerer et al., 2018). These unicellular cyanobacteria are difficult to observe and generally not considered nuisance populations, thus they are commonly discounted in surveys of cyanobacterial populations. However, some of the unicellular cyanobacteria genera such as *Synechococcus* can also produce cyanotoxins (e.g., Vareli et al 2012, Kopfmann et al., 2016) and contribute to the pigment signal used to measure cyanobacteria.

Monitoring Considerations

Microscopic examinations indicate that *Microcystis* dominates in terms of the biomass of cyanobacteria. In contrast, RNA-based qPCR methods show that single-celled cyanobacteria actually dominate the Delta cyanobacteria community. Although microscopy is useful for determining the most problematic cyanobacteria biomass, RNA methods are important for determining the picocyanobacterial community. Thus, the cyanobacteria communities generated by each method currently are complementary, not identical (MacKiegen et al., 2022). As such, monitoring efforts should consider a combined-method strategy (e.g., combination of imaging and molecular tools) to fully understand the cyanobacteria community in the Delta. It is also important to recognize that microscopy results may vary based on the laboratory conducting the analysis whereas RNA based methods are more comparable across laboratories.

2.1.5 Microcystis Visual Index (MVI)

Unique to the Delta is the development and implementation of a visual index for ranking of relative *Microcystis* colony densities. Albeit qualitative, this is the most comprehensive CHAB dataset across the Delta. Called the *Microcystis* visual index

(MVI), data for this index has been collected monthly at discrete stations since approximately 2007 by DWR and CDFW. MVI data are also collected opportunistically by other researchers and agencies. These programs rely on the same visual ranking scale that takes advantage of the relative ease of identification of *Microcystis* colonies floating on the surface of the water and gives a general idea of when and where blooms of *Microcystis* occur in the Delta. This method is performed by ranking the density of colonies in the water or in a bucket according to a scale from 1-5 where 1 is absent and 5 is relatively high as depicted in Figure 5.

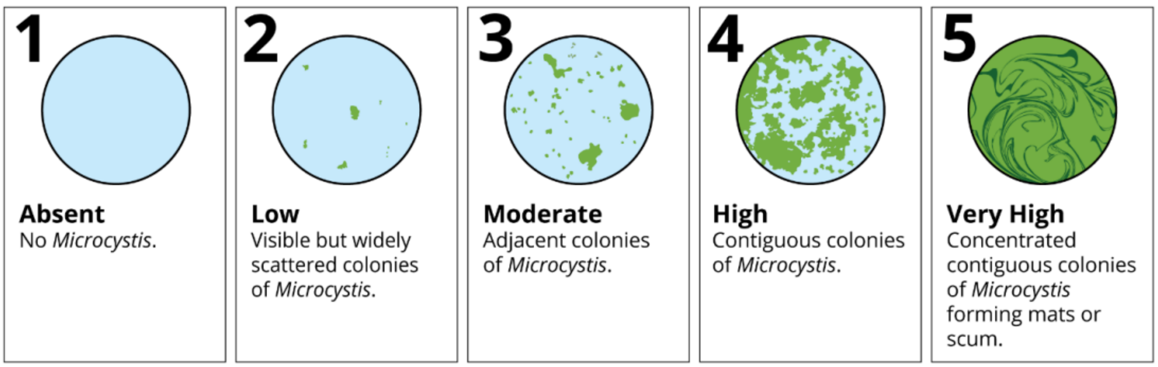

Figure 5. ***Microcystis*** **visual index (MVI) (Flynn et al., 2022)**

For the past five years, the greatest frequencies of MVI Levels 4 and 5 have occurred close to Clifton Court in the south Delta, at Mildred Island, and the Middle and upper San Joaquin River (Figure 6A). These observations are consistent with the greatest mean summertime *Microcystis* colony abundances presented in Figure 4. While combined Level 4+5 frequencies (i.e., relatively high colony abundance for the Delta) typically occur at only select stations in the Delta, combined Level 3+4+5 MVI frequencies occur much more commonly throughout the Delta, including at stations surrounding Mildred Island, most of the San Joaquin River, Old River south of Franks Tract, and in Franks Tract (Figure 6B).

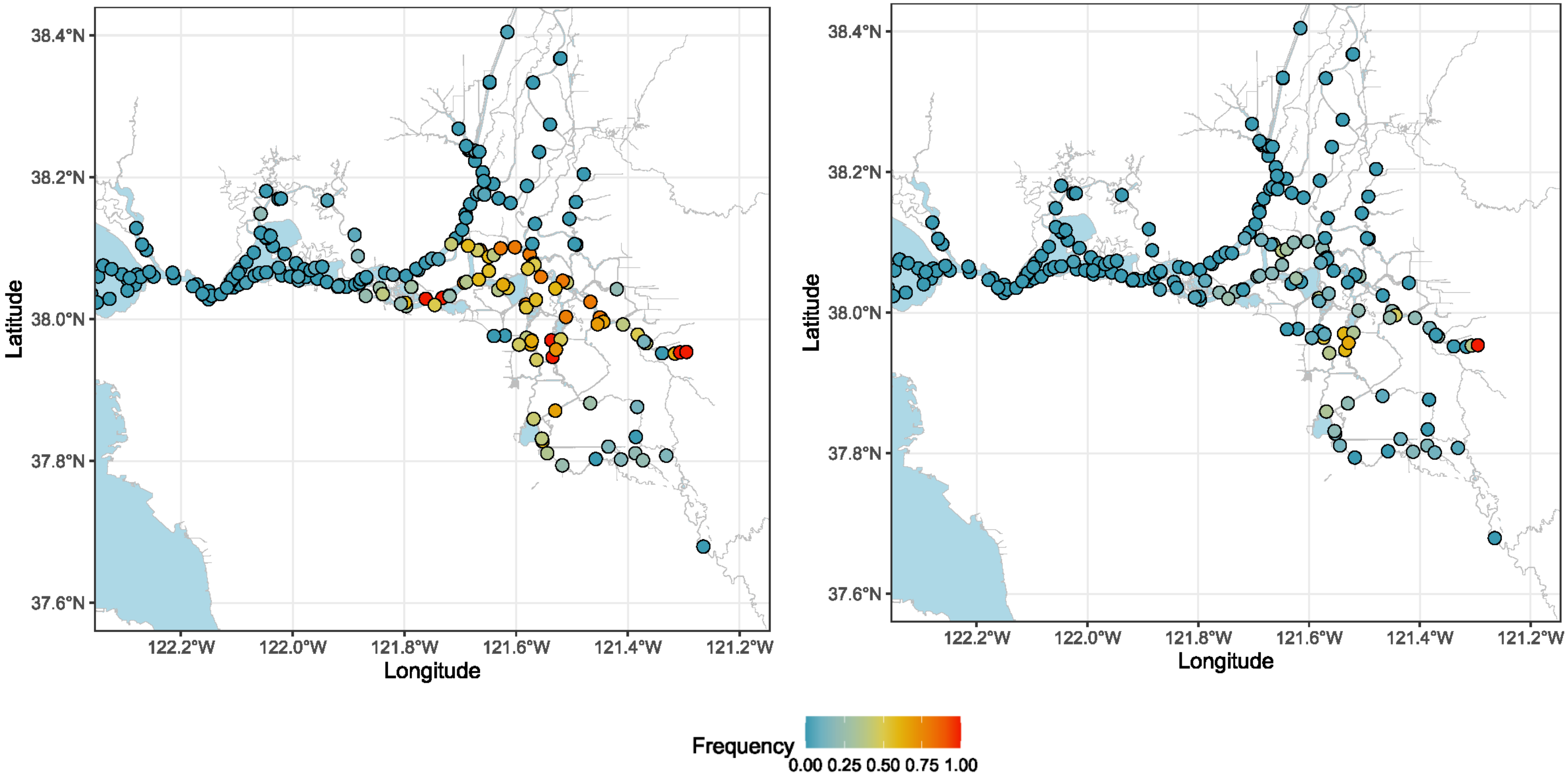

Figure 6. Map of (A) Frequency of occurrence of *Microcystis* Visual Index (MVI) levels 4+5 (Frequency=Count$_{level}$/Count$_{sumlevels}$) and (B) frequency of occurrence of MVI levels 3+4+5, for the summer season (June–September) and recent time period (years 2017–2022) for individual stations in the Delta. Data is available at: (https://portal.edirepository.org/nis/mapbrowse?packageid=edi.731.7).

In an analysis of the rank distribution of Level 1 frequencies (i.e. *Microcystis* absent from the water) by region, only the 25th percentile rank included regions with Level 4 and 5 occurrences. These regions recorded Level 4 observations annually starting in 2012, and Level 5 observations close to annually beginning in 2016, suggesting that the occurrences of Level 4+5 observations are on the rise in specific regions within the Delta (ESA 2022).

Monitoring Considerations

As this is the longest continuous CHAB dataset in the Delta it will be critical to continue collecting MVI data. It is important to note that the assignment of Levels in this index are subject to individual observer bias. As such, improvements to standardize the visualization step with this method are recommended (perhaps by use of bucket combined with digital photograph). Other recommendations include a step-by-step written protocol (see Flynn et al., 2022), and establishing a training program to ensure more consistent and reliable scoring among agencies and staff (Special Study 3.6.7 *Improve use of visual index data*).

2.2 Cyanotoxins

Concomitant with CHAB events, cyanotoxin detections have been growing in frequency and severity. Due to the high costs associated with toxin analyses, cyanotoxin monitoring has generally been associated with special studies or by opportunistic bloom response sampling. Further complicating toxin monitoring efforts, cyanotoxins are ephemeral and episodic. To date, microcystins have been the most monitored and detected cyanotoxin group throughout the Delta (Lehman et al., 2021, Kudela et al., 2023), with concentrations attributed to solely to *Microcystis* (Otten et al., 2017, Preece et al. 2024a). Thus, microcystins are discussed separately below from the other cyanotoxins that have been monitored less frequently, only detected occasionally, and/or detected at low concentrations.

For a synthesis of marine and brackish HAB toxins in San Francisco Estuary see Kudela et al., (2023).

2.2.1 Microcystins

Hepatotoxic microcystins, produced by a number of genera including, *Microcystis*, are recognized as the most common global cyanotoxin (Harke et al., 2016, Preece et al., 2017). Indeed, microcystins are the most frequently detected cyanotoxin in the

Delta (Lehman et al., 2017, Lehman et al., 2021, Robertson-Bryan, Inc, 2023, Preece et al., 2024a). The highest microcystin concentrations have been measured in edge water habitats and hydrologically isolated dead-end sloughs (CCHAB Network 2022, https://mywaterquality.ca.gov/monitoring_council/cyanohab_network/, Kudela et al., 2023, Preece et al., 2024a). This is exemplified in the dead-end Stockton Waterfront, an area known for dense CHABs. At this location in 2020, microcystins measured 1,239 µg/L in a scum sample and 61.1 µg/L in the surrounding water in 2020 (CCHAB Network 2022, https://mywaterquality.ca.gov/monitoring_council/cyanohab_network/, Preece et al., 2024a). In contrast, open water areas of the Delta where dispersed flakes of *Microcystis* dominate (instead of small dense colonies), toxin concentrations are typically below California's Danger trigger (i.e., 20 µg/L) and generally below the California Warning trigger of 6 µg/L (Lehman et al., 2017, Robertson-Bryan, Inc. 2023, *Personal Communication, Brianne Sakata, April 2023*, Preece et al., 2024a, Preece et al., 2024c). Concentrations are also frequently below the California Caution trigger of 0.8 µg/L (Lehman et al., 2017, Lehman et al., 2022). However, this is a limited dataset and cannot be extrapolated to all open water areas of the Delta.

In addition to being detected in water samples, microcystins have also been found in sediments, zooplankton, fish, and shellfish within the Delta (Lehman et al., 2010, Bolotaolo et al., 2020, Preece et al. 2024c). For example, tissue lesions consistent with liver toxins were documented in Inland Silversides (*Menidia beryllina*) and in juvenile Striped Bass (*Morone saxatilis*) caught during *Microcystis* blooms (Lehman et al., 2010). More recently, Preece et al. (2024a, 2024c) reported widespread microcystin contamination of Asian clams and crayfish collected from various locations across the Delta between 2020 to 2023.

Monitoring Considerations

Microcystins are generally most concentrated in edge water habitats such as dead-end sloughs and marinas where dense colonies are more likely to occur. Yet, toxin monitoring in these areas is reactionary and thus, there is no consistent or long-term toxin data for these locations. Routine microcystin monitoring has been implemented in a few open water areas of the Delta (e.g., Clifton Court Forebay, Banks Pumping Plant). However, a majority of the Delta has no routine microcystin monitoring. A lack of routine microcystin monitoring has made it difficult to study the temporal and spatial status and trends of the toxin.

2.2.2 Other Cyanotoxins

Low concentrations of anatoxin-a, saxitoxin, lyngbyatoxin, cylindrospermopsin, and anabaenopeptins have been detected occasionally where short-term studies funded analysis of additional toxins besides microcystins (Lehman et al., 2005, 2010, 2021, Mioni et al., 2011, Preece et al., 2024a). Because toxin monitoring has primarily focused on measuring microcystin, it is unknown if other toxins are newer to the system or if the toxins have been missed due to a lack of monitoring. Notably, a recent two-year study on cyanotoxins found no saxitoxin in Asian clam or water grab samples at locations across the Delta (Preece et al., 2024c).

These other toxins are commonly found at lower concentrations. Occasionally anatoxin-a has been detected in whole water grab samples (*Personal Communication, Keith Bouma-Gregson, February 2024*), but generally other toxins have been detected via solid phase adsorption toxin tracking (SPATT) samplers that have recently become incorporated into some discrete monitoring stations and in boat-based mapping surveys. SPATT samplers are exposed to water for longer durations and more sensitive than water grab samples at lower concentrations. However, at high and ephemeral concentrations of toxins a SPATT sampler may reflect this bias and not be representative of average concentrations, but rather represent an integrated toxin concentration over the time of their deployment. As a result, grab and SPATT sampling methods are not comparable to one another, but are complementary (e.g., Kudela 2011, Berg and Sutula 2015, Howard et al., 2017, Peacock et al., 2018).

Notably, water grab samples collected as part of the routine cyanotoxin monitoring program at Clifton Court Forebay and Banks Pumping Plant have not detected any cylindrospermopsin, or anatoxin-a between 2014 to 2022 (*Personal Communication, Brianne Sakata, April 2023*).

Monitoring Considerations

A lack of cyanotoxin monitoring has made it difficult to determine where and when these other cyanotoxins may be present. SPATT samplers are an important tool that can be used to complement grab samples and to improve our understanding of toxin dynamics within a system. SPATT's and other integrative samplers, such as shellfish, can be used to monitor a variety of cyanotoxins that may be missed through traditional water grab sample analysis.

2.3 Drivers of Delta CHABs

Knowing when and where CHABs will form is very difficult. Part of the process of getting closer to being able to predict their occurrences includes understanding how environmental drivers impact the frequency, magnitude, and intensity of their occurrences, as well as their toxicity. While the word “driver” suggests a positive impact in terms of growth, there are also negative drivers which limit the growth of different CHAB species. Negative drivers may include processes such as sediment resuspension, which decreases light availability, high water flow rates, which impacts residence time and time to grow in a region, and salinity, which may limit the distribution of a CHAB event to the freshwater and low salinity reaches of the San Francisco Estuary (i.e., much of the Delta). Biotic factors such as allelopathic compounds, infections, and grazing are also recognized as factors that can limit cyanobacteria growth or cause blooms to disappear (Harris et al., 2024). These negative drivers work in tandem with positive drivers such as nutrients, temperature, and water column light availability to control cyanobacterial growth rates and ultimately, CHAB occurrences. Figure 7 shows how these drivers work in different types of Delta habitats to support the formation of CHABs. We build on this figure below, by discussing in detail the following drivers; streamflow and residence time, sediment resuspension and water column light availability, salinity, temperature, nutrients, and cyanobacteria seedstock. Each of these drivers has been suggested to play an important role in CHAB occurrences in the Delta (e.g. Lehman et al., 2013, Berg and Sutula 2015, Lehman et al., 2017).

When possible, we used available datasets to show how these drivers may impact cyanobacteria in different regions of the Delta. The Delta was divided into six regions for analysis; Central Delta; Cache Slough Complex; East Delta; Lower Sacramento River; South Delta; and the San Joaquin River. There was not a sufficient data set available for nutrients so that region was omitted from the nutrient analysis. See Figure 7 for a depiction of the six regions.

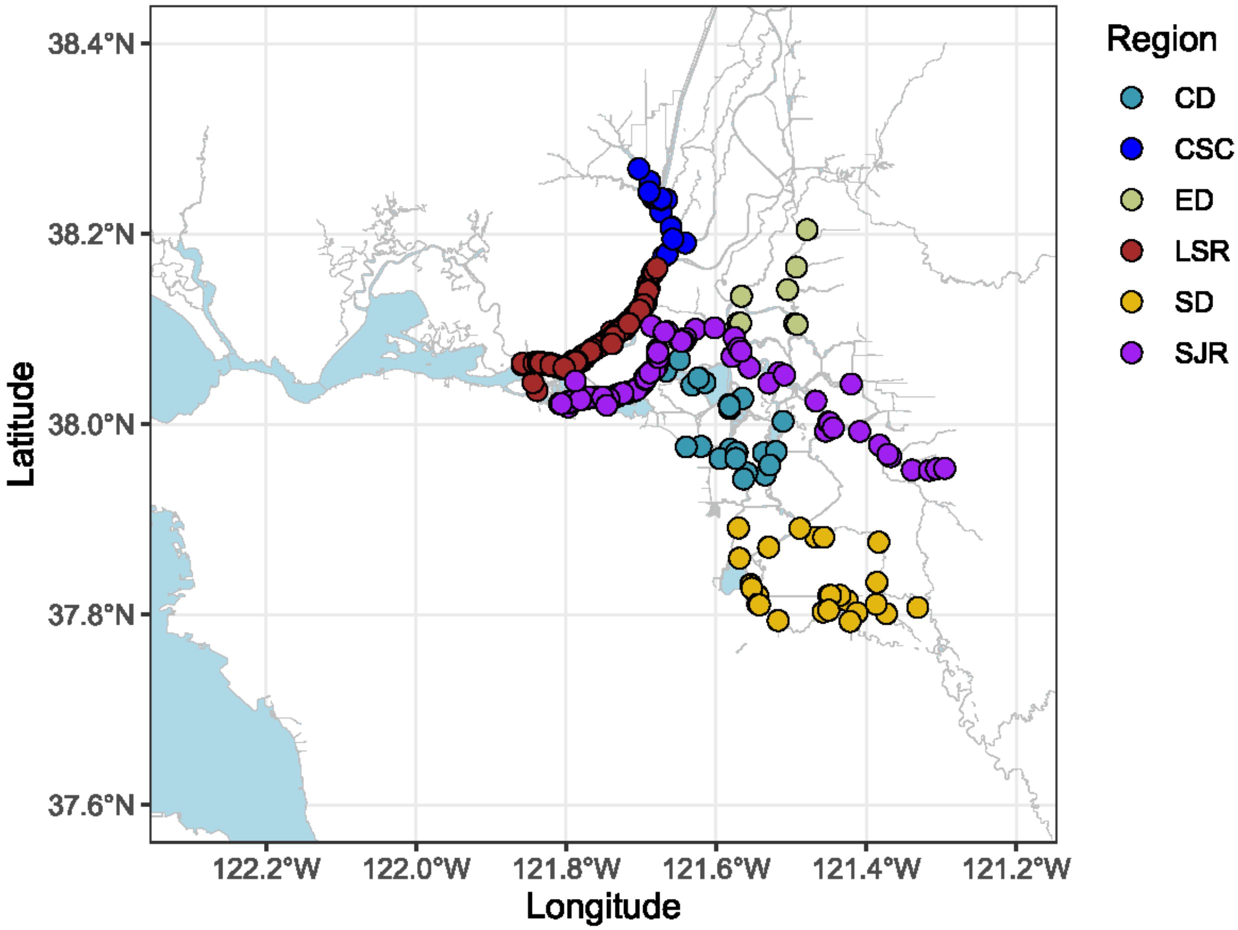

Figure 7. Six Delta regions. Central Delta (CD); Cache Slough Complex (CSC); East Delta (ED); Lower Sacramento River (LSR); South Delta (SD); and the San Joaquin River (SJR)

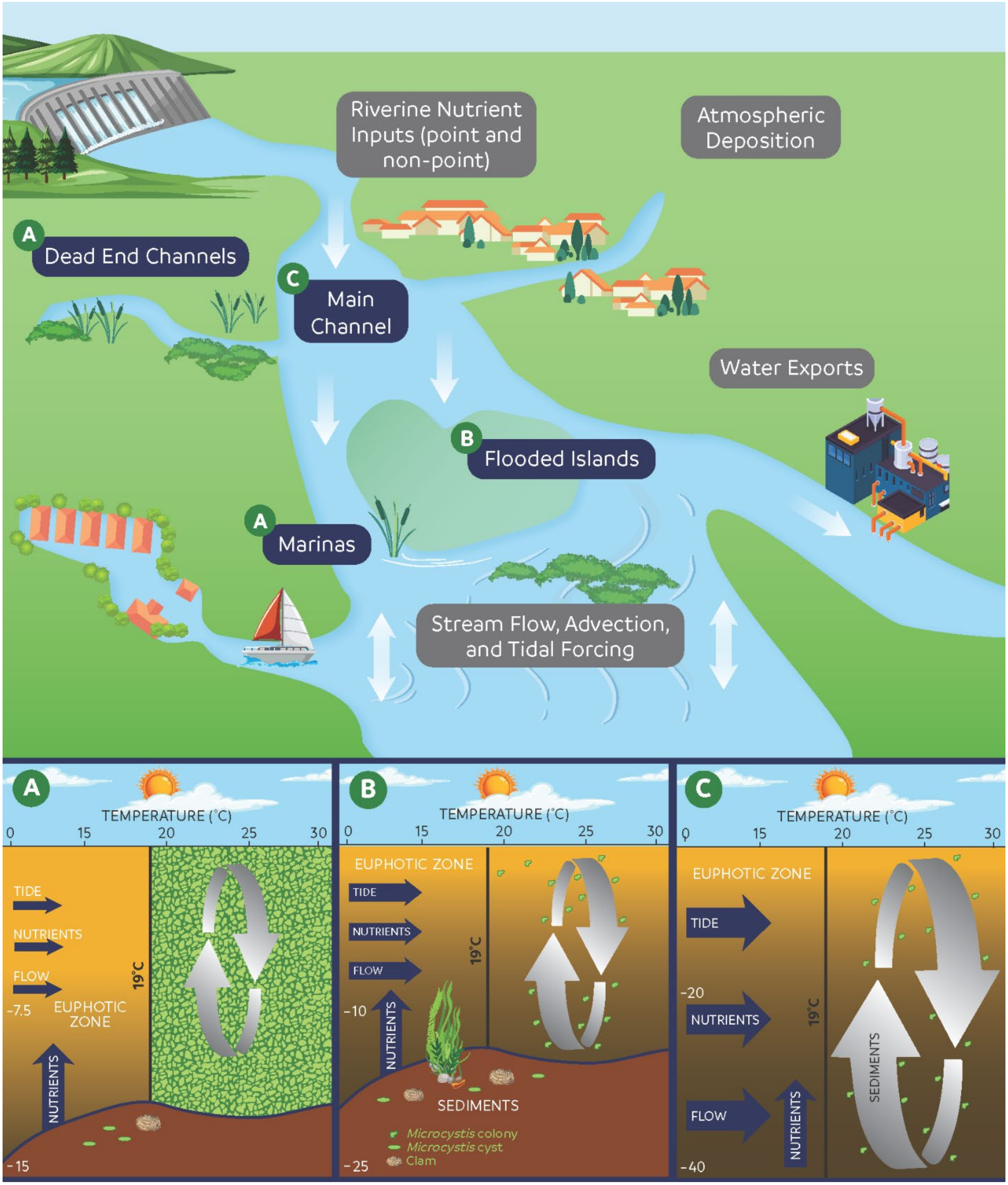

Figure 8. Conceptual model for CHAB drivers in the Delta.

Top panel: Different physical environments provided by Delta waterways that influence CHAB development, including (A) dead-end channels and marinas, (B) flooded islands with submerged aquatic vegetation (SAV) and wildlife, and (C) main channels. Processes that interact with these different types of physical environments include input of point and non-point nutrient sources, stream flow and tidal forcing, water exports, and atmospheric deposition.

