EPA Tools and Resources Webinar: Detection and Forecasting of Harmful Algal Blooms (HABs)

Jingrang Lu and Blake Schaeffer
US EPA Office of Research and Development

Donald Benkendorf
US EPA Office of Water

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Part 1: How Satellites Help Detect and Forecast Cyanobacterial HABs

Blake Schaeffer and Donald Benkendorf

Outline

- Motivation
- CyAN background
- Forecast model
- Public forecast dashboards
- What is next?
- Summary

Motivation

- 2017 Harmful Algal Bloom… Act
  - Advancing the ability to monitor and forecast

Harmful Algal Bloom and Hypoxia Research and Control Amendments Act of 2017. 33 USC 4001 note

1) Participation

The Administrator’s participation under this section shall include–

(A) Research on the ecology and impacts of freshwater harmful algal blooms; and

(B) Forecasting and monitoring and event response to freshwater harmful algal blooms in lakes, rivers, estuaries (including their tributaries), and reservoirs.

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Motivation

- Knowledge of the timing and location of cyanoHAB events

- No quantitative tool exists to forecast cyanoHABs

Motivation

- > 12 μg L^{-1} chlorophyll-a
- CI_{cyano} algorithm
- Bayesian spatiotemporal model
  - One-week in advance
  - Surface water temperature, precipitation, mean lake depth, and lake surface area

Source: Schaeffer et al. 2023. Journal of Environmental Management. 349:119518.

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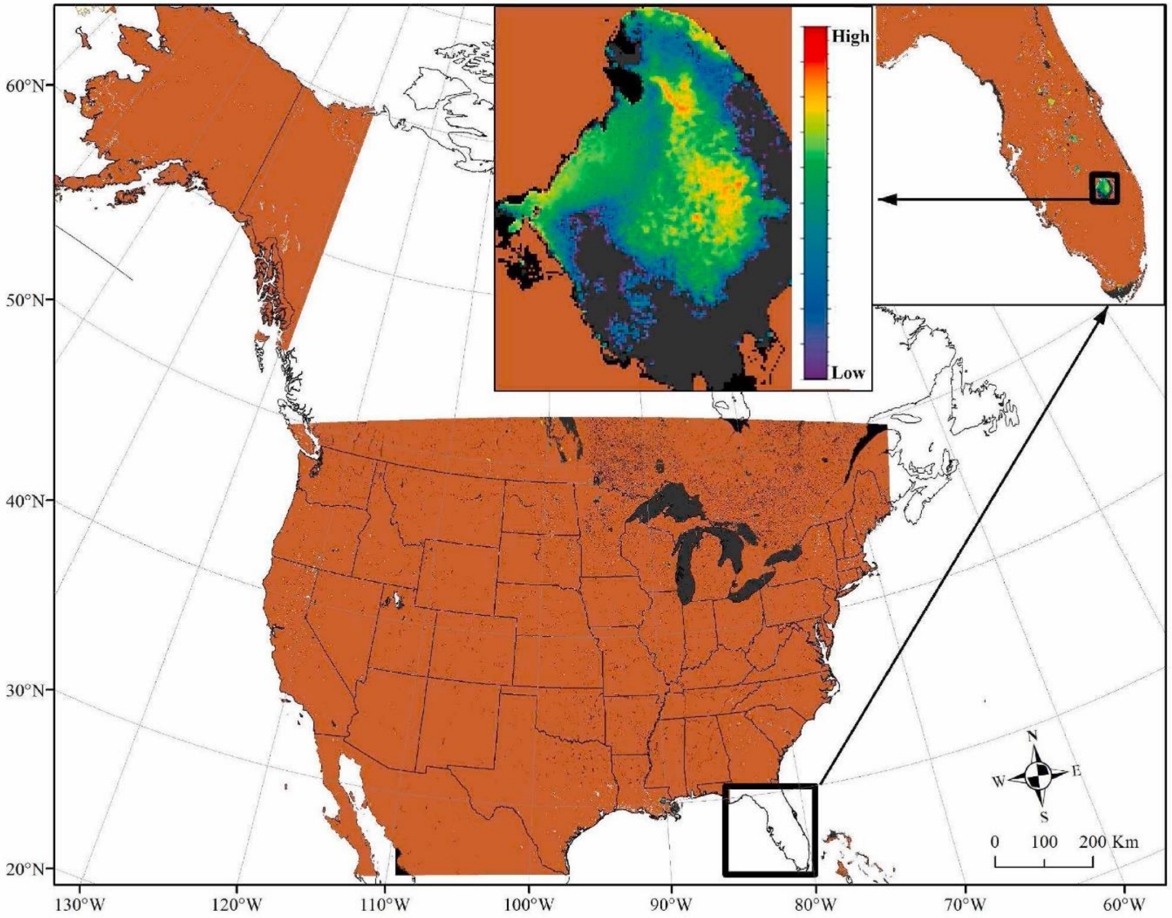
CyAN Background: Real-time data

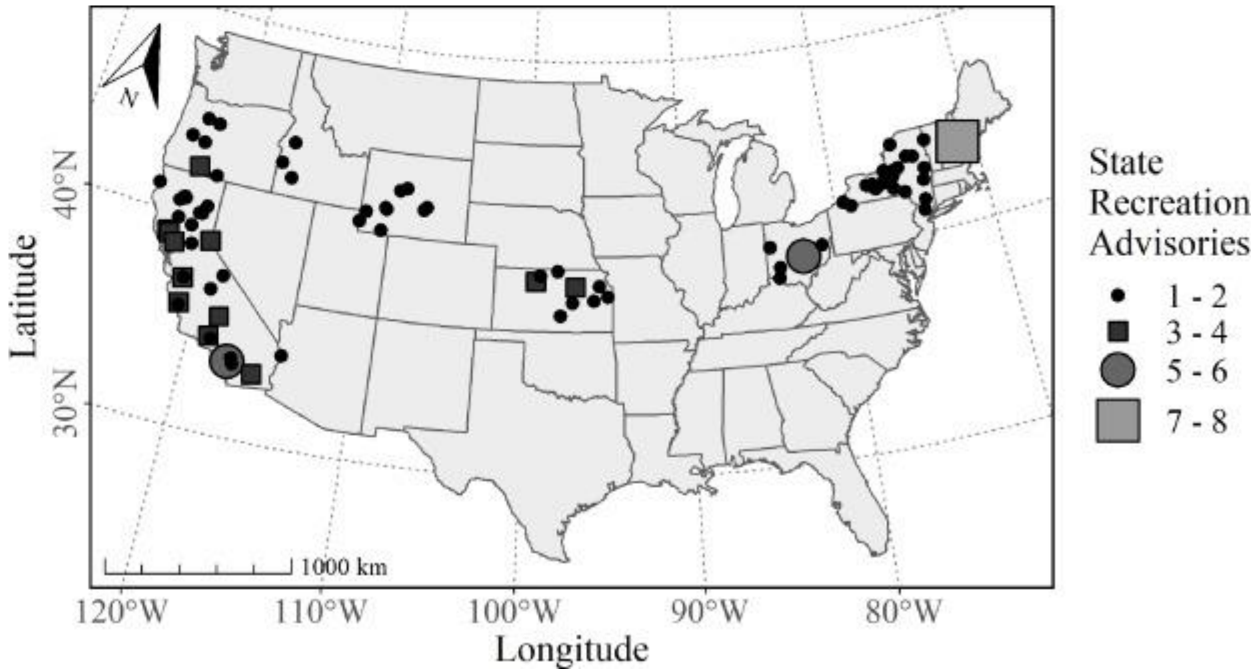
CyAN
CYANOBACTERIA ASSESSMENT NETWORK

epa.gov/cyanoproject



Source: Cooley et al. 2022. Technology in Society. 70:101994.

CyAN Background: Validation



		State Recreation Advisories: Presence	State Recreation Advisories: Absence	
CI_{cyano}	Presence	107 (*Presence-Presence*)	32 (*Misfit Presence*)	77% (*Positive Predictive Value*; eq. 8)
	Absence	47 (*Misfit Absence*)	102 (*Absence-Absence*)	68% (*Negative Predictive Value*; eq. 9)
		69% (*True Positive Rate*; eq. 6)	76% (*True Negative Rate*; eq. 7)	73% (*Overall Agreement*; eq. 5)

Source: Whitman et al. 2022. Harmful Algae. 115:102191.

