Combatting toxic cyanobacteria

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A Dreaded Forecast for Our Times: Algae, and Lots of It

By MATT RICHTEL JULY 18, 2016

greatlakesnow.org

Great Lakes Moment: Harmful algal blooms negatively impact the Lake Erie economy

Many people are aware of the environmental and health impacts of toxic algae, but harmful algal blooms have an impact on the economy as well.

Lake Erie cyanobacterial bloom rapidly expanding

By CAROLINE LLANES • AUG 14, 2019

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CREDIT NOAA DERIVED IMAGE FROM EUMETSAT COPERNICUS SENTINEL-3A SATELLITE DAT / NOAA

The cyanobacterial bloom on Lake Erie has grown 20 miles in the past week. It now covers 620 square miles of Lake Erie, taking up about 6 percent of the entire lake and covering more area than Detroit and its suburbs.

Hugh McDiarmid is with the Michigan Department of Environment, Great Lakes, and Energy. He says summer is the peak time for these blooms.

"The warm water in the heat of summer has a lot to do with it. The amount of nutrients the algae has to feed off of is greater in the summer when there's more activity in the lake. And calm conditions also tend to make the conditions right for the

CityBeat NEWS VOICES MUSIC ARTS & CULTURE FOOD & DRIN

Great Ohio River Swim Canceled Due to 'Harmful Algal Bloom'

The open-water swim across the Ohio River was canceled due to a blue-green algae bloom, which can produce harmful levels of toxins

BY MAIJA ZUMMO — OCT 10, 2019 9 AM

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02:11 Powered by Trinity Audio

Great Ohio River Swim

PHOTO: PROVIDED BY GREAT OHIO RIVER SWIM // CITYBEAT ARCHIVE

The Great Ohio River Swim — an open-water swim which invites people to cross the Ohio River from the Serpentine Wall to Kentucky and back — has been canceled due to what organizers say is a "harmful algal bloom" in the Ohio River.

The swim was postponed from its original date in September because of the bloom and, according to the website, levels of harmful algae have continued to increase. Working with the agencies responsible for water quality testing and analysis, we have determined

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Harmful algal blooms showing up in northern Michigan lakes

By KAYE LAFOND • OCT 18, 2019

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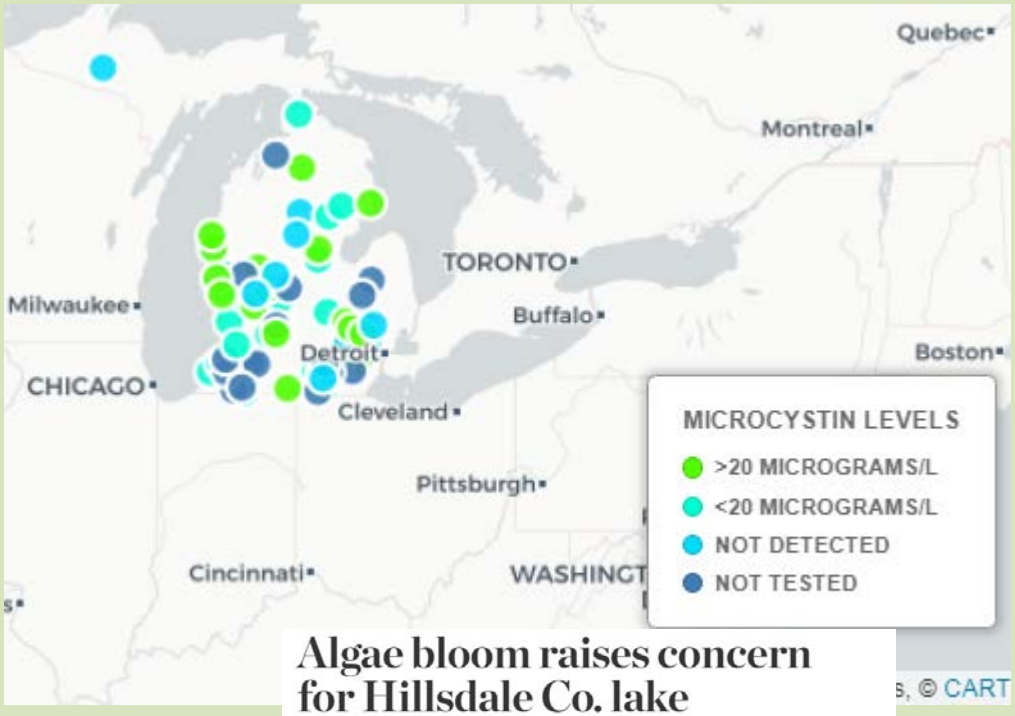


Algae bloom raises concern for Hillsdale Co. lake

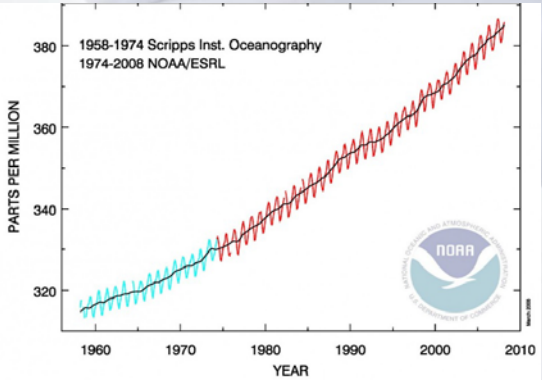
The Lake Leann Homeowners Association in Hillsdale County recently raised concerns about a white foam and a blueish green sheen on the lake

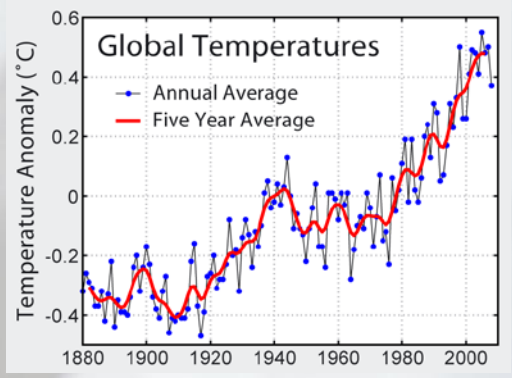
Thursday, October 24, 2019 9:44 a.m. EDT by Ken Delaney

Lake Leann in Hillsdale County, Michigan (photo courtesy of Lake Leann Homeowners Association)

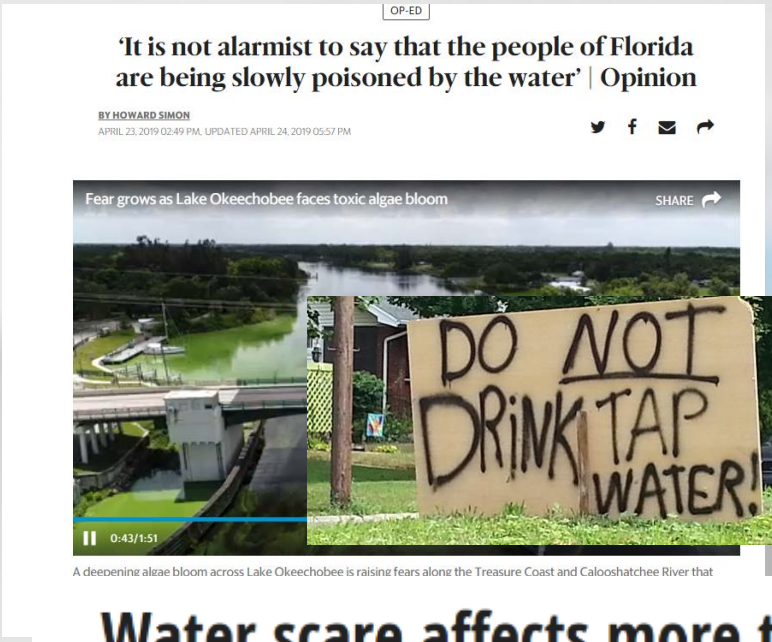
Anthropogenic Acceleration

- Environmental Changes
  - Atmospheric CO_2 passed 400ppm (NOAA)
  - UV light increases
  - Salinity increases
  - Global temperature increasing (Miller 2002)
  - Stratification
  - Water use dynamics
- Ecosystem degradation
  - Invasive species proliferation
  - Rough fish dominance
  - Eutrophication accelerated by 100's to 1000's of years (Anderson et al. 2002)





Water Supply



- Liver cancer
  - 0.19 pg mcyn per day during 4 summer months
    - Ueno et al. 1996

"A study that analyzed data from Florida determined that there is a significantly higher risk of liver cancer in residents serviced by surface water treatment plants that experience cyanobacterial blooms than those in areas serviced by groundwater."

Fleming, L. E.; Rivero, C.; Burns, J.; Williams, C.; Bean, J. A.; Shea, K. A.; Stinn, J. Blue green algal (cyanobacterial) toxins, surface drinking water, and liver cancer in Florida. *Harmful Algae* 2002, *1*, 157–168.

FORT MYERS

Doctors warn of potential airborne toxins from algae & red tide

Lee Health just released brand new numbers regarding how many patients they are seeing for algae-related health concerns.

Even in areas where blue-green algae isn't easy to see, signs are still posted warning to stay out of the water due to cyanobacteria.

Now, some doctors are saying you should stay away from the air as well.

Microsystins and cyanobacteria could be causing major health problems for those exposed.

Air Supply

- Banack et al. 2015
- Backer et al. 2010
- Wood and Dietrich 2011
- Cheng et al. 2007
- Stommel et al. 2013

(Photo: LEAH VOSS/TCPALM)

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If you've been around blue-green algae blooms, chances are you've breathed in toxins.

Everyone tested so far in a study of people who live and work around algae blooms in the St. Lucie River had "detectable levels" of the toxin microcystin in their noses, said Adam Schaefer, a Harbor Branch Oceanographic Institute epidemiologist.

"Preliminary results suggest microcystin is definitely airborne," Schaefer said Friday as people were giving blood, urine and nasal swab samples at the Florida Sportsman magazine office in Stuart.

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Health effects of breathing toxic algae in St. Lucie River is focus of Harbor Branch study

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Algae crisis: Airborne particles of toxic cyanobacteria can travel more than a mile inland, new FGCU study shows

Amy Bennett Williams, Fort Myers News-Press Published 5:42 p.m. ET March 15, 2019 | Updated 6:57 a.m. ET March 18, 2019

Food Supply

Published in final edited form as:
Harmful Algae. 2010 September 1; 9(6): 620–635. doi:10.1016/j.hal.2010.05.002.

