Implementation of a Benthic Cyanobacteria Tiered Monitoring Program for Public Health Protection in Northern California Rivers

December 2024

Freshwater Harmful Algal Bloom (FHAB) Monitoring and Response Program

California North Coast Regional Water Quality Control Board

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Executive Summary

The North Coast Regional Water Quality Control Board (Regional Water Board) recently released two reports summarizing data collected in the Eel, South Fork Eel, Navarro, and Russian Rivers from 2016 to 2019 and provided recommendations for monitoring benthic cyanobacteria in northern California rivers. In 2022 and 2023, the Regional Water Board's Freshwater Harmful Algal Bloom (FHAB) Program initiated two pilot studies to evaluate and implement these monitoring recommendations in the Eel, South Fork Eel, Navarro, and Russian Rivers. Results from the pilot studies demonstrated that Solid Phase Adsorption Toxin Tracking (SPATT) passive samplers can provide early indications of increasing cyanobacterial percent cover and toxicity in a river system. These studies confirmed that the tiered monitoring approach, with incorporating SPATTS for early detection, can be an appropriate methodology to inform posting recommendations.

These findings are a critical step to implementing the tiered monitoring recommendations that provide a cost-effective approach to identifying public health risks in the North Coast Region. Additional studies are recommended to verify that these monitoring protocols are appropriate for watersheds outside of northern California. Further, numeric trigger levels need to be developed for percent cover of cyanobacteria and cyanotoxin concentrations for both SPATTs and benthic mats to ensure objective and consistent application of the tiered approach. Agency support will be needed to integrate these findings into future benthic cyanobacteria investigations for the protection of public health.

List of Acronyms

ATX	Anatoxins
CCHAB	California Cyanobacteria Harmful Algal Bloom Network
ELISA	Enzyme-Linked Immunosorbent Assay
FHAB	Freshwater Harmful Algal Bloom
HAB	Harmful Algal Bloom
MCY	Microcystins
NOD	Nodularins
OEHHA	Office of Environmental Health Hazard Assessment
SOP	Standard Operating Procedure
SPATT	Solid Phase Adsorption Toxin Tracking

Glossary

Benthic – refers to organisms that attach to the bottom substrates of rivers or other waterbodies.

Benthic mats – cyanobacteria that grow attached as cohesive mats to the stream bottom and can subsequently detach and float as mats on the water surface; these contrast with planktonic cyanobacteria, which grow suspended and dispersed in the water column.

Congener – cyanotoxin molecule with minor molecular variation on the same general molecular structure. Cyanotoxin class can contain multiple congeners.

Cyanobacteria – historically referred to as “blue-green algae,” these organisms are prokaryotic bacteria that contain chlorophyll-a and phycocyanin pigments; these organisms co-occur with “true” eukaryotic algae.

Cyanotoxins – toxic molecules produced by cyanobacteria that can affect skin via contact (dermatoxins) or affect the liver (hepatotoxins) and central nervous system (neurotoxins) through ingestion.

Enzyme-linked immunosorbent assay (ELISA) – laboratory method for detecting and quantifying cyanotoxins by reacting proteins and antibodies then measuring color change in well plates; this analysis can measure multiple cyanotoxin congeners.

Harmful algal bloom (HAB) – a “bloom” is a rapid proliferation of algae and/or cyanobacteria. HABs in this document refer to blooms of cyanobacteria that produce cyanotoxins that are harmful to humans and animals.

Reach – delineated linear segment of a stream or river where monitoring occurs.

Solid phase adsorption toxin tracking (SPATT) – passive samplers constructed of mesh and filled with porous resin that is capable of absorbing and desorbing cyanotoxins.

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Introduction

Study Rationale and Objectives

In February 2022, the Regional Water Board released a report titled *Benthic Cyanobacteria and Cyanotoxin Monitoring in Northern California Rivers, 2016-2019* (https://www.waterboards.ca.gov/northcoast/water_issues/programs/swamp/pdf/20220208_Final_North_Coast_Benthic_Cyano_Report_2016-2019_ADA.pdf) describing the findings of a four-year study on benthic cyanobacteria in the Russian, Eel, and South Fork Eel Rivers (NCRWQCB 2022a). The study elements included: the collection of ambient water grab samples; the deployment of Solid Phase Adsorption Toxin Tracking (SPATT) passive samplers; and the collection and analysis of cyanobacterial mat samples. Based upon the study's findings, the Regional Water Board recommended a stepwise or tiered approach to monitoring benthic cyanobacteria and cyanotoxins for the protection of public health in rivers:

Tier 1. Deployment of SPATT samplers as sentinel cyanotoxin detection tools,

Tier 2. Visual assessments of cyanobacteria benthic cover and genera identification,

Tier 3. Cyanotoxin analysis of the mat-forming cyanobacteria "genera of concern[1]."

The benthic study demonstrated that SPATT samplers integrate low levels of cyanotoxins that are not captured by discrete water column grab samples. Due to their sensitivity, increases in cyanobacterial growth (i.e., biomass) or cyanotoxin production are documented by increasing cyanotoxin concentrations captured by SPATTs (Tier 1). Increases in SPATT cyanotoxin concentrations then trigger the need for visual assessments (Tier 2). Visual assessments include the identification of cyanobacteria genera of concern, coarse estimates of their physical extent (i.e., percent cover), as well as "deliverability" of benthic mats (i.e., the potential for detachment and accumulation of benthic mats resulting in greater public health risks). Increases in cyanobacterial percent cover and deliverability then trigger benthic mat testing to confirm bloom toxicity and inform public health decisions (Tier 3). Since SPATTs characterize conditions both locally and upstream, samplers can be spatially distributed throughout the river system, in areas of special significance (e.g., recreational beaches, ceremonial sites), or deployed in locations downstream of areas with recurring cyanobacterial growth.

Regional Water Board staff have monitored and evaluated cyanobacteria conditions in northern California watersheds since 2015 and have developed an expertise, or best

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[1] As identified in the report Benthic Cyanobacteria and Cyanotoxin Monitoring in Northern California Rivers, 2016-2019, the genera of concern are *Anabaena*, *Microcoleus* (*Phormidium*), and *Oscillatoria*. These genera are known to produce large benthic mats and are associated with high concentrations of cyanotoxins.

professional judgment, when identifying genera of concern and understanding their growth cycles. In the absence of developed numeric trigger levels for cyanotoxin concentrations in SPATTs and benthic mats or cyanobacterial percent cover, best professional judgment is necessary to determine when successive monitoring tiers are initiated. Regional Water Board staff recommend future development of numeric trigger levels that will allow waterbody managers to standardize the initiation of successive tiers and remove the subjectivity associated with those determinations.

In December 2022, the Regional Water Board released a second report titled *Cyanotoxin Monitoring with SPATT Passive Samplers in Northern California Rivers, 2019* (https://www.waterboards.ca.gov/northcoast/water_issues/programs/swamp/pdf/SPATT_Report_2019_ADA.pdf) describing two SPATT experiments conducted in the Navarro, Russian, and South Fork Eel Rivers (NCRWQCB 2022b). This study evaluated the most appropriate deployment length for SPATT samplers to effectively monitor for dissolved cyanotoxins in rivers in the North Coast Region. Analysis of the study results led the Regional Water Board to recommend a four- to eight-day deployment length while advocating for a weekly or seven-day deployment period as logistically optimal for routine monitoring (i.e., deployment and retrieval can be scheduled on the same day each week).

During the 2022 field season, the Regional Water Board conducted a pilot study that collected concurrent data for all three tiers of the monitoring recommendations (i.e., SPATT cyanotoxins, percent cover, mat cyanotoxins) to determine if the data types correlated to each other within and across watersheds. Samples were collected weekly at multiple sites in the Russian and South Fork Eel Rivers. The goal of the pilot study was to answer the following questions:

1) Do cyanotoxin concentrations in SPATTs increase prior to increases in percent cover by benthic cyanobacterial mats?
2) Do cyanotoxin concentrations in SPATTs increase prior to increases in cyanotoxin production in benthic cyanobacterial mats?

In 2023, the Regional Water Board expanded their pilot study by concurrently collecting all three data tiers at different sites in the Russian, South Fork Eel, and Navarro Rivers. To validate the monitoring recommendations, the tiered approach was implemented at two test sites in the Russian and mainstem Eel Rivers such that successive tiers would only be initiated when triggered. The goal of the 2023 pilot study was to determine the effectiveness of implementing the tiered approach to inform public health postings. Additionally, the study would help determine appropriate response actions for the protection of the recreating public and pets from benthic cyanobacterial blooms.

This monitoring report documents the findings of the 2022 and 2023 pilot studies that evaluated the tiered monitoring recommendations in northern California rivers. It also presents historical SPATT and flow data to evaluate any potential relationships between watershed hydrology and cyanotoxin concentrations.

Watershed Description

The Regional Water Board conducted the pilot studies in the Russian, mainstem Eel, South Fork Eel, and Navarro Rivers. Historical data was evaluated for the Russian and South Fork Eel Rivers, which represent two different hydrological regimes. A brief description of each watershed is included below. See NCRWQCB 2022a and 2022b for more information on study watersheds.

Russian River Watershed

The Russian River is a 1,485 mi^2 watershed located in Sonoma and southern Mendocino Counties with elevation that ranges from sea level to 4,300 feet. The Russian River flows southward for nearly 110 river miles from its headwaters north of Ukiah in Mendocino County, along US Highway 101, through several alluvial valleys before turning west for the last 30 miles and entering the Pacific Ocean at Jenner in Sonoma County.

The Russian River is a highly regulated river with two large dam impoundments on two primary tributaries and several seasonal summer dams on the river's mainstem. The impoundments modify the natural flows of the river by decreasing the high flows of winter and increasing the low flows of summer. Except for large storm events, the flows in the upper Russian River are dominated by releases from Lake Mendocino, and those of the lower Russian River are generally increased with the addition of outflow from Lake Sonoma.

The Russian River is heavily recreated with many access points along its length. The summertime reservoir releases provide sufficient flows for recreational activities and the distribution of drinking water within Mendocino, Sonoma, and Marin Counties. Several recreational summer dams and periodic closures of the river's mouth turn the lower sections of the Russian River into a series of shallow ponded sections connected by short free-flowing river segments. The summer seasonal flows remain relatively consistent throughout the summer season and year to year, providing a stable flow regime that allows for various ecological niches to develop within the river where benthic cyanobacteria can establish and flourish.

Eel River Watershed

The mainstem Eel River watershed (less the South Fork Eel River subwatershed) is a 3,283 mi^2 watershed in southern Humboldt and northern Mendocino Counties with elevation that ranges from sea level to 6,245 feet. The river flows for approximately 200 miles from headwaters in the coastal mountains of Lake and Mendocino Counties down to the mouth near Eureka, California. The Eel has four major tributaries: the North Fork, Middle Fork, South Fork (described below), and Van Duzen Rivers. The river supports various types of recreation including whitewater kayaking, flatwater boating, fishing, and swimming.

The mainstem Eel River has two dams, Scott Dam and Van Arsdale Dam, located in the uppermost section of the river. Flows in the upper section of the river are controlled by releases from these dams, however, as the Eel River flows toward the ocean, the addition of waters from several major undammed tributaries transitions the managed upper reaches to a more natural flow regime in the middle and lower sections.

South Fork Eel River Watershed

The South Fork Eel River is a 688 mi^2 watershed located in northern Mendocino and southern Humboldt Counties, with elevations that range from 100 to 4,500 feet. The South Fork Eel River flows northward for approximately 100 river miles from the headwaters in the Laytonville area in Mendocino County, along US Highway 101, through Humboldt Redwoods State Park in Humboldt County, and finally joins the mainstem Eel River upstream of the town of Weott, approximately 40 river miles from the Pacific Ocean. Like the mainstem Eel River, the South Fork Eel River is heavily recreated with many access points along its length.

The South Fork Eel River is a free-flowing river with no impoundments. The unregulated flows reflect the seasonality of the precipitation record with higher runoff flows in the winter and low base flows in the summer months.

Navarro River Watershed

The Navarro River is a 315 mi^2 coastal watershed in southern Mendocino County, approximately 120 miles north northwest of San Francisco, 30 miles west of Ukiah, and three miles south of the town of Albion. Elevations in the basin range from sea level to about 3,000 feet. State Highway 128 traverses much of the watershed, paralleling Rancheria Creek and the mainstem Navarro River for approximately 25 miles. The Navarro River flows through the Coast Ranges, and Anderson Valley, and out to the Pacific Ocean at Mendocino Coast State Seashore.

Methods

Sampling Sites and Design

The 2022 and 2023 pilot studies were conducted at a total of nine sites in the Russian, Eel, South Fork Eel, and Navarro Rivers (Tables 1 and 2, Figure 1). Sampling sites were selected from locations where SPATTs had previously documented cyanotoxins. Monitoring at all 2022 sites and a subset of 2023 sites included weekly collections of all three monitoring tiers, (i.e., SPATT deployment, visual surveillance, and benthic mat sampling) (Table 1). In 2023, the tiered approach was implemented at two test sites, such that SPATT results were evaluated before implementing successive tiers (Table 2).

Table 1. Monitoring sites for concurrently conducting all three tiers, 2022 and 2023.

Site Code	Site Name	Latitude	Longitude	Year
111SF2122	**South Fork Eel River near Miranda**	**40.1990**	**-123.7757**	**2023**
111SF4640	**South Fork Eel River at Cooks Valley**	**39.9999**	**-123.7866**	**2022**
111SF6221	**South Fork Eel River at Standish-Hickey**	**39.8753**	**-123.7261**	**2022, 2023**
114RR6273	**Russian River at Comminsky Station**	**38.8864**	**-123.0552**	**2022**
114RR4234	**Russian River at Alexander Valley Rd**	**38.6587**	**-122.8296**	**2022**
114RR2678	**Russian River at Syar**	**38.5633**	**-122.8530**	**2023**
113NA9055	**Navarro River at Hendy Woods**	**39.0757**	**-123.4652**	**2023**

Table 2. Monitoring sites for implementing tiered monitoring recommendations, 2023.

Site Code	Site Name	Latitude	Longitude	Year
111ER6140	**Eel River above Dos Rios**	**39.6874**	**-123.3594**	**2023**
114RR5407	**Russian River at Cloverdale Airport**	**38.7739**	**-122.9881**	**2023**

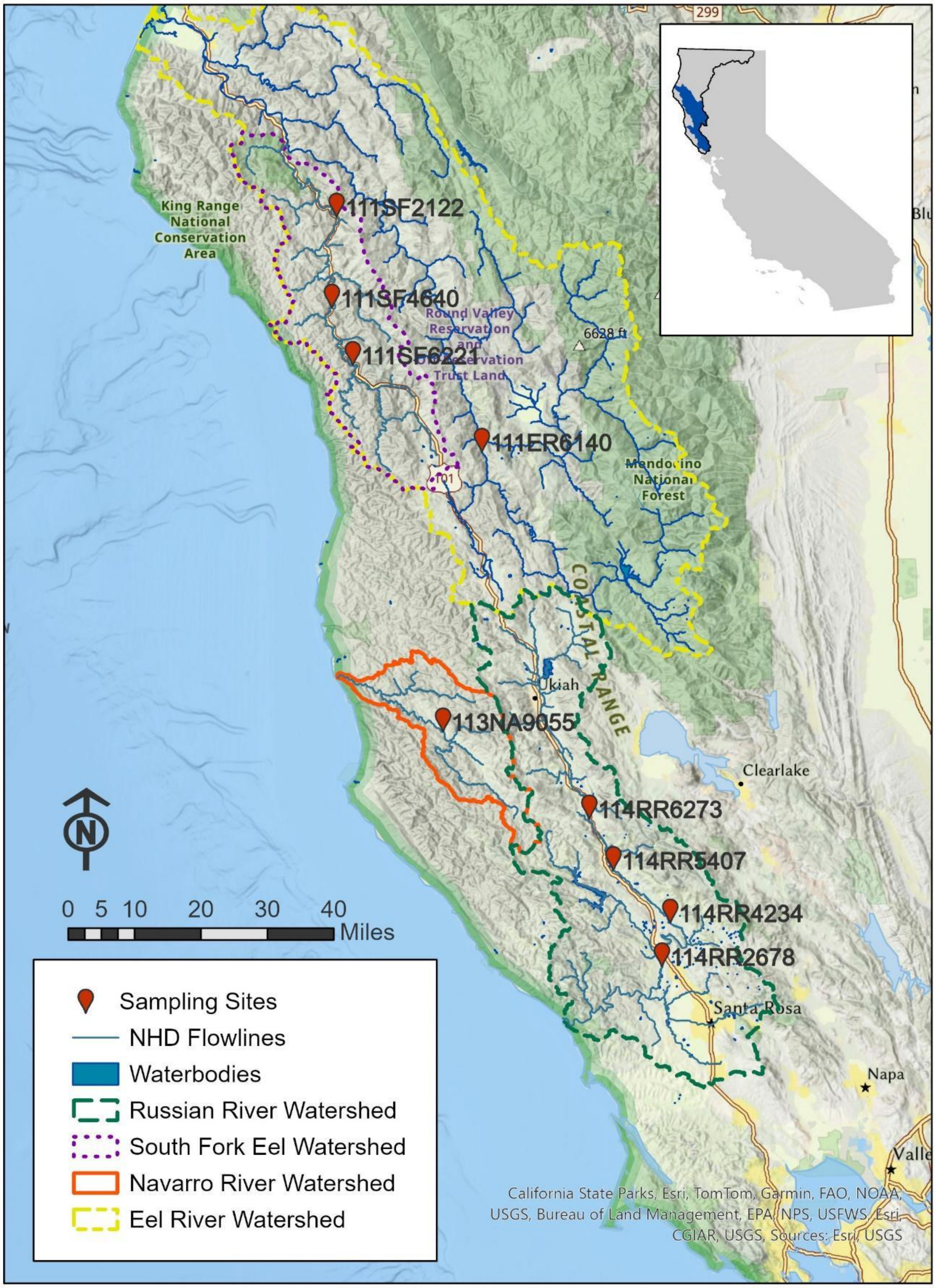

Figure 1. Map of pilot studies monitoring sites, 2022 and 2023.

Field Sampling

SPATT Passive Samplers

During each site visit, new SPATTs were deployed and previously deployed SPATTs were retrieved. All SPATTs were accounted for during the study except for a few instances when samplers were vandalized or lost due to high flows[2]. Following recommendations from the SPATT report (NCRWQCB 2022b), samplers were deployed at each monitoring location for six- to eight-days in length[3] from July 5 to October 25 in 2022, and May 16 to October 16 in 2023, totaling as many as 16 and 22 SPATT deployments per location per respective year. In some instances, SPATTs were replicated to meet quality assurance protocols.

SPATT samplers were constructed by placing 3.0 grams (g) of HP20 resin onto a 10 centimeter (cm) wide square of 100 µm Nitex cloth. A second square of Nitex was placed on top of the resin and both cloths were clipped into a 6.3 cm diameter embroidery hoop ring to create the sampler. Samplers were submerged in 100% methanol for 24 hours to clean the resin after construction. Samplers were then rinsed with Milli-Q water and stored in plastic bags with 20-50 milliliters (mL) of Milli-Q water at 4ºC in the dark until deployment.

SPATT samplers were deployed in accordance with *Standard Operating Procedure for SPATT Assemblage and Extraction of HAB Toxins* (Howard et al., 2018). Using zip ties, samplers were attached to metal stakes in well-mixed zones within the sample reach. SPATTs were deployed mid-depth in locations with enough flow velocity to generate well-mixed water, but not enough velocity to damage the SPATT.

Visual Assessment

When appropriate, Regional Water Board staff visually surveyed each study reach to determine percent cover of benthic cyanobacteria. Visual assessment included walking the length (~150 m) and breadth of the sample reach to coarsely estimate the percentage of benthic surfaces covered by cyanobacteria genera of concern (Table 3). See NCRWQCB 2022a for more information on visual surveillance protocols.

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[2] SPATTs were vandalized at Site 111SF6221 during the July 19-26, 2023, deployment. SPATTs were lost due to high flows at Site 111SF2122 during the May 23-29 and May 29-June 5, 2023, deployments. These SPATTs were not recovered and therefore are not included in study results.

[3] Due to staffing and scheduling limitations, one round of SPATTs were deployed for nine days at Sites 111SF4640 and 111SF6221 from August 8-17, 2022, and at Site 111ER6140 from September 18-27, 2023.

Table 3. Visual assessment categories

Category	Percent Cover
Indeterminant	**Flows or water clarity obscured the ability to assess conditions**
Absent	**No observable algae or cyanobacteria present**
Minimal	**< 5% cover**
Present	**5-24% cover**
Common	**25-49% cover**
Abundant	**50-99% cover**
Complete	**100% cover**

Benthic Cyanobacterial Mat Samples

Regional Water Board staff collected single species dominant mat samples, which are composites of several subsamples (N = 5-10) from various mats dominated by a single genus throughout the sample reach. By compositing subsamples, cyanotoxin concentrations are expected to be averaged across the reach by including areas that may be high or low cyanotoxin producing areas. A composite sample was collected for each genus of concern that was present in the sample reach at the time of sampling. See NCRWQCB 2022a for more information on benthic mat sampling.

Laboratory and Statistical Analysis

For both SPATT and benthic mat samples, cyanotoxin concentrations were measured via Enzyme-Linked Immunosorbent Assay (ELISA) at Bend Genetics Laboratory in Sacramento, CA. ELISA measures multiple cyanotoxin congeners within a class of cyanotoxins and cannot differentiate among congeners of a molecular structure. As a result, ELISA data are the total concentration of multiple detectable cyanotoxin congeners that may be in the sample. In this study, ELISA was used to measure anatoxins (ATX) as well as combined microcystins and nodularins (MCY/NOD) since these classes are cross-reactive. Based on the cyanotoxins present from the previous reports in these rivers, laboratory and statistical analysis focused on anatoxins and microcystins/nodularins for these pilot studies. See NCRWQCB 2022a for more information on ELISA.

Statistical analyses include summarizing data (e.g., means, percentages), plotting data trends, and determining significant correlations among data types. Based on the prevalence of non-detect data in NCRWQCB 2022b, means rather than medians were used to describe central tendencies of replicated SPATTs since medians returned zero values. ELISA method detection limits (MDLs) varied per target cyanotoxin and sample type, therefore, values below the MDL were recorded as zeros. Because data were not normally distributed, non-parametric Spearman’s rank correlations were used to describe and compare the relationships between data types.

Currently there are no numeric trigger levels associated with concentrations of anatoxins or microcystins/nodularins in SPATTs or benthic mats for posting (see NCRWQCB 2022a). Reported values and statistics are used to compare study sites and rivers; these values are not used to compare to any environmental or public health guidelines.

Framework to Evaluate Data for Public Health Postings

Current CCHAB Guidance

The CCHAB program developed a guidance document in 2020 to provide waterbody managers and health departments with defined protocols for posting alert level signage to inform and protect the recreating public from benthic cyanobacteria harmful algal blooms. The document includes posting guidance for the "General Awareness" educational sign, which is recommended to increase overall awareness even when no potentially toxigenic benthic mats are present.

Additionally, the document provides guidance on the triggers associated with posting the "Toxic Algae Alert" sign, which are: 1) the presence of potentially toxigenic benthic mats, floating mat material, or stranded mats on the shoreline at a site; or 2) detection of cyanotoxins or cyanotoxin genes within mat material. Out of an abundance of caution, these two triggers have been interpreted such that any presence of cyanobacteria (regardless of size) or any detections of cyanotoxins (including in SPATTs) would result in a Toxic Algae Alert posting. It is important to note that this guidance was developed prior to the common use of toxin passive samplers and emerging monitoring techniques.

This framework for posting was followed in 2020 and 2021, as well as during the 2022 pilot study, and has led to the posting of alert level signage in North Coast rivers when: 1) no detectable cyanotoxin production was detected within the benthic mats; 2) potentially toxigenic genera were scarcely present; or 3) in the case of positive SPATTs, the posting of alert level signage when cyanobacteria were not visibly present.

