SWAMP
Surface Water Ambient Monitoring Program

THE UNIVERSITY OF CALIFORNIA 1868

UC SANTA CRUZ

Monitoring Plan	2011

Harmful Cyanobacteria Blooms and Their Toxins in Clear Lake and the Sacramento/San Joaquin Delta (California)

March 2011

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Water Boards

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Surface Water Ambient Monitoring Program (SWAMP)

MONITORING PLAN FOR THE HARMFUL CYANOBACTERIA BLOOMS AND THEIR TOXINS IN CLEAR LAKE AND THE SACRAMENTO/SAN JOAQUIN DELTA (CALIFORNIA)

10-058-150

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For the
Central Valley Regional Water Quality Control Board

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I. INTRODUCTION

Section 305(b) of the Clean Water Act requires states to assess and report on the water quality status of waters within the states. In accordance with the Clean Water Act Section 303(d), all states must identify "impaired" bodies of water that are not meeting water quality standards and must develop monitoring and control plans for each stressors. In California, the State Water Resources Control Board (SWRCB) and Regional Water Quality Control Boards (RWQCBs) are responsible for meeting Section 303(d) requirements and to report this information on a nationwide basis. The integrated data reports are usually submitted to the U.S. Environmental Protection Agency (USEPA).

Harmful cyanobacteria (HC) and their toxins are growing contaminants of concern and USEPA recently (May 29, 2008) made the decision to add microcystin toxins as an additional cause of impairment for the Klamath River, CA. However, HC are some of the less studied causes of impairment in California water bodies and their distribution, abundance and dynamics, as well as the conditions promoting their proliferation and toxin production are not well characterized. HC affect both water quality and ecosystem health within urban, agricultural, and main-stem areas (e.g. dissolved oxygen sags, taste and odor problems in drinking water, toxins) and the efficiency of water diversion and treatment operations (clogging filters in water treatment plants, fish screens or channels). Noxious toxins produced by HC, collectively referred as cyanotoxins, reduce the water quality and may impact the supply of clean water for drinking as well as the water quality which directly impacts the livelihood of other species including several endangered species. For example, the coincident appearance of *Microcystis* (producer of the liver cancer promoting toxin called microcystin) and the decline of various pelagic organisms including the delta smelt (*Hypomesus transpacificus*) striped bass and threadfin shad (*Doromosa petenense*) and their copepod preys (*Eurytemora affinis* and *Pseudiaptomus forbesii*) in the freshwater sections of the Delta suggest that the presence of *Microcystis* is one of the factors responsible for the fishery decline since 2000 (IEP-POD 2007, Lehman et al. 2008, 2010). Indeed, a better understanding of the population and dynamics of HC and their toxins in the California water bodies is crucial for mitigating future impacts of HC blooms on water quality, assessing the risks to public health and estimating seasonal fluctuation in water quality parameters. Also, such information is also needed for enhancing existing resource management and for developing new tools and decision support systems that improve management effectiveness that will ensure low risk associated with HC blooms.

The goal of the work proposed here is to monitor the distribution of *Microcystis aeruginosa* as well as other HC of concern (e.g. *Anabaena sp.* and *Lyngbya sp.* in Clear Lake) and their toxins in the surface waters of two Californian water bodies listed in the 303(d) that have been plagued by recurrent HC blooms: the Delta and Clear Lake. Our proposed research builds on previous work on HC in these water bodies.

In the Delta, the spatial and temporal dynamics of *M. aeruginosa* blooms have been identified along with their environmental covariates (Lehman et al., 2005, 2008). Toxicology analyses have shown potential direct and indirect effects on fish (Lehman et al., 2008, 2010). These largely correlative results pave the way for a mechanistic analysis of the conditions that distinguish bloom periods and locations from non-bloom periods and locations, and that result in

production of toxins. However, these findings also point to a need for a deeper and more comprehensive understanding of *Microcystis*-dominated blooms and toxin production. Concentrations of microcystin toxin and *Microcystis* cell densities are not strongly correlated in the Delta (Lehman et al. 2008, Baxa et al. 2010, Mioni et al in prep). Different strains of *Microcystis* vary in their ability to produce toxins but cannot be distinguished by microscopy (Moisander et al., 2009). Preliminary research in the Delta also indicates that toxicity may not be due solely to *Microcystis*, but may also arise through the association of *Microcystis* with an unidentified filamentous cyanobacterium (Mioni et al *in prep*). The presence of other potentially HC has been documented. For example, the toxin-producing cyanobacterium *Cylindrospermopsis raciborskii* has been observed recently in the NSFE (Mueller-Solger, *pers. com*.). This cyanobacterium was originally thought to be a tropical or subtropical alga but has been recorded as rapidly expanding in some temperate regions and is regarded as an invasive species (Briand et al., 2004, Pearl and Huisman, 2008).