Cyanobacterial Blooms and the Occurrence of the neurotoxin beta-N-methylamino-L-alanine (BMAA) in South Florida Aquatic Food Webs

Larry E. Brand[1,*], John Pablo[2], Angela Compton[1], Neil Hammerschlag[1], and Deborah C. Mash[2]

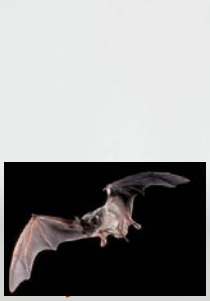
With toxic blue-green algae bloom, don't eat Lake Okeechobee fish, Audubon biologist says

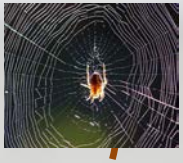
OPEN ACCESS Freely available online PLOS ONE

Maternal Transfer of the Cyanobacterial Neurotoxin β-N-Methylamino-L-Alanine (BMAA) via Milk to Suckling Offspring

Marie Andersson[1], Oskar Karlsson[1,2], Ulrika Bergström[1*], Eva B Brittebo[2], Ingvar Brandt[1*]
1 Department of Environmental Toxicology, Uppsala University, Uppsala, Sweden, 2 Department of Pharmaceutical Biosciences, Uppsala University, Uppsala, Sweden

Potential exposure routes to CHAB toxins





Terrestrial transfer

Irrigated crop accumulation

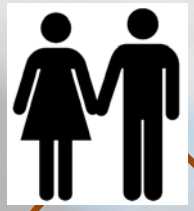
Recreation

Drinking water contamination

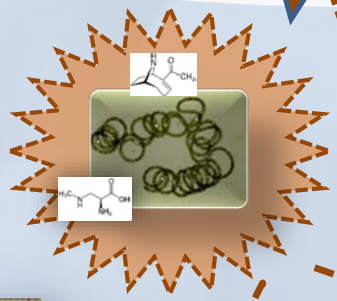
Fish accumulation

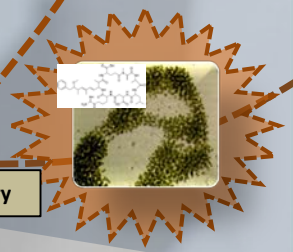
Aerosolization

Seafood accumulation



Freshwater Lakes and Reservoirs





Estuary

Ocean

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Who is impacted?

- **Dogs**
  - **Mahmood et al. 1988, Gunn et al. 1992, Edwards et al. 1992, Wood et al. 2007, Puschner et al. 2008**
- **Cows**
  - **Kerr 1987; Mez et al. 1997; Loda et al. 1999**
- **Pigs, ducks**
  - **Cook et al. 1989**
- **Sheep**
  - **Carbis et al. 1995**

J Vet Diagn Invest 20:89–92 (2008)

Diagnosis of anatoxin-a poisoning in dogs from North America

Birgit Puschner,[1] Brent Hoff, Elizabeth R. Tor

Families React to ALS Cluster

Relatives Learn of Possible Algae Link

By MARTIN F. DOWNS
Valley News staff writer

Human Fatalities from Cyanobacteria: Chemical and Biological Evidence for Cyanotoxins

Wayne W. Carmichael,[1] Sandra M.F.O. Azevedo,[2] Ji Si An,[1] Renato J. R. Molica,[3] Elise M. Jochimsen,[4] Sharon Lau,[5] Kenneth L. Rinehart,[5] Glen R. Shaw,[6] and Geoff K. Eaglesham[7]

[1]Department of Biological Sciences, Wright State University, Dayton, Ohio, USA; [2]Instituto de Biofísica Carlos Chagas Filho, Universidade do Brasil, Rio de Janeiro, Brasil; [3]Instituto Technologico de Pernambuco, Recife, Brasil; [4]Hospital Infections Program, National Center for Infectious Diseases, Centers for Disease Control and Prevention, Atlanta, Georgia, USA; [5]Roger Adams Laboratory, School of Chemical Sciences, University of Illinois, Urbana, Illinois, USA; [6]National Research Center for Environmental

Toxic algae kills 4 dogs in North Carolina, Georgia lakes. How to keep your pets safe

BY CHARLES DUNCAN

AUGUST 12, 2019 11:07 AM, UPDATED AUGUST 12, 2019 10:13 PM

Alzheimer's 'cause' discovered: Poisonous algae found in UK freshwater lakes and reservoirs could be fuelling dementia epidemic afflicting one million people

- It is the first direct evidence that a chemical, produced by algae, might be linked to devastating brain conditions
- Scientists have discovered the toxin in seafood and plants, through which it is feared it is entering the food chain
- Researchers highlighted a growing body of evidence that the toxin, named BMAA, could trigger brain diseases
- If confirmed, the chemical would be the first major environmental factor linked to increasing rates of Alzheimer's

Poison: Researchers have found the first direct evidence that a chemical, produced by algae, might be linked to devastating neurological conditions including Alzheimer's and Motor Neurone Disease (MND). Pictured, blu Lake Windermere

Toxins

- **Cyanobacteria Toxins**
  - **Hepatotoxins “liver”**
  - **Neurotoxins “brain”**
  - **LPS “stomach”**
  - **Aplysiatoxins “skin”**
- **EPA CCL** (USEPA 2012)
  - microcystin-LR, anatoxin-a, and cylindrospermopsin
- **EPA Health Advisory Drinking Water**
  - **< 6 years old; 10 day exposure**
    - 0.3 ug/L microcystins and
    - 0.7 ug/L cylindrospermopsin (USEPA 2015a,b)
    - Recreational guidelines 8ppb; 15ppb

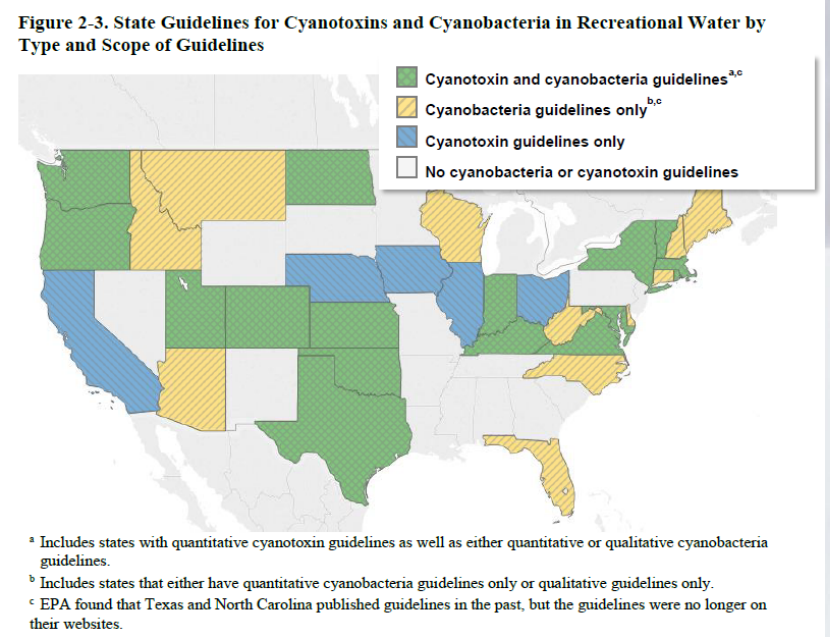
Aeruginosin
Anabaenopeptin
Anatoxin-a
Anatoxin-a(s)
Aplysiatoxins
Bacteriocins
BMAA
Cyanobactins
Cyanopeptolin
Cyclamides
Cylindrospermopsin
Fischerellin
Lyngbyatoxin-a
Microcystin
Microviridin
Microginin
Nodularin
Saxitoxin

Are we safe if no toxin detected?

- Toxin production is intermittent
- Shown to be toxic but no toxin has been isolated and characterized
  - *Coelosphaerium, Cylindrospermopsis, Fischerella, Gloeotrichia, Gomphosphaeria, Hapalosiphon, Microcoleus, Schizothrix, Scytonema, Spirulina, Symploca, Tolypothrix, Trichodesmium*
    (Scott 1991; Skulberg et al. 1992b)
- New toxin classes
  - Lyngbyaureidamides, nodulopeptins, jamaicamides, aeruginosins
    (Edwards et al. 2004; Ishida et al. 2009; Zi et al. 2012; Schumacher et al. 2012)

EPA Summary Guidelines

- **Measurement parameters**
  - Cell densities, proportion of toxigenic cyanobacteria, chlorophyll concentration, and Secchi disk depth measurement
  - State guidelines address up to four cyanotoxins, Mcyn most prevalent (n=20)



Routes of exposure. Exposure to cyanotoxins from recreational water sources can occur via oral exposure (incidental ingestion while recreating); dermal exposure (contact of exposed parts of the body with water containing cyanotoxins during recreational activities such as swimming, wading, surfing); and inhalation exposure to contaminated aerosols (**while recreating**).

USEPA 2016
Human Health Recreational Ambient Water Quality Criteria or *Swimming Advisories* for *Microcystins* and *Cylindrospermopsin*

Recommended Action

- Recreation
  - Close system, issue advisory, post warning signs, contact health department
  - Utah
    - Consider closure
  - Nebraska
    - Close beach, allow recreation
      - But public advised to use caution and avoid prolonged exposure to the water
  - Maine
    - Do not drink lake water during a bloom. Well maintained domestic water treatment systems may make lake water safe to drink in many instances, but they are not guaranteed to remove algal toxins.
      - http://www.maine.gov/dep/water/lakes/cyanobacteria.htm

One State

- Kansas
  - Extreme bloom
  - Picnic, camping and other public land activities adjacent to affected waters be closed

Kansas	cyanobacteria: ≥ 10,000,000 cells/mL	recommended that all in-lake recreation cease and that picnic, camping and other public land activities adjacent to affected waters be closed
	cyanobacteria: ≥ 250,000 cells/mL	issue public health warning
	cyanobacteria: ≥ 80,000 and < 250,000 cells/mL	issue public health watch
	microcystin: ≥ 2,000 µg/L	recommended that all in-lake recreation cease and that picnic, camping and other public land activities adjacent to affected waters be closed
	microcystin: ≥ 20 µg/L	issue public health warning
	microcystin: ≥ 4 and < 20 µg/L	issue public health watch

Close the lake

Close the system, Hope there is no exposure to the toxins

USEPA 2016
Human Health Recreational Ambient Water Quality Criteria or *Swimming Advisories* for *Microcystins* and *Cylindrospermopsin*

Ecological impacts cyanos?

Microcystin LR exposure:

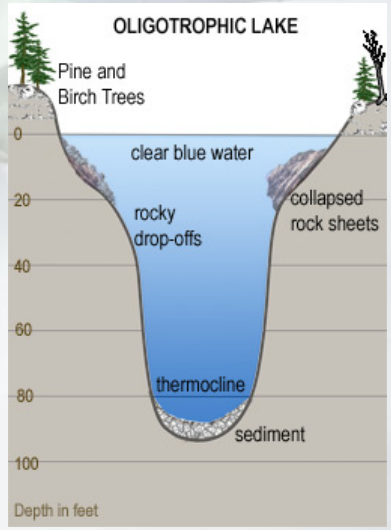
- Damaged gonad tissue in **fish**
  - Lesions, cell apoptosis, and testicular ultrastructure
    - Trinchet et al. 2011; Zhao et al., 2012; Qiao et al. 2013
- Endrocrine disruption
    - Rogers et al. 2011
- Decrease growth/ immune function of juveniles
  - Developmental defects and physiological stress
    - Liu et al. 2014; Oberemm et al. 1997; Wang et al. 2005
  - Fish embryo lethality
    - Oberemm et al. 1997; Wang et al. 2005
- Daphnia
  - Avoidance, toxins, clog feeding structures
    - Webster and Peters, 1978; DeMott et al. 2001 Lampert 1987
- Habitat destruction

Potential solutions

Proactive management

Watershed nutrients?

