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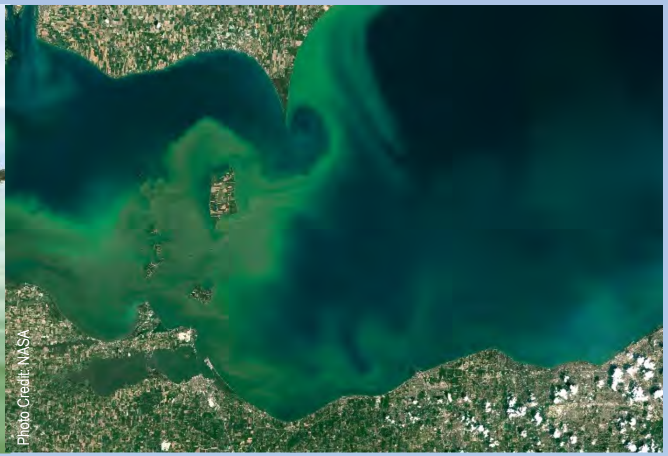
Cyanotoxin Occurrence in the United States

A 20 Year Retrospective



Jennifer L. Graham

U.S. Geological Survey

American Water Works Association and Partners Summer Webinar Series

June 23, 2021

U.S. Department of the Interior
U.S. Geological Survey

First Reports of Cyanotoxins

1878 AUS ➡ 1882 MN ➡ 1939 CO ➡ 1943 MT ➡ 1944 IA ➡ 1946 ND ➡ 1956 TX ➡ 1964 NH ➡ 1976 WA ➡ 1977 OK ➡ 1981 IL ➡ 1985 WI ➡ 1987 MS ➡ 1990 IN

After Yoo et al., 1995

First Reports of Cyanotoxins

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After Yoo et al., 1995

Photo Credit: S. Panken, University of Missouri

Toxic Algae in Iowa Lakes

By Earl T. Rose

1953

Reprinted from Proceedings of The Iowa Academy of Science, Volume 61.

Blue-Green Algae Control at Storm Lake

By Earl T. Rose

1954

- Blooms are a nuisance issue that can sometimes be toxic
- Usually, but not always, a summer phenomenon
- High nutrients and "other ideal ecological conditions" result in blooms
- Potential producers include: *Aphanizomenon*, *Anabaena*, *Coelosphaerium*, *Gloeotrichia*, *Microcystis*, and *Nodularia*
- Toxins are complex organic substances that are "almost impossible to determine"

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First Reports of Cyanotoxins

1878 AUS → 1882 MN → 1939 CO → … 1985 WI → 1987 MS → 1990 IN

After Yoo et al., 1995

In This Issue:

ET&C FOCUS

Focus articles are part of a regular series intended to sharpen understanding of current and emerging topics of interest to the scientific community.

Are Harmful Algal Blooms Becoming the Greatest Inland Water Quality Threat to Public Health and Aquatic Ecosystems?

Bryan W. Brooks,*† James M. Lazorchak,‡ Meredith D.A. Howard,§ Mari-Vaughn V. Johnson,|| Steve L. Morton,# Dawn A.K. Perkins,†† Euan D. Reavie,‡‡ Geoffrey I. Scott,§§ Stephanie A. Smith,|||| and Jeffery A. Steevens##

†Department of Environmental Science, Center for Reservoir and Aquatic Systems Research, Institute of Biomedical Studies, Baylor University, Waco, Texas, USA
‡Office of Research and Development, US Environmental Protection Agency, Cincinnati, Ohio, USA
§Southern California Coastal Water Research Project, Costa Mesa, California, USA
||Natural Resources Conservation Service, US Department of Agriculture, Temple, Texas, USA
#National Centers for Coastal Ocean Science, Center for Coastal Environmental Health and Biomolecular Research, National Oceanic and Atmospheric Administration, Charleston, South Carolina, USA
††Wisconsin State Laboratory of Hygiene, University of Wisconsin-Madison, Madison, Wisconsin, USA
‡‡Natural Resources Research Institute, Center for Water and the Environment, University of Minnesota-Duluth, Duluth, Minnesota, USA
§§Department of Environmental Health Science, Arnold School of Public Health, University of South Carolina, Columbia, South Carolina, USA
||||Beagle Bioproducts, Columbus, Ohio, USA
##US Army Engineer Research and Development Center, Vicksburg, Mississippi, USA

Toxic Algae

By Earl

Reprinted from Pro
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Blue-Green Algae (

By Ear

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Cyanotoxins are Diverse

	Hepatotoxins		Neurotoxins		Dermatoxins
	CYL	MC	ANA	SAX	
Anabaena/Dolichospermum	X	X	X	X	X
Aphanizomenon	X	?	X	X	X
Microcystis		X			X
Oscillatoria/Planktothrix		X	X	X	X

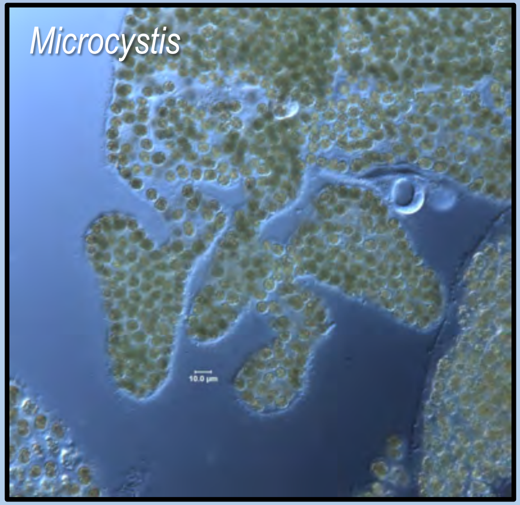

Photo Credit: A. St. Amand, PhycoTech

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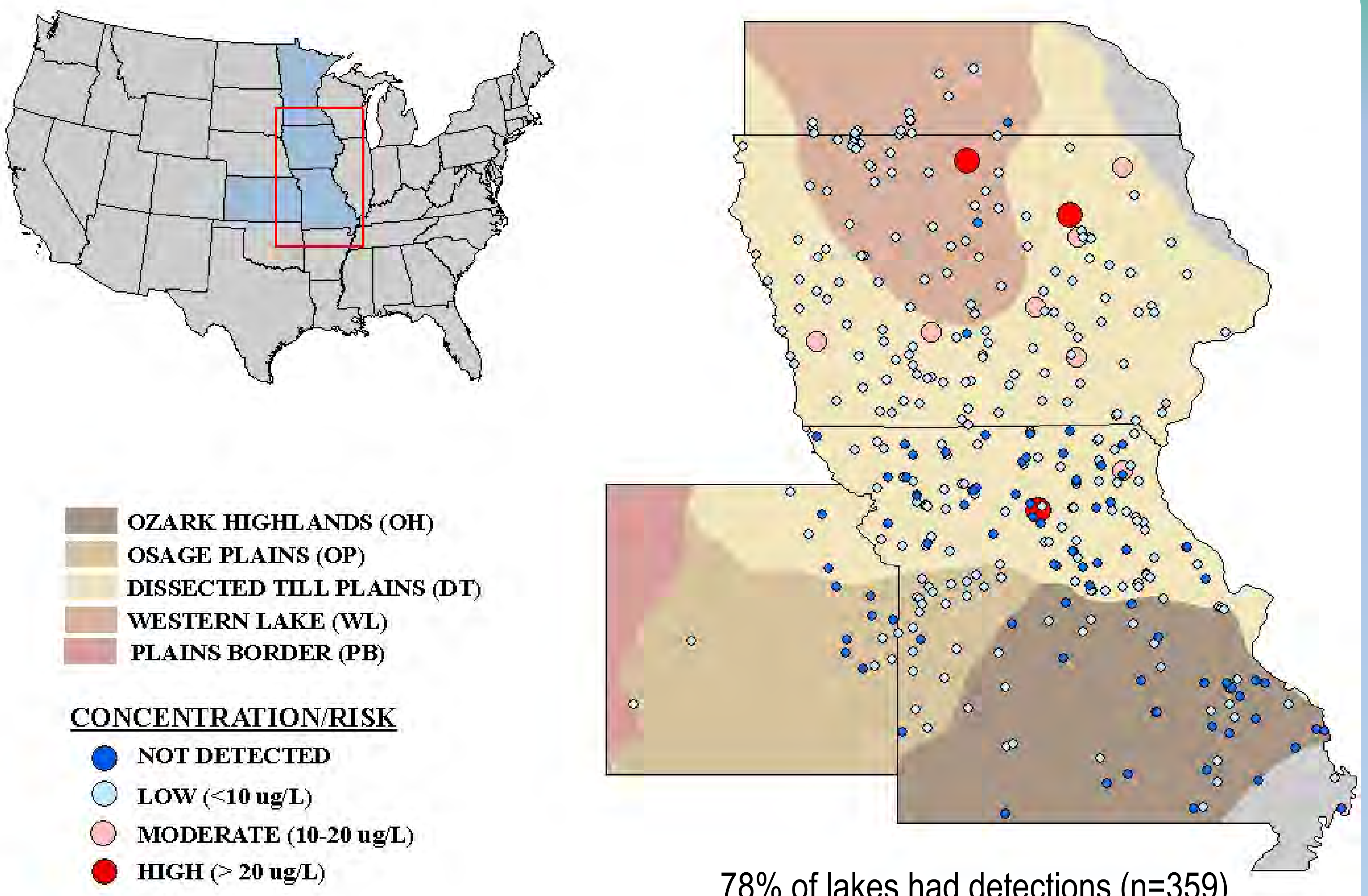
After Graham and others, 2008

Microcystins are Widespread and Common

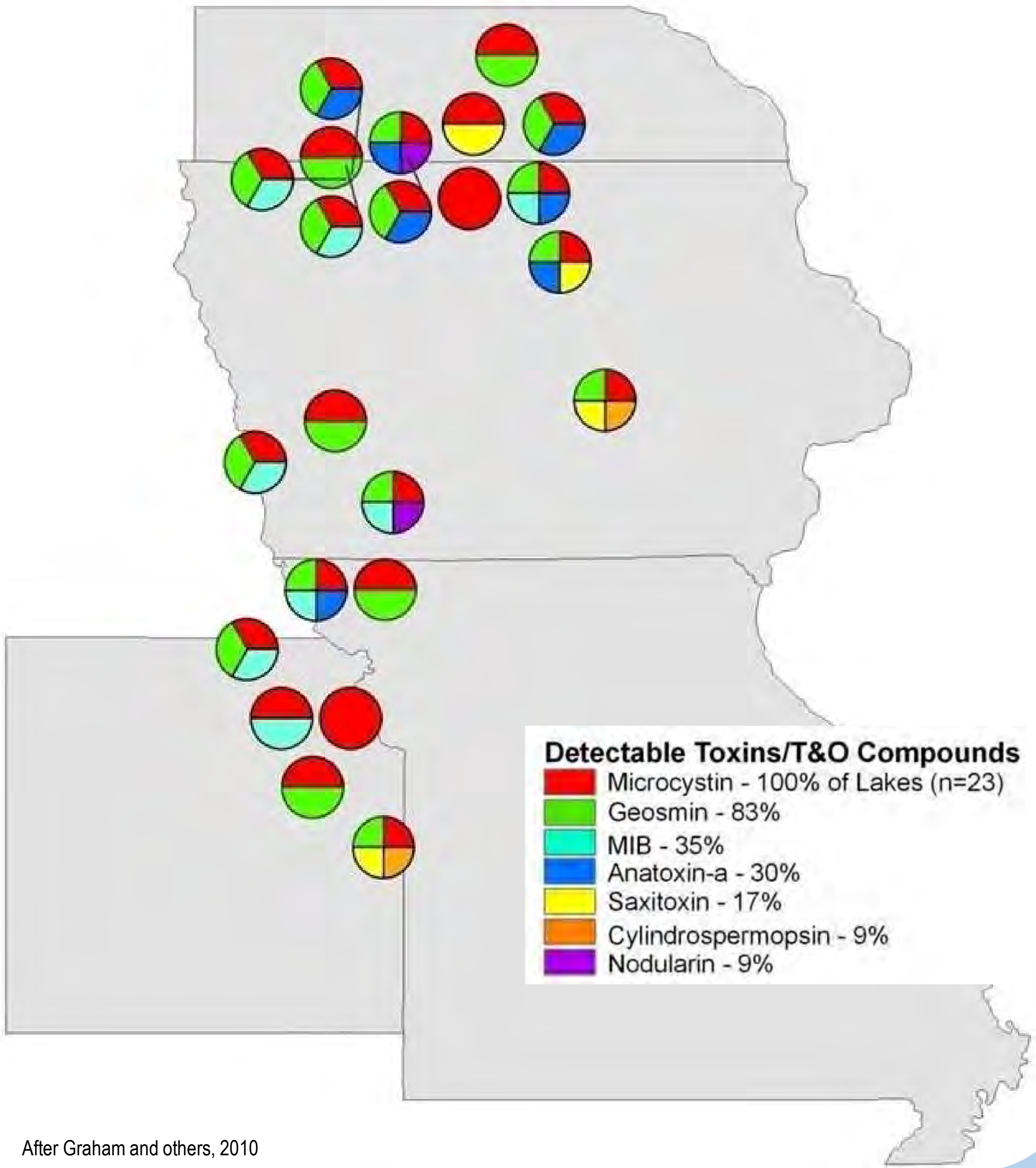


78% of lakes had detections (n=359)