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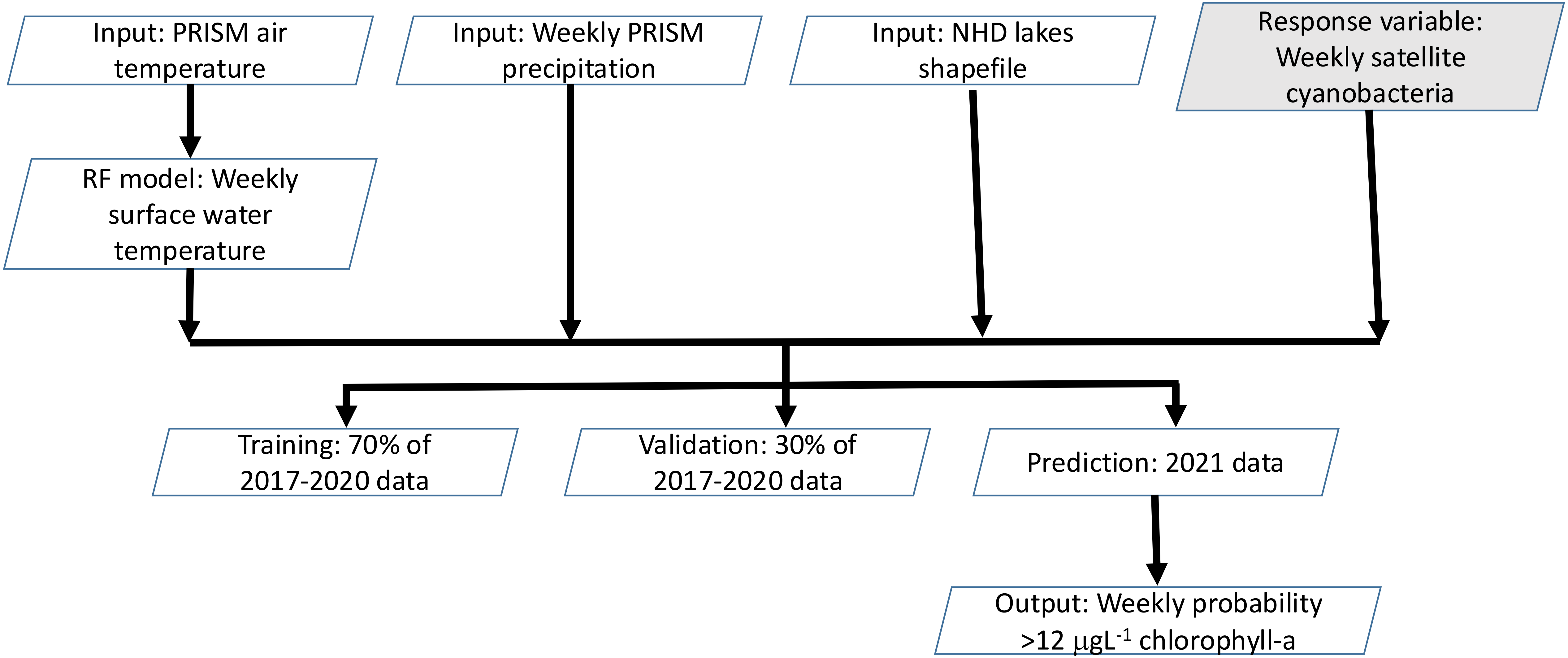
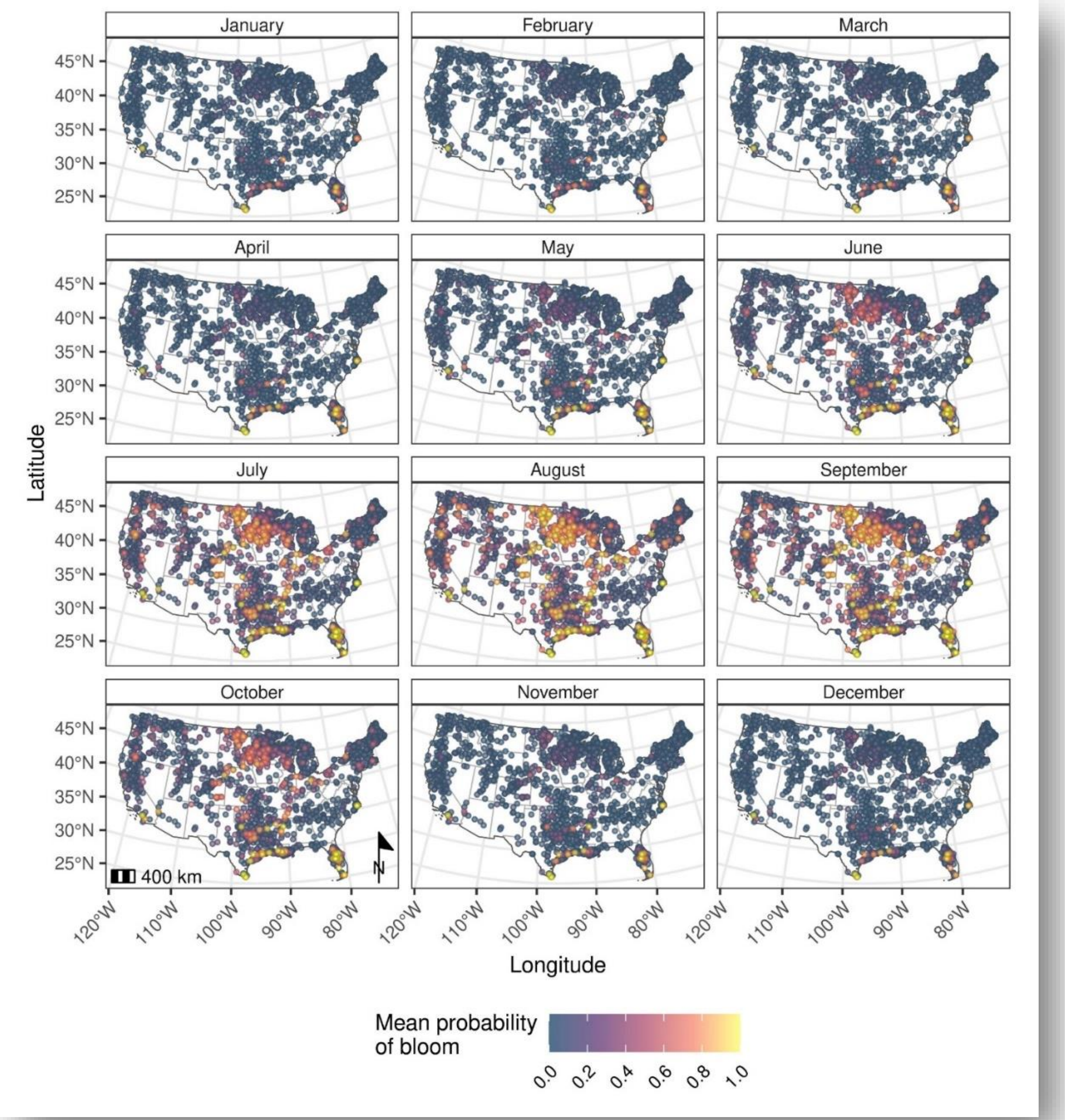
Forecast model



Source: Kreakie et al. 2021. Frontiers in Environmental Science. 9: 707874.
Schaeffer et al. 2023. Journal of Environmental Management. 349:119518.

Forecast model

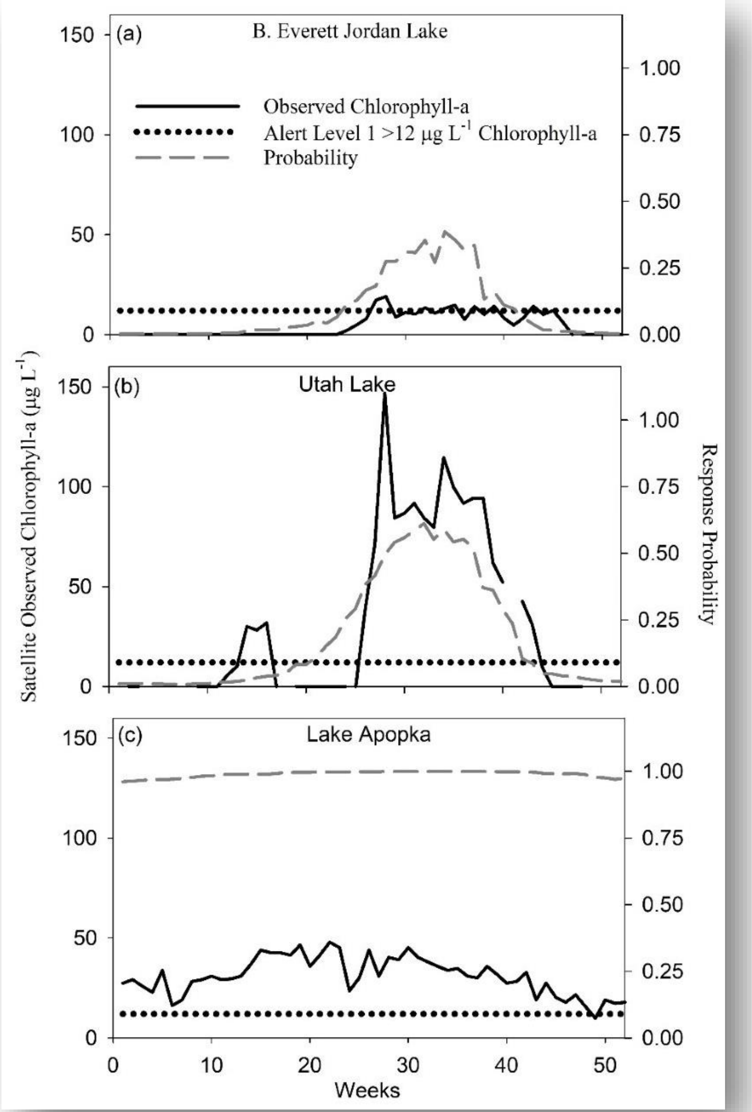
- Like weather forecasts
- Model forecasts one-week in advance



Source: Schaeffer et al. 2023. Journal of Environmental Management. 349:119518.

Forecast model

- Example cases
  - Jordan Lake, NC
  - Utah Lake, UT
  - Lake Apopka, FL



Source: Schaeffer et al. 2023. Journal of Environmental Management. 349:119518.