Bottom panels: Representations of water column characteristics of

(A) ***Dead-end channels and marinas*** **with weaker stream flow, weaker vertical mixing, lower degree of sediment resuspension, clearer water column, and longer residence times leading to less dilution of CHAB species and potentially higher primary productivity compared with the main channel. Less dilution can also result in a stronger coupling with the sediments aiding the exchange of materials including nutrients. In this environment,** ***Microcystis*** **colony size may decrease, and colonies may become denser and more evenly distributed throughout the water column.**

(B) ***Flooded islands*** **influenced by stream flow, lateral advection, and tidal forcings but with decreased depth and a Z_e:Z_m ratio of 0.5 or greater which potentially result in greater CHAB species productivity, but also greater contact and exchange with sediments containing filter-feeding grazers such as clams and SAVs competing for nutrients and resources. Both dead-end channels and flooded islands may be representative of** ***Microcystis*** **hot spots in the Delta that may contain cysts in the sediments that allow blooms to re-establish from year to year.**

(C) ***Main channels*** **with strong stream flow, lateral advection, tidal forcing, continuous vertical mixing (i.e. no change in temperature with depth), and a high degree of sediment resuspension. In this environment, CHAB species such as** ***Microcystis*** **are mixed from the top to the bottom of the water column, and spend limited time in the euphotic zone as the ratio of euphotic zone depth (Z_e) to total mixed water depth (Z_m), i.e. Z_e:Z_m may be 0.5 or less. Both limited time in the euphotic zone and vigorous physical mixing may produce lower growth rates and a colony morphology similar to small pieces of lettuce that are evenly distributed throughout the water column. In addition to vertical mixing, colony densities may also be limited by relatively short residence times and dilution.**

Stream Flow and Residence Time

Blooms of cyanobacteria are sensitive to stream flow and water residence time both directly, by the rate at which cells are flushed out of a region, and indirectly through changes in vertical mixing and turbidity following variations in stream flow (Paerl 2008). Over a Delta-wide scale, residence time (i.e. the time it takes to exchange the volume of water within a certain region) is primarily controlled by inflow. Inflow is driven by the combined streamflow in the Sacramento and San Joaquin Rivers, with the Sacramento River comprising approximately 83% of the total from these two sources (Arthur et al., 1996, Cloern and Jassby 2012). Outflow from the Delta constitutes the difference between inflow and water diversions to the state and federal pumping projects (i.e. exports) and typically varies around 70% of inflow on an annual basis (Monismith et al., 2002, Kimmerer 2004, Cloern and Jassby 2012). Inflow to the Delta varies substantially with precipitation and drought, with wet years greatly reducing residence time during the winter and spring months (Jassby et al., 1995, Kimmerer 2004). A useful index of the interannual variability in inflow, especially in the area of the Delta most influenced by the Sacramento River, is represented by "X2" which is the distance from the Golden Gate Bridge up the axis of the San Francisco Estuary to where the tidally averaged near-bottom salinity is two parts per thousand (ppt) (Jassby et al., 1995, Preece and Hartman 2024). This distance typically ranges from 70 to 80 km, being closer to the higher end of the range in a drought year and the lower end of the range in wet years (Cloern and Jassby 2012). Decreased inflow to the Delta typically occurs during the July–September period, which coincides with peak water temperatures (Lehman et al., 2022). On a Delta-wide annual scale, inflow is inversely related to phytoplankton biomass accumulation (Jassby 2008).

Over smaller, regional scales, residence time is controlled by the combined interaction of tides, diversions, and physical characteristics of the channels (Gross et al., 2019). At this scale, differences in residence time can be evident in the spring-neap tidal cycle (Kimmerer 2004). During periods of low Delta inflow and outflow, flow modifications, including salinity barriers and operation of gates such as the Delta Cross Channel, may influence residence time in localized regions (Kimmerer et al., 2019).

Compared with the main channels that intersect the Delta, there are a number of locations such as dead-end channels and sloughs, marinas, and edge water habitats that have lower tidal or riverine velocity and lower water exchange with surrounding areas (Downing et al., 2016, Lenoch et al., 2021). Whereas relatively high-velocity flows serve to maintain low residence times and high flushing rates, preventing accumulation of phytoplankton biomass in the main channels (Jassby et al., 2002, Jassby 2008), increases in chl-*a* concentrations are evident in dead-end channels and sloughs as exchange with connecting main channels decreases during the summer period (Schemel et al., 2004). This occurs in deeper dead-end channels as well as shallower dead-end floodplains, underscoring the importance of residence time in the accumulation of phytoplankton, including CHAB, biomass (Lehman et al., 2008, Downing et al., 2016, Loken et al., 2022, Preece et al., 2024b). Referred to as "hotspots", a number of these hydrologically isolated dead-end sloughs have the potential to act as CHAB incubators that seed surrounding waterways with CHAB cells (Spier et al., 2013, Preece et al., 2024b). Potential influences in flow dynamics on CHAB biomass accumulations are represented in

Figure 8 moving from a relatively fast-flowing channel (Panel B) to a dead-end slough (Panel A).

2.3.1 Sediment Resuspension and Water Column Light Availability

The main impact of sediment resuspension on CHABs is limiting the light available for photosynthesis and growth (Visser et al., 2015). This is because resuspended sediments rapidly attenuate light with depth and restrict photosynthesis to the top layer of the water column (i.e. the euphotic zone). As a result, productivity decreases the more time phytoplankton spend below the euphotic zone, and growth rates tend to vary inversely with mixed layer depth (Cloern 1987, Alpine & Cloern 1988, Lucas and Cloern 2002, Mussen et al., 2023). For CHAB species such as *Microcystis* that have low photosynthetic efficiencies (e.g. Wu et al., 2009) and require exposure to continuous light to reach maximal growth rates (Mitrovic et al., 2003), mixing out of the euphotic zone and being exposed to fluctuating light restricts their growth (Mitrovic et al., 2003, Visser et al., 2015).

A persistent feature of the San Francisco Estuary, including the Delta, is the intense mixing of the water column due to tidal oscillations (Cloern 1991, Kimmerer 2004). High-energy tidal forcing combined with riverine sediment transport (i.e. McDonald and Chang 1997, Schoellhamer et al., 2012) leads to high suspended sediment concentrations and turbidity (Cloern 1987, May et al., 2003. Thus, mixing and sediment resuspension may be important negative drivers for CHAB occurrences in the Delta. However, there has been a significant negative trend in turbidity since 1975 which could increase favorable conditions for cyanobacteria growth (Hestir et al. 2015).

Although not specifically investigated for the Delta, it is hypothesized that succession of various CHAB species could be connected with irradiance requirements. For example, *Microcystis* may be replaced by others, such as *Aphanizomenon,* as water flow and mixing increases (Lehman et al., 2022). Under even stronger mixing regimes, CHAB species may be replaced by eukaryotic green algae (Ibelings et al., 1994, Huisman et al., 1999). Summertime algal blooms in the Delta can be comprised of cryptophytes, dinoflagellates miscellaneous flagellates, diatoms, green algae, or filamentous or colonial cyanobacteria (Lehman et al., 2017). This suggests different phytoplankton groups may occupy different niches based on, among other factors, water column mixing intensity.

2.3.2 Salinity

Most freshwater cyanobacteria cannot survive for extended periods in saline waters and therefore salinity can act as barrier to, and negative driver of, blooms (e.g. Sellner et al., 1988) However, some genera have a relatively high salt tolerance (Patiño et al., 2023). *Microcystis* has one of the highest salinity thresholds of all freshwater cyanobacteria. Literature reports generally agree that *Microcystis* has a salt tolerance of around ≤10 ppt (Preece et al., 2017). However, the adaptability and/or acclimation of some *Microcystis* strains to higher salinities allows cells to persist in more saline environments. This is exemplified in a study by Miller et al., (2010) that showed survival in seawater (average salinity of 35 ppt) for up to 48 hours. Salinity throughout most of the Delta is well below the 10 ppt salt tolerance threshold for *Microcystis* (Figure 9). Although *Microcystis* has been documented at salinities up to 18 ppt in the San Francisco Estuary just downstream of the Delta, it is likely to be stressed and not actively multiplying under these conditions (Lehman et al., 2005). Fewer studies have addressed the salt tolerances of other cyanobacteria species. Based on the available literature, it appears that the salinity tolerance of *Dolichospermum* and *Anabaenopsis* is similar to that of *Microcystis* (Moisander et al., 2002, Kemp and John 2006, Tolar 2014).

Although *Microcystis* can survive at the salinities described above, *Microcystis* growth is constrained in more saline environments. Salinity impacts *Microcystis* physiology and growth through osmotic and ionic stresses that cause the inner membrane structure to contract. This disturbs the cellular osmotic balance, transport processes, and solubility of intracellular CO_2 and O_2 thereby slowing growth (Hageman 2011). Nevertheless, *Microcystis* cells have been shown to grow in a range of salinities (Otsuka et al., 1999, Tonk et al., 2007, Zhang et al., 2013, Qiu et al., 2022). Optimal salinities for *Microcystis* growth vary based on the system, strain, and or different physiological statuses of individual colonies (Bormans et al., 2023). Wang et al., (2022) reports optimal *Microcystis* growth occurred at a salinity of 0 ppt in the coastal Yuniao River, China and as salinity increased closer to the coast the relative abundance of *Microcystis* decreased. In contrast, a laboratory study found *M. aeruginosa* growth was higher at 4 and 7 ppt than in the control of 1 ppt (Qiu et al., 2022). The authors suggest these higher salinities promoted *M. aeruginosa* growth during the early stage of culture, partly because it facilitated photosynthesis. The same study found that a salinity of 10 ppt inhibited *M. aeruginosa* growth and caused irreversible damage to the organism.

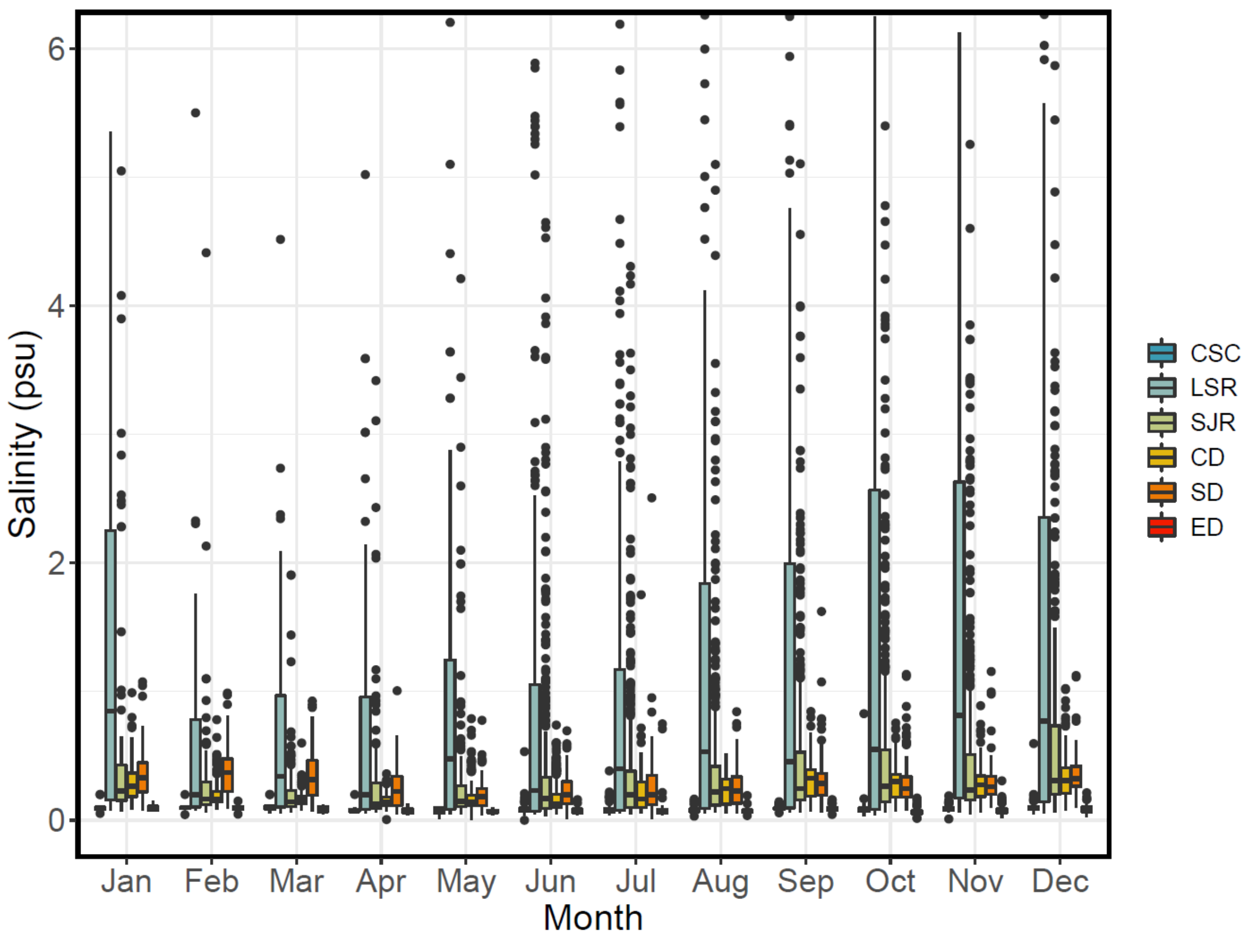

Figure 9. Boxplots of salinity by month and by region for the period 2008-2022. CD=Central Delta; CSC=Cache Slough Complex; ED=East Delta; LSR=Lower Sacramento River; SD=South Delta; SJR=San Joaquin River. Data from the Fall Midwater Trawl Survey (FMWT), Summer Townet Survey (STN), DWR-EMP, and DWR-NCRO monitoring programs available at: (https://portal.edirepository.org/nis/mapbrowse?packageid=edi.731.7).

As *M. aeruginosa* is transported through estuarine systems from freshwater to more saline environments it can cause cells to undergo a salt shock. This immediately decreases photosynthetic activity resulting in decreased growth (Georges de Aulnois et al., 2020). However, when cells are gradually exposed to increasing salinities, they can acclimate or adapt and continue growing even if the cells originated in a lower salinity environment (Melero-Jimenez et al., 2019).

Salinities of 5 ppt are associated with higher microcystin production due to the upregulation of microcystin production genes (Qiu et al., 2022). Thus, *Microcystis* with higher salt tolerance have more intracellular toxins than those in lower salinity environments (Li et al., 2024). Increased salinity also results in higher osmotic pressures that cause *Microcystis* cells to lyse and release toxins into the surrounding waters (Preece et al., 2017). Salinities in most of the Delta remain below 6 ppt (Figure 9), so issues with increased toxin production and cell lysis would be of greater concern in waters downstream of the Delta.

2.3.4 Temperature

Temperature is recognized as one of the strongest positive drivers of CHAB events around the world (Pearl and Huisman 2008, Carey et al., 2012, Lehman et al. 2022). One reason is that cyanobacteria achieve higher growth rates at warmer temperatures compared with other phytoplankton groups (Berg and Sutula 2015). For example, You et al. (2018) found optimal growth rate for *Microcystis* in the laboratory is 27.5°C. In a survey of eight cyanobacteria the growth optima of two *M. aeruginosa* strains were 30–32.5°C and that of *Aphanizomenon gracile* was 32.5°C. Lower growth temperature optima were observed in *Cynlindrospermopsis raciborskii* and *Planktothrix agardhii*, both 27.5°C, while *Dolichospermum* had an optimum of 25°C (Lurling et al., 2013). In another survey of six *Microcystis* strains, their temperature growth optima varied from 31–37° C (Bui et al., 2018). *Microcystis* also stands out with regard to being able to quickly accelerate its growth rate with increases in temperature (Carey et al., 2012). While the acceleration of growth rate with every 10°C increase in temperature (Q10) commonly varies from 1–4 for cyanobacteria, in general, it varies from 4–9 for *Microcystis*, the fastest acceleration recorded for any phytoplankton (prokaryotic or eukaryotic) species (Reynolds 2006).

Surface water temperatures recorded in the Delta during the summer are usually not as high as the growth optima of the various CHAB species mentioned above. However, water temperatures commonly exceed 23°C in Delta waterways during July–September, the period of peak CHAB abundance (Lehman et al., 2013). Notably, long-term temperature data is almost entirely restricted to main channels. In contrast with the main channels where high flushing rates may limit surface water temperatures, dead-end sloughs and marinas are more susceptible to higher absolute temperatures as well as increases over time. In these locations, surface water temperatures from July–September may range from 25–28°C or warmer (Preece et al., 2024b) and could provide ideal conditions for CHAB species to outcompete other phytoplankton groups that have lower growth temperature optima (Berg and Sutula 2015 and references therein). Although these locations appear to have warmer temperatures, limited monitoring of dead-end sloughs and marinas has made it difficult to evaluate temperature changes and trends.

Throughout the Delta, mean monthly surface water temperatures peak in July but the absolute July temperature varies substantially by region (Figure 10). The regions with the lowest July temperatures are in the northern portion and include the Cache Slough Complex region and the lower Sacramento River region (Figure 10). The highest recorded mean July surface water temperatures are in the south delta region where they have varied from 25.9°C–26.1°C, followed by the San Joaquin River varying from 22.8°C–25.1°C, and the central Delta varying from 23.7°C–24.4°C, over the last 15 years (Figure 10). In dead end sloughs and other shallow portions of the Delta, temperatures can be even warmer in July. For example, in July 2022 water temperatures in the Stockton Waterfront were above 28°C (Preece et al. 2024b).

Perhaps the most interesting month in terms of temperature changes over time in the Delta appears to be June. While at the beginning of the record presented in Figure 10 average June surface water temperatures varied around 19–20°C, the temperature hypothesized to promote the emergence of *Microcystis* from the sediments into the water column (Lehman et al., 2017); there has been a significant and linear increase in the June temperatures over time in several regions. The steepest change has been in the east Delta with a rise of 0.24°C per year, followed by the San Joaquin River at 0.15°C per year, and the central Delta at 0.10°C per year. Smaller increases have also occurred in the other regions of the Delta but are not significant (Table 1) In the south Delta temperatures are high relative to the other regions and do not appear to be increasing in the summer months like in the other regions (Figure 10). For example, in the south Delta June surface water temperatures have not increased significantly, varying between 22.4–22.7°C over the 2008–2022 time period (Figure 10, Table 2).

Mean surface water temperatures have also increased for May and October, extending the potential bloom season for *Microcystis* (e.g. Lehman et al., 2017), in several Delta locations (Figure 10). Previous studies suggest that *Microcystis* can persist in surface waters for eight months or longer if temperatures are warmer than 15°C (Lehman et al., 2017, Robertson-Bryan Inc., 2023).

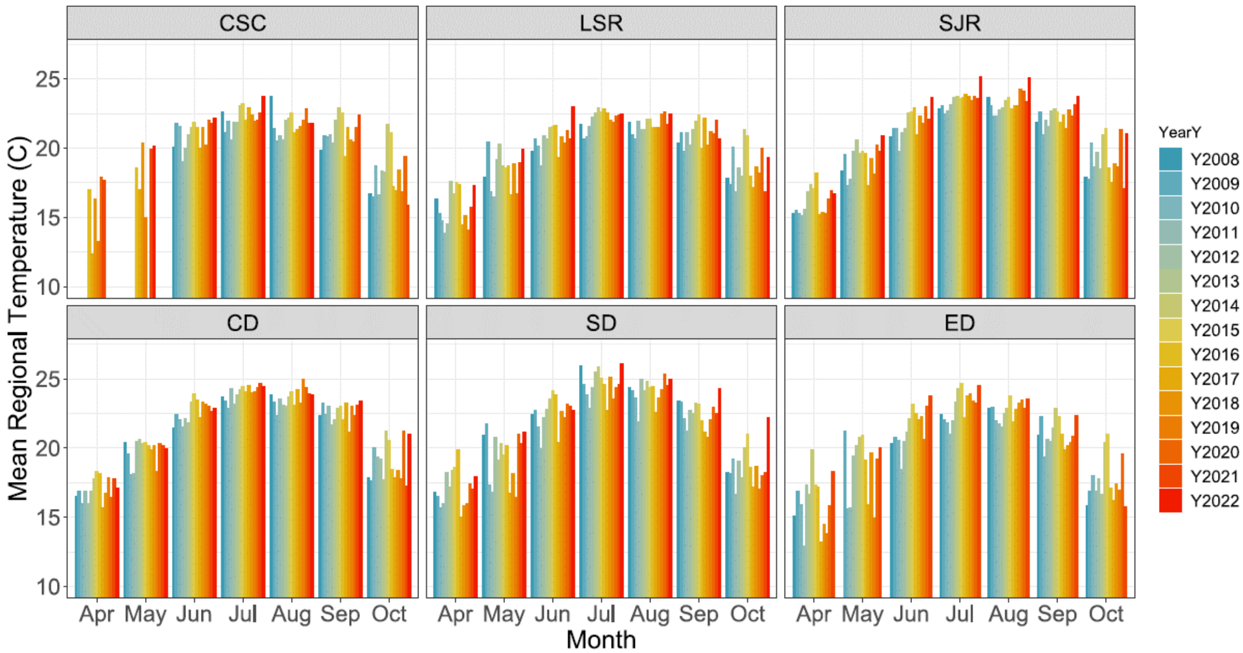

Figure 10. Monthly surface water temperatures averaged from daily surface water temperatures by year and by region for the period 2008-2022. Data from the Fall Midwater Trawl Survey (FMWT), Summer Townet Survey (STN), DWR-EMP, and DWR-NCRO monitoring programs available at: (https://portal.edirepository.org/nis/mapbrowse?packageid=edi.731.7). **CD=Central Delta; CSC=Cache Slough Complex; ED=East Delta; LSR=Lower Sacramento River; SD=South Delta; SJR=San Joaquin River.**

Table 2. Regressions of mean June surface water temperatures (°C) as a function of year (2008-2022; n=15) in six separate regions of the Delta. CD=Central Delta; CSC=Cache Slough Complex; ED=East Delta; LSR=Lower Sacramento River; SD=South Delta; SJR=San Joaquin River. Significant slopes in bold.

Region	Slope (Temp~Year)	Probability Slope	R^2
CD	**0.10**	**0.024**	**0.34**
CSC	0.09	0.132	0.17
ED	**0.24**	**0.005**	**0.50**
LSR	0.11	0.062	0.24
SD	0.06	0.372	0.06
SJR	**0.15**	**0.006**	**0.46**

2.3.5 Nutrients

Concentrations of nutrients can influence the composition, magnitude, and duration of CHAB events and is an important positive driver (e.g., Paerl 2008, Lehman et al., 2017, Wang and Zang 2020, Phlips et al., 2023). Extensive studies of the impact of nutrients (e.g., Dugdale et al., 2007, Jassby 2008, Cloern and Jassby 2012, Kraus et al., 2017) have been completed in the Delta and upper San Francisco Bay and are the focus of ongoing special studies of the Delta Regional Monitoring Program. Two principal sources of nutrients to the Delta are point-source discharges from publicly owned treatment works (POTWs) and agricultural discharges in the form of irrigation return flows and other non-point discharges associated with agriculture (Kratzer et al., 2011, Saleh and Domalgaski 2015, Dahm et al., 2016). The two primary vehicles for loading nutrients into the Delta are the Sacramento River, a principal source of nutrients from POTWs, and the San Joaquin River, a principal source of nutrients from agricultural return flows (Kratzer et al., 2011, Novick et al., 2015).

Given optimal temperatures and irradiances for growth, the upper bound on phytoplankton biomass will be set by the concentration of nutrients available in the water. Referred to as the yield of chlorophyll, the magnitude of phytoplankton biomass that can be produced per unit nutrient consumed has been investigated for freshwater systems based on phosphorus (Dillon and Rigler 1975, Schindler et al., 1978) and for estuarine and coastal systems based on nitrogen (Gowen et al., 1992, Edwards et al., 2003). It is a useful parameter for predicting the size of a harmful algal bloom and for predicting eutrophication (Tett et al., 2003). This parameter has shown remarkable consistency within pelagic mixed phytoplankton communities (i.e. including eukaryotic and prokaryotic phytoplankton groups) across the freshwater-to-marine continuum (Tett et al., 2003). The reason for this consistency can be summed up as phytoplankton containing certain amounts of chlorophyll consume the same amount of nitrogen regardless of location. For example, the yield of chlorophyll from nitrogen (µg chl-*a* produced per µmol nitrogen utilized) in the lower Sacramento River was recently measured by Mussen et al. (2023) as 1.3, which is similar to the yield of 1.1, which has been measured in Scottish coastal water (Gowen et al., 1992).

While the yield of chlorophyll can be measured and calculated for any system, it cannot be used to predict the degree of eutrophication based on nutrient concentrations unless a complete depletion of nutrients occurs in the system.

Nevertheless, the Delta has been established as a high nutrient low chlorophyll system (Cloern and Jassby 2012). As such, the yield of chlorophyll may not be a useful parameter for predicting the degree of eutrophication that can be expected in Delta waterways where nutrients are not depleted even during months of peak phytoplankton productivity (Jassby et al., 2002). Nutrients (including silica) do not limit phytoplankton growth, including diatoms, and nutrient stoichiometry tends not to control phytoplankton community composition (Strong et al., 2021).