Clear Lake is naturally eutrophic and scum forming cyanobacteria (blue-green algae) usually bloom from spring to fall and can produce solid mats and noxious odors. Some of these cyanobacteria are known toxin producers and have been reported in the surface lake water every year during the Department of Water Resources (DWR) monitoring from 1969 to the mid 1990's (Richerson et al. 1994): *Microcystis*, *Aphanizomenon* (anatoxin and saxitoxin producer), *Anabaena* (anatoxin, Microcystins and Saxitoxin producer), *Oscillatoria* (microcystins and anatoxin producer), *Lyngbya* (saxitoxin and lyngbyatoxin-a producer), *Chroococcus* (microcystin producer). In summer 1990, very low levels of microcystin toxins were reported (CDHS, 1991). No HC monitoring or toxicology strudies have been conducted since the mid-1990's. Our preliminary data for the couple of years indicate a shift in the HC composition. Mat-forming blooms of *Lyngbya sp*., which was not a dominant species prior to the mid-1990's, have plagued the lake in summer 2009 and 2010. Our preliminary data for summer 2010 indicate that the *Lyngbya* bloom might be toxic (lyngbyatoxin-a). Our preliminary data also indicate that microcystin toxins were also present in the surface waters of Clear Lake (a drinking water reservoir) in August 2010 and that total microcystin toxins concentration exceeded the World Health Organization advisory level for drinking water (1 µg/L) at three stations (2.3 – 3.2 µg/L).

This document describes the sampling plan of our monitoring program which will aim to identify and characterize the presence of harmful cyanobacteria and their toxins within the surface waters of Clear Lake and the San Joaquin Delta.

II. PLAN OBJECTIVES

We propose a bioassessment work plan that will combine monitoring and mapping of HC abundance and toxin concentrations as well as other environmental variables (temperature, electrical conductivity, pH, chl *a*, dissolved oxygen, nutrients, DOC, DIC) throughout the Delta and Clear Lake over a one-year period. The study period will be centered during HC bloom season (June – October). In order to describe the spatial and temporal distribution (occurrence and abundance) of HC and their toxins in the Delta we will work closely with preexisting monitoring programs such as CALFED funded monitoring program (PI: Peggy Lehman, DWR)

and the DWR Environmental Monitoring Program (http://www.baydelta.water.ca.gov/emp). This program includes regular monitoring of water quality variables (conductivity, pH, dissolved oxygen, turbidity, dissolved chloride, chlorophyll fluorescence, water temperature, air temperature, wind speed and direction, solar radiation) as well as biological characteristics, such as phytoplankton and zooplankton community composition and biomass in the Sacramento-San Joaquin Delta, Suisun Bay, and San Pablo Bay. All these ancillary data will be available to this project at no cost. In Clear Lake, we will collaborate with Lake County Department of Water Resources, Department of Health Services and Vector Control. This project will provide a better understanding of the mechanisms underlying the seeding, occurrence and toxicity levels of HC in Clear Lake and the Delta.

The plan and program objectives are to:

The plan and program objectives are to:

1) Collect surface water samples at discrete sampling stations located in critical habitats of the San Joaquin-Sacramento Delta and in collaboration with preexisting water quality and phytoplankton monitoring programs (see map 1). Sampling will be done on board the DWR/USBR research vessels during the routine monitoring cruises at the discrete stations.
2) Collect discrete surface water samples at discrete sampling stations located in each arm of Clear Lake (see map 2). Clear Lake Deparment of Water Resources will provide boat time and assistance with ancillary data measurements in the field.
3) Perform an assessment of the toxicity of the HC growing in Clear Lake and the Delta.
    a. We will detect and determine the concentrations of the toxins (microcystins, lyngbyatoxins, anatoxin-A, cylindrospermopsin, nodularin, saxitoxins) present in the discrete surface water samples. High throughput toxicology testings will be performed with commercially available ELISA kits. These kits provide quantitative analyses even at low concentrations and are highly sensitive to a given molecule. Samples tested positive for the targeted toxin or for toxin-producing strain(s) will be analyzed using LC/MS to validate the results and to identify the presence of isomers and congeners. Toxins such as saxitoxins and cylindrospermopsins will only be measured using ELISA kits (Abraxis) because they are not being measured routinely on LC/MS yet. On the other hand, lyngbyatoxin-a will only be tested using LC/MS because no ELISA kit targeting this toxin are currently commercially available. We have previously run laboratory intercalibrations with an LC/MS/MS system operated by the California Water Pollution Control Lab and our (LC/MS) results are comparable (with LC/MS/MS). The method detection limit (MDL) was determined to be <1ppb (ug/L) on column for all toxin congeners (Kudela 2011, submit).
    b. Because toxins concentrations varies greatly on a spatiotemporal scale in these environments (e.g. due to wind mixing or tidal mixing), we will also use the SPATT (Solid Phase Adsorption Toxins Tracking) methodology which is a modification of a method originally developed for marine lipophilic toxins by Dr Kudela (UCSC) for continuous toxin tracking by passively absorbing dissolved