The posting of proper signage at the appropriate time provides the recreating public with the information necessary to make informed decisions regarding their recreational activities. If alert level signage is posted prematurely, it may unnecessarily dissuade the public from utilizing the waterbody for recreation, leading to resource loss, which may have a negative economic impact on communities within the watershed that rely on recreation and tourism. As discussed in the next section, the tiered approach allows for waterbody managers to make better informed decisions based upon measurable data.

Tiered Monitoring Approach

During the 2023 pilot study, the CCHAB Network granted the Regional Water Board a variance from the current benthic guidance for Toxic Algae Alert postings to implement and test the tiered monitoring recommendations in the selected study rivers. The resulting interim framework (see below) was used by the Regional Water Board for recommending Toxic Algae Alerts during this portion of the study. The interim framework utilizes thresholds that incorporate best professional judgment based on historical data in northern California rivers. The numeric thresholds were chosen to capture substantial increases in toxins or mat coverage and are not based on human health risk assessments or any analysis of human or animal health endpoints.

Interim Framework for Recommending Toxic Algae Alerts in 2023:

- SPATT toxin concentrations increase 8-fold from a previous sample result that exceeded 10 ng/g at the same location within two weeks; or
- SPATT toxin concentrations exceed 100 ng/g; or
- Percent cover of benthic mats within a reach (150 feet) are equal to or greater than 15% with visual assessment including genera of concern.

Environmental Conditions

Historical SPATT and flow data were evaluated to determine any potential relationships between watershed hydrology and cyanotoxin concentrations. Flow data was evaluated for the Russian and South Fork Eel River since these watersheds have historical SPATT data and represent regulated and free-flowing hydrological regimes, respectively.

Russian River Watershed

The Russian River is a highly regulated river with two large dam impoundments on two primary tributaries and several seasonal summer dams on the river's mainstem. The impoundments modify the natural flows of the river by decreasing the number and severity of high winter flows and increasing or sustaining low flows of summer. Except for large storm events, the flows in the upper Russian River are dominated by releases from Lake Mendocino, and those of the lower Russian River are generally increased with the addition of outflow from Lake Sonoma. The controlled releases alter flows such that annual precipitation differences may not be directly correlated with instream flows.

To differentiate the instream flow conditions per sample year of historical SPATT data, a summer (June 16 – October 15) seasonal mean distribution was calculated using the USGS mean daily flows recorded near Guerneville (https://waterdata.usgs.gov/nwis/uv?site_no=11467000&legacy=1) in the lower Russian River watershed (24-year record 2000-2023). The mean daily flows were compiled and compared to that of the summer seasonal mean (green bar) for the period of record, documenting that SPATT collection occurred during three distinct flow regimes: extremely dry (dark gray- 2021, 2022), below average (white- 2018), and wet (orange, blue - 2019, 2023) (Figure 2).

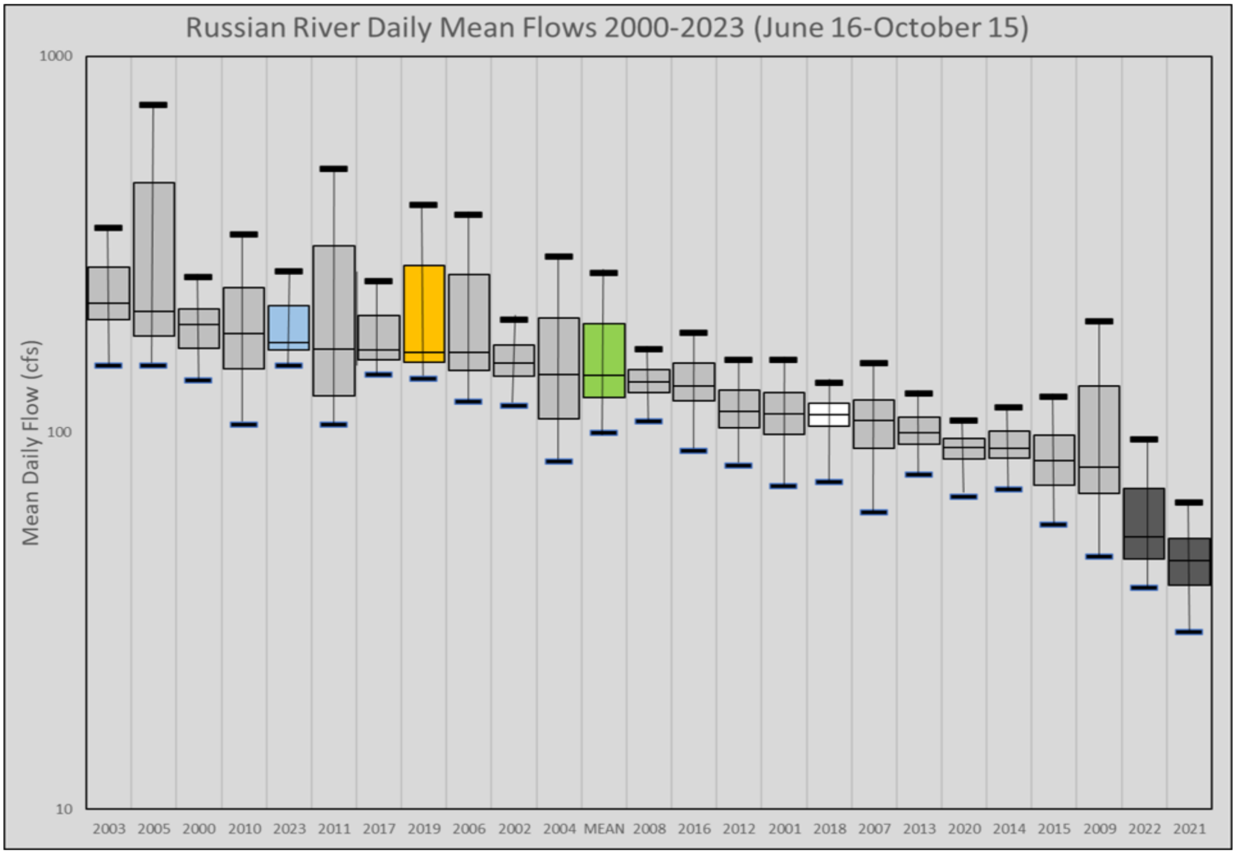

Figure 2. Russian River daily mean flows (ordered from highest to lowest) for June 16-October 15, 2000-2023. Years with historical SPATT data are shown in 2023 (blue), 2019 (orange), 2018 (white), and 2022 and 2021 (dark gray). Flows measured at USGS 11

South Fork Eel Watershed

In contrast to the Russian River, the South Fork Eel River is a free-flowing river with no impoundments. The unregulated flows reflect the seasonality of the precipitation record with higher runoff flows in the winter and low base flows in the summer months. Groundwater is the only source in the summer months. To differentiate the instream flow conditions per sample year of historical SPATT data, a summer (June 1 – September 30) seasonal mean distribution was calculated using the [USGS mean daily flows recorded near Miranda](https://waterdata.usgs.gov/monitoring-location/11476500/#period=P30D&showMedian=true&dataTypeId=continuous-00060-0) (https://waterdata.usgs.gov/monitoring-location/11476500/#period=P30D&showMedian=true&dataTypeId=continuous-00060-0) in the lower-middle South Fork Eel River (24-year record 2000-2023). The mean daily flows were compiled and compared to that of the summer seasonal mean (green bar) for the period of record, documenting that SPATT collection occurred during roughly three different flow regimes: two below average flow years (blue, white - 2018, 2023), one average (dark gray- 2022), and one wet (orange- 2019) (Figure 3).

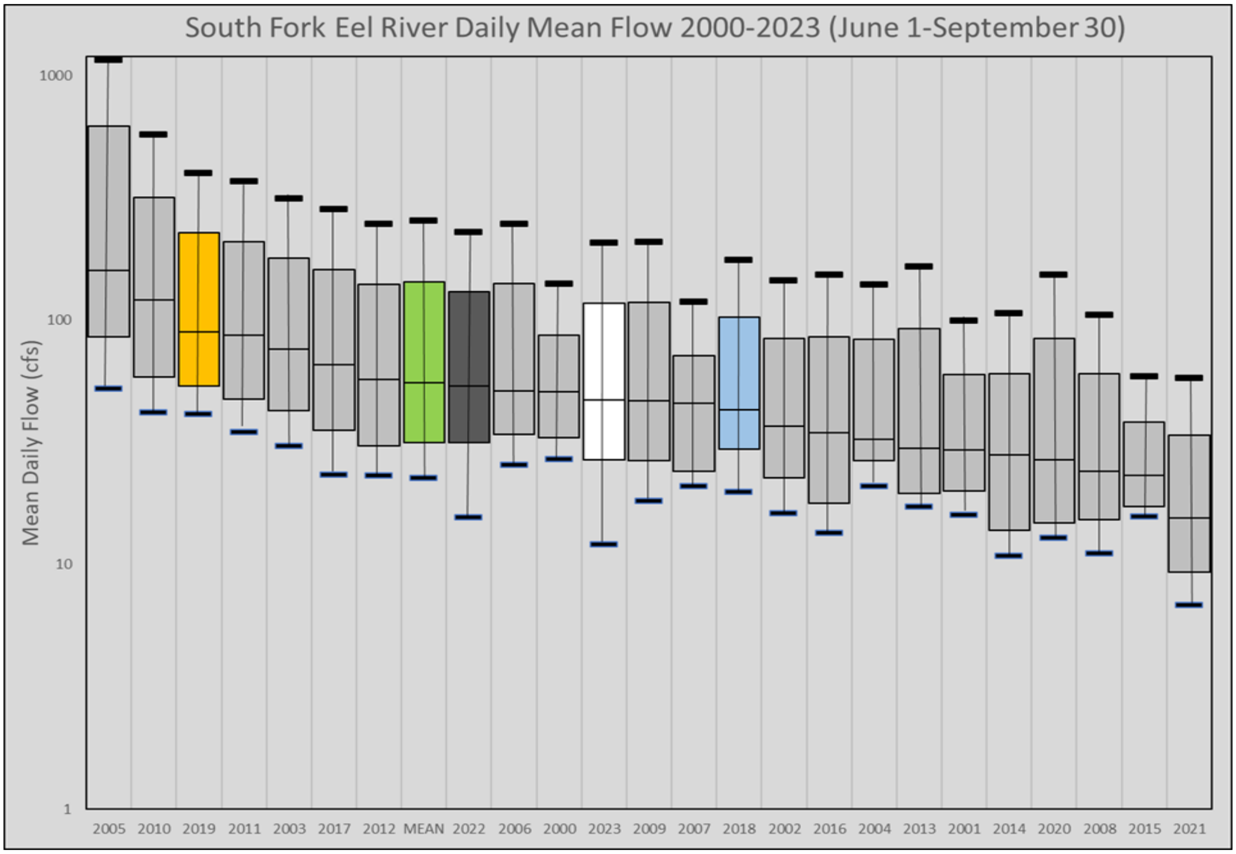

Figure 3. South Fork Eel River daily mean flows for June 1-September 30, 2000-2023. Years with historical SPATT data are shown in 2019 (orange), 2022 (dark grey), 2023 (white), and 2018 (blue). Flows measured at USGS 11476500 gauge near Miranda, CA.

Overview of Historical Data

Evaluation of historical data included results from monitoring that was conducted prior to recommendations for the four- to eight-day deployment length. In the 2019 SPATT study, samplers were deployed at varying consecutive and concurrent time intervals (ranging from one- to 14-days in length) in two separate experiments to determine how samplers absorb and desorb cyanotoxins over time (see NCRWQCB 2022b). Additionally, SPATTs were constructed of two different commercially available resins to better understand the adsorption performance of each. SPATTs were also deployed at different locations at different times of the year. As a result, historical SPATT data were not collected under a standardized approach, and results were not normalized due to differences in adsorption and desorption rates over time. Although the historical data provides valuable insight to SPATT performance under varying experimental, seasonal, and hydrological conditions, the evaluation of the historical data should be considered cursory. Additional studies are needed to build a more consistent dataset using recommendations from this report as well as NCRWQCB 2022a and 2022b.

Results for Pilot Studies

In this section, results are presented for the 2022 and 2023 pilot studies. Results are broken down by study river, monitoring approach (concurrent monitoring vs. implementing tiered approach), and/or target cyanotoxin (anatoxins vs. microcystins/nodularins).

Detection Rates and Summary Statistics

Detection rates determine cyanotoxin prevalence, and cyanotoxin mean values are used to understand cyanotoxin production across sites (see NCRWQCB 2022a, 2022b). SPATTs and benthic mats are evaluated separately because the methodologies are complementary but not directly comparable. Across all sites in 2022, detection rates in SPATTs were similar for anatoxins (range 93-100%) and microcystins/nodularins (range 94-100%) (Table 4). Except for site 114RR4234, mean values in SPATTs were higher for anatoxins (range 2.60-534 ng/g) than microcystins/nodularins (range 4.70-21.4 ng/g). In benthic mat samples, detection rates and mean values were higher at all sites for anatoxins (detection rate range 88-100%, mean value range 5.63-219 ug/L) than microcystins/nodularins (detection rate range 0-75%, mean value range ND-0.41 ug/L). Varying SPATT sample counts are due to SPATT vandalization or loss. Benthic mat samples vary based upon presence/absence during the site visit.

Table 4. 2022 detection rates and mean values in SPATT samplers and benthic mat samples. ATX, anatoxins; MCY/NOD, microcystins/nodularins; ND, non-detect; ---, not sampled.

Site	Statistic	SPATTs (ng/g)		Benthic Mats (ug/L)	
		ATX	MCY/NOD	ATX	MCY/NOD
111SF4640	Detections	16	16	14	2
	Total Samples	16	16	15	15
	Detection Rate	100%	100%	93%	13%
	Mean Value	534	21.4	91.8	0.03
111SF6221	Detections	15	15	14	0
	Total Samples	15	15	15	15
	Detection Rate	100%	100%	93%	0%
	Mean Value	422	12.4	49.5	ND
114RR6273	Detections	15	15	8	3
	Total Samples	16	16	8	8
	Detection Rate	94%	94%	100%	38%
	Mean Value	10.6	4.70	219	0.37
114RR4234	Detections	14	16	7	6
	Total Samples	15[4]	16	8	8
	Detection Rate	93%	100%	88%	75%
	Mean Value	2.60	5.50	5.63	0.41

[4] SPATT anatoxins data point for one sampling event removed due to laboratory error.

In 2023, detection rates and mean values in SPATTs were variable but higher at most sites for anatoxins (detection rate range 40-96%, mean value range 0.95-38.7 ng/g) than microcystins/nodularins (detection rate range 29-90%, mean value 0.69-15.9 ng/g) (Table 5). In benthic mat samples, detection rates were more variable for microcystins/nodularins (range 38-100%) than for anatoxins (range 69-89%), however, fewer benthic samples were analyzed for microcystins/nodularins. Mean concentrations of anatoxins (range 0.35-9,385 ug/L) were higher than microcystins/nodularins (range 0.17-0.30 ug/L) in benthic mats.

The two test sites, 114RR5407 and 111ER6410, never exceeded the Tier 1 sampling threshold, therefore visual assessments and cyanobacterial mat toxin sampling were not performed.

Table 5. 2023 detection rates and mean values in SPATT samplers and benthic mat samples. ATX, anatoxins; MCY/NOD, microcystins/nodularins; ND, non-detect; ---, not sampled.

Site	Statistic	SPATTs (ng/g)		Benthic Mats (ug/L)	
		ATX	MCY/NOD	ATX	MCY/NOD
111SF2122	Detections	17	4	14	3
	Total Samples	20	5	18	8
	Detection Rate	85%	80%	77%	38%
	Mean Value	38.7	8.71	9,385	0.17
111SF6221	Detections	21	13	14	6
	Total Samples	22	21	18	10
	Detection Rate	96%	62%	78%	60%
	Mean Value	24.5	15.9	285	0.30
113NA9055	Detections	6	6	9	9
	Total Samples	15	15	13	11
	Detection Rate	40%	40%	69%	82%
	Mean Value	0.95	3.40	0.38	0.27
114RR2678	Detections	16	6	8	1
	Total Samples	21	21	9	1
	Detection Rate	76%	29%	89%	100%
	Mean Value	1.58	0.69	2.08	0.29
114RR5407 (test site)	Detections	11	7	---	---
	Total Samples	20	20	---	---
	Detection Rate	55%	35%	---	---
	Mean Value	0.96	0.80	---	---
111ER6410 (test site)	Detections	11	18	---	---
	Total Samples	20	20	---	---
	Detection Rate	55%	90%	---	
	Mean Value	1.06	10.0	---	---

Overall, anatoxins detection rates and mean values in SPATTs were lower and more variable in 2023 than in 2022; however, the highest concentrations of anatoxins in benthic mats were observed during the 2023 season. Microcystins/nodularins detection rates in SPATTs were also lower in 2023, yet detection rates in benthic mats were higher. Both detections and concentrations of microcystins/nodularins were comparably lower than anatoxins in SPATTs and benthic mats during both years.

Concurrent Monitoring in the South Fork Eel River

The following results include data trends for concurrently conducting all three monitoring tiers (i.e., SPATT samplers, visual assessment, benthic mat sampling) at each site in the South Fork Eel River.

Results for Anatoxins

During 2022 in the South Fork Eel River, concentrations of anatoxins in SPATTs (at Sites 111SF6221 and 111SF4640) exponentially increased in mid-July, peaking in mid-August at 3,310 and 3,640 ng/g, respectively, then decreased through the season until a smaller increase was observed in mid-October (Figure 4). Anatoxins in benthic mats at the same sites (Sites 111SF6221 and 111SF4640) followed a similar trend to SPATTs, peaking in mid-August at 247 and 353 ug/L, respectively. *Microcoleus*-dominant percent cover at Site 111SF6221 increased to 20% during August, which corresponds to the anatoxins increases in SPATTs and mats; this was followed by a decrease then an increase to 70% through the end of the study. *Microcoleus*-dominant percent cover at Site 111SF4640 continually increased through early October, peaking at 40% cover.

At the start of the study, increases in anatoxins in SPATTs occurred one- to two-weeks prior to increases in benthic mat anatoxin concentrations, and two- to three-weeks ahead of an increase in percent cover. A rebound, or secondary increase in both benthic mat anatoxin production and percent cover in the late- and mid-September timeframe at Sites 111SF6221 and 111SF4640, respectively, did not elicit a commensurate increase in SPATT concentrations. SPATTs retrieved after nine days (August 17th) measured the highest concentrations of anatoxins, which was concurrent with peak concentrations in benthic mat samples, suggesting that the higher SPATT concentrations are likely a reflection of seasonal trends in cyanotoxin production rather than longer than recommended deployment length (suggested maximum deployment length is 8 days; see NCRWQCB 2022b).

Under the current CCHAB benthic guidelines, the presence of any cyanobacteria genera of concern or the presence of detectable cyanotoxins would result in a posting recommendation. On July 6, 2022, a Toxic Algae Alert was recommended for the two South Fork Eel River sites (111SF6221 and 111SF4640) due to the presence of *Nostoc*. In contrast, application of the tiered monitoring program's interim framework would have resulted in a Toxic Algae alert in early August once SPATT anatoxins exceeded 100 ng/g.

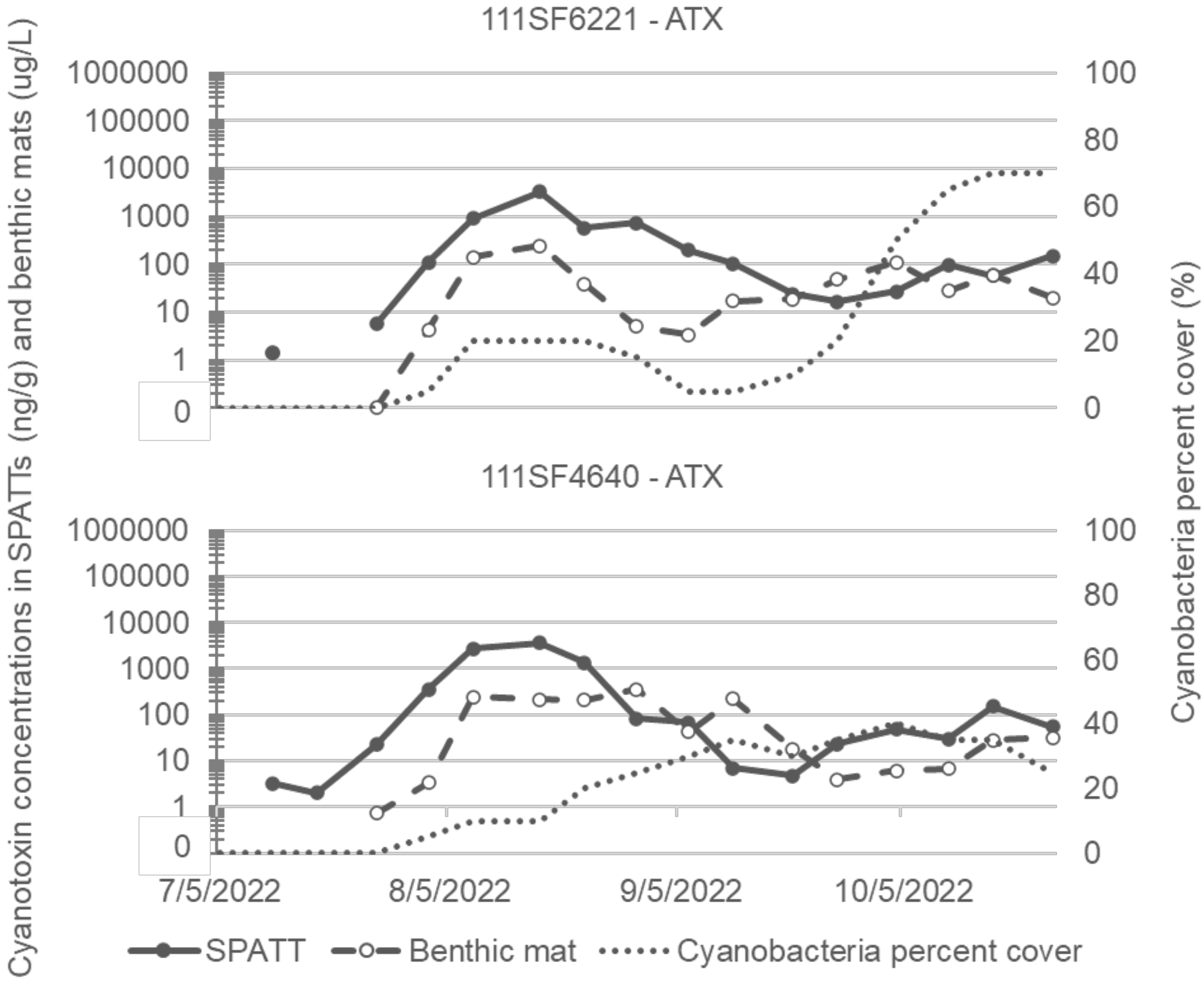

Figure 4. 2022 anatoxins (ATX) concentrations in SPATT samplers (solid line with closed circles) and benthic mat samples (dashed line with open circles) as well as cyanobacteria percent cover (dotted line) at Sites 111SF6221 and 111SF4640 in the South Fork Eel River.

In 2023, concentrations of anatoxins in SPATTs at Sites 111SF6221 and 111SF2122 started to increase in late July, peaking in mid-August and mid-September at 256 and 209 ng/g, respectively (Figure 5); these trends occurred two weeks to a month later than the peak concentrations observed in 2022. Anatoxins in benthic mats at Sites 111SF6221 and 111SF4640 followed a similar trend to SPATTs, peaking at 1,864 and 144,135 ug/L, respectively. Unlike the delay observed in 2022, initial benthic mat anatoxins concentrations increased at the same time as increases in SPATTs while percent cover was extremely low (</= 5%), demonstrating the ability of SPATTs to identify increasing toxin production in the absence of cyanobacterial growth. At Site 111SF6221, the variability in mat anatoxins production in the latter part of the season was not observed in the SPATTs. *Microcoleus*-dominant percent cover at Site 111SF6221 increased to 50% by the end of the study in mid-October, which is similar to

the late season increase observed in 2022. *Microcoleus*-dominant percent cover at Site 111SF2122 peaked at 35% in mid-August followed by a decline in mid-September down to 10% by the end of the study.

