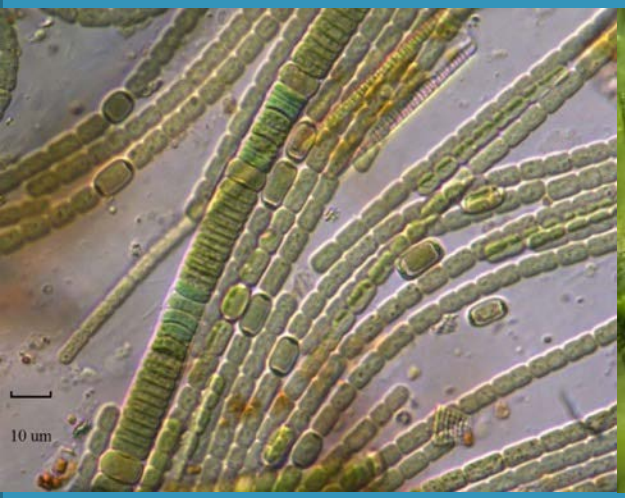
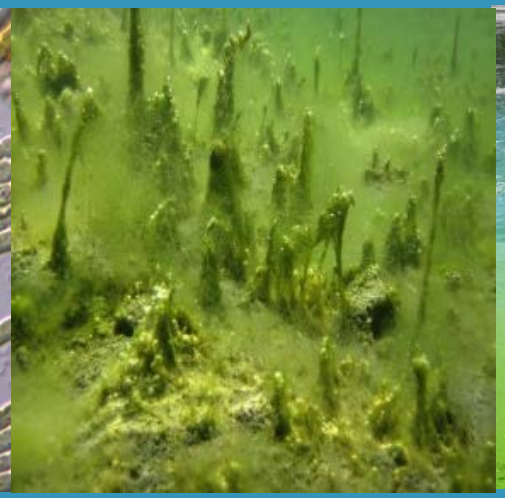
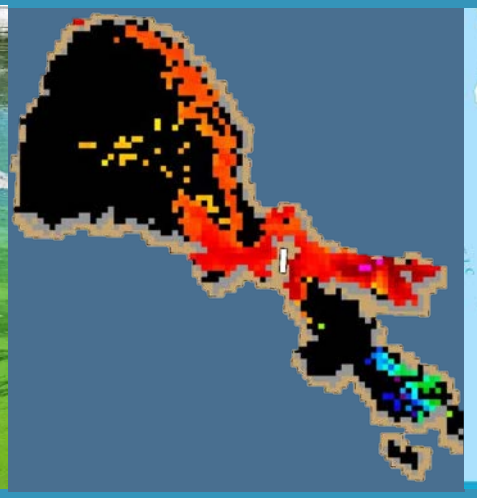
Harmful Algal Blooms:
The good, the bad, the algae



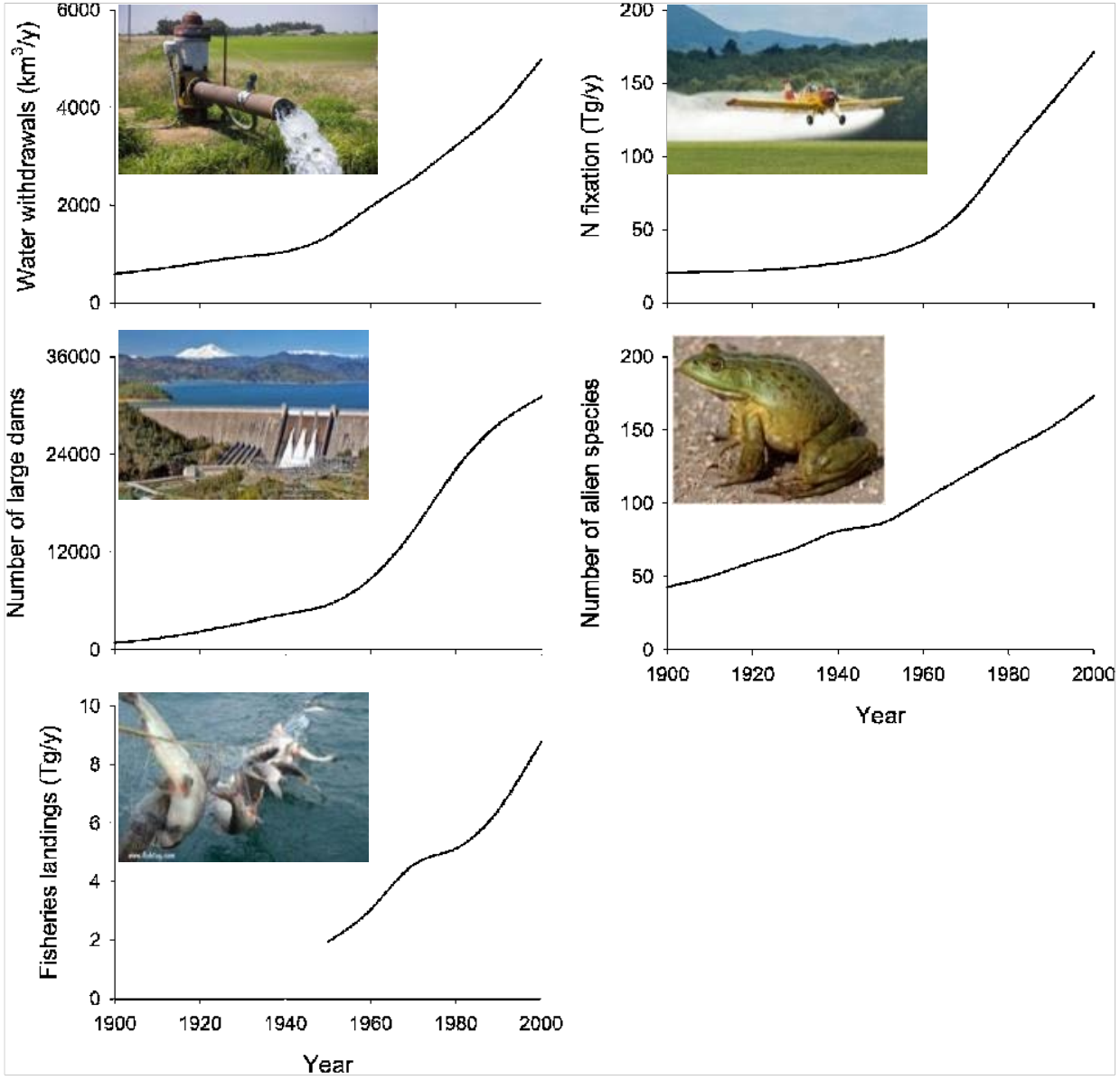





Keith Bouma-Gregson
Statewide FHAB Program Lead
State Water Resources Control Board

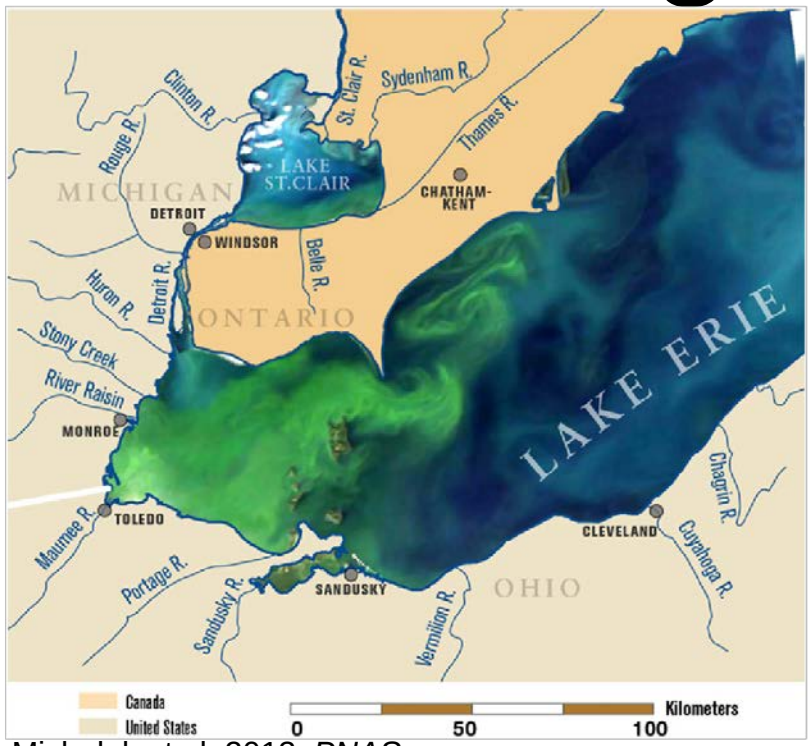
WICC Meeting | September 26, 2019

Whiskey is for drinking ...