Maximum concentration: 52 µg/L

After Graham and others 2004, 2006, and 2009

Other Cyanotoxins Occur Less Frequently



After Graham and others, 2010

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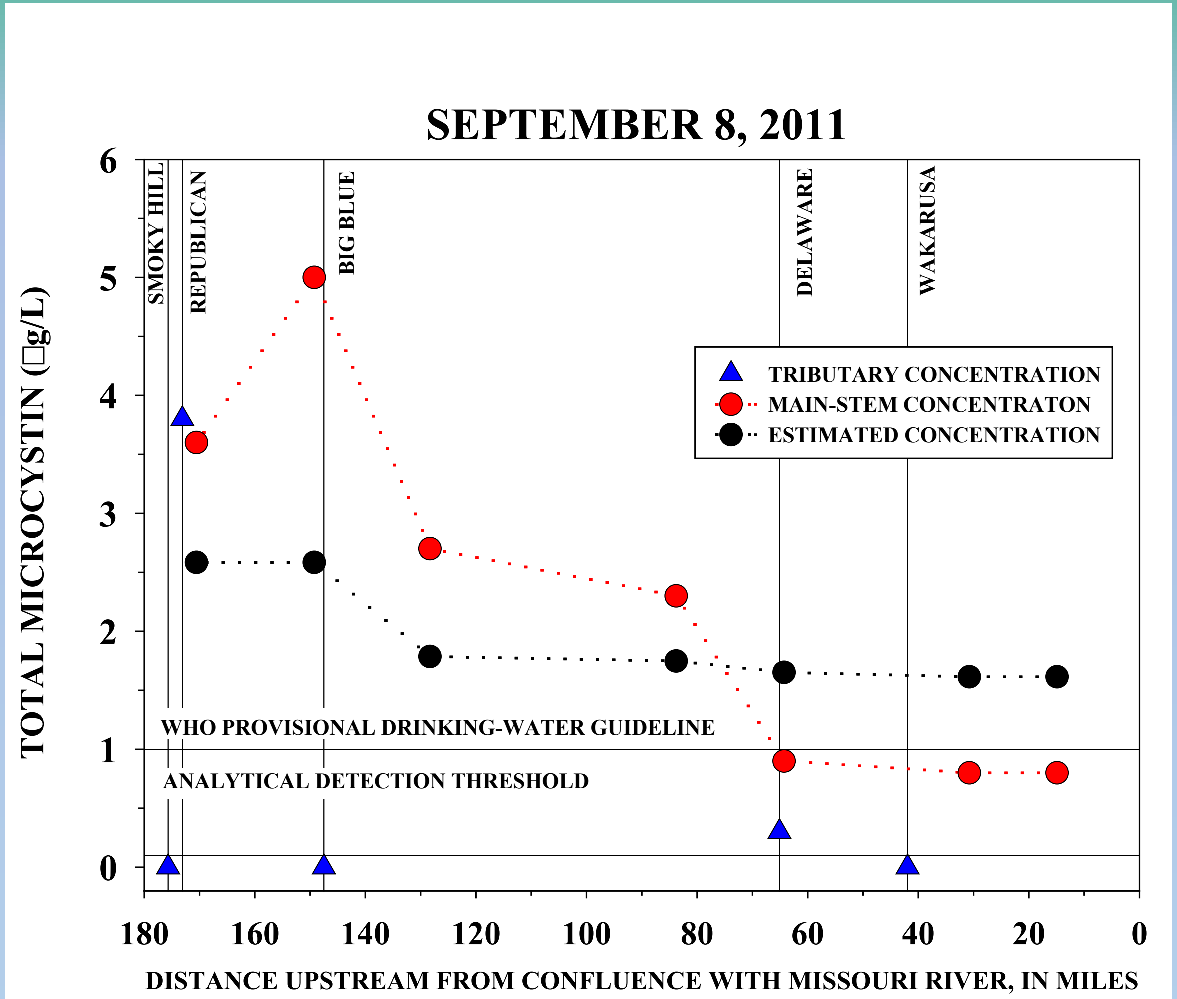
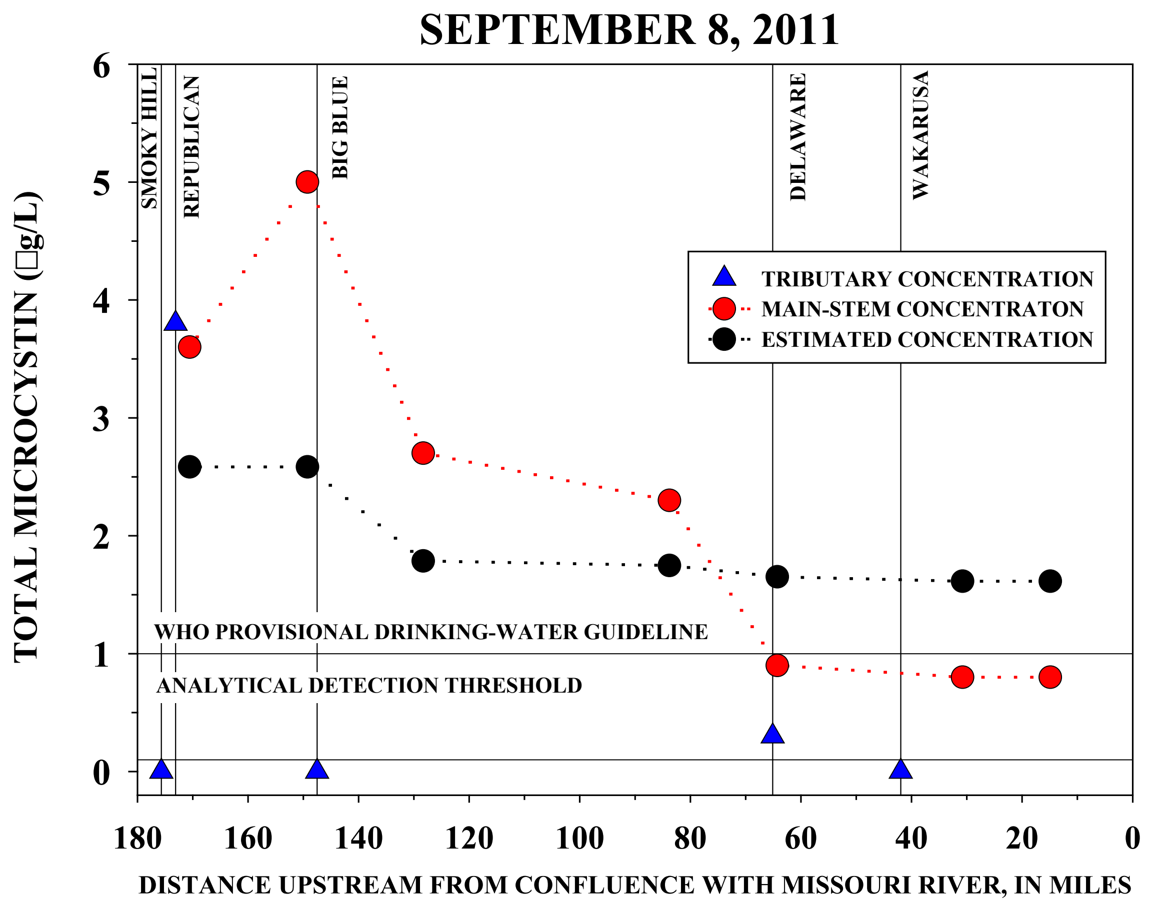
Cyanotoxins May Be Transported for Long Distances Downstream of Source Areas



Graham et al., 2012

Cyanotoxins May Be Transported for Long Distances Downstream of Source Areas



Graham et al., 2012

OPEN ACCESS Freely available online PLoS one

Evidence for a Novel Marine Harmful Algal Bloom: Cyanotoxin (Microcystin) Transfer from Land to Sea Otters

Melissa A. Miller[1,2*], Raphael M. Kudela[2], Abdu Mekebri[3], Dave Crane[3], Stori C. Oates[1], M. Timothy Tinker[4], Michelle Staedler[5], Woutrina A. Miller[6], Sharon Toy-Choutka[1], Clare Dominik[7], Dane Hardin[7], Gregg Langlois[8], Michael Murray[5], Kim Ward[9], David A. Jessup[1]

1 Marine Wildlife Veterinary Care and Research Center, California Department of Fish and Game, Office of Spill Prevention and Response, Santa Cruz, California, United States of America, 2 Ocean Sciences Depart
California Department of Fish and Game, O
Center, United States Geological Survey, Lo
States of America, 6 Department of Patholo
of America, 7 Applied Marine Sciences, Live
America, 9 Division of Water Quality, State

Photo Credit: Getty Images

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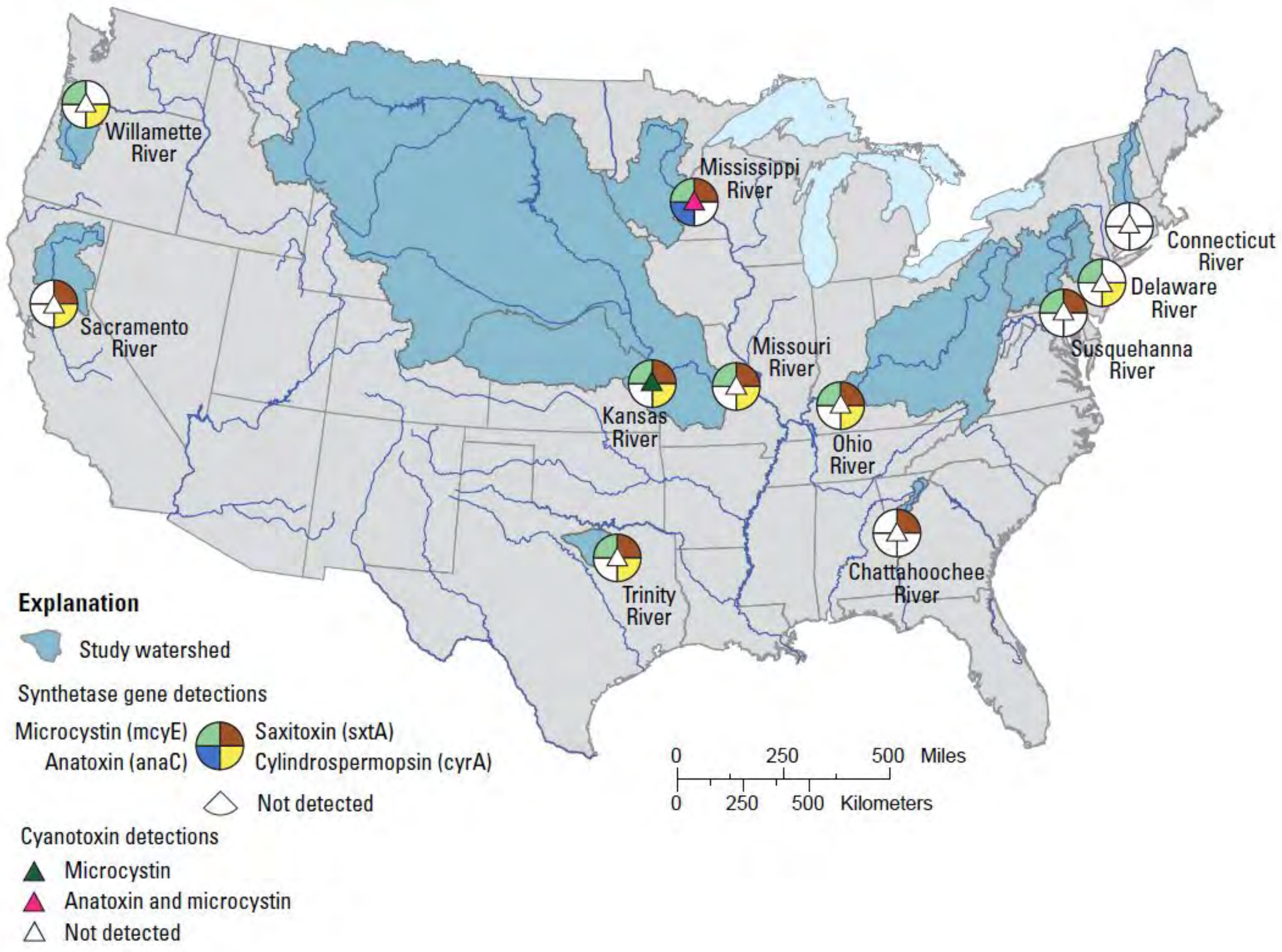
Advances in Analytical Approaches Allow Assessment of Occurrence in Novel Ways



Graham et al., 2020

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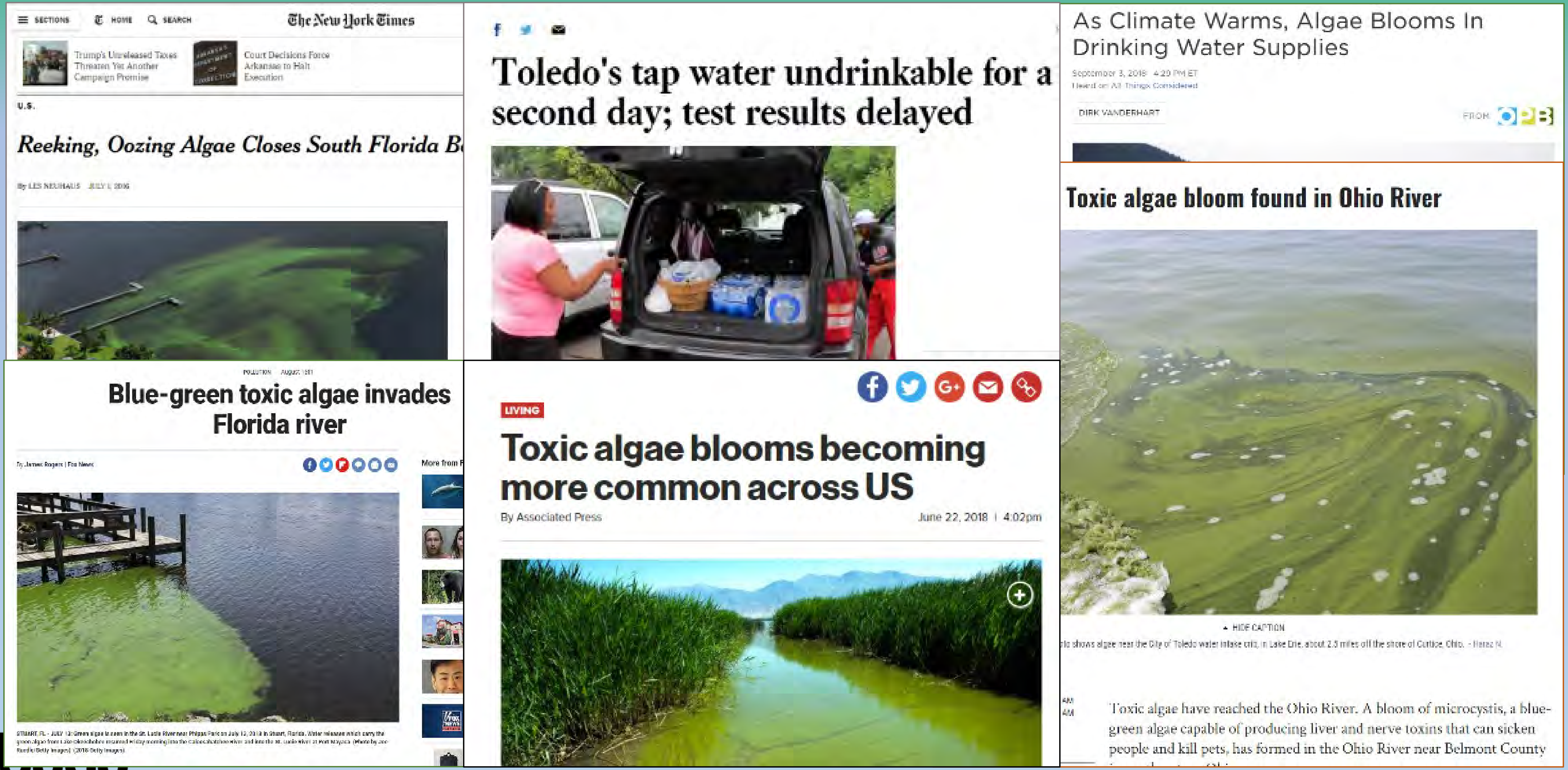
Is Cyanotoxin Occurrence Increasing?