In 2023, posting recommendations were made based on the tiered approach. Using this interim framework, a Toxic Algae Alert was recommended on August 18th due to the large increase in percent cover of *Microcoleus*; percent cover was used as the basis for posting recommendation since laboratory results for SPATT and benthic mat anatoxins were delayed. In contrast, current guidance would have resulted in a posting recommendation after the first sample in May due to low-level anatoxins detections in SPATTs.

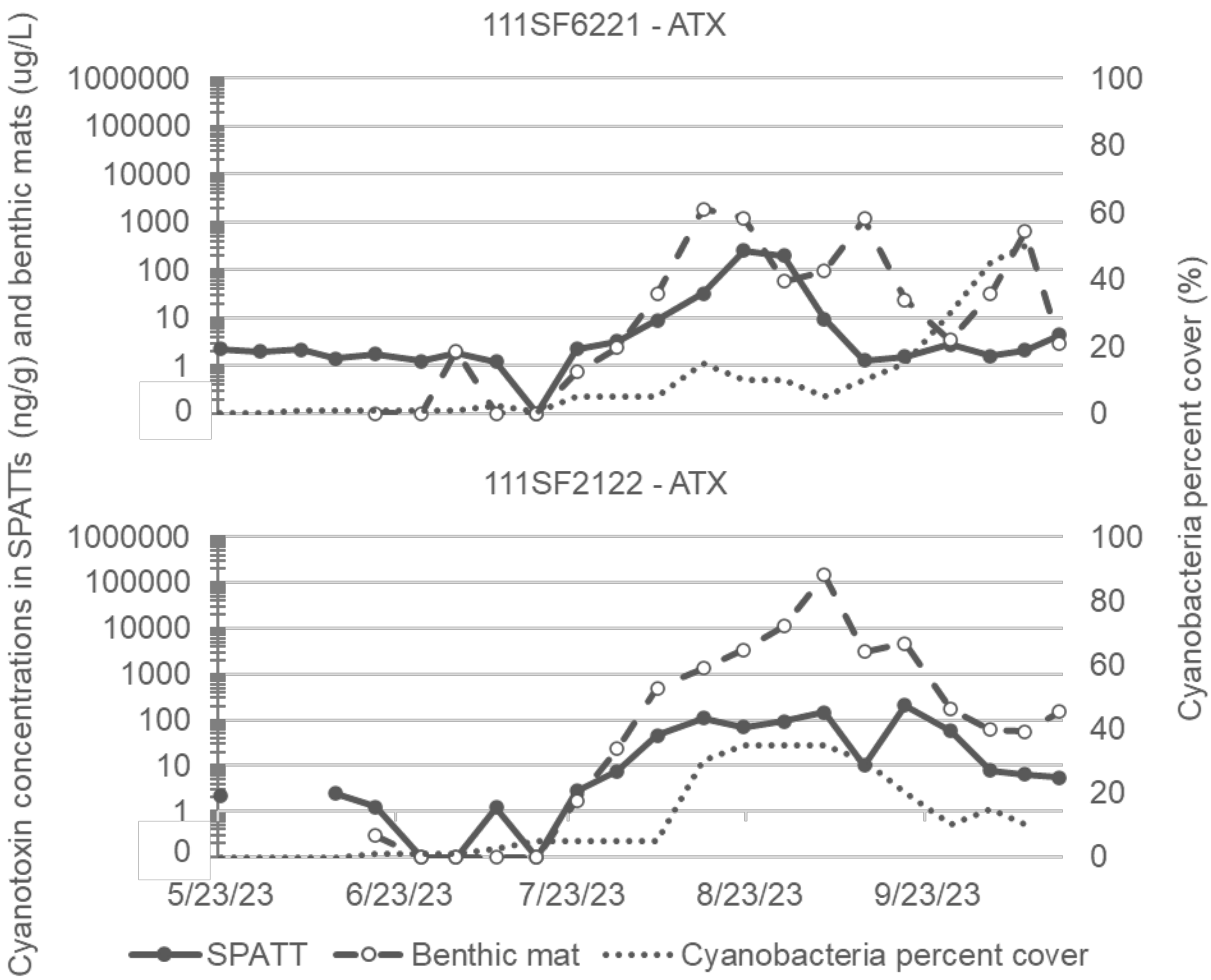

Figure 5. 2023 anatoxins (ATX) concentrations in SPATT samplers (solid line with closed circles) and benthic mat samples (dashed line with open circles) as well as cyanobacteria percent cover (dotted line) at Sites 111SF6221 and 111SF2122 in the South Fork Eel River.

Spearman's rank correlations were used to determine if concentrations of anatoxins in SPATTs and benthic mats as well as cyanobacteria percent cover corresponded to each other at each site (Table 6). Note that the dataset is small, so additional monitoring studies may be needed to further evaluate correlations among data types. In 2022, in the South Fork Eel River, anatoxins in SPATTs and benthic mats were significantly correlated ($p < 0.05$) at Site 111SF6221 ($R = 0.761$, $p = 0.001$) and Site 111SF4640 ($R = 0.539$, $p = 0.047$). However, cyanobacteria percent cover did not correlate to either SPATT or benthic mat anatoxins concentrations.

Table 6. 2022 R-values from Spearman's rank correlations for anatoxins concentrations in SPATT samplers and benthic mat samples as well as cyanobacteria percent cover at Sites 111SF6221 and 111SF4640 in the South Fork Eel River. Significant correlations (α = 0.05) are bolded with asterisk (*), and significant p-values are reported in the text.

Site	Measurement	SPATT	Benthic mat	Percent cover
111SF6221	SPATT	1		
	Benthic mat	0.761*	1	
	Percent cover	-0.076	0.173	1
111SF4640	SPATT	1		
	Benthic mat	0.539*	1	
	Percent cover	-0.371	-0.057	1

In 2023, anatoxins in SPATTs and benthic mats were significantly correlated ($p < 0.05$) at Site 111SF2122 ($R = 0.469$, $p = 0.049$) (Table 7). At the same site, SPATT anatoxins were also significantly correlated to cyanobacteria percent cover ($R = 0.653$, $p = 0.001$).

Table 7. 2023 R-values from Spearman's rank correlations for anatoxins concentrations in SPATT samplers and benthic mat samples as well as cyanobacteria percent cover at Sites 111SF6221 and 111SF2122 in the South Fork Eel River. Significant correlations (α = 0.05) are bolded with asterisk (*), and significant p-values are reported in the text.

Site	Measurement	SPATT	Benthic mat	Percent cover
111SF6221	SPATT	1		
	Benthic mat	0.339	1	
	Percent cover	0.002	0.167	1
111SF2122	SPATT	1		
	Benthic mat	0.469*	1	
	Percent cover	0.653*	0.452	1

<u>Results for Microcystins/Nodularins</u>

In the South Fork Eel River in 2022, SPATT microcystins/nodularins at Site 111SF6221 were recorded at a seasonal high at the start of the study (92.1 ng/g) then showed a decreasing trend with some variability ranging from 1.80-18.8 ng/g (Figure 6). Microcystins/nodularins were not detected in any benthic mat samples at Site

111SF6221 despite *Microcoleus*-dominant percent cover reaching 70%. Microcystins/nodularins in SPATTs at Site 111SF4640 peaked at the start of the study (176 ng/g) then decreased, fluctuating within a 3.41-21.8 ng/g range. Microcystins/nodularins were only detected in two mat samples at <1 ug/L despite cyanobacteria percent cover reaching 40%. Due to the lack of benthic mat detections, microcystins/nodularins were not evaluated with Spearman's rank correlations for both sites in the South Fork Eel River.

In 2022, a Toxic Algae Alert was recommended for the South Fork Eel River sites on July 6th due to the presence of *Nostoc*. Although microcystins/nodularins were higher at the beginning of the study, they were low for the remainder. Microcystins/nodularins in SPATTs would not have triggered additional monitoring under the interim framework.

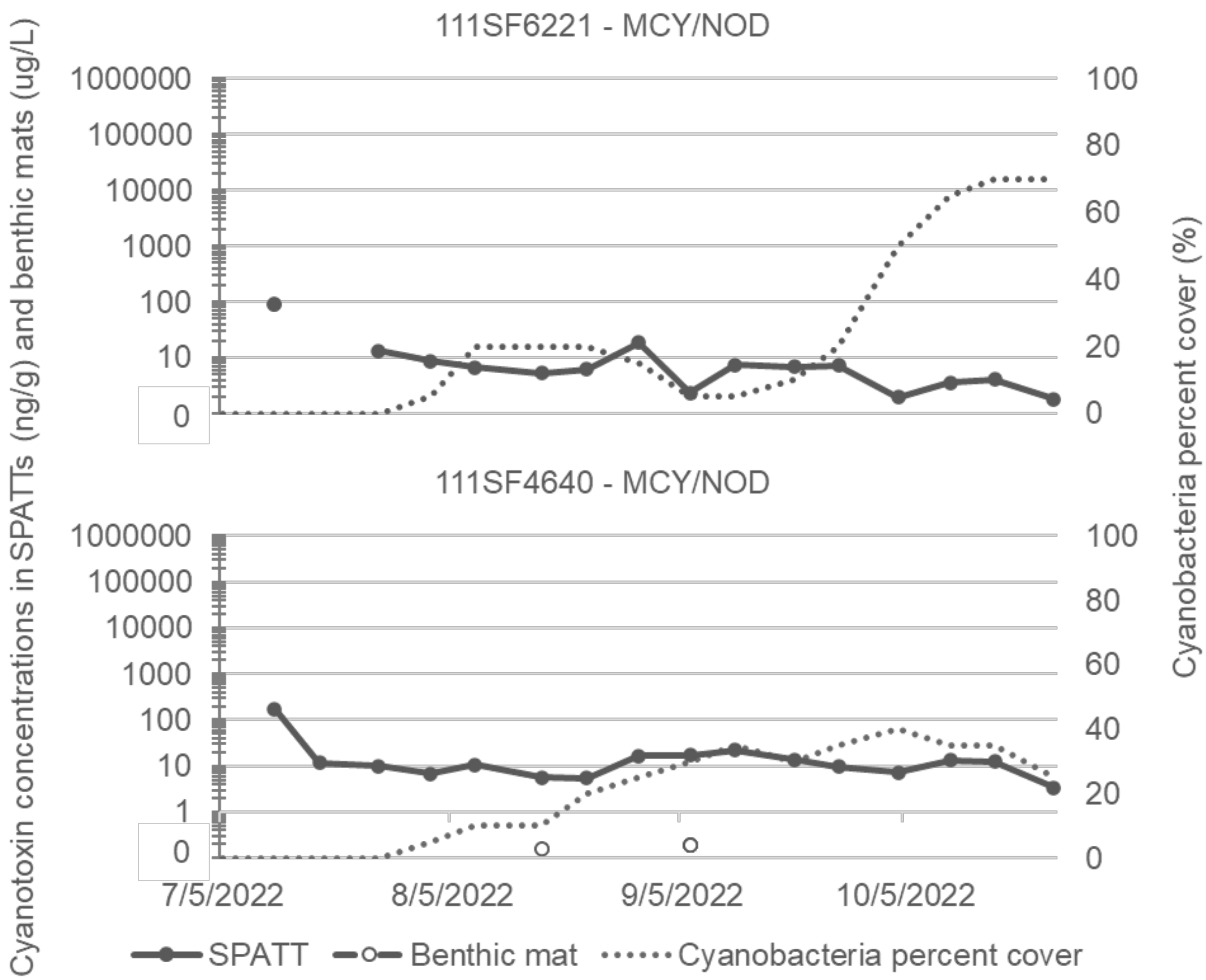

Figure 6. 2022 microcystins/nodularins (MCY/NOD) concentrations in SPATT samplers (solid line with closed circles) and benthic mat samples (dashed line with open circles) as well as cyanobacteria percent cover (dotted line) at Sites 111SF6221 and 111SF4640 in the South Fork Eel River.

In 2023, SPATT microcystins/nodularins at Site 111SF6221 were highest at the start of the study (91.9 ng/g) then showed a decreasing trend with periodic low-level variability until the end of collections (Figure 7). When detected, microcystins/nodularins in benthic mats were greatest in late June at 1.74 ug/L, despite cyanobacteria percent cover increasing to 50% at the end of the study. At Site 111SF2122, SPATTs and benthic mats were only analyzed for microcystins/nodularins towards the beginning of the study due to funding constraints. Available data show highest microcystins/nodularins in SPATTs at 19.9 ng/g in mid-June, and highest concentrations in benthic mats at 0.37 ug/L in late July. Due to non-detection at Site 111SF6221 and lack of data for Site 111SF2122, microcystins/nodularins were not evaluated with Spearman's rank correlations.

Using the interim framework in 2023, a Toxic Algae Alert was recommended for the South Fork Eel River on August 18th based on cyanobacteria percent cover and increasing trends in anatoxins. Although microcystins/nodularins were higher at the beginning of the study, they trended lower and remained low throughout the season and did not reflect the increases in cyanobacteria percent cover.

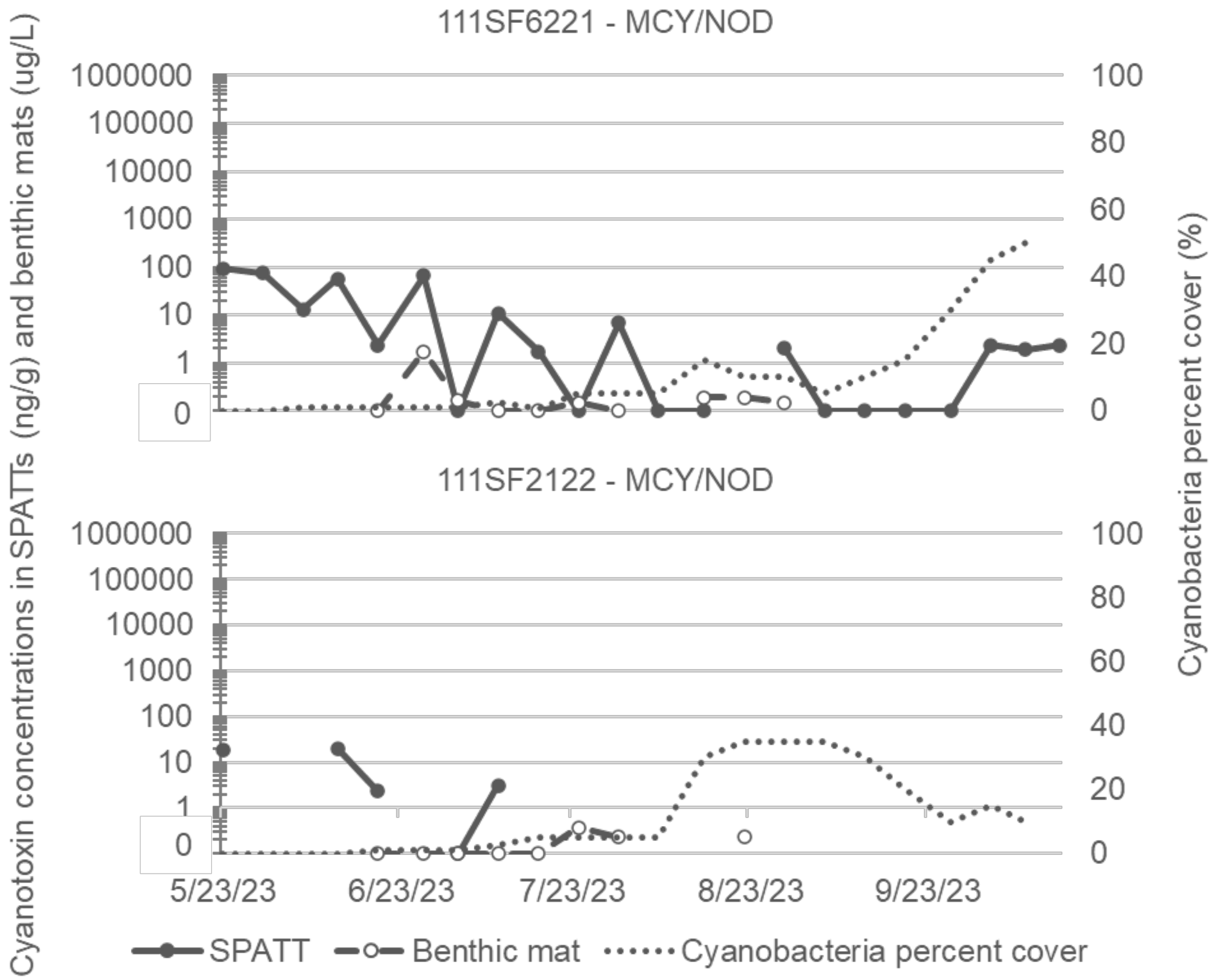

Figure 7. 2023 microcystins/nodularins (MCY/NOD) concentrations in SPATT samplers (solid line with closed circles) and benthic mat samples (dashed line with open circles) as well as cyanobacteria percent cover (dotted line) at Sites 111SF6221 and 111SF2122 in the South Fork Eel River.

Concurrent Monitoring in the Russian River

<u>Results for Anatoxins</u>

In 2022 in the Russian River, concentrations of anatoxins in SPATTs at Site 114RR6273 varied but demonstrated an overall increasing trend through mid-September with concentrations peaking at 39.7 ng/g (Figure 8). SPATTs at Site 114RR4234 measured anatoxins at lower and relatively consistent concentrations throughout the season, peaking at 6.99 ng/g. *Microcoleus*-dominant percent cover at both sites reached a maximum of 5% by mid-September, and anatoxins in benthic mats during this time were higher at Site 114RR6273 (peak 794 ug/L) than Site 114RR4234 (peak 28.1 ug/L).

Under current benthic guidelines in 2022, a Toxic Algae Alert was recommended on July 13th due to the low anatoxins detections in SPATTs. If the tiered approach were implemented, a posting would not have been recommended for either of the Russian River sites during the study.

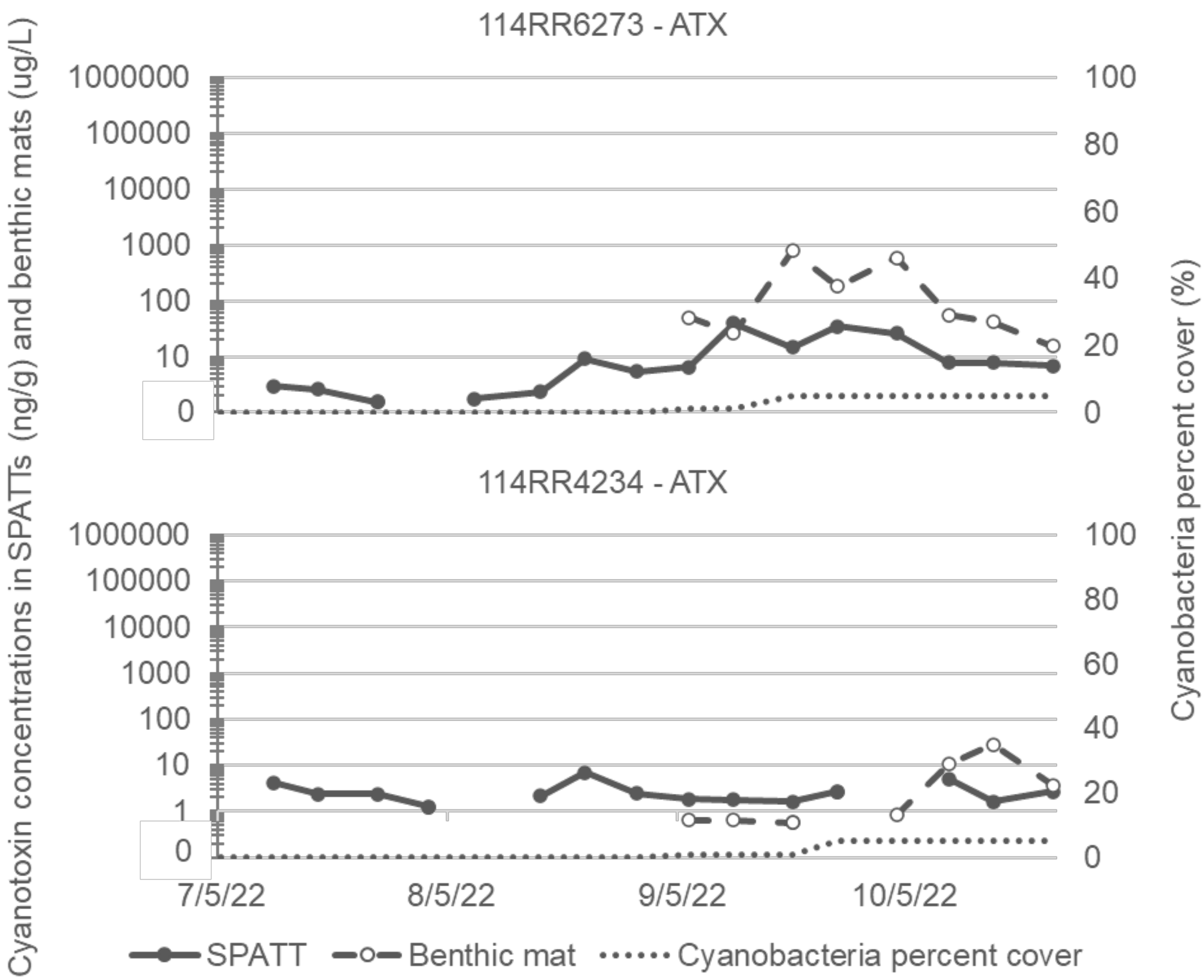

Figure 8. 2022 anatoxins (ATX) concentrations in SPATT samplers (solid line with closed circles) and benthic mat samples (dashed line with open circles) as well as cyanobacteria percent cover (dotted line) at Sites 114RR6273 and 114RR4234 in the Russian River.

In 2023, SPATTs at Site 114RR4234 were either non-detect for anatoxins or concentrations were low, peaking at 2.91 ng/g at the beginning of the study (Figure 9). *Microcoleus*-dominant percent cover was minimal (<5% or present) starting in late August. The benthic mats that were present peaked at 11.8 ug/L anatoxins by the end of the study. The lower concentrations of anatoxins in the Russian River as well as the minimal cyanobacterial growth in late August early September was similar in 2022 and 2023.

Using the tiered approach in 2023, no postings were recommended for the Russian River site. If the current guidance had been in place, a Toxic Algae Alert would have been recommended at the start of the study due to low-level anatoxins in SPATTs.

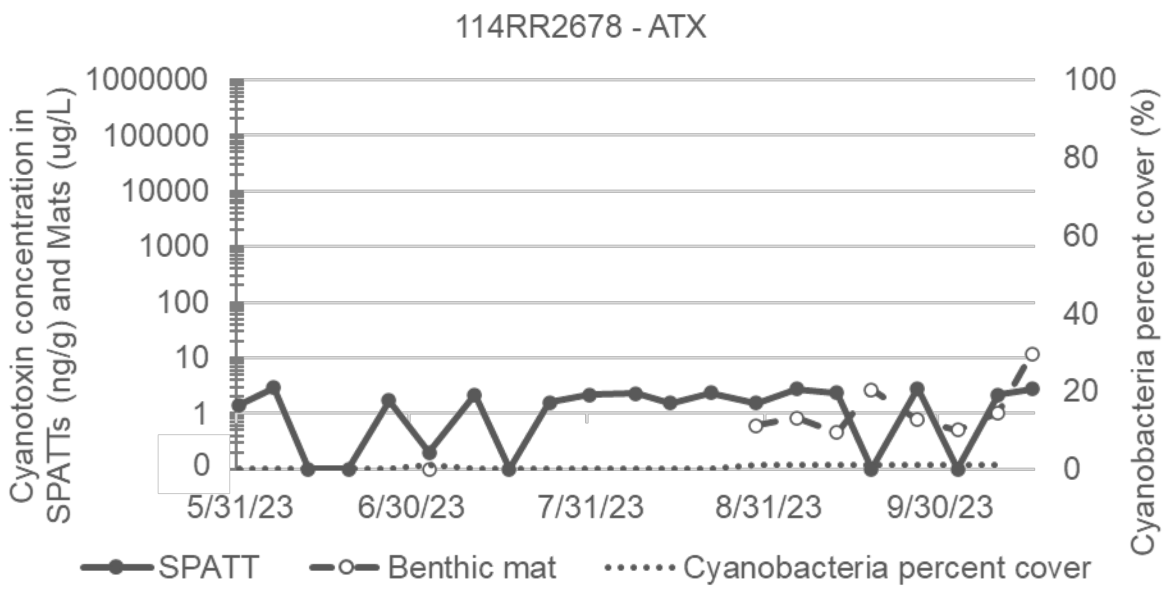

Figure 9. 2023 anatoxins (ATX) concentrations in SPATT samplers (solid line with closed circles) and benthic mat samples (dashed line with open circles) as well as cyanobacteria percent cover (dotted line) at Site 114RR2678 in the Russian River.