toxins from the water column. SPATT devices will be attached at continuous monitoring stations (maps). Such devices will allow us to integrate the temporal fluctuations by concentrating the toxins over time (by opposition to discrete sampling technique) and will allow us to detect cyanotoxins at lower levels. Comparing the levels of targeted toxins between locations will provide us with important information to track the sources of toxic HC growth and toxin production as well as the impact on these toxins on living organisms. Furthermore, the SPATTs will help us determine the persistence and transport of microcystins away from these sources (i.e. stations distal from the bloom epicenter), and therefore the half-life of this toxin. SPATTs are currently being used to monitor the toxins levels in the Monterey Bay. We will extend existing SPATT methods to include cyanotoxins. Samples will be analyzed using ELISA kits and/or LC/MS as described above.

4) Perform HC taxonomy and enumeration using traditional microscopy and molecular methods.

    a. Discrete water sample will be preserved in formalin for algal cell identification and enumeration using an inverted microscope (EcoAnalysts, Inc.). The HC abundance will also be determined using epifluorescent microscopy.

    b. Because of the high degree of phenotypic plasticity exhibited in natural assemblages it is difficult to accurately and consistently identify HC species on microscopic observation alone, requiring a phylogenetic approach for identifying species and strains. At selected stations (based on microscopic analyses and toxicology results), we will characterize molecularly the types of HC that occur in the Delta and Clear Lake using 16S ribosomal RNA fingerprinting. Using this approach, different strains within the same species can be differentiated. When applicable (i.e. when the toxin gene sequence has been published), we will determine molecularly the strains' ability to produce toxins (e.g. PCR amplification of *mcy* genes in ambient *Microcystis* strains).

5) Provide a better understanding of the mechanisms underlying the source, occurrence and toxicity levels of HC in these systems,

6) Investigate possible algae-related symptoms by Lake county residents, domestic animals and wildlife (Dr Tait, Lake County Department of Health).

7) Serve as a source of information that will direct and promote actions to improve water quality and enhance other monitoring programs. A better understanding of the population and dynamics of HC and their toxins is needed to enhance existing resource management and to develop new decision support systems that improve management effectiveness to ensure low risk associated with HC blooms. We will disseminate our results broadly (publications, presentations, reports) and provide a detailed list of recommendations relevant for regulators, local governments, industries (e.g. water treatment plants) as well as environmental managers and policy makers.

III. PERSONNEL

Sample collection will be performed by the Project Director (Cécile Mioni) in collaboration with the Central Valley Regional Quality Control Board (CVRWQCB), Lake County Water Resources and DWR (Sacramento). The toxicity testings and chemical analysis will be conducted at the UCSC Institute of Marine Sciences. The microscopic identification and enumeration of algal cells will be conducted by EcoAnalyst, Inc. on samples which exhibit toxicity. The molecular identification will be conducted by Cramer Fish Sciences.

Meghan Sullivan (Central Valley Regional Water Quality Control Board) will serve as a contract manager. The contract manager will review, evaluate and approve study design and site locations, coordinate with other monitoring efforts in the study areas, and verify the completeness of all tasks.

Cécile Mioni is an assistant researcher at the University of California, Santa Cruz (UCSC). As the Project Director she will be the project administrator and will provide technical services as needed for contract completion. She will monitor, supervise and review all work performed and coordinate budgeting and scheduling to assure that the contract is completed within budget, on schedule and in accordance with approved procedures, applicable laws and regulations. The director will also manage sub-contracts to ensure delivery of work products according to contract scope, schedule and budget. She will ensure that contract requirements are met through completion of a final report and quarterly progress reports that she will submit to the Contract Manager. She will prepare and review QA reports as the QA officer and ensure the QAPP is properly followed. She will also prepare and execute a monitoring plan with the assistance of the Field officers and in accordance with State Water Boaed SWAMP format and will submit this plan to the contract manager for peer review and approval.

