Remote Sensing of Chlorophyll-a as a Measure of Cyanotoxins in San Luis Reservoir

UNIVERSITY OF CALIFORNIA MERCED

Brittany Lopez Barreto[1], Erin L. Hestir,[1] Christine M. Lee[2], Marc Beutel[1]

[1] School of Engineering, University of California, Merced, CA, USA

[2] NASA Jet Propulsion Laboratory, California Institute of Technology Pasadena, CA, USA

INTRODUCTION

Cyanobacterial harmful algal blooms (cyanoHABs) can harm people, fauna, and affect water quality of inland waters. Cyanobacteria data is limited, while chlorophyll-a (chl-a) is a common water quality metric and has been shown to have a relationship with cyanobacteria. The World Health Organization (WHO) has recently updated their 1999 cyanoHAB recreational waters guidance values (GVs) to be more practical by basing the GVs on chl-a concentration. This creates an opportunity for widespread monitoring of cyanoHABs based on chl-a proxy measures, with satellite remote sensing (SRS) being a potentially powerful tool. This study assessed the comparability of SRS of chl-a for cyanotoxin public health advisories.

STUDY AREA

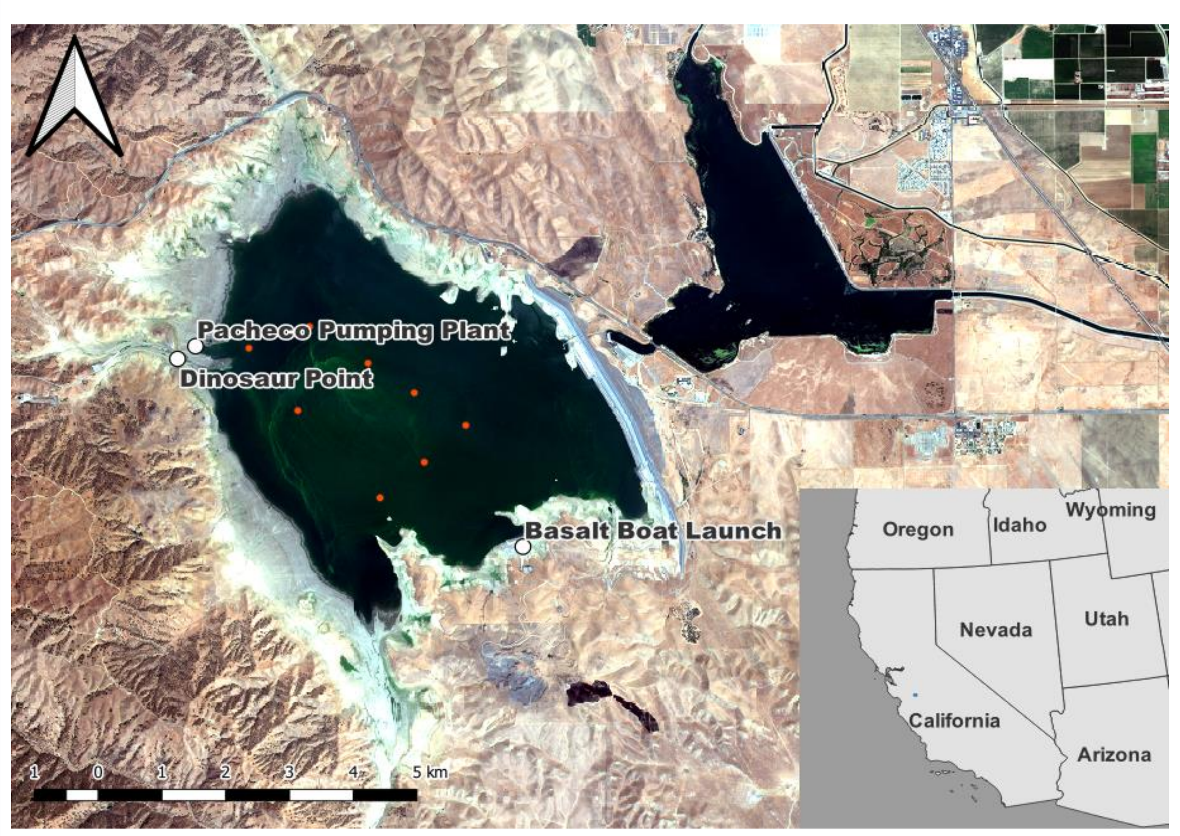


Fig 1. Overview of San Luis Reservoir, Los Banos, CA. The white points on the lake are sampling points from the Department of water Resources (DWR) while the red are from our field campaign.