At Sites 114RR6273 and 114RR4234 in 2022 as well as site 114RR2678 in 2023, there were no significant correlations ($p \geq 0.05$) between anatoxins in SPATTs and benthic mats as well as SPATTs and cyanobacteria percent cover.

<u>Results for Microcystins/Nodularins</u>

In the Russian River in 2022, microcystins/nodularins in SPATTs remained within the 1.47-11.3 ng/g range at Sites 114RR6273 and 114RR4234 except for a peak concentration of 26.4 ng/g at Site 114RR4234 at the start of the study (Figure 10). Cyanobacteria were present starting in early-September with concentrations of microcystins/nodularins in benthic mats peaking at 2.37 and 2.30 ug/L at Sites 114RR6273 and 114RR4234, respectively. *Microcoleus*-dominant mats at both sites reached 5% cover during the study.

In 2022, current benthic guidelines resulted in a Toxic Algae Alert at the start of the study due to the low-level detections of microcystins/nodularins in SPATTs. Under the tiered approach, a posting would not have been recommended for this site since cyanotoxin concentrations remained low throughout the study period.

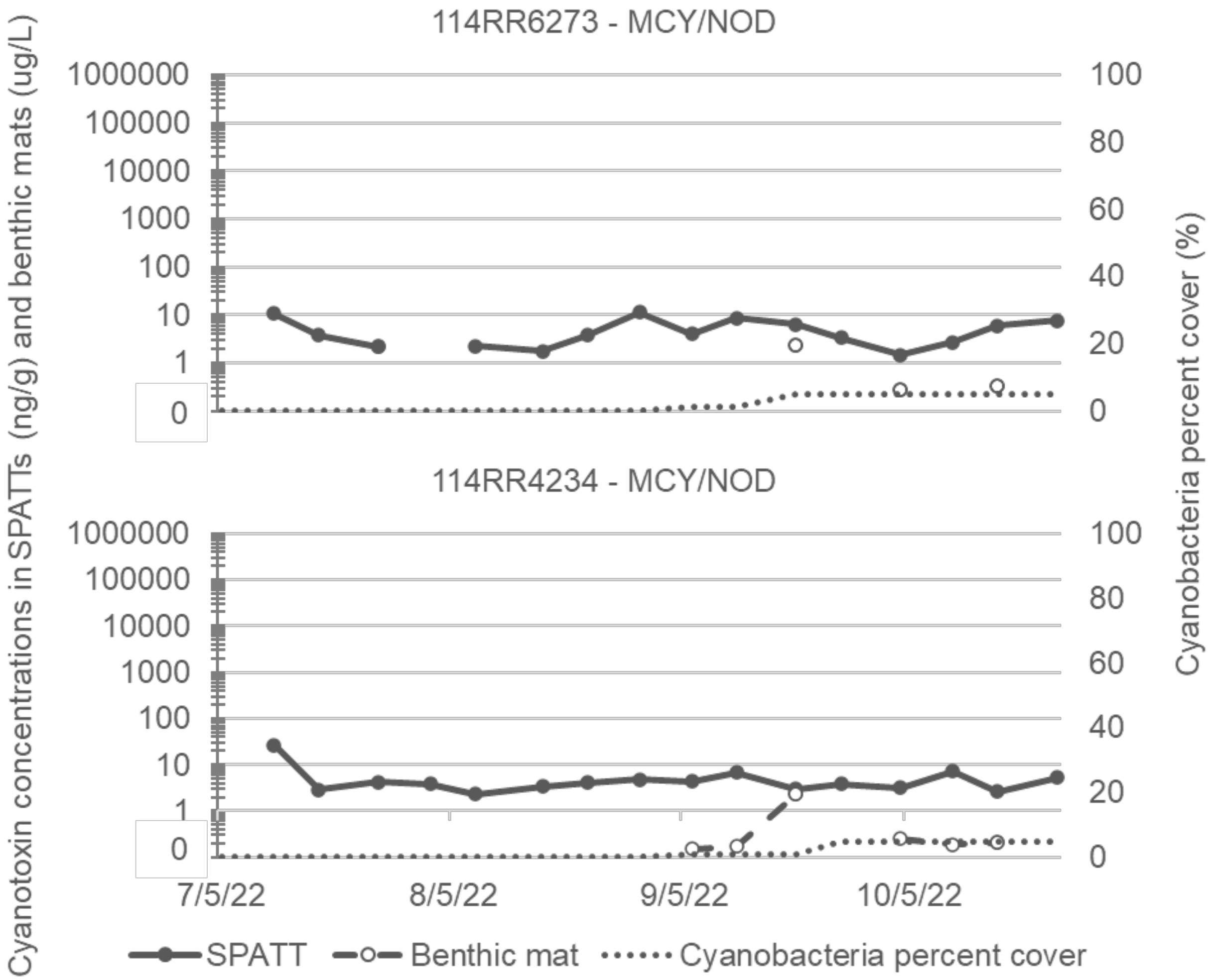

Figure 10. 2022 microcystins/nodularins (MCY/NOD) concentrations in SPATT samplers (solid line with closed circles) and benthic mat samples (dashed line with open circles), as well as cyanobacteria percent cover (dotted line) at Sites 114RR6273 and 114RR4234 in the Russian River.

At Site 114RR2678 in 2023, microcystins/nodularins in SPATTs varied between no detection and low concentrations, peaking at 3.9 ng/g in mid-July (Figure 11). Cyanobacteria were present (<5%) for one sampling event in early July and remained minimal from late August to the end of the study. *Microcoleus*-dominant mats were only analyzed once for microcystins/nodularins with a concentration of 0.29 ug/L. Due to low percent cover and few benthic mat detections, microcystins/nodularins were not evaluated with Spearman’s rank correlation for all sites in the Russian River.

In 2023, no postings were recommended for the Russian River site due to low cyanotoxin concentrations and percent cover. Under the current guidance, a Toxic Algae Alert would have been recommended in early June due to the low-level detections of microcystins/nodularins in SPATTs.

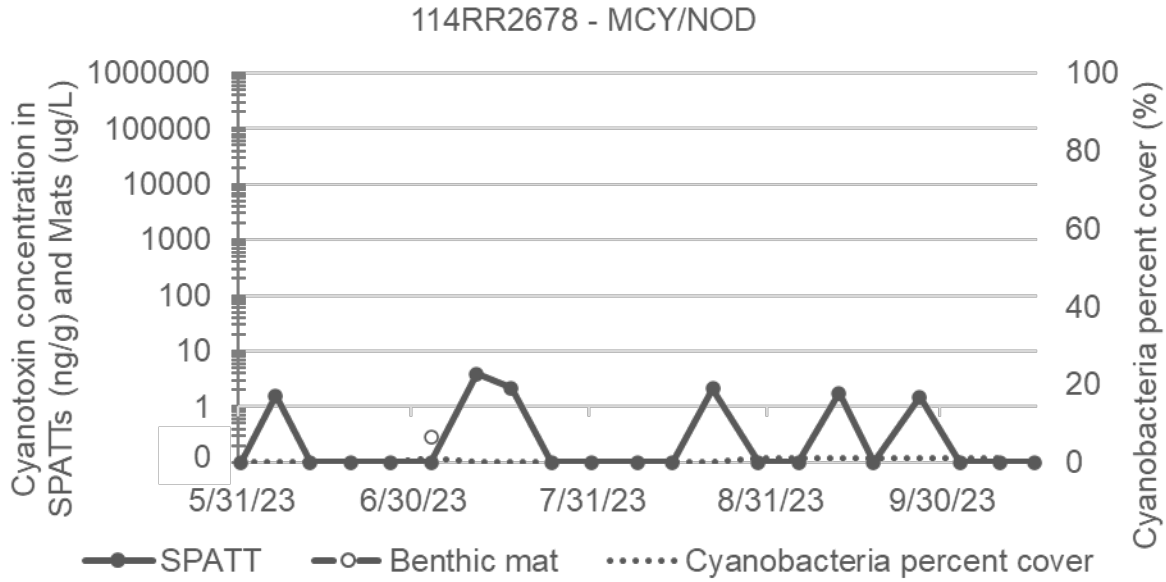

Figure 11. 2023 microcystins/nodularins (MCY/NOD) concentrations in SPATT samplers (solid line with closed circles) and benthic mat samples (dashed line with open circles), as well as cyanobacteria percent cover (dotted line) at Site 114RR2678 in the Russian River.

Concurrent Monitoring in the Navarro River

<u>Results for Anatoxins</u>

Benthic tiered monitoring was only conducted at one site in the Navarro River during 2023. SPATTs at Site 113NA9055 varied between no or low anatoxins detections, peaking at 3.46 ng/g in late July (Figure 12). Anatoxins in benthic mats followed a similar trend, peaking at 1.47 ug/L in late June. *Anabaena*-dominant percent cover exhibited a small increase in mid-July (15%) followed by exponential growth in mid-August (75%) that was maintained until the end of observations. Monitoring concluded on August 29th due to diminished flows.

Implementing the tiered approach, a Toxic Algae Alert was recommended for the Navarro River site on August 18th due to the large increase in *Anabaena* percent cover. Results for SPATTs and benthic mats were delayed, so the posting was recommended out of an abundance of caution despite anatoxins remaining low until the end of the study. Under the current benthic guidance, a posting would have been recommended at the start of the study due to the low-level detections of anatoxins and presence of cyanobacteria.

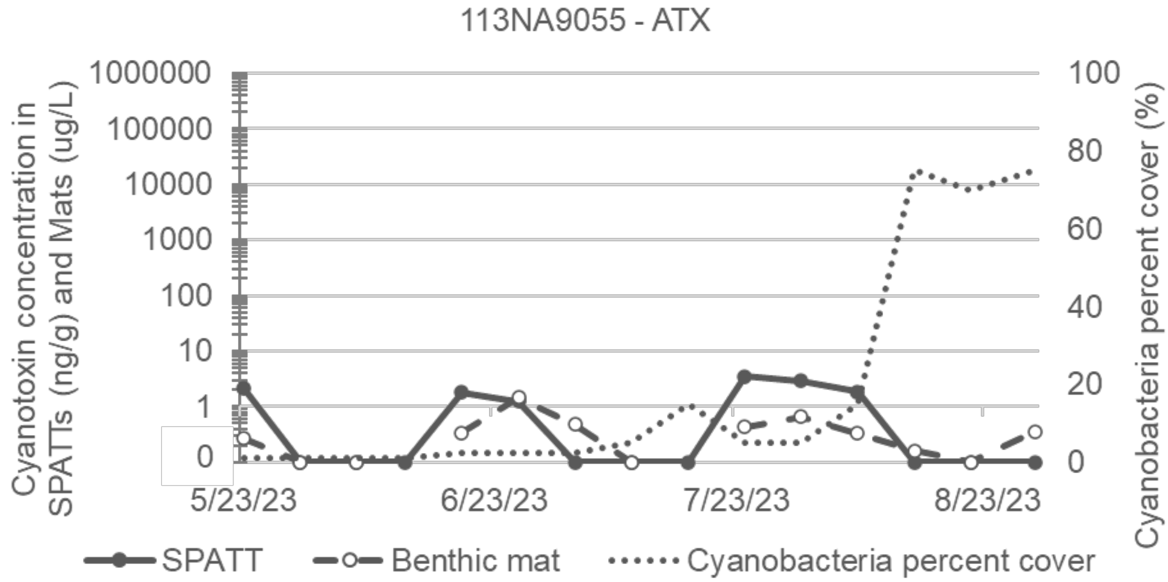

Figure 12. 2023 anatoxins (ATX) concentrations in SPATT samplers (solid line with closed circles) and benthic mat samples (dashed line with open circles) as well as cyanobacteria percent cover (dotted line) at Site 113NA9055 in the Navarro River.

There were no significant correlations ($p \geq 0.05$) between anatoxins in SPATTs and benthic mats as well as SPATTs and cyanobacteria percent cover at site 113NA9990 in 2023.

<u>Results for Microcystins/Nodularins</u>

In 2023, SPATT microcystins/nodularins at Site 113NA9055 were highest at the start of the study (36.3 ng/g) and were non-detect starting in mid-July despite *Anabaena*-dominant percent cover increasing to 75% by the end of the study (Figure 13). Available microcystins/nodularins data for benthic mats showed highest concentrations at 0.94 ug/L in mid-June.

A Toxic Algae Alert was recommended on August 18th due to the large increase in *Anabaena* percent despite cyanotoxin concentrations remaining low. Under current benthic guidance, a posting would have been recommended on the first site visit due to the presence of cyanobacteria and cyanotoxin detections.

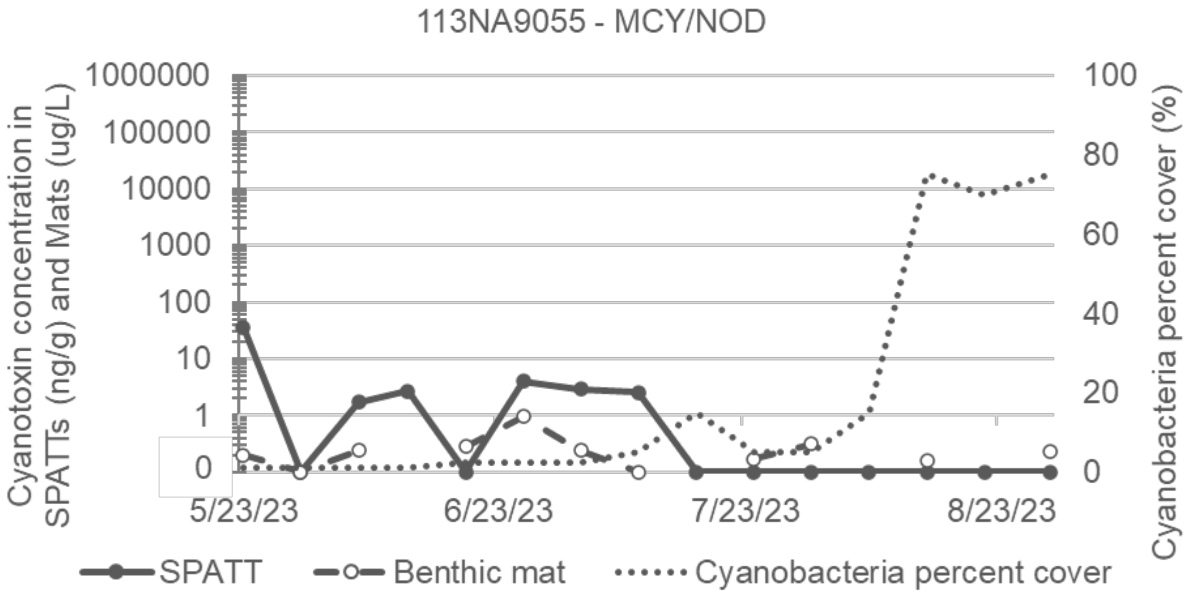

Figure 13. 2023 microcystins/nodularins (MCY/NOD) concentrations in SPATT samplers (solid line with closed circles) and benthic mat samples (dashed line with open circles), as well as cyanobacteria percent cover (dotted line) at Site 113NA9055 in the Navarro River.

There were no significant correlations ($p \geq 0.05$) between concentrations of microcystins/nodularins in SPATTs and benthic mats as well as cyanobacteria percent cover at site 113NA9990 in 2023.

Implementing the Tiered Monitoring Recommendations

In 2023, the tiered monitoring recommendations were implemented at one site in the Russian River (114RR5407) and one site in the Eel River (111ER6140) such that increases in weekly deployed SPATTs would trigger successive tiers of visual assessment and benthic mat collections. At both sites, concentrations of anatoxins in SPATTs were either non-detect or remained less than 10 ng/g throughout the study (Figure 14). Both sites had higher concentrations of microcystins/nodularins in SPATTs during the first half of the study with the highest concentrations measured at Site 111ER6140 (max 36.6 ng/g). In the latter half of the study, non-detects of microcystins/nodularins were more common with no detections occurring at Site 114RR5407 from mid-July to mid-October. On the final site visits, a visual assessment was conducted to determine cyanobacteria presence. No benthic mats were observed at either site on the final visit. Using the interim framework, no postings were recommended for either test site in 2023.

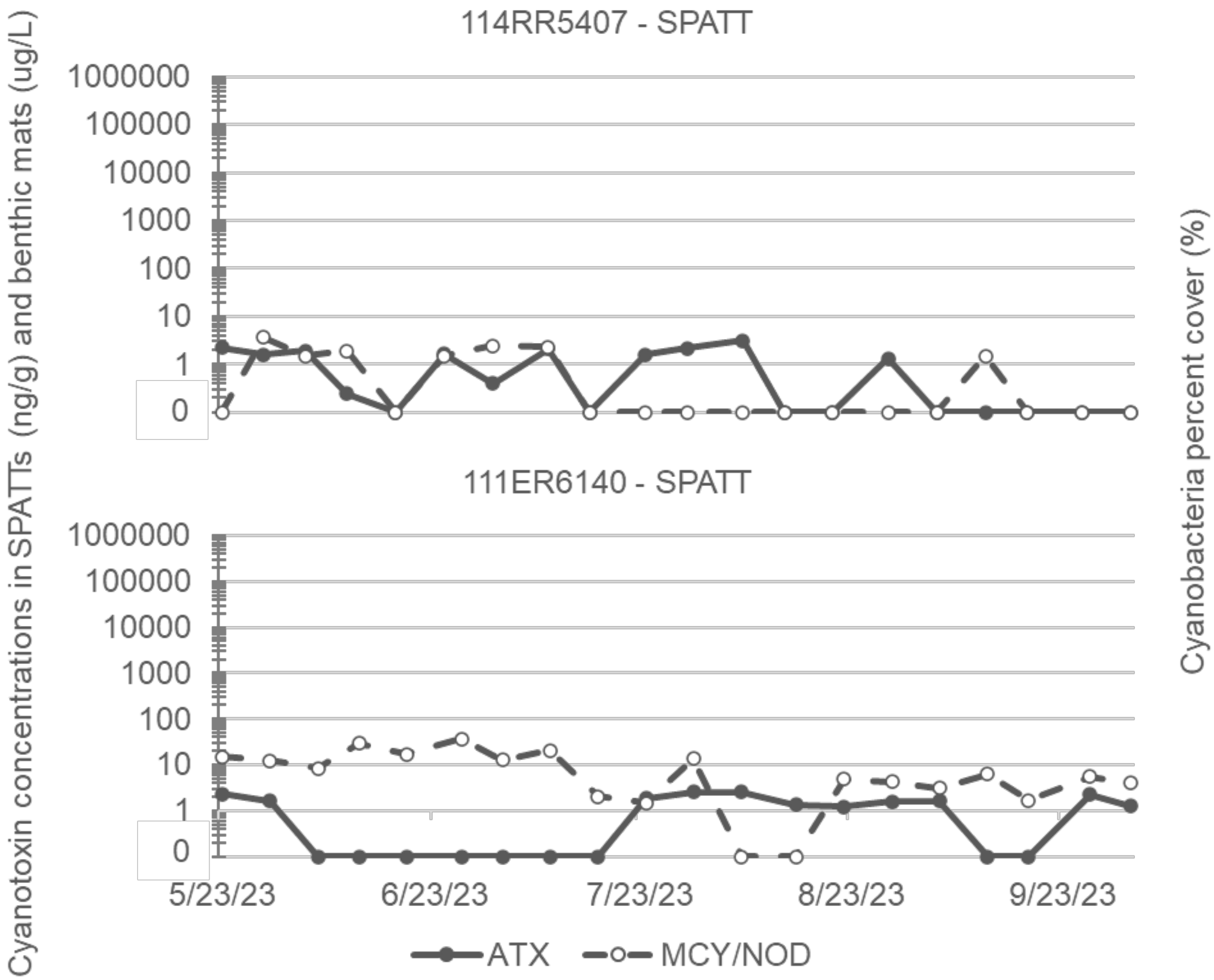

Figure 14. Anatoxins (ATX, solid line with closed circles) and microcystins/nodularins (MCY/NOD, dashed line with open circles) concentrations in SPATT samplers at Sites 114RR5407 and 111ER6140 in the Russian and Eel Rivers, 2023.

Comparing Sites and Rivers

Although the following analyses and results were not part of the original study design and questions, Spearman's rank correlations were also used to explore how cyanotoxin measurements in SPATTs compared among all sites within and across rivers. For anatoxins in 2022, SPATT measurements were significantly correlated within the South Fork Eel River at Sites 111SF4640 and 111SF6221 ($R = 0.762$, $p < 0.001$) (Table 8). SPATT anatoxins were not significantly correlated at sites within the Russian River, and sites were not significantly correlated across rivers.

Table 8. 2022 R-values from Spearman's rank correlations for anatoxins (ATX) and microcystins/nodularins (MCY/NOD) concentrations in SPATTs among all sites in the Russian and South Fork Eel Rivers. Significant correlations (α = 0.05) are bolded with asterisk (*), and significant p-values are reported in the text.

Cyanotoxin	Site	111SF4640	111SF6221	114RR6273	114RR4234
SPATT ATX (ng/g)	111SF4640	1			
	111SF6221	**0.762***	1		
	114RR6273	-0.297	-0.255	1	
	114RR4234	-0.125	-0.116	0.339	1
SPATT MCY/NOD (ng/g)	111SF4640	1			
	111SF6221	**0.954***	1		
	114RR6273	**0.510***	**0.573***	1	
	114RR4234	**0.969***	**0.957***	**0.537***	1

Microcystins/nodularins in SPATTs were significantly correlated within and across rivers in 2022 (Table 8). SPATT measurements at Site 111SF4640 were significantly correlated with Site 111SF6221 ($R = 0.954$, $p < 0.001$), Site 114RR6273 ($R = 0.510$, $p = 0.044$), and Site 114RR4234 ($R = 0.969$, $p < 0.001$); Site 111SF6221 was significantly correlated with Site 114RR6273 ($R = 0.573$, $p = 0.026$) and Site 114RR4234 ($R = 0.957$, $p < 0.001$); and Site 114RR6273 was significantly correlated with Site 114RR4234 ($R = 0.537$, $p = 0.032$).

Spearman's rank correlations were also used to compare cyanotoxin measurements in benthic mat samples as well as cyanobacteria percent cover among sites in 2022. Due to the lack of data for benthic mats and low percent cover at both Russian River sites, correlations were only performed for the two sites in the South Fork Eel River. Anatoxins in benthic mats were not significantly correlated at Sites 111SF4640 and 111SF6221 ($R = 0.253$, $p > 0.05$). Cyanobacteria percent cover at Sites 111SF4640 and 111SF6221 were significantly correlated ($R = 0.529$, $p = 0.043$). Due to few microcystins/nodularins detections in benthic mats in the South Fork Eel River, correlations were not performed.