Raphael Kudela is a professor at the University of California Santa Cruz (UCSC. As the Project Director for the UCSC component, he will be the project administrator and will oversee project coordination, purchases, budget analysis, LC-MS data management and analysis, and report writing. The director will review QA reports as the QA officer and ensure the QAPP is properly followed. The Project Manager position includes responsibility for laboratory analyses (LC-MS) and will serve as primary supervisor for student assistants participating in the UCSC component.

Kendra Hayashi is the project manager and is primarily responsible for the preparation for and coordination of laboratory activities related to the monitoring program. Kendra is lab manager in Dr Kudela's lab (UCSC) and has about a decade of experience in harmful algae bloom and phytotoxicity research. The duties include overseeing the collection, inventory and storage of water samples, assisting in the implementation of field components of the QAPP and reviewing measurements to ensure QAPP guidelines are being met; assisting laboratory activities, sample processing, data analysis, and writing project reports. Kendra will produce QA reports for the Project Director (RK)'s review, and make requested corrective actions if data quality specified in the QAPP is not met.

Dolores Baxa is molecular biologist at UC Davis and will serve as Project co-Director on this project. She will be responsible for the molecular sample processing as well as their analysis. Dr Baxa is a specialist in harmful cyanobacteria molecular identification and characterization.

Scott Waller (California Department of Water Resources) and **Tom Smythe** (Lake County) will provide access to sampling stations as well as to ancillary data. They will facilitate field collection and will provide oversight to ensure local and state regulations are met.

Student assistants under the supervision of project manager and director, student research assistants will assist with laboratory and field procedures. Responsibilities include routine analysis of water samples, washing and preparing sample bottles for fieldwork, helping to maintain the laboratory, and data entry.

Other collaborators: Peggy Lehman (DWR, Sacramento), Karen Gherts (DWR, Sacramento), Scott Waller (DWR, Sacramento), Tom Smythe (Lake County, Department of water resources), Karen Tait (Lake County, Health officer, Department of Health Services), Jamesina Scott, Lake County Vector Control, District manager/research director).