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Slide Courtesy of T. Thorpe, University of Missouri

Cyanobacterial Abundance Has Increased

Toxins **2015**, *7*, 353-366; doi:10.3390/toxins7020353

OPEN ACCESS

toxins

ISSN 2072-6651

www.mdpi.com/journal/toxins

Article

Human Illnesses and Animal Deaths Associated with Freshwater Harmful Algal Blooms—Kansas

Ingrid Trevino-Garrison [1,†,*], Jamie DeMent [2,†], Farah S. Ahmed [1], Patricia Haines-Lieber [1], Thomas Langer [1], Henri Ménager [1], Janet Neff [1], Deon van der Merwe [3,†] and Edward Carney [1,†]

Time Period	Median Number of Health Alerts*
1989-1995	13
1996-2002	18
2003-2009	25

After Trevino-Garrison et al., 2015

*Based on 2010 Kansas Department of Health Public Health Alert Criteria (advisory ≥ 20,000 cells/mL; warning ≥ 100,000 cells/mL

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Has Cyanotoxin Occurrence and Concentration Increased?

Lake and Reservoir Management, 25:253–263, 2009

ISSN: 0743-8141 print / 1040-2381 online
DOI: 10.1080/07438140903143239

Microcystin in Missouri reservoirs

Jennifer L. Graham* and John R. Jones
Department of Fisheries and Wildlife Sciences, University of Missouri, 302 Anheuser-Busch Natural Resources Building, Columbia, MO, 65211-7420, USA

Table 4.-Annual means, medians, and maxima of total microcystin values. Summary statistics are based on samples collected during each year.

			Total microcystin (µg/L)				
Year	Reservoir n	% Detection	n	% Detection	Mean	Median	Maximum
2004	76	42	514	23	0.34	<0.1	21
2005	95	52	380	26	0.25	<0.1	11
2006	127	46	508	20	0.16	<0.1	4.9

Note: Reservoir n indicates the number of reservoirs sampled each year. n indicates the number of samples collected during each year.

Percentage of Monitoring Sites with Measurable toxins

Toxin	2017 n=99	2018 n=99
Cylindrospermopsin	16%	41%
Microcystin	83%	61%

Courtesy of T. Thorpe, University of Missouri

Results from reservoir sites sampled both seasons

Cylindrospermopsin
36 reservoirs, 1 sample each
% Detection: 14
Maximum: <1 µg/L

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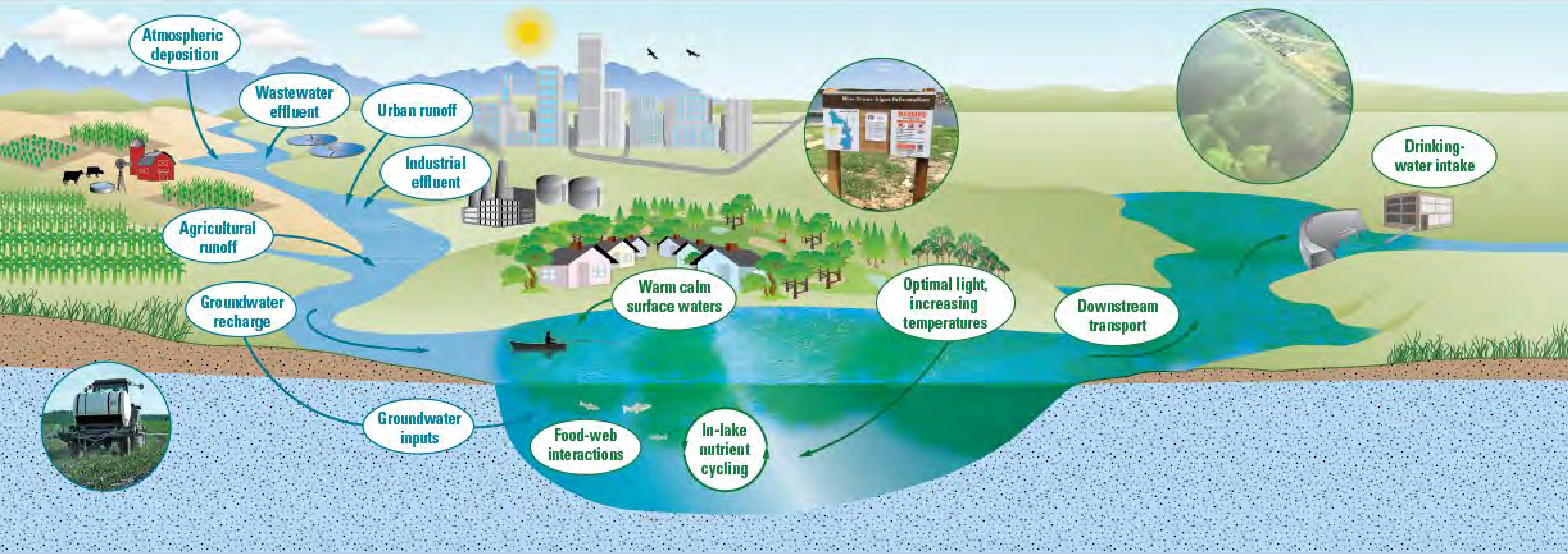
What Causes Cyanobacterial Blooms?



Graham et al., 2016

Paradigms Are Changing

Marine Pollution Bulletin 124 (2017) 591–606

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

ELSEVIER

Eutrophication, harmful algae and biodiversity — Challenging paradigms in a world of complex nutrient changes

CrossMark

Patricia M. Glibert

University of Maryland Center for Environmental Science, Horn Point Laboratory, PO Box 6775, Cambridge, MD 21613, USA

Blurred lines: Multiple freshwater and marine algal toxins at the land-sea interface of San Francisco Bay, California

Melissa B. Peacock[a,b,c,*], Corinne M. Gibble[b,d], David B. Senn[d], James E. Cloern[e], Raphael M. Kudela[b]

[a] *Northwest Indian College, 2522 Kwina Rd, Bellingham, WA, 98226, USA*
[b] *Ocean Sciences Department, 1156 High Street, University of California, Santa Cruz, CA 95064, USA*
[c] *San Francisco Estuary Institute, 4911 Central Avenue, Richmond, CA 94804, USA*
[d] *California Department of Fish and Wildlife, Office of Spill Prevention and Response, Marine Wildlife Veterinary Care and Research Center, 151 McAllister Way, Santa Cruz, CA 95060, USA*
[e] *United States Geological Survey MS496, 345 Middlefield Rd, Menlo Park, CA 94025, USA*

Review

Harmful algal blooms: A climate change co-stressor in marine and freshwater ecosystems

Andrew W. Griffith[a,b], Christopher J. Gobler[a,*]

[a] *School of Marine and Atmospheric Sciences, Stony Brook University, Southampton, NY, 11968, United States*
[b] *Department of Biological Sciences, University of Southern California, Los Angeles, CA 90089, United States*

The Spatiotemporal Variability of Cyanobacteria Poses Unique Challenges to Monitoring and Assessment

July 20, 2016 at 3:54 pm

Photo Credit: G. Foster, USGS

July 20, 2016 4:09 pm

Photo Credit: G. Foster, USGS

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Milford Lake, KS

Multiple Approaches from Cells to Satellites are Needed

Photo Credit: A. Horner, USGS

Photo Credit: PhycoTech, Inc

Landsat 8, Public Domain

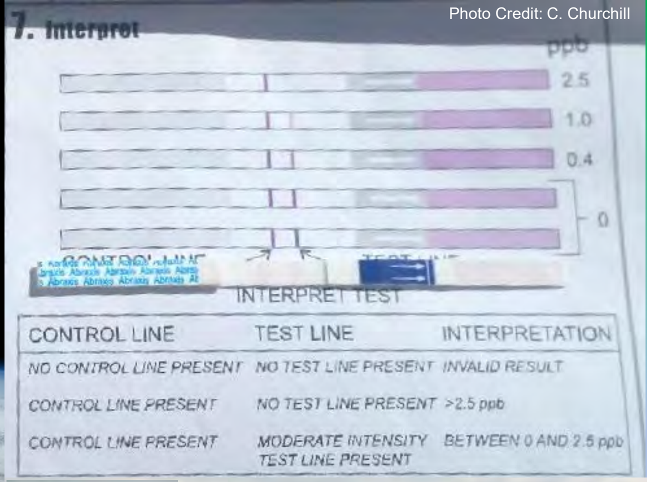
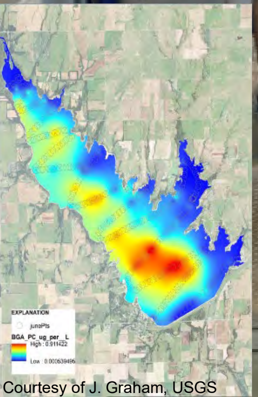


Photo Credit: C. Churchill

Photo Credit: McLane Research Laboratories, Inc.

Photo Credit: M. Broshnahan, WHOI

Photo Credit: J. Graham, USGS



Courtesy of J. Graham, USGS

Photo Credit: USGS

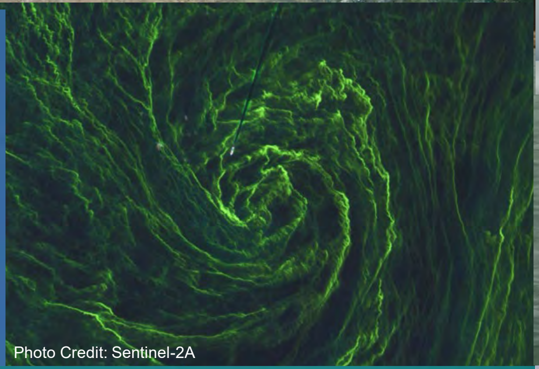
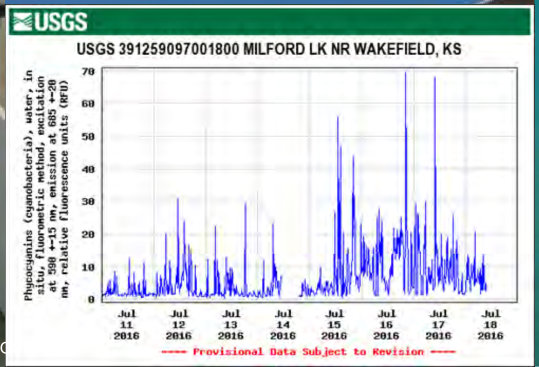


Photo Credit: Sentinel-2A



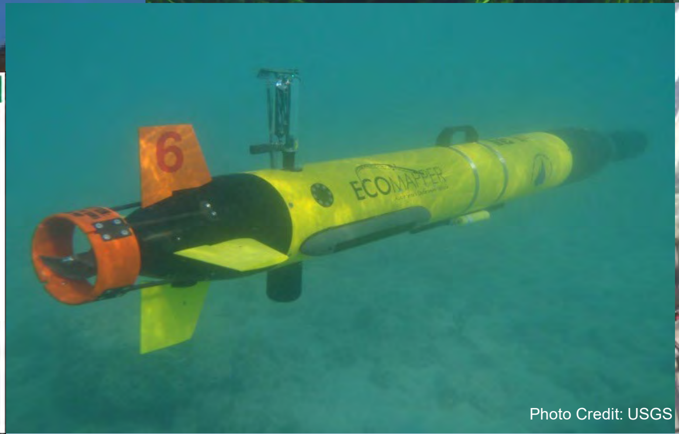


Photo Credit: USGS

Photo Credit: T. Davis

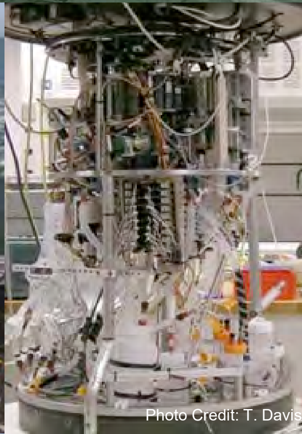
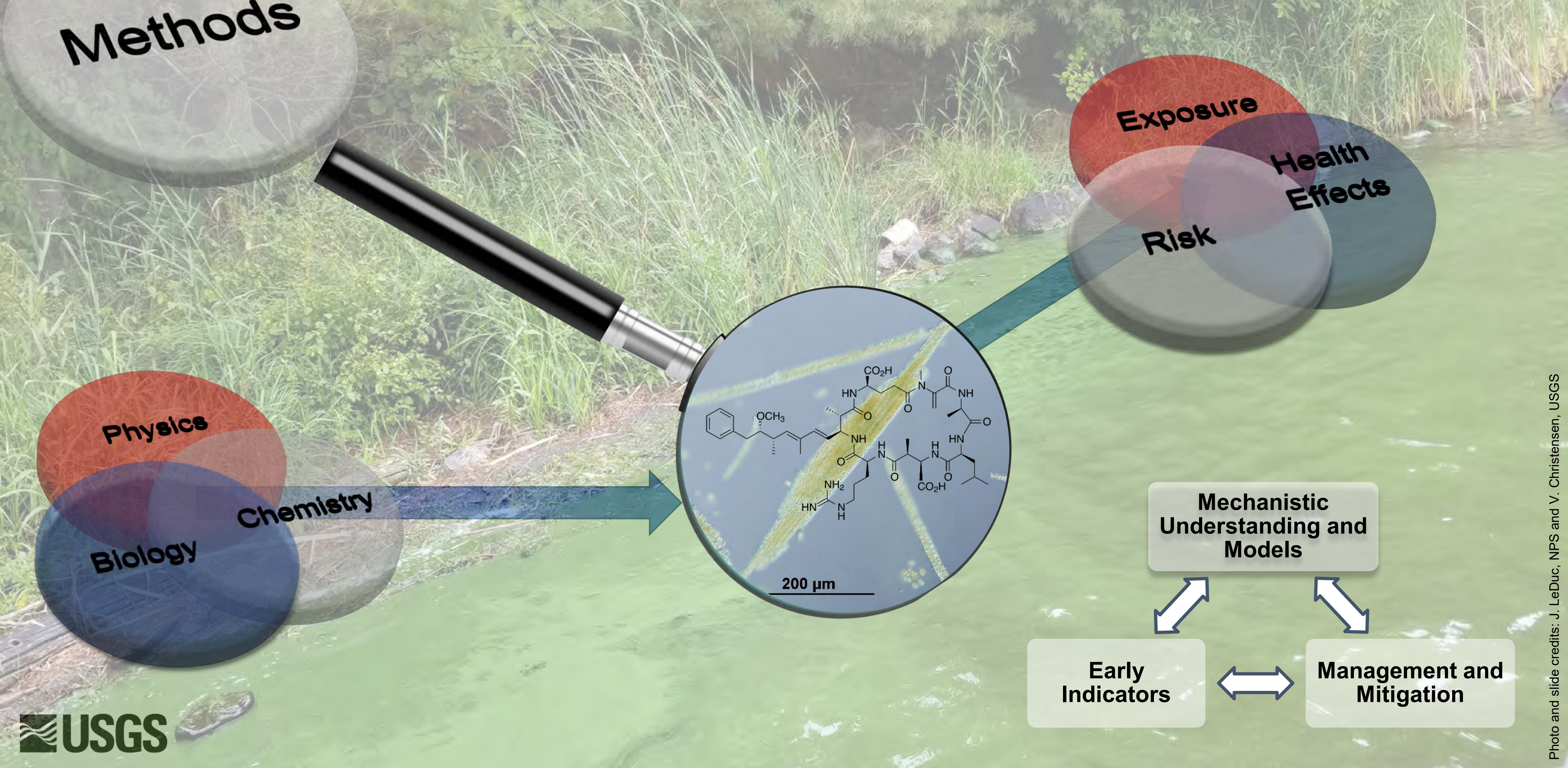


Photo Credit: T. Davis

Putting it All Together



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Harmful Algae and Cyanobacteria

Lorraine C. Backer, PhD, MPH

Senior Environmental Epidemiologist

Health Studies Section

Division of Environmental Health Science and Practice

AWWA Partners Meeting

June 23, 2021

Outline

- What are blooms?
- Marine algal toxins
- Cyanobacterial toxins
- Emerging issues
- Public health response
- CDC research

WHAT ARE BLOOMS?

