# Cyanotoxin Occurrence in the United States

## *A 20 Year Retrospective*




Jennifer L. Graham

U.S. Geological Survey

Great Plains and Midwest Harmful Algal Blooms Workshop

February 4, 2020

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

# First Reports of Cyanotoxins


After Yoo et al., 1995

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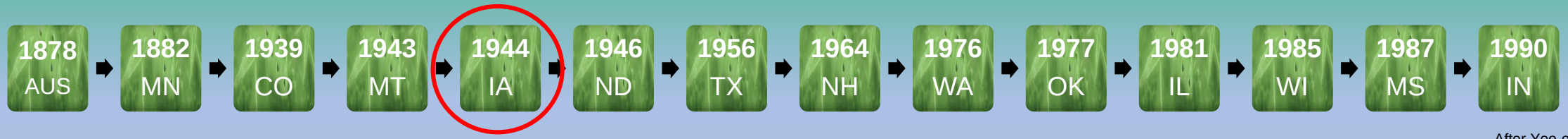
# First Reports of Cyanotoxins




After Yoo et al., 1995

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# 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

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**

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- 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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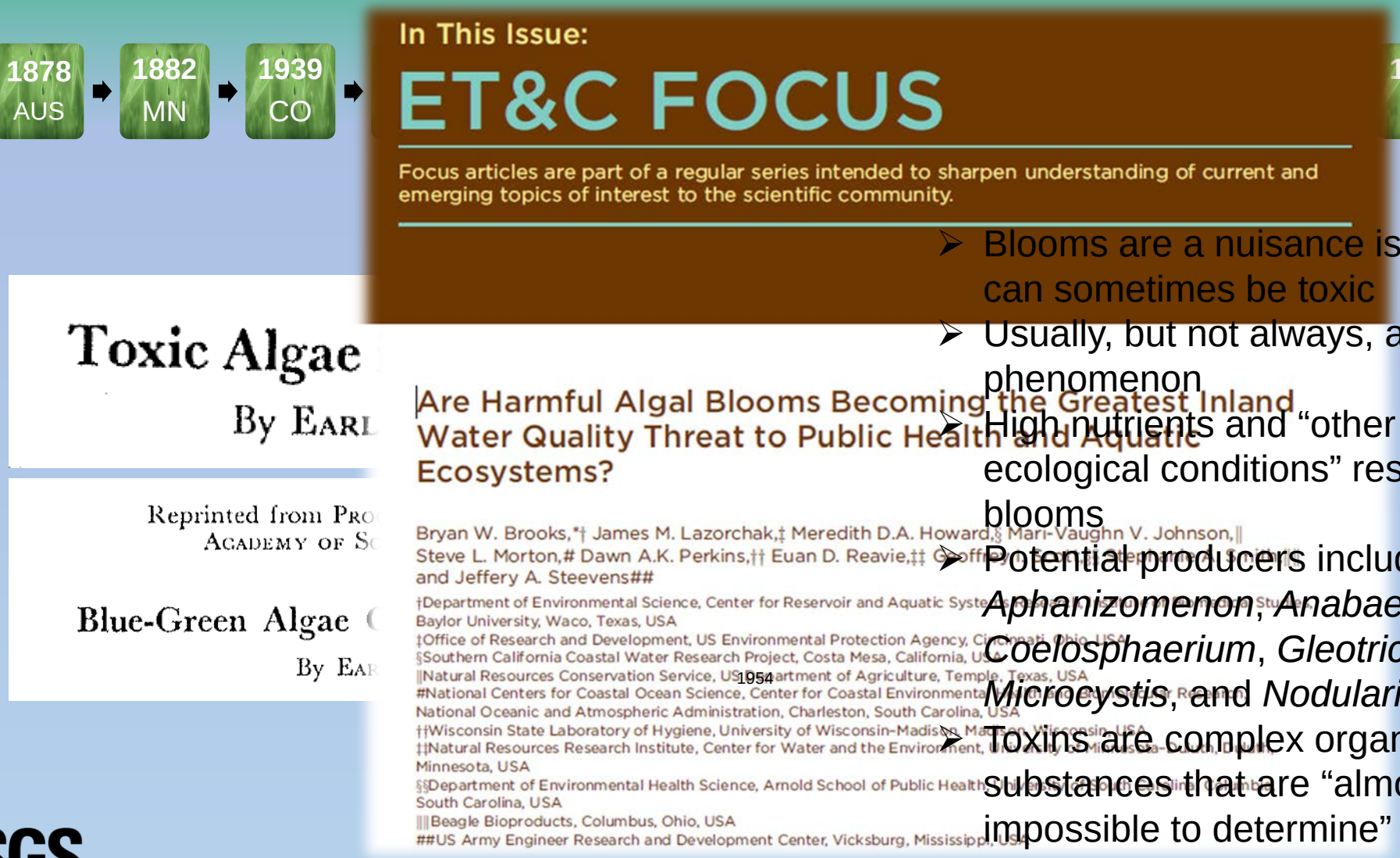


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# Cyanotoxins are Diverse

| | 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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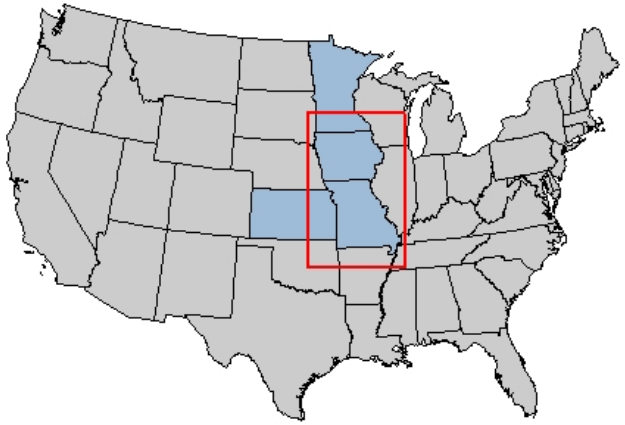
After Graham and others, 2008

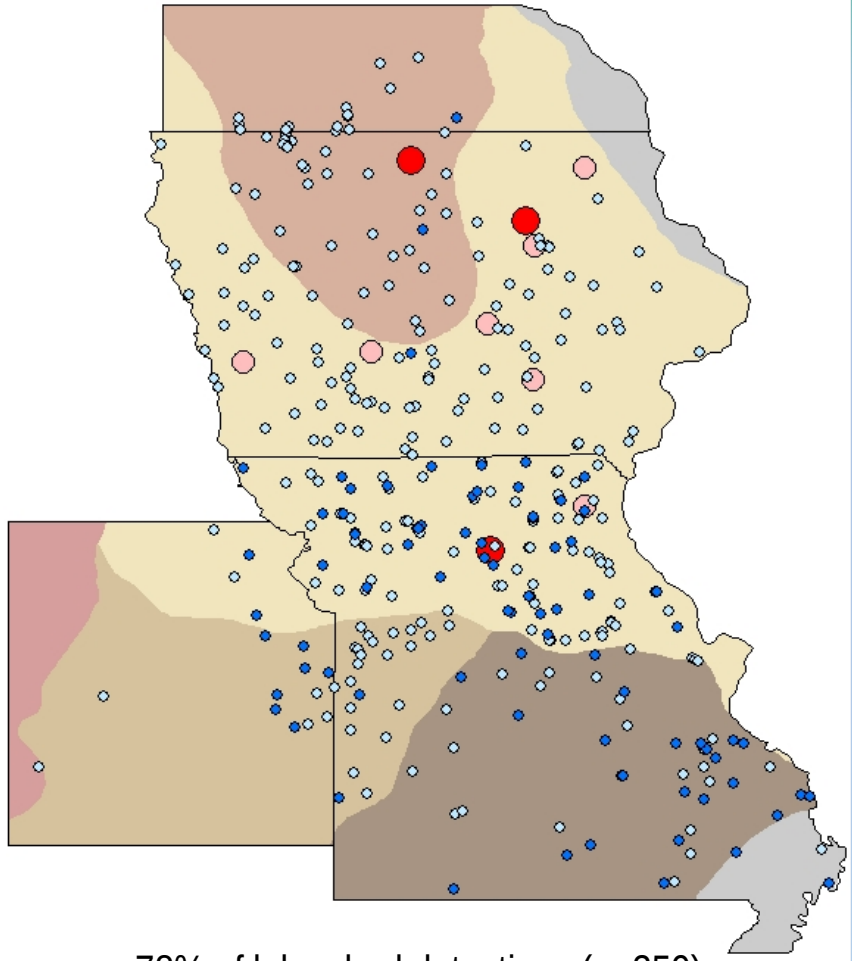
# Microcystins are Widespread and Common



OZARK HIGHLANDS (OH)
OSAGE PLAINS (OP)
DISSECTED TILL PLAINS (DT)
WESTERN LAKE (WL)
PLAINS BORDER (PB)

CONCENTRATION/RISK

- NOT DETECTED
- LOW (<10 ug/L)
- MODERATE (10-20 ug/L)
- HIGH (> 20 ug/L)



78% of lakes had detections (n=359)

Maximum concentration: 52 µg/L

After Graham and others 2004, 2006, and 2009

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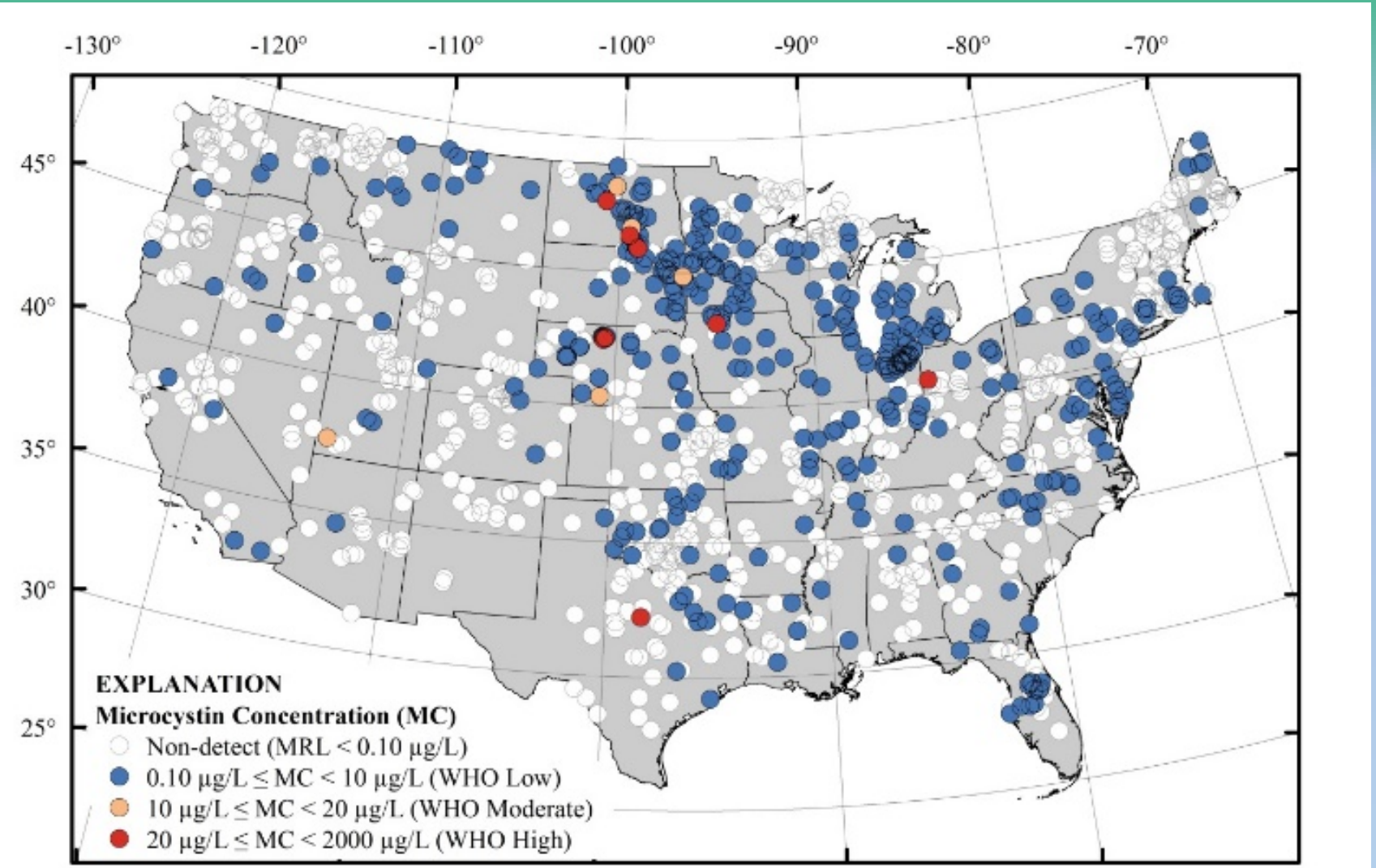
# Microcystins are Widespread and Common