One reason for phytoplankton biomass being low relative to the available nutrient pool has been discussed above and is related to light limitation of phytoplankton growth due to water column mixing and sediment resuspension (section 2.3.1). This is a physiological limitation. Other limitations at the population level may include factors such as grazing (e.g. Lopez et al., 2006) that act in concert with physiological limitations to potentially restrict the density of a bloom as well as the geographical distribution of CHABs in the Delta.

2.3.5.1 Nitrogen and Phosphorus

Dissolved inorganic nitrogen and inorganic phosphorus concentrations are relatively high across all regions in the Delta year-round (Figure 11). During summer when inflows and dilutions are at a minimum, the San Joaquin River and the Sacramento River each contribute about half of the total nitrogen load to the Delta, despite the San Joquin River contributing less than 20% of the water flow volume (Kratzer et al., 2011, Novick et al., 2015).

Because nitrogen and phosphorus are not depleted, they are often referred to as being in “excess” of phytoplankton growth requirements in the Delta (Jassby et al., 2002). Both the term “excess” and the term “limiting” with respect to nutrient concentrations are ambiguous. But they can be refined for a given system by comparing the potential yield of chlorophyll to its measured concentration. If we define “limitation” as a concentration of nutrients that does not allow for a full doubling of existing phytoplankton biomass, and “excess” as a concentration of nutrients that allows two or more doublings of phytoplankton biomass then we can describe all the different regions of the Delta using a chlorophyll yield of 1.1 (e.g. Gowen et al., 1992). Focusing on the summer season, concentrations of dissolved inorganic nitrogen (DIN), i.e. the summed concentrations of nitrate, nitrite, and ammonium, typically vary from 8–20 μmol/L in the central Delta to 27–63 μmol/L in the south Delta (Figure 11A). Compared with measured chl-*a* concentrations of 2–4 μg/L in the central Delta and 6–26 μg/L in the South Delta (Figure 3), phytoplankton

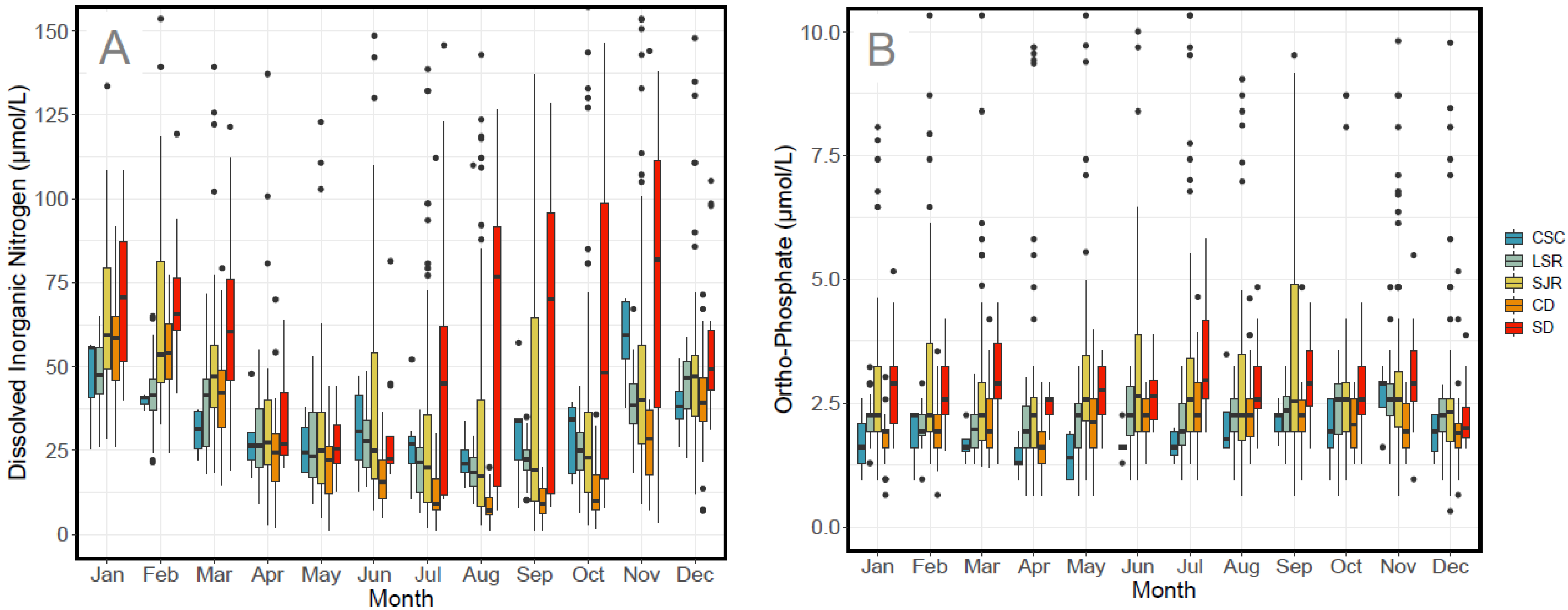

Figure 11. Boxplots of A) DIN (sum of nitrate, nitrite, and ammonium concentrations) and B) ortho-Phosphate, by month and by region for the period 2009-2022. Boxes show median concentration and 25th/75th percentiles; whiskers extend to 1.5x the interquartile range; outliers are shown as black dots. Data from IEP and NCRO programs available at (URL). CD=Central Delta; CSC=Cache Slough Complex; ED=East Delta; LSR=Lower Sacramento River; SD=South Delta; SJR=San Joaquin River. Data from DWR-EMP and DWR-NCRO monitoring programs available at: (https://portal.edirepository.org/nis/mapbrowse?packageid=edi.731.7).

biomass could double two or more times. Therefore, DIN can be described as being in excess of phytoplankton demand in all regions of the Delta.

A question that comes to mind, given the excess of nutrients available in Delta waterways, is what would happen if conditions, whether it be temperature, mixing, sediment resuspension, or grazing, changed, and phytoplankton were able to deplete the available pool of nutrients? In other words, how bad could eutrophication (and potentially CHAB events) become in the main channels if given a chance? Again, using the same chlorophyll yield relationship we can add the residual water column DIN concentration to the measured chl-*a* (because the chl-*a* represents DIN that has already been converted into phytoplankton biomass) to give the potential chl-*a* concentration that could be present in the water if nutrients were completely drawn down (Figure 12). This exercise demonstrates that the Delta phytoplankton community has "room to grow", particularly in the San Joaquin River and in the south Delta (Figure 12). Moving into a warmer and hydrologically uncertain future, this large and unused nutrient pool may present an increasing risk for CHAB events. For an excellent review of the link between nutrients and CHAB dynamics, see Ibelings et al., (2021).

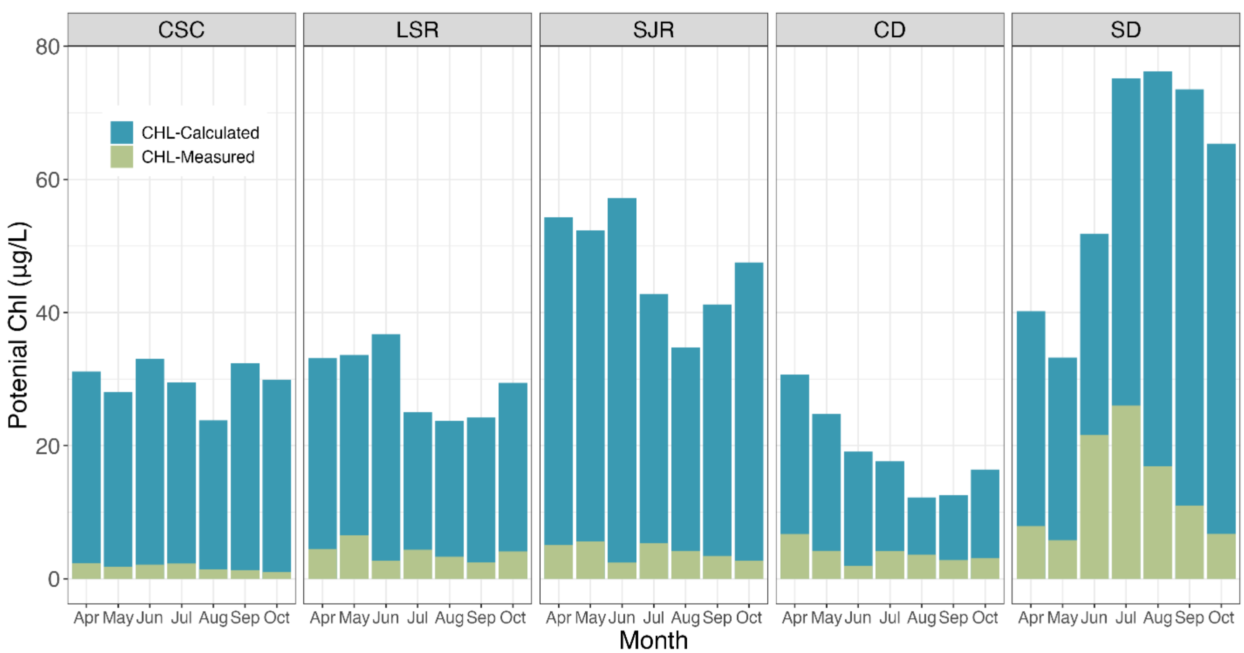

Figure 12. Potential chl-*a* averaged by month and by region for the period 2008-2022. Potential chl-*a* estimated as the sum of measured chl-*a* (CHL-measured) and chl-*a* calculated (CHL-calculated) based on the yield of chlorophyll from DIN (µg chl:µmol DIN; Gowen et al., 1992). Data from the DWR-IEP and DWR-NCRO programs, available at

(https://portal.edirepository.org/nis/mapbrowse?packageid=edi.731.7). CD=Central Delta; CSC=Cache Slough Complex; LSR=Lower Sacramento River; SD=South Delta; SJR=San Joaquin River.

2.3.5.2 Silica

The principal source of dissolved silica, or silicate, to the upper San Francisco Bay and the Delta is the Sacramento River (Schemel and Hager 1986). In Suisun Bay, silicate concentrations typically vary from 200-300 µmol/L and are 10-fold or greater compared with concentrations of DIN (Wilkerson et al., 2006). Diatoms, which require silica for their frustules, typically take up and use silicate in a ratio of 1:1 with DIN (Turner et al. 1998). As a result, silicate is not limited to phytoplankton growth in San Francisco Bay or the Delta.

2.3.5 Cyanobacteria Seedstock

Cyanobacteria cells in the water column are subject to a range of fates, including physical export, death, or dormancy. Dormant cells enter a vegetative state and sink out of the water column and into the sediment. Overwintering vegetative *Microcystis* colonies remain photosynthetically active and reenter the water column through active resuspension when environmental factors provide favorable growth conditions or through passive wind-induced resuspension (Verspagen et al., 2005). Once established in a system, this overwintering strategy allows *Microcystis* cells to form recurring, seasonal blooms (Cai et al., 2021).

With no obvious upstream sources for *Microcystis* to enter the Delta, the most likely source of summer blooms within the system is that they originate primarily from overwintering *Microcystis* seedstocks that recruit to the water column when conditions are favorable.

A recent study found that the hotspot locations of the Stockton Waterfront and Discovery Bay had significantly higher seed stock ($p<0.05$) in April than the six other study sites including main channel sites and the flooded islands Frank's Tract and Mildred Island (Preece et al., *in review*). However, other locations also retained *Microcystis* seedstock in the spring suggesting that multiple locations in the Delta may seed summertime *Microcystis* blooms. Further work is necessary to fully elucidate the importance of cyanobacteria seedstock as a positive driver of CHABs in the Delta.

3 Overview of Current CHAB Monitoring Efforts

Although a coordinated program with dedicated funding for monitoring CHABs in the Delta does not exist, long-term ambient water quality monitoring programs generate a remarkable coverage of ancillary data that can potentially be used to support CHAB monitoring. In addition, efforts have been developed to monitor a few CHAB-specific parameters. Still, most information regarding CHABs in the Delta has been obtained through short-term special studies. The fragmented nature of these studies and current monitoring efforts highlights the need to develop a strategy to achieve a coordinated and collaborative approach to CHAB monitoring.

Section 3.1 below describes the long-term continuous and discrete monitoring that is in place for water quality in the Delta that can be used to indicate the development or presence of CHABs. Maps in this section show the spatial coverage of monitoring by various partners. More information regarding the monitoring efforts of partners can be found in the Delta HABs Monitoring information sheet.

This Strategy recommends compiling a list of current and past special studies (Recommendation 4.5).

3.1 Long-term Continuous and Discrete Monitoring

Table 3 shows the ongoing monitoring programs for the Delta that collect continuous and/or discrete data that can be used to indicate the development or presence of CHABs. The spatial scope describes the general areas the monitoring program oversees. Individual monitoring sites may have been added, removed, or moved by programs over time. Monitoring frequency may also have changed over time. The phytoplankton time span column notes when each program monitored phytoplankton. The water quality time span notes when the first relevant constituents to CHAB monitoring may have been added to these monitoring programs midway through the time spans. Thus, in most cases, the full dataset these organizations offer is unavailable for these full-time spans. Agencies that manage water quality monitoring stations include the DWR, CDFW, USBR, and USGS.

Locations and water quality constituent data of the maps were consolidated from the California Data Exchange Center (CDEC), the Environmental Data Initiative (EDI) Delta Water Quality Integrated Dataset Package (Bashevkin, Perry, and Stumpner, 2022), and through personal communication with individual monitoring programs. Some stations may have been excluded from the map if they were not listed in CDEC or were no longer in service. CDFW stations were not included if data were only collected in either summer or fall, rather than in both seasons. Each monitoring program samples annually but may occur at different periods

Table 3. Temporal and spatial information about the monitoring programs included in Figures 14-17.

Agency	Dataset	Spatial Scope	Monitoring Frequency	Parameters	Phytoplankton Time Span	Water Quality Time Span
DWR	Environmental Monitoring Program	San Pablo Bay, Suisun Bay, Suisun Marsh, Montezuma Slough, Sacramento River, San Joaquin River, Old and Middle Rivers	At least monthly	Phytoplankton ID, MVI, Chl-*a*, Nutrients, Temperature, Turbidity, Conductivity, pH, Dissolved Oxygen	1975–present	1975–present
DWR	Yolo Bypass Fish Monitoring Program	Yolo Bypass, Cache Slough Complex, Sacramento River	Variable, roughly monthly, typically December/January through June	Phytoplankton ID, Chl-*a*, Temperature, Turbidity, Conductivity, pH, Dissolved Oxygen	1998–present	1998–present
DWR	Water Quality Evaluation Section	South Delta, Central Delta, North Delta	Monthly	Phytoplankton ID, Chl-*a*, Temperature, Turbidity, Conductivity, pH, Dissolved Oxygen	2019–present (FlowCam)	1999–present
CDFW	Fish Restoration Program Effectiveness Monitoring Team	Cache Slough Complex, Lower Sacramento River, Confluence, Suisun Bay, Suisun Marsh	Spring, summer, and fall	Phytoplankton ID, MVI, Chl-*a*, Nutrients, Temperature, Turbidity, Conductivity, pH, Dissolved Oxygen	2015–present	2016–present
USGS	California Water Science Center Biogeochemistry Group	Delta wide during mapping surveys (30 sites), currently ~12 fixed stations but amount of sampling depends on funded projects.	Monthly, spring, summer, fall	Phytoplankton ID, MVI, Chl-*a*, Nutrients, Temperature, Turbidity, Conductivity, pH, Dissolved Oxygen, Algal Toxins	2018–present	1971–present

Agency	Dataset	Spatial Scope	Monitoring Frequency	Parameters	Phytoplankton Time Span	Water Quality Time Span
USGS	SFB Research and Monitoring Program	San Francisco Bay, San Pablo Bay, Suisun Bay, and Lower Sacramento River	Every 2 weeks, monthly, year-round	Phytoplankton ID, Chl-*a*, Nutrients, Temperature, Turbidity, Conductivity, pH, Dissolved Oxygen	1992–present	1969–present
State Water Board/SFEI	HAB Satellite Analysis Tool	Statewide lakes and major water bodies including Cache Slough, Franks Tract and lower Sacramento and San Joaquin Rivers.	Composite 1- or 10-day pixel max.	Cyanobacterial index; Chl-*a* (beta)	2016–present, (Cyanobacterial index); 2023-present (Chl-*a*)	N/A

throughout the year. DWR (Perry et al., 2023) and USGS have collected data over the longest time frame — since the 1970s, and 1990s, respectively, though methodological changes prohibit using their full extents.

Differences in methods and monitoring locations within and between monitoring programs mean that some data are not comparable. This issue essentially shortens any one dataset and greatly limits the use of the existing data for any data-intensive project, such as forecasting CHABs. Note the lack of a cyanotoxin map. No long-term continually funded program collects routine cyanotoxin data at set stations in the Delta.

The series of maps below show where existing monitoring stations collect long-term data related to CHABs by the monitoring programs in Table 3. Data collected at these locations can potentially be leveraged toward a collaborative monitoring effort and help implement other aspects of this Strategy including providing information on the status, trends, and drivers of CHABs.

The map in Figure 13 shows the extent of the HAB Satellite Analysis Tool, as described in section 2.1.2 Remote Sensing. This tool estimates cyanobacterial abundance and chlorophyll over time in large waterbodies. It does not cover benthic blooms because measurements are based on surface reflectance. The other maps, Figure 14-Figure 17, spatially summarize long-term water quality monitoring programs with consistent funding, as defined by their agencies. The continuous stations (Figure 14) collect water quality data and chlorophyll concentrations. The nutrient monitoring stations (Figure 15) represented a mix of stations with continuous monitoring by sensors (i.e., for nitrate specifically) and stations where discrete grab samples were collected and analyzed for nitrogen and phosphorus in a laboratory. The MVI score (Flynn et al., 2022) measurements were collected discretely (Figure 16), thus, monitoring these locations occurred at different frequencies and periods of the year, including summer and fall or year-round. Routine phytoplankton monitoring stations, which monitor for the abundance of phytoplankton taxa, including cyanobacteria, and biovolume are obtained at each sampling location (Figure 17). The phytoplankton station locations were obtained from USGS's Data Integration Portal Phytoplankton dashboard and verified with each monitoring program. Additional maps with monitoring data are in Appendix A.

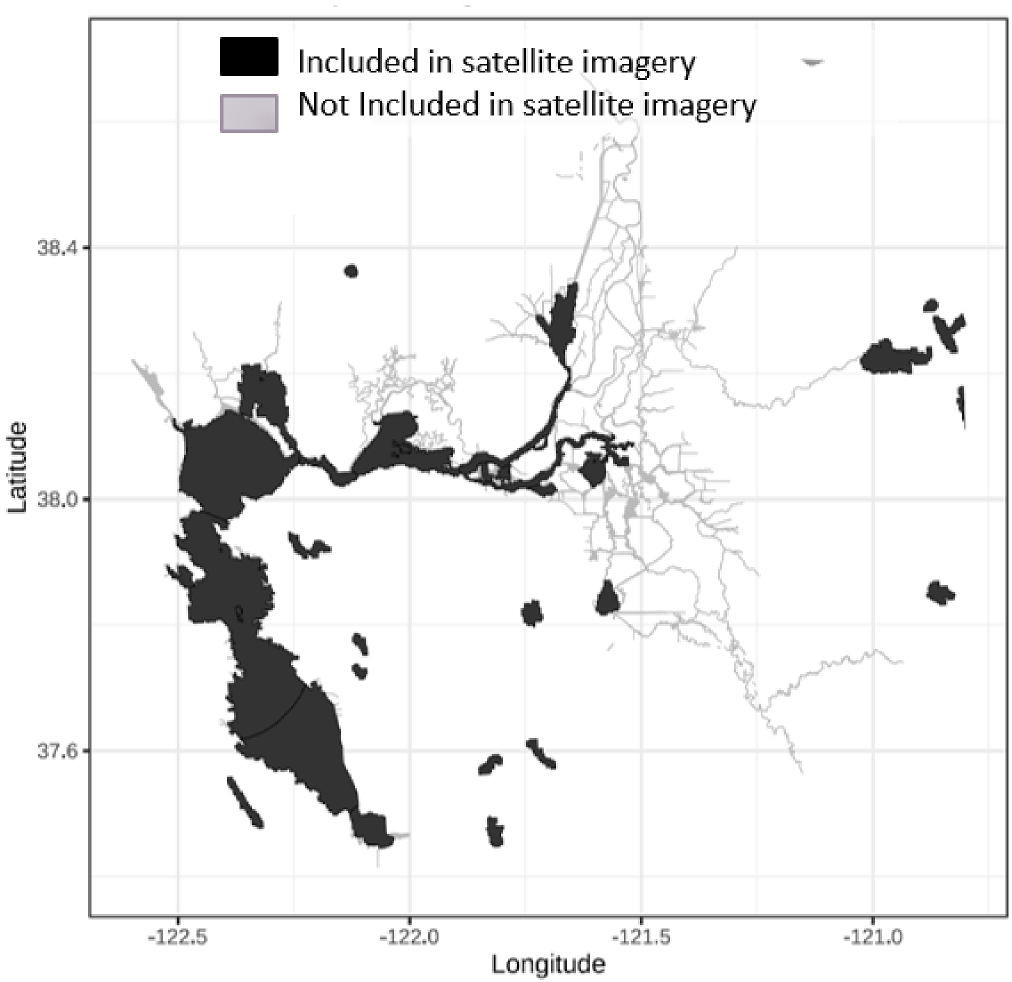

Figure 13. Map of areas covered by the State Water Board Harmful Algae Satellite Analysis Tool hosted by the San Francisco Estuary Institute. The area covered by the tool is filled in black. The tool routinely acquires satellite imagery products with data sourced from geospatial satellite imagery from Sentinel-3's Ocean Land and data post-processed by NOAA.

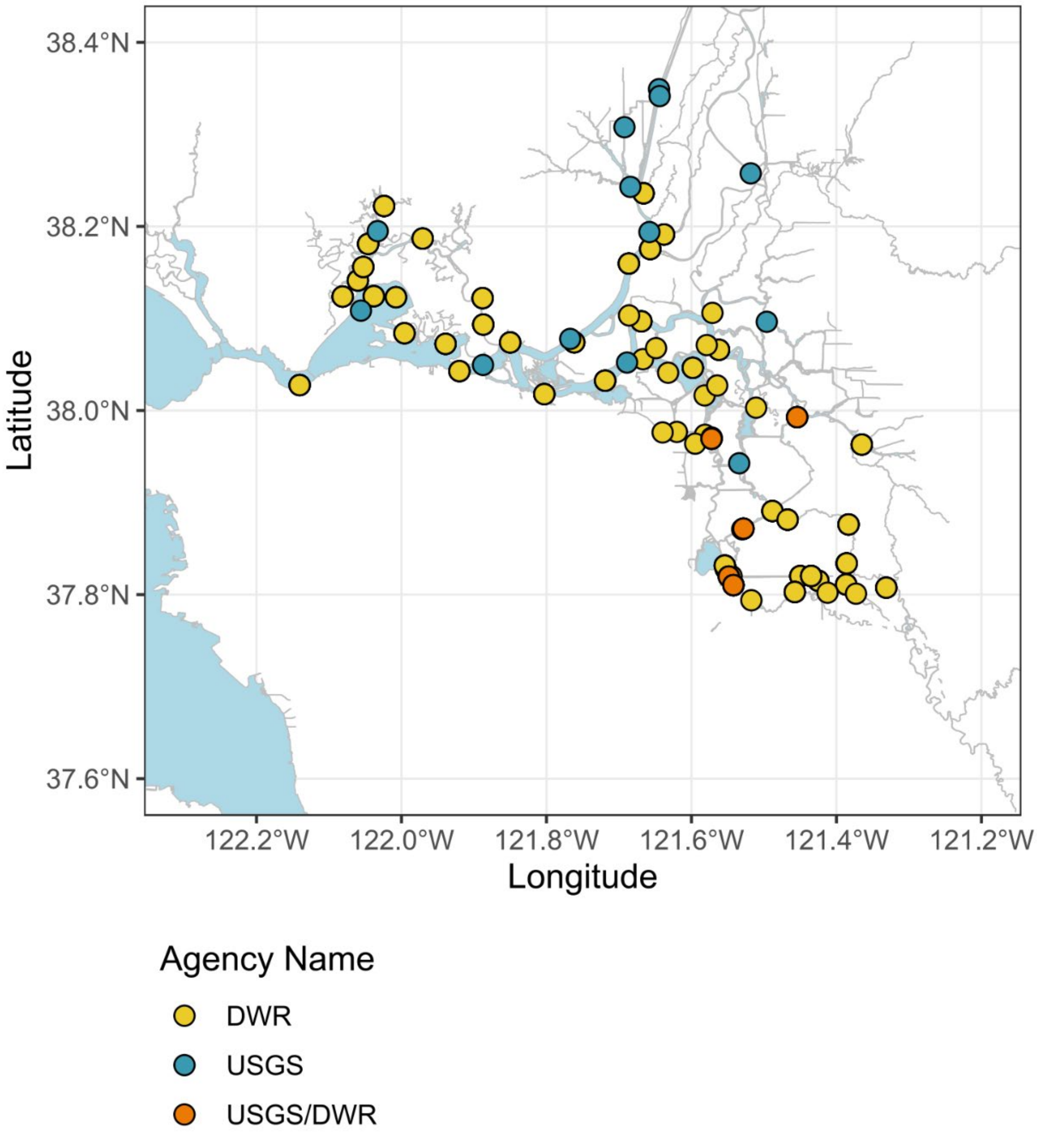

Figure 14. Map of continuous water quality stations that measure pH, dissolved oxygen, electrical conductivity, temperature, and chlorophyll.