What is a bloom?

- **A bloom is a proliferation of algae or cyanobacteria in water**
  - Supported by nutrients and warm water temperatures

Copco Lake, California, Summer 2007. Photo by Lorrie Backer

Karenia brevis red tide, Sarasota, Florida. Photo by Lorrie Backer

Blooms can be harmful to people, animals, or the environment if they

- Produce toxins (poisons);
- Become too dense;
- Use up the oxygen in the water; or
- Release harmful gases.

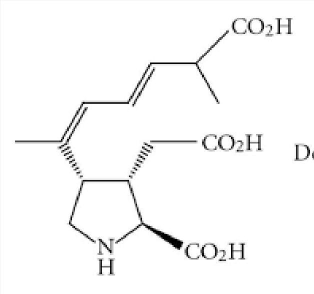
Photo courtesy of Allan Wilson


Photo by Lorrie Backer

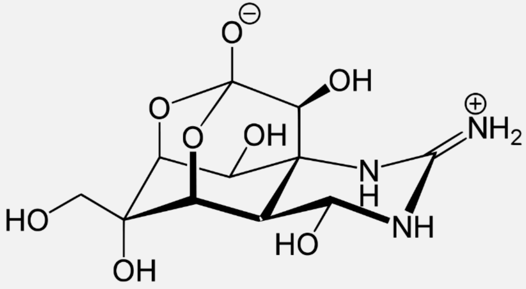
MARINE ALGAL TOXINS

Marine Algal Toxins That Affect People

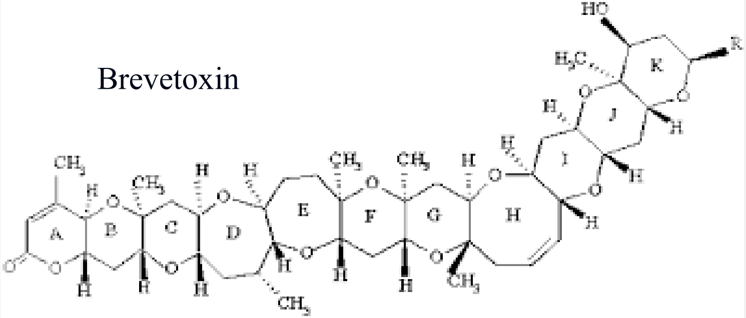
Saxitoxin



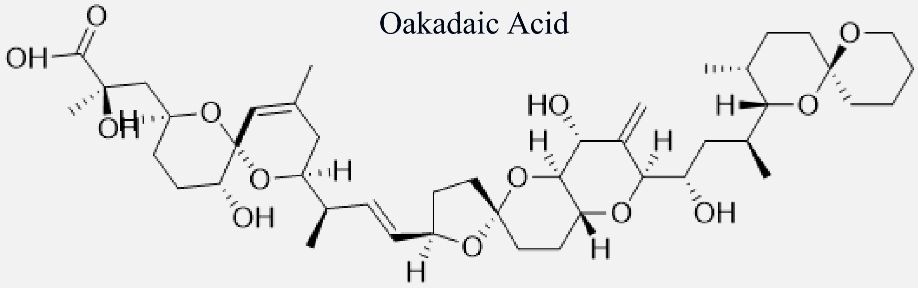
Domoic acid



Tetrodotoxin



Brevetoxin



Oakadaic Acid

Marine Algal Toxins: Potential Sources of Human and/or Animal Exposure

- **Recreational waters**
- **Shellfish**
- **Finfish**
- **Aerosols**

Photo courtesy of Dr. Robert Dickey

Photos by Lorrie Backer

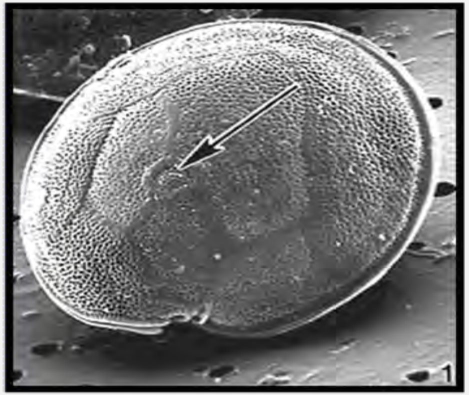
Courtesy of Dr. Lora Fleming

Marine Algal Toxins Produce Named Diseases

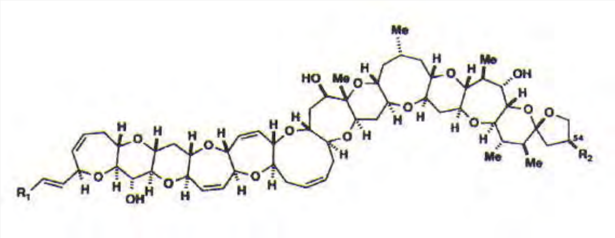
- **Shellfish Poisonings**
  - Diarrheic Shellfish Poisoning (okadaic acid)
  - Neurotoxic Shellfish Poisoning (brevetoxin)
  - Paralytic Shellfish Poisoning (saxitoxin)
  - Amnesic Shellfish Poisoning (domoic acid)
- **Fugu (pufferfish) poisoning (tetrodotoxin)**
- **Pufferfish poisoning (saxitoxin)**
- **Respiratory distress (aerosolized brevetoxins)**

Marine Algal Toxins: Ciguatera Fish Poisoning

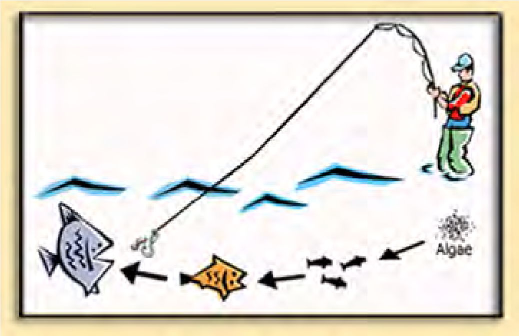
- **Most common food poisoning associated with a non-infectious agent**
- **Most common food poisoning associated with eating finfish**
- **~50,000 cases annually worldwide, many more unreported**



Gambierdiscus toxicus



Ciguatoxin



Food web transfer

Diseases/Conditions from Algal Toxins in Seafood

https://www.cdc.gov/habs/illness-symptoms-marine.html#contaminated-seafood

Disease or condition	Toxin-producing organism	Toxin(s)	Food	Acute symptoms	Chronic Symptoms
Azaspiracid poisoning (AZP)	Dinoflagellates *Proroperidiunium* species	Azaspiracid	Shellfish	GI distress, diarrhea, vomiting, stomach pain	Unknown
Diarrheic shellfish poisoning (DSP)	Dinoflagellates *Dinophysis* species, *Prorocentrum lima*	Okadaic acid	Scallops, mussels, clams, and oysters	Gastrointestinal distress, diarrhea, nausea, vomiting, stomach pain, possibly chills, headache, fever	Unknown
Domoic acid poisoning	Diatoms *Pseudo nitzchia* species	Domoic acid	Scallops, oysters, mussels, clams, oysters, possibly fish	Diarrhea, vomiting, abdominal pain	Possibly amnesia, impacts on cognitive function

Diseases/Conditions from Algal Toxins in Seafood, cont'd

Disease or condition	Toxin-producing organism	Toxin(s)	Food	Acute symptoms	Chronic Symptoms
Neurotoxic shellfish poisoning (NSP)	Dinoflagellates *Kareniabrevis* and other *Karenia* species	Brevetoxins	Mussles, oysters, scallops	GI distress, diarrhea, nausea, vomiting, numbness of lips, tongue, and throat, dizziness	Unknown
Paralytic shellfish poisoning (PSP)	Dinoflagellates *Gymonodinium catenatum*, *Pyrodinium bahamense*, *Alexandrium* species	Saxitoxins	scallops, mussels, clams, oysters, and cockles; some fish and crabs	GI distress, diarrhea, nausea, vomiting, shortness of breath, heart arrythmias, numbness of mouth and lips, weakness	Unknown
Ciguatera fish poisoning	Dinoflagellates *Gambierdiscus toxicus*, possibly others	Ciguatoxins, Maitotoxin, Scaritoxin	Reef fish such as barracuda, grouper, red snapper, and amberjack	GI distress, diarrhea, vomiting	Pain, weakness, abnormal sensations, low blood pressure

Marine Algal Toxins: Animal Health Impacts

- **2004 dolphin mortality in the Florida Panhandle**
- **Contaminated menhaden identified as the source of brevetoxin poisoning**
- **Menhaden were vectors to transfer brevetoxins up the food web**

Fleweling L., Naar J. *et al.* 2005 *Nature* 435:755-756

Courtesy of Florida Fish & Wildlife Conservation Commission

Marine Algal Toxins: Animal Health Impacts

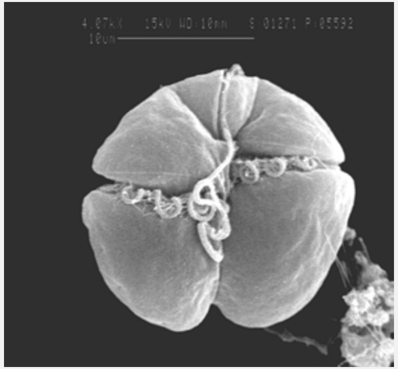
California sea lions affected by domoic acid exposure from *Pseudo-nitzschia* bloom

Photos courtesy of Lori Schwacke

Marine Algal Toxins: Ecologic impacts

- *Karenia brevis*
- Naturally-occurring dinoflagellate that produces brevetoxin
- Documented in Florida since the 1800s

Photo by Lorrie Backer



Karenia brevis courtesy of
Dr. Karen Steidinger

Marine Algal Toxins: Socio-economic Impacts

Karenia brevis red tide

Photo by Lorrie Backer

Marine Algal Toxins: Public Health Challenges

- **Harmful in minute (picogram) doses**
- **Cannot be detected by taste or smell**
- **Cannot be eliminated by storing or cooking**
    - Heat and acid stable
- **No cures for poisonings**
    - Supportive care
    - For ciguatera, IV mannitol
- **Efforts to mitigate the blooms limited**

CYANOBACTERIAL TOXINS

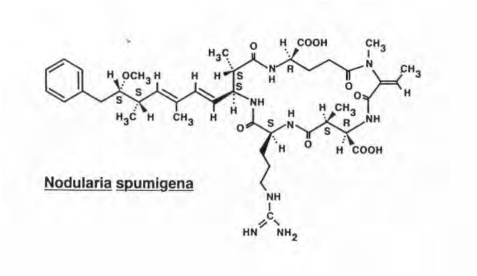
Freshwater Blooms: Cyanobacteria

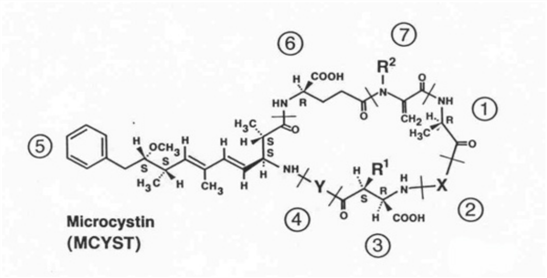
Utah Lake, Utah, summer 2016. *Photo by permission, Rick Egan, The Salt Lake Tribune*

Bloom in Lake Okeechobee, Palm Beach, Florida, summer 2016. *Photo by permission: Greg Lovett, The Palm Beach Post, via Associated Press.*

Cyanobacterial Toxins

- **Hepatoxins**
  - Microcystins
  - Nodularins
  - Cylindrospermopsin
- **Tumor promotor**
  - Microcystins

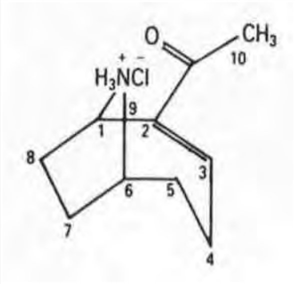




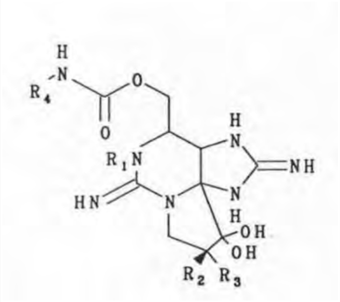
Microcystis aeruginosa
Copco Lake, California

Cyanobacterial Toxins

- **Dermatologic toxins**
  - Lyngbyatoxin
- **Neurotoxins**
  - Anatoxin
  - Anatoxin(a)
  - Saxitoxin
  - Neosaxitoxin



Anatoxin-a hydrochloride



Saxitoxin

Lyngbya wollei, Florida
Photo courtesy of Andy Reich

Cyanobacterial Toxins: Potential Sources of Human and/or Animal Exposure

- **Surface waters used for drinking water**
- **Recreational waters**
- **Hemodialysis using contaminated water**
- **Dietary supplements**
  - Klamath Blue-green Algae
- **Freshwater fish**

Lake Erie *Microcystis* bloom 2014.
Photo from NOAA.

Copco Lake, California, October 2007.
Photo by Lorrie Backer

Potential Chronic Human Health Effects

- **No “named” diseases as with marine HABs**
- **Potential effects**
  - Primary liver cancer
  - Kidney damage
  - Neurodegenerative disease

Cyanobacterial Toxins: Animal Health Impacts. Sea Otters in Monterey Bay, California, 2007

- **21 southern sea otters succumbed to poisonings**
  - Necropsies found liver toxicity typically associated with microcystin poisoning
- **High concentrations of microcystins in farmed and free-living shellfish**
  - Transferred via food web
  - Potential for human exposure
- **Three nutrient-impaired rivers that support Microcystis blooms drained into the Bay**

Miller et al. 2010. Evidence for a Novel Marine Harmful Algal Bloom: Cyanotoxin (Microcystin) transfer from Land to Sea Otters, PLOS One;5(9): e12576.

