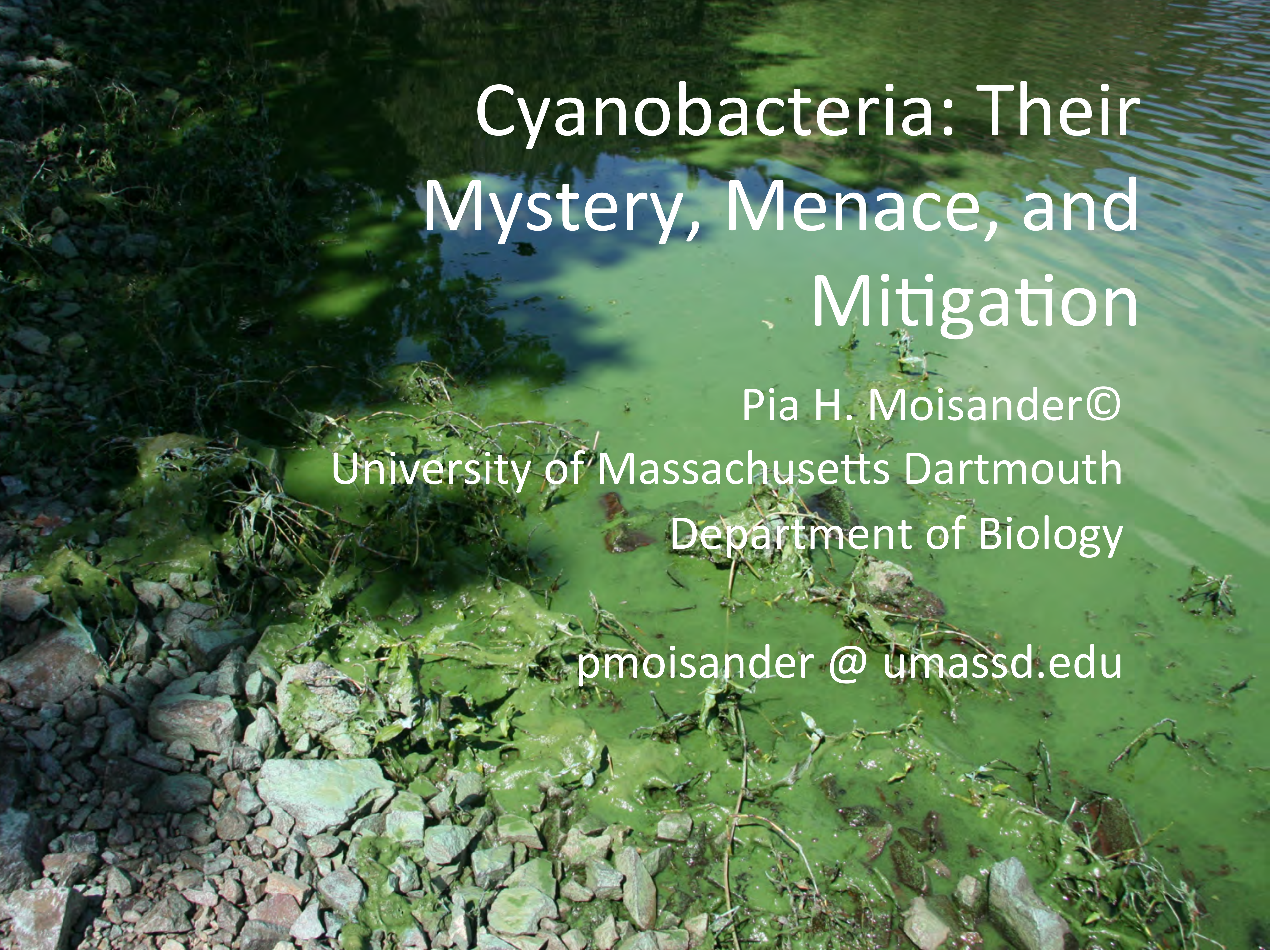

Cyanobacteria: Their Mystery, Menace, and Mitigation

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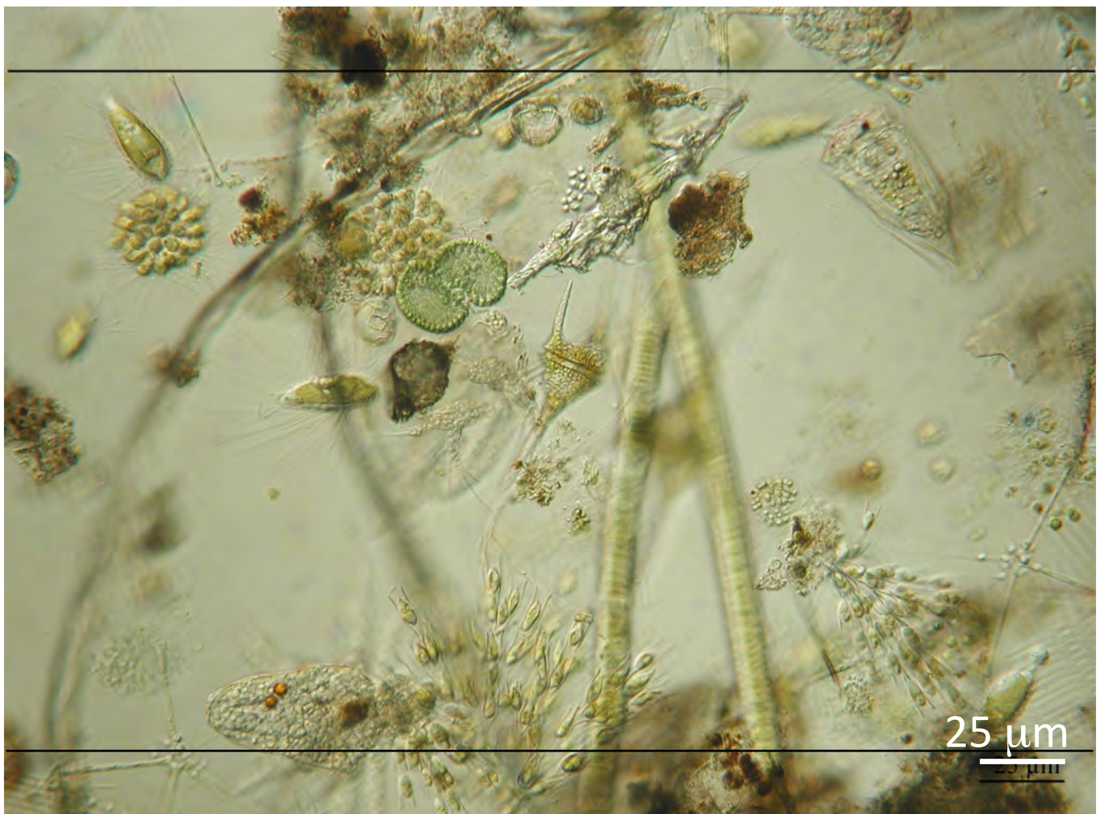
The discussion points today

1. **What is the green stuff?**
2. **Is this a recent phenomenon?**
3. **What is the story about the toxins?**
4. **What can we do to move from green to clear water?**