- BMP's may not be efficient or sufficient
  - If all retrofits conducted, New Hope Creek watershed show 6% decrease of P
    - Debusk et al. 2010
- Continued inputs
  - Soil accumulations (Reddy et al. 2011)
  - Groundwater (Martin et al. 2007; Lapointe et al. 2015)
  - Wildlife (Nürnberg and LaZerte 2016)
  - Atmospheric deposition (Wetzel 2001; Paerl et al. 2016)
- Internal load difficult and expensive to address
- The cyanobacteria may not directly relate to nutrients



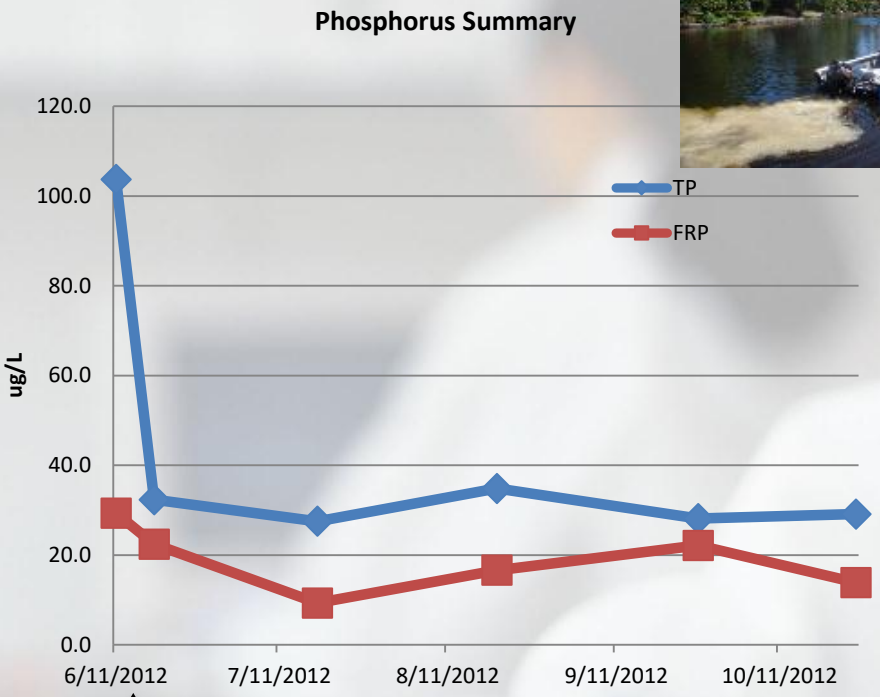
In Situ Management Options

- P mitigation
  - Aluminum sulfate (Alum, non-specific, pH/other impacts)
  - Lanthanum modified bentonite (Phoslock®, specific, no buffer, permanent)
  - Algaecide combined with phosphorus remover (SeClear)
  - Polymers (Floc Log, Chitosan)
  - Iron (non-specific, release)/ Calcium (high pH only, release)
- Other
  - Aeration/oxygenation/mixing (oxygenate benthic layers)
  - Dredging (remove/re-suspension possible)
  - Bacteria

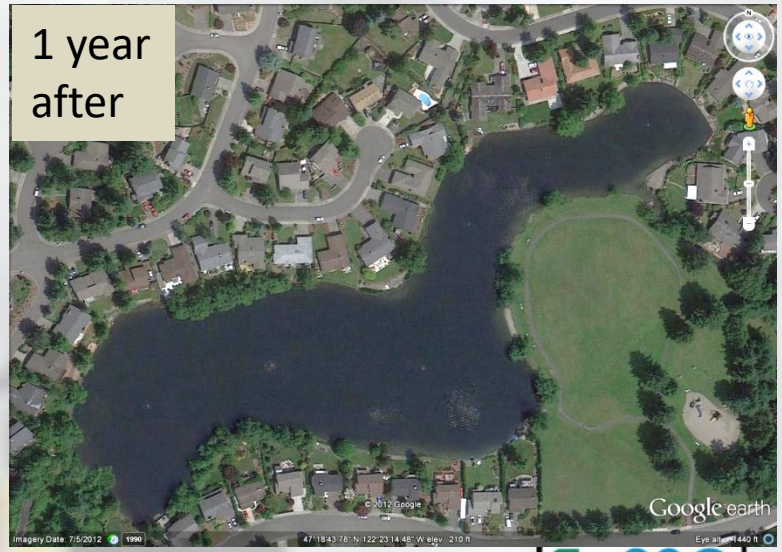
Phosphorus Mitigation Efficacy

- 8.2 surface acres; Lake Lorene, WA
- Avg. depth 5 feet, max. depth 12 feet
- Multi-purpose lake, community focal point
- Cyanobacteria blooms, toxins (mcy >2,000 ppb; atx >100ppt)

Lake Lorene, WA Summary



Lanthanum/Bentonite (Phoslock®) Application



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Nutrient mitigation

- Phosphorus amount and stoichiometric ratios with other nutrients are key factors in water resource management
- Phosphorus is tied to intensity of management and promotes nuisance algae
- *In situ* mitigation is critical to address cause of negative water quality
  - Legacy P
- Phosphorus mitigation integration can have significant impacts

Nutrients

- Yes and no

Cylindrospermopsis and nutrients

- Grows under both low and high N:P ratios
  - Many forms of nutrients (e.g. organic)
    - (Chislock et al. 2014)
- Grows with no dissolved nitrogen (O'neil et al. 2013)
  - Fixation from atmosphere (Sinha et al. 2012)
- Dominates in low phosphate
  - High uptake, affinity/ storage, scavenge episodic inputs (Wu et al. 2012)
- Likes static or mixed conditions, especially to dark zones
  - Kehoe 2010; Antenucci et al. 2005; Burford and O'Donohue 2006

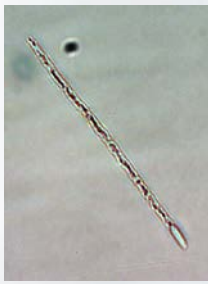
Understanding the winning strategies used by the bloom-formi
cyanobacterium *Cylindrospermopsis raciborskii*

Michele A. Burford [a,*], John Beardall [b], Anusuya Willis [a], Philip T. Orr [a,b], Valeria F. Magalhaes [c], Luciana M. Rangel [c], Sandra M.F.O.E. Azevedo [c], Brett A. Neilan [d]

Increased incidence of *Cylindrospermopsis raciborskii* in temperate zones – Is climate change responsible?

Rati Sinha [a], Leanne A. Pearson [a], Timothy W. Davis [b], Michele A. Burford [b], Philip T. Orr [c], Brett A. Neilan [a,]*

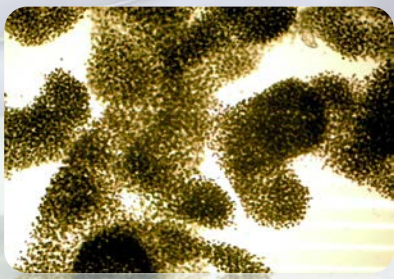
[a] School of Biotechnology and Biomolecular Sciences, University of New South Wales, Sydney, NSW 2052, Australia
[b] Australian Rivers Institute, Griffith University, Queensland, 4111, Australia
[c] Seqwater, PO Box 16146, City East, Queensland, 4002, Australia



- **Meteorological and chemical factors** were **not** related to the dominance of *C. raciborskii* (Figueredo and Giani 2009)
- "**Can tolerate a wider range of P concentrations" and "proliferate in a wide range of N conditions**" (Sinha et. al 2012)
- "In summary, the **ecological flexibility** of this organism means that **controlling blooms of *C. raciborskii* is a difficult undertaking**" (Buford and Davis 2011)

Microcystis and Phosphorus

- Massive benthic populations of *Microcystis*
  - Preston et al. 1980; Fallon & Brock 1981; Takamura et al. 1984
- Migrate to/from sediments to form blooms
  - Perakis et al. 1996
- *Microcystis* blooms resulted in high pH (9.0–10.0)
  - Induce release of dissolved P from the sediments (iron hydroxides)
    - Xie et al. 2003; Chang and Jackson, 1957
- Mutualism with heterotrophic bacteria for nutrients
  - Jiang et al. 2007, Shen et al. 2011, Lemes et al. 2008
- *Microcystis* strongly upregulates (by 50- to 400-fold) two high-affinity, phosphate-binding proteins (*pstS* and *sphX*) and alkaline phosphatase gene (*phoX*)
  - Harke et al. 2012

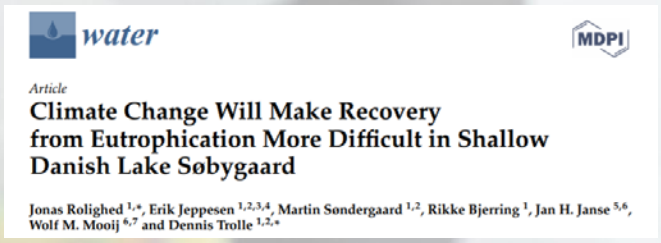


Nutrient mitigation v Climate

- “in a future warmer climate, nutrient concentrations may have to be reduced substantially from present values in many lakes if cyanobacterial dominance is to be controlled”

Kosten, S, Huszar VLM, Becares E, Costa LS, van Donk E, Hansson LA, Jeppesen E, Kruk K, Lacerot G, Mazzeo N, DeMeester L, Moss B, Lurling M, Noges T, Romo S, Scheffer M. 2012. Warmer climates boost cyanobacterial dominance in shallow lakes. Glob Change Biol. 18: 118-126.