Strayer and Dudgeon 2010, *JNABS*

Harmful Algal Blooms (HABs)



Michalak et al. 2013, *PNAS*

http://ngm.nationalgeographic.com/2013/05/fertilized-world/charles-text?_ga=2.76816656.424317726.1512142752-1048308631.1469734927

https://www.pbs.org/newshour/science/chinas-blueprint-clean-lakes-stop-algae-blooms-working

Photo: Ohio EPA

Photo: Richard Graulich/The Palm Beach Post via AP

Impacts of blooms

- Ecosystem function (e.g. fish kills)
- Aesthetics
- Odors
- **Toxins:** drinking water, recreation, agriculture


Photo: NOAA

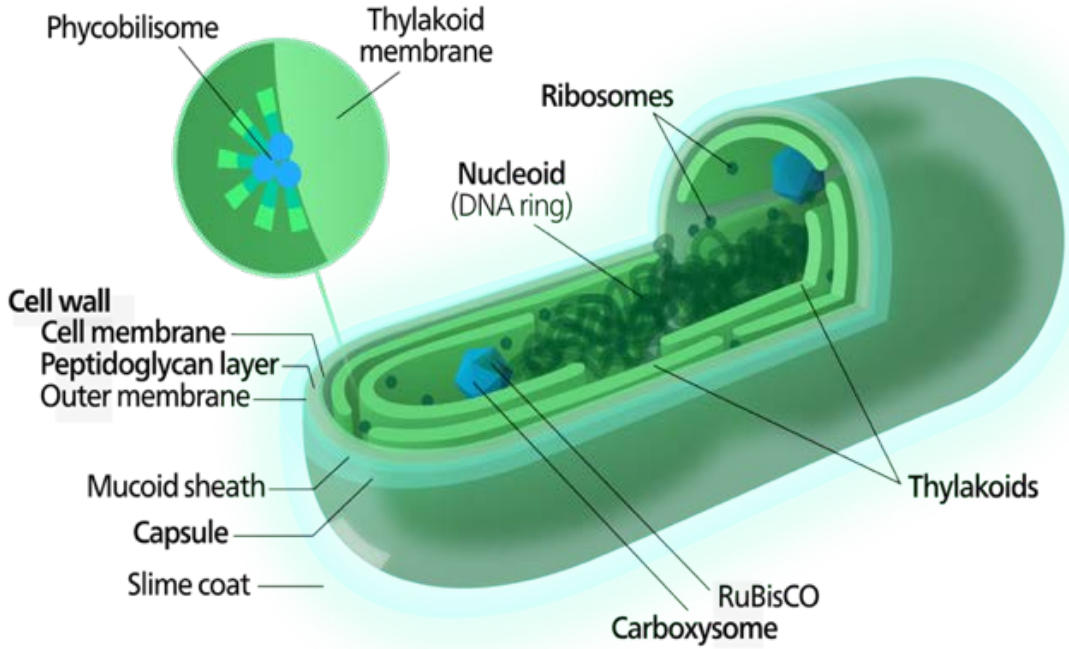

Photo: Ohio EPA


https://dogtrekker.com/user årfiles//GreenDogCCJillSiegrist.gif


Photo: NY Times

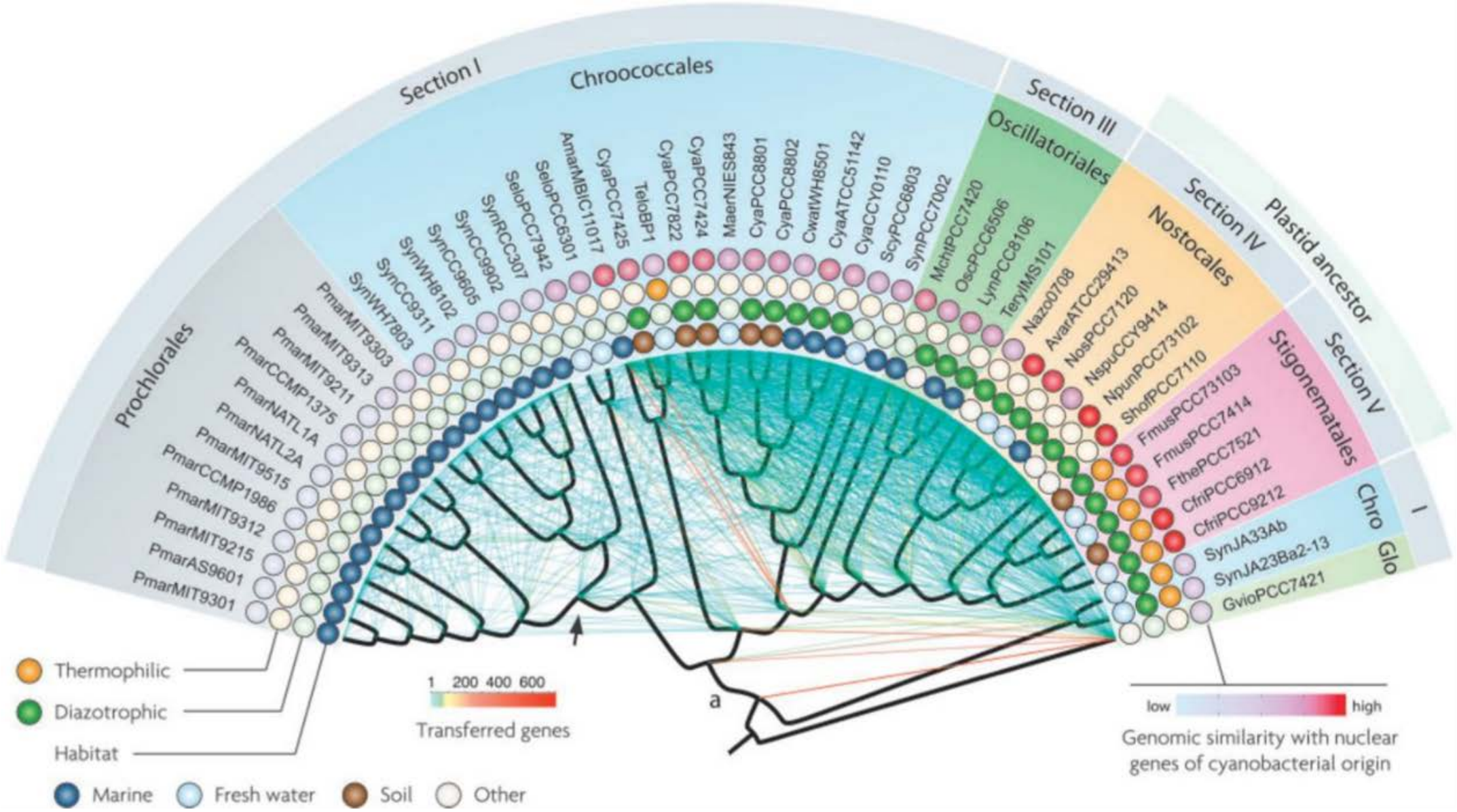
What are Cyanobacteria?

- Photosynthetic bacteria
- Evolved >2 billion years ago
- Globally distributed



https://en.wikipedia.org/wiki/File:Cyanobacterium-inline.svg

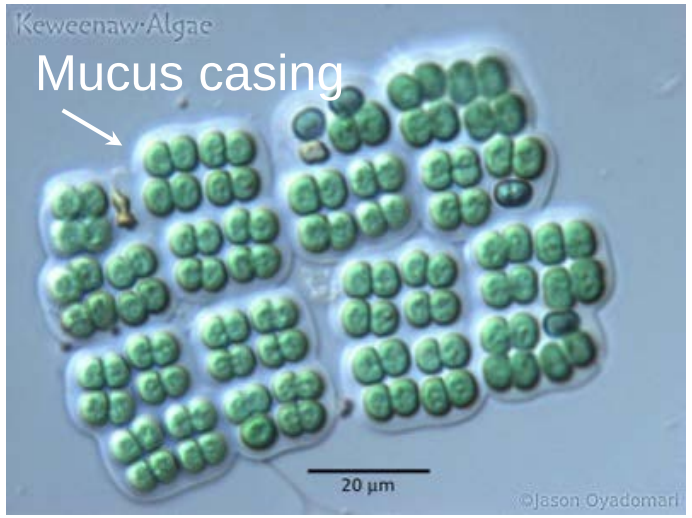
Diversity of Cyanobacteria



Dagan et al. 2013, Genome Biol Evol. 2012;5(1):31-44

Diversity of Cyanobacteria

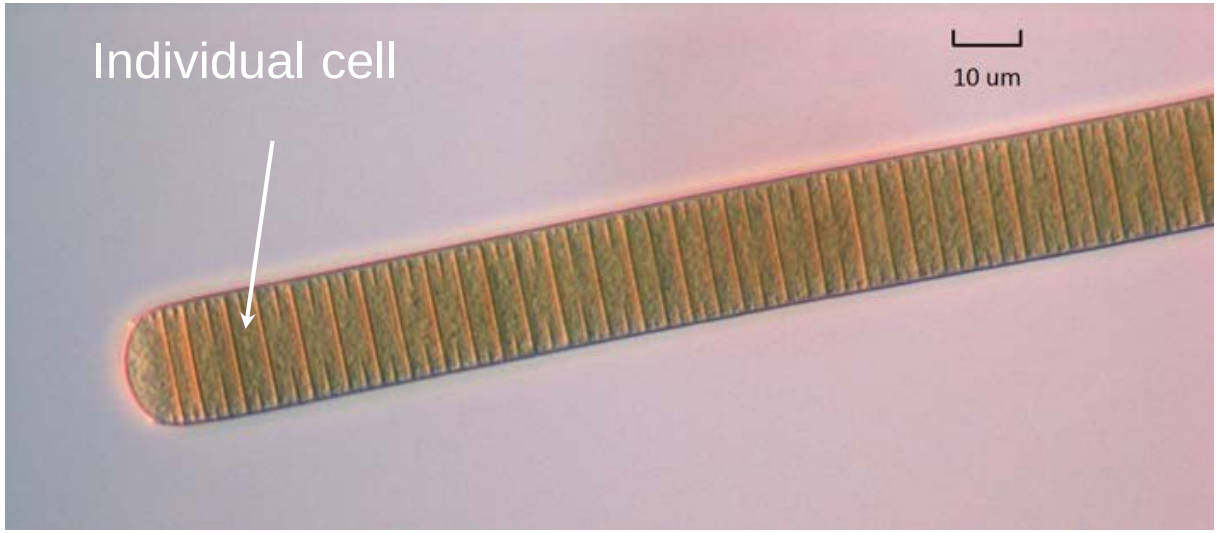
Single celled



http://www.keweenawalgae.mtu.edu/gallery_images/cyanobacteria/Merismopedia_j72a-15_402z_ec_h.jpg

http://www.keweenawalgae.mtu.edu/gallery_images/cyanobacteria/Woronichinia_p5-8a_40125.jpg

Filamentous



Diversity of cyanobacteria

Microcystis spp.