Loftin et al., 2016

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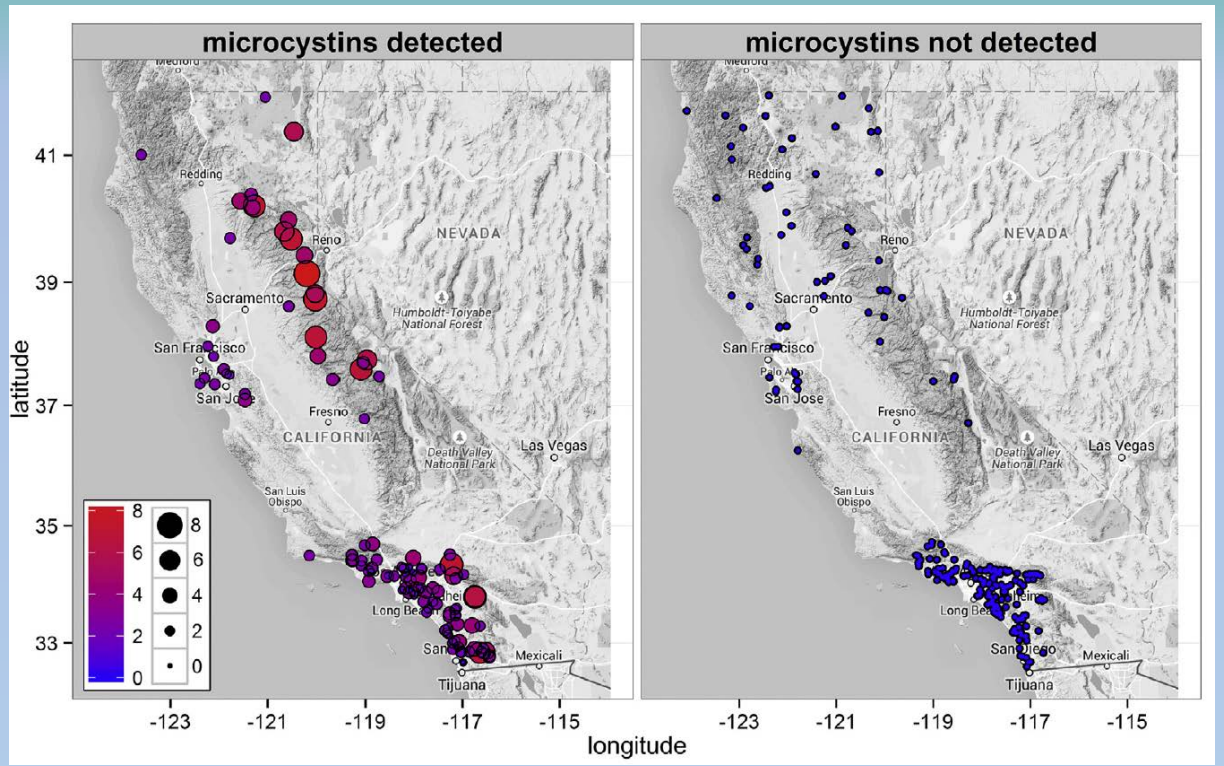
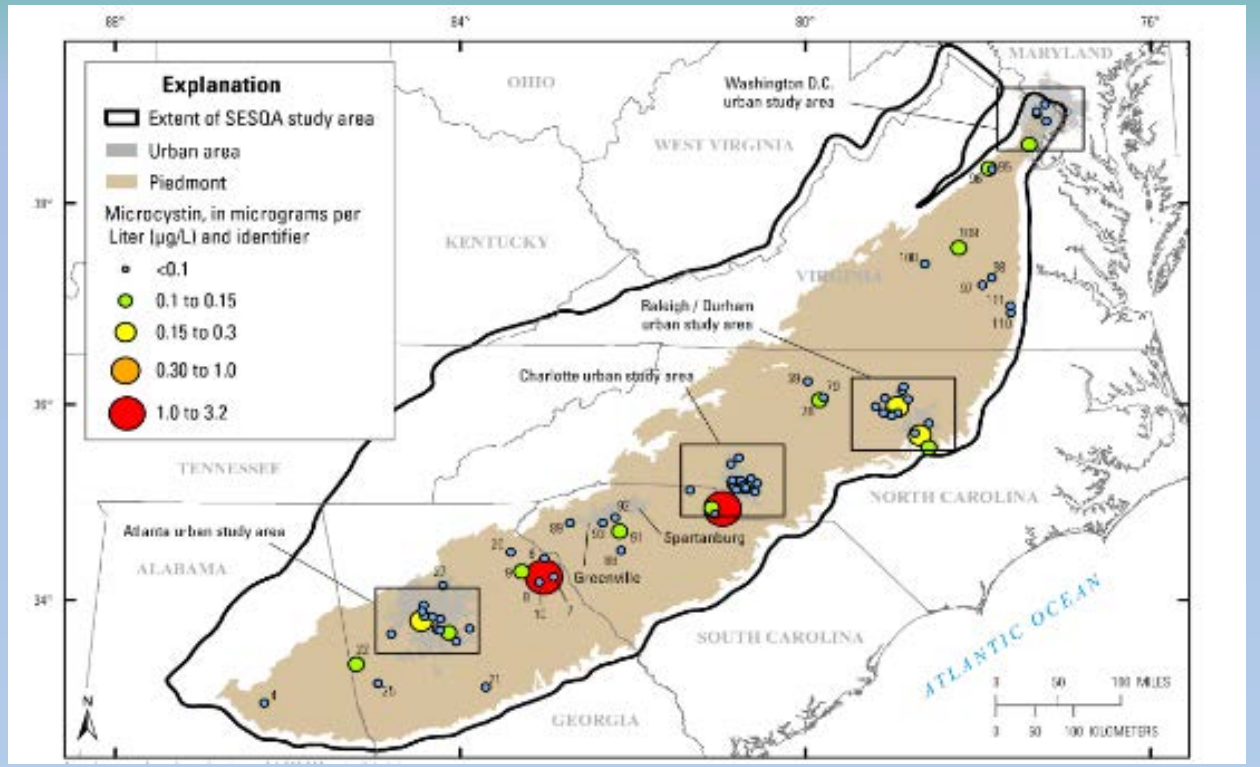



Fetscher et al.. 2015




Loftin et al., 2016

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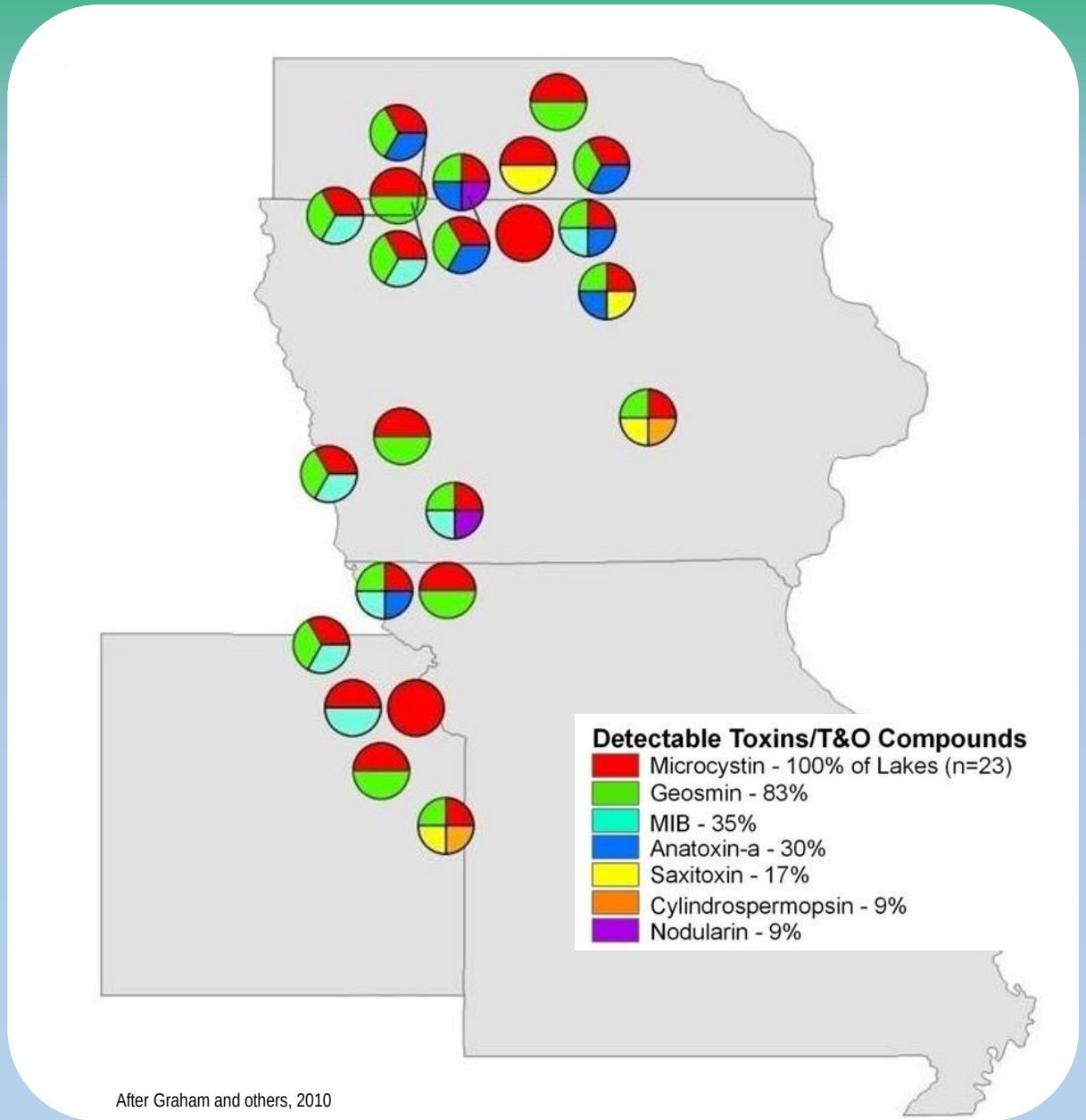
# Other Cyanotoxins Occur Less Frequently