In 2023, anatoxins in SPATTs at Site 111ER6140 were significantly correlated with Site 113NA9055 ($R = 0.563$, $p = 0.029$) and Site 114RR2678 ($R = 0.456$, $p = 0.0497$) (Table 9). Microcystins/nodularins in SPATTs at Site 111ER6140 were significantly correlated with Site 111SF6221 ($R = 0.641$, $p = 0.003$) and Site 114RR5407 ($R = 0.504$, $p = 0.023$). SPATT microcystins/nodularins were also significantly correlated at Sites 111SF6221 and 113NA9055 ($R = 0.641$, $p = 0.013$).

Table 9. 2023 R-values from Spearman's rank correlations for anatoxins (ATX) and microcystins/nodularins (MCY/NOD) concentrations in SPATTs among all sites in the Eel, South Fork Eel, Navarro, and Russian Rivers. Significant correlations (α = 0.05) are bolded with asterisk (*), and significant p-values are reported in the text.

Cyanotoxin	Site	111ER6140	111SF2122	111SF6221	113NA9055	114RR2678	114RR5407
SPATT ATX (ng/g)	111ER6140	1					
	111SF2122	0.102	1				
	111SF6221	0.145	0.271	1			
	113NA9055	**0.563***	-0.365	-0.302	1		
	114RR2678	**0.456***	0.055	0.139	0.139	1	
	114RR5407	0.410	-0.297	-0.123	0.452	0.411	1
SPATT MCY/NOD (ng/g)	111ER6140	1					
	111SF2122						
	111SF6221	**0.641***		1			
	113NA9055	0.197		**0.641***	1		
	114RR2678	0.016		-0.132	0.124	1	
	114RR5407	**0.504***		0.434	-0.116	0.161	1

Evaluation of Historical Data

In this section, results are presented for historical SPATT and stream flow data in the South Fork Eel and Russian Rivers to determine if watershed hydrology may potentially affect cyanotoxin concentrations in northern California rivers. Note that SPATT deployments varied in previous studies, ranging between one- and 14-days in length (see NCRWQCB 2022b). Beginning in 2021, all SPATT deployments were six- to eight-days in length per recommendations in the report.

Historical Data in the South Fork Eel River

Results for Anatoxins

Figure 15 shows concentrations of anatoxins in SPATTs collected in the South Fork Eel River in 2018, 2019, 2022, and 2023. Results are a consolidation of all the SPATT data for the respective years collected from five sites within a 40-mile stretch in the middle of the South Fork Eel River from approximately river mile 20 to river mile 60. Samples were not collected from all five sites in all years, but rather from a subset in each year. The number of sample sites in each year were three sites in 2019 and only two sites in 2018, 2022, and 2023. Total SPATT deployments for each year were 13 in 2018, 105 in 2019, 39 in 2022, and 52 in 2023. The large sample set in 2019 is due to the number of SPATTs needed to conduct the SPATT study (see NCRWQCB 2022b). Despite the lower sample size in 2018, anatoxins demonstrate an increasing summer seasonal trend across all years with low concentrations recorded in the early summer season, increasing to seasonal peaks in August, and decreasing through the end of summer. This trend holds true for each year regardless of existing flow conditions.

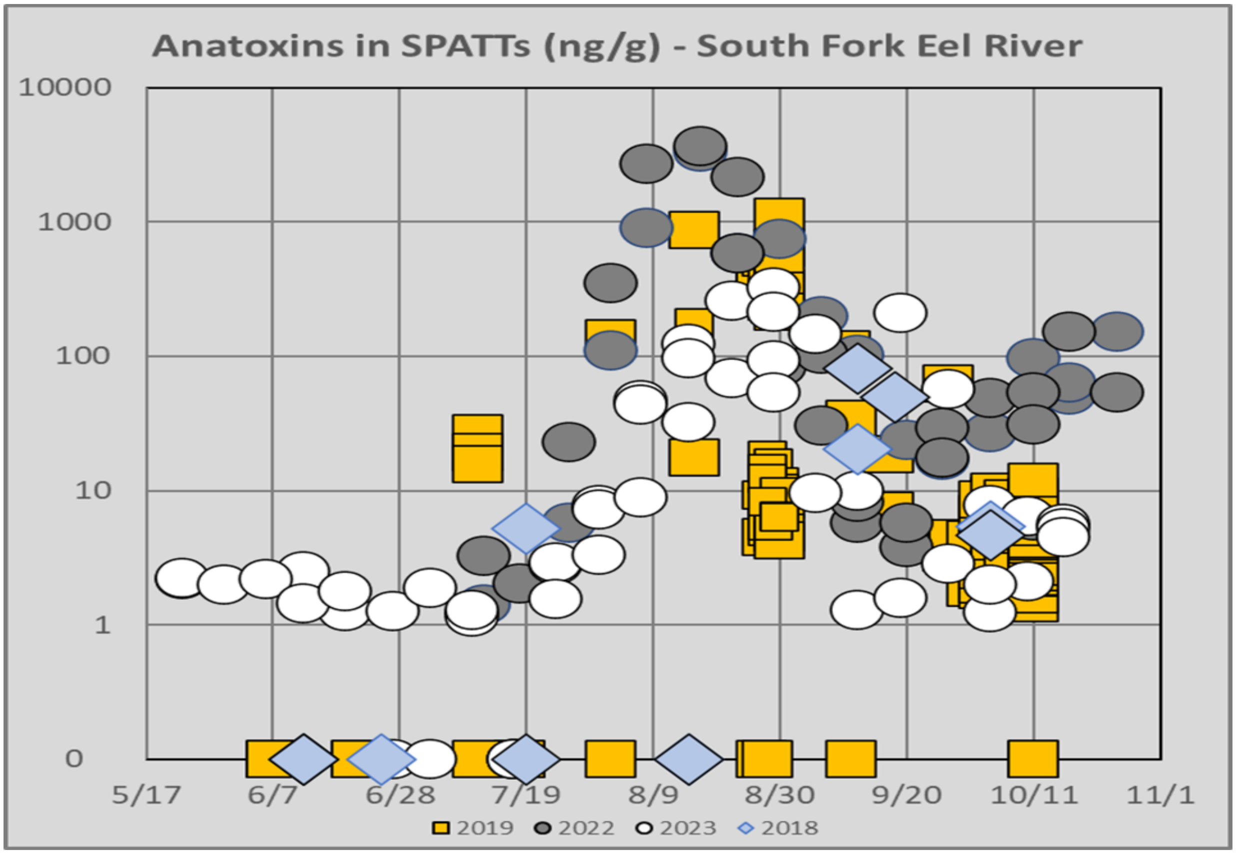

Figure 15. Historical anatoxins concentrations in SPATTs in the South Fork Eel River in 2018, 2019, 2022, and 2023.

To evaluate relationships among sample years in the South Fork Eel River, the weekly maximum concentrations of SPATT anatoxins were determined for each year regardless of site (Table 10). Samples from the various stations were generally all collected within a day or two of one another within the same week.

Table 10. Weekly maximum anatoxins concentrations for historical SPATT data in the South Fork Eel River in 2018, 2019, 2022, and 2023.

Week	Weekly Maximum SPATT Concentration (ng/g Anatoxins)			
	Max of 2018	Max of 2019	Max of 2022	Max of 2023
5/22				2.24
5/29				1.98
6/5		0.10		2.17
6/12	0.20			2.47
6/19		0.10		1.77
6/26	ND			1.27
7/3				1.87
7/10		61.62	3.24	1.28
7/17	5.23	ND	2.01	ND
7/24			22.75	2.90
7/31		134.33	352.10	7.76
8/7			2,697.10	46.97
8/14	ND	869.77	3,637.80	122.28
8/21			2,133.00	255.77
8/28		3,082.99	740.50	326.45
9/4			198.85	146.44
9/11	80.76	120.00	199.43	9.97
9/18	49.29	18.55	72.84	209.04
9/25		62.20	51.75	56.75
10/2	5.39	34.01	48.26	7.82
10/9		108.81	96.46	6.43
10/16			152.92	5.67
10/23			150.40	

Using Spearmen's rank correlations, only weekly maximum SPATT anatoxins between 2019 and 2023 were significantly correlated ($R = 0.823$, $p = 0.001$) despite the trends being similar across all years (Table 11). Correlations were not conducted for 2018 due to low sample size.

Table 11. R-values from Spearman's rank correlations between sample years for anatoxins concentrations in historical SPATT samplers in the South Fork Eel River. Significant correlations (α = 0.05) are bolded with asterisk (*), and significant p-values are reported in the text.

	Weekly Max 2019	Weekly Max 2022	Weekly Max 2023
Weekly Max 2019	1		
Weekly Max 2022	0.331	1	
Weekly Max 2023	**0.822***	0.333	1

Trends in the data also show a seasonal peak in anatoxins from 2022 that occurred two weeks earlier than in 2019 and 2023. Performing Spearmen's rank correlations on the two-week adjusted data demonstrated a strong correlation ($p < 0.05$) amongst all three years (Table 12), suggesting that cyanobacteria growth and cyanotoxin production occurred two weeks earlier in 2022 than in 2019 and 2023.

Table 12. R-values from Spearman's rank correlations between sample years for adjusted anatoxins concentrations in historical SPATT samplers in the South Fork Eel River. Significant correlations (α = 0.05) are bolded with asterisk (*), and significant p-values are reported in the text.

	Weekly Max 2019	Weekly Max 2022	Weekly Max 2023
Weekly Max 2019	1		
Weekly Max 2022	**0.959***	1	
Weekly Max 2023	**0.822***	**0.837***	1

Results for Microcystins/Nodularins

Concentrations of microcystins/nodularins were measured from the same SPATTs as anatoxins. Figure 16 shows SPATT microcystins/nodularins collected in the South Fork Eel River in 2018, 2029, 2022, and 2023. Results are a compilation of data similar to anatoxins except for 2023 where the collection of microcystins/nodularins data was limited to one sample site. Total SPATT deployments for each year were 13 in 2018, 104 in 2019, 39 in 2022, and 32 in 2023. The large sample set in 2019 is due to the number of SPATTs needed to conduct the SPATT study (see NCRQWQB 2022b). Despite the lower sample count in 2018, microcystins/nodularins show a decreasing trend across all years with elevated concentrations in early summer then decreasing through the period of observation. This trend holds true for each year regardless of flow conditions.

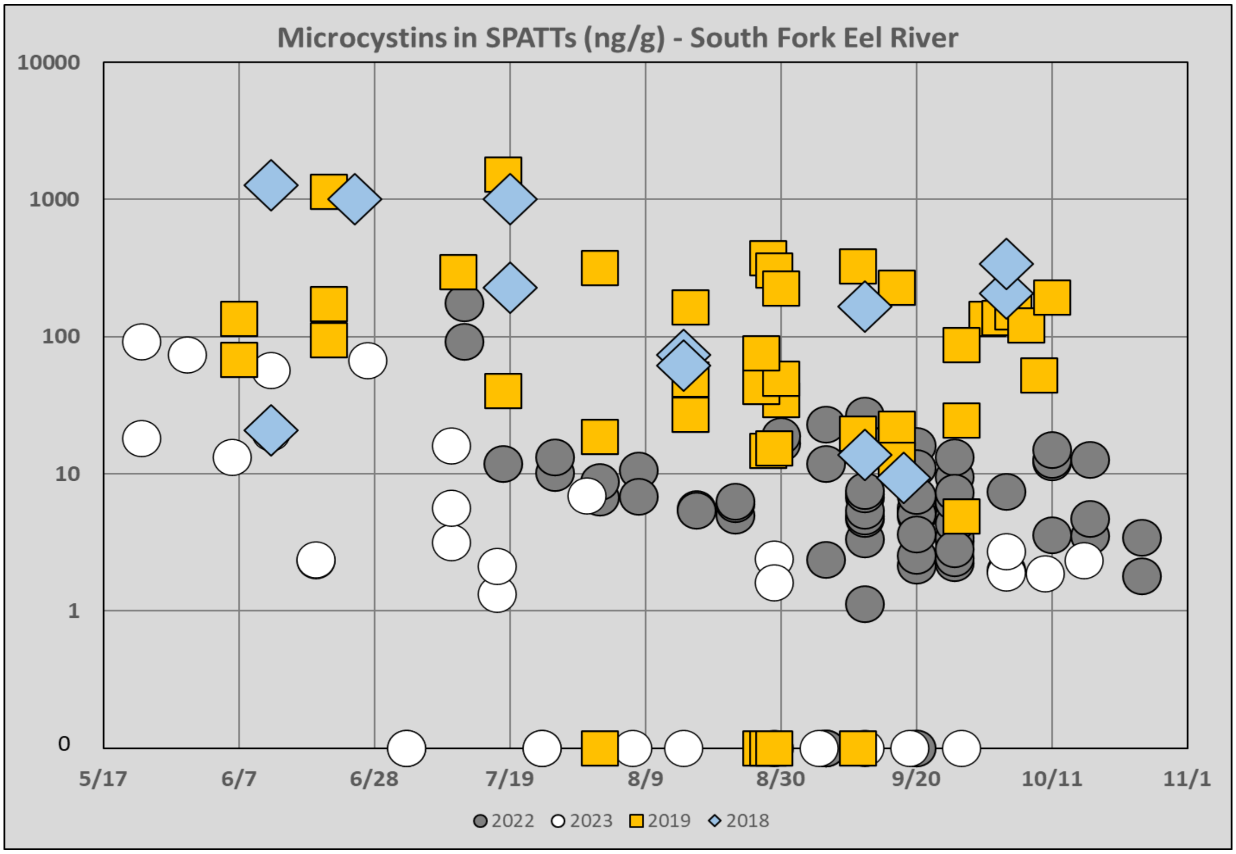

Figure 16. Historical microcystins/nodularins concentrations in SPATTs in the South Fork Eel River in 2018, 2019, 2022, and 2023.

To evaluate relationships among sample years in the South Fork Eel River, the weekly maximum concentrations of SPATT microcystins/nodularins were determined for each year regardless of site (Table 13). Samples from the various stations were generally all collected within a day or two of one another in the same week.

Table 13. Weekly maximum microcystins/nodularins concentrations for historical SPATT data in the South Fork Eel River in 2018, 2019, 2022, and 2023.

Week	Weekly Maximum SPATT Concentration (ng/g Microcystins)			
	Max of 2018	Max of 2019	Max of 2022	Max of 2023
5/22				91.94
5/29				73.93
6/5		134.42		13.09
6/12	1,272.95			56.62
6/19		1,137.50		2.36
6/26	1,000.00			66.47
7/3				ND
7/10		296.95	175.90	15.92
7/17	1,000.00	1,513.00	11.86	2.10
7/24			13.23	ND
7/31		316.00	8.68	6.88
8/7			10.57	ND
8/14	73.76	163.58	5.57	ND
8/21			6.29	
8/28		372.58	18.79	2.38
9/4			22.93	ND
9/11	165.40	325.50	26.42	ND
9/18	9.38	227.60	15.98	ND
9/25		86.50	13.12	ND
10/2	339.70	149.39	7.34	2.71
10/9		193.40	14.99	1.86
10/16			12.60	2.32
10/23			3.41	

Using Spearmen's rank correlations, only weekly maximum SPATT microcystins/nodularins between 2022 and 2023 were significantly correlated ($R = 0.872$, $p < 0.001$) despite the trends being similar across all years (Table 14).

Table 14. R-values from Spearman's rank correlations between sample years for microcystins/nodularins concentrations in historical SPATT samplers in the South Fork Eel River. Significant correlations (α = 0.05) are bolded with asterisk (*), and significant p-values are reported in the text.

	Weekly Max 2019	Weekly Max 2022	Weekly Max 2023
Weekly Max 2019	1		
Weekly Max 2022	**-0.055**	1	
Weekly Max 2023	**-0.127**	**0.872***	1

Historical Data in the Russian River

Results for Anatoxins

Figure 17 shows SPATT anatoxins in the Russian River in 2018, 2019, 2021, 2022, and 2023. Results are all SPATT data collected from six sites within a 60-mile stretch of the Russian River from approximately river mile 20 to river mile 80. Samples were not collected from all six sites in all years, but rather from a subset in each year. The number of sample sites in each year were three sites in 2018 and 2021, four sites in 2019 and 2022, and only two sites in 2023. Total SPATT deployments for each year were 21 in 2018, 61 in 2019, 34 in 2021, 68 in 2022, and 44 in 2023. The large sample set in 2019 is due to the number of SPATTs needed to conduct the SPATT study (see NCRWQCB 2022b), and the large sample size in 2022 is due to the number of sample sites in the pilot study. Despite lower sample count in 2018, concentrations of anatoxins demonstrate an increasing trend across the year with low concentrations recorded in the early summer season, increasing to seasonal peaks in August and decreasing through the end of summer. This trend holds true for each year except for 2023 where concentrations did not experience a seasonal increase at any location; this year also experienced the highest flows of all sample years. Additional sampling is needed to determine if other high flow years would result in similarly decreased production of anatoxins.

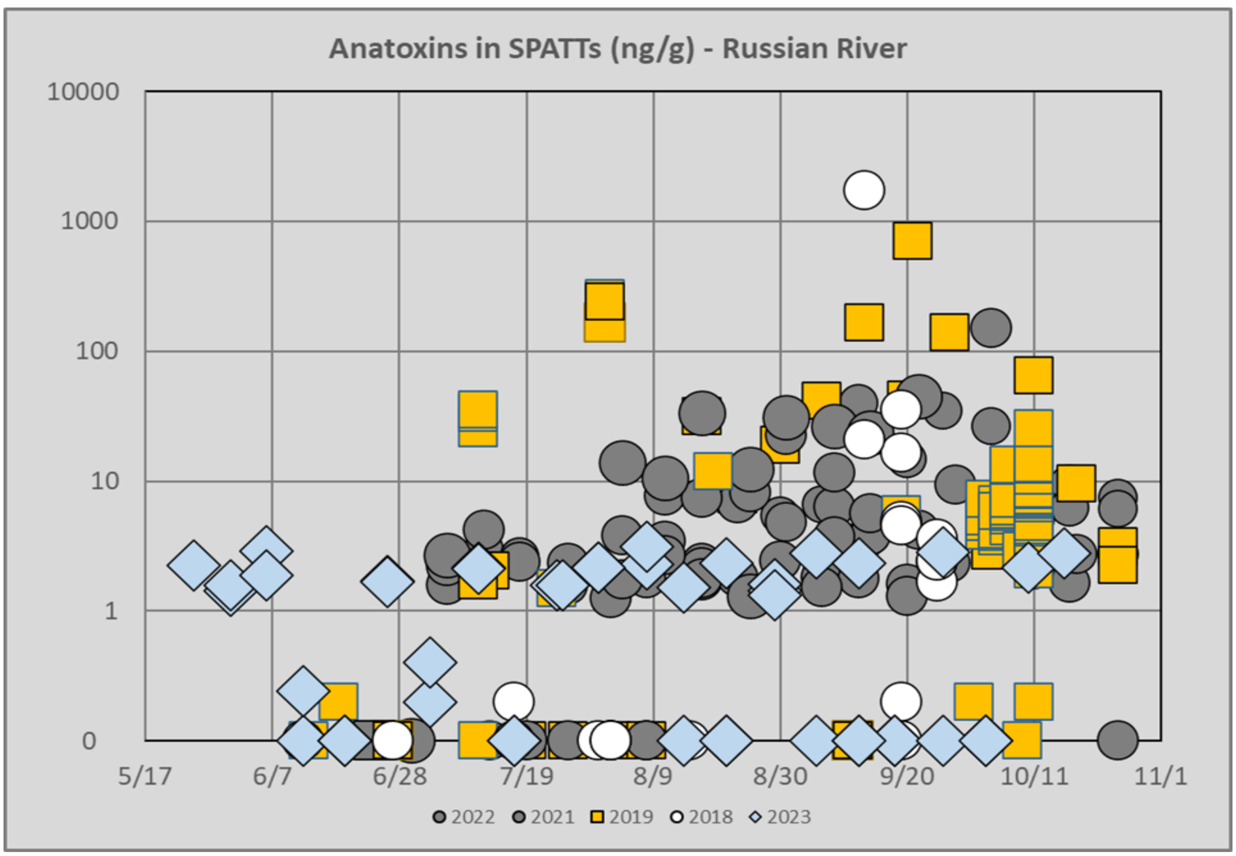

Figure 17. Historical anatoxins concentrations in SPATTs in the Russian River in 2018, 2019, 2021, 2022, and 2023.

To evaluate relationships among sample years in the Russian River, the weekly maximum concentrations of SPATT anatoxins were determined for each year regardless of site (Table 15). Samples from the various stations were generally all collected within a day or two of one another in the same week.

Table 15. Weekly maximum anatoxins concentrations for historical SPATT data in the Russian River in 2017, 2018, 2019, 2021, 2022, and 2023.

Week	Weekly Maximum SPATT Concentration (ng/g Anatoxins)					
	2017	2018	2019	2021	2022	2023
5/22						2.24
5/29						2.91
6/5		ND	ND			0.24
6/12	7.20		ND			ND
6/19	5.96	ND	ND			1.70
6/26	ND			ND		0.40
7/3			35.08	2.70		2.15
7/10	7.08	ND			4.23	ND
7/17			1.48		ND	1.58
7/24		ND	255.53		2.34	2.15
7/31	5.71	ND		13.71	1.8	3.14
8/7		ND		10.6		1.53
8/14			12	33.38	31	2.3
8/21				12.3	9	1.6
8/28				30.84	19	2.8
9/4			ND	27	41.7	2.3
9/11		1,716.97	5.5	23.34	165.7	ND
9/18		3.6		44.6	708.2	2.85
9/25			7.2	9.3	139.9	ND
10/2			13.4	7.0	151.0	2.1
10/9			25.2		65.4	2.77
10/16					9.6	
10/23					7.5	

Spearman's rank correlations showed no significant relationships ($p > 0.05$) for weekly maximum SPATT anatoxins among sample years in the Russian River (Table 16).

Table 16. R-values from Spearman's rank correlations between sample years for anatoxins concentrations in historical SPATT samplers in the Russian River. Significant correlations (α = 0.05) are bolded with asterisk (*), and significant p-values are reported in the text.

	Weekly Max 2019	Weekly Max 2021	Weekly Max 2022	Weekly Max 2023
Weekly Max 2019	1			
Weekly Max 2021	-0.232	1		
Weekly Max 2022	-0.379	0.215	1	
Weekly Max 2023	0.447	0.064	-0.474	1

Results for Microcystins/Nodularins

Figure 18 shows SPATT microcystins/nodularins collected in the Russian River in 2018, 2029, 2021, 2022, and 2023. Results were compiled similarly to anatoxins except for 2023 where the collection of microcystins/nodularins data was limited to one sample site. Total SPATT deployments for each year were 23 in 2018, 66 in 2019, 34 in 2021, 71 in 2022, and 44 in 2023. The large sample set in 2019 is due to the number of SPATTs needed to conduct the SPATT study (see NCRWQCB 2022b), and the large sample size in 2022 is due to the number of sample sites in the pilot study. Despite the lower sample count in 2018, concentrations of microcystins/nodularins demonstrate an increasing trend across years with low concentrations recorded in the early summer season, increasing to seasonal peaks in August and decreasing through the end of summer. This trend holds true for each year except for 2019 where there was an increase in concentrations towards the end of the season; this year also experienced the highest flows across all sample years.