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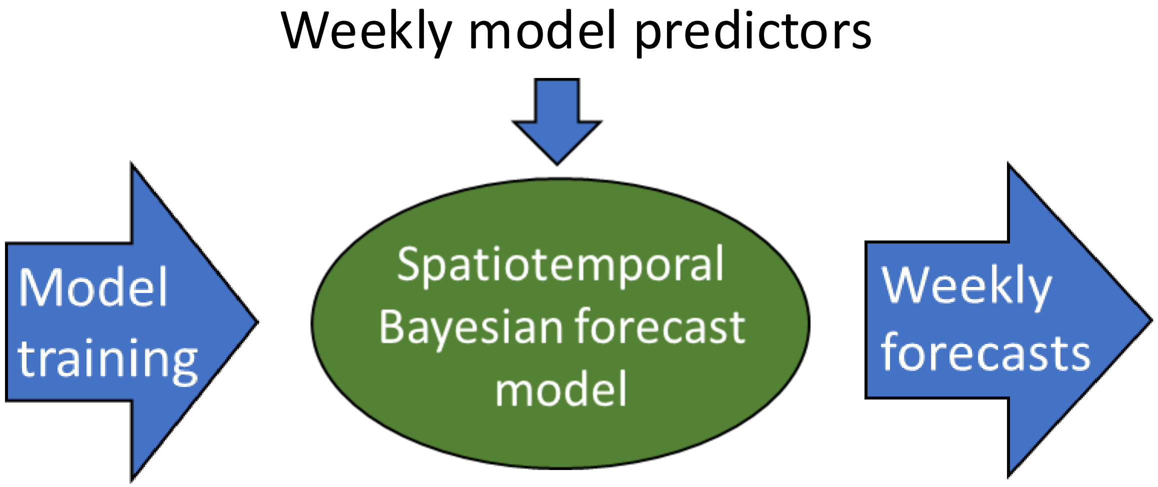
Operationalizing Weekly Forecasts

- Implement weekly workflow
- Generate weekly forecasts
- Make forecasts publicly accessible
- https://www.epa.gov/habs/hab-forecasts

<u>Predictors</u>: Surface water temperature, precipitation, lake geomorphology

<u>Response</u>: Bloom/no bloom from satellite imagery



Probabilities of cyanoHABs for 2,192 satellite resolvable lakes

Lake	Prob of cyanoHAB
1	XX.XX%
2	XX.XX%
…	…

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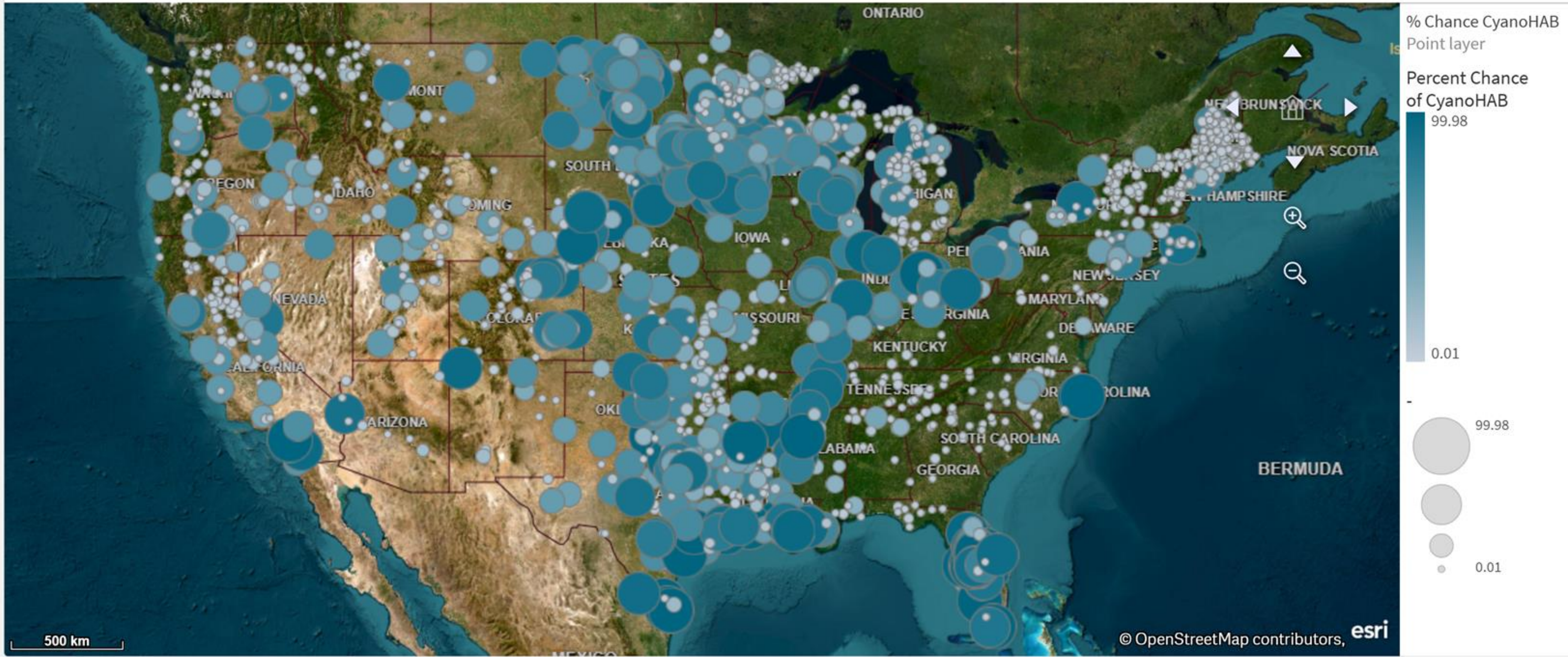
Forecast Dashboards - Map

Forecast Map

Forecast Week Ending Date

- 7/6/2024
- 7/13/2024
- 7/20/2024
- 7/27/2024
- 8/3/2024
- 8/10/2024
- 8/17/2024
- 8/24/2024
- 8/31/2024 ✓
- 9/7/2024
- 9/14/2024
- 9/21/2024
- 9/28/2024
- 10/5/2024
- 10/12/2024
- 10/19/2024
- 10/26/2024
- 11/2/2024

Percent Chance of CyanoHAB by Week



Forecast Dashboards - Table

Forecast Table

Select Most Recent Weekly Forecasts

Export Table

This table contains all of the weekly forecasts for the current year.

Lake Name	Date Range of Forecast	% Chance of CyanoHAB	State	Latitiude	Longitude	Forecast End Date	EPA Region
Big Creek Lake	ul-6-2024	1.01	AL	30.74899	-88.33521	7/6/2024	Region 4
Cedar Creek Reserv	l-6-2024	5.39	AL	34.52925	-87.92519	7/6/2024	Region 4
Grand Bay	l-6-2024	15.67	AL	30.76333	-87.99452	7/6/2024	Region 4
Lake Guntersville	l-6-2024	1.42	AL	34.54015	-86.12095	7/6/2024	Region 4
Lake Martin	l-6-2024	1.16	AL	32.77984	-85.90873	7/6/2024	Region 4
Lake Tuscaloosa	l-6-2024	1.06	AL	33.34466	-87.55662	7/6/2024	Region 4
Lewis Smith Lake	l-6-2024	2.76	AL	34.04098	-87.13662	7/6/2024	Region 4
Limestone Creek	l-6-2024	19.59	AL	34.60268	-86.86853	7/6/2024	Region 4
Shelby Lakes	l-6-2024	0.8	AL	30.26055	-87.66304	7/6/2024	Region 4
Weiss Lake (main p	l-6-2024	10.69	AL	34.19876	-85.60335	7/6/2024	Region 4
Weiss Lake (wester	l-6-2024	4.48	AL	34.15132	-85.78901	7/6/2024	Region 4
Wheeler Lake	l-6-2024	0.71	AL	34.67478	-87.05654	7/6/2024	Region 4
Wilson Lake (AL)	l-6-2024	1.44	AL	34.81659	-87.50654	7/6/2024	Region 4
Beaver Lake (AR)	l-6-2024	1.56	AR	36.34188	-93.93998	7/6/2024	Region 6
Blue Mountain Lake	l-6-2024	28.84	AR	35.09943	-93.7007	7/6/2024	Region 6

Search in listbox

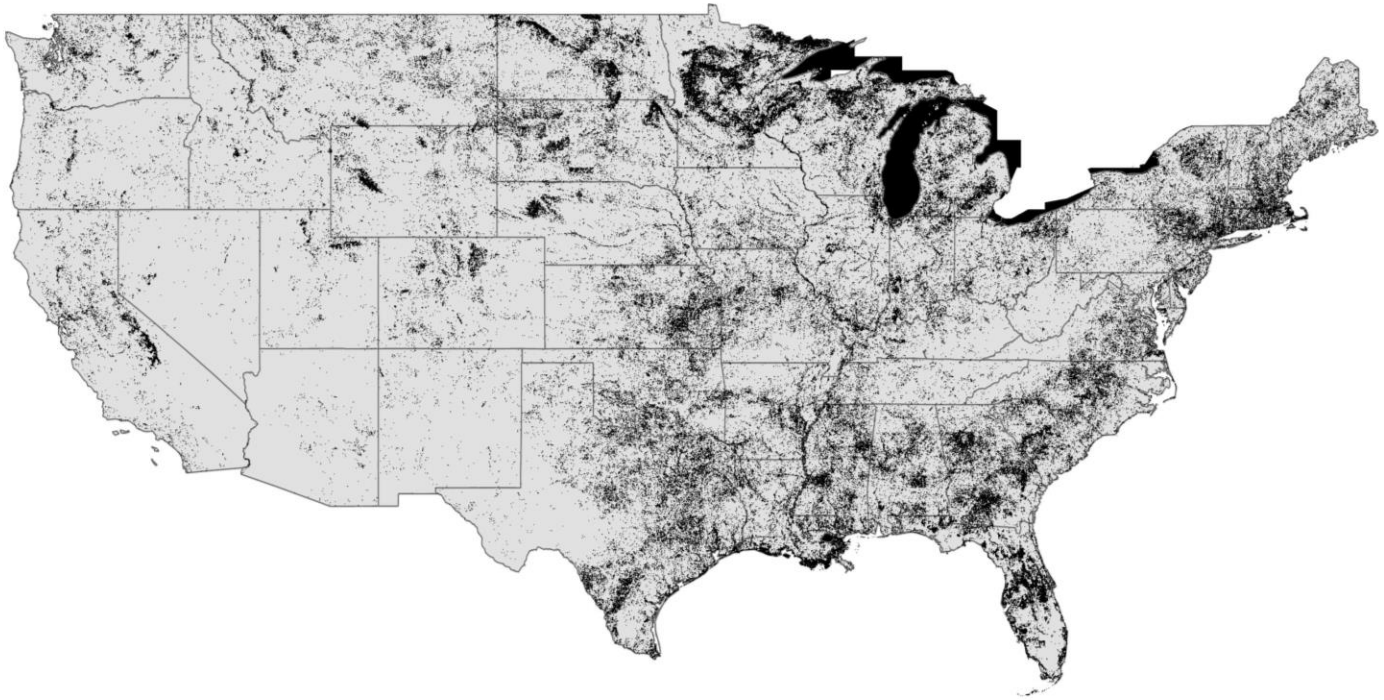
- Abarngamook Lake
- Adobe Creek Reservoir
- Aitkin Lake
- Alamo Lake
- Alamoosook Lake
- Albert Lake
- Albert Lea Lake
- Alcova Reservoir

Forecast Dashboards - Trends

What is next?