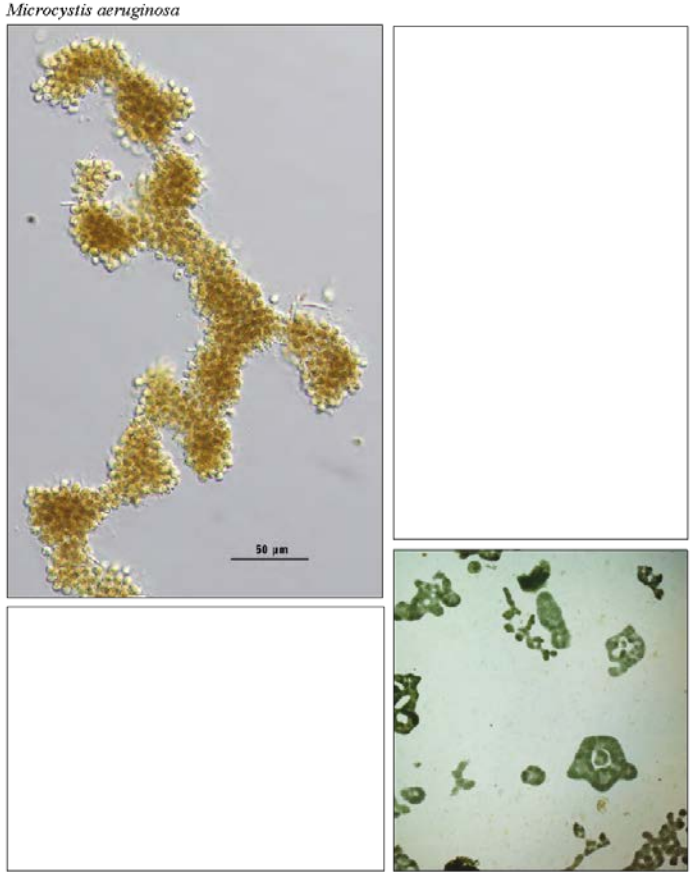
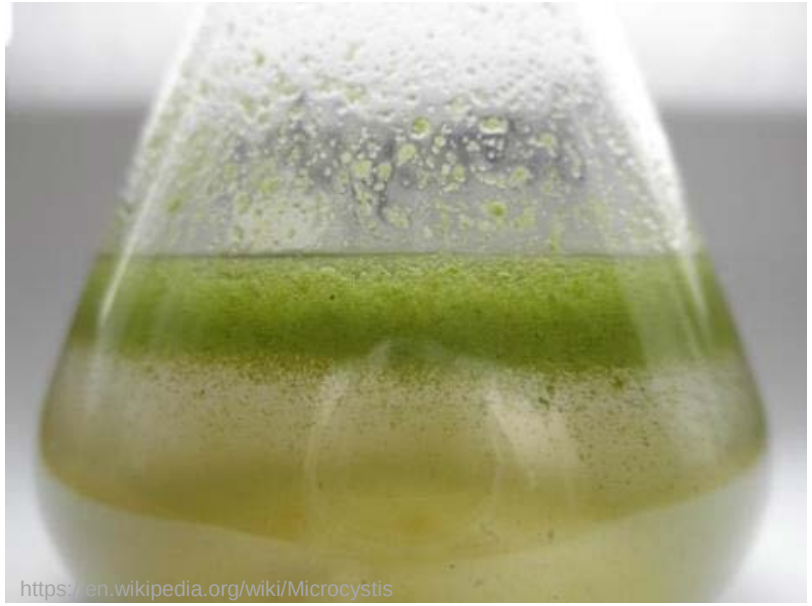


Figure 47. *Microcystis aeruginosa*. Round to oval cells embedding a mucilaginous matrix. Cell color varies from brown to various shades of green and blue-green. (Photographs: Barry H. Rosen)

Rosen and Amand 2015, *USGS*

Forms visible colonies



https://en.wikipedia.org/wiki/Microcystis

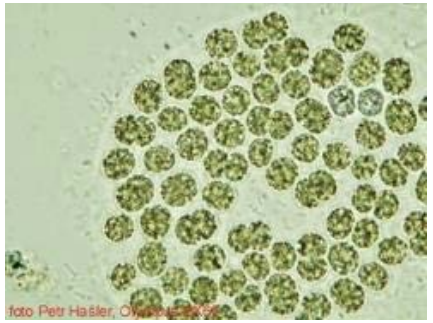


foto Petr Hašler, Ondřej Prášil

http://www.sfam.org.uk/en/news-features/news/index.cfm/microcystis-colonies-bacterial-habitat

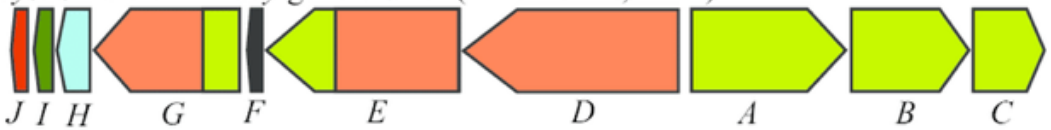
Buoyancy regulation with aerotopes

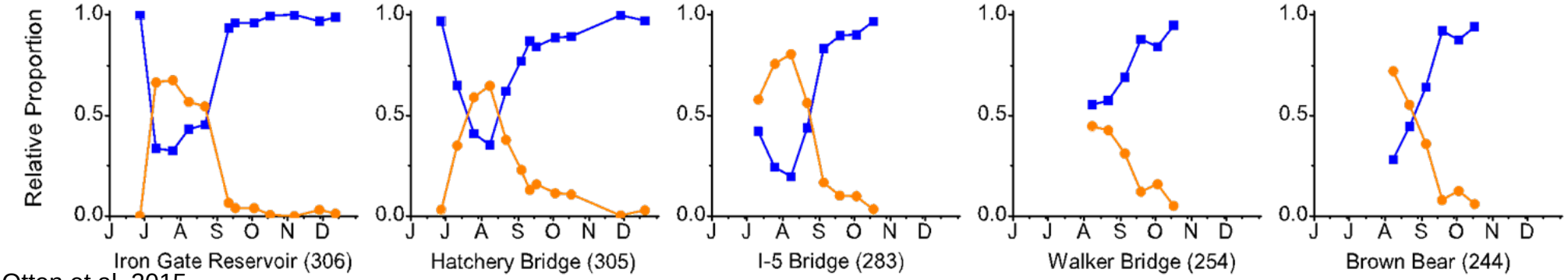
Aerotopes make cells look black under microscope

Cyanobacterial toxins

- Toxin production controlled by genes
- Not all species and strains contain toxin synthesis genes
- Changes in bloom toxicity often driven by changes in the proportion of toxin and non-toxin producing strains in the bloom

Microcystis PCC 7806 *mcy* gene cluster (Tillett et al., 2000)