- 60% more decrease in nutrients needed with 6°C temperature increase
  - Rolighed et al. 2016


water

MDPI

Article

Climate Change Will Make Recovery from Eutrophication More Difficult in Shallow Danish Lake Søbygaard

Jonas Rolighed [1,*], Erik Jeppesen [1,2,3,4], Martin Søndergaard [1,2], Rikke Bjerring [1], Jan H. Janse [5,6], Wolf M. Mooij [6,7] and Dennis Trolle [1,2,*]

Direct control

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Control Techniques

- **Action Options**
  - **Mechanical**
    - **harvesters, sonication, cavitation, aeration**
  - **Physical**
    - **dyes, raking, flushing**
  - **Biological**
    - **bacteria, grass carp, tilapia**
  - **Chemical**
    - **Nutrient binding, algaecides**

Mechanical

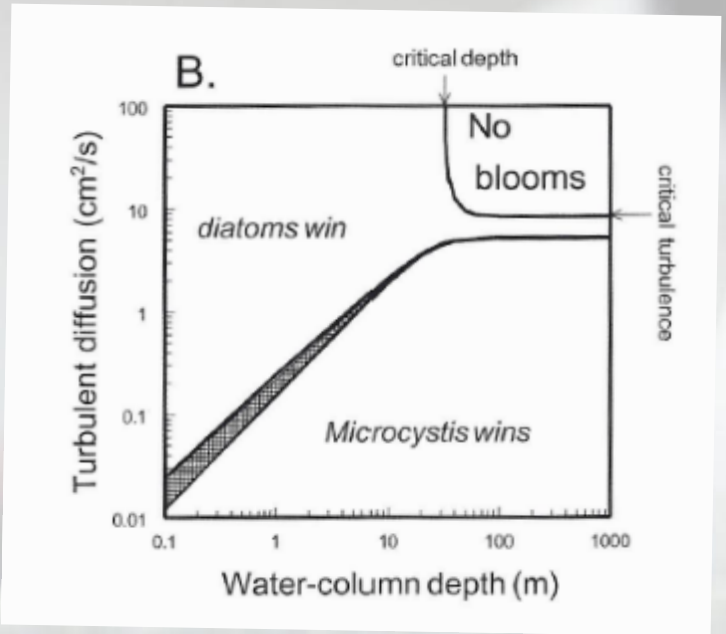
- Pros
  - Remove biomass and nutrients
  - Can open channels rapidly
  - Cost, O&M
- Cons
  - Selective efficiency
    - Algal type and location in water
  - Fragment and spread
  - Increase turbidity and suspend legacy nutrients
  - Operational feasibility

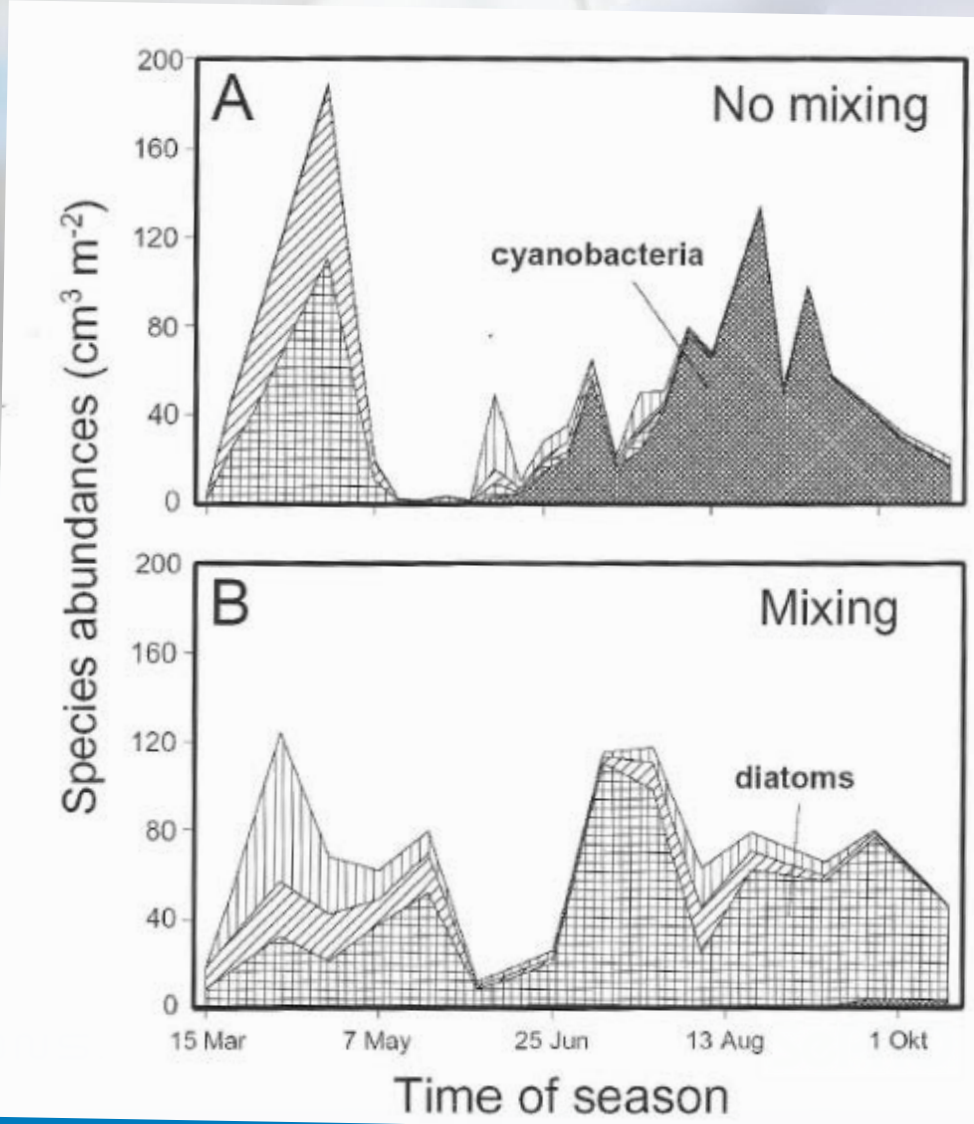
Physical: Aeration

- Pros
  - Organisms breath oxygen
  - Take the cyanobacteria buoyancy (scum) advantage out of play
  - Keep circulated to select for better types of algae.. usually
  - Oxygenated benthic zone to decrease internal phosphorus cycling, other sediment gas release
- Cons?
  - Temperature increase throughout water column
  - Carbon addition
  - Circulate nutrients from benthic zones
  - Some planktonic cyanos prefer

Turbulent mixing

- Huisman et al. 2005





Pretty good mixing: still toxic cyanos

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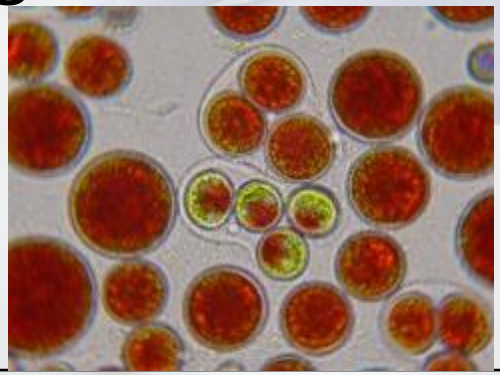
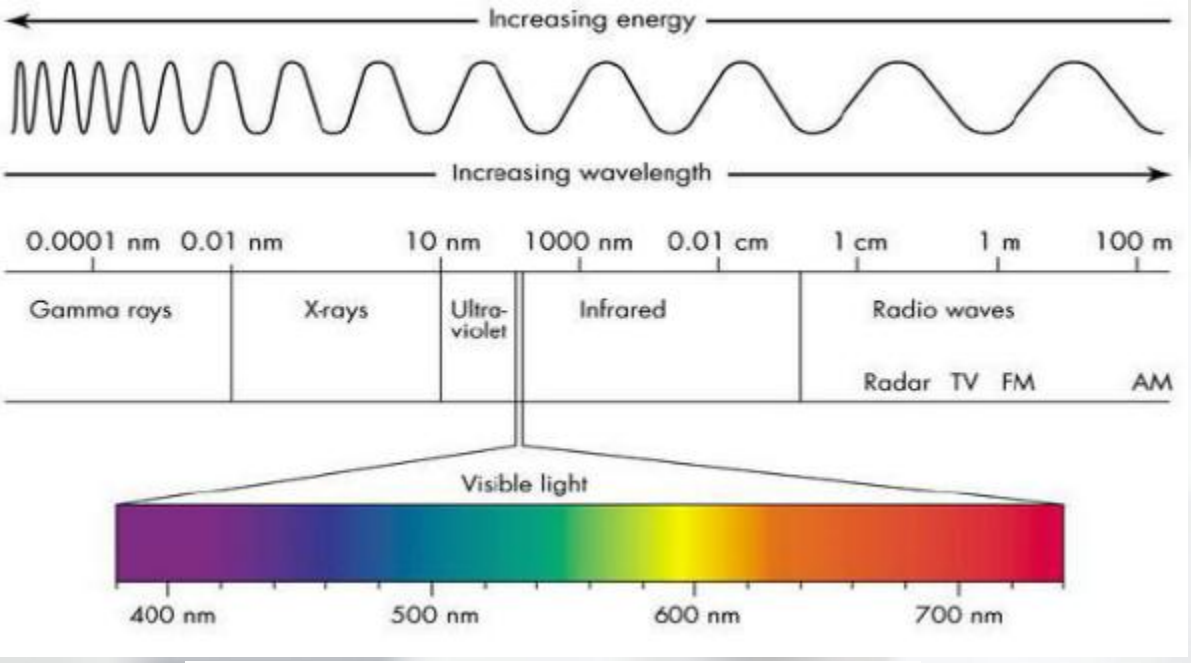
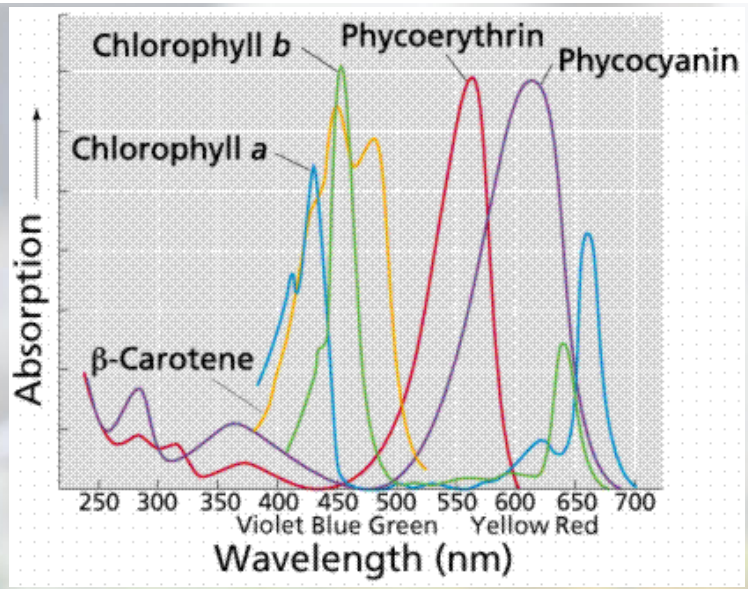
Physical: Light

- Absorb light at different wavelengths
  - Reflect different colors
- Different functions
- Diagnostic of different groups
- Carotenoids
  - Carotenes v. xanthophylls
- Chlorophylls
- Phycobilins



Algal Pigment	Divisions of algae and pigments they contain				
	Chlorophyta (Green algae)	Cyanophyta (Cyanobacteria)	Bacillariophyta (Diatoms)	Pyrrophyta (Dinoflagellates)	Haptophyta (Golden algae)
Chlorophyll a	X	X	X	X	X
Chlorophyll b	X				
Fucoxanthin			X		X
Peridinin				X	X
Phycocyanin		X			