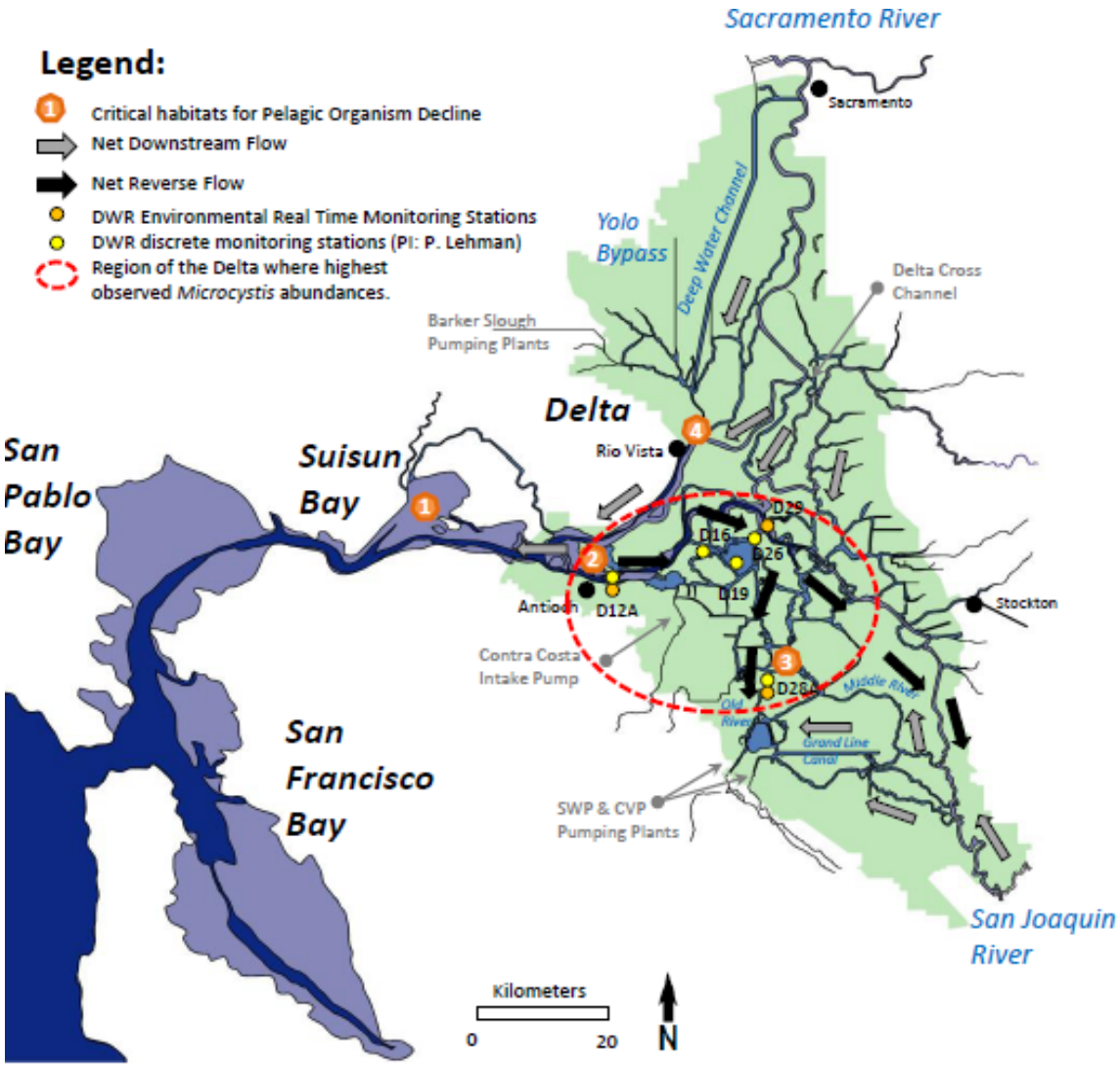
IV. SAMPLING LOCATION

Suggested sampling sites (table 1, Figures 1 A & B) and sampling frequency are based on historical data, our preliminary data and accessibility. The suggested sampling sites include the following locations but may be modified based on HC distribution. Indeed, because of temporal variations in the onset of HC abundance, we will use an adaptive monitoring strategy. For example, extra stations may be added if none of these stations coincide with the epicenter of a HC bloom in order to capture the full bloom progression and associated environmental drivers on a spatiotemporal scale. On the other hand, during the peak of the bloom season, high abundance of mat-forming HC might prevent the boat from accessing near-shore station(s) (especially in Clear Lake). In this case, due to safety concerns we might have to skip the station and attempt to collect near-shore samples from land (e.g. from a pier, provided permit or authorization).

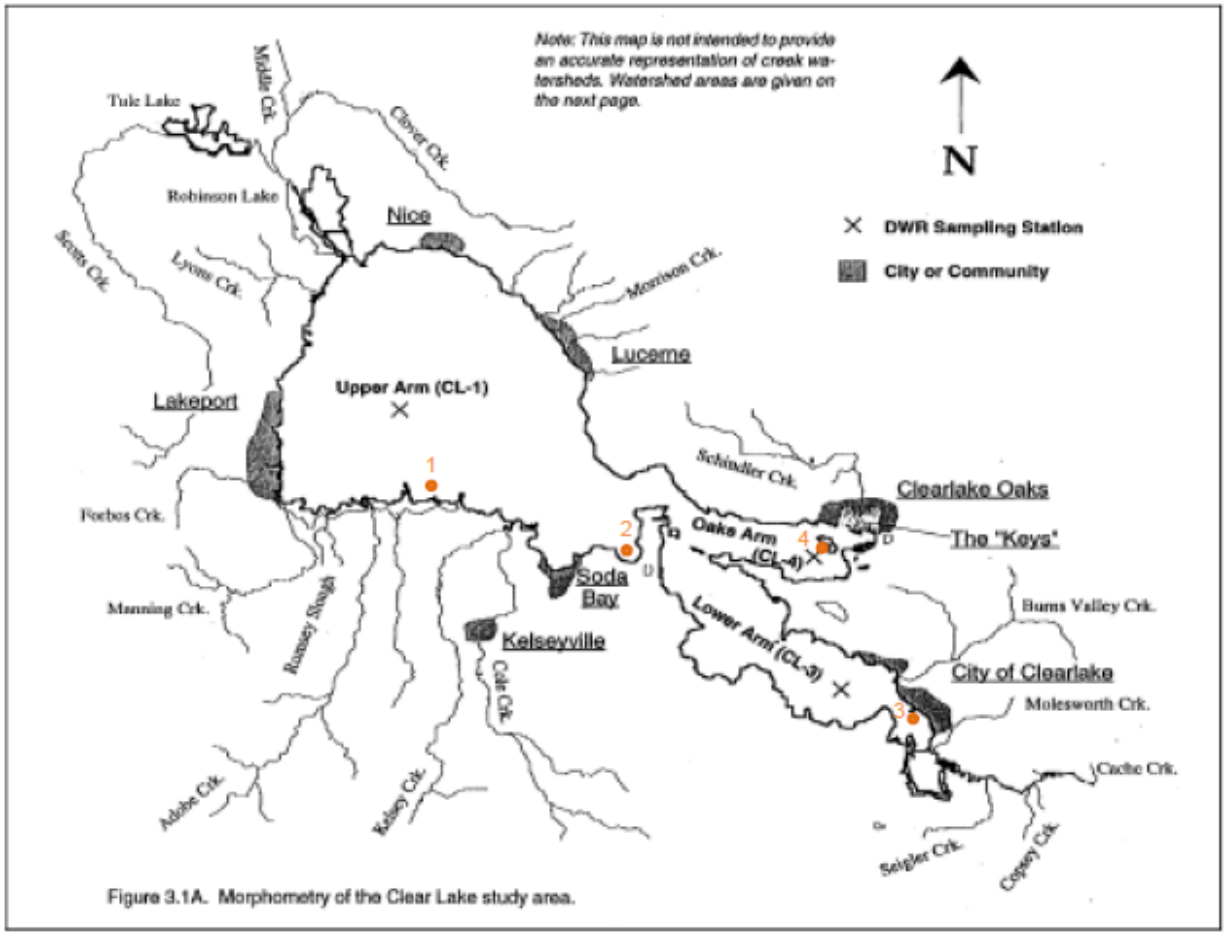
Table 1: Station codes, Site names, types of station and locations