Otten et al. 2015

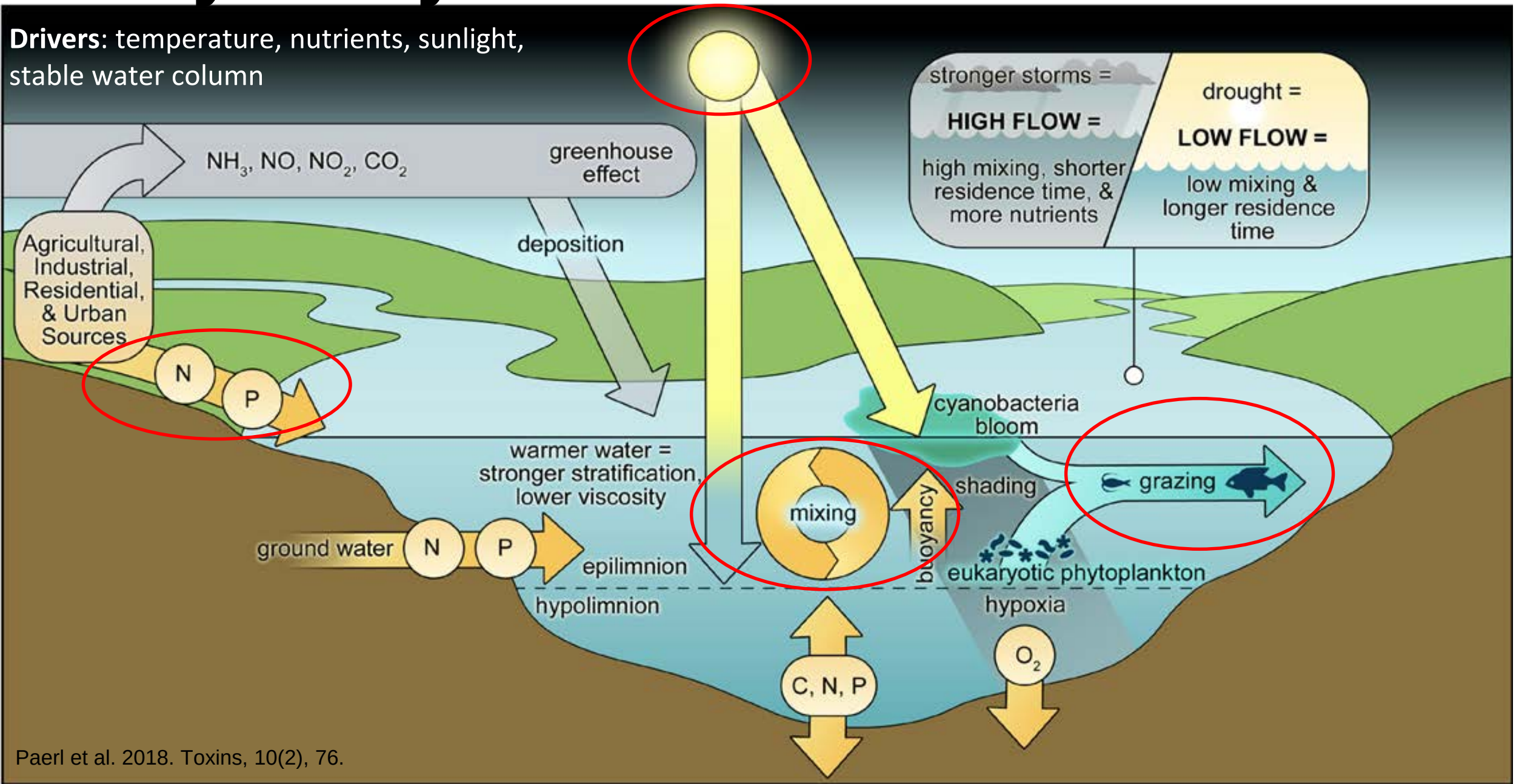
Cyanotoxins – need to test water to determine toxicity

Pinto Lake
Toxins Present

Lake Pillsbury
No Toxins Present

Cyanobacteria Genera	Hepatotoxins		Neurotoxins					Dermatoxins	
	CYN	MC	NOD	ATX	BMAA	NEO	SAX	LYN	LPS
Anabaena (Dolichospermum)	x	x		x	x	x	x		x
Anabaenopsis		x							x
Aphanizomenon	x	x		x	x	x	x		x
Aphanocapsa		x							x
Coelosphaerium (Woronichinia)		x							
Cylindrospermopsis	x	x		x	x		x		x
Gloeotrichia		x							
Limnothrix		x							
Lyngbya	x	x		x	x		x	x	
Microcystis		x			x				x
Nodularia			x		x				x
Nostoc		x	x		x				
Oscillatoria (Planktothrix)	x	x		x	x		x	x	x
Phormidium		x		x	x				
Planktolyngbya							x	x	
Pseudanabaena		x		x					x
Raphidiopsis	x			x					x
Synechococcus		x			x				x
Synechocystis		x			x				x
Woronichinia		x		x					

Why do cyanobacteria bloom?

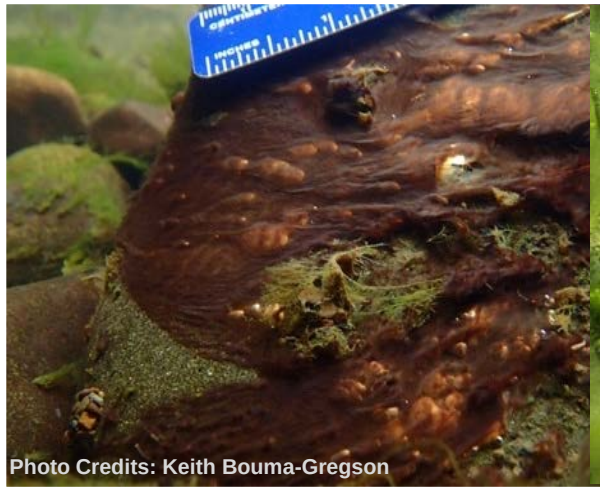
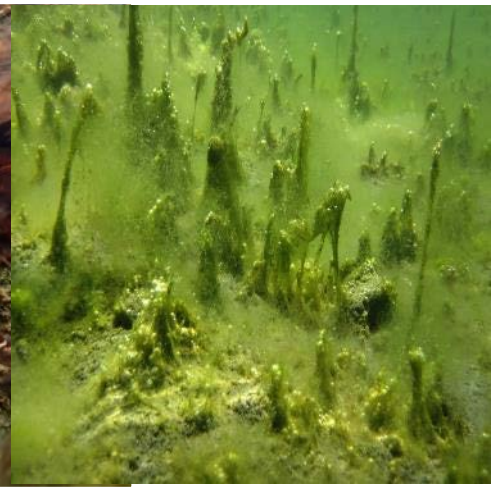
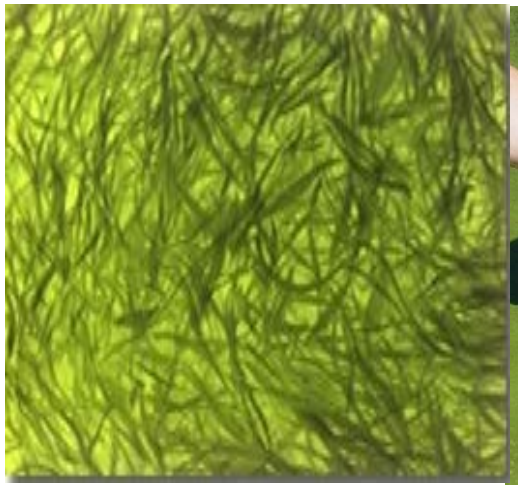


Paerl et al. 2018. Toxins, 10(2), 76.

HABs in California

- Oregon to Mexico
- High elevation to the coast
- Urban and rural areas
- Drinking water reservoirs and natural lakes
- Rivers
- Cyanotoxins in estuaries
- Occur every month, peak in summer

Diversity of HABs and cyanotoxins

Waterbody	Rivers		Lakes	
				
Taxa	***Microcoleus***	***Anabaena***	***Aphanizomenon***	***Microcystis***

Cyanotoxins

- ✓ Microcystins
- ✓ Anatoxin-a
- ✓ Saxitoxin
- ✓ Cylindrospermopsin
- ✓ And more

California FHABs Program

Why is SWAMP involved in FHABs?

Cal EPA

State Water Boards: WQ

Drinking water

OIMA

SWAMP

Cal Health & Human Services

Cal Public Health: Human and Environmental health

- SWAMP provides water quality resources and information to decision makers and the public about the condition of California waterbodies.
- Water Boards - SWAMP is the designated agency lead for the Freshwater Harmful Algal Bloom (FHAB) Program. The statewide initiative to address HAB issues and support the protection of animal, wildlife and human health throughout California.

SWAMP
Surface Water Ambient Monitoring Program

CCHAB network

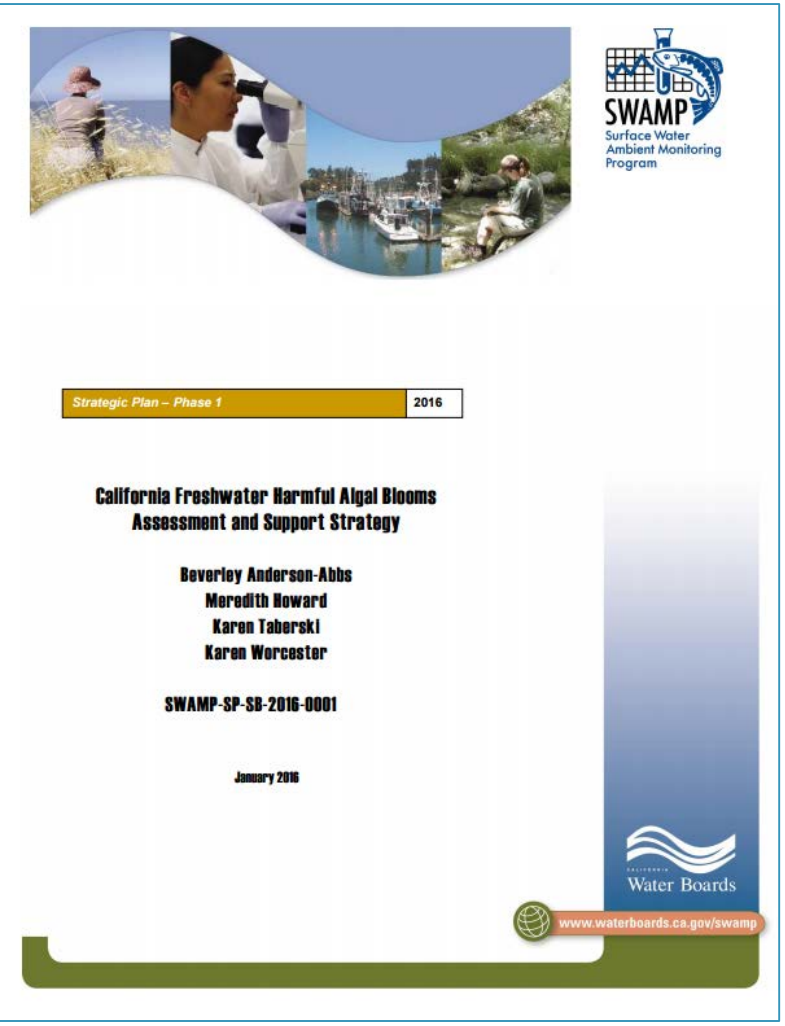
- Workgroup under the Monitoring Council; formed in 2006
- Some objectives:
  - Develop a unified multi-entity program to identify and address HABs in California's freshwater ecosystems.
  - Promote improvements in, and coordination of monitoring assessment, reporting, and management of HABs in California.
  - Work collaboratively toward public awareness of the risks associated with HABs to people, pets, livestock, and wildlife