After Graham and others, 2010

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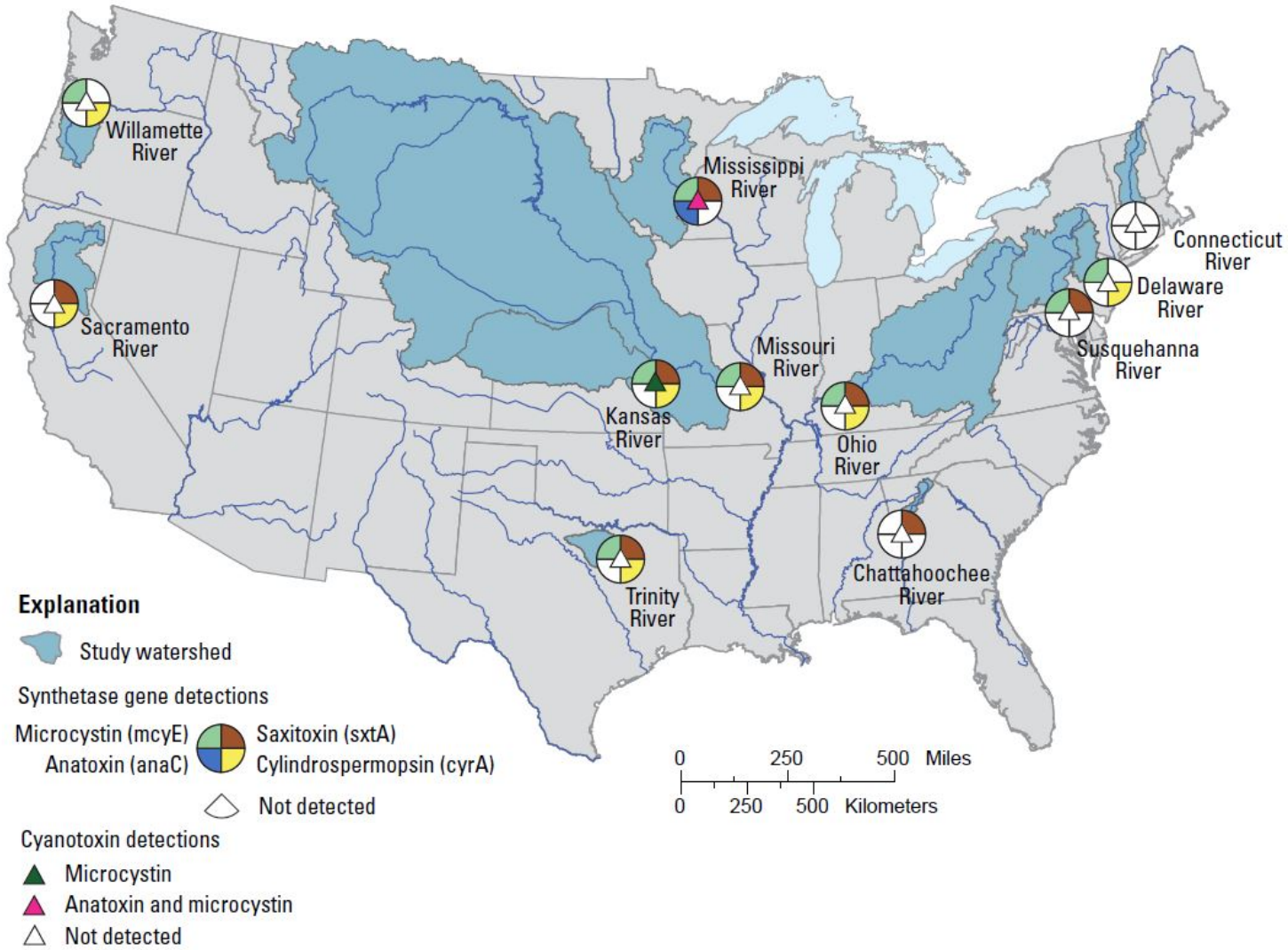
# Advances in Analytical Approaches Allow Assessment of Occurrence in Novel Ways




Graham et al., 2020

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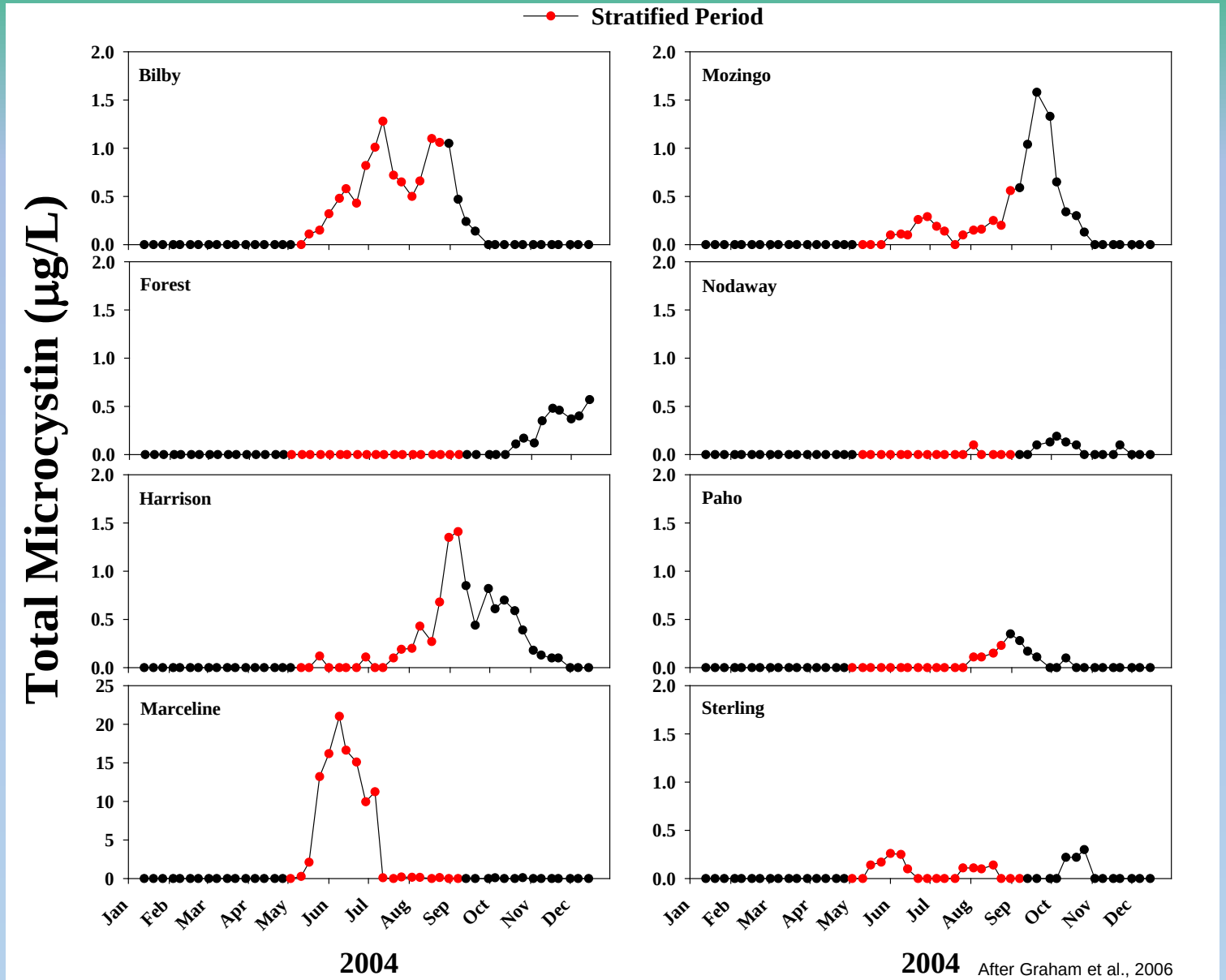
# Cyanotoxins are Usually, But Not Always, a Summer Phenomenon




After Graham et al., 2006

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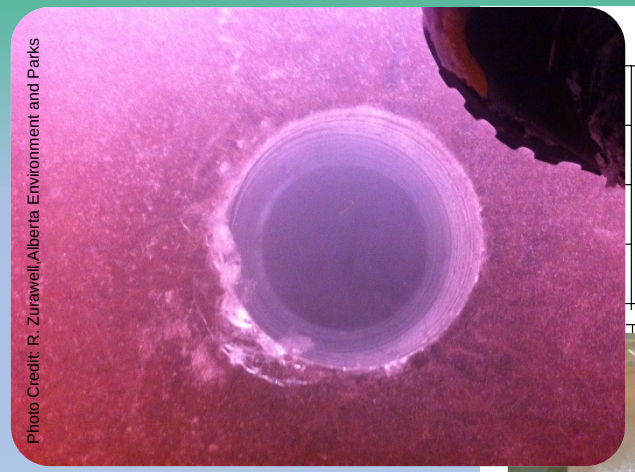
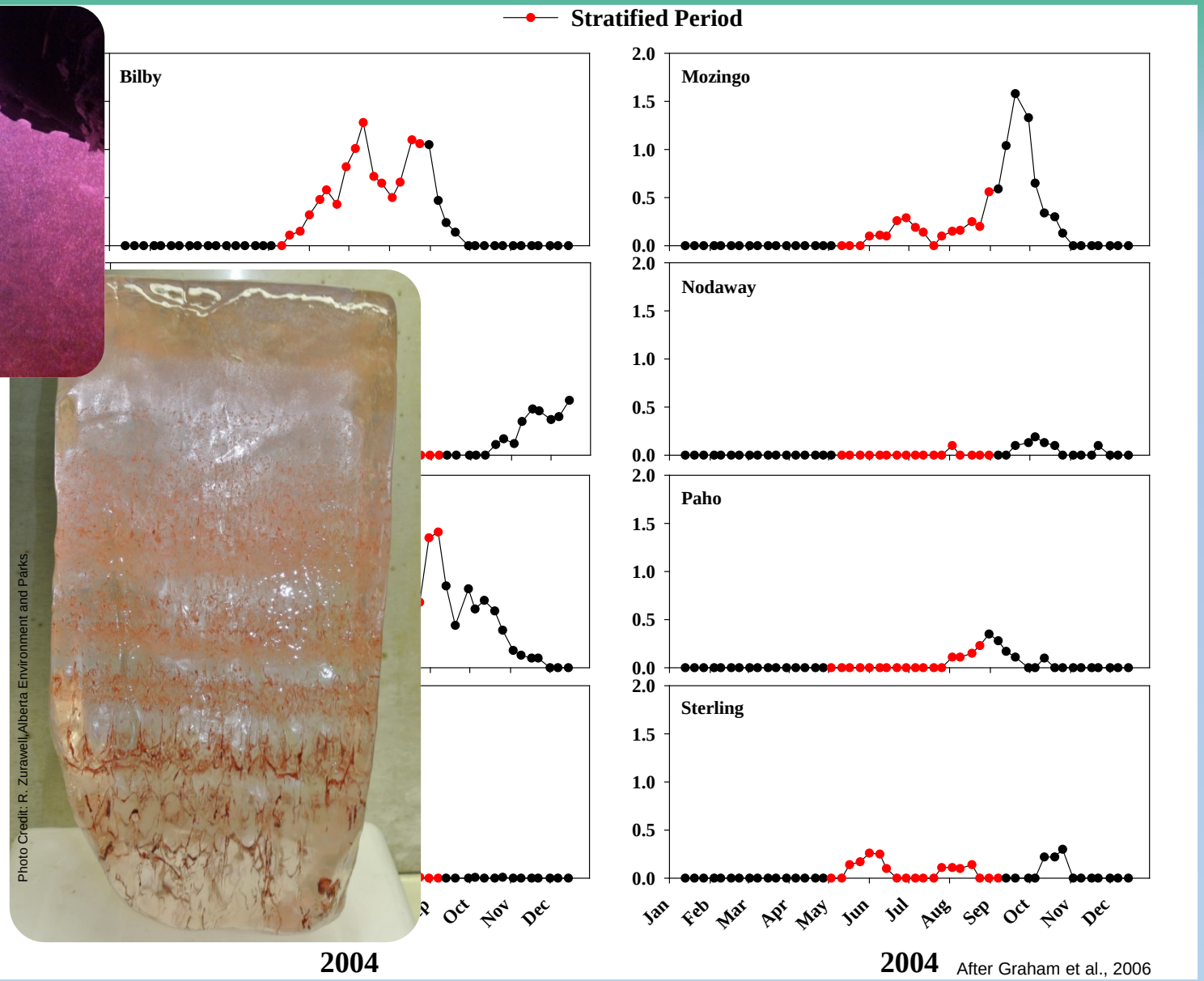
# Cyanotoxins are Usually, But Not Always, a Summer Phenomenon