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Shade balls

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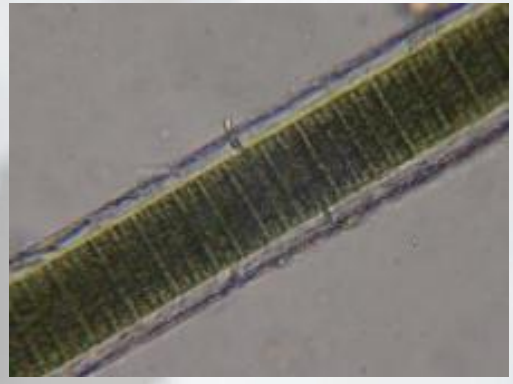
Biological

- Preferences
  - Grass carp prefer to eat *Hydrilla* 55x > *Lyngbya* (Dyck 1994)
- Increase turbidity
- Viability of algae
- Suspend legacy nutrients



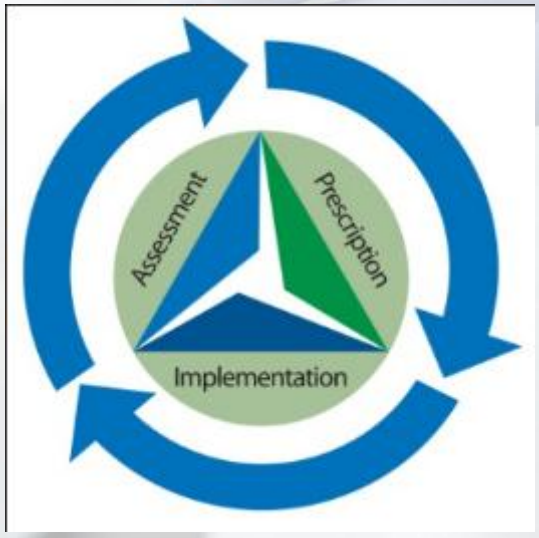
J. Aquat. Plant Manage. 53: 74–80

Grass carp do not consume the nuisance benthic cyanobacterium, *Lyngbya wollei*

JO-MARIE E. KASINAK, CRYSTAL J. BISHOP, RUSSELL A. WRIGHT, AND ALAN E. WILSON*

Chemical: USEPA registered pesticides

- **Diquat Dibromide**
  - **PSI inhibition**
- **Endothall**
  - **Proteins and lipid disruption**
- **Peroxides**
- **Copper**
  - **Chelated v. free ion**



- **Adjuvants**

USEPA Registration

- Numerous studies required
- EPA review and set label instructions
  - Negligible risks to humans and environment
    - Follow label
  - Approved use sites
  - Widely used
  - Copper, peroxide, diquat, endothall

Non-target Species?

- Present?
- Toxins impacts?

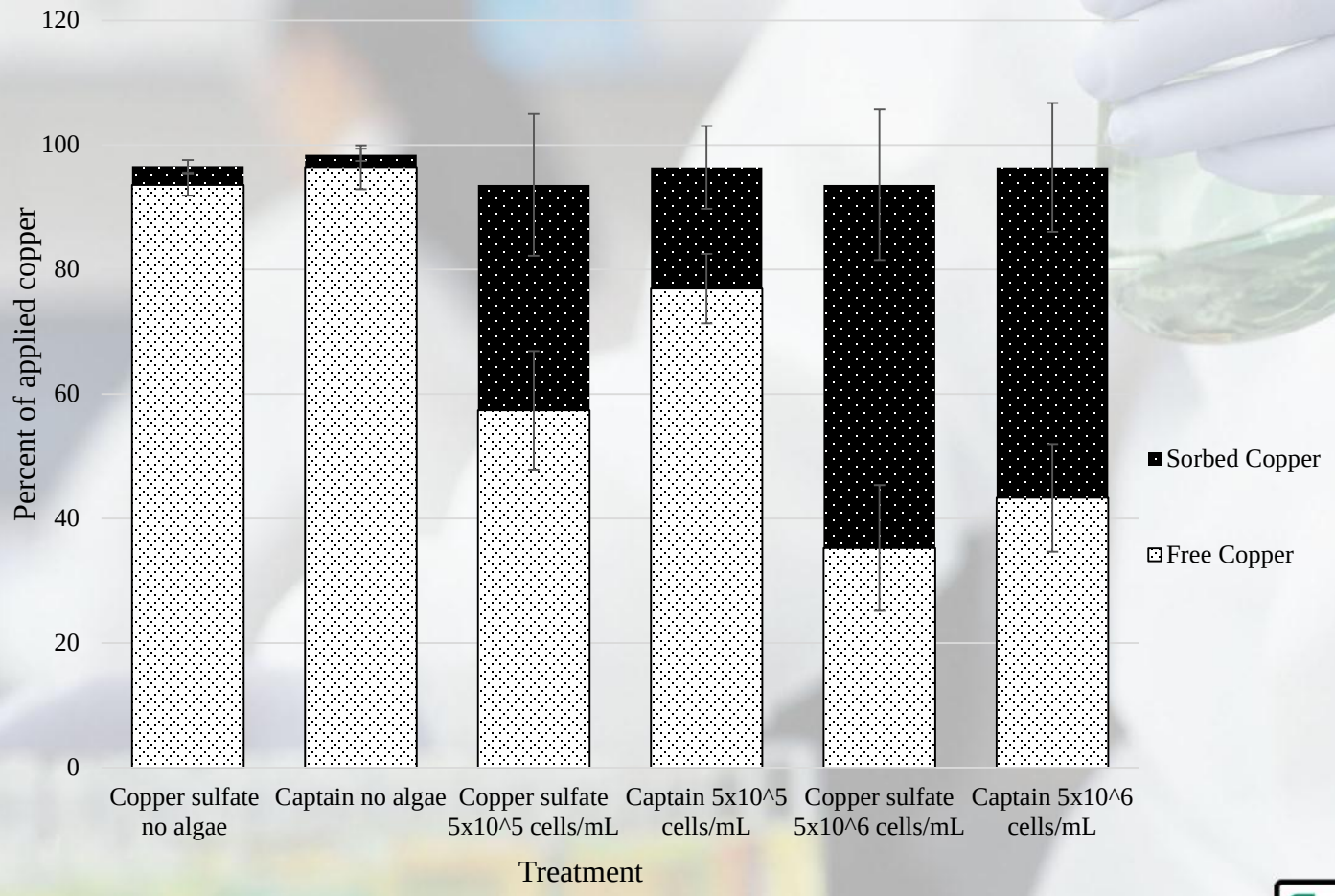
- Management objectives
  - Irrigation canals
  - Drinking water
- Accurate risk assessment

Field algaecide application

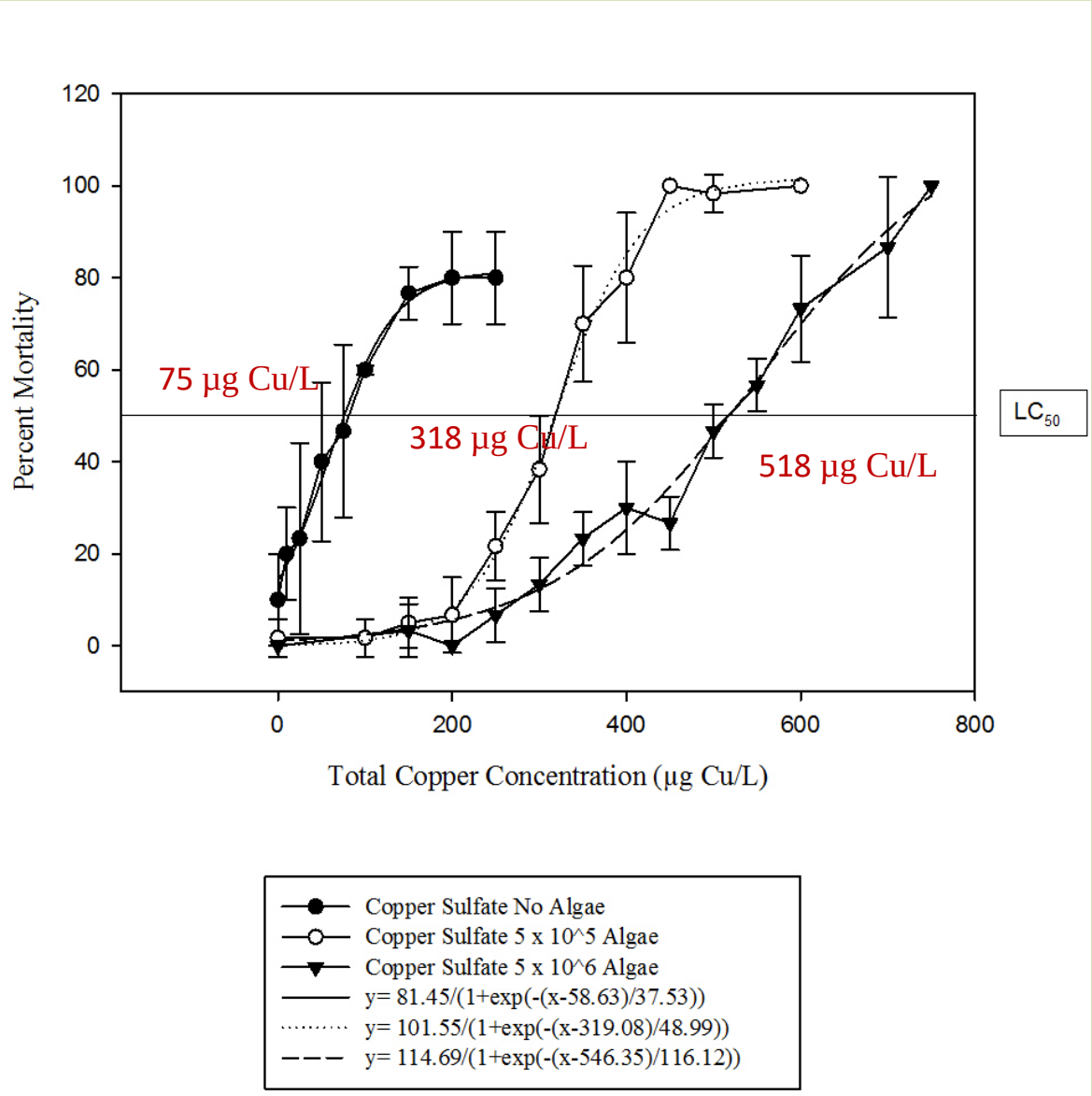
Scenedesmus **surface area (1 million cells) = 1,320mm²**