Station Codes	Station Name	Study Area	Type of Station
1	Lakeport	Clear Lake, CA	Discrete
CL-1	Upper Arm	Clear Lake, CA	Discrete
2	Horseshoe Bend	Clear Lake, CA	Discrete & Continuous
3	Clearlake (City)	Clear Lake, CA	Discrete & Continuous
CL-3	Lower Arm	Clear Lake, CA	Discrete
4	The Keys	Clear Lake, CA	Discrete & Continuous
CL-4	Oaks Arm	Clear Lake, CA	Discrete
D24A	Rio Vista (SAC)	Delta, CA	Continuous
D12	Antioch Ship Channel (SJR)	Delta, CA	Discrete
D12A	Antioch (SJR)	Delta, CA	Continuous
D19	Frank's Tract (SJR - flooded island)	Delta, CA	Discrete
D28A	Old River at Rancho del Rio	Delta, CA	Discrete & Continuous
D16	Twitchell Island (SJR)	Delta, CA	Discrete
D26	Potato Point (SJR)	Delta, CA	Discrete
D29	Prisoners Point (SJR)	Delta, CA	Continuous

SJR = San Joaquin River
SAC = Sacramento River



Map 1 – Delta sampling locations - Map of the San Francisco estuary showing codes for sampling stations throughout the freshwater to brackish water reaches of the Delta. Samples will be collected at discrete and continuous (real-time) DWR-EMP monitoring stations including the freshwater habitats in Sacramento river at Rio Vista (D24A); Freshwater habitats in San Joaquin River at Antioch (D12 & D12A), Twitchell Island (D16), Frank's tract (D19), Potato Point (D26), Old River (D28A), and Prisoner's point (D29). Stations were selected that reflect different critical habitats within the delta: 1. Suisun Bay – habitat of Delta Smelt, Longfin smelt, Striped Bass, threadfin shad and Splittail; 2. Confluence of Sacramento and San Joaquin rivers near Sherman island where the highest abundance of Delta smelt has been observed; 3. San Joaquin Delta – seasonal habitat of Delta and habitat of Threadfin shad; 4. Sacramento river/Yolo bypass – habitat of Splittail. *Microcystis* blooms in the core summer habitat of the Threadfin shad and the Striped bass and might have shifted the distribution of the Delta smelt to higher salinity during late summer 2007.



Map 2 – Clear Lake sampling locations. CL-1, CL-2 and CL-3 stations are DWR monitoring stations. They were also used for a toxicology study performed in 1990.We will use these stations as discrete monitoring stations. The stations 1, 2, 3, 4 are located at coastal buoys (county owned) and will be our continuous stations for toxins and temperature (SPATTs). We will also do discrete samples monthly at these stations.