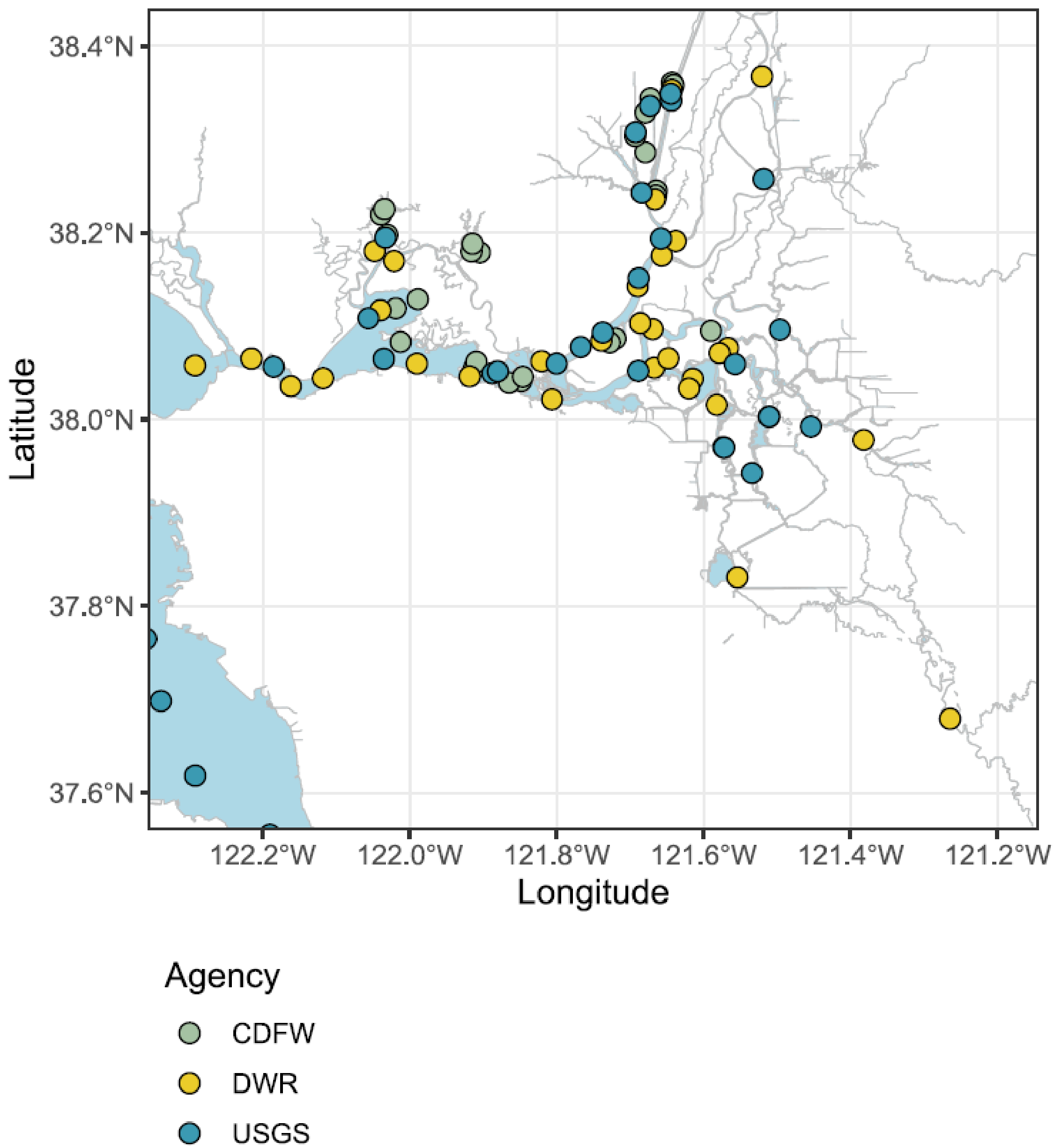

Figure 15. Map of stations that measure dissolved ammonia, dissolved nitrate/nitrite, dissolved organic nitrogen, and/or total Kjeldahl nitrogen. Total phosphorus and/or dissolved orthophosphate measurements are collected at the CDFW, DWR, DWR/USBR, and a subset of the USGS stations. See Appendix A for a map showing information on phosphorus.

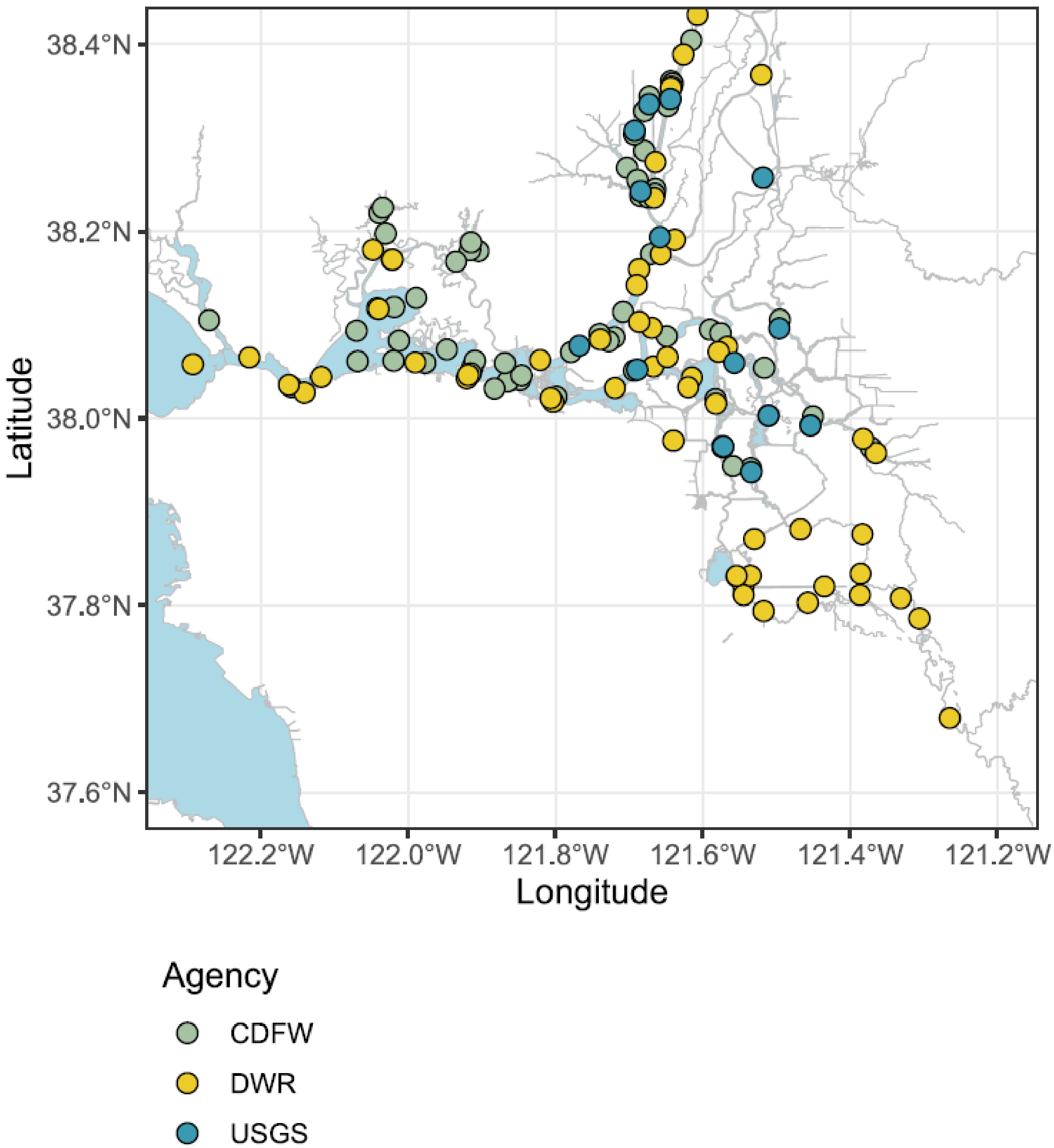

Figure 16. Map of *Microcystis* Visual Index Scale stations.

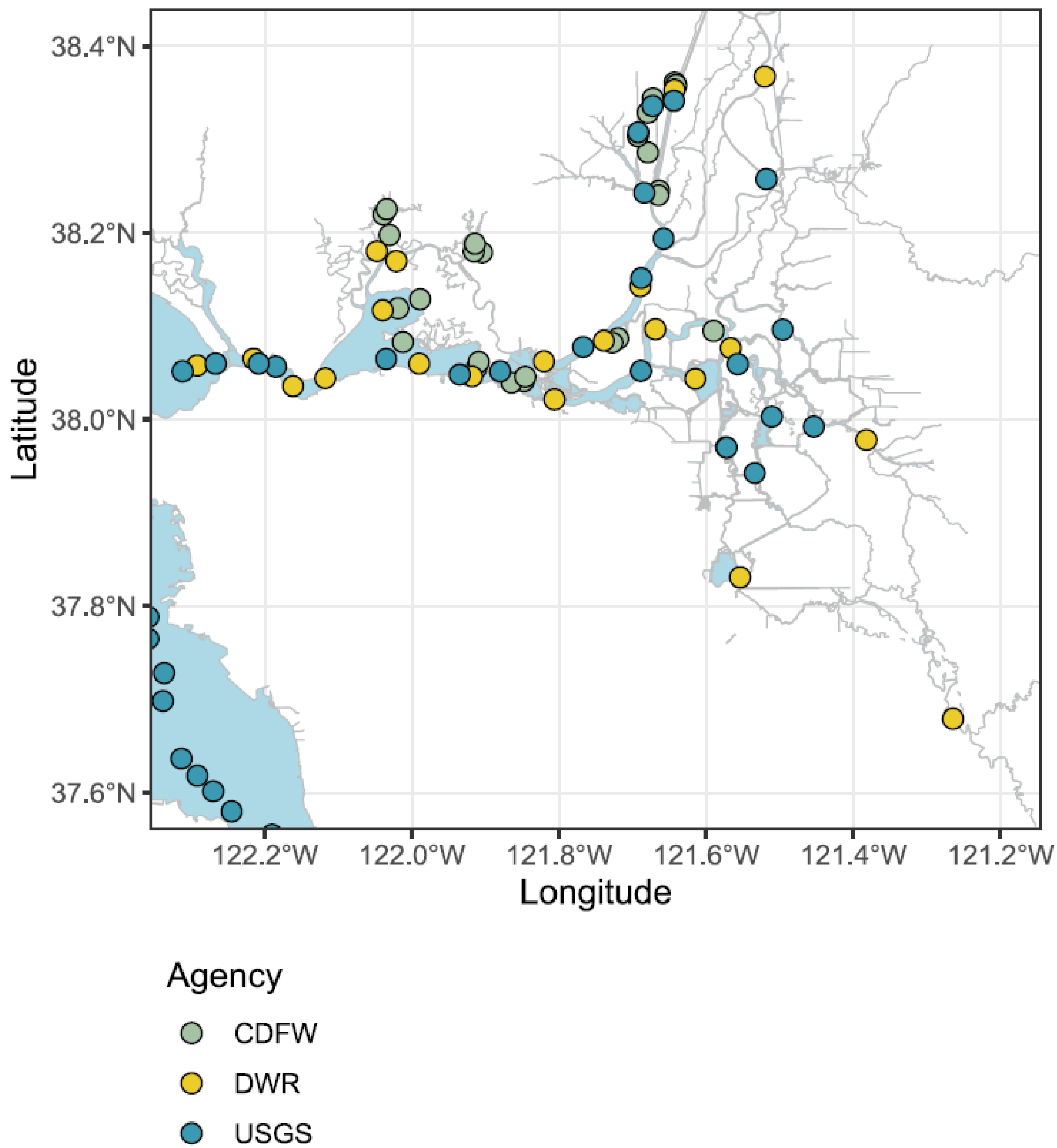

Figure 17. Map of phytoplankton identification stations at which samples were collected for taxonomic analysis and biovolume measurement. The depth of sample collection varied by program.

3.2 On-going Parallel Efforts

3.2.1 State Water Board's FHAB Framework and Strategy

The State Water Board FHAB program began in 2014, and in 2019, the Governor signed AB834 to establish a formal statewide "Estuarine and Freshwater Harmful Algal Bloom Program." In 2021, the FHAB program, in partnership with the Southern California Coastal Watershed Project, released a "Framework and Strategy for Freshwater Harmful Algal Bloom Monitoring" that provided the background for development of this Strategy.

The FHAB Framework and Strategy document is referenced throughout the recommendations in Section 5 below as goals, objectives, and recommendations build off the information contained in that document.

3.2.2 State Water Board's Bay-Delta Water Quality Control Plan Updates

The State Water Board is currently updating the Water Quality Control Plan for the San Francisco Bay and Sacramento-San Joaquin Delta (Bay-Delta Plan). The Staff Report acknowledges that CHABs are increasing in magnitude and frequency in the Bay-Delta system yet are not routinely monitored. The Staff Report states the State Water Board's intent to coordinate with the development of this Strategy as well as the broader community to ensure that the highest priority monitoring for CHABs is conducted. Additionally, the Staff Report iterates the State Water Board's interest in pursuing special studies and synthesis of HABs data in the Delta to fill knowledge gaps.

3.2.3 Delta Regional Monitoring Program

The Delta Regional Monitoring Program (DRMP) is a non-profit organization dedicated to monitoring beneficial use protections and restoration efforts in the Delta. State and federal laws require dischargers to monitor waters downstream of their discharge. For some types of data, this could be better accomplished through a coordinated monitoring program. Rather than continuing uncoordinated monitoring programs, regional monitoring allows dischargers to pool funds and expertise to more efficiently gather data to inform management and policy decisions facing the Delta. The DRMP is led by representatives of publicly owned treatment works, municipal stormwater programs, irrigated agriculture, water suppliers, and state and federal agencies. The primary focus areas for the DRMP include mercury, constituents of emerging concern, pesticides, and nutrients (including CHABs). The DRMP developed a Multi-Year Nutrient Study Plan to be implemented in the next three to five years supporting a combination of modeling exercises, special studies, and in situ monitoring. The DRMP examines how nutrient concentrations might be influenced by factors such as climate change, wetland restorations, and water management practices. One aim is to model predicted nutrient loadings and concentrations and examine how ranges of nutrient concentrations change throughout the Delta following planned reductions in nutrient loadings. The DRMP conducts research on nutrients, specifically focusing on nitrogen and phosphorus concentrations and their ratios. The aim of this research is to characterize nutrient concentrations that can limit CHAB biomass and cyanotoxin accumulation to safe levels, control nuisance macrophytes, and promote the growth of beneficial phytoplankton and macrophytes. Monitoring activities pertaining to CHABs focus on characterizing species, bloom magnitudes, geographic extent, timing of blooms, and cyanotoxin levels. The DRMP also investigates factors contributing to CHABs in the Delta and actively seeks to collaborate, leverage funding, and explore partnerships with other monitoring programs to enhance our collective understanding of status and trends in the Delta.

3.2.4 NOAA MERHAB

In September 2023, NOAA announced that it was awarding a grant, through its Monitoring and Event Response Research Program (MERHAB) to support the development of a HAB monitoring program for the San Francisco Estuary. The project, led by scientists at the SFEI, USGS, and DWR, will leverage ongoing research and monitoring activities in the Bay and Delta to build a robust system-wide HAB monitoring program for the San Francisco Estuary. Key collaborators include UC Santa Cruz, Bend Genetics, the San Francisco Bay and Central Valley Regional Water Boards, San Francisco Baykeeper, Cal Maritime Academy, Restore the Delta, and NOAA-National Centers for Coastal Ocean Science.

Major project components include:

1. Enhancing existing monitoring data sources with new technologies and tools, including remote sensing, continuous water quality sensors, molecular DNA-based methods, and community science monitoring
2. Building an online HAB dashboard to provide managers with a decision-support-tool for HAB mitigation

3. Improved understanding of HAB transport dynamics through sampling of toxins/HAB cells using multiple methods such as water grab samples, passive samplers (Solid Phase Adsorption Toxin Tracking), shellfish, and molecular tools
4. Convening a Management Transition Advisory Group (MaTAG) composed of managers, regulators, and NGOs to generate the information necessary for developing a coordinated HAB strategy

The MERHAB project is referenced throughout the recommendations in Section 5 below, as there are numerous opportunities to leverage the Delta CHAB Strategy with components of the MERHAB project.

4 Knowledge Gaps and Collaboration Opportunities

As a result of the Fall 2022 workshop and a review of available Delta CHAB information (see above in Sections 2 and 3), a number of knowledge gaps – both data and collaboration-related – were identified. Addressing these gaps will lay the foundation for the Delta science community to move beyond reactionary monitoring for CHABs to having tools to effectively gather data that can inform management and mitigation options for CHABs.

4.1 Data Gaps

1. The lack of routine CHAB monitoring data is a significant impediment to progress on mitigation and management for Delta CHABs.
2. Most monitoring to date has focused on main channels and excluded dead-end sloughs and backwaters, the areas of the Delta known for having the most severe CHAB problems. Data that has been collected in these dead-end areas have been disconnected from routine water quality monitoring programs. Thus, it is necessary to routinely monitor these areas in conjunction with interconnected Delta waterways to understand localized and broad-scale CHAB dynamics and to inform the development of mitigation strategies.
3. Although the environmental factors that drive CHABs are understood in a general sense (e.g., warm temperatures, sufficient nutrients, etc.), many questions remain about the interaction between environmental factors, annual environmental variations, site-specific processes, a changing climate, and how anthropogenic activities impact Delta CHABs.

4. There is not enough information on the importance of different CHAB drivers on a spatial or temporal scale, nor is there funding available to implement realistic mitigation approaches or to develop a predictive CHAB model.

4.2 Collaboration Gaps and Opportunities

1. There is a collaboration gap amongst the state agencies with legal responsibilities for water management and water quality.
2. There is no formal mechanism for collaboration with Delta communities, Tribes, and other interested parties.
3. The Delta science community would benefit from a standardized approach to monitoring and CHAB data analysis.
4. Data should be publicly available in a format that is accessible and able to be readily integrated.
5. Training should be made available to ensure a consistent sample collection and reporting approach.

5 Goals, Objectives and Recommendations

The overall goal of this document is to develop a collaborative and cohesive CHAB monitoring strategy for the Delta. Building upon the data and collaboration gaps, five primary goals were identified, and within each goal are two to four objectives that can help accomplish the goal (Table 3. Goals and Objectives.). Detailed recommendations are provided to expand on the goals and objectives.

This Strategy is focused on informing water quality management decisions in a 3- to 5-year horizon, consistent with the FHAB Strategy's guidance of a "near-term" implementation. However, recommendations in this Strategy may also fall under the long-term implementation of >5 years and are included for consideration as this Strategy is implemented.

Multiple recommendations are identified throughout different sections of this CHAB Strategy, some conceptual and others technical. Some recommendations that have been previously implemented but have not included a collective agreement or 'buy-in' from all Delta interested parties. The implementation of the CHAB Strategy would provide a mechanism for this collective agreement to occur.

Table 4. Goals and Objectives.

Goal 1: Enhance Delta CHAB collaboration	• Objective 1-1 Organize a collaborative approach to implement Delta CHAB Strategy • Objective 1-2 Promote coordination, collaboration, and communication among agency and community partners • Objective 1-3 Identify mechanisms to ensure sustainability of long-term Delta CHAB monitoring and collaboration.
Goal 2: Identify management questions, monitoring goals, and objectives	• Objective 2-1 Identify how monitoring results will be used by decision-makers • Objective 2-2 Consider data and monitoring gaps needed to answer management priorities • Objective 2-3 Determine how to prioritize questions and goals
Goal 3: Develop a CHAB monitoring program	• Objective 3-1 Identify specific monitoring program(s) needed to achieve the management questions and goals • Objective 3-2 Identify priority monitoring parameters, locations, sampling period/frequency, and methods for the monitoring program(s) • Objective 3-3 Create implementation guidance for Delta CHAB monitoring • Objective 3-4 Synergize Delta CHAB monitoring with ongoing CHAB efforts
Goal 4: Develop collaborative reporting protocols	• Objective 4-1 Validate and standardize current methods used for monitoring CHABs • Objective 4-2 Develop protocols for accurate and timely reporting
Goal 5: Utilize a data sharing platform	• Objective 5-1 Identify existing CHAB and HAB data repository platforms • Objective 5-2 Explore how to integrate Delta CHAB monitoring data with existing data repositories • Objective 5-3 Develop protocols to make CHAB data accessible and available to all

This section provides recommendations to address the overall goals and objectives of the Delta CHAB Strategy. Table 5 summarizes the recommendations, and the sections following provide details on each recommendation. Due to the costs associated with each recommendation, and other considerations, prioritization of the recommendations for funding will be necessary (*Recommendation 2.4 Provide approach(es) for prioritizing management questions and goals).*

Given general funding uncertainties and the lack of an overall CHAB management framework for the Delta, an adaptive management approach would be necessary to successfully implement this Strategy (Delta ISB 2022). Please see section 7 for details on the adaptive management approach.

Table 5. Recommendations and Objectives that they address

Recommendation	Primary Objective(s)	Secondary Objective(s)
Recommendation 1.1 Identify co-chairs or a mechanism for leadership of coordination and implementation of the Strategy	**1-1**	**1-2, 1-3**
Recommendation 1.2 Form CHABs Working Group to develop final goals, management questions, and monitoring Strategy and prioritize special studies.	**1-1**	**1-2, 1-3, 2-1, 2-2, 2-3, 4-1, 4-2, 5-1, 5-2, 5-3**
Recommendation 1.3 Identify existing barriers to collaboration/cooperation and identify methods for overcoming them	**1-2**	**1-1, 1-3**
Recommendation 1.4 Strengthen and expand partner relationships	**1-2, 1-3**	**1-1, 2-1, 2-2, 2-3**
Recommendation 1.5 Hold an annual meeting focused specifically on Delta CHABs	**1-2, 1-3**	**1-1, 2-1, 2-2. 2-3, 3-1, 3-2, 3-3, 3-4, 4-1, 4-2, 5-1, 5-2, 5-3**
Recommendation 1.6 Identify funding to support implementation of the Strategy	**1-3**	**1-1. 1-2**

Recommendation 2.1 Consider the amount and type of monitoring information needed by managers to support decision-making	**2-1**	**2-2, 2-3, 3-1, 3-2, 3-3, 3-4**
Recommendation 2.2 Consider regional, state, and national CHAB documents, strategies, and guidance when developing management goals and questions	**2-3**	**2-1, 2-2, 3-1, 3-2, 3-3, 3-4**
Recommendation 2.3 When possible, coordinate Delta CHAB questions and goals with ongoing local and state efforts	**2-3**	**2-1, 2-2, 3-1, 3-2, 3-3, 3-4**
Recommendation 2.4 Provide approach(es) for prioritizing management questions and goals	**2-2**	**1-1, 1-2, 1-3, 2-1, 2-3, 3-1, 3-2, 3-3, 3-4**
Recommendation 2.5 Publish and share final management questions and goals with all interested parties	**2-2**	**1-1, 1-2, 1-3, 2-1, 2-3, 3-1, 3-2, 3-3, 3-4**
Recommendation 3.1 Based on the goals and objectives developed in Goal 2 identify monitoring programs and special studies needed to achieve outcomes	**3-1, 3-2, 3-3**	**2-1, 2-2, 2-3, 3-4**
Recommendation 3.2. Develop monitoring program(s) design characteristics	**3-2, 3-3**	**2-1, 2-2, 2-3, 3-1, 3-4**
Recommendation 3.3 Based on recommendations described above, design monitoring program(s)	**3-2, 3-3**	**2-1, 2-2, 2-3, 3-1, 3-4**
Recommendation 3.4 Utilize community science	**3-4**	**2-1, 2-2, 2-3, 3-1, 3-2, 3-3**
Recommendation 3. 5 Consider resources that are currently available or that may be available in the future	**3-4**	**2-1, 2-2, 2-3, 3-1, 3-2, 3-3**
Recommendation 3.6 Implement special studies to address data gaps and technical questions	**3-3**	**2-1, 2-2, 2-3, 3-1, 3-2, 3-4**
Recommendation 4.1 Compare, review, and standardize sampling and laboratory methods	**4-1**	**4-2**
Recommendation 4.2 Ensure CHAB-related SOPs are easily accessible	**4-1**	**3-1, 3-2, 3-3, 3-4, 4-2**

Recommendation 4.3 Develop a programmatic Quality Assurance Program Plan (QAPrP) for Delta CHABs	**4-1**	**3-1, 3-2, 3-3, 3-4, 4-2**
Recommendation 4.4 Develop training and intercalibration plan	**4-1**	**3-1, 3-2, 3-3, 3-4, 4-2**
Recommendation 4.5 Report on CHAB monitoring and special study findings	**4-2**	**3-1, 3-2, 3-3, 3-4, 4-1**
Recommendation 5.1 Develop a comprehensive list of all currently used data repository platforms, data resources, and other Delta CHAB related resources	**5-1**	**5-2, 5-3**
Recommendation 5.2 Coordinate with the NOAA MERHAB data dashboard	**5-2, 5-3**	**3-1, 3-2, 3-3, 3-4, 5-1**
Recommendation 5.3 Develop and maintain list of all routine and special studies	**5-2**	**5-1, 5-3**
Recommendation 5.4 Incorporate open data principle	**5-3**	**3-1, 3-2, 3-3, 3-4, 5-1, 5-2**

5.1 Goal 1: Enhance Delta CHAB Collaboration

- **Objective 1-1 Organize a collaborative approach to implement Delta CHAB Strategy**
- **Objective 1-2 Promote coordination, collaboration, and communication among partners**
- **Objective 1-3 Identify mechanisms to ensure the sustainability of long-term Delta CHAB monitoring and collaboration**

Recommendation 1.1 Identify co-chairs or a mechanism for leadership of coordination and implementation of the Strategy

There is currently no funding associated with this Strategy; thus, to achieve this recommendation, it is necessary to build collaboration to perform role. Several potential approaches for helping to achieve this recommendation could be considered: 1) A rotation of key personnel – a representative from a different agency, two different agency representatives, etc. that rotates on a 2-3 year cycle, similar to the CCHAB Network co-chairs; 2) this work could be folded into an existing workgroup; 3) a small group of people could lead coordination and implementation of the Strategy; or 4) an individual could be appointed as the full-time lead and work with an interagency advisory panel to help direct the work.