Cyanobacterial Toxins: Socioeconomic Impacts

Microcystis aeruginosa bloom affects Toledo drinking water source (August 2014)

- *Microcystis* bloom in Lake Erie
- Near Toledo's water supply intake
  - Utilities had to respond
- Do Not Drink & Do Not Boil advisories for about 2 days
- Federal government, other entities supplied bottled water

Satellite photo: MODIS 8-13-14

Cyanobacterial Toxins: Ecologic Impacts

Copco Lake, California, Summer 2007. Photo by Lorrie Backer

EMERGING ISSUES

Emerging Issues

- **Benthic blooms**
  - Produce anatoxin and homoanatoxin
- **Increased frequency and geographic extent of harmful blooms**
  - Possibly due to increased monitoring and reporting
- **Monitoring and predicting toxicity**

PUBLIC HEALTH RESPONSE

Public Health Response: Guidance

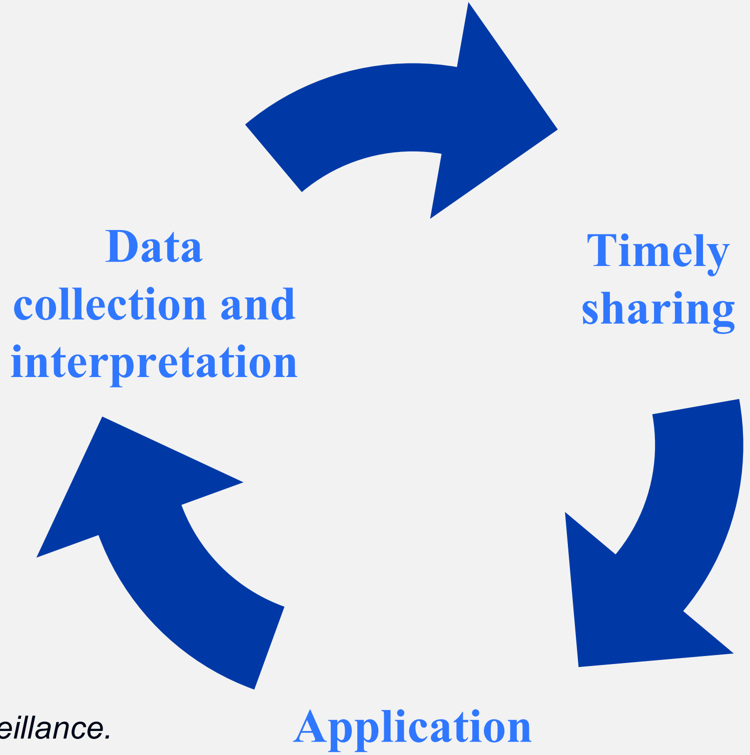
- **WHO health-based reference for anatoxin-a**
  - Drinking water (acute) 30 µg/L
  - Recreational waters 60 µg/L
- **Countries and states developed guidance**
- **U.S. EPA Health Advisories**

Cyanotoxin	Drinking Water Health Advisory (10-day)	
	Bottle-fed infants and pre-school children	School-age children and adults
Cylindrospermopsin	0.7 µg/L	3.0 µg/L
Microcystins	0.3 µg/L	1.6 µg/L

Public Health Response: Disease Surveillance

What is public health surveillance?

The ongoing, systematic collection, analysis, and interpretation of outcome-specific data for use in the planning, implementation, and evaluation of public health practice.



Teutsch and Churchill , Principles and Practice of Public Health Surveillance. 2000. Oxford University Press

Public Health Response: Disease Surveillance

Voluntary, electronic reporting to CDC

- Systematic data collection: HAB events, human cases, animal cases
- Nationally available (voluntary reporting, launched in 2016)
  - State and territorial public health partners and their designated environmental health and animal health partners
- Web-based, password-protected system
- Event-based reporting (not routine monitoring)

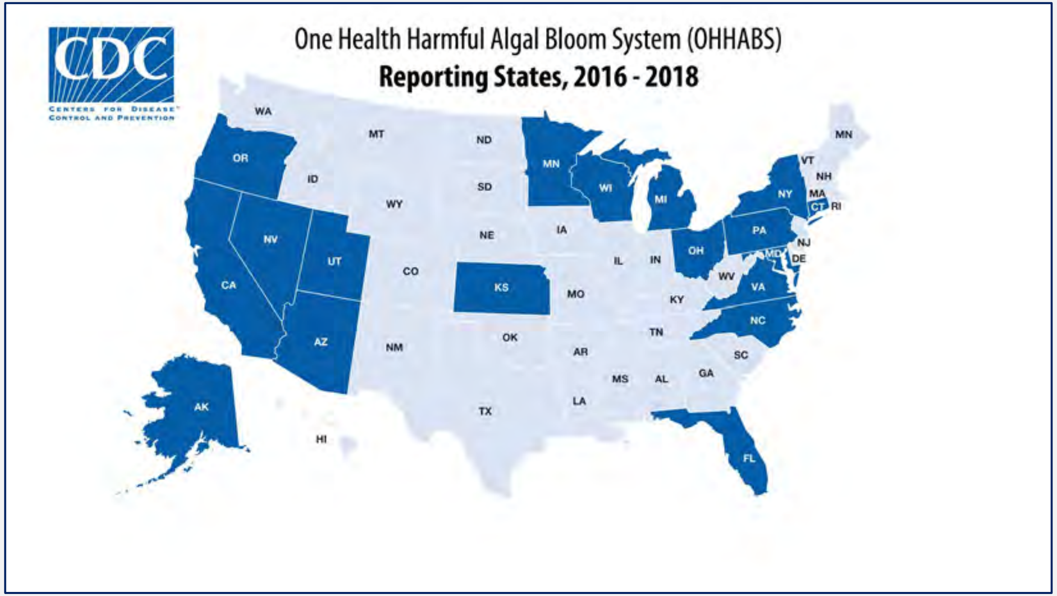
Reporting frequency

- Passive surveillance
- Not a real-time notification or case investigation system

Public Health Response: Disease Surveillance, cont’d

For 2016—2018, 18 states were early adopters of OHHABS and reported 421 HAB events

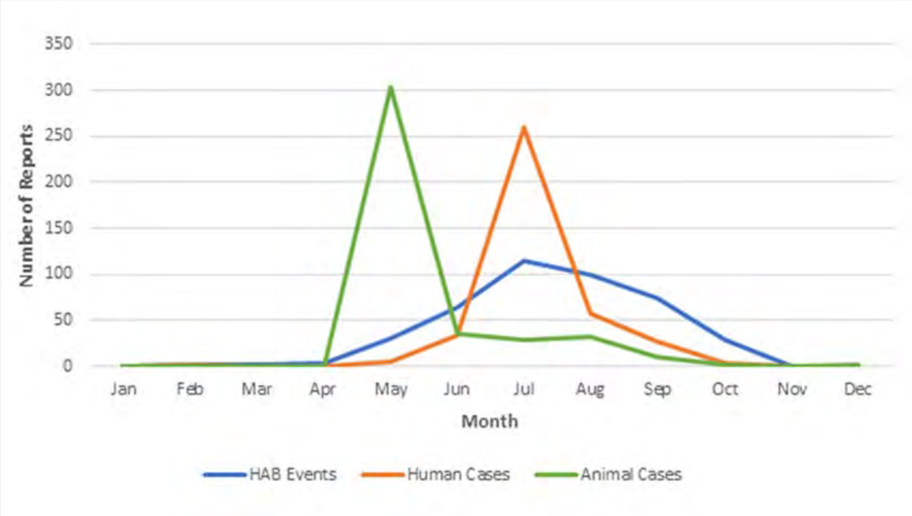
- **389 human illnesses**
  - No deaths
- **413 animal illnesses**
  - 369 deaths



https://www.cdc.gov/mmwr/volumes/69/wr/mm6950a2.htm?s_cid=mm6950a2_w

Public Health Response: Disease Surveillance, cont'd

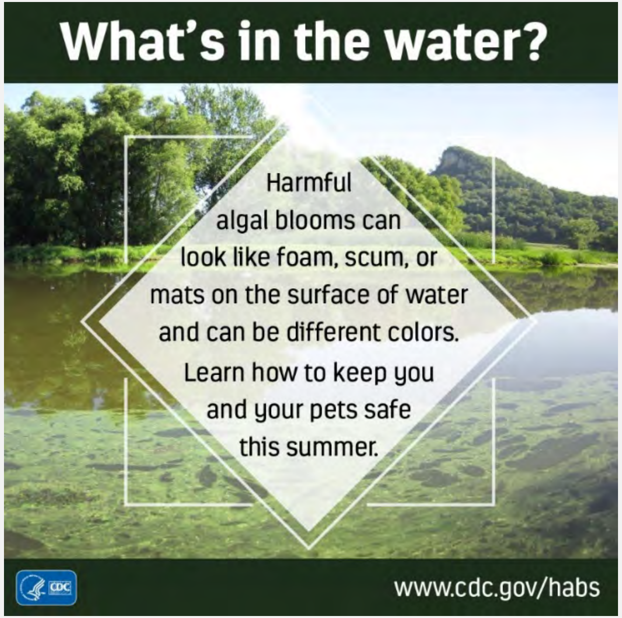
- **Almost all reported HAB events (90%) were freshwater cyanobacterial blooms**
- **Two events resulted in**
  - 51% of human cases
  - 73% of animal cases



Public Health Response: Disease Surveillance, cont'd

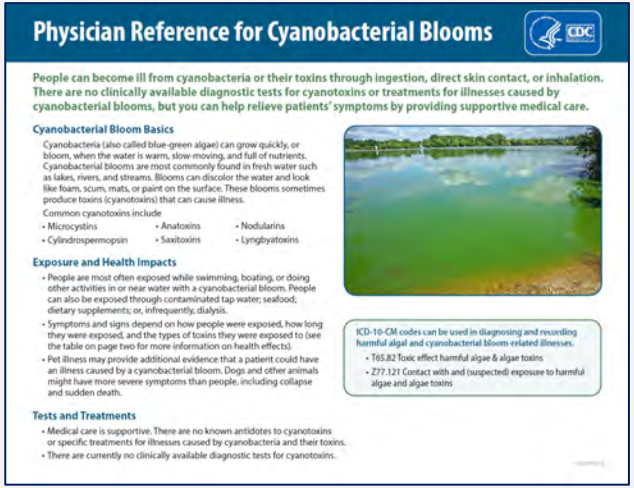
- **A continued One Health approach to surveillance, paired with scientific research findings and increased access to specimen testing, will improve the system**

Public Health Response: Communication



https://www.cdc.gov/habs/materials/buttons-badges.html

Public Health Response: Communication


Physician Reference for Cyanobacterial Blooms

CDC

People can become ill from cyanobacteria or their toxins through ingestion, direct skin contact, or inhalation. There are no clinically available diagnostic tests for cyanotoxins or treatments for illnesses caused by cyanobacterial blooms, but you can help relieve patients' symptoms by providing supportive medical care.

Cyanobacterial Bloom Basics

Cyanobacteria (also called blue-green algae) can grow quickly, or bloom, when the water is warm, slow-moving, and full of nutrients. Cyanobacterial blooms are most commonly found in fresh water such as lakes, rivers, and streams. Blooms can discolor the water and look like foam, scum, mats, or paint on the surface. These blooms sometimes produce toxins (cyanotoxins) that can cause illness.

Common cyanotoxins include

- Microcystins
- Anatoxins
- Nodularins
- Cylindrospermopsin
- Saxitoxins
- Lyngbyatoxins

Exposure and Health Impacts

- People are most often exposed while swimming, boating, or doing other activities in or near water with a cyanobacterial bloom. People can also be exposed through contaminated tap water; seafood; dietary supplements; or, infrequently, dialysis.
- Symptoms and signs depend on how people were exposed, how long they were exposed, and the types of toxins they were exposed to (see the table on page two for more information on health effects).
- Pet illness may provide additional evidence that a patient could have an illness caused by a cyanobacterial bloom. Dogs and other animals might have more severe symptoms than people, including collapse and sudden death.

ICD-10-CM codes can be used in diagnosing and recording harmful algal and cyanobacterial bloom-related illnesses.

- T65.82 Toxic effect harmful algae & algae toxins
- Z77.121 Contact with and (suspected) exposure to harmful algae and algae toxins

Tests and Treatments

- Medical care is supportive. There are no known antidotes to cyanotoxins or specific treatments for illnesses caused by cyanobacteria and their toxins.
- There are currently no clinically available diagnostic tests for cyanotoxins.


Veterinarian Reference for Cyanobacterial Blooms

CDC

Dogs, livestock, and other animals can suffer severe illness or death within minutes to days of swallowing toxins from cyanobacterial blooms. Providing supportive medical care soon after exposure can save an animal's life.

Cyanobacterial Bloom Basics

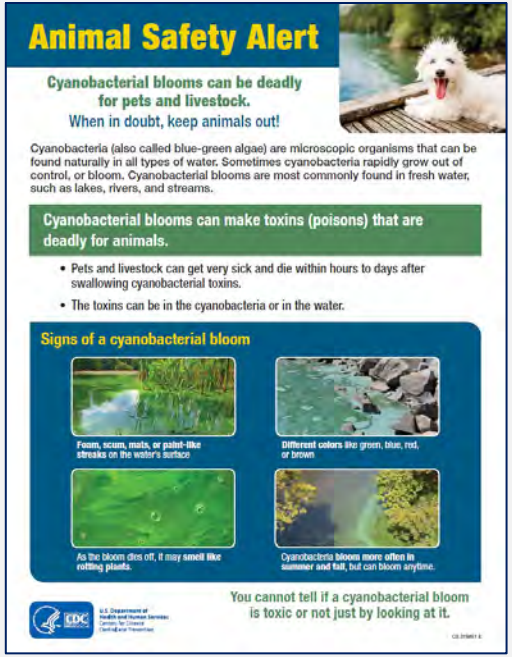
Cyanobacteria (also called blue-green algae) can grow quickly, or bloom, when water is warm, slow-moving, and full of nutrients. Cyanobacterial blooms are most commonly found in fresh water, such as lakes, rivers, and streams. These blooms can discolor the water and look like foam, scum, mats, or paint on the surface, but some blooms are hard to see because they grow below the water's surface. These blooms sometimes produce toxins (cyanotoxins) that can be lethal to animals.

Exposure and Health Impacts

- Dogs and other animals are often exposed by drinking contaminated water, swallowing water while swimming, or licking cyanobacteria from their fur.
- Dogs and other animals can become seriously ill or die suddenly after exposure. Signs depend on how they were exposed, how long they were exposed, and the types of toxins they were exposed to.
- Monogastric animals appear to be less sensitive than ruminants or birds; however, the dose-response curve is very steep in dogs—up to 90% of a lethal dose may elicit no clinical signs.

Tests and Treatments

- There are currently no clinically available tests or designated treatments.
- Medical care is supportive. There are no known antidotes to these toxins.
- Activated charcoal may be useful within the first hour, and atropine has efficacy with saxitoxin exposure.
- There is some evidence that treatment with cholestyramine may be helpful for dogs exposed to microcystins.


Animal Safety Alert

Cyanobacterial blooms can be deadly for pets and livestock.
When in doubt, keep animals out!

Cyanobacteria (also called blue-green algae) are microscopic organisms that can be found naturally in all types of water. Sometimes cyanobacteria rapidly grow out of control, or bloom. Cyanobacterial blooms are most commonly found in fresh water, such as lakes, rivers, and streams.

Cyanobacterial blooms can make toxins (poisons) that are deadly for animals.

