Climate Change Effects on Cyanobacteria Blooms in the San Francisco Estuary Delta

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Climate change and the associated increase in temperature are predicted to promote cyanobacteria blooms globally. This is evident in some fresh water systems such as China's Lake Taihu, Lake Victoria in East Africa and the Great Lakes of North America and may also be occurring in the San Francisco Delta (Delta). Blooms of toxic cyanobacteria (cyanoHABs) in the Delta have been increasing since 1999 and affect water quality, the estuarine food web and potentially human health. Of the cyanobacteria occurring in the Delta, the cyanoHAB *Microcystis aeruginosa* tends to dominate the community during the summer. With the goal of understanding how the effects of climate change, especially temperature, influence cyanobacterial growth and microbial biogeochemistry, a series of 20-L enclosure experiments were conducted using water collected at sites within the Delta where cyanobacteria have been observed. Enclosures were maintained at different temperatures and monitored over 3-5 days for chlorophyll-a, dissolved inorganic carbon (DIC) and nutrients, as well as phytoplankton community composition. Chlorophyll-a increased in all enclosures, but accumulated more quickly at higher temperatures. DIC drawdown, indicating primary production, was greater in enclosures held at higher temperature. Cyanobacteria responded well to the higher temperatures, compared to other Delta phytoplankton. These data linking the growth of cyanobacteria to elevated water temperature offers insight into changes that may occur in the San Francisco Estuary under climate change scenarios. As observed in China, higher water temperatures will likely result in proliferation of cyanobacteria and possibly cyanoHABs in the Delta.

Keywords: phytoplankton Microcystis climate change temperature cyanobacteria cyanoHAB

Poster Cluster Title: Understanding Cyanobacterial Blooms in the San Francisco Estuary Delta: Current Trends, Causes and Implications for Ecosystem Function 1

Nitrogen Uptake Kinetics of *Microcystis aeruginosa* in the San Francisco Estuary Delta

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Blooms of the cyanobacterium *Microcystis* are now a regular feature of the ecology of the San Francisco Estuary Delta from mid-summer through the fall. *Microcystis* blooms can be detrimental to water quality and may negatively affect the health of aquatic organisms because some strains of *Microcystis* produce toxins called microcystins. Despite these problems, relatively little is known about the nutrient uptake ability of *Microcystis,* and why this cyanobacterium can outcompete other phytoplankton taxa. Nitrogen uptake kinetics can be used to evaluate the affinity for uptake of ambient nutrients and kinetic parameters can then be compared with those for other phytoplankton. Uptake of three nitrogenous nutrients (nitrate, ammonium or urea) by *Microcystis aeruginosa* was measured using nutrient depletion and uptake of ^{15}N-labeled substrates, in both lab cultures and field-collected water samples from the Delta dominated by *Microcystis*. The maximum uptake rates and affinity for these substrates by *M. aeruginosa* will be compared with published values for other phytoplankton taxa, to establish whether the nitrogenous nutrition capability of this cyanobacterium offers a competitive advantage over other algae during conditions of nitrogen-limited growth. Nutrient management, along with other strategies, may be considered as part of a comprehensive plan to control future *Microcystis* blooms.

Keywords: *Microcystis, Microcystis aeruginosa*, nutrient uptake kinetics, nitrogen uptake kinetics

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Reproductive Success of the Calanoid Copepod *Pseudodiaptomus forbesi* in the Presence of Sublethal Levels of *Microcystis aeruginosa*

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Microcystis aeruginosa blooms have become increasingly frequent in the San Francisco Estuary in the last decade, coincident with a decrease in pelagic organisms. A possible association between these two observations is that copepods, an important food source for many affected pelagic organisms, have impaired survival in *M. aeruginosa* blooms. The toxicity and nutritional inadequacy of the cyanobacteria make it a poor food source to copepods. Even when blooms are not large enough to be lethal, egg production rate and egg hatching success are still negatively affected. This study focuses specifically on the calanoid copepod *Pseudodiaptomus forbesi* and its reproductive success in the presence of low levels of *M. aeruginosa*. The first part of this study compares the egg hatching success of gravid females caught at bloom and non-bloom *M. aeruginosa* sites from the Low Salinity Zone to freshwater locations on the Sacramento and San Joaquin Rivers. In 2011 no *M. aeruginosa* blooms were found, and preliminary results show no significant differences in egg hatching success between sites. The second part of this study will compare toxicity effects on both egg production and egg hatching success of cultured *P. forbesi* exposed to different sublethal levels (2, 4, 6, or 8% of dietary carbon) of either microcystin-producing or non-producing *M. aeruginosa*. If such low toxicity levels are found to have a significant negative effect on reproductive success, then this implies even small blooms of *M. aeruginosa* could impact copepod populations in the San Francisco Estuary. Also, because copepods compose much of their diet, larval and juvenile fish in the Estuary would also suffer from small blooms indirectly.