San Luis Reservoir (SLR) is the largest off-stream reservoir in the U.S and a key piece of infrastructure in California's water system. SLR stores water diverted from the Sacramento-San Joaquin River Delta and is popular for recreational activities for locals.

OBJECTIVES

1. Quantify the reliability of SRS chl-a for public health advisories for potential cyanotoxin exposure.
2. Evaluate the utility of using chl-a as a public health warning system for potential cyanotoxins exposure in a major water body.

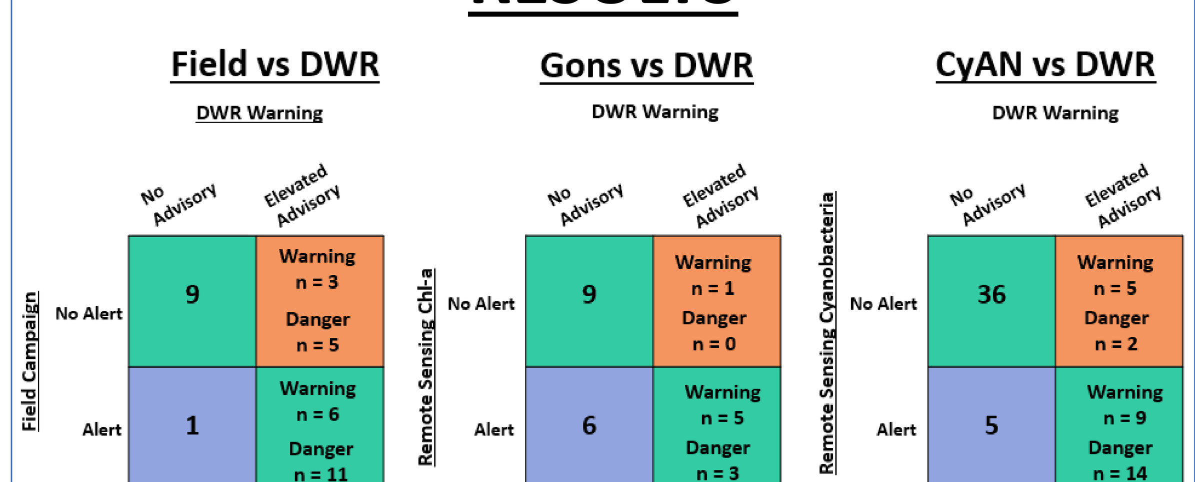
METHODS

Chl-a field samples were collected (**Fig 1**) during Sentinel-2 (S2) satellite overpass. Field campaign samples, SRS derived S2 chl-a and cyanobacteria from the Cyanobacteria Assessment Network (CyAN) using Sentinel-3 (S3) were then classified based on the WHO GVs and then compared to the California Department of Water Resources (DWR) (**Fig 2**) field collected cyanotoxin data and their advisories (**Table 1**).

Authority	Quantity	Guideline Value Classification	Method
CA DWR	0.8 - 5.99 μg/L Microcystins	Caution	Field Sampling
	6 - 19.99 μg/L Microcystins	Warning	
	20 μg/L ≤ Microcystins	Danger	
WHO (2021)	Chl-a ≤ 12 μg/L	No Alert	Sentinel-2
	Chl-a ≥ 24 μg/L	Alert	
WHO (1999)	≤ 20,000 cyanobacterial cells/ml or ≤ 10 chl-a μg/L	Low	Sentinel-3
	20,000-100,000 cyanobacterial cells/ml or 10.1 - 50 chl-a μg/L	Moderate	
	≥ 100,000 cyanobacterial cells/ml or ≥ 50 chl-a μg/L	High	

Table 1. The GVs by the WHO for recreational waters and cyanotoxin recreational health advisory levels set by the DWR.

RESULTS



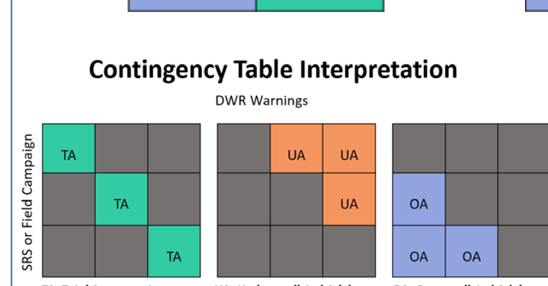


Fig 2. Contingency tables comparing the field campaign samples, SRS S2 Gons et al. (2002) algorithm, and S3 CyAN to the advisory level determined by the DWR. Elevated advisories are the sum of warning and danger.

RESULTS CONTINUED

Source	Product	Warning Agreement	Danger Agreement
Field Campaign	Lab	66.7%	68.8%
Sentinel-2	Gons	83.3%	100%
Sentinel-3	CyAN	35.7%	87.5%
Machine Learning	Random Forest	100%	100%

Table 2. The SRS chl-a algorithms and how well they were able to distinguish within the elevated advisory alerts.