- Pets and livestock can get very sick and die within hours to days after swallowing cyanobacterial toxins.
- The toxins can be in the cyanobacteria or in the water.

Signs of a cyanobacterial bloom

- Foam, scum, mats, or paint-like streaks on the water's surface
- Different colors like green, blue, red, or brown
- As the bloom dies off, it may smell like rotting plants.
- Cyanobacteria bloom more often in summer and fall, but can bloom anytime.

You cannot tell if a cyanobacterial bloom is toxic or not just by looking at it.

CDC U.S. Department of Health and Human Services Centers for Disease Control and Prevention

https://www.cdc.gov/habs/materials/reference-cards.html

CDC RESEARCH

Past Reports:

- **During past blooms, community members reported various non-specific symptoms**
  - Respiratory irritation, nausea, headache, asthma exacerbations

- **Some evidence that exposure may affect biomarkers**
  - Serum liver enzyme levels

Field Research

- **Past work: respiratory effects from brevetoxins and microcystins**
  - Brevetoxins are detectable in sea water and sea breezes
    - Healthy people experience respiratory irritation that resolves once the exposure ends
    - People with asthma may have lingering health effects
  - Microcystins are detectable in fresh water, aerosols, and on nasal swabs
    - Healthy people did not report respiratory symptoms after 1 hour exposure doing recreational activities

Field Research: Cyanotoxins in Aerosols Study (CAST)

- Recruit participants in Florida near Lake Okeechobee
- Collect data over 5 days throughout the bloom season
  - Biospecimens (blood, urine, nasal swabs)
  - Lung function tests
  - Symptom surveys
  - Environmental samples

Research with Existing Data

- **Lavery et al. Evaluation of Electronic Health Records to Monitor Illness From Harmful Algal Bloom Exposure in the United States**
  - Marketscan research databases
  - *Lavery A, Backer L, Daniel J. Evaluation of electronic health records to monitor illness from harmful algal bloom exposure in the United States. Journal of Environmental Health. 2021;83(9):8-15.*
- **Lavery et al. Evaluation of Syndromic Surveillance Data to Monitor Illness from Harmful Algal Bloom Exposure, United States 2017 – 2019**
  - MMWR—in review

Research with Existing Data, cont'd

- **Long-term project to use existing data to estimate the probability a given water body will experience a bloom that poses a public health risk**
  - Partners: U.S. EPA, USGS, NOAA, NASA, states
  - Environmental data
    - CyAN: Cyanobacteria Assessment Network
    - USGS monitoring
  - Health data
    - Electronic health records

CONCLUSIONS

Summary

- **Toxins from algae and cyanobacteria pose a public health threat**
- **There is a record of marine HAB toxin poisonings going back many centuries**
- **Much more to learn about harmful cyanobacterial blooms**

Thank you!

Contact information
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lbacker@cdc.gov
770-488-3426

Cyanobacterial bloom in Bear Lake, MI. Photo by Lorrie Backer

Karenia brevis red tide fish kill. Photo by Lorrie Backer

For more information, contact NCEH
1-800-CDC-INFO (232-4636)
TTY: 1-888-232-6348 www.cdc.gov
Follow us on Twitter @CDCEnvironment

Strategies For Preventing, Managing, And Responding To Harmful Cyanobacteria Blooms

TEAM LEADERS:

ANGELA SHAMBAUGH, VT DEPARTMENT OF ENVIRONMENTAL CONSERVATION (RETIRED)

BECKYE STANTON, CA OFFICE OF ENVIRONMENTAL HEALTH HAZARD ASSESSMENT

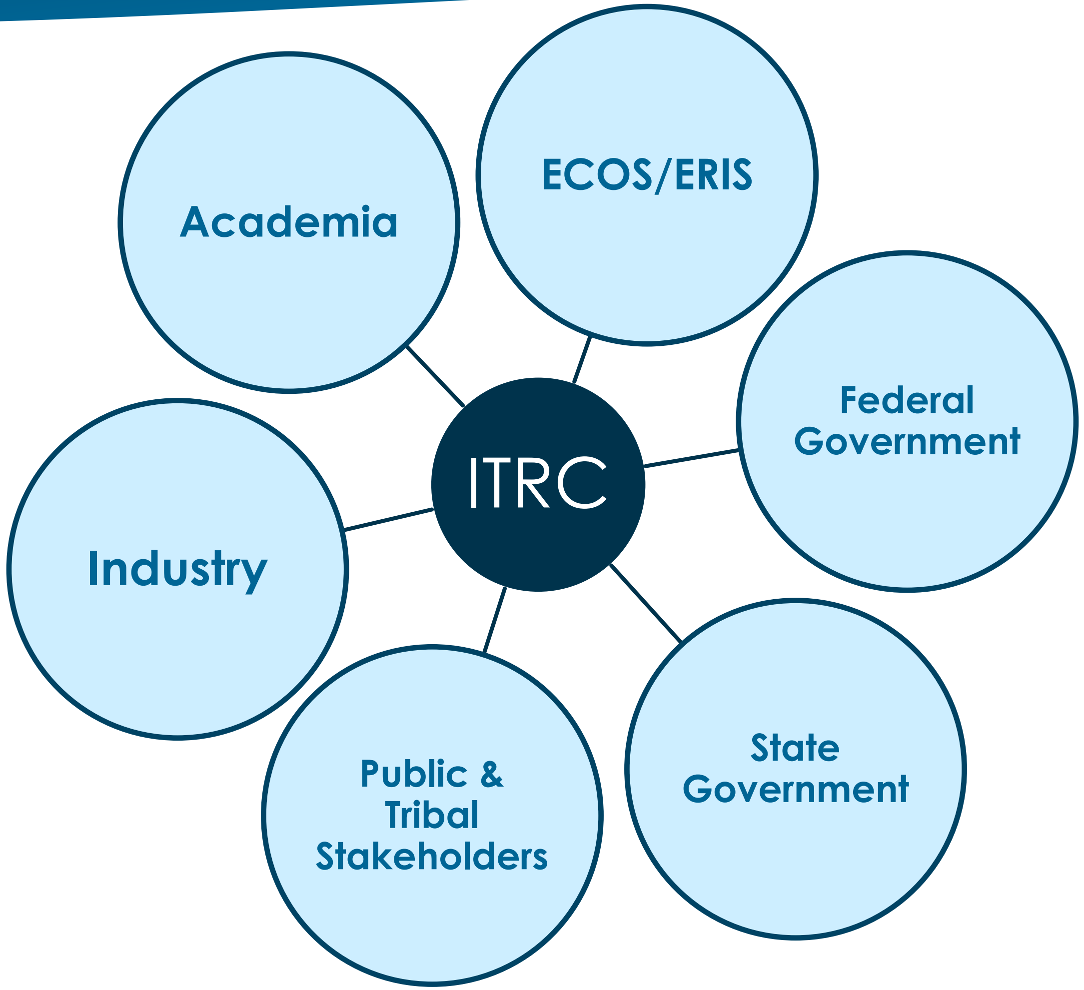
BEN HOLCOMB, UT DIVISION OF WATER QUALITY

CHERRI BAYSINGER, CYMBELLA CONSULTING

USACE, NALMS, AWWA, APMS Source Water Protection
Summer Series
June 23, 2021

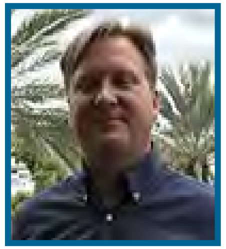
What is the Interstate Technology and Regulatory Council (ITRC)?

- a state-led coalition.
- Share innovative technologies
- Use good science
- Create **networks of technical experts**



The Harmful Cyanobacteria Bloom Team: 2019 - 2020

Team Leaders



Ben Holcomb
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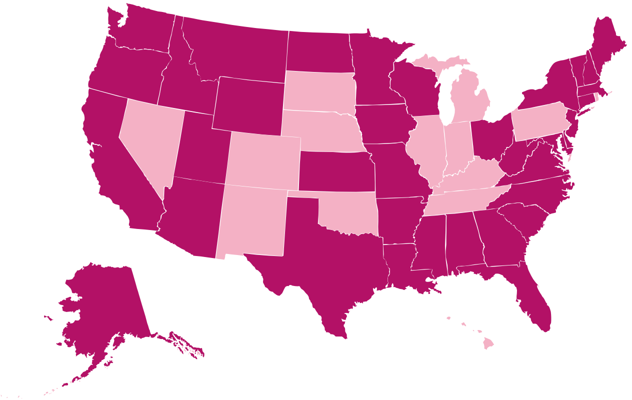
Angela Shambaugh
Vermont DEC, retired
adshambaugh@myfairpoint.net

- Nearly 300 participants from
  - State staff
  - Regional and municipal staff
  - Academia
  - Federal Agencies
  - Industry
  - Lake associations, NGOs



Consensus-driven Process To Final Guidance

Team Outlines Document Goals

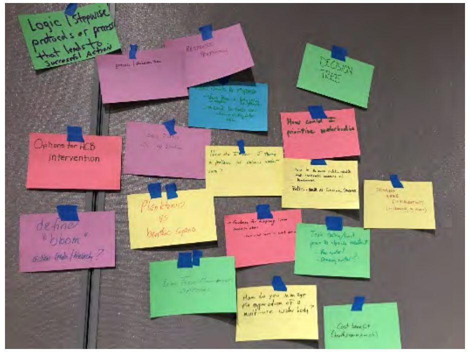
→ Writing Group A
→ Writing Group B
→ Writing Group C

→ Team Meetings:

Monthly calls

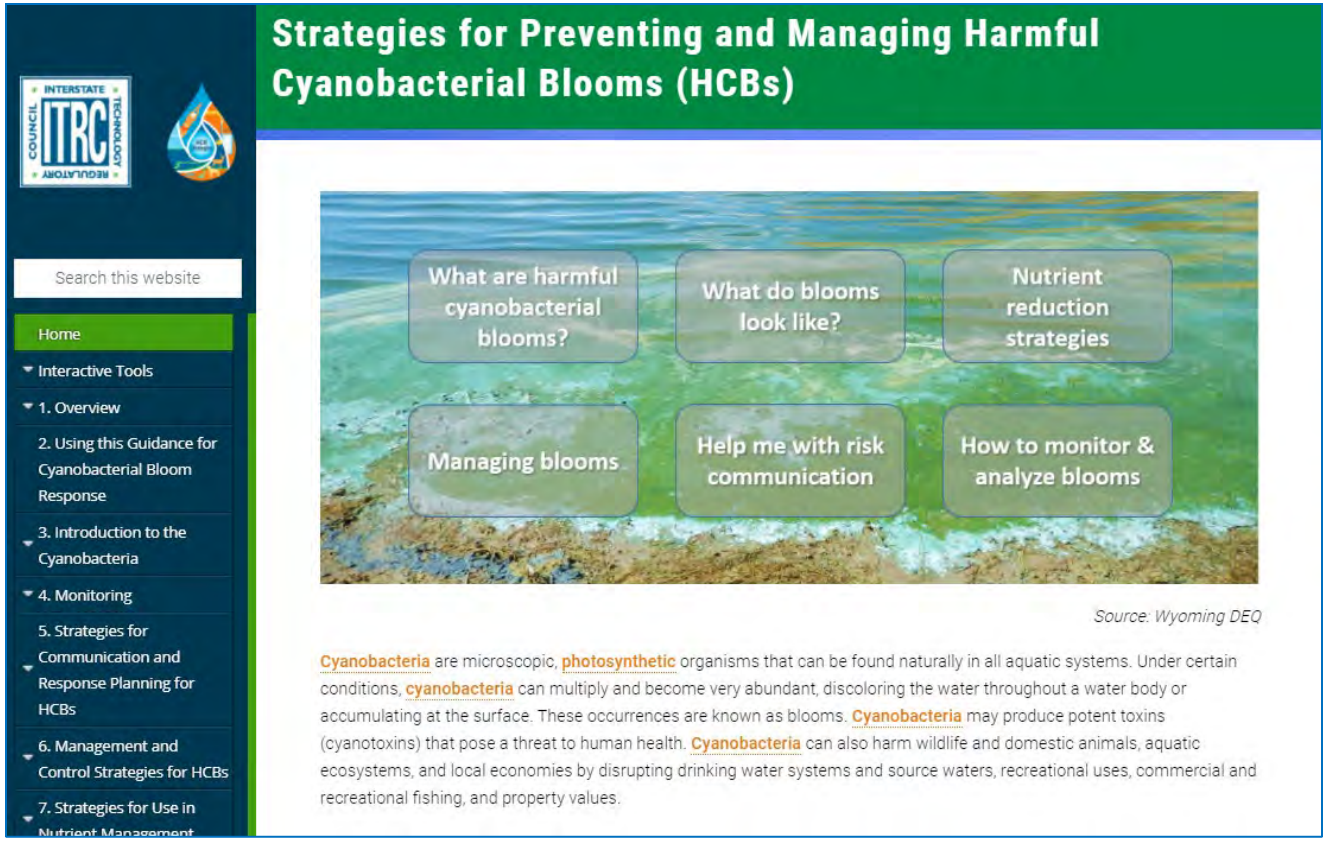
In person meetings (2/year)

→ External Review



Key Elements Of The HCB Guidance

- Introduction to Cyanobacteria
- Monitoring
- Communication and Response
- In-lake Management
- Nutrient Management for Prevention
- Recommendations
- Visual Guide



Section 3 - Introduction To Cyanobacteria

- Summarizes current knowledge
  - Health impacts
    - People and animals
  - Environmental impacts
  - Economic impacts

Figure A - 42. *Microcystis aeruginosa*, Marion Reservoir, KS.

Photo: Elizabeth Fabri Smith. Used with permission.