1. What is the green stuff?

Answer: Phytoplankton

- Phyto → plant
- Plankton → drifting



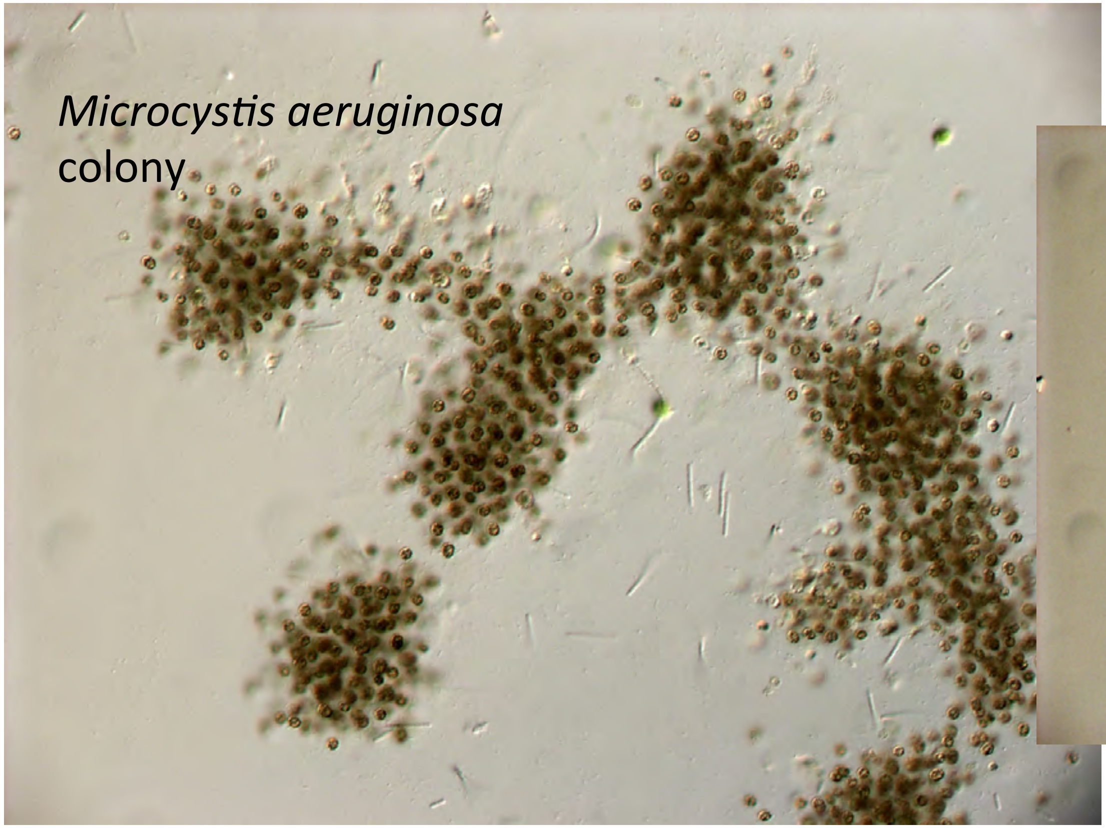
diatom.org

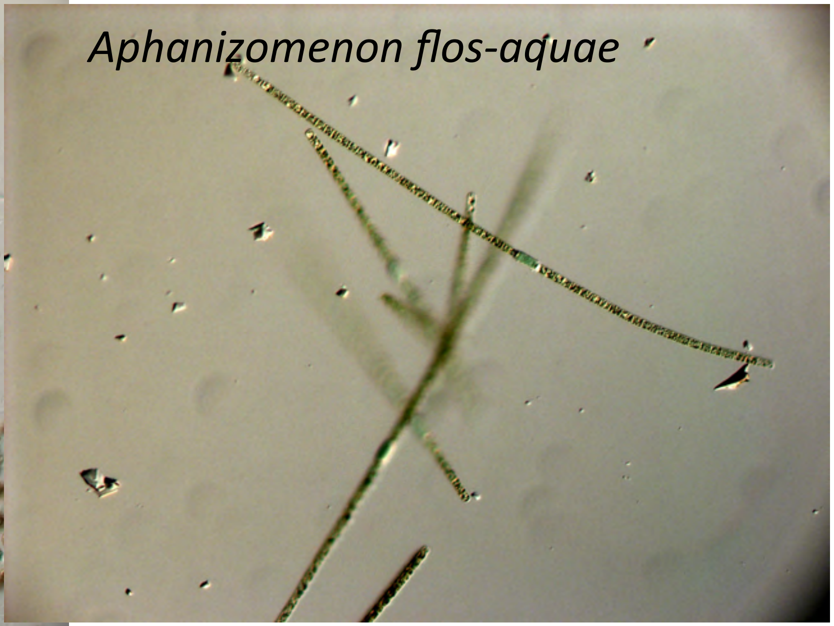
Phytoplankton from Kieser Pond, VT

The diversity of shapes is amazing

Lake Mondesee phytoplankton