This final option is most feasible if funding were secured to develop a funded position with a leadership role in representing all Delta CHAB partners and being a collective voice for all Delta-related CHAB issues. That position could implement this plan, develop any successor plans and policies for CHABs in the Delta, and scale to all HABs generally in the watershed including the San Francisco Bay. This position could potentially be developed by an agency or agencies or filled by a consultant.

Recommendation 1.2 Form CHABs Working Group to develop final goals, management questions, and monitoring strategy and prioritize special studies.

This recommendation is in place to develop the CHABs Working Group to work closely with the lead(s) described in *Recommendation 1.1 Identify co-chairs or mechanism for leadership of coordination and implementation of the Strategy.* To ensure that this group is effective and able to work together effectively to develop final management goals and questions, it is recommended that approximately 8 to 10 representatives serve on this group. One of the major roles of the CHABs Working Group will be to work together to develop and finalize the management goals and questions (see Goal 2 and Recommendations below). In addition to developing and finalizing the management goals and questions the CHABs Working Group should also plan to develop a prioritization structure to address the recommendations within this document (*Recommendation 2.4 Provide approach(es) for prioritizing management questions and goals*).

The first step in developing the CHABs Working Group is to identify key personnel from government, citizenry, and stakeholder groups. This key personnel group should be willing and able to allocate sufficient time to work on developing the management goals and questions and develop the monitoring Strategy. The CHABs Working Group should seek input from managers to ensure the Strategy is able to address management needs. This can be achieved by including managers on the CHABs Working Group or having manager representatives with technical expertise participate. For the key personnel, representatives may include those listed above in Section 1.4 Multi-Organization Coordinated Monitoring.

It will be critical to have the voices of many people heard in the CHABs Working Group, *Recommendation 1.4 Strengthen and expand partner relationships,* below, focuses on how to include a wider group of people in the ongoing CHAB related work.

The CHABs Working Group will coordinate with the MERHAB MaTAG to build consistency between efforts.

Table 6 lists the Strategy Recommendations that are the responsibility of the CHABs Working Group to carry out. This table can be used to identify action items to carry out these Recommendations when the CHABs Working Group is formed.

Table 6. CHABs Working Group Responsibilities for Strategy implementation.

Recommendation 1.1	*Identify co-chairs or mechanism for leadership of coordination and implementation of the Strategy*
Recommendation 1.4	*Strengthen and expand partner relationships*
Recommendation 1.5	*Hold an annual meeting focused specifically on Delta CHABs*
Recommendation 2.4	*Provide approach(es) for prioritizing management questions and goals*
Recommendation 2.5	*Publish and share final management questions and goals with all interested parties*
Recommendation 3.1	*Based on the goals and objectives developed in Goal 2 identify monitoring programs and special studies needed to achieve outcomes*
Recommendation 3.4	*Utilize community science*
Recommendation 4.1	*Compare, review, and standardize sampling and laboratory methods*
Recommendation 4.1.1	*Standardize terminology*
Recommendation 4.2	*Ensure CHAB related SOPs are easily accessible*
Recommendation 4.2.1	*Create an inventory of SOPs*
Recommendation 4.3	*Develop a Programmatic Quality Assurance Program Plan (QAPrP) for Delta CHABs*
Recommendation 4.4	*Develop training and intercalibration plan*
Recommendation 5.1	*Develop a comprehensive list of all currently used data repository platforms, data resources, and other Delta CHAB related resources*
Recommendation 5.2	*Coordinate with the NOAA MERHAB data dashboard*
Recommendation 5.3	*Develop and maintain list of all routine and special studies*

Recommendation 1.3 Identify existing barriers to collaboration/cooperation and identify methods for overcoming them

It is well recognized that there are many interested parties on the topic of CHABs in the Delta. This recommendation seeks to ensure that groups with a vested interest are allowed access to discussions on implementing all components of this Strategy.

Special attention should be given to including those historically disenfranchised by government work such as Tribal nations and disadvantaged communities[12]. The groups identified above in Section 1.4 Multi-Organization Coordinated Monitoring involves organizations that have already been identified as having significant interest in this work and serve as a starting point for including the right individuals in this effort.

The goals of each represented group should be defined and opportunities to synergize efforts should be identified to promote the most mutually beneficial monitoring goals. Where goals are so dissimilar or valuable data collection or perspectives cannot be brought into this work, representatives for these groups could be brought together to discuss how to best work together and what could make partnerships more tenable. Depending on the severity of the differences, third-party negotiation might be helpful in advancing these conversations.

Methods recommended for identifying and including interested parties include:

- Annual event focused on identifying ways to develop partnerships specific to CHABs in the Delta. (*Recommendation 1.5 Hold an annual meeting focused specifically on Delta CHABs*)
- Maintaining all materials associated with implementing of the Strategy in an accessible and public location. (*Recommendation 5.1 Develop a comprehensive list of all currently used data repository platforms, data resources, and other Delta CHAB related resources* and *Recommendation 5.2 Coordinate with the NOAA MERHAB data dashboard*)
- Upholding the FAIR principles for all data created as a result of implementing of this Strategy. (*Recommendation 5.4 Incorporate open data principle*)
- Adhering to best practices for integrating Indigenous Knowledge (e.g., data sovereignty) where appropriate and where Tribes lead the way in doing so.

Recommendation 1.4 Strengthen and expand partner relationships

Several relationships have been developed in the Delta CHAB community over the past decade. However, there continues to be a need to strengthen those existing relationships to ensure everyone has a voice in how CHAB are monitored in the

[12] https://deltacouncil.ca.gov/pdf/public-reviews/2024-08-29-dsc-tribal-ej-issue-paper-public-review-draft.pdf

Delta. Existing relationships can be strengthened by reviewing current approaches and making adjustments based on community input.

There is also the need to expand the partner base by engaging with new members interested in water quality issues. This expansion can include people directly/indirectly involved in monitoring, or other interested community members. These groups will be involved by receiving updates from the key personnel group and the co-chair of the overall Strategy. These partners will also be invited to the annual meeting (*Recommendation 1.5 Hold an annual meeting focused specifically on Delta CHABs*) and asked for continued input as this Strategy continues to be developed and refined.

The CHABs Working Group should develop an email subscription option for all Delta CHAB partners to ensure information related to this Strategy, and Delta CHABs in general, reaches all interested parties.

Recommendation 1.5 Hold an annual meeting focused specifically on Delta CHABs

As recommendations are implemented and lessons are learned, consistent meetings with people engaged in Delta CHAB monitoring are necessary. This allows a cohesive approach to CHAB monitoring and community-based course correction to support adaptive management.

An annual meeting is an important event that can be used to inform the community about ongoing efforts related to CHABs. An annual meeting will require someone to lead the meeting each year. It will also likely require a funding source to pay for an event space Several approaches can be used to identify a lead. First, a single agency or partnership of agencies could partner to lead the meeting each year. Second, the co-chairs in *Recommendation 1.1 Identify co-chairs or mechanism for leadership of coordination and implementation of the Strategy* could identify leads for the meeting. Following the approach taken to lead the Interagency Ecological Program (IEP) Annual Workshop would be helpful for either option. For the IEP Annual Workshop, the leads rotate on a two-year basis – having a 2nd person sit in to learn from the lead and then leading the meeting the following year.

The first meeting can orient people to the goals, objectives, and recommendations of this Strategy (*Recommendation 2.5 Publish and share final management questions and goals with all interested parties*) and hold the first training (*Recommendation 4.4 Develop training and intercalibration plan*). Subsequent meetings can also include trainings, provide a mechanism to implement the adaptive management strategy (see Section 6), and provide updates on monitoring and special studies (*Recommendation 4.5 Report on CHAB monitoring and special study findings*).

Recommendation 1.6 Identify funding to support implementation of the Strategy

To ensure the sustainability of Delta CHAB monitoring, it will be necessary to secure funding, continue collaboration, and collaboratively share data. Full implementation of this Strategy will require funding from multiple sources. In addition to acquiring new funding, the funding may include in-kind contributions (e.g., staff time or direct funding), cost-sharing, regulatory actions, and/or grants. Various agencies have expressed interest that certain components of this Strategy are priorities for them to fund. The CHABs Working Group (*Recommendation 1.2 Form CHABs Working Group to develop final goals, management questions, and monitoring strategy and prioritize special studies*) can be used to have funding-related discussions and to identify different components of this Strategy that partners can implement.

New legislative efforts may also be needed to address CHAB monitoring. For example, at the federal level, the Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. In 2014, the Harmful Algal Bloom and Hypoxia Research and Control Amendments Act[13] was signed into law. In 2019, the California Legislature established the Freshwater and Estuarine Harmful Algal Bloom Program[14]. Building on this, the Legislature could consider allocating funds for CHAB monitoring in the state, including in the Delta.

Under the CWA, the State Water Board and Regional Water Boards (collectively, Water Boards) have regulatory responsibility for protecting the water quality and thus regulatory pathways that require and fund robust and regular monitoring. These pathways may include adding CHAB monitoring or payment for CHAB monitoring into existing permits. It is also possible that CHABs could be included in the State Water Board Water Right Decisions and Central Valley Water Board's Basin Plan.

[13] https://www.congress.gov/bill/118th-congress/senate-bill/3348/text
[14] https://legiscan.com/CA/text/AB834/id/2055354

5.2 Goal 2: Identify Management Questions, Monitoring Goals, and Objectives

- **Objective 2-1 Identify how monitoring results will be used by decision-makers**
- **Objective 2-2 Consider data and monitoring gaps needed to answer management priorities**
- **Objective 2-3 Determine how to prioritize management questions and goals**

Recommendation 2.1 Consider the amount and type of monitoring information needed by managers to support decision-making

Identifying management questions is necessary to inform the monitoring goals and objectives and to ensure that the monitoring plans are fit for their purpose (Howard et al., 2022). The amount and type of information needed to support decision-making should be considered when developing management questions and goals. Since needs and interests will differ based on the specific needs and interests of each partner, there will be several questions and goals. This will require a wide variety of monitoring information to be collected (e.g., Box 2).

Box 2. Management question development

1. Identify need (e.g., CHABs are increasing in frequency)
2. What decisions need to be made? (e.g., create management solutions to reduce CHABs frequency)
3. Determine necessary data needed before a management solution can be identified (e.g., what types of data are needed, how many sampling locations are needed?)
4. Develop management question (e.g., What are the most effective mitigation and prevention measures for CHABs in the Delta over short- and long-term periods?)

Table 7 contains example management questions that highlight the nexus between the management questions and potential decisions that may be made based on each question. This set of example management questions can provide a working framework for the CHABs Working Group (*Recommendation 1.2 Form CHABs Working Group to develop final goals, management questions, and monitoring strategy and prioritize* *special studies*) to use when finalizing the management questions for this Strategy. Importantly, even after the management questions are finalized the adaptive management process should be used to continue to evaluate and refine these questions as more data is collected and collaboration is enhanced (Section 6).

Table 7. Example management questions and linkages to decision-making

*Drawn from the State Water Board FHAB Framework and Strategy

Category	Management question (large/regional spatial scale)	Examples of decisions that are supported by the monitoring	Management question (small/localized monitoring scale)	Examples of decisions that are supported by the monitoring
Status	What is the overall magnitude and spatial extent of CHABs within the Delta region?	• Prioritize waterbodies or hydrologically distinct areas; • 305(b) report; • Briefings for the legislature and state agencies; • Inform status and trends report to the public	Are CHABs degrading water quality in this area of the Delta and when will CHABs occur?	• 303(d) listing; total maximum daily load (TMDL) compliance; • Catchment conservation/ protection; • Public health advisory posting; • Inform changes to compliance monitoring
Trends	How are the magnitude, extent, and frequency changing over time?	• Prioritize waterbodies or hydrologically distinct areas; • 305(b) report;	Are CHABs in this area of the Delta getting better or worse over time?	• 303(d) listing; total maximum daily load (TMDL) compliance;

Category	Management question (large/regional spatial scale)	Examples of decisions that are supported by the monitoring	Management question (small/localized monitoring scale)	Examples of decisions that are supported by the monitoring
		• Briefings for the legislature and state agencies; • Inform status and trends report to the public		• Catchment conservation/ protection; • Public health advisory posting; • Inform changes to compliance monitoring
Environmental Driver* (Natural and Human causes)	What are the relative influences of flow and water residence time, nutrients, temperature, and other environmental factors in driving CHABs in hot spots and other areas of the Delta?	• Biostimulatory objectives and implementation policy • Environmental flow policy • State/regional nonpoint source control strategies • Irrigated lands program/Ag waiver requirements	What are the environmental drivers and controllable factors of CHABs in this area of the Delta?	• TMDL development and implementation through municipal stormwater (MS4), NPDES, and industrial permits; • Irrigated Lands Program/Ag Waiver Requirements, etc.; • Modification of water operations

Category	Management question (large/regional spatial scale)	Examples of decisions that are supported by the monitoring	Management question (small/localized monitoring scale)	Examples of decisions that are supported by the monitoring
		• NPDES permit requirements		
Public health*	What Delta waterbodies have recently had CHAB events?	• Prioritization of funding for monitoring	Should human use or domestic animal use be restricted in the water body? When is it safe to resume active use?	• Incident response/public health posting and de-posting • Public decisions to use/avoid use (fishing, recreation) • Drinking water advisories
CHAB Prediction*	Which hydrologically distinct areas of the Delta are at risk of experiencing CHABs?	• Prioritization of funding for monitoring; • Inform development of management actions	What are the time periods that this area of the Delta most likely has a CHAB problem?	• Timing to go out to sample a waterbody for a bloom; • Prioritization of management actions, including monitoring requirements;

Category	Management question (large/regional spatial scale)	Examples of decisions that are supported by the monitoring	Management question (small/localized monitoring scale)	Examples of decisions that are supported by the monitoring
				• Modification of water operations
Mitigation and Prevention*	What are the most effective mitigation and prevention measures for CHABs in the Delta over short- and long-term periods? What are short- and long-term management measures of HABs that would be applicable and effective in the Delta to restore and maintain beneficial uses,	• Briefings for Legislature and State Water Board; • Status and trends report to the public on MyWaterQuality portal; • Inform funding mechanisms and prioritize funding; • Development and testing of CHAB mitigation measures	How effective are management actions in mitigating the CHAB problem in this area of the Delta?	• Adaptive management of watershed or waterbody-specific restoration actions (best management actions, floodplain restoration, water column mixing)

Category	Management question (large/regional spatial scale)	Examples of decisions that are supported by the monitoring	Management question (small/localized monitoring scale)	Examples of decisions that are supported by the monitoring
	and what steps would need to be taken prior to implementation?			
Management Activities	In what ways do different water management actions during drought affect the risk of CHABs?	• Prioritization of funding for restoration; • Prioritization of funding for monitoring of management actions • Inform water management actions • Inform Drought Contingency Plans	How do drought management actions affect CHABs in localized areas?	• Document, and to the extent possible, mitigate the impact of drought barrier(s), temporary barriers, operable gates, flow actions on CHABs
Environmental Impacts	What are the ecological impacts of CHABs? What species are highest at risk to CHABs?	• Informing mechanisms to obtain funding; • Prioritization of funding for monitoring;	Are the ecological impacts of CHABs most severe in hot spot locations?	• Prioritization of funding for monitoring of management actions

Recommendation 2.2 Consider regional, state, and national CHAB documents, strategies, and guidance when developing management goals and questions

Several documents address potential CHAB management goals and questions. These documents were considered in developing the example management questions in *Recommendation 2.1 Consider the amount and type of monitoring information managers need to support decision-making*. At a minimum, the following documents should continue to be considered when finalizing the management goals and questions. Existing efforts have been captured in this document and will be included throughout the implementation of this Strategy.

- State Water Board's Framework and Strategy for Freshwater Harmful Algal Bloom Monitoring
- CCHAB Network's guidance to respond to CHABs
- SWAMP's California Freshwater Harmful Algal Bloom Field Guide and standard operating procedures (SOPs)
- Delta Regional Monitoring Program Nutrient Research Plan
- Interstate Technology Regulatory Council (ITRC) Strategies for Preventing and Managing Harmful Cyanobacterial Blooms
- ITRC Strategies for Preventing and Managing Benthic Harmful Cyanobacterial Blooms
- Delta Conservancy Compendium of Resources, Protocols, and Guidelines for Environmental Monitoring
- Delta Independent Science Board's Review of the Monitoring Enterprise in the Sacramento-San Joaquin Delta
- IEP Phytoplankton and Water Quality Project Work Team
- IEP Phytoplankton enumeration synthesis project

Recommendation 2.3 When possible, coordinate Delta CHAB questions and goals with ongoing local and state efforts

Building off *Recommendation 2.2 Consider regional, state, and national CHAB documents, strategies, and guidance when developing management goals and questions*, it will be important to coordinate questions and goals with ongoing local and state efforts (e.g., see Section 1.4). There may be opportunities to leverage ongoing monitoring efforts and management questions and goals may build off ongoing work. Coordinating local and state efforts will also be useful for sharing ideas and information.

Recommendation 2.4 Provide approach(es) for prioritizing management questions and goals

Several different management questions and goals are necessary to inform collaborative management and mitigation decisions. Different groups will likely have different ideas about prioritizing the management questions and goals presented in this Strategy. The CHABs Working Group should identify a process for prioritizing the management questions and goals. This will allow different perspectives to be considered when choosing the prioritization structure. The prioritization structure and approach should also be discussed at the annual meeting (*Recommendation 1.5 Hold an annual meeting focused specifically on Delta CHABs*) to ensure open communication on the topic.

There are several approaches that could be considered by the CHABs Working Group when developing the prioritization structure. One approach is to identify the monitoring needs that can be leveraged with existing monitoring programs or special studies that are currently in place (e.g., see Section 3.2). Another approach is to identify potential constraints, such as inadequate resources, funding, time, or other factors that may impact the ability to meet a specific management question or goal. It may also be useful to identify certain questions/goals for agencies who are willing to provide resources to ensure sufficient monitoring is available to achieve the questions/goals.

This Strategy was developed to inform management decisions in a 3–5-year horizon, consistent with the FHAB Strategy's guidance of a "near-term" implementation. However, recommendations in this Strategy may also fall under the long-term implementation of >5 years and are included for consideration as this Strategy is implemented. The CHABs Working Group could choose to prioritize near-term recommendations as part of the prioritization structure.

Recommendation 2.5 Publish and share final management questions and goals with all interested parties

Once the management questions and goals have been identified, it will be important to share this information with all potential interested parties. The management questions and goals could be shared via the CCHAB Network webpage, through an email listserv (see *Recommendation 1.4 Strengthen and expand partner relationships*), or through other means.

It will also be important to share the management questions and goals at the annual meetings (*Recommendation 1.5 Hold an annual meeting focused specifically on Delta CHABs*). The adaptive management process is an important part of this Strategy. As additional information is learned about Delta CHABs and the science on the topic evolves, the management goals and objectives will likely be adjusted to adapt to this additional information. Thus, it will be important to keep the published version of the management questions and goals up to date.

5.3 Goal 3: Develop a Delta CHAB Monitoring Program

- **Objective 3-1 Identify specific monitoring program(s) needed to achieve the management questions and goals**
- **Objective 3-2 Identify priority monitoring parameters, locations, sampling period/frequency, and methods for the monitoring program(s)**
- **Objective 3-3 Create implementation guidance for Delta CHAB monitoring**
- **Objective 3-4 Synergize Delta CHAB monitoring with ongoing HAB efforts**

Recommendation 3.1 Based on the goals and objectives developed in Goal 2 identify monitoring programs and special studies needed to achieve outcomes

A combination of a routine monitoring program(s) and special studies will be needed to achieve management goals. Routine CHAB monitoring is necessary to provide information on current conditions and data to understand status and trends. Design characteristics that should be considered in developing the routine monitoring program(s) are described below in *Recommendation 3.2. Develop monitoring program(s) design characteristics*.

Despite the need for routine monitoring of CHABs in the Delta, it is recognized that some questions would be better addressed through special studies. These special studies can address technical questions related to the factors that cause CHABs, evaluate different monitoring techniques, evaluate feasible mitigation options, and address specific management actions. Collectively, special studies can advance the development of routine monitoring program(s) components and be used in the adaptive management process. A list of potential special studies is provided below in *Recommendation 3.6 Implement special studies to address data gaps and technical questions*.

Recommendation 3.2. Develop monitoring program(s) design characteristics

A monitoring program or programs will need to be designed to satisfy the management questions and goals. The monitoring program(s) should also have enough flexibility to adapt to unforeseen circumstances and take advantage of novel techniques and technologies (Delta Independent Science Board (ISB) 2022). During the design phase it will be critical to consider how the data that will be collected can be used to address the management questions, goals, and management decisions identified in Goal 2.

The ITRC Strategies for Preventing and Managing Harmful Cyanobacterial Blooms (HCB-1) and State FHAB Strategy have identified considerations for developing a CHAB monitoring program and are a good resource to use while designing Delta CHAB monitoring program(s). These considerations are incorporated into the following Recommendations to provide Delta-relevant guidance for the monitoring program(s).

Decisions on the locations, frequency of samples, and specific sample types should be based on monitoring goals and objectives since different combinations may be used (Howard et al., 2022). While designing the monitoring program(s), it will be important to consider the funding, time, and personnel available to complete the monitoring and to leverage these resources with other projects when possible. Sustainability of the monitoring program(s) is important, thus design strategies should be incorporated to increase the likelihood of maintaining the monitoring program(s) over the long term.

The following sections identify specific characteristics that should be incorporated into the monitoring design.

Recommendation 3.2.1 Identify geographic areas for monitoring

Based on the management questions and goals, different geographic areas may be prioritized for monitoring. For example, as identified in Data Gap 4.1.1.-2 the majority of CHAB sampling to date has occurred in the main channels. As such, static peripheral areas that often experience the most severe CHABs have been chronically understudied. This data gap is addressed in the management question "What are the relative influences of flow and water residence time, nutrients, temperature, and other environmental factors in driving CHABs in hot spots and other areas of the Delta?" To address this management question, it would be important to include areas that have historically been under-sampled but have annual CHABs.

Other criteria may include identifying areas with annual blooms, areas most utilized by disadvantaged communities, areas most commonly used by special status species, areas already part of other routine water quality monitoring, etc.