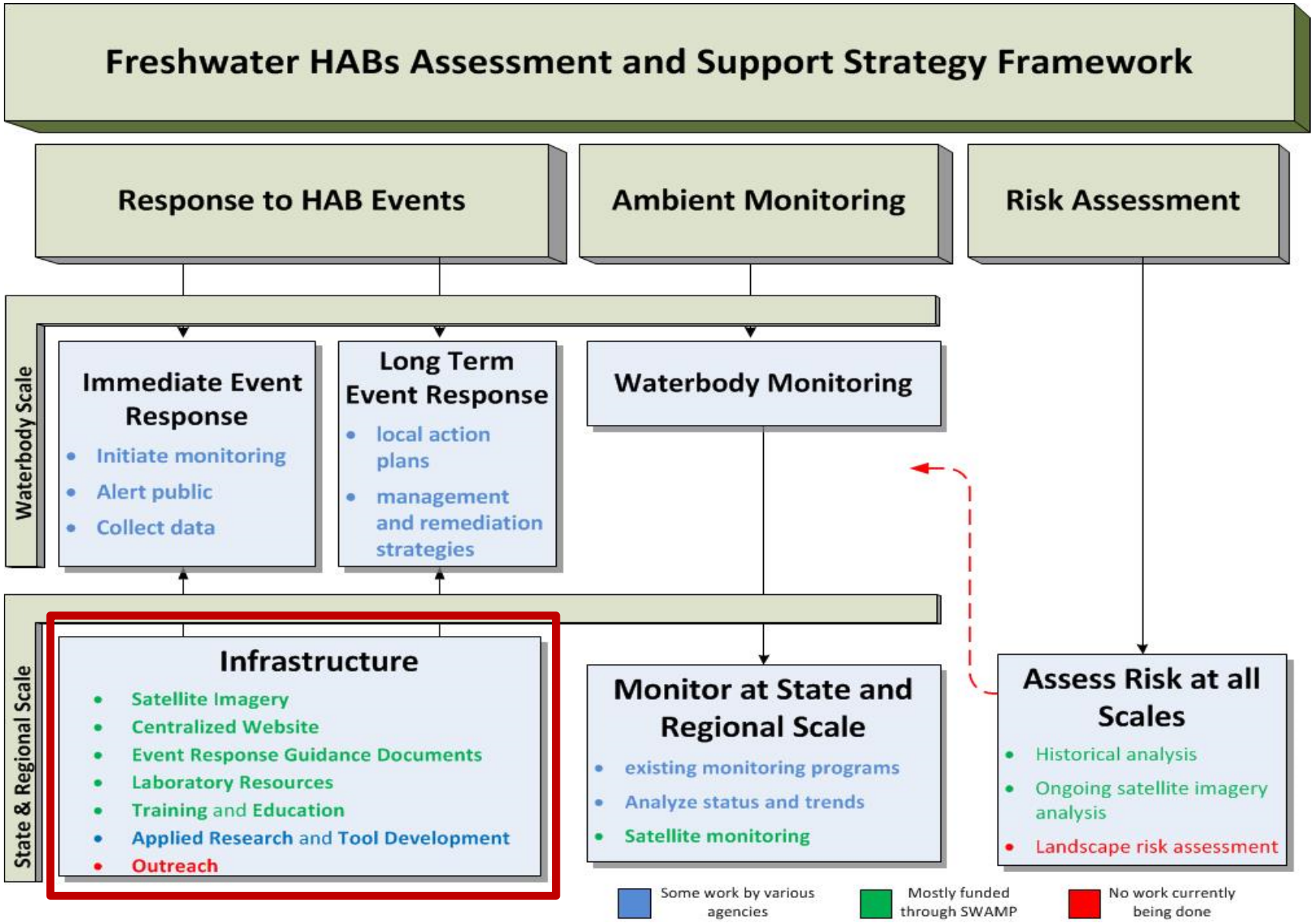
CALIFORNIA
WATER
QUALITY
MONITORING COUNCIL

Regional Board FHAB Leads

FHAB Program Leads at Regional Water Boards		
1	Katharine Carter Rich Fadness	9 Regional Water Boards -At least 1 staff per region -Supported by HAB Illness Workgroup -Lead HAB event response Coordinates response with: • State Board FHAB leads • SWAMP staff • Local health agencies • Waterbody managers • Tribal groups • Division Drinking Water • Interested community members & watershed stakeholders
2	Carrie Austin	
3	Melissa Daugherty	
4	Jun Zhu	
5	Christine Joab Matt Krause Alice Lopes	
6	Mary Fiore-Wagner Tom Browne	
7	Jeff Geraci	
8	Heather Boyd Mark Smythe	
9	Betty Fetscher Carey Nagoda	

HABs assessment and support strategy (2016)





CA HABs Portal

https://mywaterquality.ca.gov/habs/index.html

Portals | About Us | Work Groups | HABs Links

California Harmful Algal Blooms (HABs) Portal

The CA HABs Portal is the central resource for HABs in the state of California. HABs can pose a health risk to people and animals, harm aquatic ecosystems, and limit the use of drinking and recreational waterbodies due to the toxins, odors, and scums or mats they can produce.

The Portal is an informational resource for the public and also functions as a tool to support coordination with statewide partners to address HABs. The content is developed by the CA Cyanobacteria and HAB Network and participating state agencies.

Note: Much of the content included here focuses on freshwater and estuarine HABs; similar content for marine (coastal) HABs is included on the California Harmful Algal Bloom Monitoring and Alert Program (CalHABMAP) webpages.

Interactive Maps	
	HAB Incident Reports Map HAB Incident Reports Map provides data on voluntarily reported blooms in California. The data may include reports under investigation and/or confirmed incidents of HABs.
	HAB Data Viewer HAB Data Viewer currently provides all data on popular recreational water bodies that are monitored prior to summer holiday weekends. Dots represent all monitoring locations and are color coded by the advisory level recommended (No advisory, Caution, Warning, Danger) based on the latest water testing results. Additional data viewing tools will be available in Fall 2018.

Toolbox

- Report a Bloom
- HAB Incident Reports Map
- Frequently Asked Questions
- Signs and Guidance for HAB Response
- Field Guide and Forms

Resources

- Announcements
- HAB Data Viewer
- Healthy Water Habits
- Human Health Impacts
- Domestic Animal Impacts
- Fish and Wildlife Impacts

- Training and Collaboration
- Drinking Water
- Monitoring
- Laboratory Resources
- Control and Treatment of Blooms
- HAB Freshwater Incident Response and Interagency Coordination
- State Agency Contacts
- Related Programs and Organizations
- Other Resources

Satellite imagery tool

https://mywaterquality.ca.gov/habs/data_viewer/#satellite

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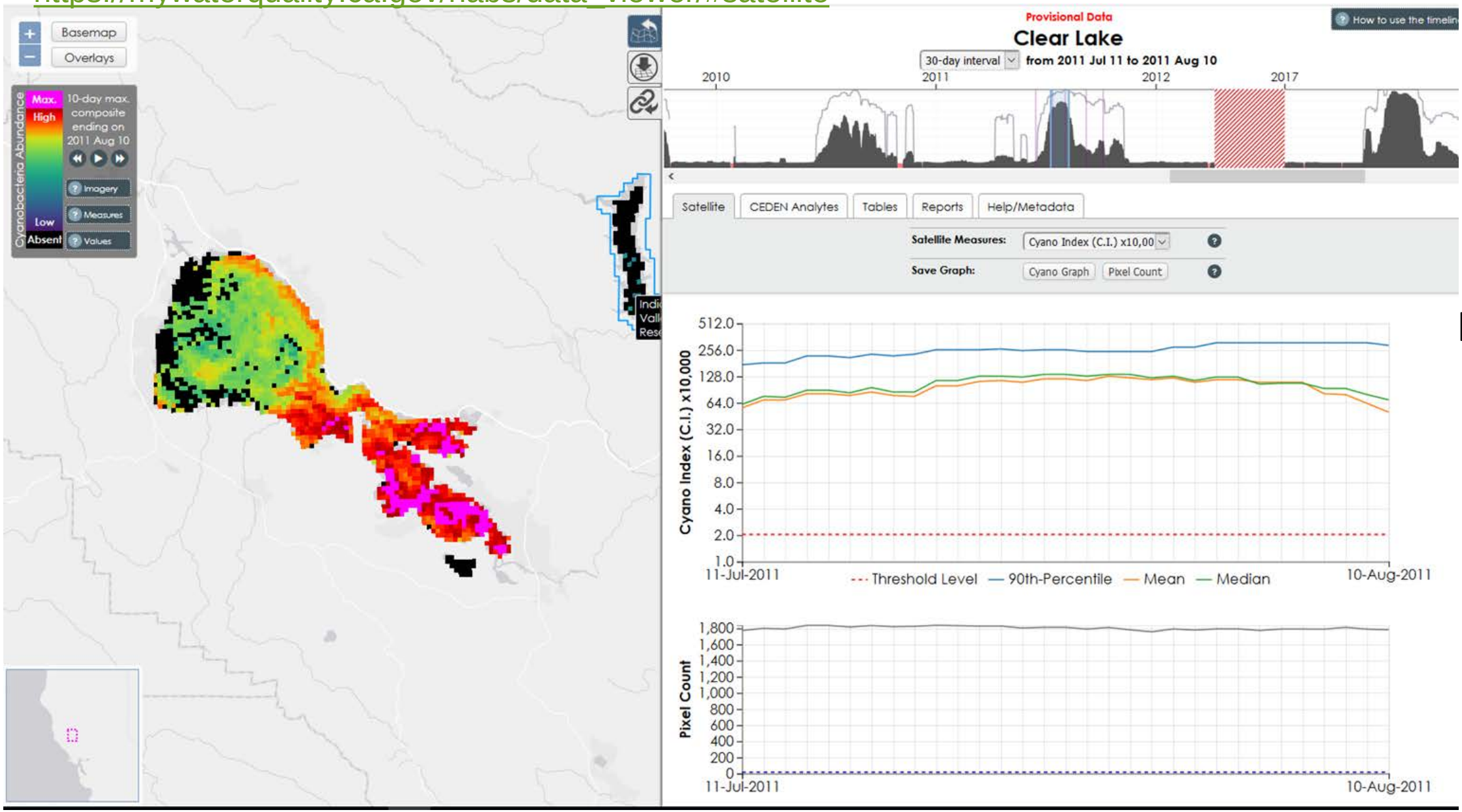