Daphnia **average gill surface area = 7.57mm²**

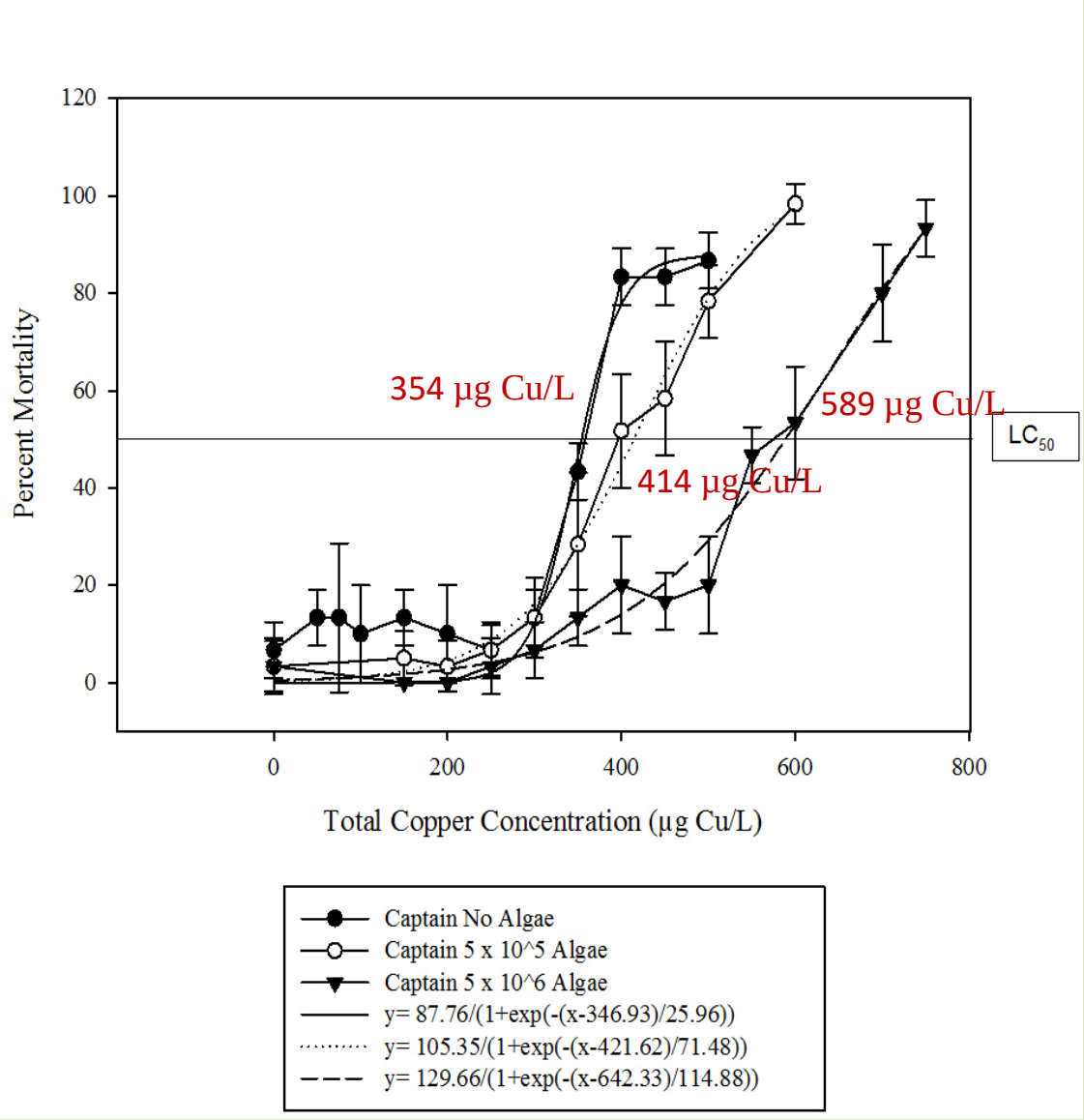
Copper exposure



Copper sulfate shift

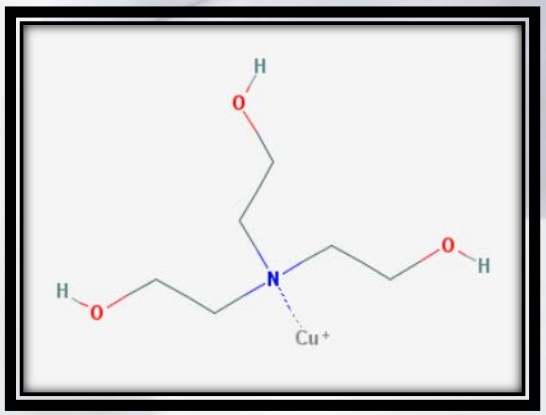


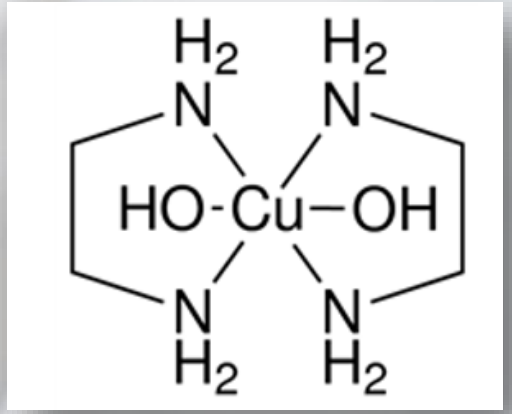
Captain shift



Formulation

- Chelating agents
  - Stability, corrosivity, water chemistry
  - Degree of interaction
- Toxicity to targets
  - Lipid soluble can diffuse through membrane
    - Stauber and Florence 1987
  - Membranes impermeable to charged/polar species
    - Sunda 1989
  - TEA
    - Decrease surface tension
    - Emulsifier: water-soluble and oil-soluble ingredients can be blended
  - EDA is a solvent
    - Miscible with polar solvents
    - Solubilize proteins
    - Bidentate chelating ligand





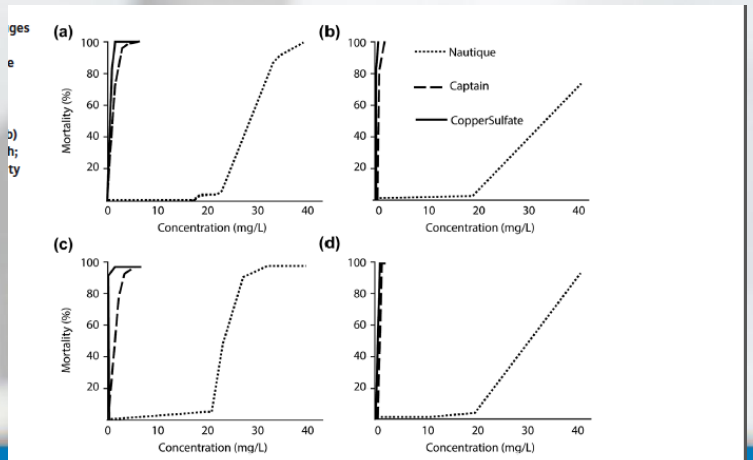
Chelation safety

- Komeen
  - Delta smelt
  - LC_{50} 1.4 mg Cu/L
- Komeen/Nautique
  - Bluegill/bass/shiner/perch
  - LC_{50} 5.4-496 ppm Cu
- Nautique
  - 96 hr LC_{50} > 20 mg Cu/L
  - Trout, fathead minnow
  - Wagner et al. 2017

ACUTE TOXICITIES OF HERBICIDES USED TO CONTROL. WATER HYACINTH AND BRAZILIAN ELODEA ON LARVAL. DELTA SMELT AND SACRAMENTO SPLITTAIL by. Frank *Riley and Sandra Finlayson*. California Department of Fish and Game. Aquatic Toxicology Laboratory

catfish (LC50 = 0.064 ppm Cu for Cutrine®) and ornamental carp like koi and goldfish. Based on the available evidence Komeen® and Nautique™ may be moderately toxic to practically non- toxic (LC50 = ~0.1 ppm on salmonids and LC50 = 5.4 to ~500 ppm on most other species of fish) while K-Tea™, Cutrine®, Copper Control® Clearigate® and Captain™ are generally more toxic to the sensitive species but highly toxic to moderately toxic to other species (LC50 = ~0.01 to ~0.03 ppm on salmonids, striped bass and channel catfish, and 0.2 to ~6 ppm Cu on most other species of fish). In soft, low alkalinity water (<50 ppm $CaCO_3$), the toxicity of the commercial copper-complexes may be high

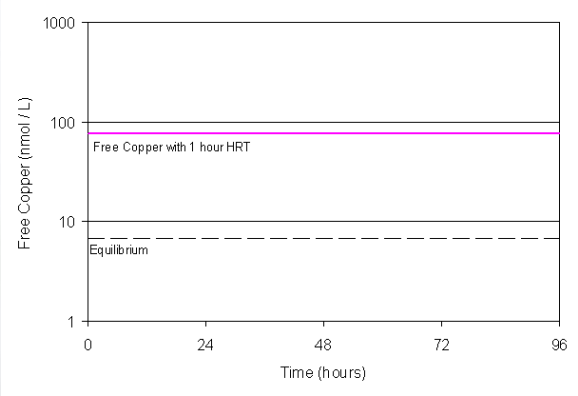
WA DOE Supplemental Environmental Impact Statement Assessments o
Aquatic Herbicides volume 6: copper

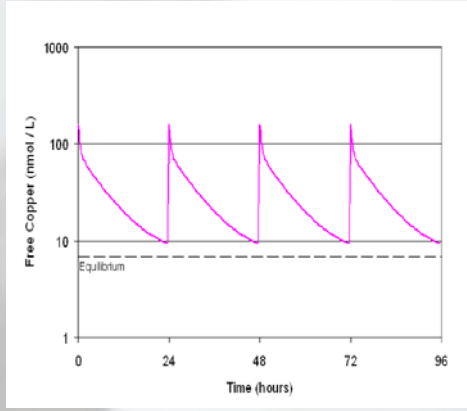


Nautique™ was significantly less toxic to brook trout and fathead minnows than the other formulations (Table 3). With time and concentration held constant, the percentage of brook trout that died

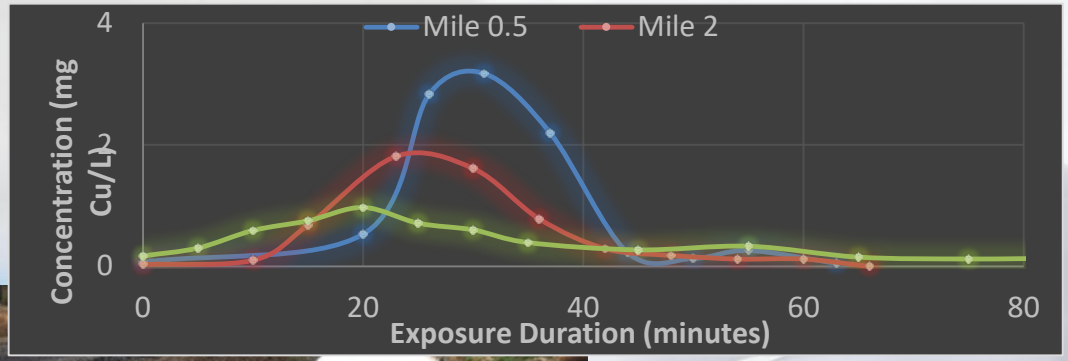
Frequency

- Standard Tox Tests copper
  - Constant concentration
  - Flow through or static renewal
  - Field
    - 14 days between treatments
    - Fraction of max label rate
    - 1/3 - 1/2 of the system