Recommendation 3.2.2 Identify spatial coverage, temporal coverage, and monitoring frequency

Monitoring during and in response to a CHAB event is a reactive approach that can make it difficult to understand the conditions that caused the bloom to form. Thus, monitoring criteria should consider sampling before, during, and after a bloom event which in the Delta may require sampling throughout much of the calendar year (ITRC 2024).

The time of sampling should also be considered as cyanobacteria are strongly responsive to sunlight. To understand status and trends of CHABs it is useful to complete sampling during the same time period of a day.

When considering spatial coverage it is important to recognize that cyanobacteria blooms are often patchy and not uniformly distributed. CHABs are often most dense along the shoreline relative to the open water. Thus, the spatial design should consider multiple grab samples or a composite sample. The spatial component of the monitoring design should also consider where in the water column samples should be collected and if it is worthwhile to collect integrated samples.

Some other questions to address spatial coverage, temporal coverage, and monitoring frequency include:

- How many sampling points are needed to answer each question?
- Should CCHAB Network guidance that recommends monitoring events occur at least twice per month at select stations be followed?
- Should temperature threshold (e.g., 19^{o}C) be used to increase sampling events?

- How do other environmental factors (e.g., water year type) influence sampling needs?
- How do tidal cycles impact sampling, and how could this influence sample comparisons?
- How do various management actions impact the spatial design?

Recommendation 3.2.3 Identify the metrics/parameters that should be collected for the monitoring program(s)

There are a wide range of metrics that can be included in a monitoring program. These include collecting discrete water quality samples for nutrient, chlorophyll, molecular, and/or toxin analysis, time-integrated samples such as solid phase adsorption toxin tracking bags (SPATT), remote sensing, etc. Depending on the management question, a collection of different sets of metrics may be needed to help answer the question. Regardless of the metrics that are utilized, it will be important for there to be consistency between laboratory and analysis methods (e.g., ELISA vs LC-MS to measure toxins, phytoplankton enumeration, etc.).

Modern technologies also continue to evolve, and there will likely be opportunities for machine learning/artificial intelligence methods to be integrated with more conventional sampling metrics to monitor cyanobacteria (e.g., Saleem et al., 2023). Although many of these newer technologies have limitations in their current state of development, there will likely be increasing opportunities to incorporate these technologies over the next few years. As such, the adaptive management process should be used to incorporate technologies into monitoring programs when appropriate.

Recommendation 3.2.4 Identify how data will be used and communicated

Design characteristics should include plans for how the data would be used, adequate data management (*Recommendation 5.2 Coordinate with the NOAA MERHAB data dashboard*), quality control (*Recommendation 4.3 Develop a programmatic Quality Assurance Program Plan (QAPrP) for Delta CHABs, Recommendation 4.4 Develop training and intercalibration plan*), and data analysis and synthesis (*Recommendation 4.1 Compare, review, and standardize sampling and laboratory methods, Recommendation 4.2 Ensure CHAB related SOPs are easily accessible*). Data collected in the monitoring program(s) should be readily available to the public (*Recommendation 5.2*

Coordinate with the NOAA MERHAB data dashboard, *Recommendation 5.4 Incorporate open data principle*) (Delta ISB 2022).

A communication plan should also be developed to ensure that data is interpretable by diverse audiences and adequately communicated to individuals who may be the most affected (i.e., incident reporting).

Recommendation 3.3 Based on the recommendations described above, design monitoring program(s)

Develop a document(s) that provides a design for the monitoring program(s). This document(s) should include the design characteristics outlined in *Recommendation 3.2. Develop monitoring program(s) design characteristics*. It should also describe the resources that will be used to collect and analyze the samples. If there are multiple monitoring documents to address the different management questions and goals, it will be important that documents are coordinated so that data can be compared across monitoring efforts if necessary.

Table 8. Example of management questions and associated design considerations and plan for use of monitoring data

Management Question	Geographic	Spatial, temporal, frequency	Metrics	Data	Additional Considerations
Which hydrologically distinct areas of the Delta are at risk of experiencing CHABs?	• Identify locations known for having CHABs • Identify locations that may be prone to CHABs based on hydrologic characteristics • Identify high use areas that may be prone to CHABs	• Identify sampling frequency to capture bloom development • Consider the number of samples needed to represent distinct areas	• Select relevant driver data for chosen site • Are genetic and toxin data needed? • how can remote sensing be used to monitor CHABs in these areas?	• Do methods and SOPs meet data management and quality control measures to be used for management decisions?	• e.g., Does public access or other use require modifications to the design? • How much data is needed to inform management decisions? • How can this work be leveraged with ongoing routine water quality monitoring?

Recommendation 3.4 Utilize community science

Including community members in Delta CHAB monitoring will ensure a successful and comprehensive approach to collecting data. Community science is useful for engaging community groups and individuals to collect data that informs management decisions. Involving community members can significantly increase the amount of water quality data available for areas of the Delta that may not be targeted for routine monitoring.

Being a community water monitor is relatively simple, especially for people who are frequently near a waterway. At a minimum volunteers can collect visual index data for early detection of water quality changes and potential problems. This type of data collection is inexpensive but can be used by decision-makers to protect, maintain, and restore waterbodies. Further, collecting data promotes a deeper understanding of water quality and the changes that can occur over time. This type of data could be supported by the training in *Special Study 3.6.7 Improve use of visual index data.*

The State Water Resources Control Board and many Regional Water Quality Control Boards are actively involved in community-based monitoring. They have developed specific monitoring techniques and identified important ways to ensure techniques are valid. Although much of the community monitoring effort in the state has focused on creeks, rivers, and beaches, the Surface Water Ambient Monitoring Program (SWAMP) Clean Water Team Citizen Monitoring Program would be a good place to start for establishing a community monitoring group. The SWAMP Citizen Monitoring Program is willing to teach volunteers monitoring techniques and facilitate trainings between interested volunteers and local technical experts. Additional information on this program can be found at this website: https://www.waterboards.ca.gov/water_issues/programs/swamp/cwt_volunteer.html

Recommendation 3.5 Consider resources that are currently available or that may be available in the future

As described above in Section 2, there are several routine water quality monitoring programs in the Delta; however, none of these are CHAB-focused. Adding focused CHAB monitoring to these existing programs may be a good option for leveraging resources to address CHAB management questions and goals. However, additional resources will be necessary to answer all the management questions and goals since many of the established water quality monitoring programs do not sample in the areas that experience the most severe CHAB.

The availability of various resources may impact the ability to implement certain recommendations in this document.

Recommendation 3.6 Implement special studies to address data gaps and technical questions

The following special studies represent some potential ideas to advance this recommendation but should not be treated as an exclusive list. The special studies listed below can be used by those who have the ability to pursue CHAB related research from independent funding sources as well as providing guidance for agencies and work groups that have funding to pursue special studies.

Management questions and goals identified in Goal 2, *Recommendation 2.4 Provide approach(es) for prioritizing management questions and goals* above can also be used to prioritize special studies. However, in cases where independent researchers have funding to pursue special study projects, studies may not follow the same priorities identified through this *Recommendation 2.4*. In this case, the plan for implementing special studies will be based on the researchers or partners that provide funding for the special study. *Recommendation 5.3 Develop and maintain list of all routine and special studies* is in place to encourage collaboration among those working on special studies.

The design of each special study will be specific to the type of study that is implemented and the resources available to complete each study.

Environmental Processes, CHAB development, CHAB decline

Special Study 3.6.1 Investigate role of different nutrient sources on CHAB bloom formation throughout the Delta

Nutrients have been identified as non-limiting for cyanobacteria growth throughout the Delta. However, there are numerous questions remaining about how nutrient manipulations may impact CHABs in various areas of the Delta. Some examples include:

- What is the site-specific role of external vs internal nutrient loading?
- What is the relationship between macrophytes, cyanobacteria, and nutrients?

- Do nutrient limitations that prevent cyanobacteria dominance in the literature apply to the Delta?
- If nutrients are reduced to limiting amounts would nitrogen fixing cyanobacteria become problematic?

Special Study 3.6.2 Investigate how changing atmospheric carbon levels may impact CHABs in the Delta

Rising atmospheric CO_2 concentrations associated with climate change are anticipated to stimulate cyanobacteria blooms, shift the genetic composition of cyanobacteria blooms, and potentially change growth responses of different phytoplankton species (Visser et al., 2016). Field- and laboratory-based studies should be developed to assess how rising CO_2 will impact CHABs in the Delta. This information will be an important component of a predictive model as well as helping managers understand how to plan for potential changes to CHAB ecology in the Delta.

Special Study 3.6.3 Investigate how localized flow conditions, site specific residence times, and tidal velocity influence CHAB formation

It is well accepted in the scientific community that flow, velocity, and residence time play an important role in the ability of cyanobacteria to grow, aggregate, and form blooms. There are some studies that suggest flow thresholds for disrupting CHABs in the literature (e.g., Mitrovic et al., 2011), but there is little to no work on this topic in the Delta. Similarly, studies have shown that long residence times increase the potential for CHABs, but it remains unknown how long residence time in number of hours or days is sufficient for CHABs to form. Studies should be developed to address impacts of flow, residence time, and tidal velocity on CHABs in different areas of the Delta (e.g., static peripheral areas, canals, edge water habitats, main channels, etc.) and how these factors relate to other environmental conditions that are conducive to CHABs.

Special Study 3.6.4 Investigate role of cyanobacteria seed stock in Delta CHABs

Growing evidence suggests that overwintering cyanobacteria inoculates summertime cyanobacteria blooms. Determining the role of seed stock in bloom formation will be important to identify potential areas to implement targeted mitigation practices.

Special Study 3.6.5 Study factors that cause bloom decline/collapse (viruses, decreasing light, nutrient depletion, salinity changes, etc.) and whether those factors can be manipulated

Factors that cause a cyanobacteria bloom to disappear or collapse are less studied than the factors that drive the formation of CHABs (Harris et al., 2024). This is also true for the Delta, where little is known about what causes cyanobacteria blooms to decline or collapse.. Field- and laboratory-based studies could be implemented to understand the various abiotic and biotic factors that result in cyanobacteria cell lysis and collapse. Harris et al., 2024 provides a review of how various biotic and abiotic processes cause a bloom to collapse and can be used as a guide for developing special studies to investigate factors that cause bloom declines/collapse in the Delta. Examples of such special studies may include impacts of oxidative stress, UV light, infections, viruses, grazing, and/or programmed cell death.

Monitoring Methods

Special Study 3.6.6 Coordinate with State Water Board to collect field data and other information needed to support remote sensing needs

There are many studies that could be developed to address this specific recommendation. Coordination with the State Water Board can be used to prioritize remote sensing needs. One idea is to explore the feasibility of generating drone imagery of hotspot locations as an early warning indicator, to track seasonal variation, and to better understand how CHABs are transported from peripheral areas into the main Delta. A second idea is to compare in-situ chlorophyll data with remotely sensed chlorophyll-a data. A number of remote sensing recommendations are also defined in the State FHAB Strategy (Smith et al., 2021). These recommendations provide good ideas for special studies and can be amended, if necessary, to include the most up to date information on remote sensing.

Special Study 3.6.7 Improve use of visual index data

The visual index data is one of the largest and longest-term data sets of *Microcystis* available in the Delta. Visual index data may not be used to make regulatory decisions, but it is easy and inexpensive to collect and can be used to supplement routine monitoring and special studies. Currently, the visual index data is subjective based on the observer collecting the data and it remains unknown how well correlated it is with actual *Microcystis* presence. Several ideas for studies to improve the use of visual index data are described below.

- First, the collection of visual index should be standardized. To achieve this, there should be annual visual index training or workshop in the spring prior to the start of the CHAB season (see *Recommendation 1.5 Hold an annual meeting focused specifically on Delta CHABs* and *Recommendation 4.4 Develop training and intercalibration plan*). As part of this training there should be an explanation of what the visual index is supposed to represent. A standard operating procedure could be developed and shared at each training to ensure that people from different agencies and other groups are collecting the data in the same way.
- Second, measurements should be taken to compare *Microcystis* visual index data with cell abundances and chlorophyll concentrations, which could include comparing it to remote sensing data. This information can be used as a line of evidence in understanding the temporal and spatial extent of cyanobacteria. This data will be especially helpful if no other data is collected in certain areas of the Delta.
- Third, develop a revised visual index score procedure that incorporates visual indicators common to non-*Microcystis* species. This procedure should be incorporated into the visual index training once it has been developed. A step-by-step instructional document should be developed to ensure a standard procedure is used for the revised visual index score.

Special Study 3.6.8 Evaluate the effectiveness of chlorophyll sensors to detect cyanobacteria

In-situ optical and fluorometric measurements have the potential to fill the gap that exists from relying only on laboratory-based extractions. However, it remains unknown how effective various chlorophyll sensors are at measuring chlorophyll from buoyant cyanobacteria. Studies should explore the relationship between chlorophyll fluorescence measurements and laboratory extracted chlorophyll. There is also evidence that different brands of sensors provide varying chlorophyll readings so it would be useful to continue exploring the differences between sensors. Eventually, it would also be useful to relate in-situ measurements to cyanobacterial cell density.

Special Study 3.6.9 Determine how well mixed Microcystis is throughout the water column and its contribution to total community chlorophyll-a

Different sampling groups collect phytoplankton samples at varying depths in the water column (typically at the surface or one meter below the surface). It would be useful to measure the distribution of *Microcystis* vertically (at multiple depths in the water column) and correlate this with chl-*a* profiles.

Special Study 3.6.10 Determine if benthic cyanobacteria occur in the Delta and if so, contribute toxins to the water column.

Little work has been conducted to determine if benthic cyanobacteria are an issue in the Delta. Due to the depth and width and turbid nature of many Delta channels, it has been difficult to monitor for benthic cyanobacteria. Since benthic cyanobacteria are often invisible from the surface of the water column it would be best to develop a monitoring plan to identify priority locations and techniques for benthic cyanobacteria. The ITRC provides guidance on developing a benthic cyanobacteria monitoring plan that includes a number of different potential monitoring techniques (https://hcb-2.itrcweb.org/monitoring-for-benthic-cyanobacteria/). A first step would be to investigate areas of the Delta that have habitats conducive to the formation of benthic cyanobacteria.

Special Study 3.6.11 Determine concentrations at which cyanobacteria become a management concern

A CHAB “event” is largely determined by regulatory agencies concerned with food and human safety. These CHAB events are, at times, based on visual appearance of a waterbody, and there is often no toxicity data associated with observed blooms. Studies could investigate the relationship between water column toxicity and cyanobacteria cell abundance to determine if there is any relationship in the Delta. This could be investigated for different species of cyanobacteria and at different times of the year when toxin producing strains may or may not be present.

Special Study 3.6.12 Explore use of artificial intelligence and machine learning for monitoring Delta CHABs

Artificial intelligence and machine-learning algorithms can be applied to cyanobacteria monitoring through cell imaging and predicting changes in water quality. For example, CHABs monitoring data, such as chl-*a* or phycocyanin, together with environmental data such as flow, temperature, and nutrients, can be used to train machine learning algorithms to hindcast and predict when cyanobacteria blooms may form. Special studies could work on integrating multiple algorithms and available datasets to apply machine learning models to the Delta. Information that comes out of these studies may inform the types of monitoring data that are needed to validate such technologies.

Special Study 3.6.13 Explore mechanistic approach to predict CHAB events

A mechanistic approach, specifically coupled hydrodynamic and biogeochemical models, can potentially be effective in modeling CHABs. Unlike the data-driven nature of machine learning methods, these predictive models establish causal connections between phytoplankton biomass and environmental drivers. While observational data aids in parameter tuning and model calibration, the mechanistic approach inherently requires less data and imposes fewer stringent requirements on data structures compared to machine learning techniques. These two approaches also complement each other; while the mechanistic method enriches machine learning by proving a more comprehensive training dataset, insights from machine learning can enhance the robustness of mechanistic linkages. Notably, mechanistic models have already been successfully employed to model non-HABs-related blooms in the Delta.

CHAB Toxicity

Special Study 3.6.14 Develop methods to identify and detect novel or emerging cyanotoxins

Current laboratory methods are focused on detecting the most common cyanotoxins (i.e., microcystin, anatoxin-a, cylindrospermopsin, and saxitoxin). Indeed, the majority of research has focused on microcystins, specifically the microcystin congener microcystin LR. Yet, new toxins and their congeners continue to be discovered and may have adverse impacts on the environment. Investigations of cyanobacteria peptides and other compounds will be useful for understanding the true impacts of CHABs across the Delta.

Special Study 3.6.15 Compare analytical methods for toxin detection in complex matrices

There is evidence in the literature that cyanotoxin detection may differ between ELISA and LC-MS methods, especially in complex matrices such as sediments and biota. There is evidence of matrix interference with both methods (Preece et al. 2015, Preece et al. 2024c); however, both offer a good option for measuring cyanotoxins. Since microcystin is the most common cyanotoxin observed in the Delta, and a stable toxin that is commonly observed in matrices other than water, it would be useful to conduct special laboratory studies on this toxin. Studies can focus on the comparison of ELISA and LC-MS to study microcystin concentrations in sediments and biota and work on developing standard methods that can be adopted by laboratories.

Special Study 3.6.16 How do changes in cell physiology (e.g., manipulated by nutrient limitation vs. sufficiency) impact toxin formation?

There is growing evidence in the literature that nitrogen and micronutrients disproportionally influence the toxicity of CHABs dominated by *Microcystis* (e.g. Wagner et al., 2019, Wagner et al., 2021). However, many questions remain about how nutrient availability affects toxin production and potential for presence of different microcystin congeners. Gradients of nitrogen and salinity have also been shown to have physiological costs and benefits in toxin-producing cyanobacteria. Investigations could further study how the combinations of high and low salinity with high and low nitrogen concentrations impact toxin production by *Microcystis* and *Aphanizomenon* (Osburn et al., 2023).

Special Study 3.6.17 Are there conditions that promote more toxic strains of cyanobacteria?

Do warmer temperatures, changes in salinity, decreases in turbidity, nutrient limitation, changes in atmospheric carbon, or other factors contribute to more toxic strains of cyanobacteria in the Delta? Studies could explore various combinations of these factors to better understand how environmental drivers impact the potential for toxic strains to enter the water column.

Special Study 3.6.18 What are the impacts of cyanotoxins, mixtures of multiple cyanotoxins, and/or mixtures of cyanotoxins with other contaminants, on aquatic resources?

Limited information is available on how cyanotoxins impact the health of managed fish species such as Green and White Sturgeon. Since these species are benthic feeders and consume shellfish in the Delta, the fish may be exposed to cyanotoxins through their diets (Preece et al., 2024c). Studies should investigate how cyanotoxins, and the combination of cyanotoxins with other environmental contaminants, may impact aquatic resources including managed species in the Delta.

Mitigation

Special Study 3.6.19 Identify practicable Delta CHAB mitigation options

Many CHAB mitigation options are not practical for the hydrologically complex Delta. Various CHAB mitigation options should be assessed to determine which are feasible for the Delta. Once feasible mitigation options are identified, they can be refined for different habitat types (e.g., flowing channels, backwater areas, channel margins, etc.). Considering scale, it would also be useful to identify the potential costs of implementing applicable mitigation measures. Finally, a plan should be developed to outline the mitigation measures that require pilot studies to confirm applicability in the Delta.

Special Study 3.6.20 Conduct pilot studies in laboratory-based environments or localized areas of the Delta to evaluate potential mitigation techniques

Special studies could conduct small-scale experiments to test different mitigation techniques. To understand the true feasibility of mitigation techniques, they should be explored under a range of environmental conditions.

5.4 Goal 4: Define Collaborative Reporting Protocols

- **Objective 4-1 Validate and standardize current methods used for monitoring CHABs**
- **Objective 4-2 Develop protocols for accurate and timely reporting**

Recommendation 4.1 Compare, review, and standardize sampling and laboratory methods

Standardizing species identifications, extraction protocols, and laboratory analysis for cyanotoxins across the Delta is important for ensuring that monitoring data collected by different groups are consistent and comparable (Stauffer et al., 2020).

This is especially important for data collected as part of a regular monitoring activity (i.e., not for a special study).

Participating agencies and groups such as IEP have SOPs for various monitoring efforts that should be considered when defining SOPs for Delta CHAB monitoring. SWAMP protocols may also exist for many environmental factors that drive CHABs. However, these are for immediate response and not for routine monitoring. These protocols include SOPs that should be utilized to develop a Delta CHAB monitoring SOP. Data collection methods should follow established norms in the Delta by existing surveys (mostly IEP) whenever possible.

Sampling and laboratory methods and SOPs should be consistent and documented. SOPs should be compared across monitoring groups for consistency and reviewed to determine where they can be optimized, including quality control (QC) requirements, to allow standardization across monitoring groups. Where significant discrepancies across SOPs exist, SOPs should be evaluated, and a community consensus should attempt to mitigate these differences.

Recommendation 4.1.1 Standardize terminology

In addition to standardizing methods and SOPs, major relevant terms for Delta CHABs need to be consistent. “Bloom” is an example of a term that needs a specific definition and metric to meaningfully agree on monitoring practices.

Recommendation 4.2 Ensure CHAB related SOPs are easily accessible

After SOPs are reviewed and standardized, they should be retained in a common location for use by all current and future monitoring practitioners. Maintaining this common location for materials means there is no barrier to access for novel monitoring programs and materials are not lost as staff and programs turn over. Below, *Recommendation 5.2 Coordinate with the NOAA MERHAB data dashboard* describes one option for the common location to store these materials.

Recommendation 4.2.1 Create an inventory of SOPs

An inventory listing methods and SOPs for CHAB monitoring and analysis should be created in the same common location to easily locate this information. When an SOP or method is already published (e.g., IEP, SWAMP, USGS), the webpages for those documents should be linked to the inventory.

Recommendation 4.3 Develop a Programmatic Quality Assurance Program Plan (QAPrP) for Delta CHABs

A QAPrP, similar to the WaterBoards SWAMP QAPrP, should be developed to allow projects implemented by partners to "enroll" under it as long as they used the standardized procedures, approved lab methods and labs, etc. This allows project-specific flexibility while upholding a high standard of quality assurance. The QAPrP should include QA metrics, standardized procedures, and training plan quality control protocols such as data quality requirements for participating groups. This QAPrP can be developed so that participating agencies can leverage the QAPrP for individual projects implemented under the overall programmatic QAPrP. Each CHAB monitoring participant should also maintain a quality assurance project plan (QAPP) that adheres to the values outlined in the programmatic QAPrP

Recommendation 4.4 Develop training and intercalibration plan

The first step of the training and intercalibration plan will be identifying a person, group, or agency that can organize and lead this annual training. The advisory group in *Recommendation 1.2 Form CHABs Working Group to develop final goals, management questions, and monitoring strategy and prioritize special studies* could take the lead on this or a volunteer could agree to take on this recommendation. It would be useful to have a document prepared that describes the training procedures and the intercalibration plan. This document could be used as the resource for the in-person training described below.

The training should be held annually for all personnel collecting CHAB-related field data. This training could be included in the annual meeting identified in *Recommendation 1.5 Hold an annual meeting focused specifically on Delta CHABs*. Ideas for the annual training include reviewing standard operating procedures, equipment maintenance and calibration, decontamination protocols, health and safety protocols, and data quality assurance and quality control protocols and standards. The lead for the training should also consider equipment and sampling standardization that is missing. This training could be a good opportunity to discuss ideas for troubleshooting any issues and for identifying approaches that ensure better standardization in the future.

Participating agency members may hold their own trainings, but it is essential that training is provided to all personnel. Ideally, all trainings should be recorded and documented.

Recommendation 4.5 Report on CHAB monitoring and special study findings

Present CHAB monitoring and special study findings at annual meetings (*Recommendation 1.5 Hold an annual meeting focused specifically on Delta CHABs*). Consider using speed talks and posters if there is not sufficient time available to present on studies. Researchers should focus on an open science mindset and work to distribute findings to the best of their ability to all interested parties. When possible, researchers should publish research papers as open access to ensure accessibility to all interested parties.

5.5 Goal 5: Utilize a Data Sharing Platform

- **Objective 5-1 Identify existing CHAB and HAB data resources**
- **Objective 5-2 Explore how to integrate Delta CHAB data with existing data repositories**
- **Objective 5-3 Develop protocols to make CHAB data accessible and available to all**

Recommendation 5.1 Develop a comprehensive list of all currently used data repository platforms, data resources, and other Delta CHAB-related resources

The CHABs Working Group should develop a comprehensive list that can then be used in *Recommendation 5.2 Coordinate with the NOAA MERHAB data dashboard*. Recognizing that the list may evolve over time as new resources become available is important.