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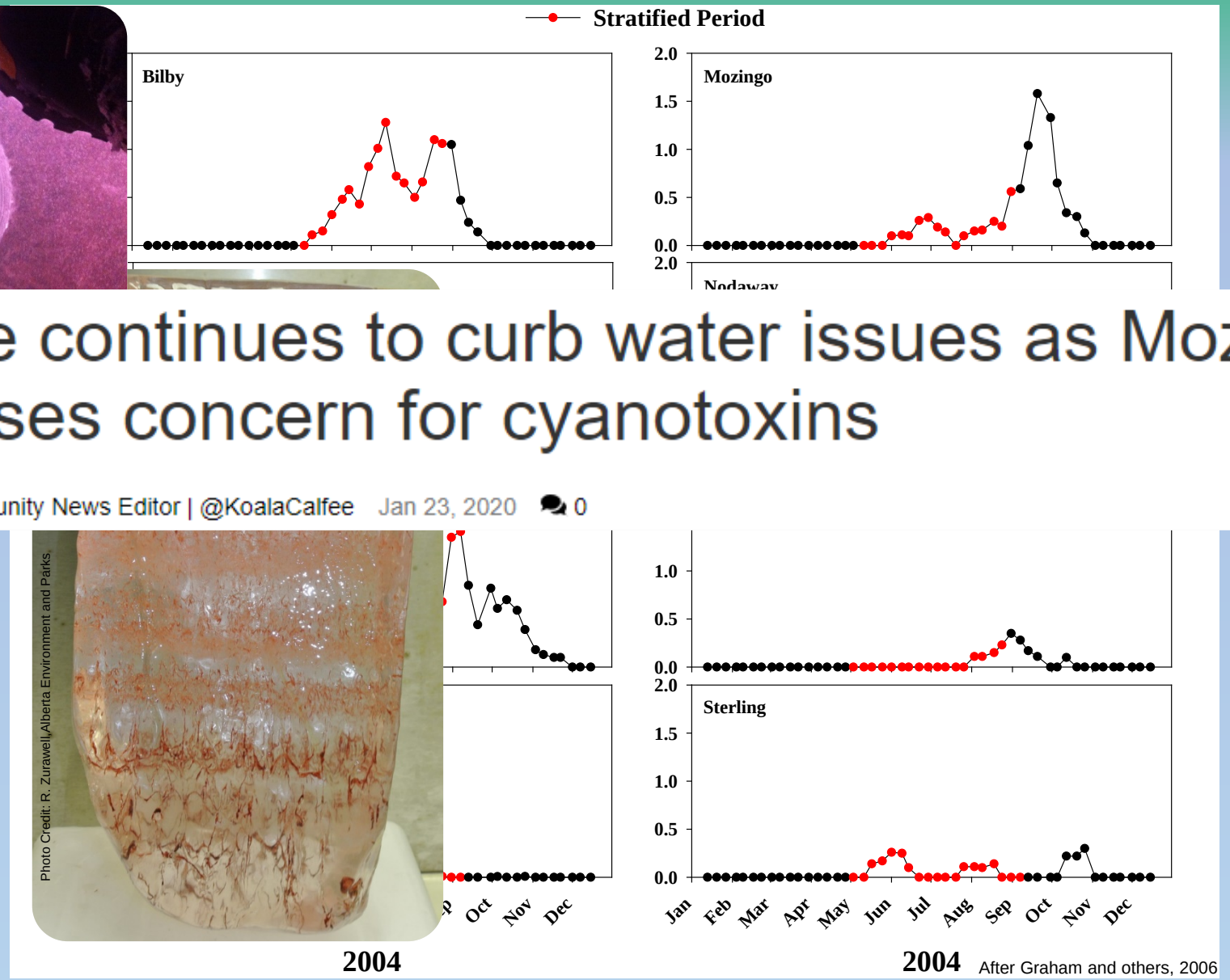


Maryville continues to curb water issues as Mozingo Lake raises concern for cyanotoxins

Kendrick Calfee | Community News Editor | @KoalaCalfee Jan 23, 2020 0




After Graham and others, 2006

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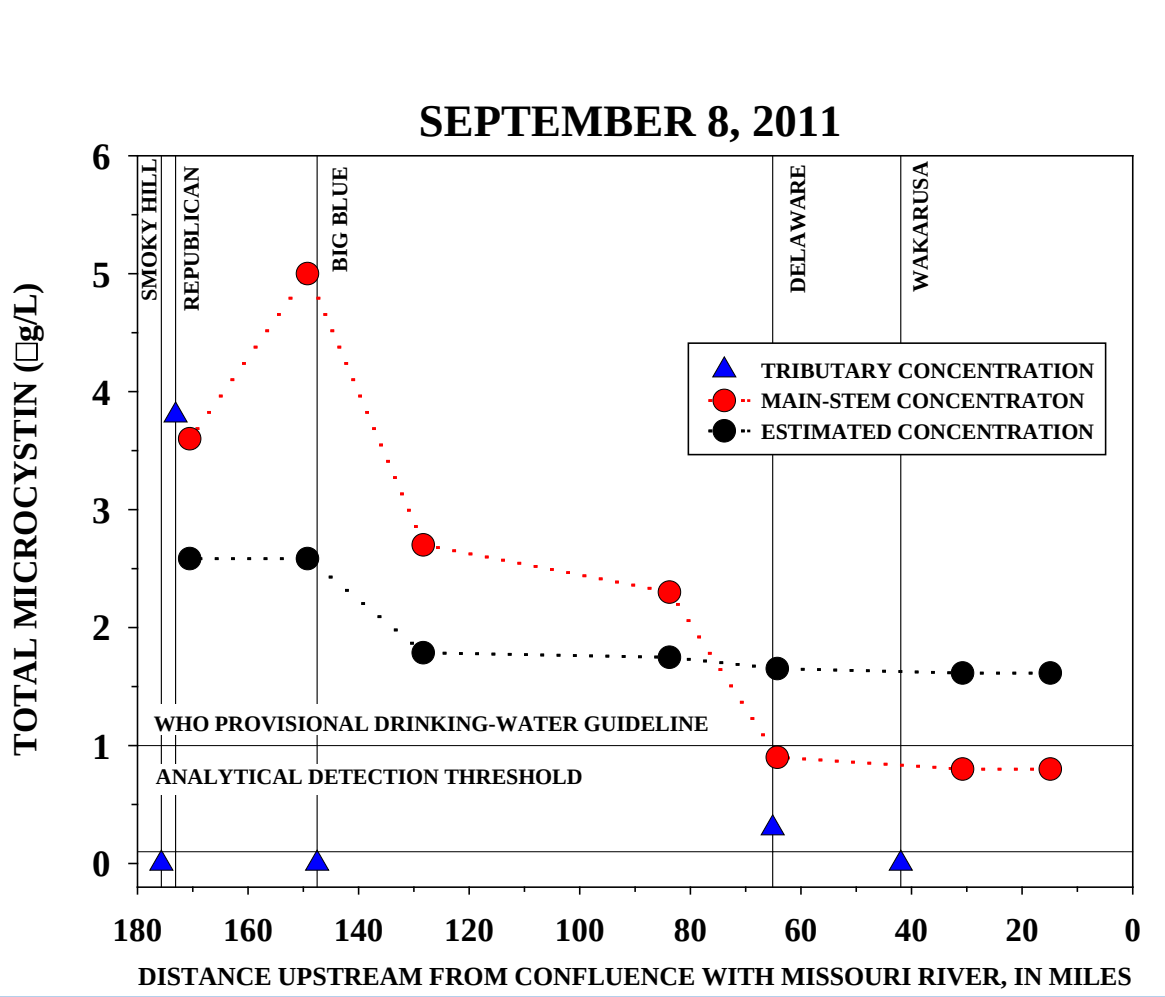
# Cyanotoxins May Be Transported for Long Distances Downstream of Source Areas




Graham et al., 2012

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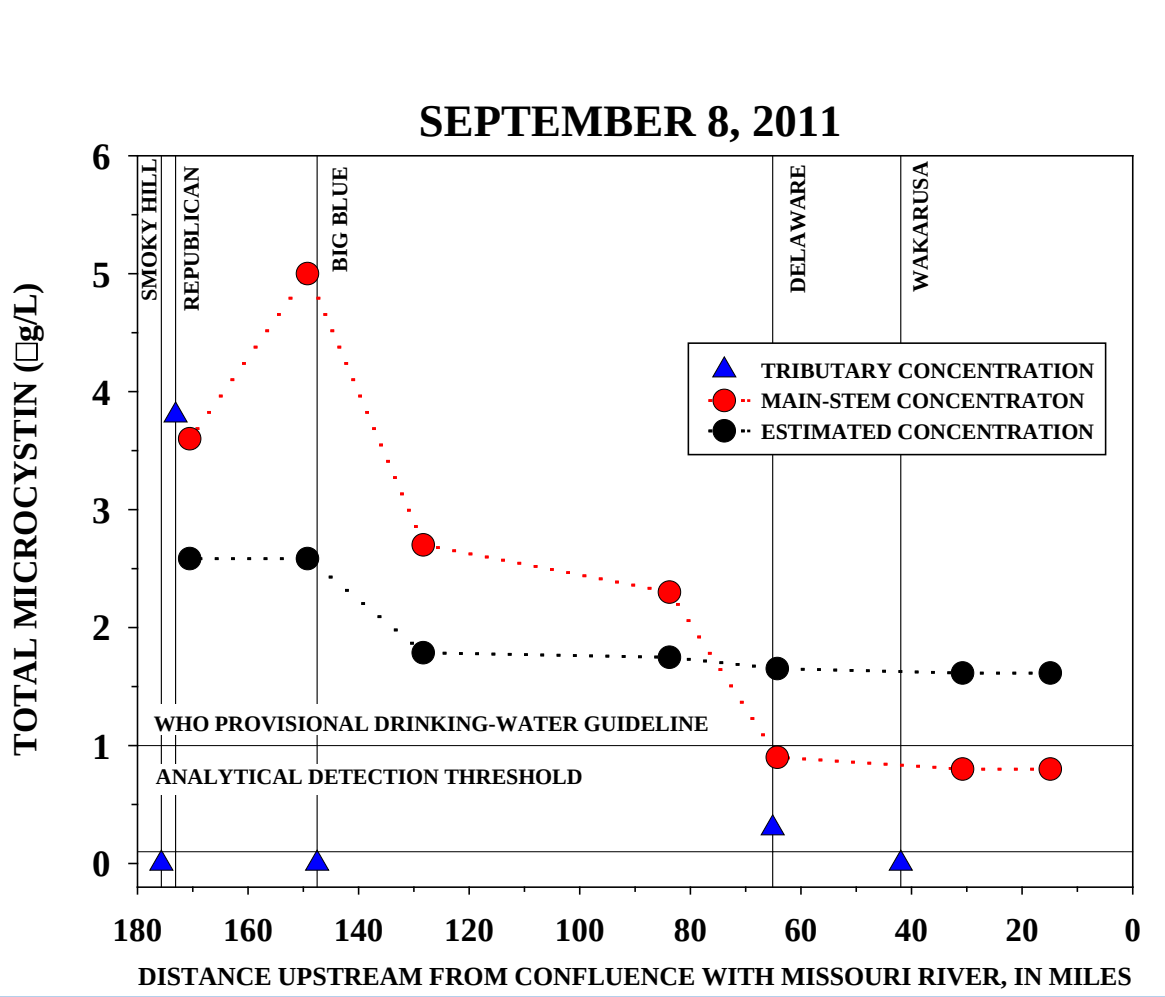