Control 8 miles downstream



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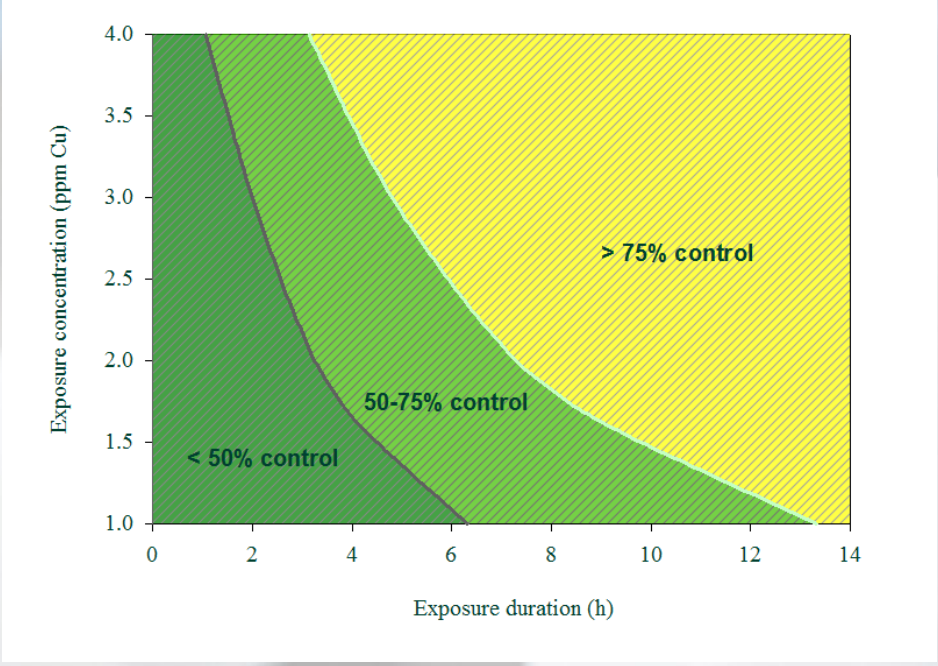
Willis et al. 2018

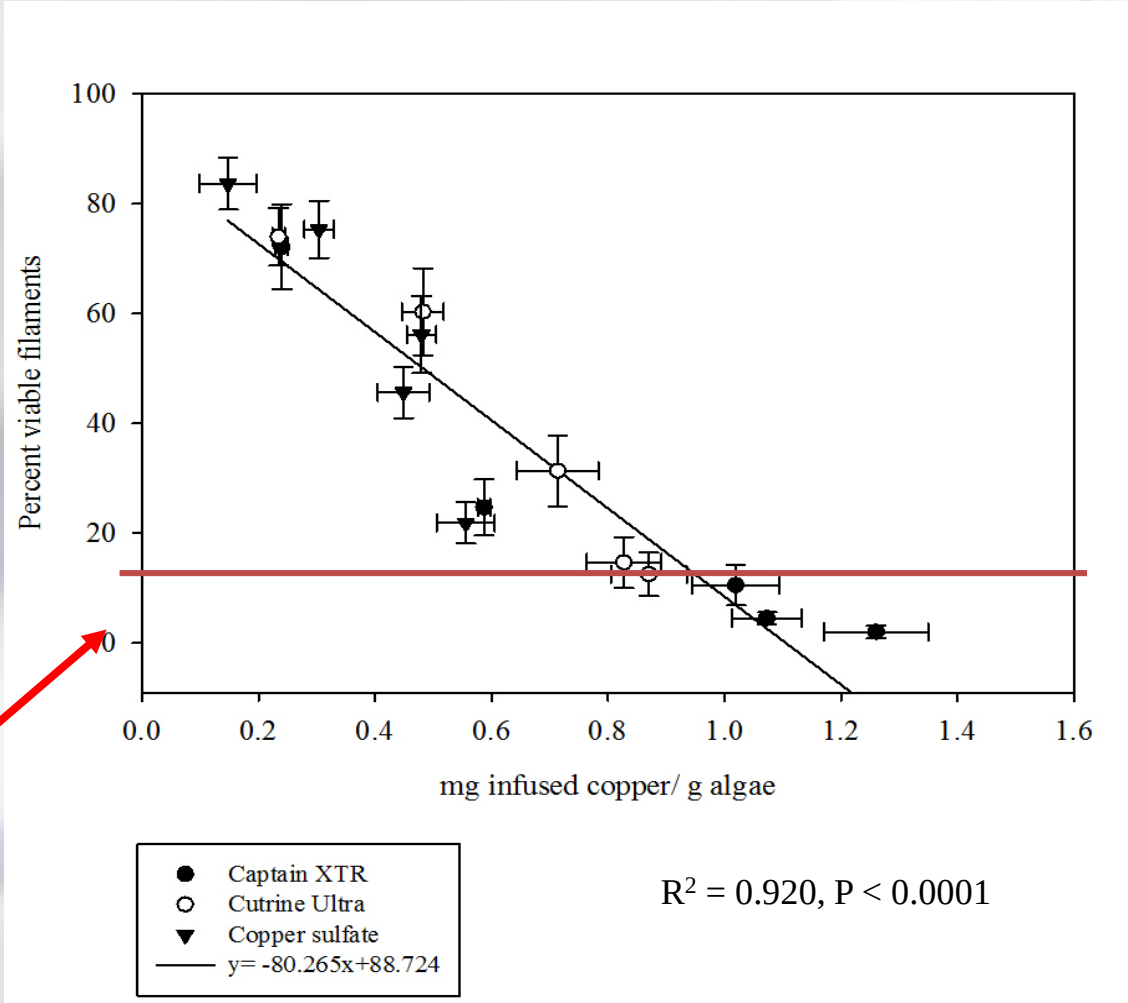
DRIVEN TO DISCOVER

CET *Lyngbya wollei*

- Factor
  - Concentration
  - Duration
- Formulation efficiency
- Critical infused Copper threshold

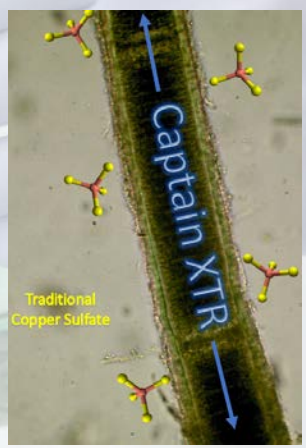


Infusion = control: *Lyngbya wollei*



$R^2 = 0.920$, $P < 0.0001$

internal threshold
=
same for all
treatments



CONTROL

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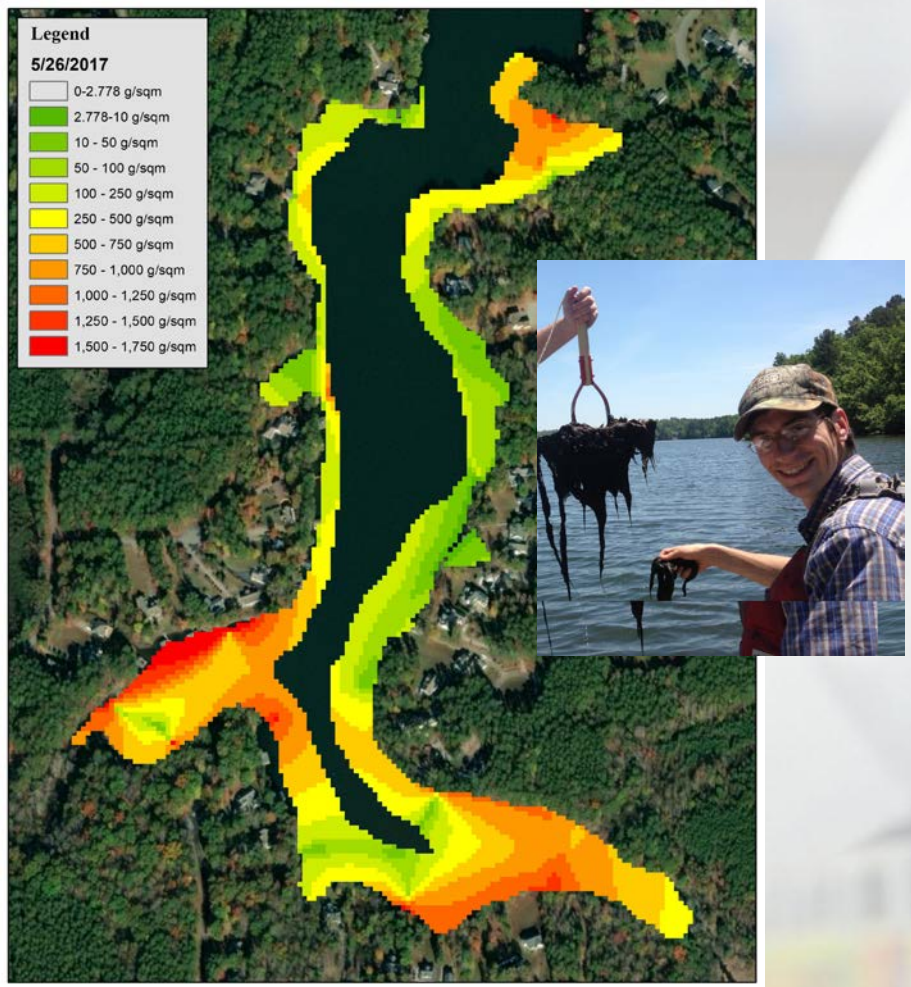
Bishop et al. 2018

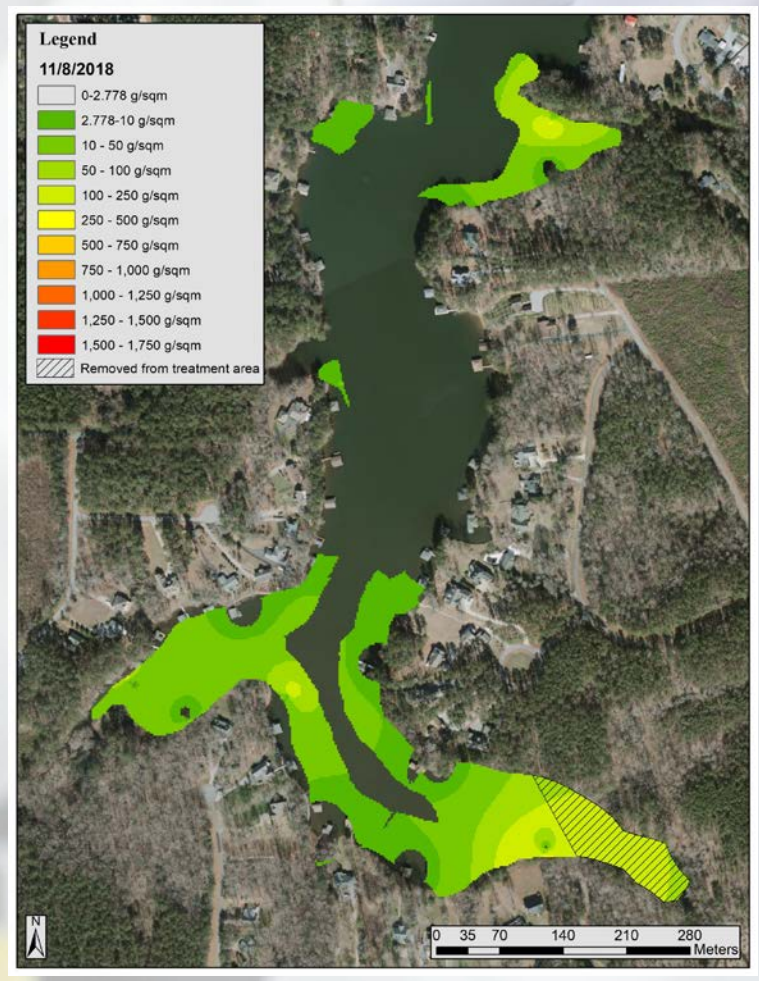
DRIVEN TO DISCOVER

Lyngbya control

May 2017 biomass



Nov 2018 biomass



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Toxin Release?