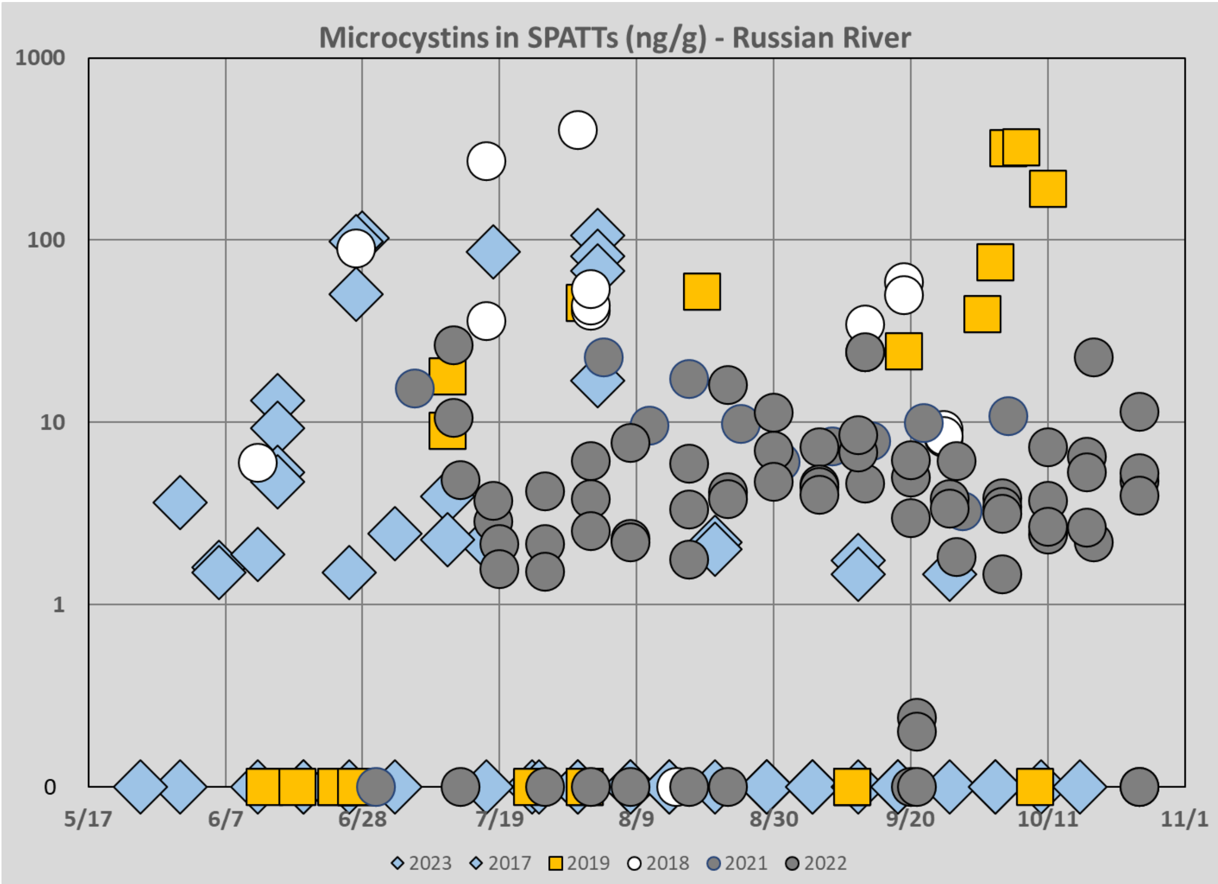

Figure 18. Historical microcystins/nodularins concentrations in SPATTs in the Russian River, 2017, 2018, 2019, 2021, 2022, and 2023.

To evaluate relationships among sample years in the Russian River, the weekly maximum concentrations of SPATT microcystins/nodularins were determined for each year regardless of site (Table 17). Samples from the various stations were generally all collected within a day or two of one another in the same week.

Table 17. Weekly maximum microcystins/nodularins concentrations for historical SPATT data in the Russian River in 2018, 2019, 2021, 2022, and 2023.

Week	Weekly Maximum SPATT Concentration (ng/g Microcystins)				
	2018	2019	2021	2022	2023
5/22					ND
5/29					3.63
6/5					1.59
6/12	6.02	ND			1.89
6/19		ND			ND
6/26	90.00	ND	ND		1.49
7/3			15.28		2.44
7/10		17.81		26.37	3.90
7/17	271.33			3.70	2.16
7/24		ND		4.19	ND
7/31	400.67	45.25	22.78	6.13	ND
8/7			9.61	7.72	ND
8/14	ND	52.17	17.23	5.90	ND
8/21			9.75	16.09	2.20
8/28			6.09	11.25	ND
9/4			7.34	7.28	ND
9/11	34.47	ND	7.90	24.27	1.75
9/18	59.00	24.57	9.89	6.21	ND
9/25	9.10		3.26	6.15	1.47
10/2		321.67	10.80	3.85	ND
10/9		192.40		7.31	ND
10/16				22.63	ND
10/23				11.39	

Using Spearmen's rank correlations, weekly maximum SPATT microcystins/nodularins between 2022 and 2023 were significantly correlated ($R = 0.568$, $p = 0.027$) (Table 18).

Table 18. R-values from Spearman's rank correlations between sample years for microcystins/nodularins concentrations in historical SPATT samplers in the Russian River. Significant correlations (α = 0.05) are bolded with asterisk (*), and significant p-values are reported in the text.

	Weekly Max 2019	Weekly Max 2021	Weekly Max 2022	Weekly Max 2023
Weekly Max 2019	1			
Weekly Max 2021	0.117	1		
Weekly Max 2022	-0.408	-0.263	1	
Weekly Max 2023	-0.345	-0.229	**0.568***	1

Discussion

The 2022 and 2023 pilot studies evaluated the tiered approach for monitoring benthic cyanobacteria and their cyanotoxins in rivers for the protection of public health. By concurrently implementing all three recommended tiers (i.e., SPATT deployment, visual assessment, and benthic mat testing) at all sites in 2022 and a subset of sites in 2023, the Regional Board was able to evaluate the response of each method to changes in benthic cyanobacteria growth and cyanotoxin production during the study period. The studies demonstrate that increases in cyanotoxin concentrations in SPATTs can provide an early indication of increasing cyanobacteria percent cover and/or cyanotoxin production, thereby initiating successive tiers for visual assessments and benthic mat testing. Conversely, low cyanotoxin concentrations in SPATTs suggest that cyanobacteria percent cover and/or cyanotoxin production is minimal, and initiation of the second or third monitoring tier may not be necessary. The efficacy of the tiered monitoring approach was confirmed at two test sites in 2023 where no postings were recommended due to low SPATT concentrations and the absence of benthic blooms. The pilot studies also provide additional confirmation that anatoxins rather than microcystins/nodularins are a better indicator of bloom conditions when monitoring benthic cyanobacteria and their cyanotoxins in northern California rivers.

Evaluation of Concurrent Monitoring

At both sites in the South Fork Eel River in 2022, increases in anatoxins were observed in SPATTs one- to two-weeks prior to anatoxins increases in benthic mats, and these measurements were significantly correlated. Cyanobacteria percent cover was not significantly correlated to anatoxins in SPATTs or benthic mats, however, percent cover increased over the course of the study. In 2022, peak anatoxins production occurred two weeks earlier than 2019 and 2023 with benthic mat concentrations increasing at the same time and at higher concentrations than SPATTs. As in 2022, both SPATT and benthic mats increased prior to increases in cyanobacteria percent cover. Differences between 2022 and 2023 in the timing and magnitude of all three monitoring tiers may reflect the differences in water years in the South Fork Eel River. Regardless of flows, SPATT anatoxins in the South Fork Eel River provided an early indication that cyanobacterial growth and cyanotoxin toxin production were increasing.

Since numeric trigger levels have not been developed for anatoxins in SPATTs or benthic mats as well as cyanobacteria percent cover, best professional judgment was used to determine when results would initiate successive monitoring tiers. In the South Fork Eel River, large increases in SPATT concentrations (Tier 1) signaled that cyanobacteria percent cover and/or toxicity was increasing, and that visual assessments (Tier 2) should be conducted to document benthic mat development and condition. Visual assessments documented increasing cyanobacteria percent cover, including eventual detachment of benthic mats from substrates and accumulation in the river, thereby resulting in increased deliverability to the recreating public. The observed increases in percent cover initiated benthic mat sampling (Tier 3), which confirmed elevated anatoxins, and therefore an elevated risk to public health. Following the tiered monitoring program framework, the Regional Water Board recommended a Toxic Algae Alert for South Fork Eel River sites on August 18th; this recommendation was solely based on the observed increase in cyanobacteria percent cover (≥15%) due to long laboratory turnaround times of up to two weeks. Although anatoxins data were not available at the time to inform posting recommendation, anatoxins in SPATTs and benthic mats were exhibiting an increasing trend in late July early August, indicating the need to implement the subsequent monitoring tiers

Concentrations of SPATT anatoxins were orders of magnitude lower at all sites in the Russian River during 2022 and 2023, which corresponds to the low cyanobacteria percent cover that was observed in the latter portion of the studies. There were also no significant correlations among data types. Applying the tiered approach, low anatoxins in SPATTs (Tier 1) indicated that toxigenic benthic mats were present, yet ongoing visual assessments (Tier 2) would not be recommended since cyanobacteria percent cover is likely low. Visual assessments confirmed low benthic percent cover and low deliverability; therefore, benthic mat analysis (Tier 3) would not be recommended. Following the interim framework, no postings were recommended for the Russian River site in 2023.

In the Navarro River, variability of anatoxins in SPATTs and benthic mats occurred in tandem throughout the 2023 season. Although anatoxins remained low, a Toxic Algae Alert was recommended for Site 113NA9055 on August 14th based on a significant increase in cyanobacteria percent cover (75%). In this scenario, SPATT results (Tier 1) would not have triggered visual assessments (Tier 2) and benthic mat collections (Tier 3). Nonetheless, the Regional Water Board recommended the Toxic Algae Alert out of an abundance of caution to account for any potential increases in cyanotoxin production since laboratory result turnaround times were up to two weeks. Anatoxins in SPATTs and benthic mats remained low until the end of observations despite the significant increase in percent cover, which was dominated by *Anabaena*. This finding lends support to previous work that has not found toxin biosynthesis genes within *Anabaena*, suggesting that this genus of cyanobacteria is not an anatoxins producer (Kelly et al. 2019). However, results from Regional Board monitoring have shown anatoxins in *Anabaena*-dominated mats where *Microcoleus,* a known anatoxins-producer, was a sub-dominant component.

At all sites in the South Fork Eel, Russian, and Navarro Rivers during 2022 and 2023, microcystins/nodularins were detected by SPATTs at comparable or lower rates to, and at lower concentrations than, anatoxins. The highest concentrations of microcystins/nodularins in SPATTs were observed at the start of the study in the absence of any detectable cyanobacteria, providing support to previous findings that this class of cyanotoxins may be produced earlier in the season by an unknown source (NCRWQCB 2022a). Although abundant non-detects precluded any correlations analyses, the low concentrations of microcystins/nodularins in SPATTs in the Russian River correspond to the low concentrations measured in benthic mats as well as cyanobacteria percent cover. In the South Fork Eel and Navarro Rivers, microcystins/nodularins remained low in SPATTs and benthic mats despite increasing cyanobacteria percent cover during the studies. The absence of elevated microcystins/nodularins, especially in response to increasing benthic cover, confirm previous recommendations that trends in SPATT anatoxins are a more reliable indicator for monitoring cyanobacteria percent cover and toxicity in northern California rivers (NCRWQCB 2022a, 2022b). Additional studies need to be performed to determine whether microcystins/nodularins can act as an indicator of increasing cyanobacteria percent cover and/or cyanotoxin production in other rivers of California.

Implementation of Tiered Monitoring

At the Russian and Eel River test sites in 2023, microcystins/nodularins in SPATTs remained low (<10 ng/g) throughout the study. Anatoxins also remained low (<10 ng/g) in the Russian River. At the Eel River test site, anatoxins were measured at higher concentrations in the first half of the study but did not exhibit an eight-fold increase over a previous sampling event nor exceed the 100 ng/g threshold, as outlined in the tiered monitoring framework for 2023 posting recommendations. Based on these SPATT results, successive tiers were never initiated, and no postings were recommended for either test site. A visual assessment was conducted on the final site visit, and no benthic mats were observed, thus confirming the decision not to post.

By comparing posting dates in 2022 and 2023, it is evident that the current benthic guidelines, which recommend postings based on any cyanobacteria or cyanotoxin detections, resulted in much earlier postings when benthic blooms and health risks were a lower threat (Table 19). When implementing the tiered approach, posting recommendations occurred later in the season when benthic mat deliverability as well as cyanotoxin production increased. Posting signage that reflects actual health risks at the appropriate time is critical for the recreating public to make informed decisions. Posting signs prematurely when health risks are not present can lead to public distrust, sign fatigue, and economic loss to local communities. To ensure that the tiered approach is effective and protective, cyanobacteria and cyanotoxins of concern must be identified for local river systems, and laboratory results must be received on a timely basis.

Table 19. Comparing posting dates under actual and proposed guidelines. Current benthic guidance was implemented in 2022, and the interim framework for the tiered approach was implemented in 2023.

Year	Site Code	Site Name	Posting Date	
			Actual: Current Guidelines	**Proposed: Tiered Approach**
2022	111SF4640	South Fork Eel River at Cooks Valley	July 6 *	August 5
2022	111SF6221	South Fork Eel River at Standish-Hickey	July 6 *	August 5
2022	114RR4234	Russian River at Alexander Valley Rd	July 13 *	None
2022	114RR6273	Russian River at Comminsky Station	July 13 *	None
			Proposed: Current Guidelines	**Actual: Tiered Approach**
2023	111ER6140	Eel River above Dos Rios	May 23 *	None
2023	111SF2122	South Fork Eel River near Miranda	May 23 *	August 18
2023	111SF6221	South Fork Eel River at Standish-Hickey	May 23 *	August 18
2023	113NA9055	Navarro River at Hendy Woods	May 23 *	August 18
2023	114RR2678	Russian River at Syar	May 31 *	None
2023	114RR5407	Russian River at Cloverdale Airport	May 23 *	None

*First sample event of the year.

Evaluation of Historical Data

Although the historical dataset is comprised of studies with different objectives and study designs, the data suggest that there are seasonal trends in the rivers evaluated. Based on the evaluation of historical data in the South Fork Eel and Russian Rivers, flow did not have an effect on the magnitude of concentrations of anatoxins or microcystins/nodularins in SPATTs. Regardless of high or low water years, each cyanotoxin class exhibited similar seasonal trends for each river. However, correlation analyses suggest that high water years may delay cyanotoxin production, as was evident by the two-week delay in the South Fork Eel in 2022.

Recommendations for Future Studies

Correlations among all pilot study sites within and across rivers were presented to inform future studies that may evaluate the applicability of the tiered monitoring approach across watersheds. In 2022, anatoxins measurements in SPATTs as well as cyanobacteria percent cover were significantly correlated at both pilot study sites in the South Fork Eel River, suggesting that these metrics can be relatively consistent over extensive free-flowing river reaches. Concentrations of anatoxins in benthic mats were not correlated, demonstrating that although *Microcoleus*-dominated mats may vary in toxin-production per site, SPATT concentrations may remain consistent since these passive samplers reflect both local and upstream conditions. SPATT anatoxins were also correlated at pilot study sites within the Russian River, which vary in their watershed positioning, hydrology, and anthropogenic influence; however, determining the influence of these contributing factors is beyond the scope of this study. For microcystins/nodularins, SPATT measurements were significantly correlated at several pilot study sites across both rivers. These 2022 results suggest that the seasonal or temporal production of microcystins/nodularins is relatively consistent over a regional scale, but this correlation may also be due to consistently low concentrations of microcystins/nodularins across all sites. This finding provides further evidence that microcystins/nodularins are not a good indicator for implementing the tiered monitoring recommendations in these rivers.

Correlations among data types in 2023 were less clear and consistent, with most significant correlations for SPATT anatoxins and microcystins/nodularins occurring at sites with low measurements. The difference in correlations between years may reflect how higher flows in 2023 delayed colonization of toxin-producing cyanobacteria in each watershed. Nonetheless, the significant correlations in SPATT anatoxins across sites and rivers in 2022 provide some evidence that the tiered monitoring approach may be consistent across large river segments and watersheds, but additional studies are needed to verify its applicability. This is especially relevant if SPATTs are to be used as sentinel samplers to characterize larger upstream networks from their point of deployment. Future studies should include more sites in different watersheds throughout the region.

In the South Fork Eel and Navarro Rivers during the 2023 pilot study, long laboratory turnaround times led to posting recommendations based on cyanobacteria percent cover rather than SPATT or benthic mat concentrations. Once results were received for the South Fork Eel River, they confirmed the need for a posting; this scenario demonstrates the importance of visual assessments in the absence of cyanotoxin results. In the Navarro River, cyanotoxin results remained low despite increases in cyanobacteria percent cover; under this scenario, Tier 2 (i.e., visual assessments for percent cover) would not have been triggered based on SPATT results. This finding demonstrates that to effectively implement the tiered approach, future studies need to ensure the timely delivery of laboratory results.

The historical SPATT dataset includes results from exploratory deployments as well as experimental studies that were conducted to determine appropriate deployment lengths. Now that the Regional Water Board has provided recommendations on the appropriate deployment length and use of SPATTs (see NCRWQCB 2022b), additional data need to be collected under these protocols to build out a more standardized dataset, including watersheds outside of the study rivers presented here. Additional data from other rivers in California can also determine whether SPATT anatoxins remain as the preferred indicator while implementing the tiered approach, or if other cyanotoxins such as microcystins/nodularins are also effective.

Best professional judgment and an interim framework were used to determine when successive monitoring tiers were initiated. Future studies should develop numeric trigger levels for cyanotoxin concentrations in SPATTs and benthic mats as well as determine cyanobacterial percent cover thresholds. These values will remove potential bias and allow for consistent application of the tiered monitoring recommendations.

Resource Considerations

Table 20 compares the relative staff time and cost for three monitoring scenarios: 1) traditional benthic cyanobacteria monitoring that incorporates repeated visual assessments and benthic mat samples to evaluate public health risk; 2) concurrent monitoring of all three tiers to evaluate relationships among data types; and 3) the tiered approach that uses SPATTs to indicate when successive tiers are needed. Under traditional monitoring, there are no sentinel SPATTs to indicate potential risks upstream, so more time and cost is spent conducting visual assessments as well as collecting benthic mat samples. Concurrent monitoring is a more research-oriented approach to determine genera of concern and their cyanotoxins, so there are significant costs and time required for repeated benthic mat sampling; however, by deploying SPATTs, there is some indication of whether benthic biomass and cyanotoxins are increasing, which saves time and cost for visual assessments. By implementing the tiered approach, most of the cost is associated with SPATTs, but these sentinel samplers ultimately save time and costs by determining when visual assessments are necessary. Once benthic blooms are identified under the tiered approach, mat toxicity can be confirmed with a minimum of one benthic mat sample.

Table 20. Rankings of relative staff time and costs associated with three monitoring scenarios. Rankings are: 0) not performed; 1) least resource intensive; 2) moderate resources needed; and 3) most resource intensive. Averages are rounded to closest ranking.

Protocol	Traditional Monitoring		Concurrent Monitoring		Tiered Approach	
	Staff Time	Cost	Staff Time	Cost	Staff Time	Cost
SPATTs	0	0	1	2	1	2
Visual assess.	3	1	2	1	1	1
Benthic mats	3	3	3	3	1	1
Average:	2	2	2	2	1	1

Disclaimer

The tiered approach is expected to reduce exposure incidents by identifying major health risks in riverine systems and is ultimately the most time- and cost-effective option. However, backwater areas or isolated patches of mat-forming cyanobacteria will always be present in a river system, so even the most robust monitoring program cannot guarantee that the public will be fully protected at any given time and location.

Conclusion

By concurrently collecting all three monitoring tiers over two seasons, the Regional Water Board was able to document the response of each data type during low and high water years. Further, implementation of the tiered approach at two test sites in 2023 was successful since SPATTs correctly identified the need for no postings. These pilot studies demonstrate that anatoxins measurements in SPATTs can provide an early indication of increasing cyanobacteria percent cover and toxicity in northern California rivers and therefore identify public health risks. The Regional Water Board was able to focus its efforts on anatoxins and several cyanobacterial genera of concern after conducting extensive monitoring in the North Coast Region (see NCRWQCB 2022a, 2022b). The Regional Water Board presents the model framework for a cost-effective approach to monitoring benthic cyanobacteria and their cyanotoxins in a river system. However, for the tiered monitoring approach to be effective in rivers outside of northern California, water quality and public health entities will need to identify the benthic cyanobacteria and cyanotoxins of concern in their watersheds. As demonstrated here, the tiered approach allows for accurate and timely postings so the recreating public can make informed decisions about their water activities. Previous guidelines result in premature posting when health risks are not present, which can lead to public distrust, sign fatigue, and economic loss to local communities.

References

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Appendices

Appendix 1. Anatoxins (ATX) and microcystins/nodularins (MCY/NOD) concentrations in SPATTs and benthic mats at all study sites in 2022 and 2023. Non-numeric abbreviations for results are non-detect (ND) and not sampled (NS).