blooms

Report a bloom

Portals | About Us | Work Groups | HAB

California Freshwater & Estuarine Harmful Algal Bloom Report Form

Please use the form below to provide information about the suspected or confirmed algal bloom and any related human or animal illnesses. Only questions marked with bold text and an asterisk are required. Please provide as much information as possible to assist us in investigating the bloom.

Submit Form: Click the submit button at the end of the form to send the information. You will be provided an Incident Tracking ID number.

Photos: This form will not support the upload of photographs. After you submit the form, please send bloom photographs and any additional information to CyanoHAB.Reports@waterboards.ca.gov and reference your Incident Tracking ID number.

Questions: If you have questions or concerns please contact the HAB Hotline:
Email: CyanoHAB.Reports@waterboards.ca.gov; Phone: 1-844-729-6466 (toll free).

Other Resources:

- For more information on harmful algal blooms, visit: Frequently Asked Questions
- Symptoms of HAB-related illness in people and animals are available from the Center for Disease Control and Prevention (CDC) and by contacting the California Poison Control Center (1-800-222-1222).
- Report a bloom with your smart phone: bloomWatch App - available as a free download (Android, iOS).
- Report a marine (coastal) bloom (e.g. red tide), visit: https://jellywatch.org/

This page is maintained by CA State Water Resources Control Board - Surface Water Ambient Monitoring Program.

Waterbody Information

Report Type (*): ○ New Report ○ Follow Up from Previous Report

Incident ID from previous report, if known:

Incident response map

This map only shows locations where harmful algal blooms (HABs) have been voluntarily reported. California currently does not have adequate funding for a statewide routine monitoring program so monitoring data is limited. A waterbody with no data is not an indication that a bloom is not present. Dots represent reported locations with pop-up windows providing additional data for each HAB incident such as field and/or lab results. Several routine monitoring programs exist for some locations (Klamath Basin, East Bay Regional Parks, Clear Lake, and reservoirs along State Water Project), which may share monitoring data to present in this map.

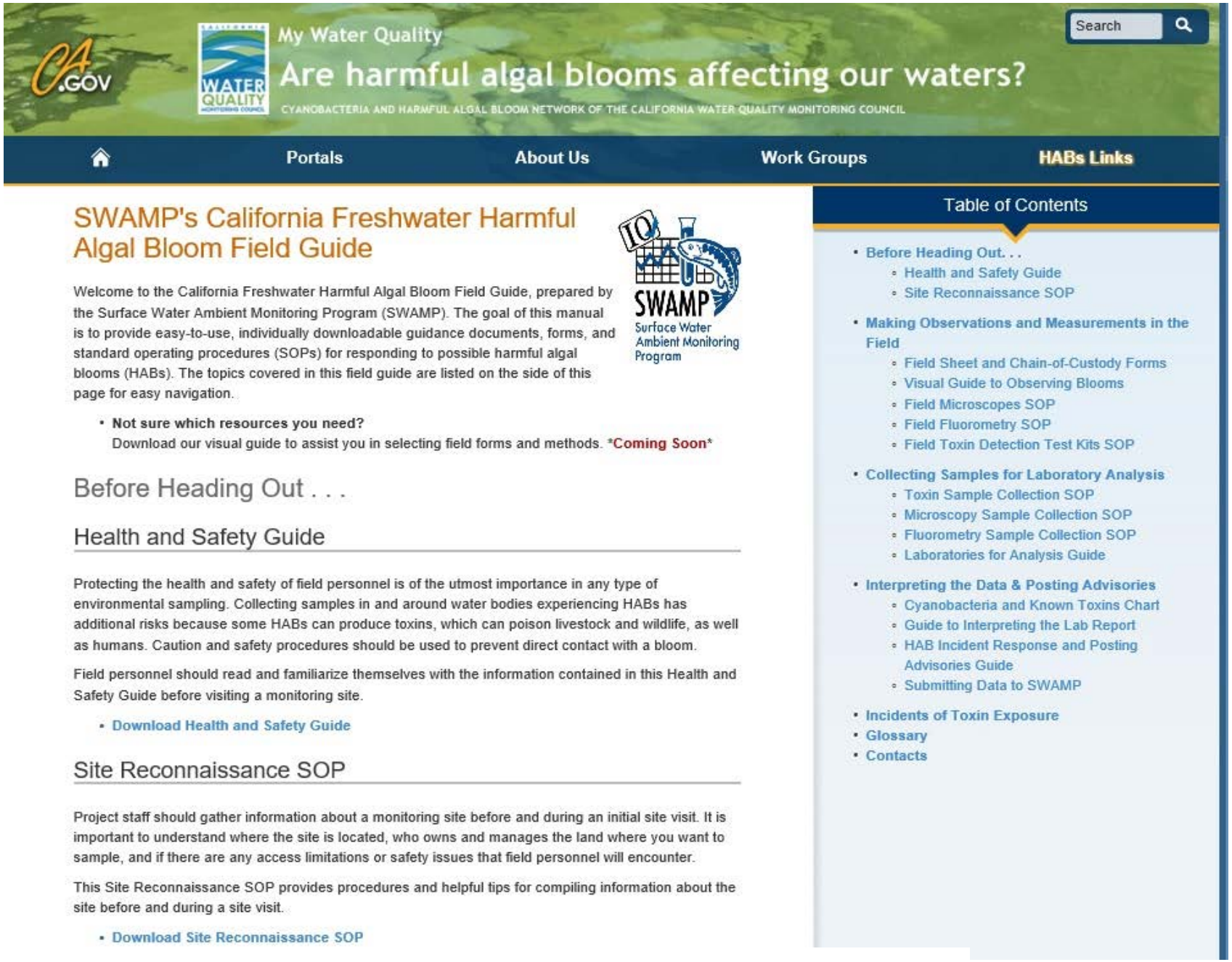
Note - The exact location, extent, and toxicity of the reported bloom may not be accurate and may not be affecting the entire waterbody. Please use data presented in this map for general purposes only, as it may contain errors. The data are subject to change as new information is received. Please check back for daily updates.

- To download the full data set, click the download button located on the bottom right of the map below

Regional Water Board	Waterbody Name	Day of First Observed	Day of Bloom Last Ver.	
Region 1 - North Coast	Big Lagoon	August 23, 2017	August 31, 2017	Details
	Bel River, Near Miranda, Sout..	August 28, 2017	September 14, 2017	Details
Region 2 - San Francisco Bay	Arroyo Del Valle in Shadow Cliffs Regional Park	June 1, 2016	July 1, 2016	Details
		August 28, 2017	October 19, 2017	Details
	Hulchica Pond 8, near Napa River	June 30, 2017	April 11, 2018	Details
		January 12, 2018	May 1, 2018	Details
	Lake Almaden	August 24, 2017	December 20, 2017	Details
	Lake Anza	May 20, 2016	December 29, 2016	Details
		June 5, 2017	July 25, 2017	Details
		September 18, 2017	November 29, 2017	Details
		January 2, 2018	January 2, 2018	Details
	Lake Chabot (Alameda Co)	August 5, 2016	December 8, 2016	Details
		January 1, 2017	December 28, 2017	Details
		January 10, 2018	May 24, 2018	Details
	Lake Cunningham	January 4, 2017	December 20, 2017	Details
		January 10, 2018	May 15, 2018	Details
	Lake del Valle	April 28, 2016	December 8, 2016	Details
		December 5, 2016	December 5, 2016	Details
		April 14, 2017	July 21, 2017	Details
	Lake Temescal	June 28, 2016	December 8, 2016	Details
		June 6, 2017	December 18, 2017	Details
		January 2, 2018	January 2, 2018	Details
	McNabney Marsh	September 12, 2017	September 12, 2017	Details
	O'Neill Slough, San Mateo	October 27, 2017	October 27, 2017	Details
	Quarry Lakes	March 4, 2016	December 8, 2016	Details
		March 9, 2017	December 26, 2017	Details
		January 11, 2018	May 24, 2018	Details
	Richardson Bay, at Coyote Cr..	April 30, 2017	April 30, 2017	Details
	Scottsdale Pond (btwn Hwy 1..	July 27, 2017	October 5, 2017	Details
	Shadow Cliffs Lake	January 24, 2017	January 24, 2017	Details
		June 2, 2017	June 6, 2017	Details
Region 3 - Central Coast	Atascadero Lake	April 19, 2017	April 20, 2017	Details
	Cachuma Lake, near boat ramp	May 22, 2017	May 22, 2017	Details
	Jim May Park Lake	August 10, 2017	August 10, 2017	Details
	Kelly Lake	July 18, 2016	August 2, 2016	Details
	Laguna Lake	September 27, 2016	September 22, 2016	Details
	Lake San Antonio	June 26, 2017	June 26, 2017	Details
		May 23, 2018	May 23, 2018	Details