Section 3 - Introduction To Cyanobacteria

- Discusses environmental interactions that may offer control or management options

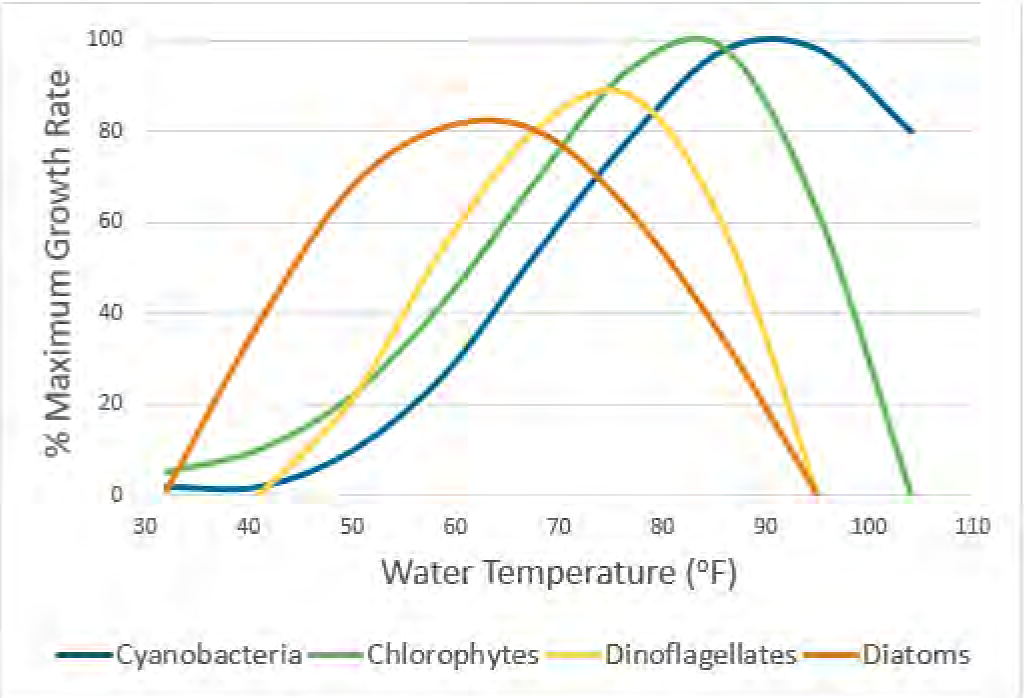
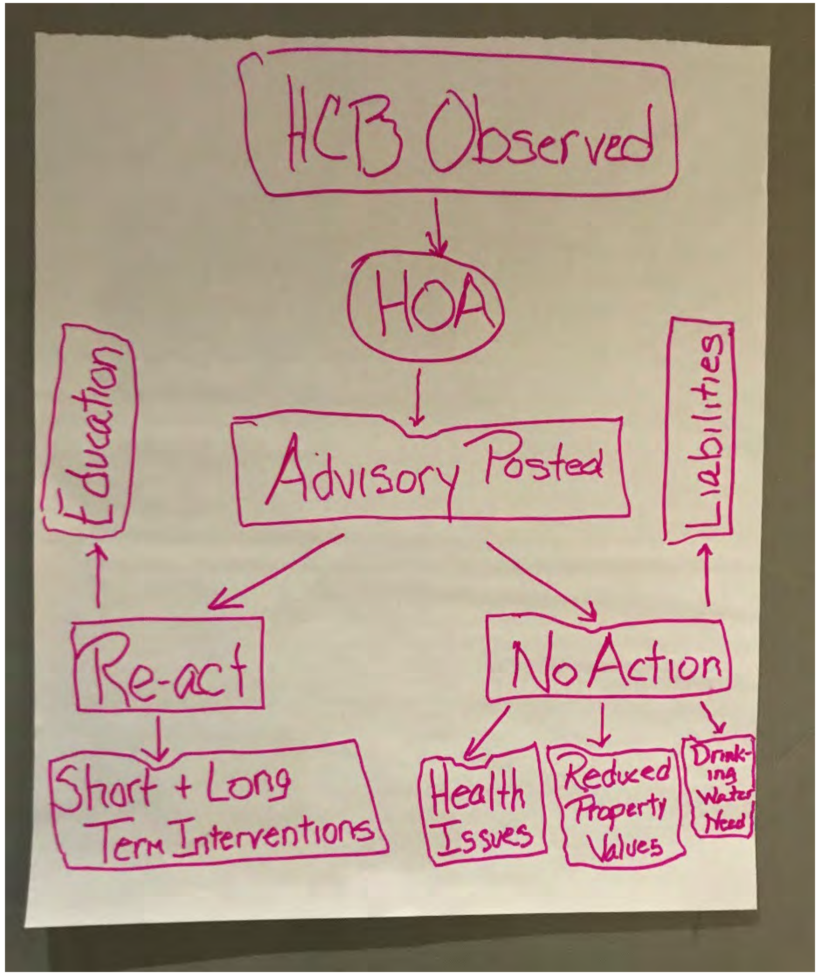


Figure 1. High temperature selection of cyanobacteria relative to other common phytoplankton groups.

Figure source: Modified from Paerl 2014. Used with permission.

Section 3 - Introduction To Cyanobacteria

- Guidance to create a HCB Management Plan
  - Finding and using historical data
  - Working with partners and stakeholders
  - Identifying strategies
  - Resources



Appendix A - The ITRC Visual Guide

- Images of Common HCB taxa
  - Field view
  - Microscopic views
- Cyanotoxin overview

Dolichospermum (Anabaena) lemmermannii **– Description and Microscopic Images**

Description: Gas vesicles occur obligatorily in cells in vegetative phase. They are joined into irregular aerotopes (sooner "gas vesicles") over the whole cell volume; aerotopes are recognizable in cells under optical microscope. Heterocytes arise intercalarly, solitary. Akinetes develop paraheterocytically (in the middle of filaments), heterocytes adjacent to or in between akinetes. Often forms the pattern of akinete-heterocyte-akinete. Akinetes often arise after fusion of two or few neighboring vegetative cells. The ripe akinetes are usually three or more-times larger than vegetative cells. Planktic in vegetative state, never form sessile mats on the substrate. The filaments in small, contorted clusters with akientes clustered in center of colony. Protozoans (Vorticella) often attached to colonies.

Secondary Compounds: Toxin, Taste and Odor Producer

Growth Habit: Forms scums in calm weather, can look like blue-green, cyan, or pink paint on the water surface or on substrates around the shoreline.

Appendix A - The ITRC Visual Guide

- Images of things commonly mistaken for HCBs

MANY thanks to Ann St. Amand, PhycoTech,
for putting this together!

Mougeotia sp.

Figure A - 132. Chlorophyte, *Mougeotia* sp.

Photo: Steve Heiskary, MPCB. Used with permission.

Figure A - 133. Chlorophyte, *Mougeotia* sp.

Photo: Steve Heiskary, MPCB. Used with permission.

Section 4 - Monitoring For Cyanobacteria

- Counts and measures cyanobacteria and/or cyanotoxins
  - What kind
  - How much
  - When
  - Where
- Other water quality parameters of potential use

Figure A-61. ***Planktothrix*** **spp., Clear Lake, MN. This taxon often forms dispersed subsurface blooms.**

Source: Rachel Crabb, Minneapolis Park & Recreation Board. Used with permission.

Section 4 - Methods For Monitoring

Cyanobacteria:

Visual Assessment
Jar/stick Tests
Pigments
Remote Sensing
Microscopy
Genetic Methods for ID
Automated Methods

Cyanotoxins:

Strip Test/Dipsticks
PPIA
ELISA
Mass Spectroscopy
Chromatography
Genetic Methods for Cyanotoxins

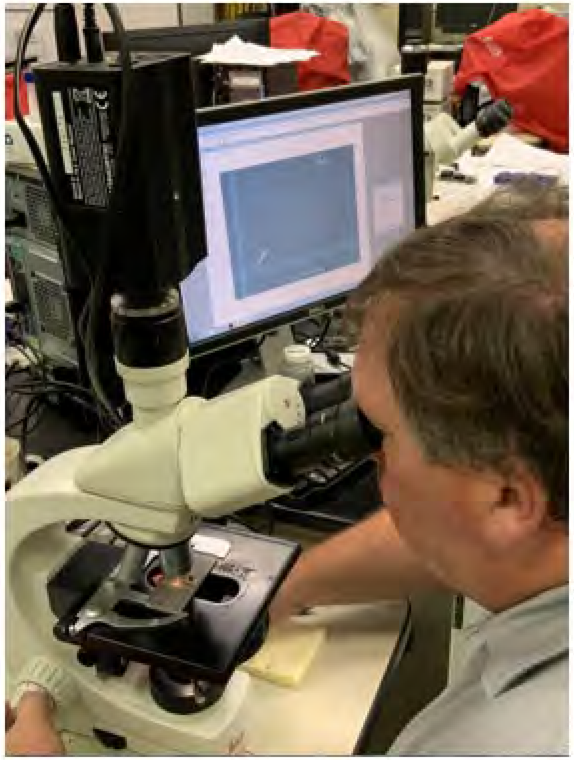


Figure 8. Using a microscope to identify cyanobacteria.

Figure Source: NJ DEP

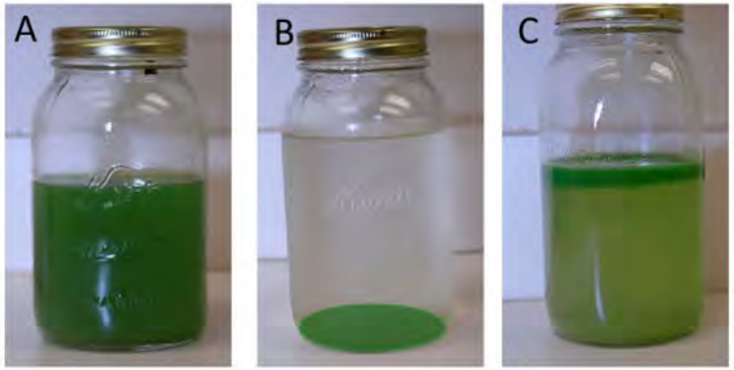
Section 4 - Monitoring For Cyanobacteria

- Each method is evaluated using a set of criteria
- Advantages/disadvantages
- Resources and examples

4.3.1.2 Jar and stick tests

• Result: Qualitative • Sampling Type: Point Sampling • Turn-around time: < 1 day • Level of Training: Novice • Lab Required: No	• Relative Cost: $ • Cyanobacteria Presence/Absence: Suitable • Cyanobacteria Identification: Not suitable • Cyanobacteria Density: Not suitable • Cyanotoxin Presence/Absence: Not Suitable

The Jar Test uses the ability of some cyanobacteria to regulate buoyancy to separate them from



Photos: KDHE

s

Figure 6. Using the jar test to assess the presence of planktonic cyanobacteria. Well mixed sample (A), settled material not likely to be cyanobacteria (B) and floating material likely to be cyanobacteria (C).

Section 4 - Monitoring Selection Tool

Select your monitoring requirements:

Target Analyte		Lab Required		Turnaround Time	
☑	Cyanobacteria	☐	Yes	☑	Less than 24 hours
☑	Cyanotoxin	☑	No	☐	1 to 3 days

Web-based and interactive

Method	Cyanobacteria			Cyanotoxin			Result Type	Sample Type	Relative Cost	Level of Training
	P/A	ID	DEN	P/A	CGN	TOT				

Explore Options For Your Lake

Method	Cyanobacteria			Cyanotoxin			Result Type	Sample Type	Relative Cost	Level of Training
	P/A	ID	DEN	P/A	CGN	TOT				
Visual Assessments	🟢	🔴	🔴	🔴	🔴	🔴	Qualitative	Variable	$	Novice
Jar and Stick Tests	🟢	🔴	🔴	🔴	🔴	🔴	Qualitative	Point sampling	$	Novice
Pigments	🟢	🔴	🟢	🔴	🔴	🔴	Quantitative	Point sampling	$$	Intermediate
Remote Sensing	🟢	🔴	🟢	🔴	🔴	🔴	Quant./Qual.	Indirect	$	Intermediate / Expert

🟢 👍

🔴 👎

Section 4 - Elements Of HCB Monitoring Programs

- Managing costs and resources
- Supporting your HCB response plan

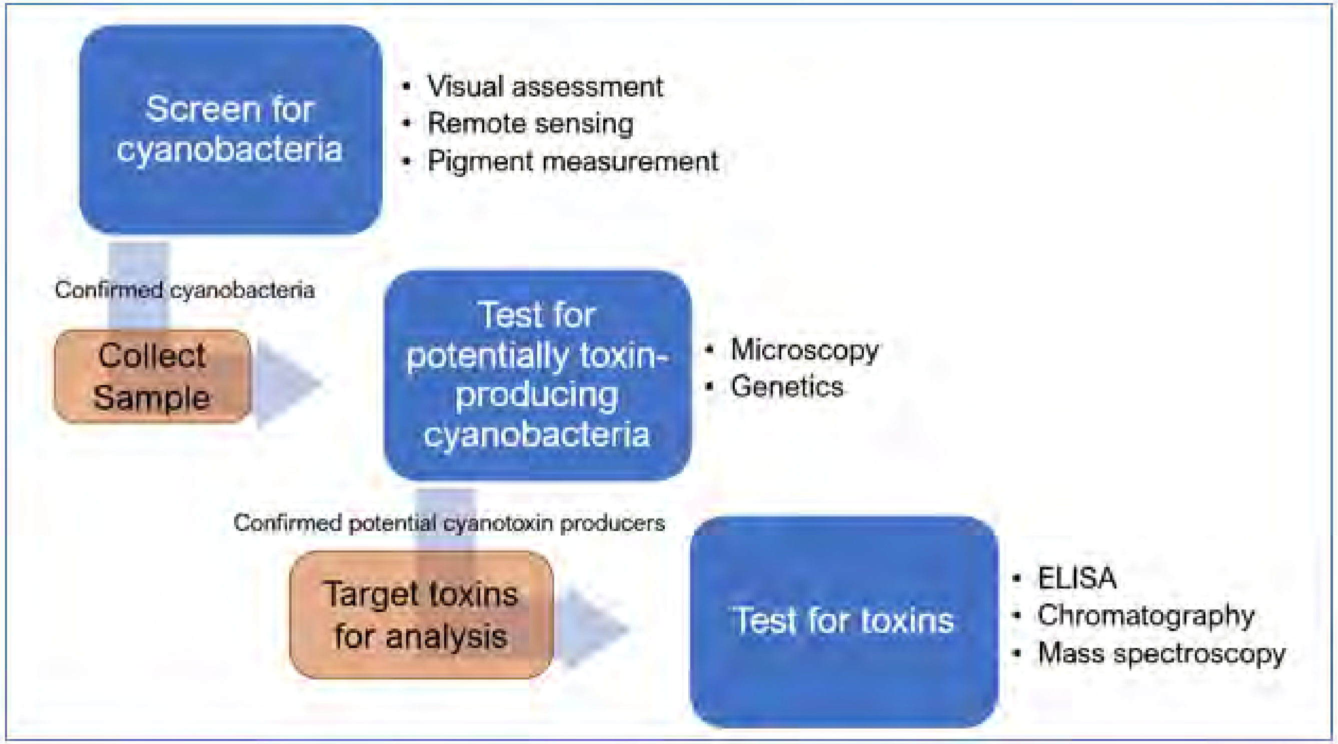


Figure 5. Common sequence of monitoring steps used to evaluate risk from cyanobacteria

Section 5 - Communication & Response Planning

- Basics of risk communication
- What should you be doing during a HCB event?
- What can you do later?