Graham et al., 2012

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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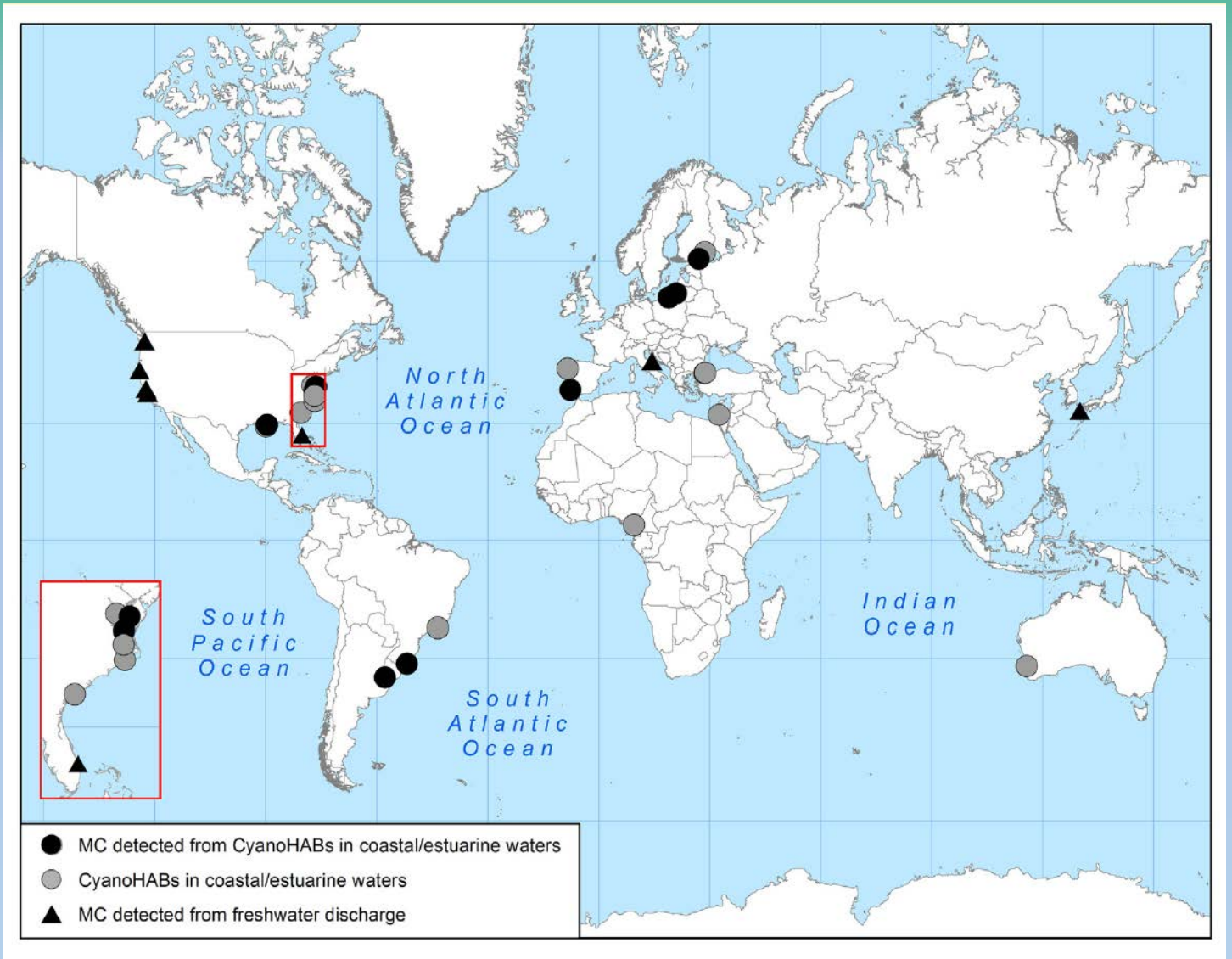
# Cyanotoxins May Occur in Coastal and Estuarine Environments




Preece et al., 2017

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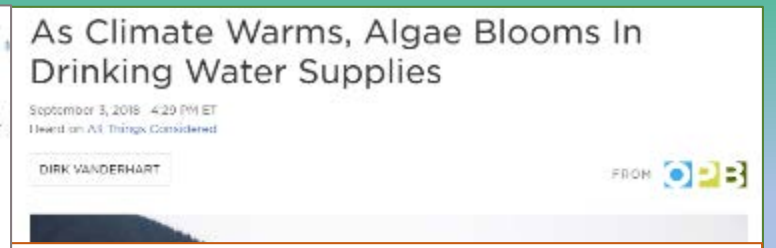
# Is Cyanotoxin Occurrence Increasing?









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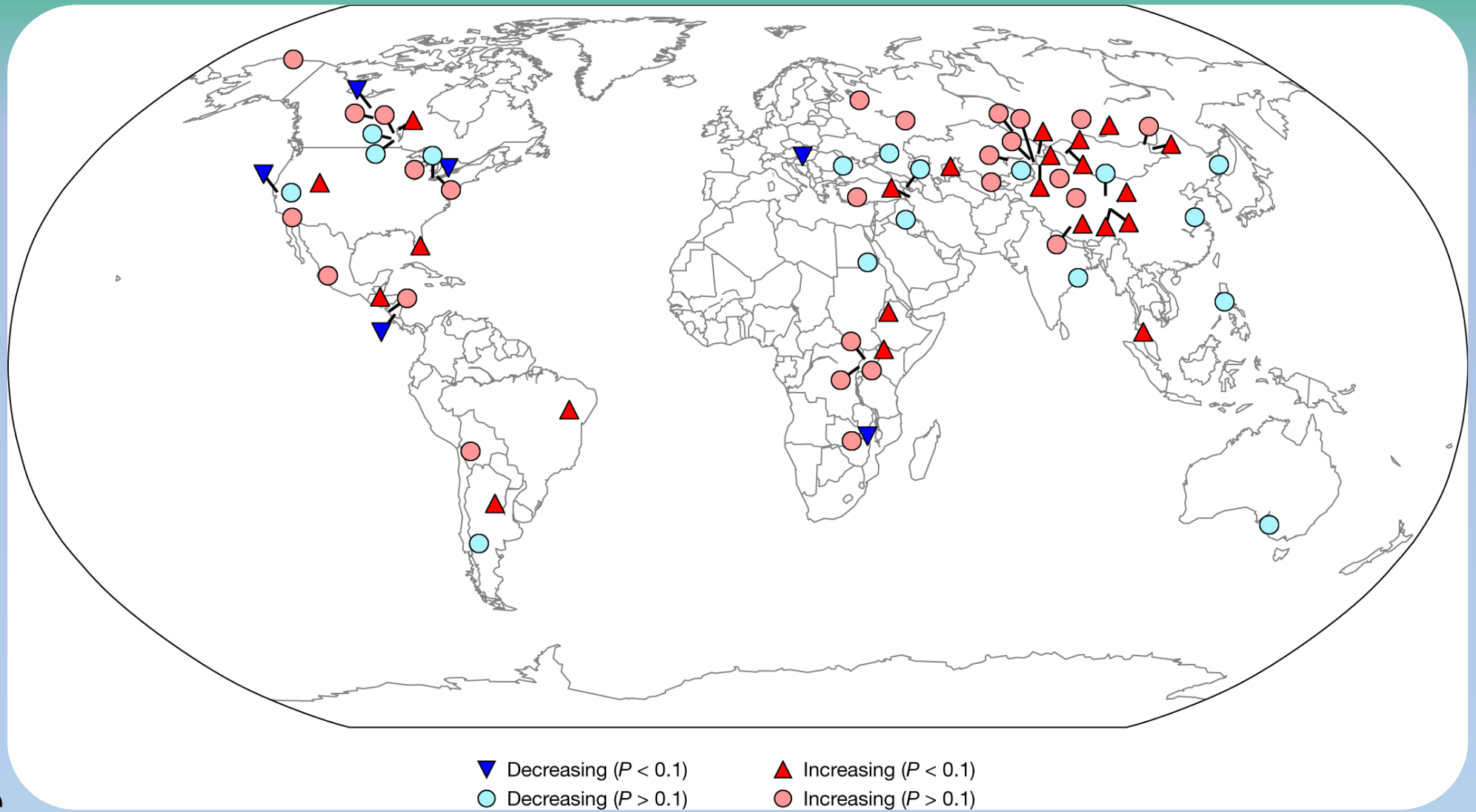
Slide Courtesy of T. Thorpe, University of Missouri

# Since the 1980's, Peak Summertime Bloom Intensity Has Increased in Some Lakes




Ho et al., 2019

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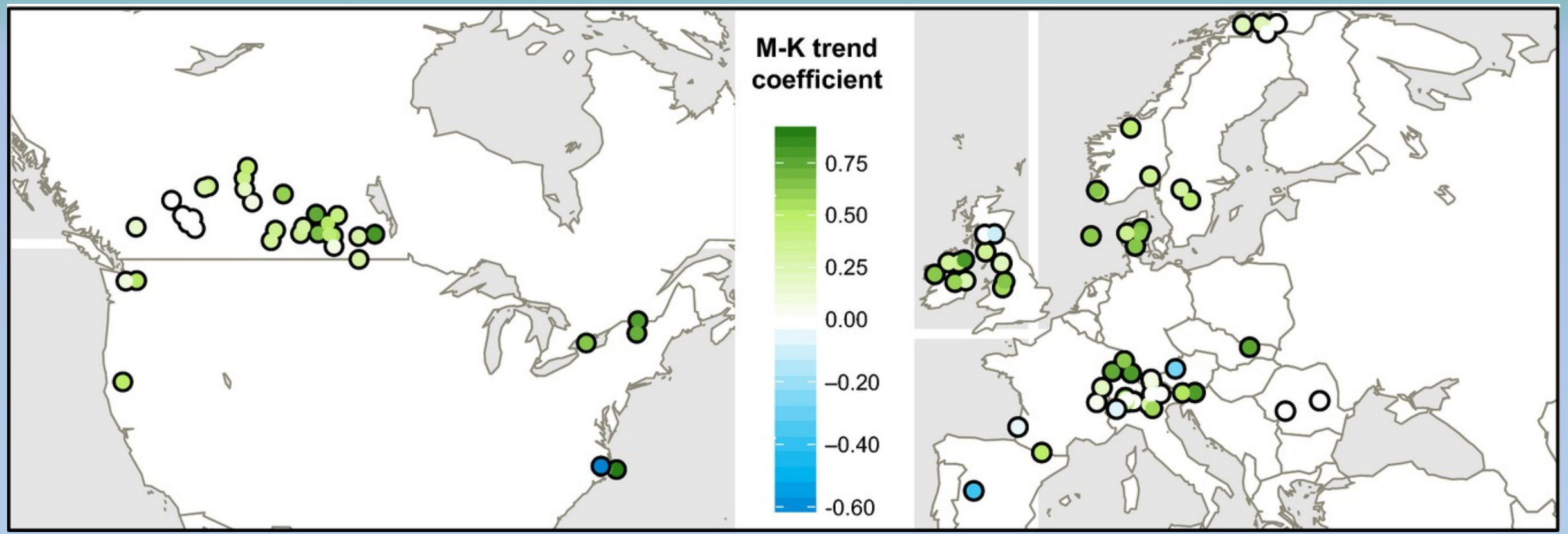
# Cyanobacterial Abundance Has Also Increased




Taranu et al., 2015

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# Cyanobacterial Abundance Has Also 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 ($\mu$g/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

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

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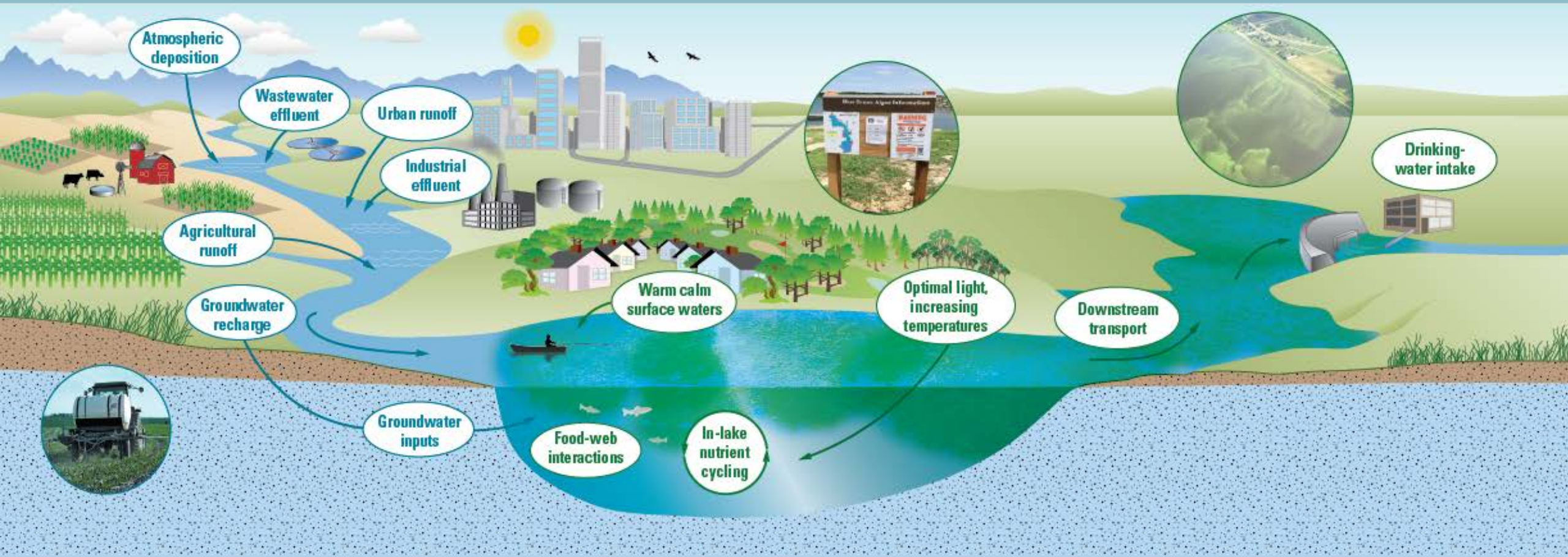
# What Causes Cyanobacterial Blooms?