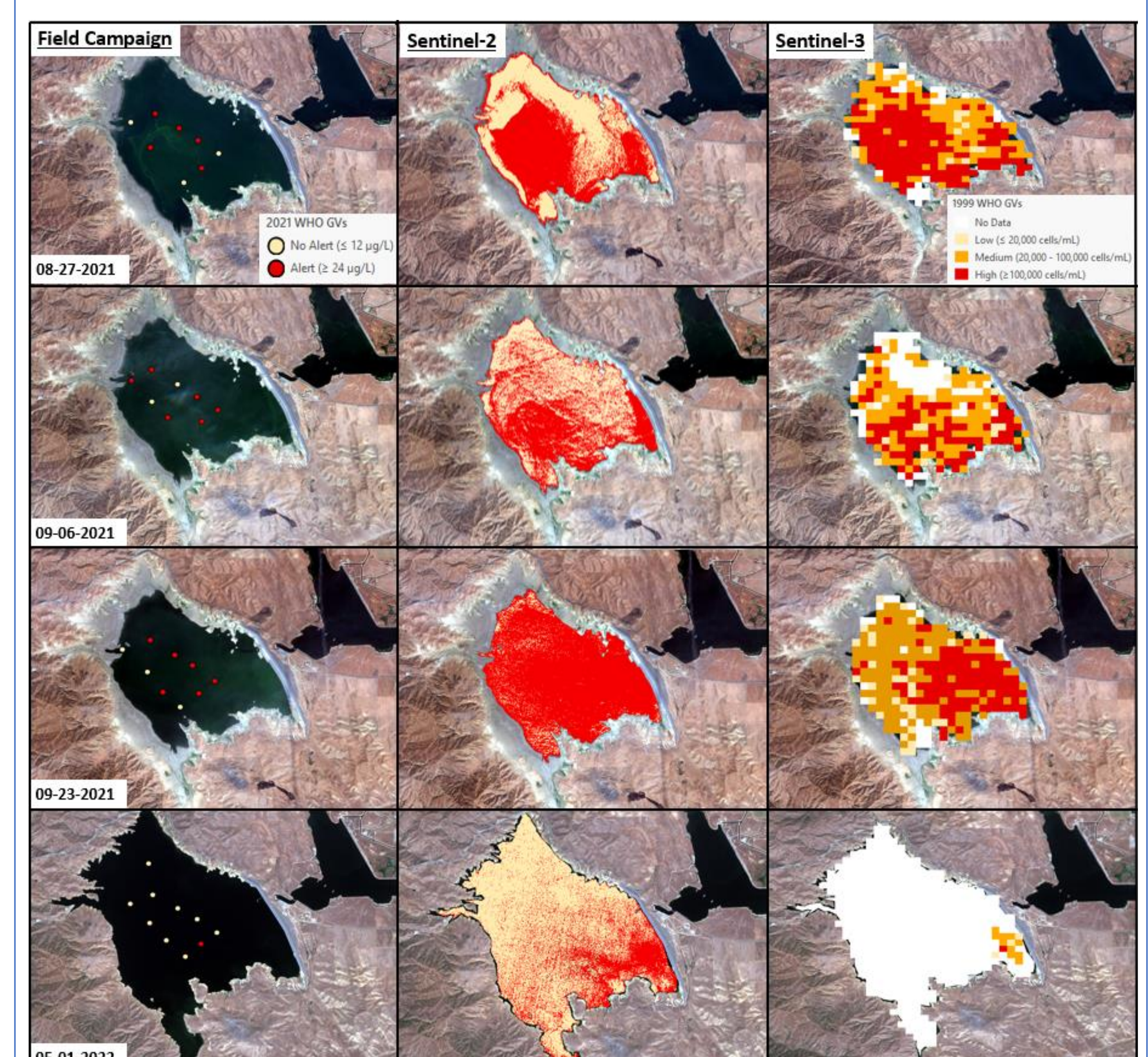


Fig 3. Field campaign points are labeled and color coded based on the 2021 WHO GV (Table 1). The S2 maps are the Gons algorithm map with shading based on the 2021 WHO GVs. The right image is of the S3 product for the same date with the 1999 WHO GVs.

DISCUSSION

SRS can measure areas where DWR does not and during dates they do not measure (**Fig 1 &3**). We see an inverse of UA and OA for the field campaign and Gons. OAs would keep safety as a priority since we are not missing a bloom, however, imposing multiple closures when there is no actual HAB would create revenue loss and inconvenience locals and visitors. In **Fig 4** we see the agreement in seasonality of blooms in all graphs, where we see all spiking during the same time of the year. When chl-a is > 24 μg/L in the SRS data, there is no cyanotoxins collected yet from the DWR, making SRS to be a potential important monitoring utility for public health advisories.