Examples of data resources that should be considered include:

- California Environmental Data Exchange Network (CEDEN)
- California Data Exchange Center (CDEC)
- Water Data Library
- Electronic Data Exchange Portal (EDI)
- United States Geological Survey Data Integration Portal Phytoplankton dashboard

Examples of other resources that should be considered include:

- Documents listed in *Recommendation 2.2 Consider regional, state, and national HAB documents, strategies, and guidance when developing management goals and questions*
- Delta CHAB-related journal publications

Recommendation 5.2 Coordinate with the NOAA MERHAB data dashboard

In the fall of 2023 SFEI, USGS, DWR, and project partners received funding for a five-year project to address HABs across the San Francisco Estuary, as described in section 3.2.4 NOAA MERHAB. As part of this funding, the team at SFEI is developing a data dashboard that will bring together various data types, including remotely sensed data, high-frequency data, and discrete data samples. The team has assembled data transformation libraries and special scripts to perform these integration tasks affordably and reliably. The data integration platform and data dashboard work hand-in-hand to ensure alignment among various partners, community members, Tribes, researchers, and decision-makers. The MERHAB project team agrees that this data dashboard offers a promising platform to integrate historic and existing CHAB data from the Delta in line with the recommendations in this Strategy.

The data dashboard is still in the early stages of development, but crosswalks to make data more available and comparable across agencies are planned. Crosswalks will allow databases to remain with their hosts yet be findable in a central location.

Although the funding for the data dashboard is tied to the MERHAB project funding, the goal of the MERHAB team to secure long-term funding for the data dashboard. Leveraging the MERHAB data dashboard provides a unique opportunity to integrate all San Francisco Estuary HAB data and resources into a single platform.

Recommendation 5.3 Develop and maintain list of all routine and special studies

Many groups are working on various aspects of CHAB monitoring. This Strategy is intended to increase coordination among these different entities. Nevertheless, due to discrete funding opportunities and the large number of people working on CHAB issues in the Delta it is often difficult to be aware of all the different monitoring efforts and special studies occurring at any given time. Organizing a location within the data dashboard (*Recommendation 5.2 Coordinate with the NOAA MERHAB data dashboard*) where people can list a high-level overview of their work and contact information would increase coordination efforts. This recommendation will rely on individuals to self-report. However, with the common goal of sharing the information identified here, individuals participating in the CHABs Working Group and other associated groups will have access to all relevant CHAB information and can encourage individuals to self-report.

Recommendation 5.4 Incorporate open data principles

In line with the special study recommended in the FHAB Strategy "SS4: Develop partner program open data systems" it will be important to incorporate open data principals for all Delta CHAB data and findings. Incorporating open data principles means data should be freely accessible, usable, and shareable for any purpose.

Open data principles are outlined in AB 1755 Open Water Data Act, which directs all water data in the state to be accessible and available to the public (AB-1755 (ca.gov)), FAIR principles (https://www.go-fair.org/fair-principles/), and State Water Board's Open Data Resolution's Handbook (Data Tool Kit - Open Data Handbook | California State Water Resources Control Board). These resources should be utilized when considering how to best consolidate and share data.

The MERHAB data dashboard will utilize open data principles by providing data management and visualization infrastructure to communicate Delta CHAB findings. However, as noted in the FHAB Strategy, some disadvantaged communities may have poor access to electronic information. Thus, those with data to share should consider multiple dissemination modes and not rely entirely on the data dashboard. The annual meeting (*Recommendation 1.5 Hold an annual meeting focused specifically on Delta CHABs*) will be one tool that can be used to communicate findings beyond the data dashboard.

6 Adaptive Management

To create a monitoring plan that best meets management needs, an adaptive management approach should be incorporated (Delta ISB 2022). This document supports adaptive management through iterative implementation of the goals and objectives:

1. Monitoring is tied to management questions, goals, and objectives (Goal 2)
2. The management questions are used to design the monitoring program (Goal 3)
3. Information from monitoring efforts is communicated widely (Goals 4 and 5) to facilitate learning.

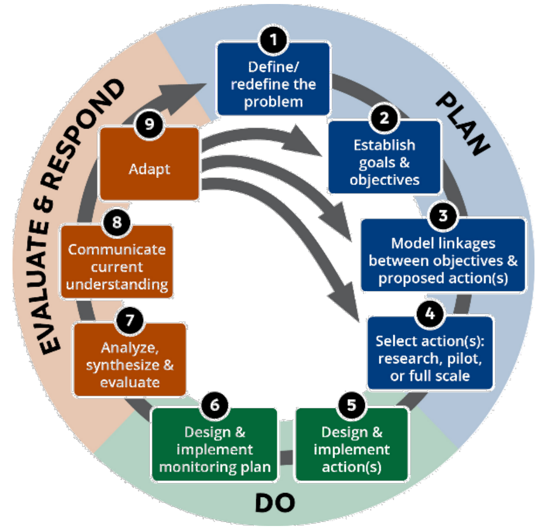

Figure 18. Adaptive Management Cycle

Recommendations 2.4 Provide approach(es) for prioritizing management questions and goals and *2.5 Publish and share final management questions and goals with all interested parties* detail more information about prioritization of management questions, which should be used to define criteria for achieving progress made toward addressing goals and objectives of the monitoring program.

Recommendation 1.5 Hold an annual meeting focused specifically on Delta CHABs calls for a yearly meeting to discuss findings from monitoring and progress made on CHABs data collection which creates a natural opportunity to discuss progress made toward defined management objectives and evaluate the monitoring program plan to adapt before the next data collection season.

The structure proposed in this Strategy can be iteratively applied to evaluate progress toward defined management goals and to inform adjustments to the Strategy as needed. At a minimum this Strategy should be revisited every 3 to 5 years. However, since there is no funding attached to this Strategy the CHABs Working Group will need to seek participants to spend time working through the adaptive monitoring process.

As part of the review process the following items should be considered:

1. Assess and report progress towards each of the goals and objectives.
2. Describe any changes in management objectives or needs

3. Describe any new technologies that could be leveraged in the Strategy
4. Assess the extent to which the Strategy is meeting current management objectives and information needs
5. Propose any necessary changes to the Strategy to better meet current management objectives and information needs, while maintaining long-term data comparability

7 Implementation

Full implementation of the recommendations in this Strategy will require considerable time and funding. As stated above, there is no funding associated with this Strategy and implementation of the recommendations within this document. As such, it will be necessary for CHABs Working Group members to implement recommendations in this document and for additional funding to be secured. As described in *Recommendation 1.6 Identify funding to support the implementation of the Strategy* there are several mechanisms through which funding could be secured to help implement this entire Strategy.

Implementation of all the recommendations in this document would benefit from the development of implementation guidance with input from partners to develop a coordinated monitoring program. This could be done through the CHABs Working Group (*Recommendation 1.2 Form CHABs Working Group to develop final goals, management questions, and monitoring strategy and prioritize special studies*) or through some other mechanism. Although implementation guidance will ensure that the recommendations in this document are undertaken through a coordinated approach there are several recommendations that can be implemented immediately if resources are available to undertake the efforts.

It will also be important to leverage ongoing related work to implement these recommendations. When possible, these leveraging opportunities have been identified throughout this document.

This Strategy is focused on informing water quality management decisions in a 3- to 5-year horizon, consistent with the FHAB Strategy's guidance of a "near-term" implementation. However, recommendations in this Strategy may also fall under the long-term implementation of >5 years and are included for consideration as this Strategy is implemented. Recommendations that are identified as long-term priorities can be implemented once funds and resources become available.

7.1 Near-Term Implementation

The first steps in the near-term implementation of this Strategy will be to implement *Recommendation 1.1 Identify co-chairs or mechanism for leadership of coordination and implementation of the Strategy* and *Recommendation 1.2 Form CHABs Working Group to develop final goals, management questions, and monitoring strategy and prioritize special studies.* Many of the following recommendations involve action to lead the Strategy and the CHABs Working Group. Once these recommendations have been achieved the next high-priority task will be to implement Goal 2 – Identify management questions, monitoring goals, and objectives. This will be important to ensure that there is a coordinated approach to implementing this Strategy.

Within Goal 2 is *Recommendation 2.4 Provide approach(es) for prioritizing management questions and goals* which can be used in deciding next steps in the implementation process.

It is important to recognize that this Strategy and ongoing Delta CHAB efforts are fluid. Components of this Strategy are being implemented while the document is being written. The adaptive management framework can be used to address this fluidity, but it is also important to recognize that some components will be implemented prior to the full adoption of the document. Part of the real-time process involves meetings where partners work to take on components of this document. Ideally, future meetings would be conducted through the CHABs Working Group for a coordinated Delta CHAB approach.

7.2 Long-Term Implementation

The Strategy should be revisited every 3 or 5 years via the adaptive management process. This should include new data, new technologies, and an assessment of the near-term implementation process. The process should also consider identifying long-term goals beyond those that are captured in the document.

Appendix A: Additional station maps

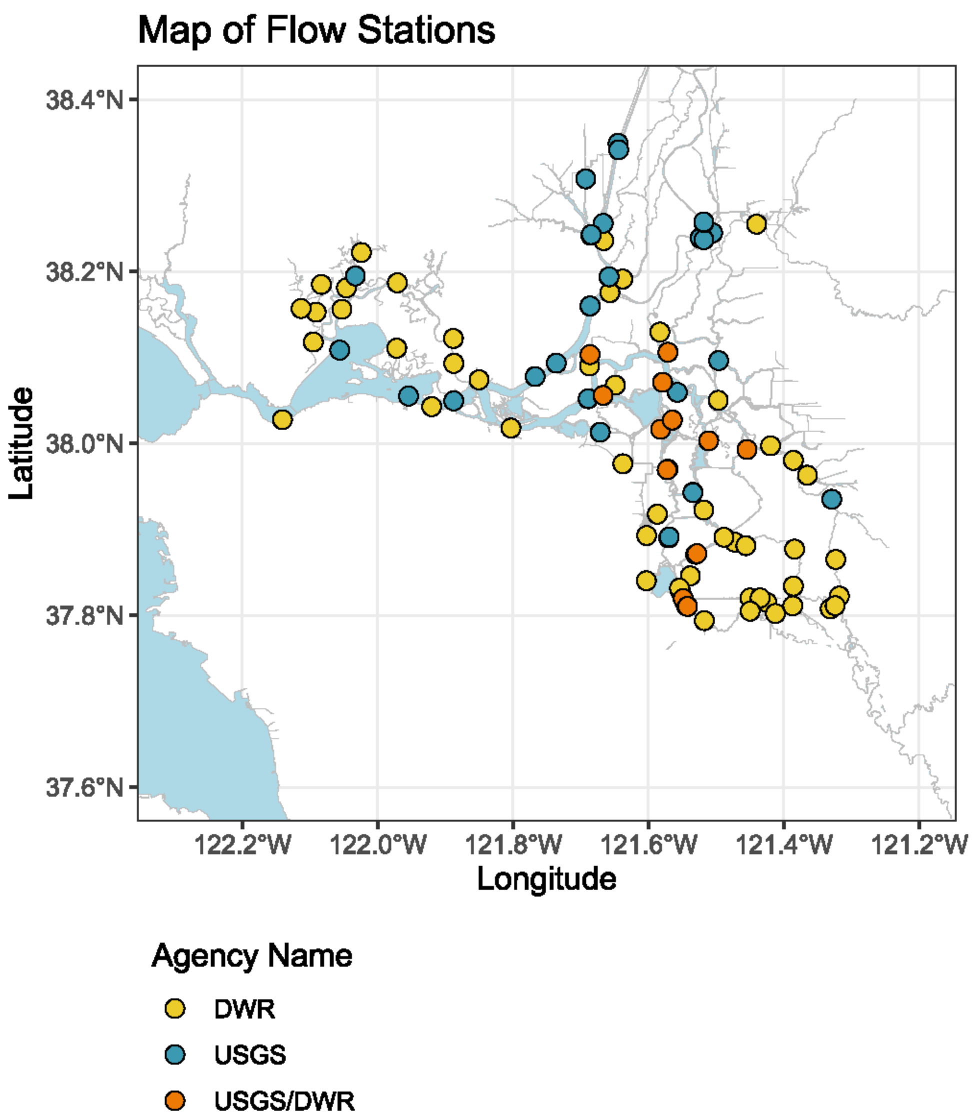

Figure 19. Map of continuous water flow stations that measure flow, velocity, and/or river stage.

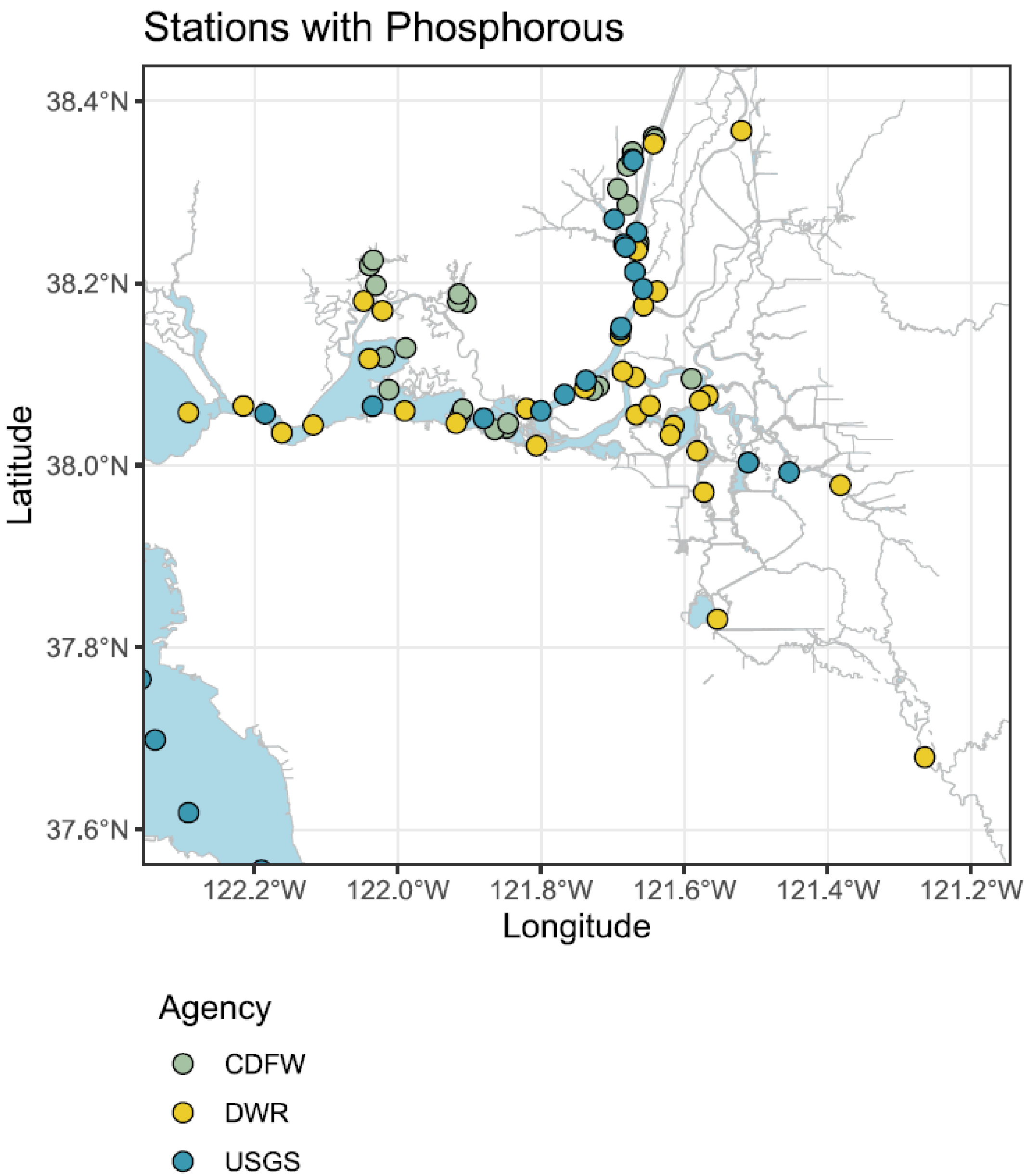

Figure 20. Map of total phosphorus and/or dissolved orthophosphate measurement locations.

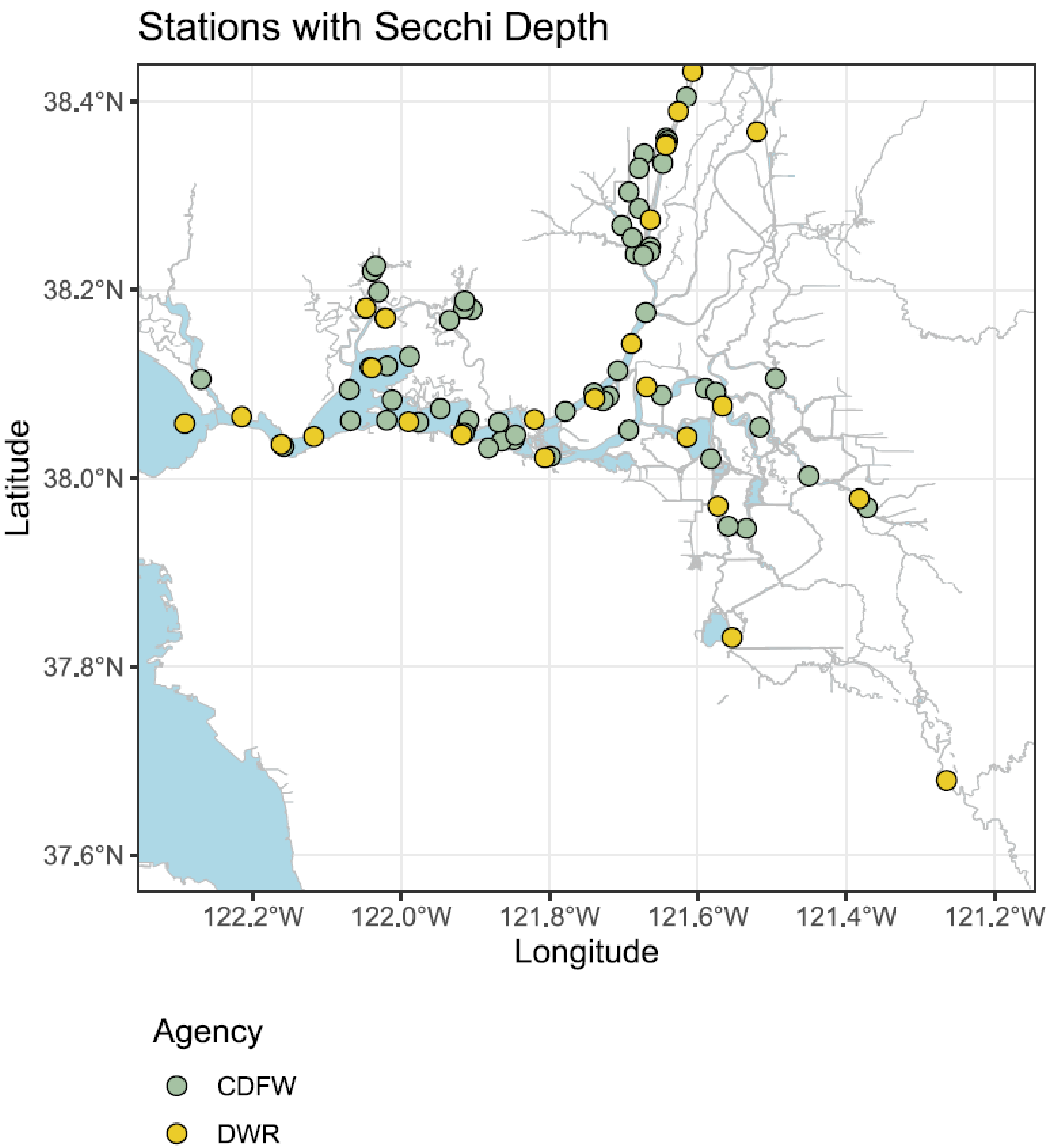

Figure 21. Map of Secchi depth measurement locations.

Appendix B: Strategy Development and Outreach

This Strategy is intended to be a tool for and by the community. Although a core group of authors led the development of this Strategy, this appendix details the methods used to ensure that the Strategy is based in the needs of the Delta science community.

Outreach

November 2022 Workshop

Monthly to bi-monthly meetings were held December 2021-November 2022 to plan a Harmful Algal Blooms workshop hosted by the Delta Science Program November 8-9, 2022.

The workshop planning team included the following individuals and their associated affiliation.

Name	**Organization**
Tricia Lee (lead facilitator)	DSC-DSP
Eva Bush	DSC
Tabitha Birdwell	DSC-DSP
Jenna Rinde	CDFW
Steve Culberson	DSC-IEP
Marisa VanDyke	State Water Board
Carly Nilson	State Water Board
Janis Cooke	Central Valley Water Board
Karen Atkins (now Odkins)	Central Valley Water Board (now CDFW)
Meghan Klasic	University of Minnesota
Keith Bouma-Gregson	USGS
Spencer Fern	Restore the Delta
Ted Flynn	DWR

Other Contributors:

Name	**Organization**
Louise Conrad	DSC-DSP (now DWR)
Christine Joab	CDFW/IEP
Stephanie Fong	CDFW/IEP
Diane McKnight	University of Colorado/Delta ISB

Meredith Howard	Central Valley Water Board
Scott Navarro	DSC
Rachael Klopfenstein	DSC-DSP
Henry DeBey	DSC-DSP
Laurel Larsen	Delta Lead Scientist

Draft Strategy Development

The authorship met monthly to bimonthly from February 2023 – February 2024, when the Draft Delta CHABs Monitoring Strategy was released for public comment.

Through the recommendations of the workshop planning team, the lead author, Ellen Preece (DWR), was suggested for the development of the CHABs Monitoring Strategy. An additional author, Mine Berg (ESA), was identified and received partial funding from the Delta Science Program for her contributions to the Strategy. Tricia Lee (DSC-DSP) continued to lead facilitation and shared authorship responsibilities. Karen Odkins and Jenna Rinde (CDFW) contributed extensive visualizations to the draft strategy.

Targeted Meetings and Discussions

Throughout the development of the strategy, the authorship team met with members of the community with targeted questions, as follows.

May 8, 2023: Coordination with State Water Board

Attendees:

Name	**Organization**
Ellen Preece	DWR
Janis Cooke	Central Valley Water Board
Laura Twardochleb	State Water Board
Sam Bashevkin	State Water Board
Keith Bouma-Gregson	USGS
Diane Riddle	State Water Board
Martina Koller	DSC
Scott Navarro	DSC
Rachael Klopfenstein	DSC-DSP
Marisa VanDyke	State Water Board
Steve Culberson	DSC-IEP

Laurel Larsen	Delta Lead Scientist
Stephen Louie	State Water Board
Meredith Howard	Central Valley Water Board
Erin Foresman	State Water Board
Tamara Kraus	USGS

August 2023: Early draft of Delta CHABs Monitoring Strategy released. Feedback received from:

Name	Organization
Janis Cooke	Central Valley Water Board
Meredith Howard	Central Valley Water Board
Scott Navarro	DSC
Henry DeBey	DSC-DSP
Laurel Larsen	Delta Lead Scientist
Rachael Klopfenstein	DSC-DSP
Ted Flynn	DWR
Rosemary Hartman	DWR
Silvia Angles	DWR
Steve Culberson	IEP
Shawn Acuna	Metropolitan Water District
Sam Bashevkin	State Water Board
Laura Twardochleb	State Water Board
Carly Nilson	State Water Board
Marisa VanDyke	State Water Board
Keith Bouma-Gregson	USGS
Emily Richardson	USGS

August 18, 2023: Briefing to State Water Board member Laurel Firestone. Attendance:

Name	Organization
Laurel Firestone	State Water Boardmember
Eric Oppenheimer	State Water Board
Karen Mogus	State Water Board
Diane Riddle	State Water Board

Greg Gearheart	State Water Board
Jay Ziegler	Delta Watermaster
Meredith Howard	Central Valley Water Board
Laurel Larsen	Delta Lead Scientist
Tricia Lee (Strategy author)	DSC-DSP
Jessica Pearson	DSC-DSP
Henry DeBey	DSC-DSP

September 22, 2023: Meeting with CVRWB

Attendance:

Name	**Organization**
Ellen Preece	DWR
Mine Berg	ESA
Karen Odkins	CDFW
Meredith Howard	Central Valley Water Board
Janis Cooke	Central Valley Water Board

October 2, 23, 25, November 20, 2023: Coordination with State Water Board – Division of Water Rights. These meetings were to coordinate presentation at the State Water Board's Bay-Delta Plan Updates Tribal Engagement Workshop on November 9. Meetings included Tricia Lee (DSC-DSP) and Laura Twardochleb (State Water Board).