Graham et al., 2016

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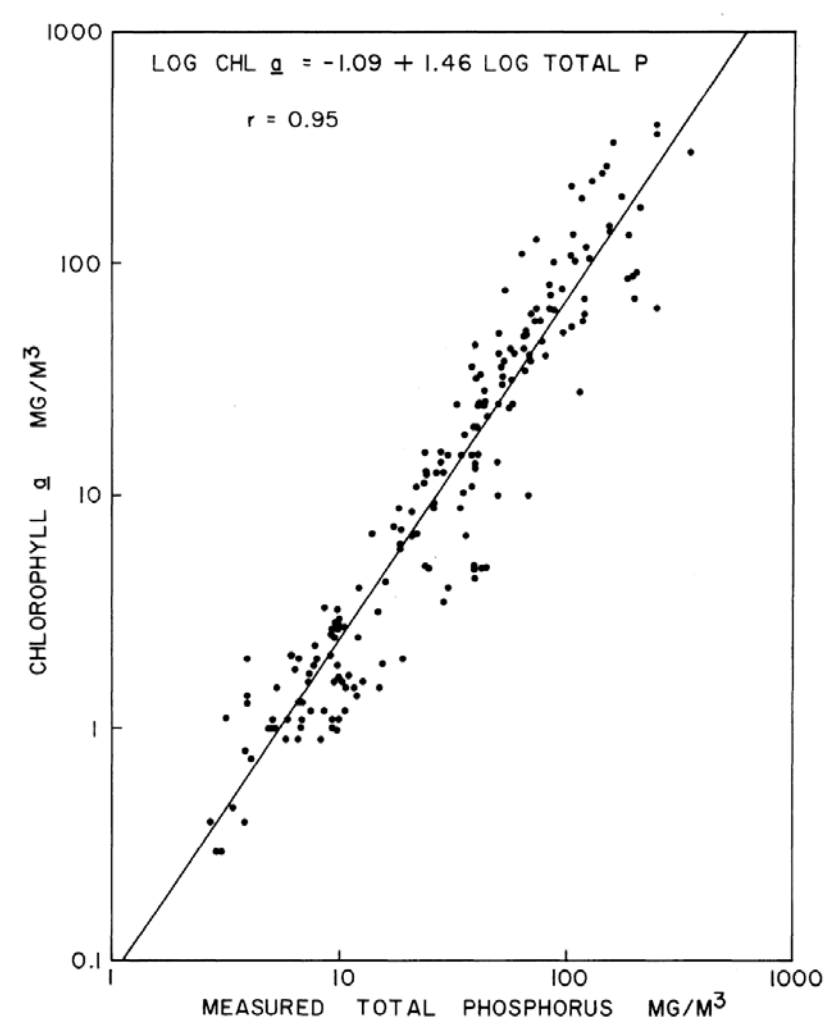
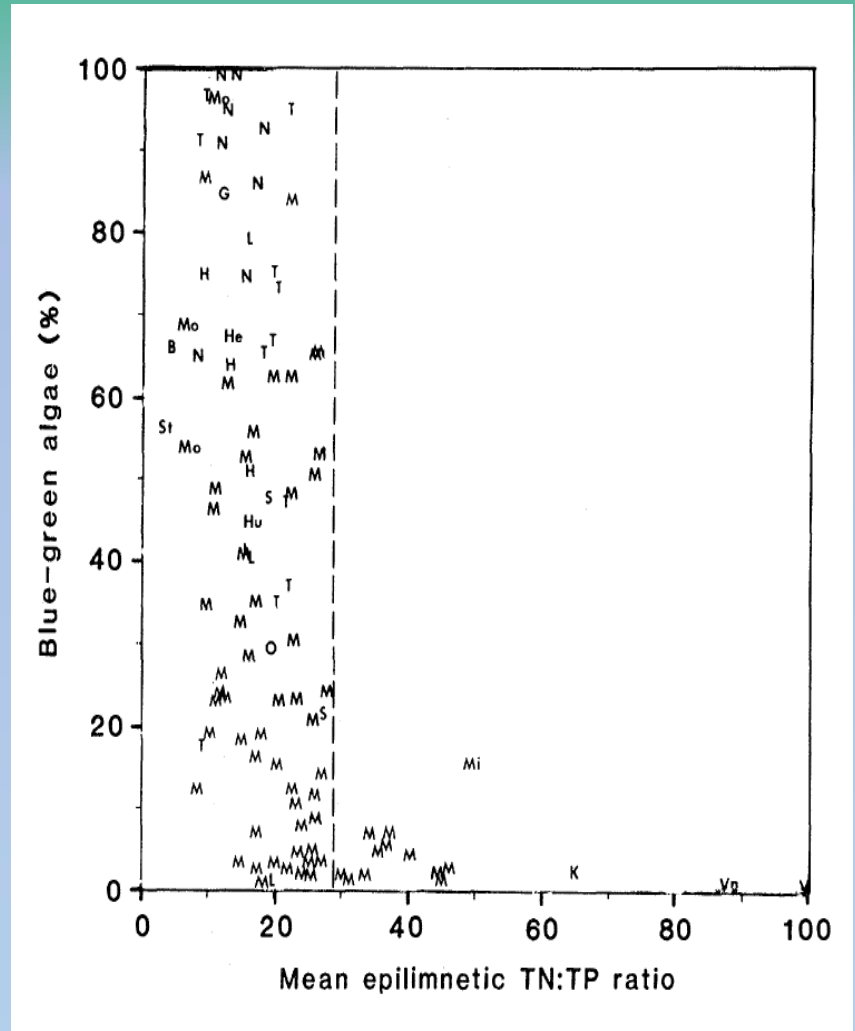
# Nutrients Play a Key Role




Jones and Bachmann, 1976




Smith, 1983

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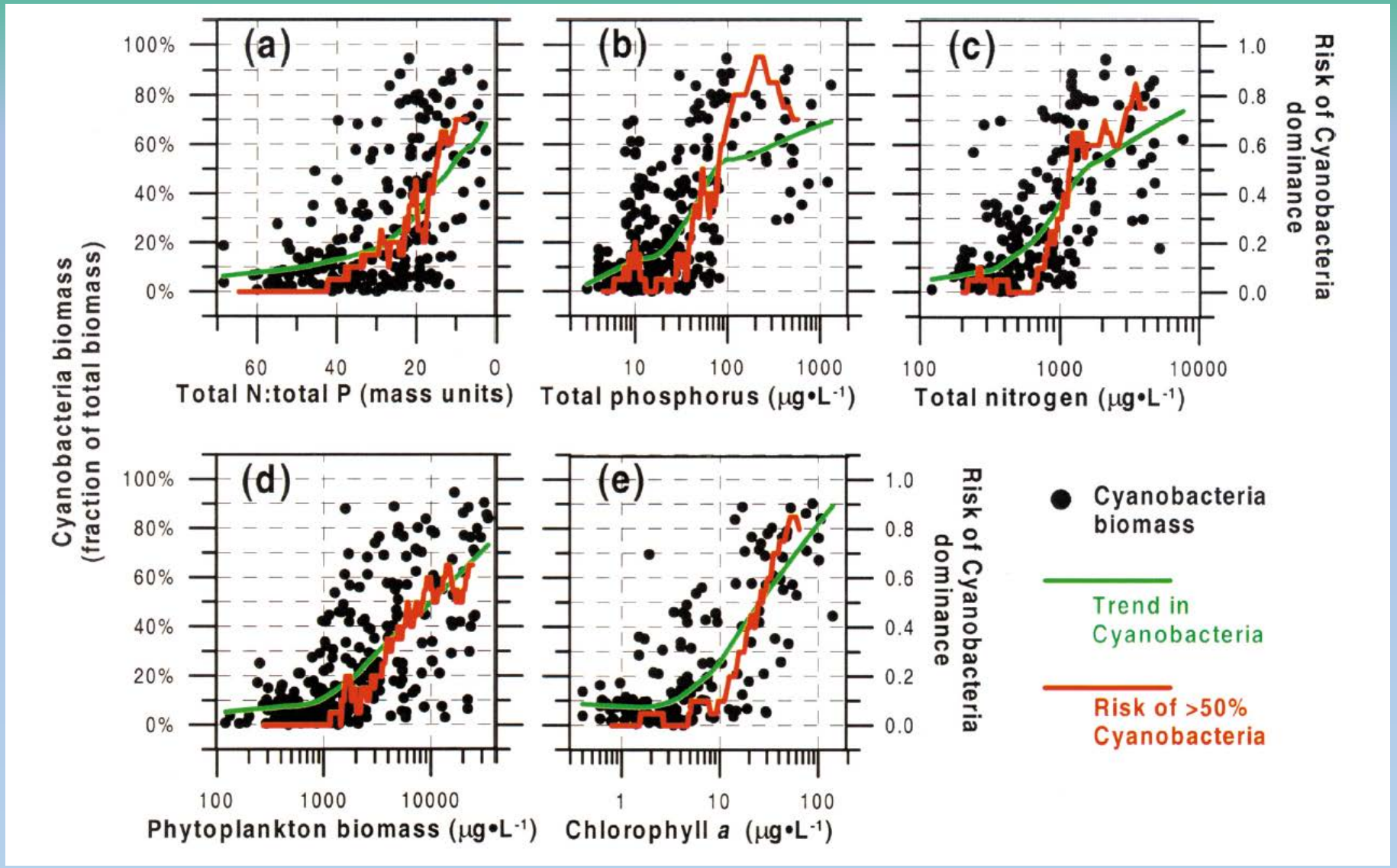