Leaky Cell Hypothesis

- Internal toxin can be released with some chemical treatments/concentrations
  - Kenefick et al. 1993; Jones and Orr 1994; Peterson et al. 1995; Daly et al. 2007; Touchette et al. 2008; Greenfield et al. 2014; Lurling et al. 2014; Tsai 2015
- If treat:
  - Dilutes through water/ biodegrades
    - Even leaky cell papers < 1 d half-life open water
    - Dermal absorbed dose of microcystins is likely to be negligible (EPA 2016)
  - No hot spot accumulation potential
  - Total toxin decreases
  - Possible to treat without releasing
    - Formulation/ concentration
    - Tsai 2015; Iwinski et al. 2016
- If fear free toxin, need to fear total toxin
- Only way to not have an exposure is not have produced

Total *or* free toxin?

- In latter bloom stages, more cells lyse, extracellular Mcyn becomes more abundant
  - White et al. 2005
- Mcyn release cultured *M. aeruginosa* began to occur late in exponential growth phase and increased significantly in stationary phase
  - Chorus and Bartram 1999
- Increase in population numbers could produce a more intense toxin level (described or unknown) and impending natural release
  - White et al. 2005; Lehman et al. 2013
- Dried Ma scums may contain high concentrations of mcyn for several months
  - Released back into the water when re-immersed
- "Under bloom conditions, a substantial proportion of toxin would also be expected to be released to the water column, making removal of soluble toxin an unavoidable concern."
  - Chorus and Bartram 1999 (and references therein)

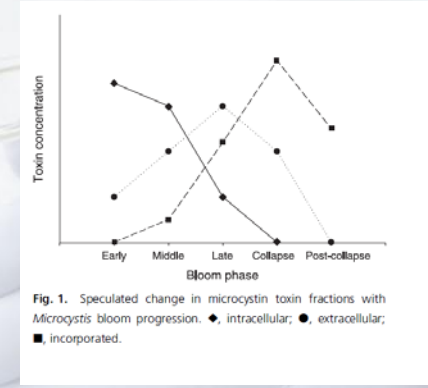


Fig. 1. Speculated change in microcystin toxin fractions with *Microcystis* bloom progression. ◆, intracellular; ●, extracellular; ■, incorporated.

White et al. 2005

Cylindrospermopsin

- CYN is hydrophilic and commonly found in extracellular toxin fractions
  - Sivonen & Jones 1999; Shaw *et al*. 2000; Griffiths & Saker 2003
- Cyn production can correlate with cell division in exponential growth phase
  - Though 2x toxin produced in stationary phase verses cell division; Hawkins et al. 2001
- Extracellular CYN accounted for 50% in day 20 of culture of one *C. raciborskii strain*
  - Saker and Griffiths 2000
- Extracellular CYN varied between 19% and 98% of total in *C. raciborskii,* based on bloom stage
  - Chiswell et al. 1999
- 85% of the CYN produced by *Aphanizomenon ovalisporum* was extracellular
  - Shaw et al. 1999

Risk-based Analysis

Cyano toxins

- No good level to have
- EPA candidate contaminate list drinking water; HA listings
- 0.3µg/L MCYN in drinking water- EPA guideline children
- WHO/ EPA guidelines in recreational water
- WHO possible carcinogen list
- Accumulates through time
- Multiple exposure routes
- ALS, PDS, Alzheimer's link
- Caused deaths of cows, elk, dogs, birds, people etc.

Copper

- Essential nutrient
  - Hemocyanin
  - Suggested Daily Intake (2mg)
- 1,300 µg/L is MCL in drinking water
- 26th most abundant element in Earths Crust
- Does not bio-accumulate
- Transfers to less available sediment forms through time
- **No** swimming/ drinking/ irrigation restrictions on USEPA approved label

Peroxide based algaecides

- NSF approval is for use in drinking water
- OMRI certified
- All ingredients in PAK 27 have either Generally Recognized as Safe (GRAS) food additive status from the U.S. Food and Drug Administration (FDA)
- Peroxide gone within hours, decomposition leads to the formation of water and oxygen (Bauza et al. 2014)
  - Cyanobacteria more sensitive than green algae and diatoms (Drabkova et al. 2007b)

- Long-term impacts
  - Cyanobacterial population and microcystin concentration collapsed by 99%; remained very low until 7 weeks after treatment (Matthijs et al. 2012)
  - 'prolonged suppression of cyanobacteria' and "new state with a diverse phytoplankton community" (Weenink et al. 2015)

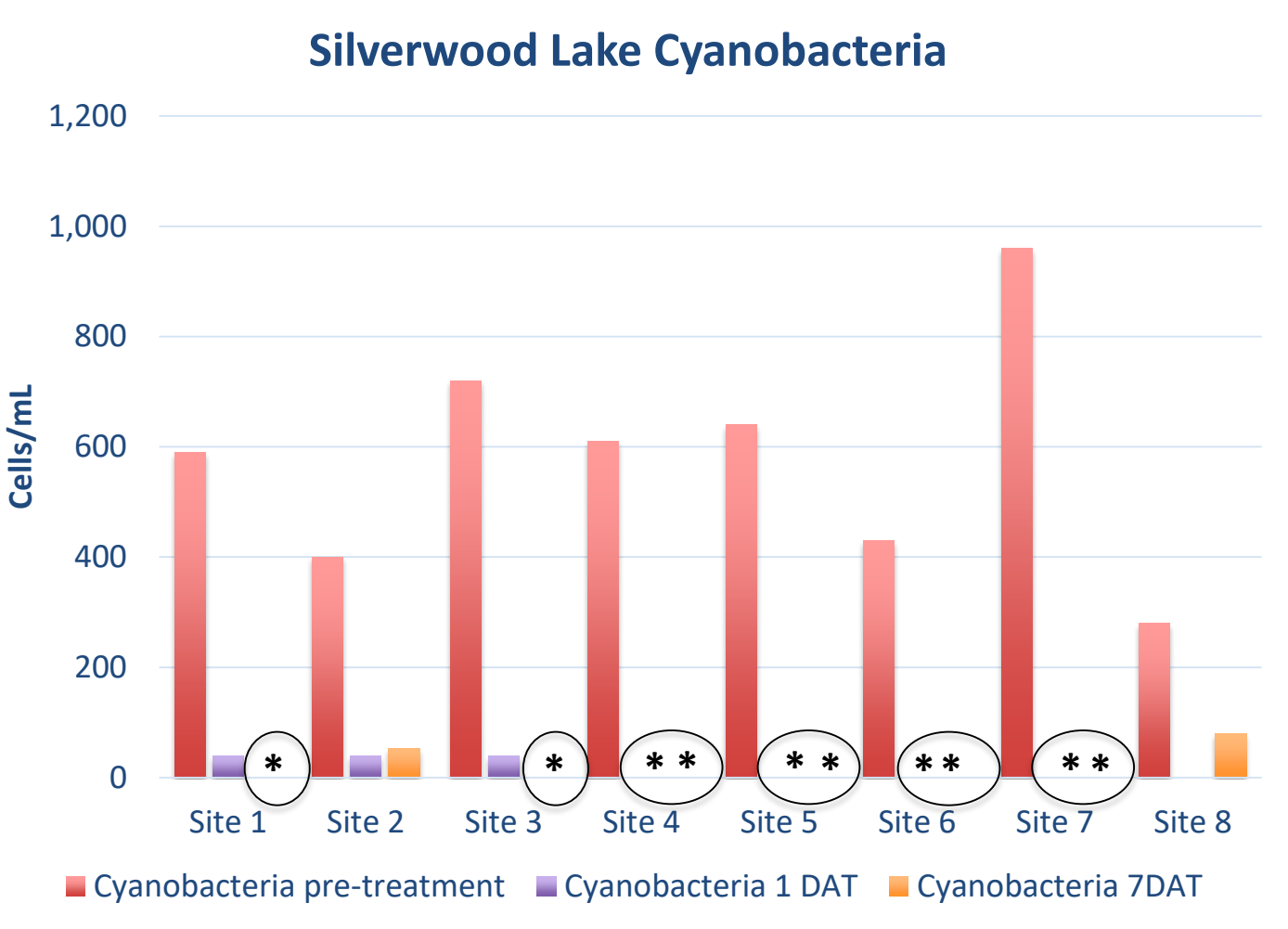
PAK 27 Algaecide

Silverwood Lake, CA

- 935 acres (73,000 AF)
- Supplies 3 Million people in Los Angeles area
- Severe taste/odor issues
- *Anabaena* sp. culprit

Summer Algae Bloom Stinks Up Southern California's Water

Implementation



Cyanobacteria significantly decreased

*** non-detect at most sites 1 and 7 DAT**

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Summary

- Copper widely use, less risk than the disease
- Copper formulation matters
  - Non-target safety
  - Target specificity
- Other non-copper options can be effective in some scenarios
  - Peroxide
- Site character and management objectives need to be considered

Summary

- Nutrient mitigation tricky, but important
- Not directly managing is not without risk
- Released toxin mindset flawed
  - Total risk, accumulation risks, external toxin, wildlife, other exposures
- Source control of bacterial infections critical

Suggested Approach

- 'guilty until proven innocent approach'
  - Otten and Paerl 2015
  - *Data support more toxins being identified, more exposure routes, more knowledge on impacts (acute and chronic)*
  - *Acknowledge both known and unknown risks*

- Approach to ensure safety of the water resource
  - Low tolerance for toxic cyanobacteria
  - Try to prevent
  - Not allow toxin to be produced in sufficient amounts to harm humans/wildlife
  - Mitigate source and/or toxin if found
    - Nutrient mitigation may not correlate

Questions

Solutions to Preserve our most Precious Natural Resource…Water

SePRO

The Stewards of Water

West Bishop, Ph.D., CLP; *Algae Scientist and Water Quality Research Manager*

SePRO Research and Technology Campus,

16013 Watson Seed Farm Rd., Whitakers, NC 27891

252-801-1623 (mobile); westb@sepro.com (email)

Host Algae Corner

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