Field Sampling Lab Analyses Drinking Water Planning Advisories and Outreach HCB Illness Data Management


USA TODAY

COVID-19 RESOURCES
Your questions answered

CORONAVIRUS NUMBERS
Virus numbers by state

News | Sports | Entertainment | Life | Money | Tech | Travel | Opinion

NATION

Puppy dies at Zion National Park in toxic algae bloom that is dangerous to humans, animals

K. Sophie Will St. George Spectrum & Daily News

Published 7:54 p.m. ET Jul. 15, 2020 | Updated 7:58 p.m. ET Jul. 15, 2020

Section 5 - Communication & Response Planning

- Have a plan before HCBs are an issue
- Review annually, update as needed
- Resources and examples for generating communication plans, stakeholder networks, and communication platforms

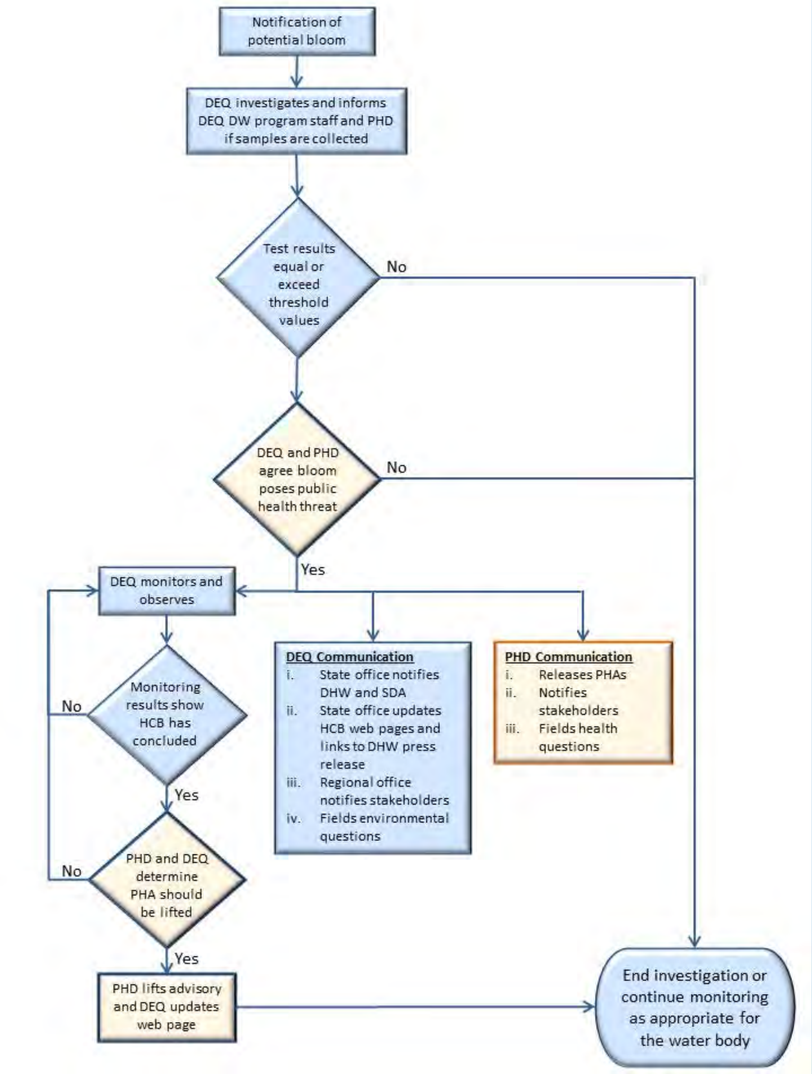


Figure 5-2. Idaho Department of Environmental Quality HCB response flow chart.

Source: Idaho Department of Environmental Quality. Used with permission.

Section 6 – In-Lake Management & Control of HCBs

- MANY options
- Our focus
  - Supported by peer review literature
  - Established and emerging approaches

Figure C- 1. (A) Barley straw lining a stream entering an HCB-dominated lake in eastern Maryland and (B) along the shoreline of a brackish lagoon in Chesapeake Bay.

Figure source: (A) Place and (B) K. Sellner. Used with permission.

Section 6 - In-Lake Management Selection Tool

Select the criteria that describes your needs, situation and/or water body:

Strategy Type	Supporting Field Data	Waterbody Type	Surface Area	Residence Time	Trophic State	Depth	Non-HCB Limiters
☑ Intervention	☑ Emerging	☑ Pond	☑ Small	☑ Long	☑ Oligo- or Mesotrophic	☑ Shallow	☑ Turbidity
☑ Prevention	☑ Limited	☑ Lake or Reservoir	☑ Large	☑ Short	☑ Eutrophic	☑ Deep	☑ Special Mixing Regime Concerns
	☑ Substantial						☑ Internal Nutrienty Loading Primary
							☑ Drinking Water Source

Web-based and interactive

Section 6 - In-Lake Management Selection Tool

Select the criteria that describes your needs, situation and/or water body:

Strategy Type	Supporting Field Data	Waterbody Type	Surface Area	Residence Time	Trophic State	Depth	Non-HCB Limiters
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	☑ Substantial						☑ Internal Nutrienty Loading Primary
							☑ Drinking Water Source

Management Strategy
Copper algaecides
Food web manipulation
Microbial biomanipulation
Monitored natural attenuation
Nanoparticles
Organic biocides
Shading with dyes
Skimming/Harvesting

Helps You Explore Options

Each Factsheet Covers

- Technical Overview
- Effectiveness
- Advantages/Limitations
- Estimated Costs
- Shares examples

BARLEY AND RICE STRAW

In-lake Prevention Strategy *Substantial Supporting Field Data*

Barley straw (*Hordeum vulgare*) has been used for over four decades to prevent the growth of cyanobacteria. Initial reports showed widespread success in the United Kingdom, and barley straw deployment has spread to the United States in the past 20 years (Sellner and Rensel 2018 ▻). Decomposition of barley straw leads to the breakdown of lignin-containing cell walls within the straw. Lignin decomposition produces two types of residues that limit cyanobacterial growth. Some are specific compounds that individually inhibit cyanobacteria, while others yield strong oxidizing agents that rapidly reduce cell viability. For details and examples, please see Huang et al. (2015) ▻, Matthijs et al. (2012) ▻, Pillinger, Cooper, and Ridge (1994) ▻, Ridge and Pillinger (1996) ▻, Xiao et al. (2010) ▻, and Xiao et al. (2014) ▻.

The general procedure is as follows: 1–1.5 months prior to an expected HCB, stake or otherwise secure <1-year-old, fungicide-free bales of barley straw into the littoral zone of ponds, lakes, or incoming streams. Bales should be applied at a rate of 7 bales/acre, with several bales saved to deploy halfway through the summer. Bales should be reapplied each year thereafter, again saving some bales for mid-summer deployment. Ranges for barley straw treatment of cyanobacteria in other systems are 6–50 mg barley straw/L in longer residence time waters, such as lakes or reservoirs (Sellner and Rensel 2018 ▻).

EFFECTIVENESS

- Water body type: Pond, lake/reservoir, bay/estuary
- Any surface area or depth
- Any trophic state
- Any mixing regime
- Water body uses: Recreation, drinking water

NATURE OF HCB

- All HCB types in ponds to estuaries
- Singular or repeating HCBs
- Toxic and nontoxic HCBs
- Prevention strategy

This technique (7 bales/acre) is effective for most ponds, lakes, reservoirs, and low-salinity estuarine areas and is even more effective if enriched with fungi to aid in lignin decomposition (Sellner et al. 2015 ▻). There are some concerns about tannin removal in drinking water facilities from decomposing straw. This technique will not work if applied after the HCB has appeared, and it will not be as effective if the bales are placed in low-light or dark areas. Straw is used in eutrophic systems where blooms have historically occurred; hence, their decomposition results in minimal nutrient additions relative to available levels for bloom growth.

ADVANTAGES

LIMITATIONS

Section 7 - Nutrient Management

STILL the best option

for reducing HCBs in the long run

We leverage existing resources nationwide

Photo Credit: "Carver County Turbidity and Excess Nutrient photo" by MN Pollution Control Agency is licensed under CC BY-NC 2.0

Section 7 – Nutrient Sources

- Covers major sources
- Shares common approaches
  - Structural
  - Non-structural
  - Regulatory
- Points you to resources and examples
- Interactive source graphic

HCB Guidance - Interactive Nutrient Graphic

Section 8 - Recommendations

- So much we don't know!
- Overarching recommendations:
  - Common language for management and response
  - National freshwater planning structure for HCBs

Photo by Laura Kapfer on Unsplash

What's Next for the HCB Team?

Our Guidance is on-line NOW hcb-1.itrcweb.org

Training – 5 Modules available

Benthic HCB Team

Benthic Harmful Cyanobacterial Blooms (HCBs)

January 2021 – December 2021

- Visit the Team Website
- HCB Team Fact Sheet

Team Leaders:

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- Ben Holcomb

  bholcomb@utah.gov

Program Advisor

- Cherri Baysinger

  cbaysinger@socket.net

Interstate Technology and Regulatory Council

Strategies for Preventing and Managing Benthic Harmful Cyanobacterial Blooms

Fact Sheet

THE INTERSTATE TECHNOLOGY REGULATORY COUNCIL (ITRC) IS EXCITED TO START A TEAM IN JANUARY 2021 ON STRATEGIES FOR PREVENTING AND MANAGING HARMFUL CYANOBACTERIAL BLOOMS (BENTHIC)

The Interstate Technology Regulatory Council (ITRC) is a state-led coalition dedicated to reducing barriers to the use of innovative environmental technologies. ITRC represents over 1,000 individuals, across 50 states, working to produce guidance and training on innovative environmental solutions. Bringing together teams of state, federal, tribal, industry, academic, and stakeholder experts, ITRC broadens and deepens technical knowledge and reduces barriers to expedient regulatory approval. Since 1995, the collective success of this coalition has generated huge benefits to the environment, inspired new technical innovations, and saved hundreds of millions of dollars.

ITRC is a program of the Environmental Research Institute of the States, managed by the Environmental Council of the States. This partnership is based on a commitment to protect and improve human health and the environment across the country.

BENTHIC HARMFUL CYANOBACTERIAL BLOOMS (HCBs)

Freshwater inland lakes and reservoirs supply approximately 70% of our nation's drinking water and industry withdrawals. They serve as vibrant hubs for recreation, tourism, and local identity. Human activities can influence and alter their natural ecological equilibrium.

Harmful Cyanobacterial Blooms (HCBs) are complex ecological phenomenon that can occur where cyanobacteria proliferate and dominate aquatic ecosystems.

Much of what we know about HCBs is based on those planktonic forms that occur on the water surface or in the water column. Benthic HCBs grow along the bottom until pieces detach, float to the surface, or strand along the shoreline. As with planktonic HCBs, many benthic cyanobacteria produce toxins that can impact dermatologic, respiratory, hepatic, and neurologic systems. When these toxins are present in freshwater, they can threaten humans, wildlife, livestock, and pets.

HCB Strategies

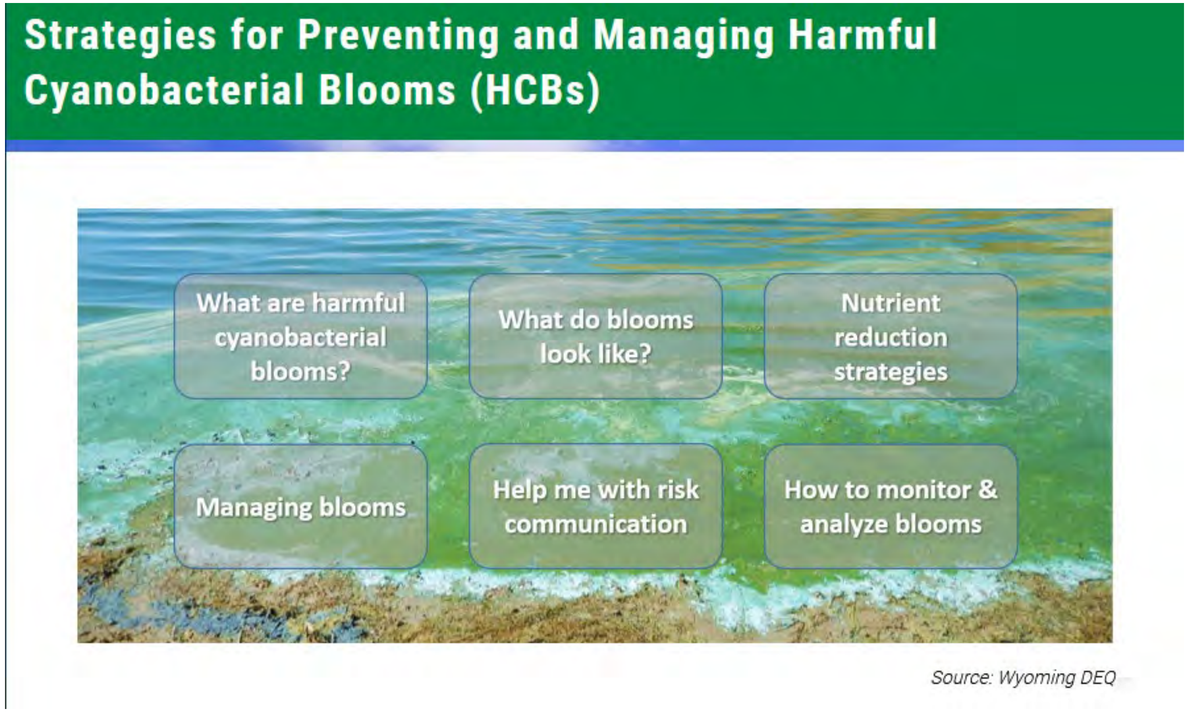
Team Goal

- **Background**
  - Benthic cyanobacteria have unique characteristics compared to planktonic cyanobacteria.
  - Benthic cyanobacteria-specific resources are limited for:
    - Field screening methods
    - Sampling and analytical methods for mat samples
    - Thresholds for cyanotoxins in mat samples
    - Thresholds for neurotoxins or dermal toxins in mat or water samples
    - Advisories
    - Prevention and management and control measures

- **Team Goal**
  - To enhance the ITRC HCB technical and regulatory guidance document with more detailed information focused on benthic cyanobacteria.

Companion To New ITRC HCB Guidance

- ITRC HCB Guidance now live (http://hcb-1.itrcweb.org/)
  - Benthic cyanobacteria are briefly mentioned throughout the HCB guidance
  - ITRC HCB training (April 29th)
- Proposed Benthic HCB Guidance
  - Not totally stand alone and do not need to duplicate information already included
  - Will share some resources (tools, Visual Guide)
  - Follow same general framework and primary audience (water body manager)



Team Deliverables

- Companion web-based technical regulatory guidance and training focused on:
  - Introduction to benthic cyanobacteria and connection to existing HCB document
  - Field screening and sampling for benthic cyanobacteria
  - Analytical toxin testing methods for mat samples
  - Toxin Thresholds
    - All cyanotoxins in mats
    - Neurotoxins and dermal toxins in water
  - Communication and Response Planning
    - Specific advisory signage and messaging
  - Specific considerations for Prevention and Management and Control Strategies

Benthic HCB Team Activities

- Monthly team calls
- Bi-monthly sub-group calls
  - Introduction
  - Methods (field and lab)
  - Toxin thresholds
  - Communication and signage
  - Management strategies
- External review (Fall 2021)
- Final document and training (Spring 2022)

Benthic HCB Team – Get Involved!

- Join us!
  - Click on the "Sign In" button at the top to go to the login page (https://connect.itrcweb.org/login).
  - Click on "New User/Register Now" in the Sign In box.
  - Don’t have a lot of time? Sign up as an Interested Party
  - Ready to get to work with us? Sign up as an Active Member
- Welcome email will provide details on our team’s next steps