November 1, 2023: Presentation to DSC Environmental Justice Experts Group

Attendance:

Name	**Organization**
Tricia Lee	DSC-DSP
Ellen Preece	DWR
Amanda Bohl	DSC
Megan Thomson	DSC
Sherri Norris	California Indian Environmental Alliance
Bob Erlenbusch	Sacramento Regional Coalition to End Homelessness
Gloria Alonzo	Little Manila Rising

November 9, 2023: Presentation at State Water Board's Bay-Delta Plan Updates Tribal Engagement Workshop. Attendance not taken.

November 13, 2023: Presentation to Delta Science Roundtable

Attendance:

Name	**Organization**
Tricia Lee	DSC-DSP
Pooja Balaji	DSC-DSP
Rachael Klopfenstein	DSC-DSP
Maggie Christman	DSC-DSP
Laurel Larsen	Delta Lead Scientist
Daniel Swain	UCLA
John Callaway	University of San Francisco
Levi Lewis	UC Davis
Newsha Ajami	Lawrence Berkeley National Laboratory
Steve Lindley	NOAA
Josue Medellin-Azuara	UC Merced

November 15, 2023: Presentation at Coastal and Estuarine Research Federation conference (virtual only- attendance not taken).

January 10, 2024: Workgroup Kickoff Meeting

Attendance:

Name	**Organization**
Tricia Lee	DSC-DSP
Ellen Preece	DWR
Mine Berg	ESA
Karen Odkins	CDFW
Laura Twardochleb	State Water Board
Sam Bashevkin	State Water Board
Carly Nilson	State Water Board
Marisa VanDyke	State Water Board
Janis Cooke	Central Valley Water Board
Dana Shultz	Central Valley Water Board
Ted Flynn	DWR
Rosemary Hartman	DWR

Zhenlin Zhang	DWR
Tiffany Brown	DWR
Keith Bouma-Gregosn	USGS
Andrea Jaegge	USGS
Spencer Fern	Restore the Delta
Scott Navarro	DSC
Shawn Acuna	Metropolitan Water District
Silvia Angles	DWR
Isabel Jones	EPA
Yeana Kwagh	EPA
Dierdre Des Jardins	California Water Research
Peggy Lehman	Peggy Lehman Consulting
Atlasi Daneshvar	Valley Water
Zach Gigone	Shingle Springs Band of Miwok Indians

January 25, 2024: Coordination with State Water Board

Attendance:

Name	Organization
Laura Twardochleb	State Water Board
Sam Bashevkin	State Water Board
Marisa VanDyke	State Water Board
Greg Gearheart	State Water Board
Jay Ziegler	Delta Watermaster
Zane Poulson	State Water Board
Rebecca Fitzgerald	State Water Board
Ellen Preece	DWR
Mine Berg	ESA
Karen Odkins	CDFW
Tricia Lee	DSC-DSP
Rachael Klopfenstein	DSC-DSP
Henry DeBey	DSC-DSP
Lisamarie Windham-Myers	Delta Lead Scientist
Alex Stella	DSC-DSP

February 22-March 25, 2024: Public comment period, see Appendix C for more information.

Spring 2024: Briefings to discuss Delta Agency Science Workgroup (DASW) and Delta Plan Interagency Implementation Committee (DPIIC)

- Feb 1: Cynthia Fowler, United States Army Corps of Engineers (USACE)
- Feb 2: Richard Looker, Robert Schlipf, Kevin Lunde, Eileen White, Tom Mumley, SFRWB
- Feb 8: Patricia Bohls, Trevor Fox, California Department of Food and Agriculture (CDFA)
- Feb 14: Mandy Michalsen, Todd Steissberg, Cynthia Fowler, Jennifer Seiter-Moser USACE
- April 11: Deanna Sereno, Contra Costa Environmental Health; Jay Ziegler. Delta Watermaster; Diane Burgis, Contra Costa County Board of Supervisors

March 20, 2024: Delta Agency Science Workgroup meeting

DPIIC agency representative attendance:

Name	**Organization**
Lisamarie Windham-Myers	Delta Lead Scientist
Patricia Bohls	CDFA
Ellen Preece	DWR
Meredith Howard	Central Valley Water Board
Mick Porter	USACE
Todd Plain	USBR
Keith Bouma-Gregson	USGS

April 15, 2024: Presentation to DPIIC Spring Meeting and ask for endorsement on Strategy.

DPIIC member attendance:

Name	**Organization**
Josh Grover	CDFW
Tawny Mata	CDFA
Cindy Messer	DWR
Anna Naimark	California Environmental Protection Agency
Nancy Vogel	California Natural Resources Agency

Diane Burgis	Delta Protection Commission
Amanda Cranford	NOAA
Campbell Ingram	Sacramento-San Joaquin Delta Conservancy
Joaquin Esquivel	State Water Board
Eric Reichard	USGS
Mike Chotkowski	USGS
Rachel Orellana	USACE

Appendix C: Comments and Responses

Author	Comment	Response
CVCWA	Brief description of Delta RMP...does not accurately capture the scope and extent of the program, and the statement that the Delta RMP is "conducted by entities with discharges or project activities that will likely impact Delta water quality" is somewhat vague and inaccurate.	We will work with Delta RMP to include satisfactory language.
	on pages 51-52...there may be a potential regulatory pathway for adding and funding CHAB monitoring through the addition of requirements in existing permits under the Clean Water Act. Many participants in the Delta RMP already contribute to funding to support the Delta RMP and its monitoring, including the planned CHAB monitoring and research described in the Delta RMP's existing nutrient work plan. This allows for coordination and monitoring efficiency to support coordinated monitoring for Delta water quality issues, including planned CHAB monitoring and research described in the Delta RMP's existing nutrient work plan.	Thank you for this comment, language in this recommendation is just to provide examples and does not endorse any one funding pathway.
	Permitted entities already face multiple and expensive monitoring requirements. A "regulatory pathway" to develop funding to implement the Draft Monitoring Strategy would unnecessarily add to this burden and should not be considered a viable strategy for funding. In this regard, CVCWA notes that the statement on page 52 that the California Legislature could allocate funds from existing programs to pay for monitoring in the Delta. CVCWA agrees that funding should come from the Legislature, not individual permittees,	Thank you for this comment, language in this recommendation is just to provide examples and does not endorse any one funding pathway.

	to pay for the proposed program. CVCWA also requests that the DSP provide a scope and budget for the CHAB monitoring program so that stakeholders can evaluate the funding needs and potential sources.	
Delta ISB	The executive summary should better reflect the context and scope for the report. The summary is vague in outlining the reasons for which CHABs were identified as "most problematic in Delta waterways" during the Delta Science Program workshop on HABs. The protection of public health as a goal in developing the strategy is also not mentioned or explained. Further, the funding context is also unclear in the summary, e.g., the lack of funding is noted in the second paragraph, but in the next paragraph the need for a phased approach to prioritize investment is highlighted.	We changed from "most problematic" to "type of HAB that dominates" We expanded and refined that there is no funding associated with this project, but rather the implementation of the strategy will lean on the collaboration of the community. We do not mention specific goals in the executive summary, but more information can be found in the body of the text and public health is no longer omitted.

	While chapters 1, 2, and 3 provide a good overview of current monitoring and the state of science in CHAB dynamics, there is a need to present the problem more explicitly and firmly from the perspective of public health and the risks associated with CHAB toxins as neurotoxins. For example, in section 1.5, the exclusion of public health protection is noted, but the reasons for the delays in developing a plan for public health protection are not explained. In addition, the regulatory framework for monitoring CHABs could be more clearly explained.	Public health has been included in the final version of the strategy. This monitoring strategy can be used to address any CHAB management question that implementers desire, therefore public health management questions could be addressed.
	The draft strategy correctly identifies satellite observations as a valuable potential component of a monitoring strategy. The report only mentions a subset of potential space-borne instruments, however. While the report does discuss data from the Sentinel-3 satellite, it does not acknowledge the potential role of other instruments. For example, NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) satellite that launched in February 2024 could be instrumental for CHAB monitoring. In addition, the use of NASA's Earth Surface Mineral Dust Source Investigation (EMIT) instrument aboard the international space station for monitoring blooms is an active area of research. There are also potential opportunities for use of private sector data, such as those from Planet Labs, which have been used for monitoring HABs.	We added more information on this into the strategy. At this time a lot of the remote sensing data is not very useful for the small Delta Waterways. However, we recognize that moving forward these tools will be useful. We generally refer to the FHAB strategy for remote sensing recommendations as they have already taken a deep dive into this issue and we did not want to recreate the

		work they have already completed on the topic.
	More broadly, there is an opportunity to think more deeply about what an integrated monitoring approach that includes satellite remote sensing, drone flights, and *in situ* observations might look like. An integration of these monitoring approaches in real-time could be used to support effective management decisions to mitigate severe CHABs in specific vulnerable habitats for example.	We appreciate this input and agree. Again, we largely defer to the FHAB strategy for this type of work. Please see special study 3.6.6 that addresses the combined use of remote sensing and drone imagery.

	The draft strategy covers many of the primary drivers of CHABs but does not address interactions between them to a sufficient degree. For example, the relationship between precipitation and nutrient loading has been the focus of a number of recent studies. Another example of an interaction to consider is that of nutrient stoichiometry in controlling the composition of the phytoplankton populations. In this context, the relative amounts of available nitrogen, phosphorus, and silica may be important. Because diatoms require dissolved silica to bloom, greater silica availability may mitigate the dominance of the phytoplankton by cyanobacteria. These could also be topics for additional "special studies" (Chapter 5)	Thank you for this comment. Extensive studies of the impact of nutrients (Dugdale et al. 2007, Jassby 2008, Cloern and Jassby 2012, Kraus et al. 2017) have been completed in the Delta and upper San Francisco Bay (SFB) and is the focus of ongoing special studies of the Delta Regional Monitoring Program (Delta RMP). In the revised CHAB strategy document we will describe in greater detail the nutrient studies being conducted by the Delta RMP and the synergy with the current monitoring strategy. Based on past work, it has been established that the Delta is a high nutrient low chlorophyll system (Cloern and Jassby 2012) and that nutrients (including silica) do not limit growth of

		phytoplankton, including diatoms. Because nutrients are at non-limiting levels, ratios of nutrients (i.e. nutrient stoichiometry) tends not to control phytoplankton community composition (Strong et al. 2021). Other factors limiting growth or impeding competition by diatoms and other beneficial algal blooms (BABs) appear to be residence time (Jassby 2008), light attenuation due to high turbidity (Jassby et al. 2002, Berg et al. 2019, Strong et al. 2021), and grazing by clams (Lopez et al. 2006, Lucas and Thompson 2012, Kimmerer and Thompson 2014).

	The draft strategy focuses very strongly on the growth rates and abundance of cyanobacteria and much less so on the concentrations of toxins produced by the cyanobacteria. Recent studies have shown that the abundance of cyanobacteria does not consistently track with toxin concentrations and that these two quantities respond to drivers differently. Because toxin concentrations are of critical importance for assessing human and ecosystem health, the monitoring strategy must address them more directly.	Thank you for this comment, we certainly agree which is why we have included special studies to address this issue looking at cyanobacterial biomass and species.
	The draft strategy does not sufficiently examine the role of selective grazing on population dynamics in promoting the dominance by cyanobacteria. Cyanobacteria can become the dominant members of the phytoplankton community because other taxonomic groups of phytoplankton, such as diatoms or chlorophytes that do not produce toxins, are a preferential food source for zooplankton. Thus, the role of selective grazing on phytoplankton taxa that could potentially compete with cyanobacteria for nutrients could contribute to the increase in cyanobacteria, allowing their populations to proliferate. This scenario would correspond to a top-down control on the phytoplankton community composition. At a fundamental level, greater understanding of the competitive benefit to the cyanobacterial population in producing toxins, which is energy intensive, could be useful in informing management actions.	This is a great comment and top-down control of phytoplankton community composition is something that we are not aware has been investigated for the Delta. In this region, total phytoplankton biomass (or lack thereof) has been the focus for grazing studies (Mueller-Solger et al. 2002, Kimmerer et al. 2014, 2018). We will add a suggestion for a special study to investigate the impact of grazing on phytoplankton community composition.

	The strategy mentions the idea of holding regular training on the use of the Microcystis visual index (MVI). We strongly support this idea as the MVI, although qualitative, is the longest-running data record of HABs in the Delta and could be as effective as an indicator for high concentrations of cyanotoxins.	Thank you for this comment.
	We recommend that the strategy consider exploring lessons learned from the development of CHAB monitoring strategies in other well-studied systems across the United States, such as the Great Lakes. This could include technological and scientific aspects as well as adaptive management strategies.	We did consider other CHAB monitoring strategies when developing this strategy. For example, we refer to the ITRC in the strategy. Technological and scientific aspects of the monitoring design should consider other monitoring strategies when working on the detailed design. We also wrote Recommendation 2.2 to ensure that the implementation phase continues to learn from existing materials.

	Overall, the draft strategy is quite general and is not sufficient for forming the basis of a detailed monitoring plan. The phased approach for developing and implementing a plan over a 5-year period also seems to be mismatched with the rapidly increasing frequency and severity of CHABs and the general urgency of addressing the extremely high concentrations of toxins that have been observed in some locations in the Delta. Considering the recommendations in the "Review of the Monitoring Enterprise in the Sacramento-San Joaquin Delta" authored by the Delta Independent Science Board in March 2022 may also be helpful.	We agree that this is a highly urgent issue, and we encourage the science community and decisionmakers to identify methods for prioritizing implementation of this strategy. The general approach to the strategy was recommended by numerous stakeholders during the draft writing and draft review of the document. Implementation of the strategy will be a collaborative effort to identify additional details based on community priorities. It is also important to note that many efforts are currently in place to monitor CHABs in the Delta and these are continuing.

		We considered prioritizing the special studies, but different groups have different priorities. Thus, we specifically chose not to prioritize the special studies. Special studies are often funded by discrete funds that may need to be focused on a certain topic. We wouldn't want these studies to not move forward because they were not identified as high priority for a certain group.
	There is a very large number of "special studies" proposed in the report. The final report should attempt to identify which of these are of higher priority, especially given existing funding limitations. If prioritizing the special studies is not achievable at this stage, at a minimum the strategy document should outline the criteria by which the special studies should be prioritized.	We have decided to include prioritization of special studies as part of the first step of implementation after discussion with the Delta ISB (June 21, 2024)
	While beyond the scope of the monitoring strategy document itself, we want to emphasize that securing funding for CHAB monitoring should be a high priority. In support of this goal, the connection between the potential funding approach and the regulatory framework for managing water quality and ecosystem protection in	Thank you for this comment, the authors agree that funding and resources are imperative to advance this strategy. This document

	the Delta could be identified more clearly in the final strategy document.	doesn't intend to determine regulatory mechanisms for funding monitoring.
Delta RMP	The DRMP looks for opportunities to collaborate or leverage funding and explore partnerships and funding opportunities with existing monitoring programs. The DRMP is receptive to providing funds toward sample supplies, laboratory analyses, and shipping to add cyanotoxins and cyanobacteria to existing efforts.	Thank you for this comment.
	Looking to the future, the DRMP is excited about the opportunities for increased collaboration and coordination with the Delta science community. Together, we can ensure that the Delta remains a vibrant ecosystem and a vital water supply source. The DRMP is committed to continuing our support for initiatives, like those outlined in the Delta Science Plan and the CHABs Monitoring Plan, that enhance our collective understanding and stewardship of the Delta.	Thank you for this comment and the recognition for the need for increased collaboration.
Limnotech and Freeboard Technology	The current monitoring network and plan seem a little thin on real-time continuous measurements of phycocyanin and nutrients (see buoy and nutrient attachments), even though they cover many other parameters. Without this information to assess bloom dynamics, it is difficult to make informed within-season management and supplemental grab sampling decisions, and to calibrate models (e.g., Special Study 3.5.12) with hindcasting targets that have high temporal resolution.	We agree with this comment. However, funding is needed to increase real time measurements of these parameters.

	The toxin monitoring program could be improved with at least weekly to daily sampling near water intakes and areas of high recreational use. See the State of Ohio guidance documents available here: 1. https://epa.ohio.gov/static/Portals/28/documents/habs/PWS-HAB-Strategy.pdf 2. https://www.scph.org/sites/default/files/editor/EH/5%202020%20HABResponseStrategy.pdf	We agree with this comment. However, funding is needed to increase toxin monitoring.
	Most of the sensor deployments seem to be on fixed stations rather than buoys (see attached), which makes it hard to measure open water conditions and stratification (e.g., using thermistor strings), or at least shallow and deep pairing of sensors.	We agree with this comment. However, funding is needed to increase real time measurements of these parameters. Please note that much of the Delta does not stratify.
	Using citizen science/community science strategies and synoptic snapshot sampling (e.g., HABs Grabs – see Chaffin et al. paper attached) can be valuable complements to satellite imaging and grab sampling. The current HAB reporting system and map (https://viewperformance.deltacouncil.ca.gov/pm/harmful-algal-blooms) could be enhanced and better integrated into the overall strategy, including the use of EnviroDIY devices (see attached).	We agree with this comment and encourage citizen science/community science to participate in this effort. We have also included a new recommendation 3.4 to explicitly include community science.

Restore the Delta	More collaborative work needs to be done to include more Tribal Nations in this work. We understand the list is not exclusive, but improved outreach in this process to tribes outside of the Shingle Springs Band of Miwok Indians, Buena Vista Rancheria of Me-Wuk Indians, other Tribal nations whose communities engage with the area, and California Indian Environment Alliance needs to happen in a timely manner. Tribal ecological knowledge is invaluable for managing our waterways, as tribes have been stewarding the land since time immemorial. Setting up resources for tribes to monitor and contribute to larger monitoring efforts in a way that helps to protect their way of life should be a top priority. Disadvantaged communities and Tribes share in this burden of being the first to be affected and the last in line to receive aid for environmental hardships; we advocate that this strategy highlight those needs to match science with community needs.	We agree with this comment and hope to continue to broaden our engagement with frontline communities affected by CHABs in the Delta and have created Recommendation 1.3 for this purpose. We welcome interweaving TK into any mainstream science activities where Tribes would be interested to do so.

	We agree that identifying geographic areas for monitoring should be prioritized, as in Recommendation 3.2.1. As the strategy becomes finalized, we believe that disadvantaged communities and tribes should be a priority for determining those areas for monitoring. Acknowledging that there will likely be differences in HAB formations between different areas within the Sacramento-San Joaquin Delta, means of monitoring will likely differ. Incorporating this into the monitoring strategy would be necessary and could work for community resources. Recommendations 3.2.4 and 3.3 also highlight that data and monitoring processes will be made available to the public; still this information needs to be distributed in a way that explains what everything means. This strategy is centered around ensuring a standard collection process for HAB monitoring, so it's essential that these processes be explained in a way that makes implementation easy. Also, Special Study 3.5.10 highlights that determining when concentrations at which cyanobacteria become a management concern is a problem with the lack of a current HAB standard, which further puts disparate impacts on disadvantaged communities.	We encourage input on priority monitoring locations from all interested parties during the implementation phase. We are open to additional groups being included to allow ample feedback on this process. We have added communication to recommendation 3.2.4 to demonstrate our commitment to ensuring information is communicated beyond the small circle of monitoring practitioners.

	This monitoring strategy highlighted a few areas of study that need further study, and we believe there should be priority for a few. We strongly agree that flow studies need to be prioritized because of the factors that drive HAB formations. Flow is one of the few factors water agencies can control down the Sacramento and San Joaquin Rivers. With the previous year of record snowpack and a Delta-wide decrease in HAB formations, flow control is pivotal for HABs. Studies between wet and dry years that compare snowpack melt and flow through the Delta during summer months are necessary. The data gap for dead-end sloughs and marinas that exist throughout the Delta must be monitored and added into the broad scale dynamics in order to develop specific management methods. Understanding the changing atmospheric carbon levels and how they may affect CHABs also needs more research as we move into more carbon capture and sequestration implementation in the Delta. Atmospheric carbon is a leading cause of climate change, which increases temperatures and drought periods. However, understanding what could become a problem from carbon leaking and what impact that could have on HAB formations Delta-wide is worth exploring more.	Thank you for these comments, please see example management question (Table 4) on Environmental Drivers including flow. We also have included special study 3.5.2 to "Investigate how changing atmospheric carbon levels may impact CHABs in the Delta"

	Focusing on further research and setting up guidelines is great, but if there is no prioritization of public health advisories and outbound communication strategies for disadvantaged communities, the application of the strategy will fall short of the much need execution it has been created for. Bridging the gap between incident reports and monitoring strategies within the Delta communities is necessary. With the lack of funding for HAB monitoring, a solution is to allow the communities to fill in those data gaps with a reasonable HAB monitoring strategy that is easily implemented with community outreach and training from State water agencies. Community members are likely the first to see HAB outbreaks without knowing what they are and are the first affected by the health impacts. The strategy should have public information on HABs to help disadvantaged communities understand what HABs are and to help build a communally lead montioring effort across the Sacramento-San Joaquin Delta. The communities that live, work, and recreate to the Delta and the HABs prone areas are the most likely to be affected by poor water quality conditions.	Thank you for this comment, we believe that integration of community science can be a worthwhile tool and have included recommendation 3.4 to include this. We agree that public health and incident response are core to the intent of managing and mitigating Delta CHABs. We have added an example management question on incident response from the FHAB Framework and Strategy to "Table 4. Example management questions and linkages to decision making"

	We recognize that this work is unfunded, but the amount of work put into this expanded strategy will pay dividends in HAB management throughout the Sacramento-San Joaquin Delta. Keep these processes open and accessible to the public. Implementing an annual meeting for updates on HAB work from the government to the community level is a great idea. However, we argue that a baseline of bi-annual (March-April prior to general HABs season, September-October after general HABs season) approach to meetings would likely address monitoring problems more efficiently. We believe that with coordination across the State, the framework for a HABs standard for protection for beneficial uses and drinking water quality will follow this strategy.	Thank you for this comment, we appreciate RTD's continued collaboration. We would prefer to have as open communication as possible, and believe that more frequent informal technical meetings (Recommendation 1.2) will provide an opportunity for information sharing outside of the annual meeting.
SWRCB-OIMA	We are concerned that public health was not highlighted as a main goal (lines 8-21, page 5). As part of Assembly Bill 834 (Quirk, 2019), one of the mandates is to coordinate immediate and long term HAB incident response across the state with responsible entities including the California Water Quality Monitoring Council, Office of Environmental Health and Hazard Assessment, State Department of Public Health, Department of Water Resources, Department of Fish and Wildlife, Department of Parks and Recreation, other appropriate state and federal agencies, and California Native American tribes. Based on this language, the implementing agencies and partner organizations implementing the Strategy are legislatively mandated to address public health. This goal is also re-iterated in the Statewide FHAB Monitoring Strategy to leverage existing monitoring efforts to	We agree that public health and incident response are core to the intent of managing and mitigating Delta CHABs. The intent of page 5, lines 8-21 was to establish that the strategy does not go so far as to establish toxin health thresholds, but we have reframed 1.5 Strategy Scope to maintain that any management question that

	inform public health risk from exposure to HABs. We also heard at the 2022 Delta HAB Workshop that this was a priority from participants, and we've heard it re-iterated at supplemental meetings during the rollout of this Strategy. Our FHAB Program also receives these comments that we should be expanding our FHAB incident response, especially for disadvantaged communities where exposure may be heightened.	is chosen during implementation of the strategy can be addressed with this strategy- whether that management question is for public health or water quality. "Table 4. Example management questions and linkages to decision making" also lists "Public health advisory posting" as an example of a decision that is supported for multiple example management questions. We have also added an example management question on incident response from the FHAB Framework and Strategy.

	We appreciate the detailed synthesis of existing monitoring occurring in the Delta. It's a great first step in understanding where gaps may exist and where current monitoring efforts could be leveraged. We recognize that the Microcystis visual index is a valuable qualitative tool readily used within the Delta to determine presence or absence of Microcystis (lines 5-26, pg. 13). As recommended from several participants in the 2022 Delta HAB workshop, we also recommend that the Strategy explicitly document the need for additional project to review the visual index protocol for consistent collection of this type of data across the Delta. The project should also include evaluation of the current application, to prevent inaccurate use of the protocol, and the refined methodology can be integrated into a Standard Operating Procedures document.	"Special Study 3.5.6 Improve use of visual index data" was included to address this problem. We also believe that the Annual Meetings (Recommendation 1.5) could provide an opportunity to conduct trainings on tools such as the MVI.
USEPA	EPA recommends adding the EPA/USGS Water Quality Portal (WQP) to the list of data resources to consider for data integration with the NOAA MERHAB data dashboard. Under the Clean Water Act (CWA) Section 106 grant program, EPA requires water quality monitoring data to be submitted into EPA's Water Quality eXchange (WQX), which becomes publicly available in the WQP. Beginning in FY25, that WQX requirement will extend to tribal CWA 106 funding recipients in addition to state recipients, so more HAB-related data will likely soon become available in WQP.	Thank you for this comment.

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