Downing et. al, 2001

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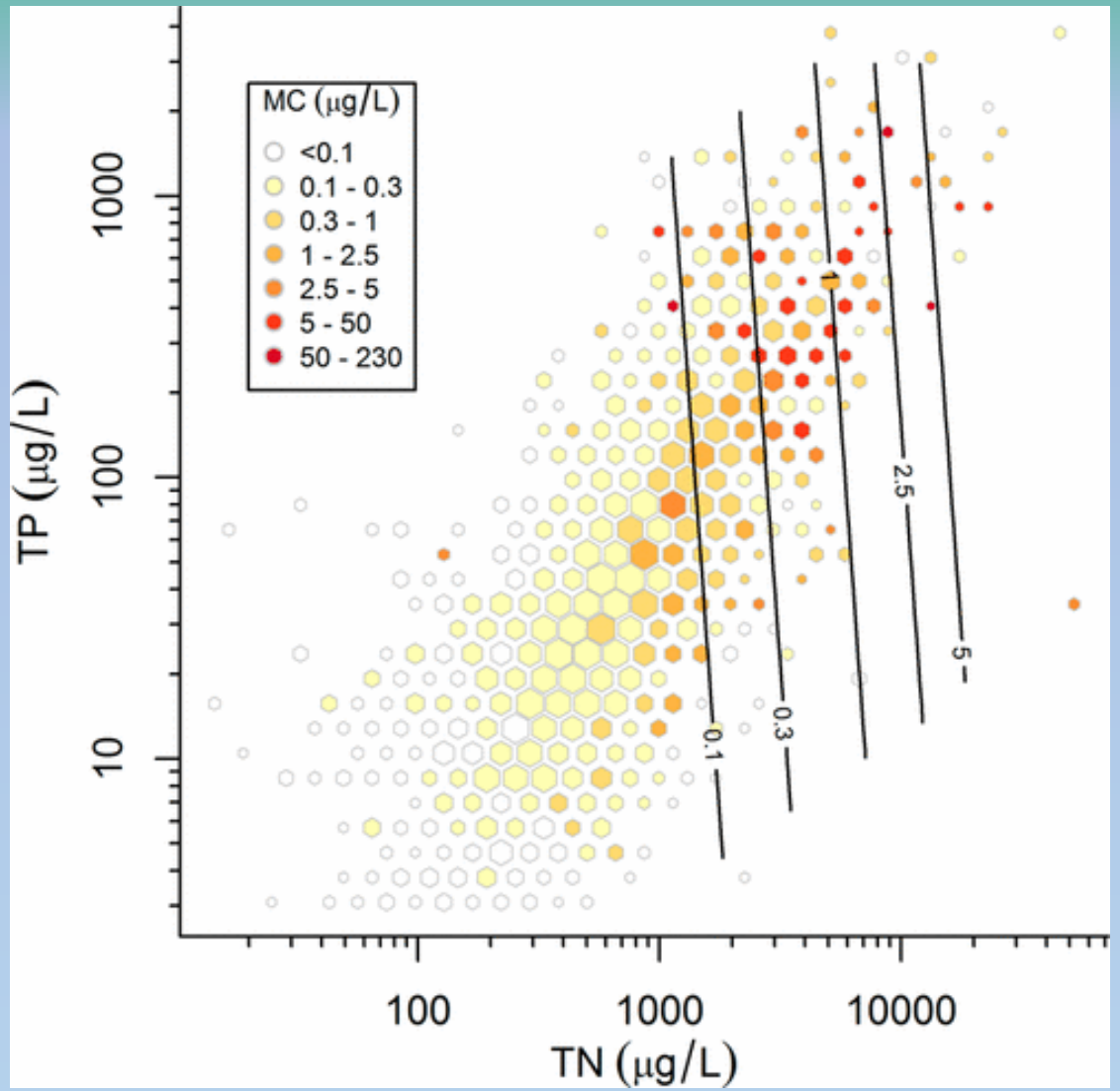
# Relations Between Cyanotoxins and Environmental Variables are Similar to Those Observed for Cyanobacteria




Yuan and Pollard, 2017

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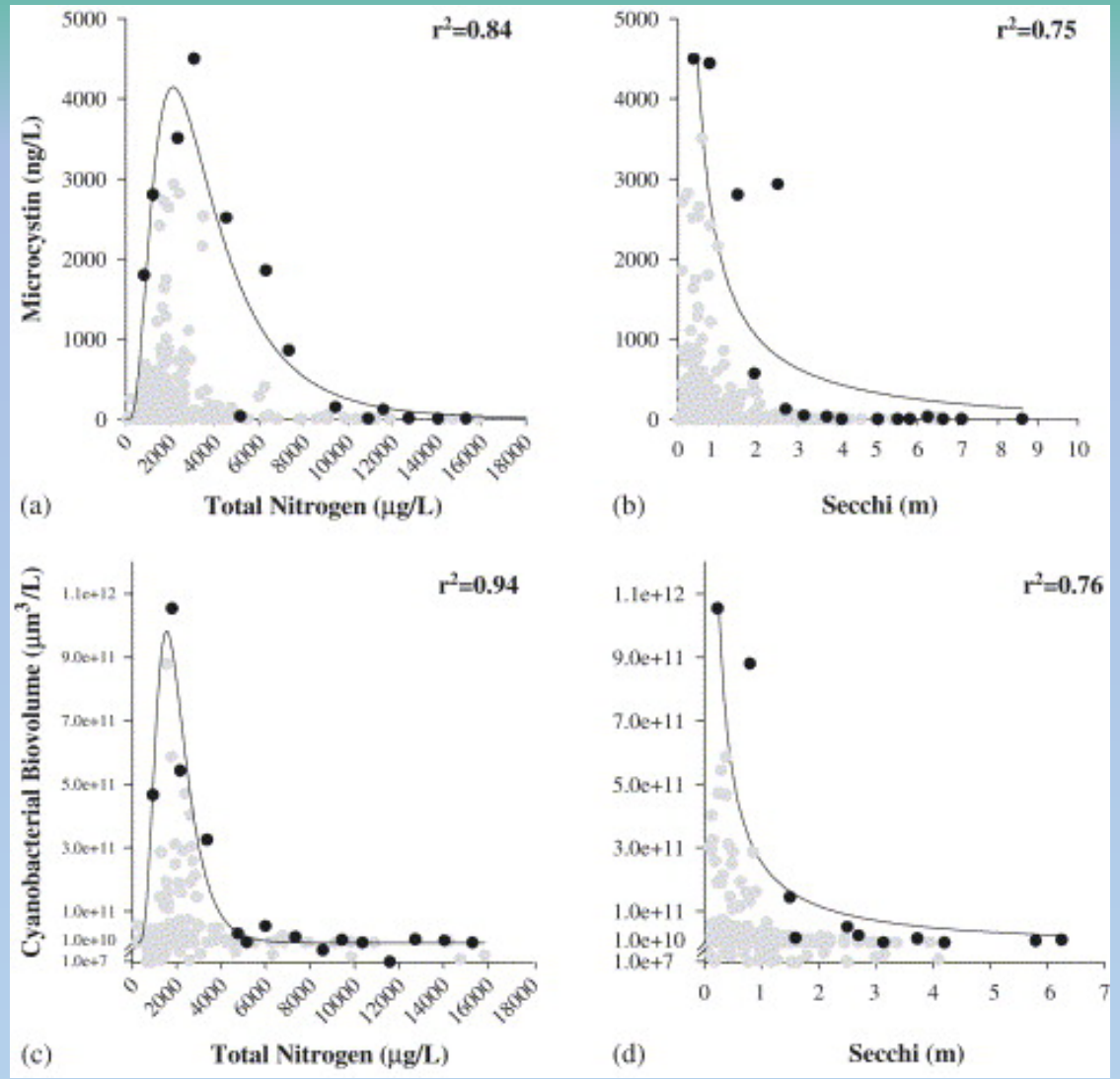


Graham et al., 2004

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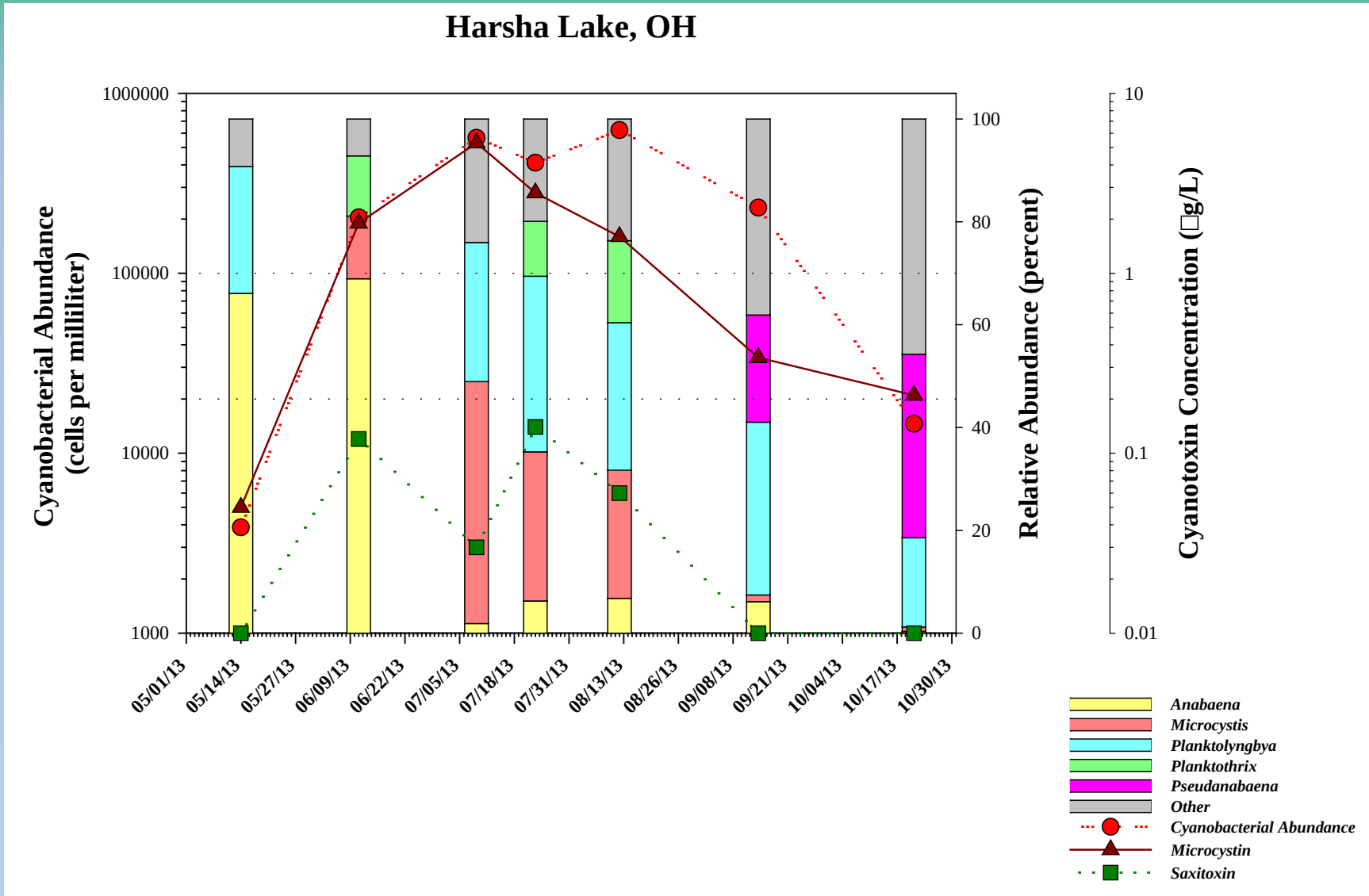
# Cyanotoxin Occurrence is Not Necessarily Tightly Coupled to Cyanobacterial Abundance or Community Composition




Francy et al., 2015

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# Individual Lakes Are Unique

| Reservoir | Strongest Correlate | $r_s$ | p-value | n |
|---|---|---|---|---|
| Bilby | Conductance | -0.86 | <0.01 | 48 |
| Forest | Chlorophyll > 35 µm | 0.67 | <0.01 | 49 |
| Harrison | Total Nitrogen | 0.78 | <0.01 | 49 |
| Marceline | Dissolved Organic Carbon | 0.66 | <0.01 | 49 |
| Mozingo | Magnesium | -0.84 | <0.01 | 13 |
| Nodaway | Nitrate | -0.46 | <0.01 | 49 |
| Paho | *Ceriodaphnia* abundance | 0.81 | <0.01 | 28 |
| Sterling | Sodium | 0.60 | 0.03 | 13 |

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# 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


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

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[c], 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*