+ableau

Standard Operating Procedures for Monitoring & Sample Collection



http://www.mywaterquality.ca.gov/habs/resources /field.html

Event response guidance documents

Table 1: Trigger Levels For Human and Animal Health

	Caution Action Trigger	Warning TIER I	Danger TIER II
Primary Triggers			
Total Microcystins [b]	0.8 µg/L	6 µg/L	20 µg/L
Anatoxin-a	Detection [c]	20 µg/L	90 µg/L
Cylindrospermopsin	1 µg/L	4 µg/L	17 µg/L
Secondary Triggers			
Cell Density (Toxin Producers)	4,000 cells/mL	--	--
Site Specific Indicators of CyanoHAB	Visible bloom/discoloration, scum, algal mats, satellite imagery.	--	--

a. The primary triggers are met when ANY toxin exceeds criteria
b. Microcystins refers to the sum of all measured microcystin congeners
c. Must use an analytical method that detects ≤ 1 µg/L Anatoxin-a

- Bloom reported
- Waterboards or other entity staff perform visual assessment and collect water samples
  - Bloom notification sent out to health agencies and waterbody managers
- Cyanotoxin analysis results compared with trigger levels
- Appropriate signage posting recommended to Environmental Health Departments
- Follow up sampling and de-posting

Event response process

Report of a Bloom

HAB Coordinator

REPEAT STEPS 1 – 5, AS NECESSARY

1. REVIEW & ASSESS INFORMATION
2. COMMUNICATE & SHARE INFORMATION
3. COORDINATE MONITORING & RESPONSE
4. COORDINATE WITH DDW DISTRICT OFFICE
5. COORDINATE NOTIFICATION & SIGNAGE

HAB Lead Coordinates with:

Questions?