What is next?

Sentinel-2



>270,000 (98%) lakes
312 (83%) estuaries
85 (100%) sub estuaries

Annual potential avoided costs
~$42 million/year

Sources: Clark et al. 2017. Ecological Indicators; Papenfus et al. 2020. Environmental Monitoring and Assessment

Summary

- Real-time cyanobacteria detected using satellite technology
- Bayesian spatiotemporal model
- Public forecast dashboard
  - https://www.epa.gov/habs/hab-forecasts
- Future efforts with Sentinel-2 20 m

QR link to forecast dashboard
Suggest using computer browser

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Part 2: Toxic Cyanobacteria Detection and Early Warning for Cyanotoxin Production in Source and Recreational Waters

Jingrang Lu

United States Environmental Protection Agency

Outline

- Problem
- Roadmap and Tools
- Review for characterization/identification of a HAB pattern
- Microcystin (MC) dominated blooms
- Anatoxin-a (ATX) producer dominated blooms
- Take Home Messages
- Current work – onsite qPCR operation and programmatic monitoring

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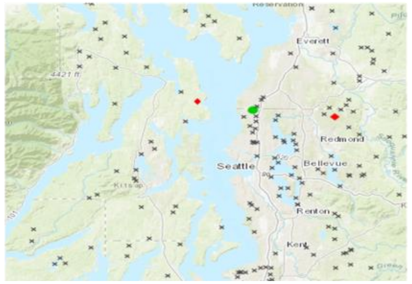
Problem

- Mass production of cyanotoxins is the major issue for source and recreational water. HAB events that occurred in many states caused significant losses in water supply, recreational activity, etc. (e.g., Lake Erie HAB outbreak (2014), Florida HAB emergency (2016) and Oregon HAB advisory (2018)).
- Existing algal monitoring & prediction methods (e.g., visual observation, microscopic counting, CyAN Web, remote sensing, modeling and machine learning) are unable to distinguish toxic or nontoxic cyanobacteria. As monitoring approaches, some methods are limited; some are complicated and difficult to use.
- Direct cyanotoxin measurements need to consider the high cost and time issue.
- **Accurately determining cyanotoxin types and predicting cyanotoxin production are needed to develop effective cyanotoxin prevention strategies for the states to make timely environmental/public health decisions, and to protect source and recreational water from mass contamination of cyanotoxins.**

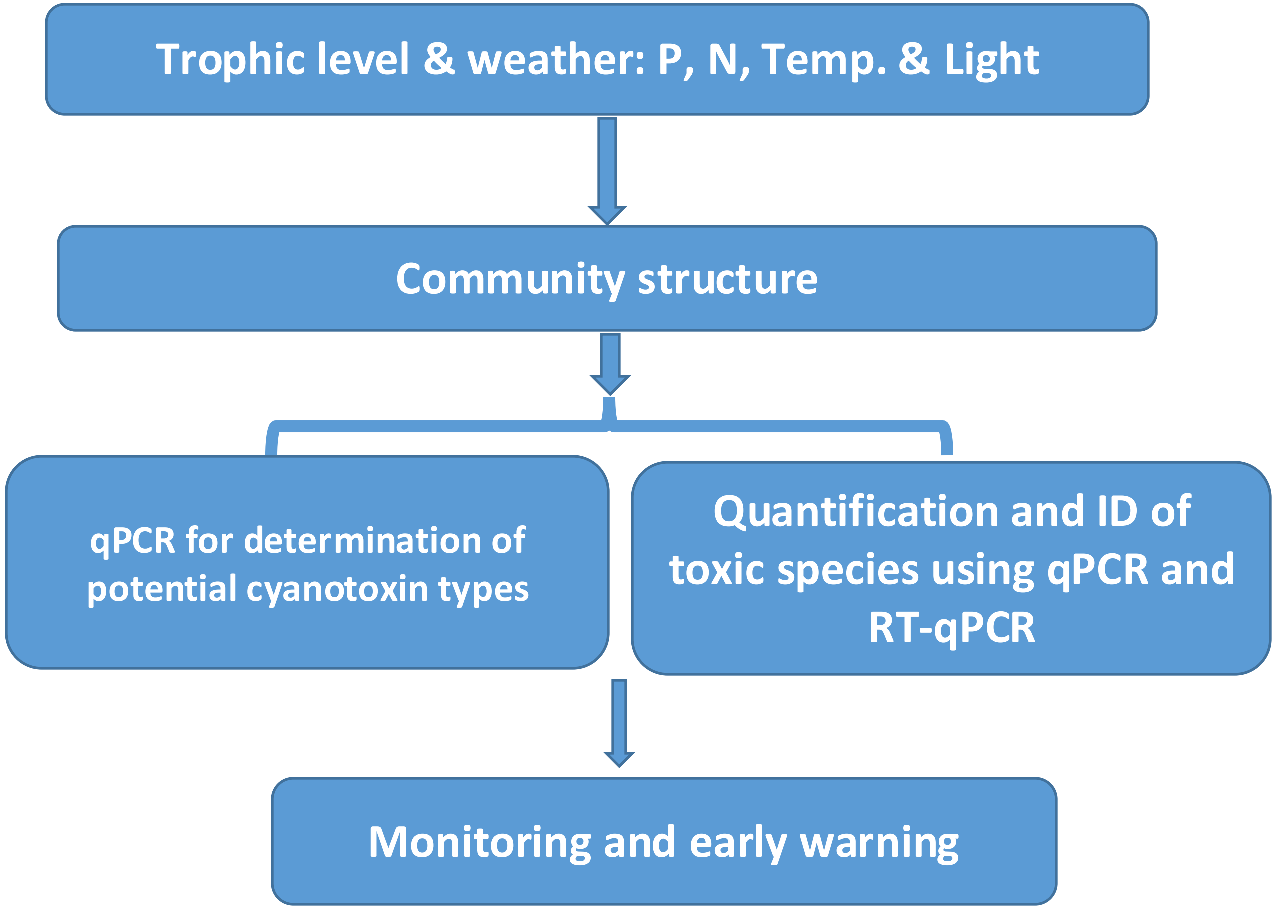
Cyanobacteria/cyanotoxins resources for each of the States can be found by clicking selected state (https://www.epa.gov/habs/state-tribal-hab-programs-and-resources)

Toxic cyanobacteria/cyanotoxins in Washington State (Exceeded state recreation guideline, within state recreation guideline (https://www.epa.gov/habs/state-tribal-hab-programs-and-resources)



Roadmap: A diagram for detection & prediction of HAB events and cyanotoxin production

- Characterization of a water body: Would a HAB occur?
- Characterization of toxic cyanobacteria and dominance: What type of cyanotoxin produced?
- How to determine dominant cyanotoxin types?
- How to make a short-term prediction of cyanotoxin production?