V. SAMPLE AND DATA COLLECTION

Sampling frequency will be based on pre-determined collection and bloom events, which will be coordinated through CVRWQCB and UCSC. Sample collection will follow the protocols outlined in "SWAMP Bioassessment procedure 2009 - Standard Operating Procedures for Collecting Stream Algae Samples and Associated Physical Habitat and Chemical Data for Ambient Bioassessments in California" (June 2009) and in SWAMP Quality Assurance Program Plan (September 1, 2008).

Prior to the beginning of sample collection at each site, GPS coordinates will be checked for accuracy. After collection, sample containers will be placed in ice chests with wet ice or dry ice (toxins, nutrients, Chl *a*, molecular samples). Proper precautions will be taken at all times in order to avoid transferring invasive organisms and pathogens between sites. Samples containers will be labeled with site identification code, collection and date time, and sampler's ID. After collection, samples will be delivered to the lab as soon as possible (e.g. same day) to meet all designated holding time requirements. The receipt of all samples will be logged in the sample logbook.

At each discrete stations, we will collect sub-surface grab samples for toxicity and algal identification and biomass assessment (chl *a*, enumeration, molecular analysis) along with GPS coordinates, notable field conditions (weather conditions, evidence of recent rainfall and fires, human influence and other habitat characteristics such as microalgae thickness, presence/absence of cyanobacterial mat), water chemistry measurements (temperature, specific conductance, pH, dissolved oxygen, nutrients, DOC). Additionally, photo documentation of the sampling site will be collected when relevant and archived. The sampling team will record all relevant information in the field log book and the chain of custody.

Hand-held quality water meter (YSI) and analytical instrument will be calibrated prior to sample analysis in accordance to the manufacturer's guidelines and to the SWAMP Quality Assurance Program Plan. For the determination of toxins, 50-mL subsamples will be collected in 60-mL glass jars (certified clean by Environmental Sampling Supply, Inc.), transported on dry ice, and stored frozen (- 20°C) until analysis. Algal samples will be collected in sterile 50-mL polypropylene tubes and fixed with buffered formalin (final concentration 2%) immediately after collection. Algal samples will be transported in the dark and kept away from heat (e.g. in wet ice chests, cold room) and analyzed by EcoAnalysts, Inc. lab. For Chl *a*, 50-mL of sample water will be filtered onto Whatman glass fiber filters (GF/F) in the dark and transported on dry ice. Samples will be kept frozen (-20°C) in the dark until analysis. Chl *a* will detected using a Turner fluorometer. For molecular samples, 50-100 mL of water samples will be filtered onto a sterile 0.2-µm supor membrane filter and shipped on dry ice to Cramer Fish Sciences lab. Samples will be kept frozen (- 20/-80°C) until analysis. For dissolved inorganic nutrients, 50 mL water will be filtered through sterile 0.45 µm filters directly into sterile 60-mL polypropylene centrifuge flasks and the filtrate will be transported on dry ice and will be kept frozen (-20°C) until analysis. Ammonium, NOx, and PO4 will be detected using a Flow Injection Autoanalyzer (Lachat Instrument) using EPA methods 350.1, 353.2, and 365.1, respectively. A certified QA/QC standard (e.g. SCP Science) will be included for all nutrient analytical runs. Samples for DOC analysis will be filtered through a sterile 0.2-µm filter and collected into acid washed and combusted 40 mL borosilicate glass scintillation vials with teflon lined screw caps. Samples will be acidified with HCl and purged to remove inorganic (and purgeable organic) carbon, kept cool

(4°C) in the dark until analysis. Samples will be analyzed using a Shimadzu TOC analyzer (EPA method 415.1, American Public Health Association Method 5310 B).

SWAMP requires that some sample analysis be initiated within 48 hours of sample collection (e.g. nutrients, toxicity tests). UCSC will make every effort to initiate tests within 48 hours of sample collection; however, due to the intense sampling schedule of this project, a 48-h holding time may not be feasible (e.g. weekends and holidays). If UCSC is unable to initiate sample analysis within 48-hrs, the CVRWQCB will be consulted.

VI. QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance will be included in this project to ascertain the reliability of data gathered, including whether UCSC data can be duplicated. Precision will be determined through field duplicate samples according to the SWAMP Quality Assurance Program Plan. Contamination will be evaluated though field blanks and analytical blanks. UCSC will test ca. 10% of samples for ensuring QA/QC requirements. The UCSC analytical crew is trained to conduct wide variety of activities using standards protocols (manufacturer's SOPs, USEPA methods) to ensure samples are analyzed in a consistent manner.