Keith Bouma-Gregson

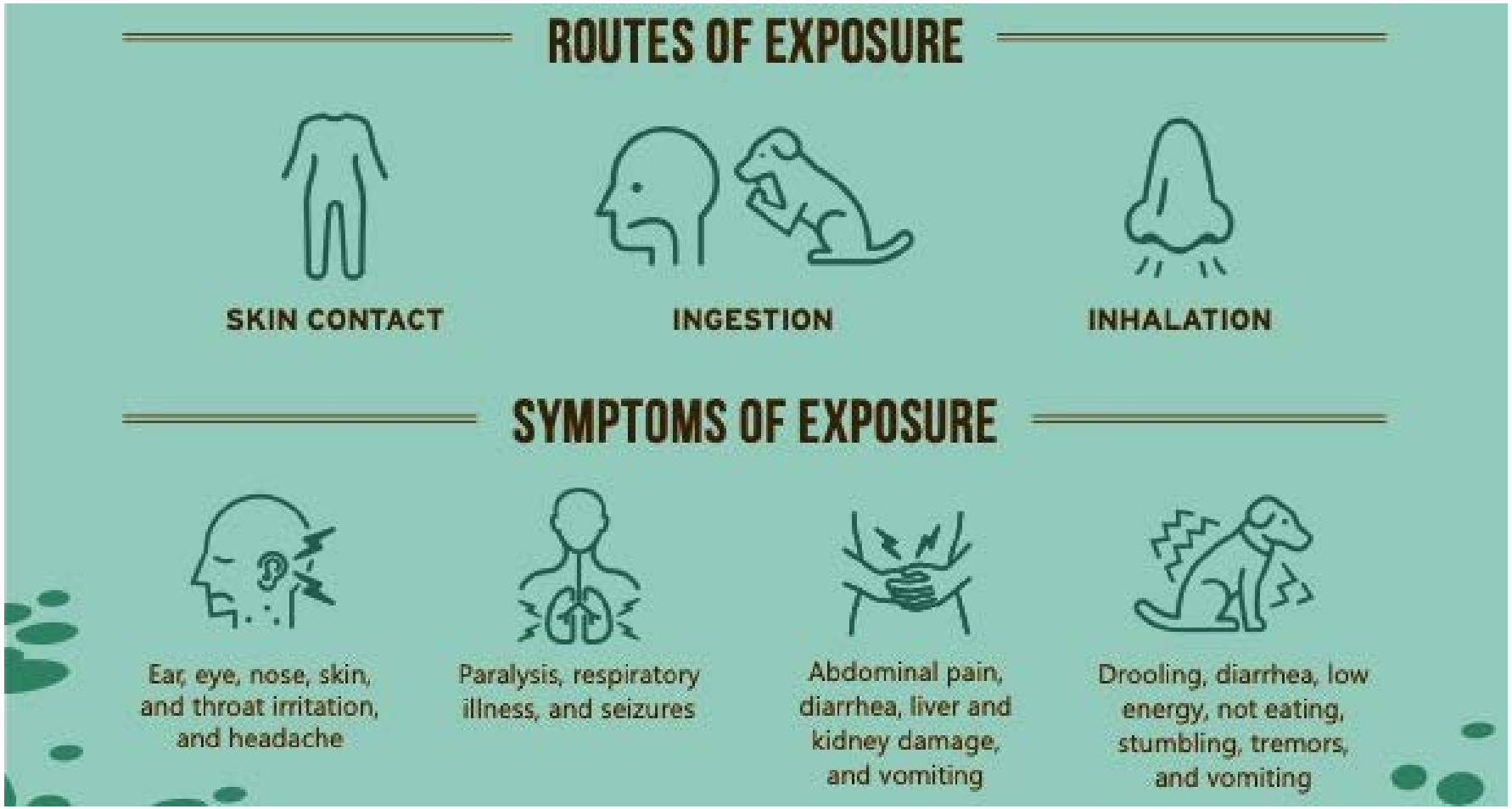
Freshwater HABs Program

State Water Resources Control Board

keith.bouma-gregson@waterboards.ca.gov

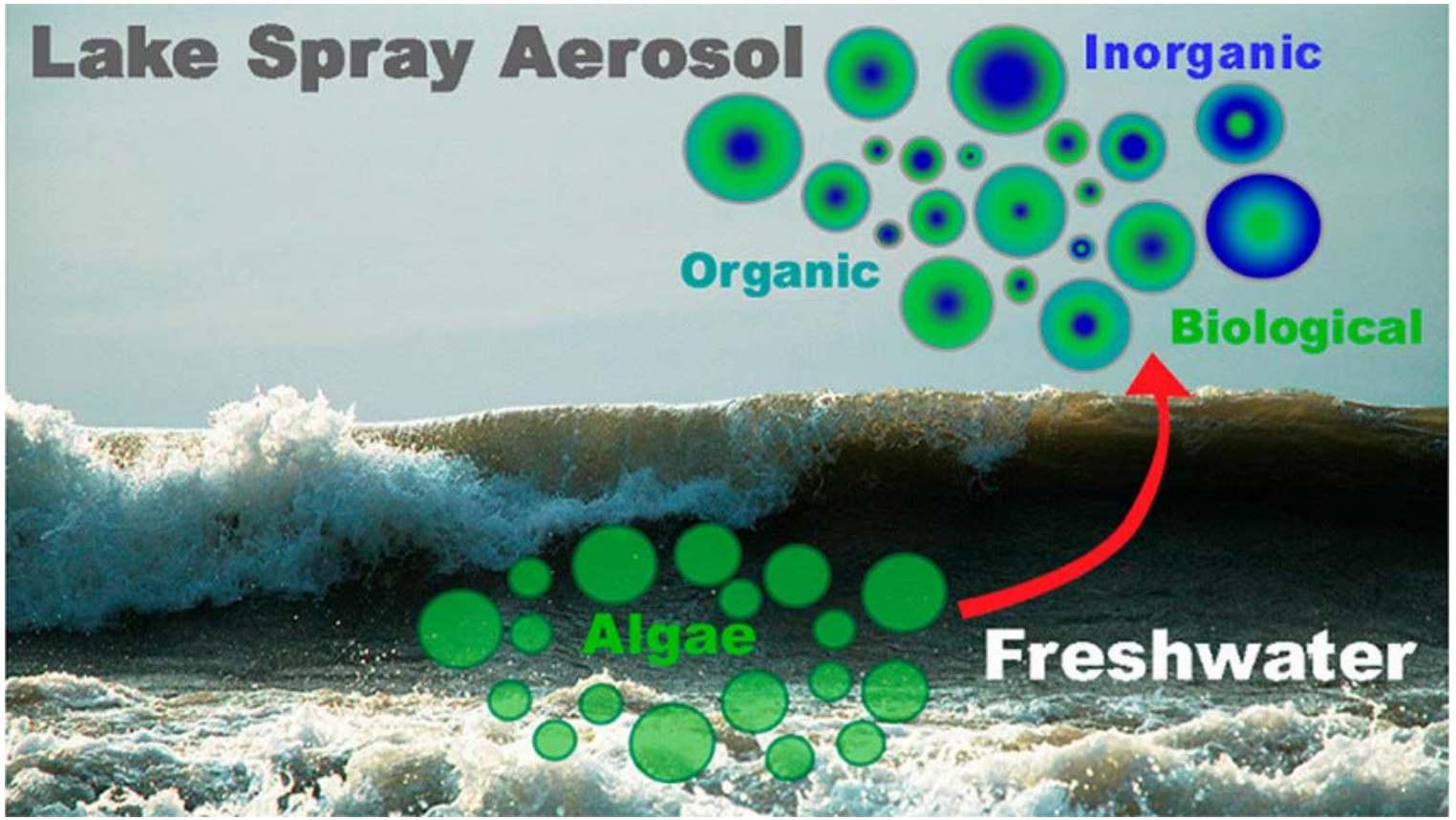
mywaterquality.ca.gov/habs

Cyanobacterial toxins



EPA infographic: https://www.epa.gov/cyanohabs/infographics-help-educate-public-habs-basics

Aersolized cyanotoxins



https://www.kwrwater.nl/en/actueel/airborne-dispersal-of-cyanobacteria/

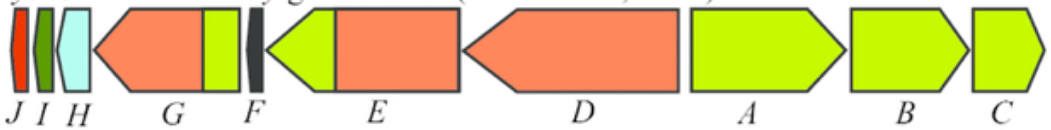

Photo: Ohio EPA

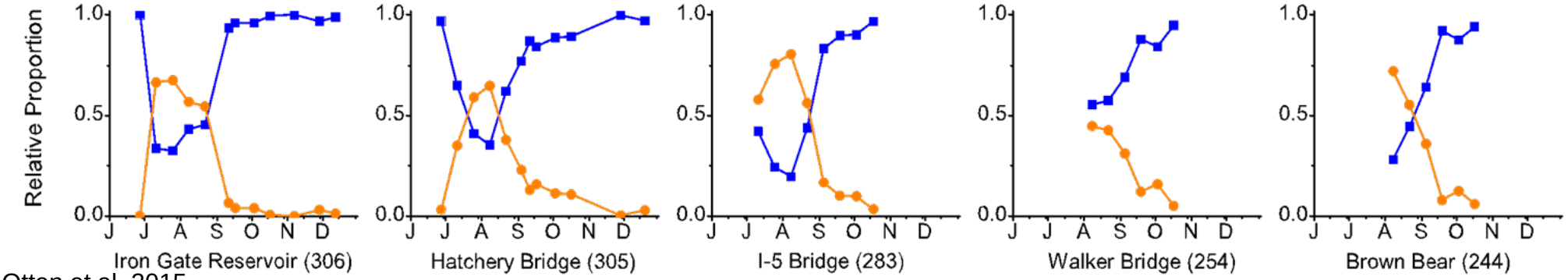
Increasing research attention given to inhalation exposures

Cyanobacterial toxins

- Toxin production controlled by genes
- Not all species and strains contain toxin synthesis genes
- Changes in bloom toxicity often driven by changes in the proportion of toxin and non-toxin producing strains in the bloom

Microcystis PCC 7806 *mcy* gene cluster (Tillett et al., 2000)





Otten et al. 2015

Cyanobacterial toxins

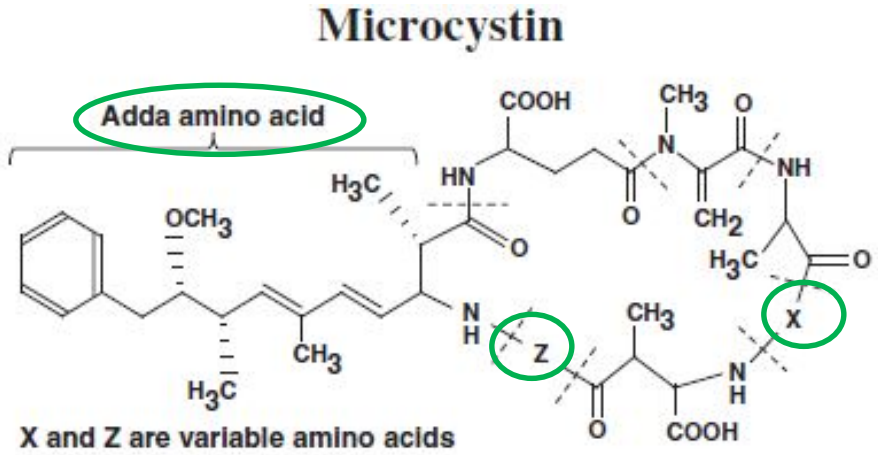
- US EPA does not regulate cyanotoxins
- Issued advisory levels for 10 day drinking water and recreational exposures

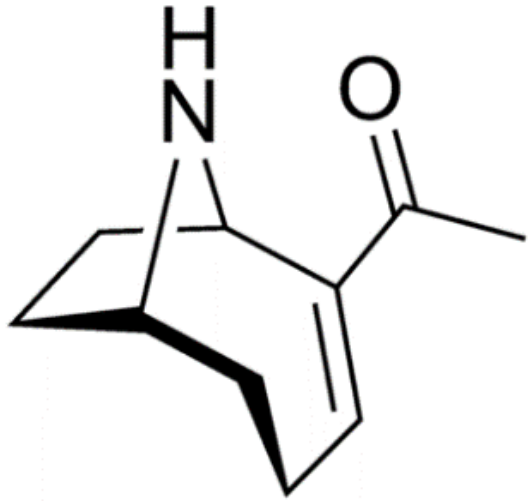
Toxin	Toxicity	US EPA 10 day Drinking (ug/L)	US EPA 10 day Recreational (ug/L)
Microcystin	Liver	0.3 for <6 yr. old 1.3 for >6 yr. old	8
Anatoxin	Neurotoxin	None	None
Cylindrospermopsin	Liver & kidney	0.7 for <6 yr. old 3.0 for >6 yr. old	15
Saxitoxin	Neurotoxin	None	None

Cyanobacteria Genera	Hepatotoxins		Neurotoxins					Dermatoxins	
	CYN	MC	NOD	ATX	BMAA	NEO	SAX	LYN	LPS
Anabaena (Dolichospermum)	x	x		x	x	x	x		x
Anabaenopsis		x							x
Aphanizomenon	x	x		x	x	x	x		x
Aphanocapsa		x							x
Coelosphaerium (Woronichinia)		x							
Cylindrospermopsis	x	x		x	x		x		x
Gloeotrichia		x							
Limnothrix		x							
Lyngbya	x	x		x	x		x	x	
Microcystis		x			x				x
Nodularia			x		x				x
Nostoc		x	x		x				
Oscillatoria (Planktothrix)	x	x		x	x		x	x	x
Phormidium		x		x	x				
Planktolyngbya							x	x	
Pseudanabaena		x		x					x
Raphidiopsis	x			x					x
Synechococcus		x			x				x
Synechocystis		x			x				x

Cyanobacterial toxins

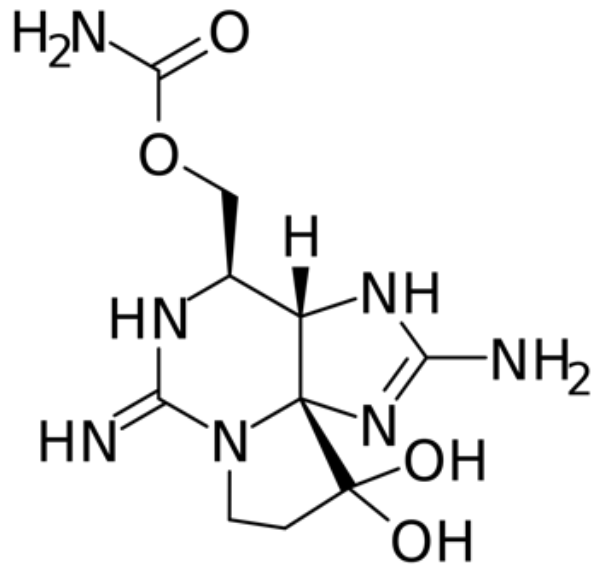
- **Microcystins**: liver toxin, causes liver hemorrhaging
  - 100+ variants with different toxicity for different variants
  - Symptoms in hours to days
- **Anatoxin**: neurotoxin, disrupts muscle functions
  - 4 variants (anatoxin, homo-, dihydro-)
  - Symptoms in minutes to hours





Cyanobacterial toxins

- **Saxitoxin**: neurotoxin. Blocks sodium channels
  - Produced by cyanobacteria and marine algae
  - Paralytic shellfish poisoning (PSP)



- **Cylindrospermopsin**: liver and kidney toxin. Affects protein synthesis.
  - Stable toxin in the environment
  - Few variants