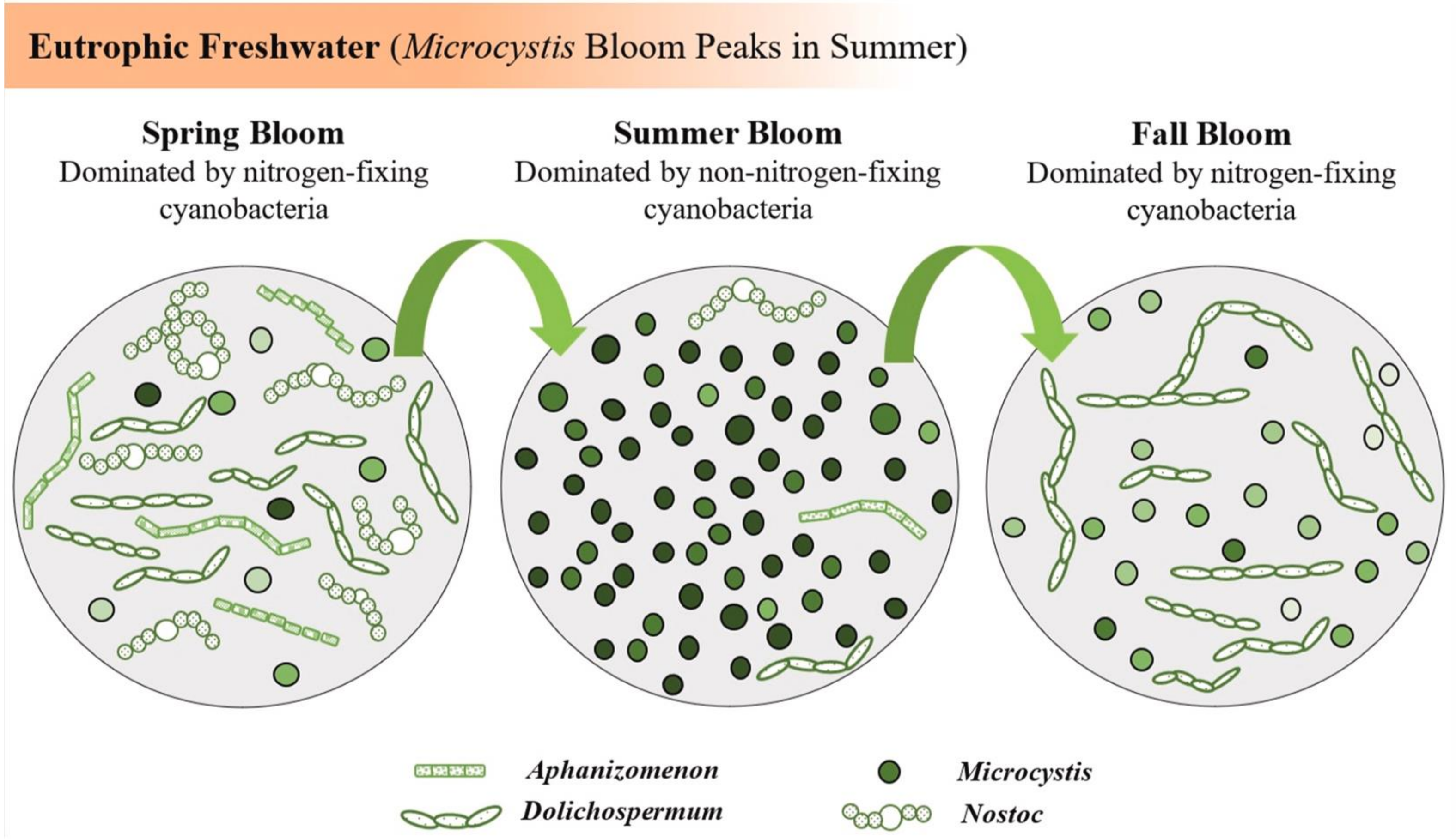
Basis of prediction: Cyanobacterial community structure and its successions

Developed tools (qPCR assays)

Potential cyanotoxin type	Cyanotoxin producers in USA
Microcystin (MC), mcyEcya	• mcyEmic: *Microcystis* (nationwide) • mcyEana: *Anabaena*, *Dolichospermum* (e.g., Detroit Lake, OR) • mcyApla: *Planktothrix* (e.g., Ohio lakes) • Other assays for insignificant MC-producers: *Nostoc, Cylindrospermopsis, Synechococcus, etc.*
Anatoxin-a (ATX), anaC	• anaA: *Dolichospermum*, *Anabaena*, *Aphanizomenon* (e.g., R10) • anaFosc: *Oscillatoria* (benthic) • anaFpho: *Phormidium* (benthic)
Saxitoxins (STX), sxtA	• sxtA5: *Aphanizomenon flos-aquae* (Big Eleven Lake, KS)
Cylindrospermopsin (CYN), cyrA	• cyrA: *Aphanizomenon* (e.g., Detroit Lake, OR)

Characterization/Identification of a HAB pattern

- Toxic cyanobacteria present in all observed waterbodies.
- Cyanobacterial HABs occur most probably in those eutrophic freshwater bodies (TP>0.03 mg/L, T>20 °C).
- A common succession pattern is from N_2-fixing cyanobacterial spring bloom to non-N_2-fixing cyanobacterial summer bloom.
- Non-N_2-fixing cyanobacteria-summer bloom is common in majority of waterbodies, while there are some water bodies observed with significant spring blooms.
- Occasionally there is a fall bloom dominated by filamentous cyanobacteria.



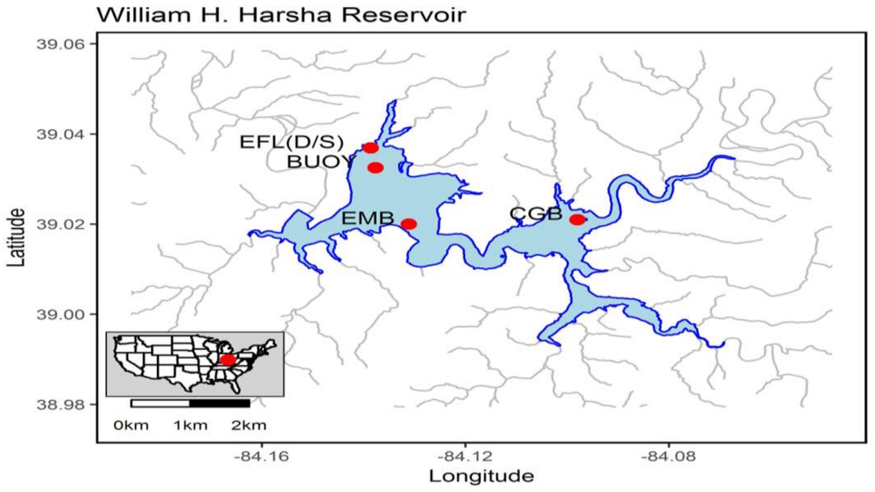
(Tanvir et al. 2021)

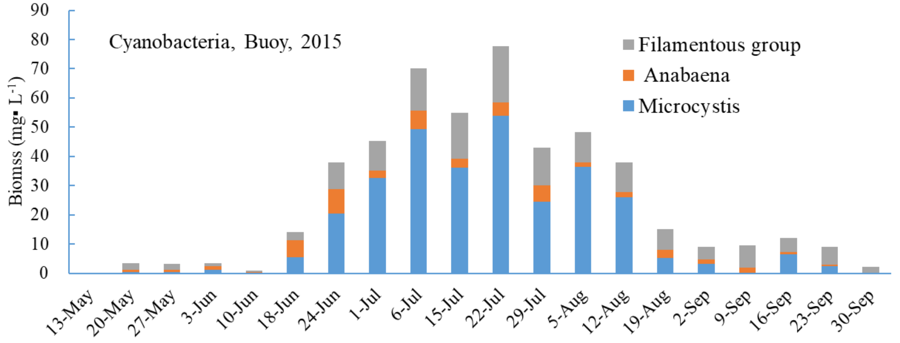
Microcystin (MC) producer dominated blooms: Characterization

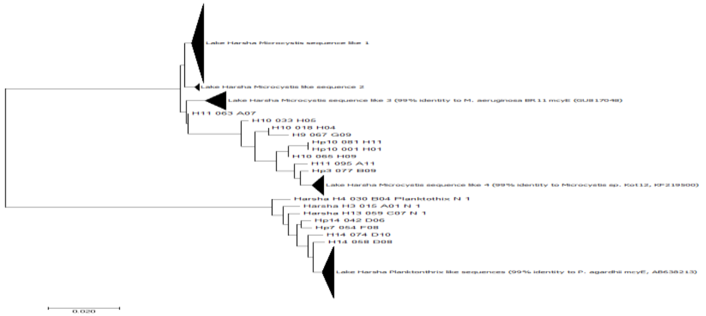
Sampling location: Harsha Lake, Cincinnati, OH, has been an EPA HAB sampling station since 2015

HAB recurrence: Experienced MC-dominated HAB event almost each summer

MC-producers: *Microcystis aeruginosa* and *Planktothrix agardhii.*







(Chen *et al*. 2017, Zhu et al. 2018)

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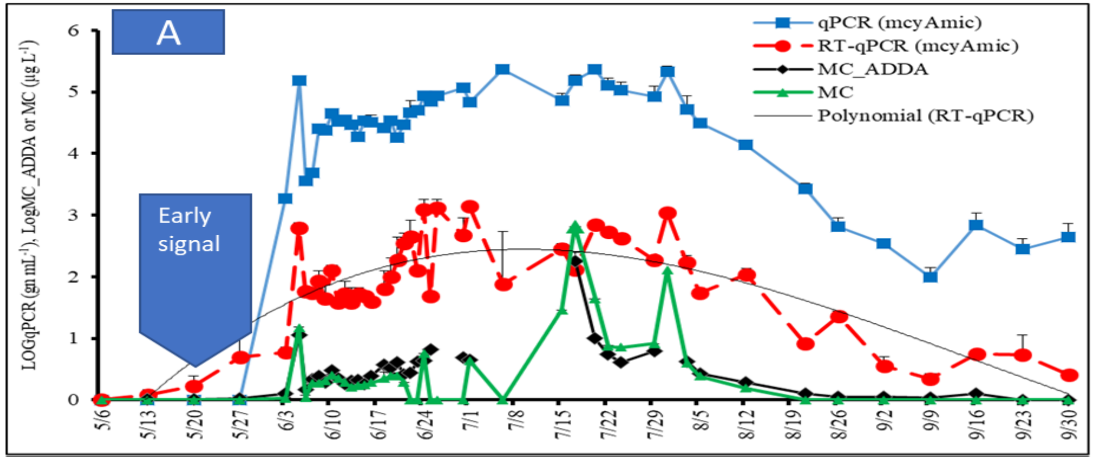
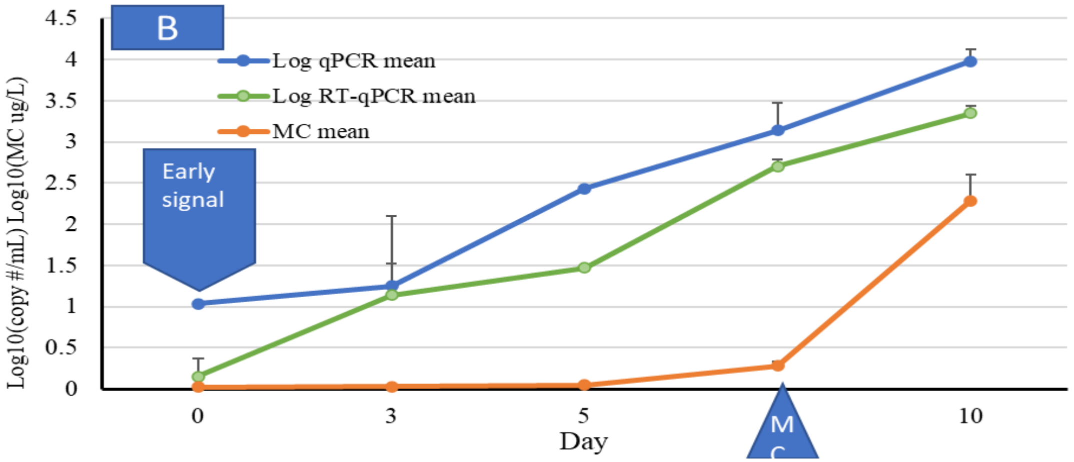
MC producer dominated blooms: Monitoring and early warning