Keywords: *Microcystis aeruginosa*, copepods, egg hatching success

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Isotope Identification of Particulate Organic Matter and Nutrient Sources During Microcystis Blooms in San Francisco Estuary

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The factors that have sustained *Microcystis* blooms in San Francisco Estuary since they appeared in1999 are not understood. It was hypothesized that most of the *Microcystis* colonies and inorganic or organic nutrients that support the bloom originated in the San Joaquin River where the bloom biomass is elevated and that *Microcystis* has an impact on the quantity and quality of dissolved organic carbon production in the estuary. In order to test these hypotheses, stable isotopes were measured biweekly on particulate and dissolved organic and inorganic matter in the water column during *Microcystis* blooms in the summers of 2007 and 2008. At each station, *Microcystis* abundance, dissolved organic carbon, carbon to nitrogen ratio and chlorophyll *a* and toxic total microcystins concentration were measured along with the stable isotopic composition of the particulate and dissolved organic matter fractions, POM-$\delta^{13}C$, POM-$\delta^{15}N$ and DOC-$\delta^{13}C$. The stable isotopes of dissolved inorganic nitrate, NO3-$\delta^{15}N$ and NO3-$\delta^{18}O$, and water, H_2O-$\delta^{18}O$ and H_2O-$\delta^{2}H$, were also measured. The isotope data were supplemented by a suite of physical and chemical water quality measurements including water temperature, specific conductance, pH, dissolved oxygen, total suspended solids and concentrations of the nutrients nitrate, ammonium and soluble reactive phosphorous. Hydrodynamic modeling was used to characterize the percentage of streamflow from riverine sources. *Microcystis* entered the estuary from the San Joaquin and Old Rivers and was associated with a shift in the quality of the dissolved organic carbon. Dual isotopes for nitrate and water demonstrated that nutrients and POM isotopic signals differed for the Sacramento and San Joaquin Rivers and varied along the salinity gradient. The San Joaquin River was the primary source of nitrate while the Sacramento River was the primary source of ammonium to the delta. The ammonium from the Sacramento River was also the primary source of nitrogen for growth of *Microcystis*.

Keywords: Microcystis, cyanobacteria, isotopes, water quality, streamflow

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Trends of Microcystis Abundance and Toxicity in San Francisco Estuary, 2004 to 2008

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Data collected from research studies conducted in 2004, 2005, 2007 and 2008 were used to assess if *Microcystis* abundance and toxin concentration increased over time, what factors controlled bloom initiation and persistence and if there was a long term impact of the bloom on mesozooplankton abundance or toxin content and dissolved organic carbon concentration. *Microcystis* abundance and total microcystins concentration increased over time due to the greater abundance in the dry years 2007 and 2008 than the wet years 2004 and 2005. A bloom occurred in the upstream portions of the delta in the San Joaquin River for all water year types and spread into the western delta during dry years. Total microcystins toxin concentration in *Microcystis* and mesozooplankton tissue increased with bloom abundance. The associations between *Microcystis* abundance and environmental conditions were nonlinear. Bloom initiation required water temperature above 19^{o}C and photosynthetically active irradiance in the photic zone above 500 µM photons m^{-2} s^{-1}. Persistence of the bloom was associated with a range of conditions, pH greater than 7.5, DIN:DIP ratios between 6 and 13, ammonium, nitrate, soluble reactive phosphorus and chloride concentration of 0.01-0.08 mg l^{-l}, 0.1-0.4 mg l^{-l} , 0.03-0.09 mg l^{-1} and < 700 mg l^{-1} with streamflows in the Sacramento River at Rio Vista near 250 m^3 s^{-1} and reverse streamflows in the San Joaquin River at Jersey Point near 100 m^3 s^{-1}. At individual stations, *Microcystis* abundance was closely correlated with turbidity and streamflow. In addition, the importance of elevated water temperature in initiating the bloom and low streamflow in maintaining the bloom indicated that the projected increased frequency and severity of warm temperature and drought in California due to climate change will increase the frequency and severity of *Microcystis* blooms in SFE.

Keywords: *Microcystis*, cyanobacteria, hydrology, nutrients, water quality

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