DISCUSSION CONTINUED

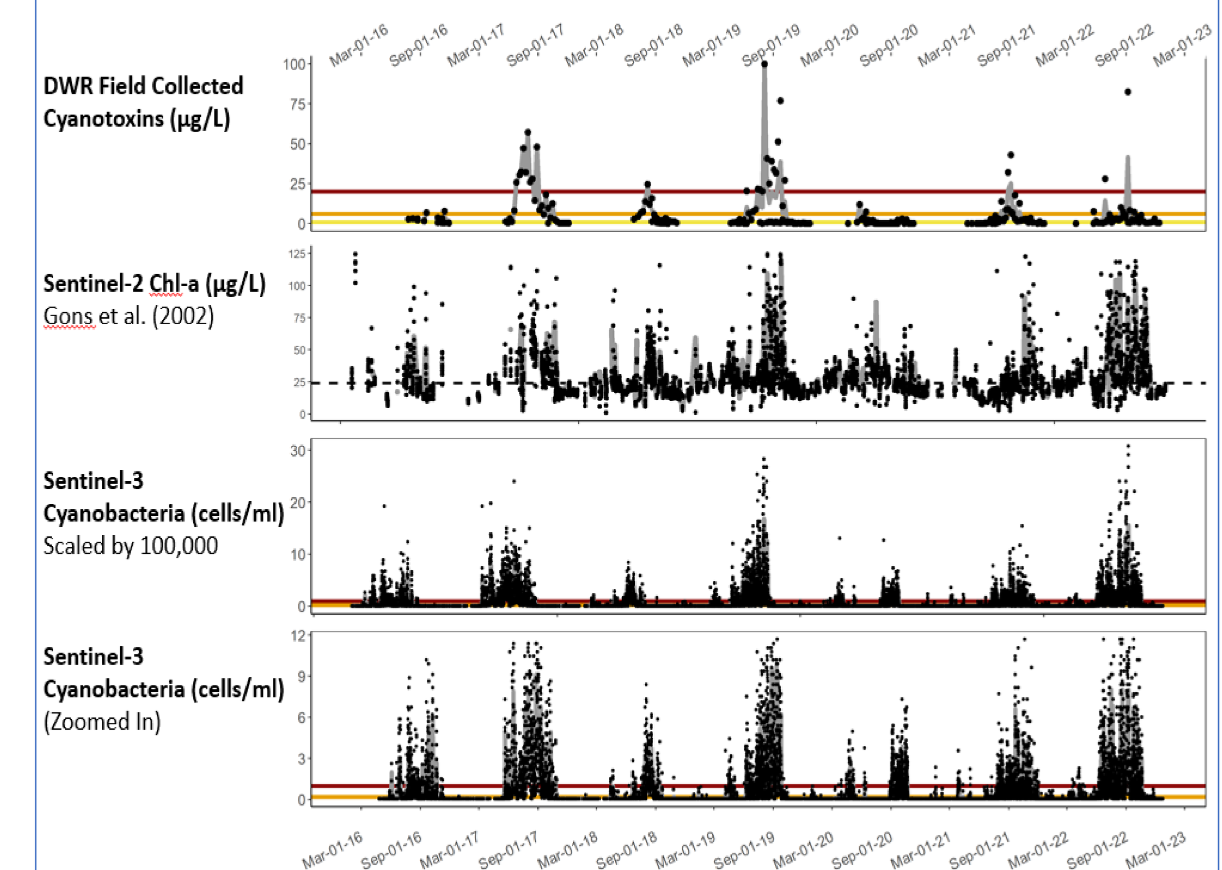


Fig 4. A: S2 Chl-a using the Gons et al. (2002). B: Microcystis from the DWR with the DWR alert levels indicated on the horizontal. C: Cyanobacteria abundance from S3 with the 1999 WHO GVs on the horizontal scaled by 100,000. D: Cyanobacteria abundance (S3) for levels <1,000,000 cells/ml.

CONCLUSIONS

Using SRS-based chl-a as an early indicator for possible exposure advisories and as a trigger for in-situ sampling may be effective to improve public health warnings. SRS can help fill temporal and spatial data gaps which are not available from using only in-situ data (**Fig 4**). This study serves as a framework for evaluating the use of SRS for public health alerts and can be tested elsewhere in cyanobacteria dominated lakes.

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Contact: Brittany Lopez Barreto
blopezbarreto@ucmerced.edu

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