- **Detected MC producers** and monitored their variations and bloom events with qPCR and RT-qPCR.
- qPCR and RT-qPCR signals were **detected 1-week before MC-production.**
- **One-week early warning** prediction of MC exceeded the >0.3 µg/L detected threshold can be made.
- **MC <u>predictions using</u> qPCR and RT-qPCR were <u>confirmed</u>** using laboratory *Microcystis aeruginosa* culture tests

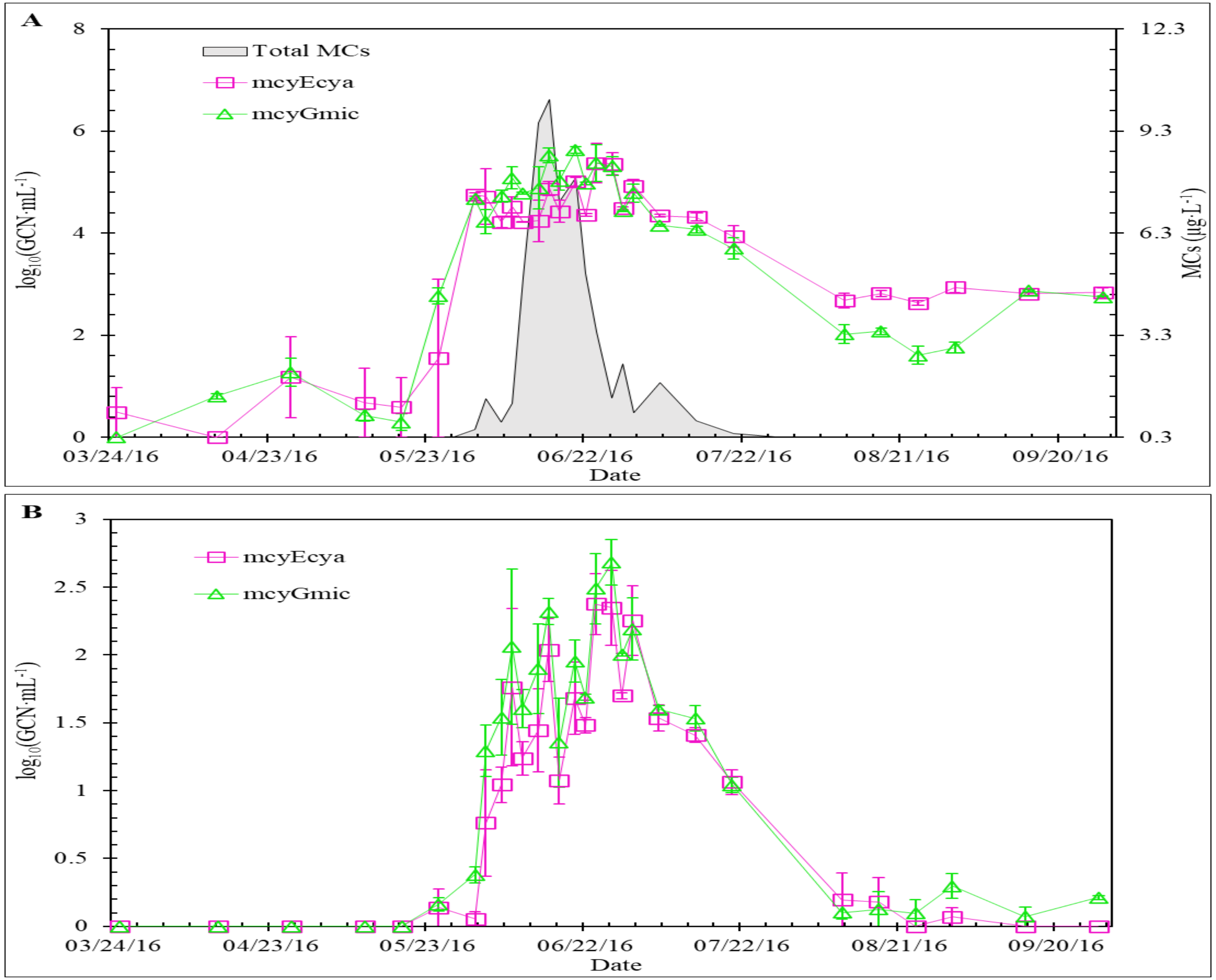




One-week early signaling MC-production in Harsha lake, OH (Lu et al. 2020) and *Microcystis* culture (Struewing et al. 2022)

MC producer dominated blooms: Monitoring and early warning in a reoccurring HAB event

- The 1-week early signals of qPCR and RT-qPCR occurred in the flowing HAB event
- The *mcy* RT-qPCR signals had positive correlation with MC and signaled two-weeks ahead of detectible MC

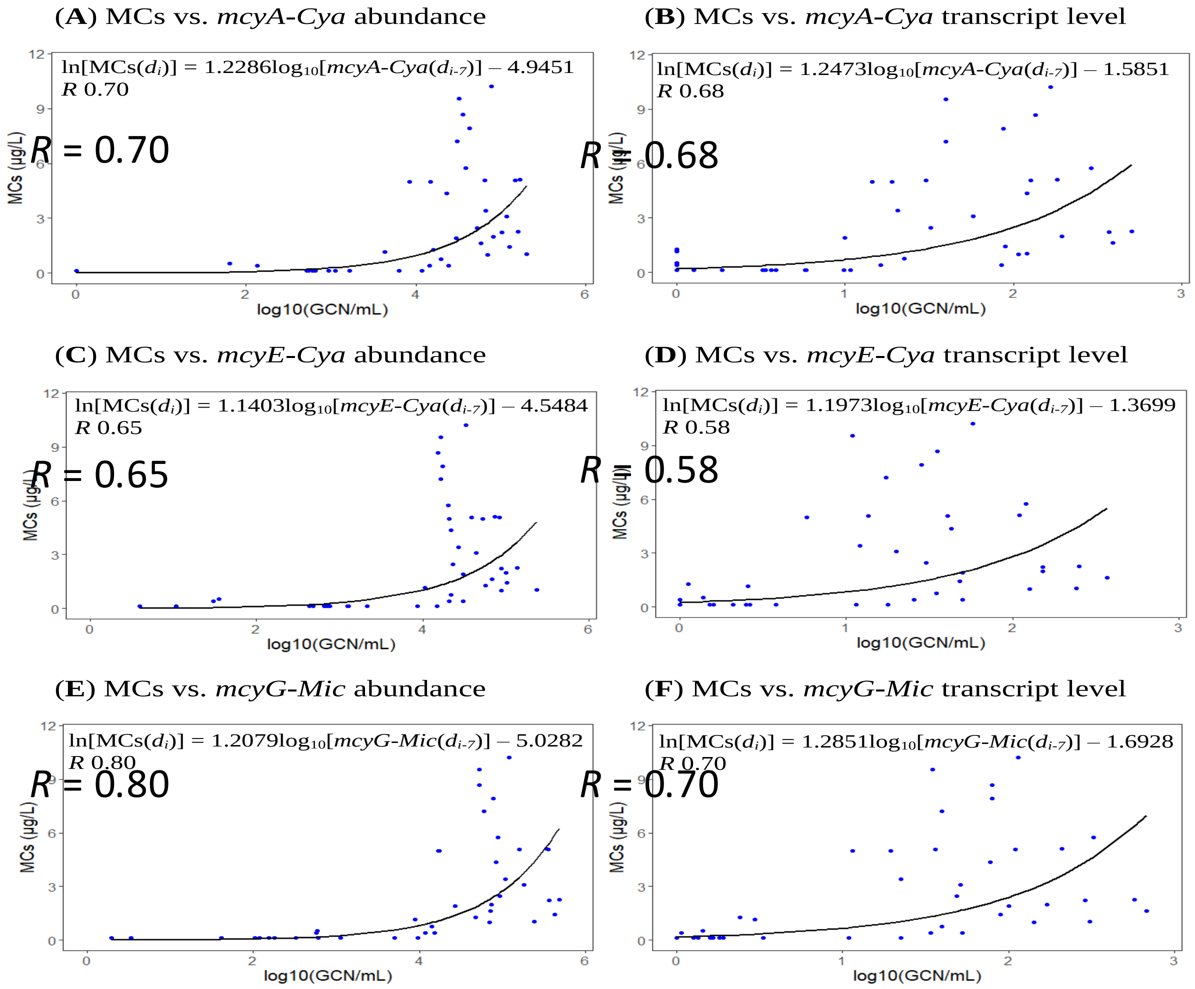


MC producer dominated blooms: Prediction of the 7-d later (di) total MC concentrations in a reoccurring HAB event