VII. DATA REPORT

The PI will provide brief quarterly reports to the CVRWQCB PD which will include a summary of completed activities and data results in tabular form summarizing toxicity tests, biological, physical, and chemical analyses of project samples completed during the previous quarter. The SWAMP field sheets will also be provided during the life of the project.

At the end of the project, a final report will be prepared to include a description of methods, all raw data in tabular form, results of all work to ensure QA/QC, and a discussion of the results including conclusions of the basic monitoring and other special studies. The discussion of the results of this study shall include, where possible, the frequency and level of toxicity in the sampled waters, and identification of the toxin or associated with observed HC bloom, the probable source(s) of the toxin(s), a review of pertinent literature, and a comparison of study results with similar studies performed in California and other parts of the United States. The report will also include recommendations for future studies. A preliminary draft of the data report should be submitted to the CVRWQCB by January 31, 2012. Comments on the draft data report should be submitted by February 1, 2012. The data report will be finalized by March 30, 2012.

VIII. TIMETABLE

Schedule of tasks undertaken and reporting requirements, as well as the anticipated time line for the performance of each task are listed in Table 2.

Table 2. Timetable.

TASK	PRODUCT	DATE
1	Project Administration	
	1.1 Program Coordination	Ongoing
	1.2 Draft Final Report	January 31, 2012
	1.2 Final Report	March 30, 2012
	1.2 Monthly Reports	July 29, 2011, and monthly thereafter (during bloom season: June – October 2011)
2	Quality Assurance Project Plan	
	2.1 Draft QAPP	March 1, 2011
	2.2 Final QAPP	March 31, 2011
	2.3 Review and Revise	Ongoing
3	Monitoring Plan	
	3.1 Draft Monitoring Plan	March 1, 2011
	3.2 Final Monitoring Plan	March 31, 2011
	3.3 Review and Revise	Ongoing
4	Sample Collection	June 2011 – October 2011
	4.1 SWAMP Field Sheets	October 31, 2011
5	Sample Analysis	Completed by November 21, 2011
	5.5 Analytical Results	December 16, 2011

IX. REFERENCES

Baxa D.V., Kurobe T., Ger K.A., Lehman P.W., and S.J. The. 2010. Estimating the abundance of toxic *Microcystis* in the San Francisco Estuary using quantitative real-time PCR. *Harmful Algae*, 9: 342-349.

Briand, J.-F., Leboulanger, C., Humbert, J.-F., Bernard, C., and Dufour, P. 2004. *Cylindrospermopsis Raciborskii* (cyanobacteria) invasion at mid-latitudes: selection, wide physiological tolerance, or global warming? *J. Phycol*. 40, 231–238.

California Department of Health Services, Office of Drinking Water. 1991. Draft report – Toxicity of Blue Green Algae in Clear Lake, California, April 5 1991.

IEP_POD synthesis report. 2007. http://www.science.calwater.ca.gov/pdf/workshops/POD/IEP_POD_2007_synthesis_report_031408.pdf

Lehman, P. W., Boyer, G., Hall, C., Waller, S., Gehrts, K. 2005. Distribution and toxicity of a new colonial Microcystis aeruginosa bloom in the San Francisco Bay Estuary, California. *Hydrobiologia* 541, 87–99.

Lehman, P. W. , Boyer, G. , Satchwell M. , Waller, S. 2008. The influence of environmental conditions on the seasonal variation of Microcystis cell density and microcystins concentration in San Francisco Estuary. *Hydrobiologia* 600, 187–204.

Lehman PW, Teh SJ, Boyer GL, Nobriga ML, Bass E, Hogle C. 2010. Initial impacts of Microcystis aeruginosa blooms on the aquatic food web in the San Francisco Estuary. *Hydrobiologia* 637:229-248.

Moisander, P.H., Lehman, P.W., Ochiai, M., Corum, S. 2009. Diversity of *Microcystis aeruginosa* in the Klamath River and San Francisco Bay delta, California, USA Aquatic *Microbial Ecology*, 57: 19-31.

Paerl, H.W. and J. Huisman (2008). Blooms like it hot. *Science*, 320: 57-58.

Richerson, P.J., Suchanek, T.H., Woodmansee, C-E. and T. Smythe. 1994. The causes and control of algal blooms in Clear Lake. Clean lakes diagnostic/feasibility study for Clear Lake, California.