River	Site	Type	Replicate	Date Collected	Lab ID	ATX (ng/g)	MCY/NOD (ng/g)
Eel	111ER6140	SPATT	1	5/23/2023 9:00	WB4470	2.29	15.19
Eel	111ER6140	SPATT	1	5/30/2023 9:15	WB4477	1.65	12.2
Eel	111ER6140	SPATT	1	6/6/2023 9:30	WB4494	ND	8.52
Eel	111ER6140	SPATT	1	6/12/2023 9:30	WB4519	ND	29.71
Eel	111ER6140	SPATT	1	6/19/2023 15:00	WB4557	ND	17.25
Eel	111ER6140	SPATT	1	6/27/2023 9:30	WB4631	ND	36.55
Eel	111ER6140	SPATT	1	7/3/2023 9:30	WB4650	ND	12.78
Eel	111ER6140	SPATT	1	7/10/2023 9:30	WB4667	ND	20.81
Eel	111ER6140	SPATT	1	7/17/2023 9:30	WB4705	ND	2.03
Eel	111ER6140	SPATT	1	7/24/2023 8:15	WB4733	1.83	1.5
Eel	111ER6140	SPATT	1	7/31/2023 15:30	WB4744	2.55	13.69
Eel	111ER6140	SPATT	1	8/7/2023 9:15	WB4772	2.58	ND
Eel	111ER6140	SPATT	1	8/15/2023 15:00	WB4816	1.34	ND
Eel	111ER6140	SPATT	1	8/22/2023 16:00	WB4896	1.24	4.94
Eel	111ER6140	SPATT	1	8/29/2023 10:30	WB4944	1.6	4.27
Eel	111ER6140	SPATT	1	9/5/2023 9:00	WB4968	1.63	3.12
Eel	111ER6140	SPATT	1	9/12/2023 10:45	WB4985	ND	6.27
Eel	111ER6140	SPATT	1	9/18/2023 18:00	WB5012	ND	1.68
Eel	111ER6140	SPATT	1	9/27/2023 9:30	WB5053	2.57	6.06
Eel	111ER6140	SPATT	2	9/27/2023 9:30	WB5054	2	5.1
Eel	111ER6140	SPATT	1	10/3/2023 9:30	WB5086	1.25	3.98
Navarro	113NA9055	Algal mat	1	5/23/2023 15:00	WB4473	0.27	0.2
Navarro	113NA9055	Algal mat	1	5/23/2023 15:00	WB4472	ND	ND
Navarro	113NA9055	Algal mat	1	5/30/2023 16:30	WB4480	ND	ND
Navarro	113NA9055	Algal mat	1	5/30/2023 16:30	WB4481	ND	ND
Navarro	113NA9055	Algal mat	1	6/6/2023 16:45	WB4492	ND	ND

River	Site	Type	Replicate	Date Collected	Lab ID	ATX (ng/g)	MCY/NOD (ng/g)
Navarro	113NA9055	Algal mat	1	6/6/2023 16:45	WB4493	ND	0.24
Navarro	113NA9055	Algal mat	1	6/12/2023 16:30	WB4518	ND	ND
Navarro	113NA9055	Algal mat	1	6/19/2023 12:00	WB4569	ND	0.2
Navarro	113NA9055	Algal mat	1	6/19/2023 12:00	WB4567	ND	ND
Navarro	113NA9055	Algal mat	1	6/19/2023 12:00	WB4568	0.34	0.28
Navarro	113NA9055	Algal mat	1	6/26/2023 9:00	WB4635	ND	ND
Navarro	113NA9055	Algal mat	1	6/26/2023 9:00	WB4634	ND	0.18
Navarro	113NA9055	Algal mat	1	6/26/2023 9:00	WB4633	1.47	0.94
Navarro	113NA9055	Algal mat	1	7/3/2023 17:15	WB4649	0.48	0.24
Navarro	113NA9055	Algal mat	1	7/10/2023 16:30	WB4666	ND	ND
Navarro	113NA9055	Algal mat	1	7/10/2023 16:30	WB4665	ND	ND
Navarro	113NA9055	Algal mat	1	7/24/2023 14:45	WB4724	0.43	0.17
Navarro	113NA9055	Algal mat	1	7/31/2023 9:15	WB4746	0.66	0.31
Navarro	113NA9055	Algal mat	1	8/7/2023 16:30	WB4774	0.33	NS
Navarro	113NA9055	Algal mat	1	8/7/2023 16:30	WB4775	NS	ND
Navarro	113NA9055	Algal mat	1	8/14/2023 10:00	WB4818	0.16	0.16
Navarro	113NA9055	Algal mat	1	8/21/2023 10:30	WB4902	ND	NS
Navarro	113NA9055	Algal mat	1	8/21/2023 10:30	WB4903	NS	ND
Navarro	113NA9055	Algal mat	1	8/29/2023 9:30	WB4943	0.36	0.23
Navarro	113NA9055	SPATT	1	5/23/2023 15:00	WB4471	2.13	36.3
Navarro	113NA9055	SPATT	1	5/30/2023 16:30	WB4479	ND	ND
Navarro	113NA9055	SPATT	1	6/6/2023 16:45	WB4491	ND	1.69
Navarro	113NA9055	SPATT	1	6/12/2023 16:30	WB4517	ND	2.68
Navarro	113NA9055	SPATT	1	6/19/2023 12:00	WB4566	1.79	ND
Navarro	113NA9055	SPATT	1	6/26/2023 9:00	WB4632	1.31	4.61
Navarro	113NA9055	SPATT	2	6/26/2023 9:00	WB4636	1.17	3.37
Navarro	113NA9055	SPATT	1	7/3/2023 17:15	WB4648	ND	2.92
Navarro	113NA9055	SPATT	1	7/10/2023 16:30	WB4664	ND	2.53
Navarro	113NA9055	SPATT	1	7/17/2023 17:00	WB4706	ND	ND
Navarro	113NA9055	SPATT	1	7/24/2023 14:45	WB4723	3.46	ND

River	Site	Type	Replicate	Date Collected	Lab ID	ATX (ng/g)	MCY/NOD (ng/g)
Navarro	113NA9055	SPATT	1	7/31/2023 9:15	WB4745	2.89	ND
Navarro	113NA9055	SPATT	1	8/7/2023 16:30	WB4773	1.83	ND
Navarro	113NA9055	SPATT	1	8/14/2023 10:00	WB4817	ND	ND
Navarro	113NA9055	SPATT	1	8/21/2023 10:30	WB4901	ND	ND
Navarro	113NA9055	SPATT	1	8/29/2023 9:30	WB4942	ND	ND
Russian	114RR2079	SPATT	1	7/13/2022	WB3291	ND	ND
Russian	114RR2079	SPATT	1	7/19/2022	WB3337	ND	2.15
Russian	114RR2079	SPATT	1	7/26/2022 11:30	WB3344	ND	ND
Russian	114RR2079	SPATT	1	8/2/2022 11:00	WB3344	ND	6.13
Russian	114RR2079	SPATT	1	8/8/2022 13:30	WB3899	ND	7.72
Russian	114RR2079	SPATT	1	8/17/2022	WB3449	1.71	5.9
Russian	114RR2079	SPATT	1	8/23/2022 10:45	WB3546	6.77	4.45
Russian	114RR2079	SPATT	1	8/23/2022 14:20	WB3644	1.82	16.09
Russian	114RR2079	SPATT	1	9/6/2022 9:30	WB3671	1.52	7.28
Russian	114RR2079	SPATT	1	9/13/2022 10:41	WB3709	3.51	24.27
Russian	114RR2079	SPATT	1	9/20/2022 11:20	WB3709	1.31	4.98
Russian	114RR2079	SPATT	1	9/27/2022 10:00	WB3840	2.33	6.15
Russian	114RR2079	SPATT	1	10/4/2022	WB3956	4.3	3.85
Russian	114RR2079	SPATT	1	10/11/2022 10:10	WB4029	2.08	3.72
Russian	114RR2079	SPATT	1	10/18/2022	WB4116	2.71	22.63
Russian	114RR2079	SPATT	1	10/25/2022 9:30	WB4162	ND	4.79
Russian	114RR2655	Algal mat	1	10/19/2022	WB4118	2.51	ND
Russian	114RR2655	Algal mat	1	10/19/2022	WB4119	ND	ND
Russian	114RR2655	SPATT	1	7/13/2022	WB3292	2.04	4.83
Russian	114RR2655	SPATT	1	7/19/2022	WB3338	ND	1.57
Russian	114RR2655	SPATT	1	7/26/2022 12:02	WB3343	ND	1.51
Russian	114RR2655	SPATT	1	8/2/2022 11:35	WB3343	ND	2.52
Russian	114RR2655	SPATT	1	8/8/2022 10:55	WB3898	ND	ND
Russian	114RR2655	SPATT	1	8/17/2022	WB3450	31.3	ND
Russian	114RR2655	SPATT	1	8/23/2022 11:30	WB3545	7.85	ND

River	Site	Type	Replicate	Date Collected	Lab ID	ATX (ng/g)	MCY/NOD (ng/g)
Russian	114RR2655	SPATT	1	8/30/2022 15:26	WB3643	18.91	6.99
Russian	114RR2655	SPATT	1	9/6/2022 8:40	WB3672	41.67	4.54
Russian	114RR2655	SPATT	1	9/13/2022 11:20	WB3708	165.68	4.62
Russian	114RR2655	SPATT	1	9/20/2022 12:00	WB3708	42.37	ND
Russian	114RR2655	SPATT	1	9/27/2022 10:40	WB3841	139.9	1.83
Russian	114RR2655	SPATT	1	10/4/2022	WB3955	2.87	3.42
Russian	114RR2655	SPATT	1	10/11/2022 11:00	WB4030	65.35	2.41
Russian	114RR2655	SPATT	1	10/18/2022	WB4117	9.57	2.2
Russian	114RR2655	SPATT	1	10/25/2022 10:10	WB4161	3.12	ND
Russian	114RR2655	SPATT	2	10/25/2022 10:10	WB4163	2.23	ND
Russian	114RR2678	Algal mat	1	7/3/2023 10:15	WB4657	ND	0.29
Russian	114RR2678	Algal mat	1	8/29/2023 12:00	WB4958	0.6	NS
Russian	114RR2678	Algal mat	1	9/5/2023 9:30	WB4970	0.84	NS
Russian	114RR2678	Algal mat	1	9/12/2023 9:30	WB4990	0.45	NS
Russian	114RR2678	Algal mat	1	9/12/2023 9:30	WB4989	0.3	NS
Russian	114RR2678	Algal mat	1	9/18/2023 16:30	WB5015	2.67	NS
Russian	114RR2678	Algal mat	1	9/26/2023 9:30	WB5057	0.76	NS
Russian	114RR2678	Algal mat	1	10/3/2023 14:00	WB5089	0.5	NS
Russian	114RR2678	Algal mat	1	10/10/2023 8:30	WB5097	1.04	NS
Russian	114RR2678	Algal mat	1	10/16/2023 9:00	WB5113	11.75	NS
Russian	114RR2678	SPATT	1	5/31/2023 13:15	WB4475	1.43	ND
Russian	114RR2678	SPATT	1	6/6/2023 10:30	WB4497	2.91	1.59
Russian	114RR2678	SPATT	1	6/12/2023 9:30	WB4523	ND	ND
Russian	114RR2678	SPATT	1	6/19/2023 8:00	WB4558	ND	ND
Russian	114RR2678	SPATT	1	6/26/2023 12:00	WB4623	1.7	ND
Russian	114RR2678	SPATT	1	7/3/2023 10:15	WB4655	0.2	ND
Russian	114RR2678	SPATT	1	7/11/2023 13:15	WB4675	2.15	3.9
Russian	114RR2678	SPATT	1	7/17/2023 10:00	WB4707	ND	2.16
Russian	114RR2678	SPATT	1	7/24/2023 16:45	WB4734	1.58	ND
Russian	114RR2678	SPATT	1	7/31/2023 9:45	WB4747	2.14	ND

River	Site	Type	Replicate	Date Collected	Lab ID	ATX (ng/g)	MCY/NOD (ng/g)
Russian	114RR2678	SPATT	1	8/8/2023 14:15	WB4776	2.3	ND
Russian	114RR2678	SPATT	1	8/14/2023 12:45	WB4819	1.53	ND
Russian	114RR2678	SPATT	1	8/21/2023 13:00	WB4904	2.32	2.2
Russian	114RR2678	SPATT	2	8/21/2023 13:00	WB4905	ND	2.02
Russian	114RR2678	SPATT	1	8/29/2023 12:00	WB4956	1.42	ND
Russian	114RR2678	SPATT	2	8/29/2023 12:00	WB4957	1.6	ND
Russian	114RR2678	SPATT	1	9/5/2023 9:30	WB4969	2.76	ND
Russian	114RR2678	SPATT	1	9/12/2023 9:30	WB4986	2.33	1.75
Russian	114RR2678	SPATT	1	9/18/2023 16:30	WB5013	ND	ND
Russian	114RR2678	SPATT	1	9/26/2023 10:30	WB5055	2.85	1.47
Russian	114RR2678	SPATT	1	10/3/2023 14:00	WB5087	ND	ND
Russian	114RR2678	SPATT	1	10/10/2023 8:30	WB5096	2.14	ND
Russian	114RR2678	SPATT	1	10/16/2023 9:00	WB5112	2.77	ND
Russian	114RR4234	Algal mat	1	9/6/2022 16:30	WB3679	0.64	0.15
Russian	114RR4234	Algal mat	1	9/12/2022 17:00	WB3707	0.64	0.17
Russian	114RR4234	Algal mat	1	9/20/2022 15:00	WB3707	0.57	2.3
Russian	114RR4234	Algal mat	1	9/26/2022 15:30	WB3829	ND	ND
Russian	114RR4234	Algal mat	1	10/4/2022	WB3954	0.83	0.25
Russian	114RR4234	Algal mat	1	10/11/2022 14:45	WB4028	10.58	0.19
Russian	114RR4234	Algal mat	1	10/17/2022 14:00	WB4071	28.1	0.21
Russian	114RR4234	Algal mat	1	10/19/2022	WB4120	ND	ND
Russian	114RR4234	Algal mat	1	10/19/2022	WB4121	2.78	ND
Russian	114RR4234	Algal mat	1	10/25/2022 14:45	WB4160	3.68	ND
Russian	114RR4234	SPATT	1	7/12/2022 15:00	WB3290	4.23	26.37
Russian	114RR4234	SPATT	1	7/18/2022 15:00	WB3336	2.39	2.85
Russian	114RR4234	SPATT	1	7/26/2022 13:45	WB3348	2.34	4.19
Russian	114RR4234	SPATT	1	8/2/2022 14:00	WB3348	1.24	3.78
Russian	114RR4234	SPATT	1	8/8/2022 14:30	WB3897	ND	2.28
Russian	114RR4234	SPATT	1	8/17/2022 14:30	WB3448	2.14	3.33
Russian	114RR4234	SPATT	1	8/23/2022 14:00	WB3544	6.99	4.13

River	Site	Type	Replicate	Date Collected	Lab ID	ATX (ng/g)	MCY/NOD (ng/g)
Russian	114RR4234	SPATT	1	8/30/2022 14:30	WB3642	2.42	4.73
Russian	114RR4234	SPATT	1	9/6/2022 16:30	WB3669	1.82	4.41
Russian	114RR4234	SPATT	1	9/12/2022 17:00	WB3706	1.77	6.86
Russian	114RR4234	SPATT	1	9/20/2022 15:00	WB3706	1.61	2.97
Russian	114RR4234	SPATT	1	9/26/2022 15:30	WB3828	2.68	3.78
Russian	114RR4234	SPATT	1	10/4/2022	WB3953	151.01	3.14
Russian	114RR4234	SPATT	1	10/11/2022 14:45	WB4027	5.04	7.31
Russian	114RR4234	SPATT	1	10/17/2022 14:00	WB4070	1.63	2.64
Russian	114RR4234	SPATT	1	10/25/2022 14:45	WB4159	2.73	5.26
Russian	114RR5407	SPATT	1	5/25/2023 8:15	WB4474	2.24	ND
Russian	114RR5407	SPATT	1	5/31/2023 12:15	WB4476	1.58	3.63
Russian	114RR5407	SPATT	1	6/6/2023 9:00	WB4498	1.89	1.49
Russian	114RR5407	SPATT	1	6/12/2023 8:30	WB4524	0.24	1.89
Russian	114RR5407	SPATT	1	6/19/2023 9:30	WB4559	ND	ND
Russian	114RR5407	SPATT	1	6/26/2023 11:00	WB4624	1.66	1.49
Russian	114RR5407	SPATT	1	7/3/2023 8:45	WB4656	0.4	2.44
Russian	114RR5407	SPATT	1	7/11/2023 9:45	WB4676	2.1	2.26
Russian	114RR5407	SPATT	1	7/17/2023 9:00	WB4708	ND	ND
Russian	114RR5407	SPATT	1	7/25/2023 13:00	WB4735	1.57	ND
Russian	114RR5407	SPATT	1	7/31/2023 8:45	WB4748	2.15	ND
Russian	114RR5407	SPATT	1	8/8/2023 12:30	WB4777	3.14	ND
Russian	114RR5407	SPATT	1	8/14/2023 12:00	WB4820	ND	ND
Russian	114RR5407	SPATT	1	8/21/2023 12:00	WB4906	ND	ND
Russian	114RR5407	SPATT	1	8/29/2023 11:00	WB4955	1.32	ND
Russian	114RR5407	SPATT	1	9/5/2023 8:00	WB4971	ND	ND
Russian	114RR5407	SPATT	1	9/12/2023 8:30	WB4987	ND	ND
Russian	114RR5407	SPATT	2	9/12/2023 8:30	WB4988	ND	1.47
Russian	114RR5407	SPATT	1	9/18/2023 16:00	WB5014	ND	ND
Russian	114RR5407	SPATT	1	9/26/2023 9:30	WB5056	ND	ND
Russian	114RR5407	SPATT	1	10/3/2023 12:30	WB5088	ND	ND

River	Site	Type	Replicate	Date Collected	Lab ID	ATX (ng/g)	MCY/NOD (ng/g)
Russian	114RR6273	Algal mat	1	9/6/2022 15:30	WB3678	50.74	ND
Russian	114RR6273	Algal mat	1	9/12/2022 16:00	WB3692	26.27	ND
Russian	114RR6273	Algal mat	1	9/20/2022 14:15	WB3705	793.57	2.37
Russian	114RR6273	Algal mat	1	9/26/2022 15:00	WB3827	181.44	ND
Russian	114RR6273	Algal mat	1	10/4/2022	WB3952	1,143.90	0.28
Russian	114RR6273	Algal mat	1	10/4/2022	WB3957	23.4	0.27
Russian	114RR6273	Algal mat	1	10/11/2022 13:45	WB4026	56.16	ND
Russian	114RR6273	Algal mat	1	10/17/2022 13:15	WB4069	41.66	0.33
Russian	114RR6273	Algal mat	1	10/25/2022 13:45	WB4158	15.54	ND
Russian	114RR6273	SPATT	1	7/12/2022 14:00	WB3289	3	10.59
Russian	114RR6273	SPATT	1	7/18/2022 14:15	WB3335	2.6	3.7
Russian	114RR6273	SPATT	1	7/26/2022 12:45	WB3347	1.54	2.14
Russian	114RR6273	SPATT	1	8/2/2022 13:30	WB3343	ND	ND
Russian	114RR6273	SPATT	1	8/8/2022 13:30	WB3896	1.75	2.2
Russian	114RR6273	SPATT	1	8/17/2022 13:45	WB3447	2.37	1.77
Russian	114RR6273	SPATT	1	8/23/2022 13:15	WB3543	9.14	3.78
Russian	114RR6273	SPATT	1	8/30/2022 14:00	WB3641	5.45	11.25
Russian	114RR6273	SPATT	1	9/6/2022 15:30	WB3670	6.56	4.01
Russian	114RR6273	SPATT	1	9/12/2022 16:00	WB3691	39.74	8.54
Russian	114RR6273	SPATT	1	9/20/2022 14:15	WB3704	14.57	6.21
Russian	114RR6273	SPATT	1	9/26/2022 15:00	WB3826	34.55	3.36
Russian	114RR6273	SPATT	1	10/4/2022 13:30	WB3951	26.22	1.47
Russian	114RR6273	SPATT	1	10/11/2022 13:45	WB4025	7.77	2.66
Russian	114RR6273	SPATT	1	10/17/2022 13:15	WB4067	9.56	6.5
Russian	114RR6273	SPATT	2	10/17/2022 13:15	WB4068	6.26	5.32
Russian	114RR6273	SPATT	1	10/25/2022 13:45	WB4156	7.47	3.96
Russian	114RR6273	SPATT	2	10/25/2022 13:45	WB4157	6.09	11.39
SF Eel	111SF2122	Algal mat	1	6/19/2023 18:45	WB4564	0.29	ND
SF Eel	111SF2122	Algal mat	1	6/19/2023 18:45	WB4562	ND	ND
SF Eel	111SF2122	Algal mat	1	6/27/2023 12:00	WB4629	ND	ND

River	Site	Type	Replicate	Date Collected	Lab ID	ATX (ng/g)	MCY/NOD (ng/g)
SF Eel	111SF2122	Algal mat	1	6/27/2023 12:00	WB4630	ND	ND
SF Eel	111SF2122	Algal mat	1	7/3/2023 12:00	WB4653	ND	ND
SF Eel	111SF2122	Algal mat	1	7/10/2023 11:30	WB4670	ND	ND
SF Eel	111SF2122	Algal mat	1	7/10/2023 11:30	WB4669	ND	ND
SF Eel	111SF2122	Algal mat	1	7/17/2023 11:45	WB4703	ND	ND
SF Eel	111SF2122	Algal mat	1	7/24/2023 10:30	WB4729	1.22	0.37
SF Eel	111SF2122	Algal mat	1	7/24/2023 10:30	WB4730	1.23	0.2
SF Eel	111SF2122	Algal mat	1	7/24/2023 10:30	WB4731	1.72	0.22
SF Eel	111SF2122	Algal mat	1	7/24/2023 10:30	WB4732	0.22	0.28
SF Eel	111SF2122	Algal mat	1	7/31/2023 12:45	WB4743	23.18	0.23
SF Eel	111SF2122	Algal mat	1	7/31/2023 12:45	WB4742	6.68	ND
SF Eel	111SF2122	Algal mat	1	8/7/2023 11:15	WB4766	494.05	NS
SF Eel	111SF2122	Algal mat	1	8/7/2023 11:15	WB4765	182.8	NS
SF Eel	111SF2122	Algal mat	1	8/7/2023 11:15	WB4767	0.17	NS
SF Eel	111SF2122	Algal mat	1	8/15/2023 10:15	WB4810	1,331.60	NS
SF Eel	111SF2122	Algal mat	1	8/15/2023 10:15	WB4809	25.1	NS
SF Eel	111SF2122	Algal mat	1	8/15/2023 10:15	WB4811	1,204.10	NS
SF Eel	111SF2122	Algal mat	1	8/22/2023 11:00	WB4893	1,590.60	ND
SF Eel	111SF2122	Algal mat	1	8/22/2023 11:00	WB4892	260.93	NS
SF Eel	111SF2122	Algal mat	1	8/22/2023 11:00	WB4894	NS	ND
SF Eel	111SF2122	Algal mat	1	8/22/2023 11:00	WB4895	3,431.00	0.24
SF Eel	111SF2122	Algal mat	1	8/29/2023 13:30	WB4946	68.38	NS
SF Eel	111SF2122	Algal mat	1	8/29/2023 13:30	WB4947	11,245.80	NS
SF Eel	111SF2122	Algal mat	1	9/5/2023 11:15	WB4962	246.85	NS
SF Eel	111SF2122	Algal mat	1	9/5/2023 11:15	WB4963	2.27	0.22
SF Eel	111SF2122	Algal mat	1	9/5/2023 11:15	WB4964	144,135.00	NS
SF Eel	111SF2122	Algal mat	1	9/12/2023 13:30	WB4977	47.17	NS
SF Eel	111SF2122	Algal mat	1	9/12/2023 13:30	WB4979	2.94	NS
SF Eel	111SF2122	Algal mat	1	9/12/2023 13:30	WB4980	9	NS
SF Eel	111SF2122	Algal mat	1	9/12/2023 13:30	WB4978	3,096.60	NS

River	Site	Type	Replicate	Date Collected	Lab ID	ATX (ng/g)	MCY/NOD (ng/g)
SF Eel	111SF2122	Algal mat	1	9/19/2023 10:30	WB5007	130.28	NS
SF Eel	111SF2122	Algal mat	1	9/19/2023 10:30	WB5008	4,722.50	NS
SF Eel	111SF2122	Algal mat	1	9/27/2023 11:30	WB5052	170.8	NS
SF Eel	111SF2122	Algal mat	1	10/4/2023 10:45	WB5082	61.92	NS
SF Eel	111SF2122	Algal mat	1	10/10/2023 13:00	WB5099	55.44	NS
SF Eel	111SF2122	Algal mat	1	10/16/2023 15:00	WB5116	150.8	NS
SF Eel	111SF2122	SPATT	1	5/23/2023 12:00	WB4469	2.16	18.12
SF Eel	111SF2122	SPATT	1	6/12/2023 12:00	WB4520	2.47	19.87
SF Eel	111SF2122	SPATT	1	6/19/2023 18:45	WB4560	1.25	2.33
SF Eel	111SF2122	SPATT	1	6/27/2023 12:00	WB4628	ND	NS
SF Eel	111SF2122	SPATT	1	7/3/2023 12:00	WB4651	ND	ND
SF Eel	111SF2122	SPATT	1	7/10/2023 11:30	WB4668	1.21	3.14
SF Eel	111SF2122	SPATT	1	7/17/2023 11:45	WB4700	ND	NS
SF Eel	111SF2122	SPATT	1	7/24/2023 10:30	WB4728	2.81	NS
SF Eel	111SF2122	SPATT	1	7/31/2023 12:45	WB4740	7.14	NS
SF Eel	111SF2122	SPATT	2	7/31/2023 12:45	WB4741	7.76	NS
SF Eel	111SF2122	SPATT	1	8/7/2023 11:15	WB4763	43.56	NS
SF Eel	111SF2122	SPATT	2	8/7/2023 11:15	WB4764	46.97	NS
SF Eel	111SF2122	SPATT	1	8/15/2023 10:15	WB4807	122.28	NS
SF Eel	111SF2122	SPATT	2	8/15/2023 10:15	WB4808	95.83	NS
SF Eel	111SF2122	SPATT	1	8/22/2023 11:00	WB4891	68.25	NS
SF Eel	111SF2122	SPATT	1	8/29/2023 13:30	WB4945	92.51	NS
SF Eel	111SF2122	SPATT	1	9/5/2023 11:15	WB4961	146.44	NS
SF Eel	111SF2122	SPATT	1	9/12/2023 13:30	WB4976	9.97	NS
SF Eel	111SF2122	SPATT	1	9/19/2023 10:30	WB5006	209.04	NS
SF Eel	111SF2122	SPATT	1	9/27/2023 11:30	WB5051	56.75	NS
SF Eel	111SF2122	SPATT	1	10/4/2023 10:45	WB5081	7.82	NS
SF Eel	111SF2122	SPATT	1	10/10/2023 13:00	WB5098	6.43	NS
SF Eel	111SF2122	SPATT	1	10/16/2023 15:00	WB5114	5.23	NS
SF Eel	111SF2122	SPATT	2	10/16/2023 15:00	WB5115	5.67	NS