- The current (d_{i-7}) abundance or transcript levels correlated to MC using a tobit regression analysis

- The "*R*"s indicate the correlation coefficients between the predicted and observed values

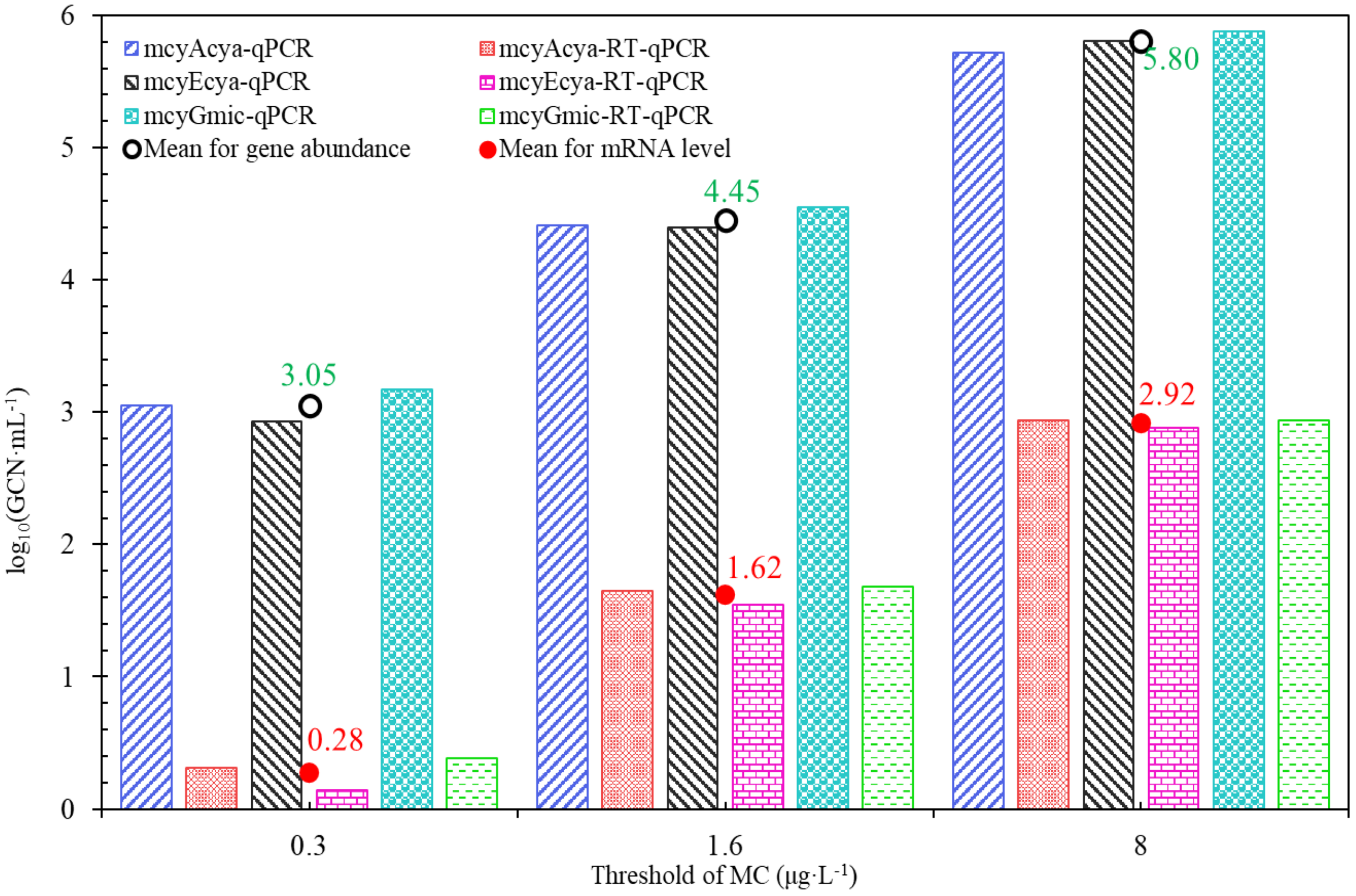
- The future (7-d later) MC level could be predicted from the log correlation prior to a HAB event



MC producer dominated blooms: Estimated threshold of qPCR signals in a reoccurring HAB event

- The three health advisory limits: **0.3** µg·L^{-1} for infants and young children, **1.6** µg·L^{-1} for six and older, and **8.0** µg·L^{-1} for recreational water) (US EPA, 2015; 2019b)

- The estimated qPCR and RT-qPCR threshold values were similar between 2015 and 2016 HAB events



The estimated abundance and transcript levels of *mcyA-Cya*, *mcyE-Cya*, and *mcyG-Mic* that predicts exceedance of the 0.3, 1.6, and 8.0 µg L^{-1} health advisory thresholds

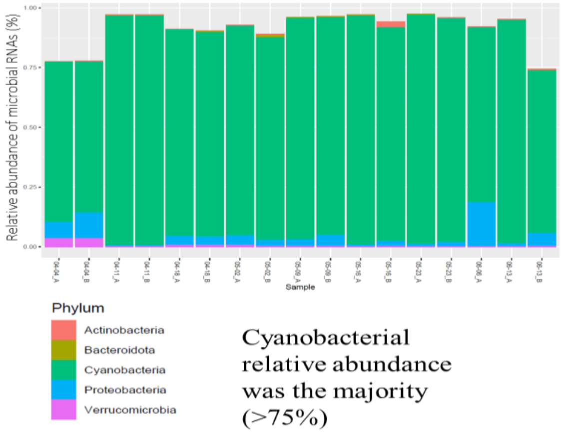
Anatoxin (ATX) dominated blooms: Characterization

Sampling location: Anderson Lake, Chimacum, WA, was selected for anatoxin (ATX) study since 2019

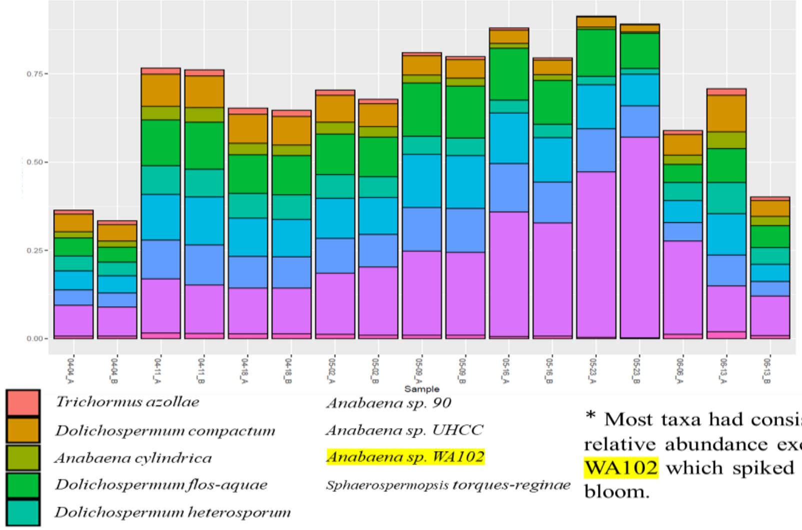
HAB recurrence: Experienced ATX-dominated HAB each year

ATX-producers: *Dolichospermum* sp. WA102

Source: https://en.wikipedia.org/wiki/Anderson_Lake_(Jefferson_County,_Washington)



Cyanobacterial relative abundance was the majority (>75%)



* Most taxa had consistent relative abundance except WA102 which spiked during bloom.

(Linz *et al.* 2025)

ATX producer dominated blooms: Data analysis after an anatoxin producing bloom in 2021

- ATX-producing bloom started from early May and ended in late June
- Early *anaC* RT-qPCR signals were detected 3-weeks before significant ATX measurements by ELISA
- Table 1 showed observed *anaC* abundance and transcripts for the days to reach ATX limit. A linear model was also developed for more accurate prediction