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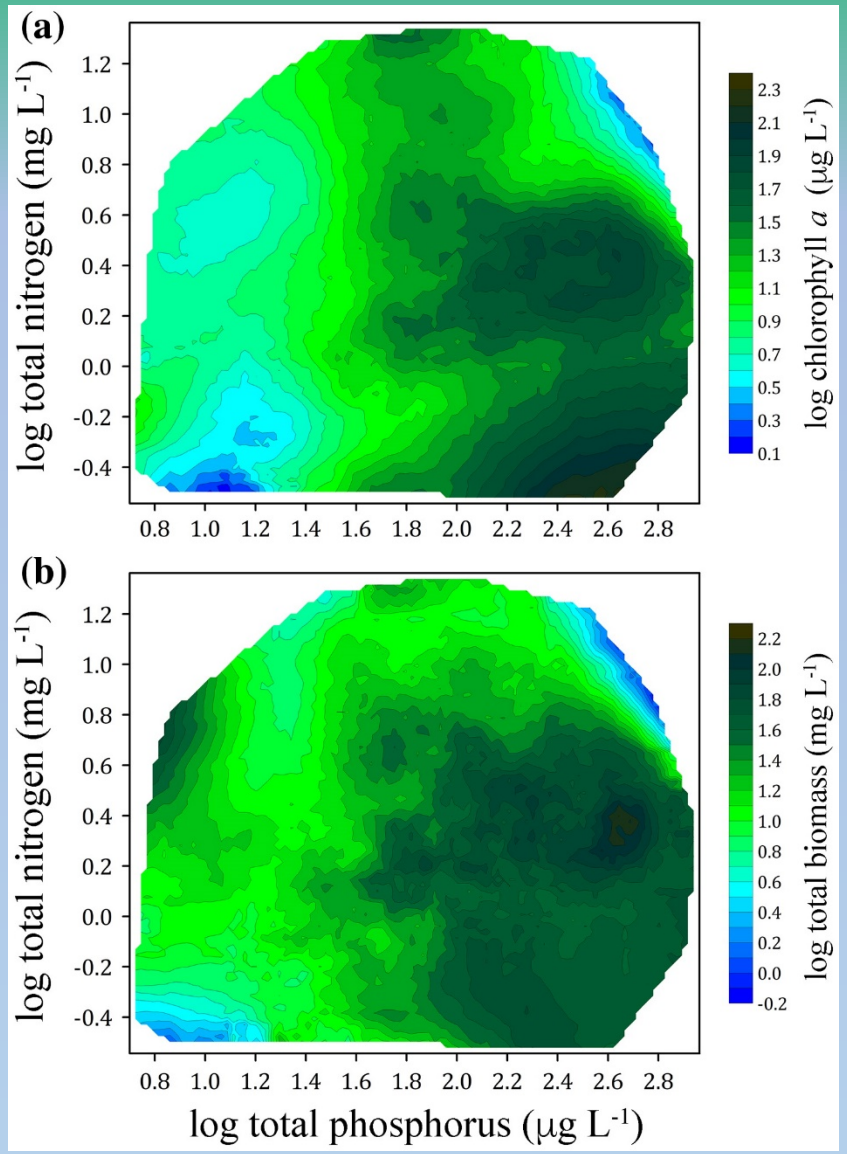
# Paradigms Are Changing




Filstrup and Downing, 2017

**Relationship of chlorophyll to phosphorus and nitrogen in nutrient-rich lakes**

Christopher T. Filstrup & John A. Downing

Pages 385-400 | Published online: 09 Oct 2017

Download citation https://doi.org/10.1080/20442041.2017.1375176 Check for updates

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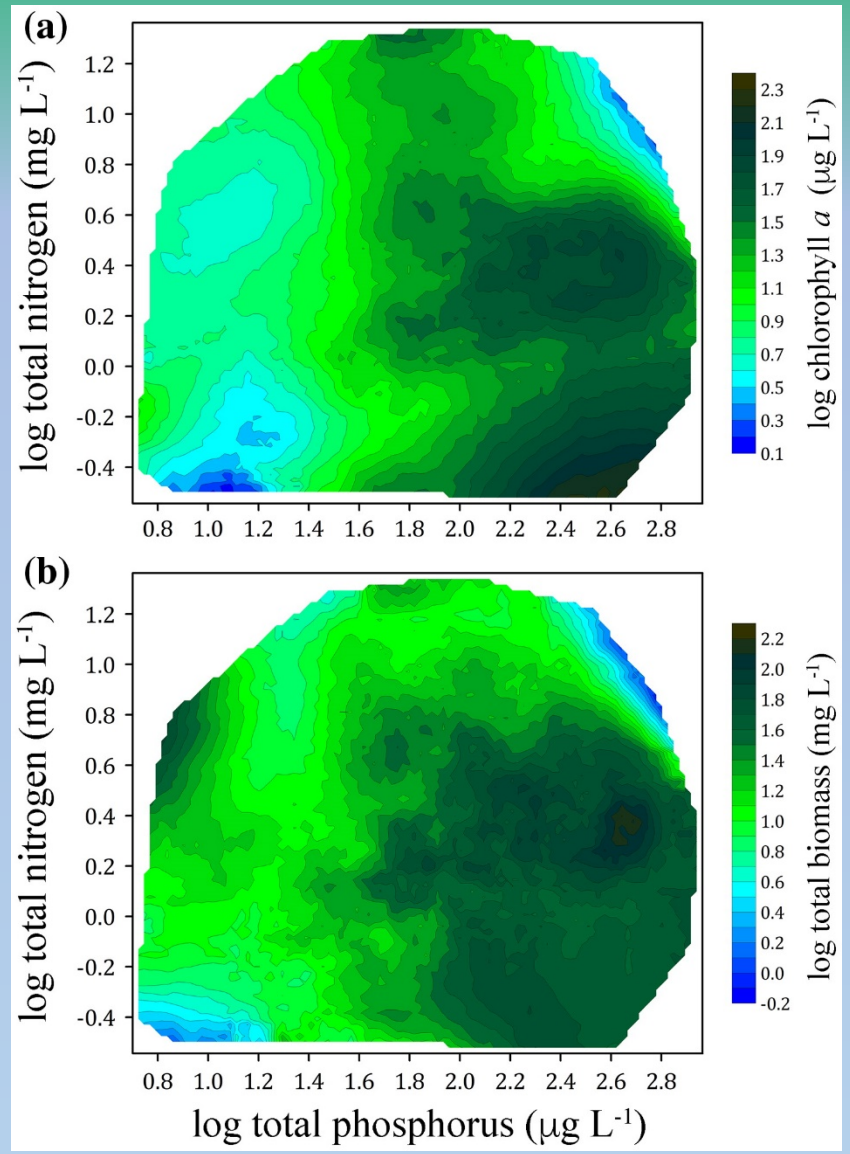


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- High nutrients and low biomass did not coincide with shifts in nutrient limitation, light availability, cellular Chl-*a* content, phytoplankton composition, or zooplankton grazing pressure.
- Nitrate comprised most of TN and occurred with reduced dissolved organic matter.
- Hypothesis: Photolysis of nitrate may produce reactive oxygen species that damage DOM and phytoplankton.

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# Cyanotoxin Blooms Are Occurring in Oligotrophic Systems

## Skaneateles Lake algae outbreak could be toxic, state DEC says

Updated Aug 6; Posted Aug 6 2018

The state has confirmed that algae floating in Skaneateles Lake near the village of Skaneateles is toxic. (Gregory Simmons | Special to Syracuse.com)

## Skaneateles Lake beaches closed after harmful algae blooms pop up

Updated Aug 7; Posted Aug 7

SKANEATELES LAKE

## DEC confirms harmful algal bloom on Skaneateles Lake, now dissipated

The Citizen staff Aug 7, 2018

## Swimmers, Pets Told to Avoid Algal Bloom on Skaneateles Lake; City Monitoring Water Quality

By SCOTT WILLIS & CAMERON TIRADO • AUG 8, 2018

## Toxin-producing algae found again in Skaneateles Lake

Updated Sep 6, 1:51 PM; Posted Sep 6, 1:36 PM

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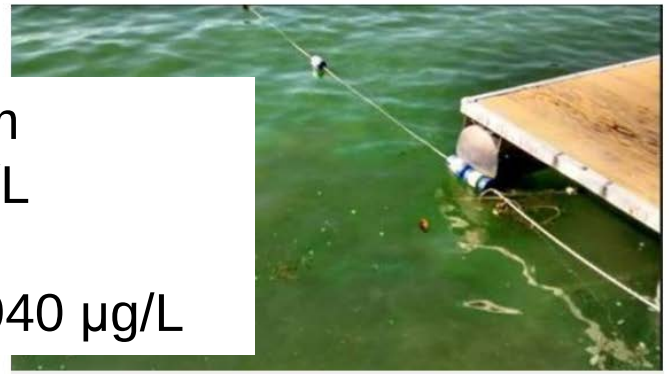

The state has confirmed that algae floating in Skaneateles Lake near the village of Skaneateles is toxic. (Gregory Simmons | Special to Syracuse.com)

2018 Summer Maximum
Total Phosphorus: 7 µg/L
Chlorophyll: 1.6 µg/L
Shoreline Microcystin: 940 µg/L

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


Photo Credit: G. Foster, USGS

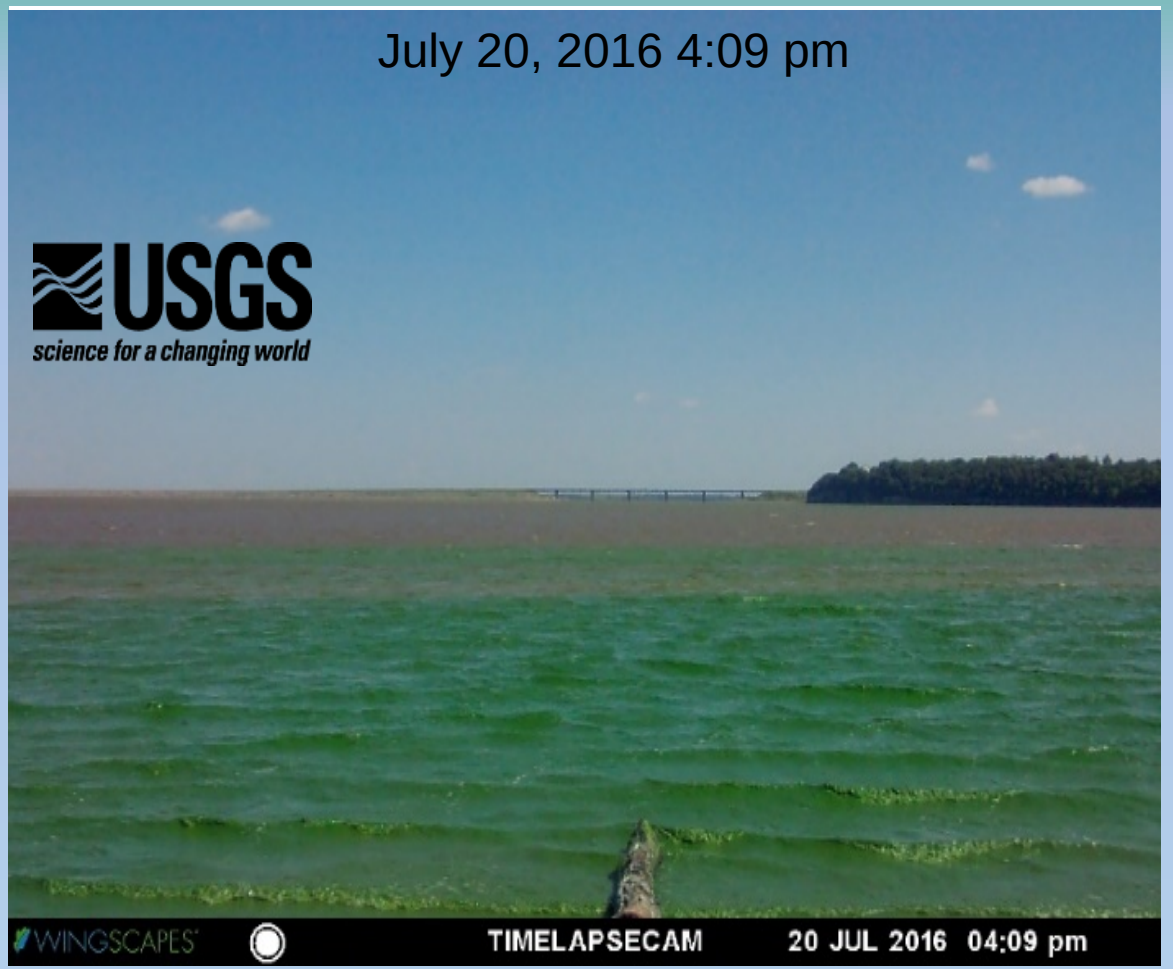


Photo Credit: G. Foster, USGS

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Milford Lake, KS

# Knowledge Gaps

***A considerable amount of research is being conducted…toward the determination of causes and control of algal blooms. An expansion and integration of these studies is indicated as a very real need.***

***~E. T. Rose, 1953***

- Status and trends
- Environmental fate and transport
- Environmental drivers
- Ecosystem effects
- Exposure and health
- Drinking water and food impacts
- Mitigation and management


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