River	Site	Type	Replicate	Date Collected	Lab ID	ATX (ng/g)	MCY/NOD (ng/g)
SF Eel	111SF4640	Algal mat	1	7/26/2022 9:30	WB3340	0.73	
SF Eel	111SF4640	Algal mat	1	8/2/2022 10:00	WB3340	3.34	ND
SF Eel	111SF4640	Algal mat	1	8/8/2022 10:00	WB3893	242.41	ND
SF Eel	111SF4640	Algal mat	1	8/17/2022 10:15	WB3444	214.4	0.16
SF Eel	111SF4640	Algal mat	1	8/23/2022 10:00	WB3548	206	ND
SF Eel	111SF4640	Algal mat	1	8/30/2022 10:00	WB3638	352.6	ND
SF Eel	111SF4640	Algal mat	1	9/6/2022 10:00	WB3673	41.75	0.19
SF Eel	111SF4640	Algal mat	1	9/6/2022 10:00	WB3677	0.74	ND
SF Eel	111SF4640	Algal mat	1	9/12/2022 10:30	WB3705	221.1	ND
SF Eel	111SF4640	Algal mat	1	9/20/2022 10:00	WB3693	18.2	ND
SF Eel	111SF4640	Algal mat	1	9/26/2022 10:00	WB3815	3.95	ND
SF Eel	111SF4640	Algal mat	1	10/4/2022 10:00	WB3948	6.17	ND
SF Eel	111SF4640	Algal mat	1	10/11/2022 10:00	WB4022	6.76	ND
SF Eel	111SF4640	Algal mat	1	10/17/2022 10:00	WB4063	27.85	ND
SF Eel	111SF4640	Algal mat	1	10/25/2022 10:00	WB4153	32	ND
SF Eel	111SF4640	SPATT	1	7/12/2022 10:30	WB3284	3.24	175.9
SF Eel	111SF4640	SPATT	1	7/18/2022 10:00	WB3334	2.01	11.86
SF Eel	111SF4640	SPATT	1	7/26/2022 9:30	WB3345	22.75	10.08
SF Eel	111SF4640	SPATT	1	8/2/2022 10:00	WB3343	352.1	6.75
SF Eel	111SF4640	SPATT	1	8/8/2022 10:00	WB3892	2,697.10	10.57
SF Eel	111SF4640	SPATT	1	8/17/2022 10:15	WB3443	3,637.80	5.57
SF Eel	111SF4640	SPATT	1	8/23/2022 10:00	WB3541	585.5	4.97
SF Eel	111SF4640	SPATT	2	8/23/2022 10:00	WB3547	2,133.00	6
SF Eel	111SF4640	SPATT	1	8/30/2022 10:00	WB3637	82.3	16.67
SF Eel	111SF4640	SPATT	1	9/6/2022 10:00	WB3666	30.06	11.86
SF Eel	111SF4640	SPATT	2	9/6/2022 10:00	WB3667	104.33	22.93
SF Eel	111SF4640	SPATT	1	9/12/2022 10:30	WB3703	5.69	26.42
SF Eel	111SF4640	SPATT	2	9/12/2022 10:30	WB3704	8.18	17.1
SF Eel	111SF4640	SPATT	1	9/20/2022 10:00	WB3691	3.79	15.98
SF Eel	111SF4640	SPATT	2	9/20/2022 10:00	WB3692	5.69	11.05

River	Site	Type	Replicate	Date Collected	Lab ID	ATX (ng/g)	MCY/NOD (ng/g)
SF Eel	111SF4640	SPATT	1	9/26/2022 10:00	WB3813	29.44	13.12
SF Eel	111SF4640	SPATT	2	9/26/2022 10:00	WB3814	17.66	6.14
SF Eel	111SF4640	SPATT	1	10/4/2022 10:00	WB3947	48.26	7.34
SF Eel	111SF4640	SPATT	1	10/11/2022 10:00	WB4019	53.8	12.17
SF Eel	111SF4640	SPATT	2	10/11/2022 10:00	WB4020	31.19	12.68
SF Eel	111SF4640	SPATT	3	10/11/2022 10:00	WB4021	5.95	14.99
SF Eel	111SF4640	SPATT	1	10/17/2022 10:00	WB4185	152.92	12.6
SF Eel	111SF4640	SPATT	1	10/25/2022 10:00	WB4152	53.86	3.41
SF Eel	111SF6221	Algal mat	1	7/5/2022 11:15	WB3244	ND	ND
SF Eel	111SF6221	Algal mat	1	8/2/2022 11:00	WB3341	4.36	ND
SF Eel	111SF6221	Algal mat	1	8/8/2022 11:00	WB3895	142.6	ND
SF Eel	111SF6221	Algal mat	1	8/17/2022 11:30	WB3446	246.8	ND
SF Eel	111SF6221	Algal mat	1	8/23/2022 11:00	WB3549	38.73	ND
SF Eel	111SF6221	Algal mat	1	8/30/2022 11:00	WB3640	5.04	ND
SF Eel	111SF6221	Algal mat	1	9/6/2022 13:45	WB3675	3.4	ND
SF Eel	111SF6221	Algal mat	1	9/12/2022 14:00	WB3694	17.15	ND
SF Eel	111SF6221	Algal mat	1	9/20/2022 12:15	WB3703	18.57	ND
SF Eel	111SF6221	Algal mat	1	9/26/2022 13:00	WB3825	48.05	ND
SF Eel	111SF6221	Algal mat	1	10/4/2022 11:00	WB3950	110.11	ND
SF Eel	111SF6221	Algal mat	1	10/11/2022 11:00	WB4024	27.52	ND
SF Eel	111SF6221	Algal mat	1	10/17/2022 10:45	WB4066	60.3	ND
SF Eel	111SF6221	Algal mat	1	10/25/2022 11:15	WB4155	19.77	ND
SF Eel	111SF6221	Algal mat	1	6/6/2023 14:00	WB4496	ND	ND
SF Eel	111SF6221	Algal mat	1	6/12/2023 13:45	WB4522	ND	0.23
SF Eel	111SF6221	Algal mat	1	6/19/2023 16:45	WB4565	ND	ND
SF Eel	111SF6221	Algal mat	1	6/19/2023 16:45	WB4563	ND	0.28
SF Eel	111SF6221	Algal mat	1	6/27/2023 14:45	WB4626	ND	1.74
SF Eel	111SF6221	Algal mat	1	6/27/2023 14:45	WB4627	0.56	ND
SF Eel	111SF6221	Algal mat	1	7/3/2023 14:15	WB4654	2.03	0.16
SF Eel	111SF6221	Algal mat	1	7/10/2023 13:20	WB4674	ND	ND

River	Site	Type	Replicate	Date Collected	Lab ID	ATX (ng/g)	MCY/NOD (ng/g)
SF Eel	111SF6221	Algal mat	1	7/10/2023 13:30	WB4673	ND	ND
SF Eel	111SF6221	Algal mat	1	7/17/2023 14:00	WB4704	ND	ND
SF Eel	111SF6221	Algal mat	1	7/24/2023 12:30	WB4727	0.75	0.15
SF Eel	111SF6221	Algal mat	1	7/31/2023 14:00	WB4739	2.39	ND
SF Eel	111SF6221	Algal mat	1	8/7/2023 13:30	WB4770	31.26	NS
SF Eel	111SF6221	Algal mat	1	8/7/2023 13:30	WB4769	0.51	NS
SF Eel	111SF6221	Algal mat	1	8/7/2023 13:30	WB4771	NS	ND
SF Eel	111SF6221	Algal mat	1	8/15/2023 12:30	WB4814	451.33	0.19
SF Eel	111SF6221	Algal mat	1	8/15/2023 12:30	WB4813	714.2	NS
SF Eel	111SF6221	Algal mat	1	8/15/2023 12:30	WB4815	1,863.80	NS
SF Eel	111SF6221	Algal mat	1	8/22/2023 13:30	WB4899	23.25	0.19
SF Eel	111SF6221	Algal mat	1	8/22/2023 13:30	WB4898	1,206.10	NS
SF Eel	111SF6221	Algal mat	1	8/22/2023 13:30	WB4900	NS	ND
SF Eel	111SF6221	Algal mat	1	8/29/2023 15:30	WB4953	2.48	0.15
SF Eel	111SF6221	Algal mat	1	8/29/2023 15:30	WB4951	171.82	NS
SF Eel	111SF6221	Algal mat	1	8/29/2023 15:30	WB4991	22.03	NS
SF Eel	111SF6221	Algal mat	1	8/29/2023 15:30	WB5050	72.33	NS
SF Eel	111SF6221	Algal mat	1	8/29/2023 15:30	WB5095	8.22	NS
SF Eel	111SF6221	Algal mat	1	8/29/2023 15:30	WB4952	58.73	NS
SF Eel	111SF6221	Algal mat	1	8/29/2023 15:30	WB4954	0.6	NS
SF Eel	111SF6221	Algal mat	1	9/5/2023 14:00	WB4966	95.53	NS
SF Eel	111SF6221	Algal mat	1	9/5/2023 14:00	WB4967	1.73	ND
SF Eel	111SF6221	Algal mat	1	9/12/2023 16:30	WB4981	1,165.60	NS
SF Eel	111SF6221	Algal mat	1	9/12/2023 16:30	WB4982	3.07	ND
SF Eel	111SF6221	Algal mat	1	9/12/2023 16:30	WB4983	3.78	ND
SF Eel	111SF6221	Algal mat	1	9/12/2023 16:30	WB4984	0.53	0.16
SF Eel	111SF6221	Algal mat	1	9/19/2023 18:45	WB5011	23.75	NS
SF Eel	111SF6221	Algal mat	1	9/27/2023 15:00	WB5049	3.42	NS
SF Eel	111SF6221	Algal mat	1	10/4/2023 14:00	WB5085	31.11	NS
SF Eel	111SF6221	Algal mat	1	10/10/2023 14:30	WB5101	634.41	NS

River	Site	Type	Replicate	Date Collected	Lab ID	ATX (ng/g)	MCY/NOD (ng/g)
SF Eel	111SF6221	Algal mat	1	10/16/2023 13:00	WB5118	2.91	NS
SF Eel	111SF6221	SPATT	1	7/12/2022 11:30	WB3287	1.41	92.08
SF Eel	111SF6221	SPATT	1	7/26/2022 10:30	WB3346	5.77	13.23
SF Eel	111SF6221	SPATT	1	8/2/2022 11:00	WB3343	109	8.68
SF Eel	111SF6221	SPATT	1	8/8/2022 11:00	WB3894	906.1	6.78
SF Eel	111SF6221	SPATT	1	8/17/2022 11:30	WB3445	3,312.80	5.37
SF Eel	111SF6221	SPATT	1	8/23/2022 11:00	WB3542	580.3	6.29
SF Eel	111SF6221	SPATT	1	8/30/2022 11:00	WB3639	740.5	18.79
SF Eel	111SF6221	SPATT	1	9/6/2022 13:45	WB3668	198.85	2.36
SF Eel	111SF6221	SPATT	1	9/12/2022 14:00	WB3693	102.48	7.51
SF Eel	111SF6221	SPATT	1	9/20/2022 12:15	WB3702	23.78	6.91
SF Eel	111SF6221	SPATT	1	9/26/2022 13:00	WB3824	16.78	7.24
SF Eel	111SF6221	SPATT	1	10/4/2022 11:00	WB3949	26.88	1.98
SF Eel	111SF6221	SPATT	1	10/11/2022 11:00	WB4023	96.46	3.58
SF Eel	111SF6221	SPATT	1	10/17/2022 10:45	WB4064	51.64	3.53
SF Eel	111SF6221	SPATT	2	10/17/2022 10:45	WB4065	63.92	4.68
SF Eel	111SF6221	SPATT	1	10/25/2022 11:15	WB4154	150.4	1.8
SF Eel	111SF6221	SPATT	1	5/23/2023 10:45	WB4468	2.24	91.94
SF Eel	111SF6221	SPATT	1	5/30/2023 11:00	WB4478	1.98	73.93
SF Eel	111SF6221	SPATT	1	6/6/2023 14:00	WB4495	2.17	13.09
SF Eel	111SF6221	SPATT	1	6/12/2023 13:45	WB4521	1.43	56.62
SF Eel	111SF6221	SPATT	1	6/19/2023 16:45	WB4561	1.77	2.36
SF Eel	111SF6221	SPATT	1	6/27/2023 14:45	WB4625	1.27	66.47
SF Eel	111SF6221	SPATT	1	7/3/2023 14:15	WB4652	1.87	ND
SF Eel	111SF6221	SPATT	1	7/10/2023 13:30	WB4671	1.14	15.92
SF Eel	111SF6221	SPATT	2	7/10/2023 13:30	WB4672	1.28	5.59
SF Eel	111SF6221	SPATT	1	7/17/2023 14:00	WB4701	ND	1.33
SF Eel	111SF6221	SPATT	2	7/17/2023 14:00	WB4702	ND	2.1
SF Eel	111SF6221	SPATT	1	7/24/2023 12:30	WB4725	2.9	ND
SF Eel	111SF6221	SPATT	2	7/24/2023 12:30	WB4726	1.56	ND

River	Site	Type	Replicate	Date Collected	Lab ID	ATX (ng/g)	MCY/NOD (ng/g)
SF Eel	111SF6221	SPATT	1	7/31/2023 14:00	WB4738	3.29	6.88
SF Eel	111SF6221	SPATT	1	8/7/2023 13:30	WB4768	8.87	ND
SF Eel	111SF6221	SPATT	1	8/15/2023 12:30	WB4812	32.37	ND
SF Eel	111SF6221	SPATT	1	8/22/2023 13:30	WB4897	255.77	NS
SF Eel	111SF6221	SPATT	1	8/29/2023 15:30	WB4948	326.45	2.38
SF Eel	111SF6221	SPATT	2	8/29/2023 15:30	WB4949	53.08	ND
SF Eel	111SF6221	SPATT	3	8/29/2023 15:30	WB4950	215.07	1.61
SF Eel	111SF6221	SPATT	1	9/5/2023 14:00	WB4965	9.48	ND
SF Eel	111SF6221	SPATT	1	9/12/2023 16:30	WB5009	1.29	ND
SF Eel	111SF6221	SPATT	1	9/19/2023 18:45	WB5010	1.57	ND
SF Eel	111SF6221	SPATT	1	9/27/2023 15:00	WB5048	2.82	ND
SF Eel	111SF6221	SPATT	1	10/4/2023 14:00	WB5083	1.24	1.9
SF Eel	111SF6221	SPATT	2	10/4/2023 14:00	WB5084	2	2.71
SF Eel	111SF6221	SPATT	1	10/10/2023 14:30	WB5100	2.11	1.86
SF Eel	111SF6221	SPATT	1	10/16/2023 13:00	WB5117	4.45	2.32

Appendix 2. Benthic cyanobacterial percent cover at all study sites in 2022 and 2023.

River	Site	Date	Percent Cover (%)
SF Eel	111SF6221	7/5/2022	0
SF Eel	111SF6221	7/12/2022	0
SF Eel	111SF6221	7/19/2022	0
SF Eel	111SF6221	7/26/2022	0
SF Eel	111SF6221	8/2/2022	5
SF Eel	111SF6221	8/8/2022	20
SF Eel	111SF6221	8/17/2022	20
SF Eel	111SF6221	8/23/2022	20
SF Eel	111SF6221	8/30/2022	15
SF Eel	111SF6221	9/6/2022	5
SF Eel	111SF6221	9/12/2022	5
SF Eel	111SF6221	9/20/2022	10
SF Eel	111SF6221	9/26/2022	20
SF Eel	111SF6221	10/4/2022	50
SF Eel	111SF6221	10/11/2022	65
SF Eel	111SF6221	10/17/2022	70
SF Eel	111SF6221	10/25/2022	70
SF Eel	111SF4640	7/5/2022	0
SF Eel	111SF4640	7/12/2022	0
SF Eel	111SF4640	7/18/2022	0
SF Eel	111SF4640	7/26/2022	0
SF Eel	111SF4640	8/2/2022	5
SF Eel	111SF4640	8/8/2022	10
SF Eel	111SF4640	8/17/2022	10
SF Eel	111SF4640	8/23/2022	20
SF Eel	111SF4640	8/30/2022	25
SF Eel	111SF4640	9/6/2022	30
SF Eel	111SF4640	9/12/2022	35
SF Eel	111SF4640	9/20/2022	30
SF Eel	111SF4640	9/26/2022	35
SF Eel	111SF4640	10/4/2022	40
SF Eel	111SF4640	10/11/2022	35
SF Eel	111SF4640	10/17/2022	35
SF Eel	111SF4640	10/25/2022	25
Russian	114RR6273	7/5/2022	0
Russian	114RR6273	7/12/2022	0
Russian	114RR6273	7/18/2022	0
Russian	114RR6273	7/26/2022	0
Russian	114RR6273	8/2/2022	0
Russian	114RR6273	8/8/2022	0

River	Site	Date	Percent Cover (%)
Russian	114RR6273	8/17/2022	0
Russian	114RR6273	8/23/2022	0
Russian	114RR6273	8/30/2022	0
Russian	114RR6273	9/6/2022	1
Russian	114RR6273	9/12/2022	1
Russian	114RR6273	9/20/2022	5
Russian	114RR6273	9/26/2022	5
Russian	114RR6273	10/4/2022	5
Russian	114RR6273	10/11/2022	5
Russian	114RR6273	10/17/2022	5
Russian	114RR6273	10/25/2022	5
Russian	114RR4234	7/5/2022	0
Russian	114RR4234	7/12/2022	0
Russian	114RR4234	7/18/2022	0
Russian	114RR4234	7/26/2022	0
Russian	114RR4234	8/2/2022	0
Russian	114RR4234	8/8/2022	0
Russian	114RR4234	8/17/2022	0
Russian	114RR4234	8/23/2022	0
Russian	114RR4234	8/30/2022	0
Russian	114RR4234	9/6/2022	1
Russian	114RR4234	9/12/2022	1
Russian	114RR4234	9/20/2022	1
Russian	114RR4234	9/26/2022	5
Russian	114RR4234	10/4/2022	5
Russian	114RR4234	10/11/2022	5
Russian	114RR4234	10/17/2022	5
Russian	114RR4234	10/25/2022	5
Russian	114RR2655	7/5/2022	0
Russian	114RR2655	7/13/2022	0
Russian	114RR2655	7/19/2022	0
Russian	114RR2655	7/26/2022	0
Russian	114RR2655	8/2/2022	0
Russian	114RR2655	8/8/2022	0
Russian	114RR2655	8/17/2022	0
Russian	114RR2655	8/23/2022	0
Russian	114RR2655	8/30/2022	0
Russian	114RR2655	9/6/2022	0
Russian	114RR2655	9/13/2022	0
Russian	114RR2655	9/20/2022	0
Russian	114RR2655	9/27/2022	0
Russian	114RR2655	10/4/2022	0

River	Site	Date	Percent Cover (%)
Russian	114RR2655	10/11/2022	0
Russian	114RR2655	10/18/2022	0
Russian	114RR2655	10/25/2022	0
Russian	114RR2079	7/5/2022	0
Russian	114RR2079	7/13/2022	0
Russian	114RR2079	7/19/2022	0
Russian	114RR2079	7/26/2022	0
Russian	114RR2079	8/2/2022	0
Russian	114RR2079	8/8/2022	0
Russian	114RR2079	8/17/2022	0
Russian	114RR2079	8/23/2022	0
Russian	114RR2079	8/30/2022	0
Russian	114RR2079	9/6/2022	0
Russian	114RR2079	9/13/2022	0
Russian	114RR2079	9/20/2022	0
Russian	114RR2079	9/27/2022	0
Russian	114RR2079	10/4/2022	0
Russian	114RR2079	10/11/2022	0
Russian	114RR2079	10/18/2022	0
Russian	114RR2079	10/25/2022	0
SF Eel	111SF6221	5/23/2023	0
SF Eel	111SF6221	5/30/2023	0
SF Eel	111SF6221	6/6/2023	1
SF Eel	111SF6221	6/12/2023	1
SF Eel	111SF6221	6/19/2023	1
SF Eel	111SF6221	6/27/2023	1
SF Eel	111SF6221	7/3/2023	1
SF Eel	111SF6221	7/10/2023	2.5
SF Eel	111SF6221	7/17/2023	0.5
SF Eel	111SF6221	7/24/2023	5
SF Eel	111SF6221	7/31/2023	5
SF Eel	111SF6221	8/7/2023	5
SF Eel	111SF6221	8/15/2023	15
SF Eel	111SF6221	8/22/2023	10
SF Eel	111SF6221	8/29/2023	10
SF Eel	111SF6221	9/5/2023	5
SF Eel	111SF6221	9/12/2023	10
SF Eel	111SF6221	9/19/2023	15
SF Eel	111SF6221	9/27/2023	30
SF Eel	111SF6221	10/4/2023	45
SF Eel	111SF6221	10/10/2023	50
SF Eel	111SF2122	5/23/2023	0

River	Site	Date	Percent Cover (%)
SF Eel	111SF2122	5/29/2023	0
SF Eel	111SF2122	6/5/2023	0
SF Eel	111SF2122	6/12/2023	0
SF Eel	111SF2122	6/19/2023	1
SF Eel	111SF2122	6/27/2023	1
SF Eel	111SF2122	7/3/2023	1
SF Eel	111SF2122	7/10/2023	2.5
SF Eel	111SF2122	7/17/2023	5
SF Eel	111SF2122	7/24/2023	5
SF Eel	111SF2122	7/31/2023	5
SF Eel	111SF2122	8/7/2023	5
SF Eel	111SF2122	8/15/2023	30
SF Eel	111SF2122	8/22/2023	35
SF Eel	111SF2122	8/29/2023	35
SF Eel	111SF2122	9/5/2023	35
SF Eel	111SF2122	9/12/2023	30
SF Eel	111SF2122	9/19/2023	20
SF Eel	111SF2122	9/27/2023	10
SF Eel	111SF2122	10/4/2023	15
SF Eel	111SF2122	10/10/2023	10
Russian	114RR2678	5/31/2023	0
Russian	114RR2678	6/6/2023	0
Russian	114RR2678	6/12/2023	0
Russian	114RR2678	6/19/2023	0
Russian	114RR2678	6/26/2023	0
Russian	114RR2678	7/3/2023	1
Russian	114RR2678	7/11/2023	0
Russian	114RR2678	7/17/2023	0
Russian	114RR2678	7/24/2023	0
Russian	114RR2678	7/31/2023	0
Russian	114RR2678	8/8/2023	0
Russian	114RR2678	8/14/2023	0
Russian	114RR2678	8/21/2023	0
Russian	114RR2678	8/29/2023	1
Russian	114RR2678	9/5/2023	1
Russian	114RR2678	9/12/2023	1
Russian	114RR2678	9/18/2023	1
Russian	114RR2678	9/26/2023	1
Russian	114RR2678	10/3/2023	1
Russian	114RR2678	10/10/2023	1
Navarro	113NA9055	5/23/2023	1
Navarro	113NA9055	5/30/2023	1

River	Site	Date	Percent Cover (%)
Navarro	113NA9055	6/6/2023	1
Navarro	113NA9055	6/12/2023	1
Navarro	113NA9055	6/19/2023	2.5
Navarro	113NA9055	6/26/2023	2.5
Navarro	113NA9055	7/3/2023	2.5
Navarro	113NA9055	7/10/2023	5
Navarro	113NA9055	7/17/2023	15
Navarro	113NA9055	7/24/2023	5
Navarro	113NA9055	7/31/2023	5
Navarro	113NA9055	8/7/2023	15
Navarro	113NA9055	8/14/2023	75
Navarro	113NA9055	8/21/2023	70
Navarro	113NA9055	8/29/2023	75
Russian	114RR5407	10/3/2023	0
Eel	111ER6140	10/3/2023	0