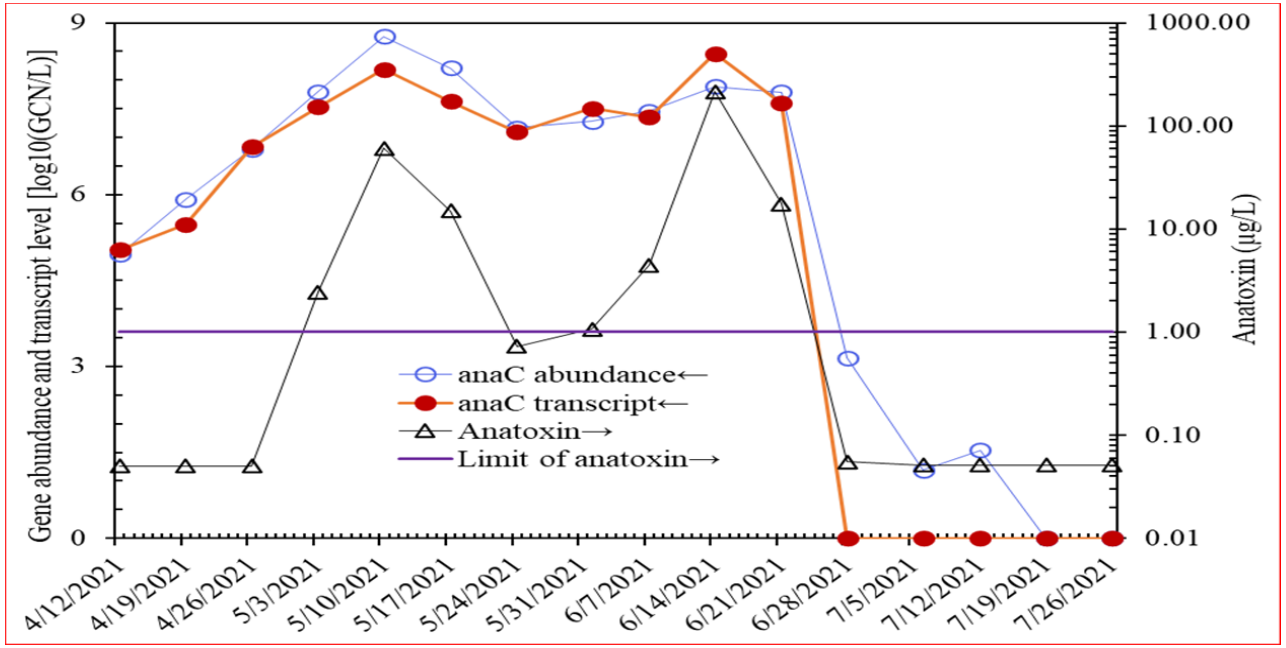
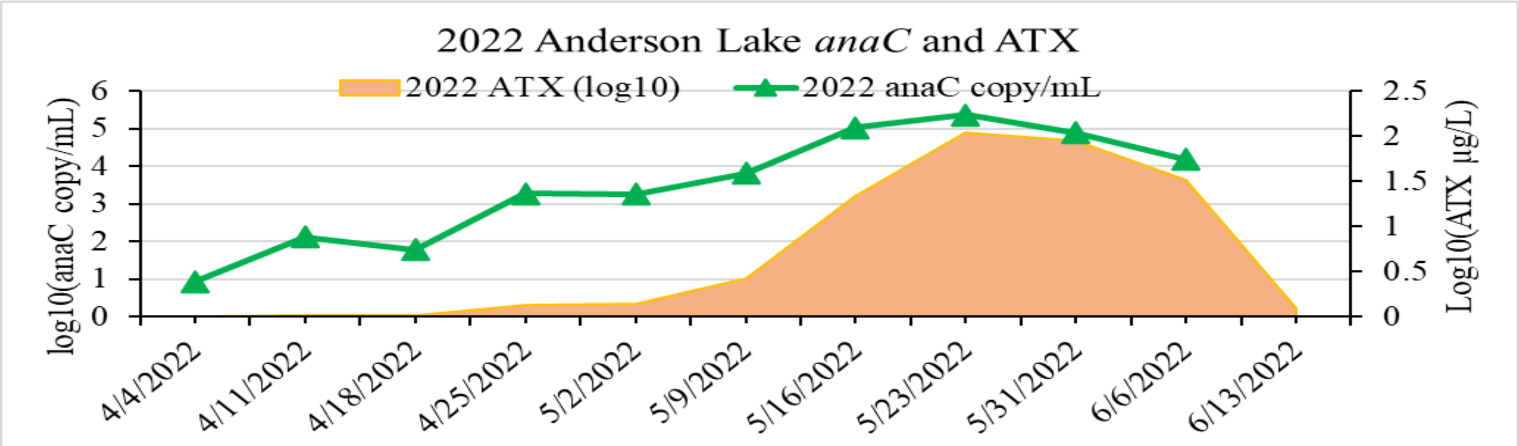


Table 1. Observed *anaC* gene abundance and *anaC* transcript levels on different days prior to May 2nd, 2021 (*: >50% in ROC curves)

Time lag (d)	Time	anaC abundance [log_{10}(GCN/L)]	anaC transcript level [log_{10}(GCN/L)]
0	05/02/2021	7.5*	7.3*
7	04/25/2021	6.5*	6.5*
14	04/18/2021	5.7*	5.4*
21	04/11/2021	4.8*	4.8*

ATX producer dominated blooms: An early warning systems using qPCR signals

- On-site monitoring of Anatoxin-a (ATX) production in **Anderson Lake, WA** using qPCR in 2022
- 2021 data suggested that ATX production may be **predicted and used to make an early warning 1-3 weeks before** the bloom
- In 2022, **ORD validated this early warning concept** using qPCR signals obtained immediately after sampling-shipping-processing
- We made a rough prediction of the presence (e.g., 4/11 or later), its increase, and peak level (e.g., 5/9) of ATX



ATX-producer bloom event in Anderson Lake, WA in 2022. It was detected using *anaC*-qPCR immediately after sampling-shipping-processing.

Take Home Messages

- The waterbodies for the states collaborating with EPA Regions 3, 4, 5, 7, 8, 9 & 10 for the MC-, ATX-, SXT- and CYN-producer dominated blooms have been characterized, and facilitated the following monitoring and early warning of toxin production.
- The use of qPCR can identify and quantify 4 types of potential cyanotoxin (MC, ATX, STX and CYN) producers. The tools and protocols have been used by several state labs.
- Demonstrated ability to monitor for MC-producing cyanobacteria during a bloom season, as well as monitoring and early warning an ATX production and a bloom event.
- The research collaborations with regions and states have been recognized with EPA National Honor Award for understanding and preventing HABs.

- For more information about these methods:
  - https://doi.org/10.1016/j.watres.2019.115262
  - https://doi.org/10.1016/j.scitotenv.2022.154568
  - https://doi.org/10.1016/j.chemosphere.2025.144124
  - https://doi.org/10.3390/toxins15010003
  - https://doi.org/10.1016/j.envpol.2021.118056

Current developing – onsite qPCR operation and programmatic monitoring and predicting

1. Method for Early warning and monitoring cyanotoxin progress

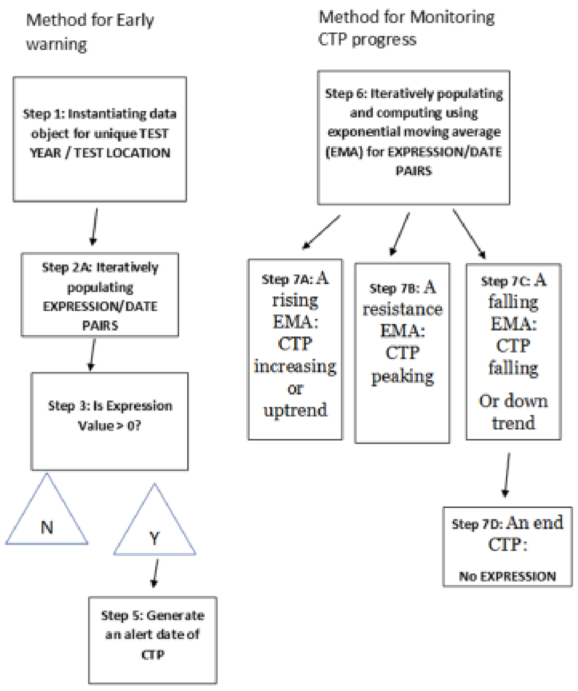


Figure 1

2. Estimate of potential level of cyanotoxin production (CTP) and alert for a hazardous risk to public

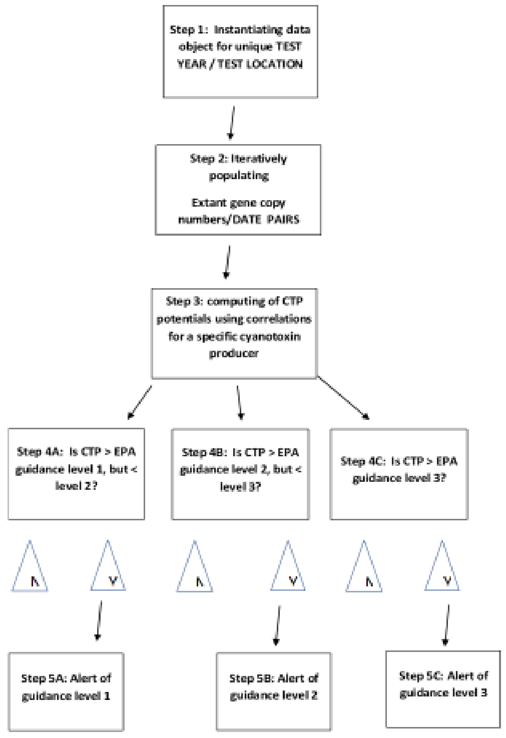


Figure 2.

3. Long term prediction of probable occurrence dates, intensity and duration of cyanotoxin production in a year

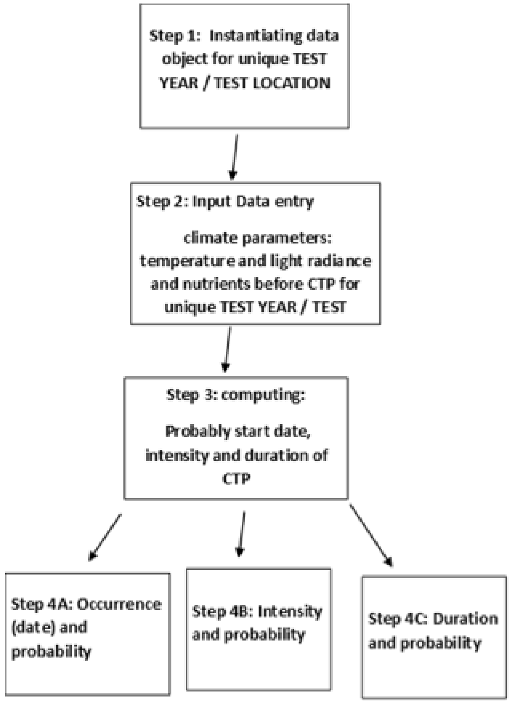


Fig. 3

Contacts

Donald Benkendorf
Physical Scientist
US EPA Office of Water
benkendorf.donald@epa.gov

Blake Schaeffer
Physical Scientist
US EPA Office of Research and Development
schaeffer.blake@epa.gov

Jingrang Lu
Research Biologist
US EPA Office of Research and Development
lu.jingrang@epa.gov

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