Image by T. Weisse

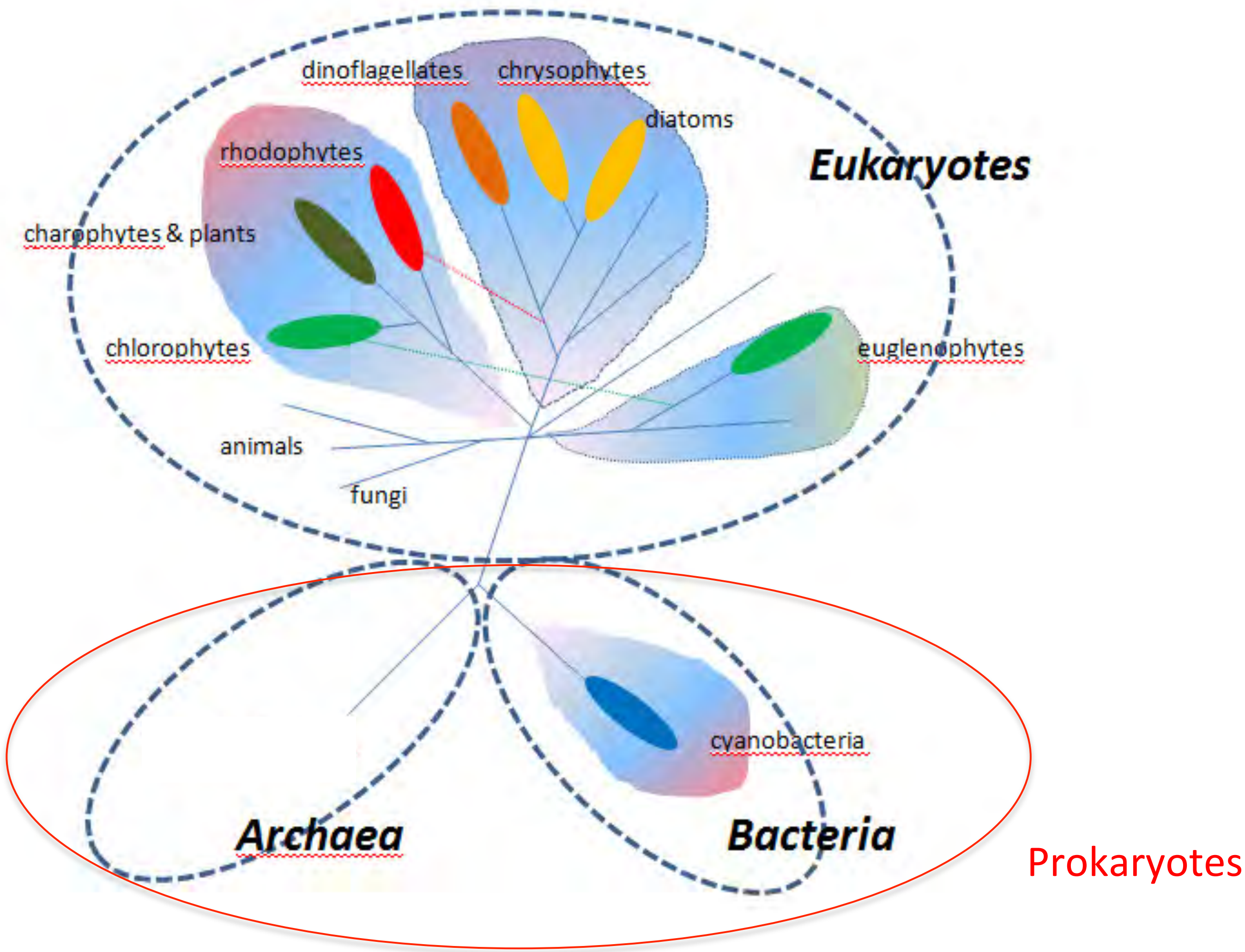
Cyanobacteria are a natural part of phytoplankton





Images: Moisander, unpubl.

Great phylogenetic diversity in phytoplankton reflects evolution



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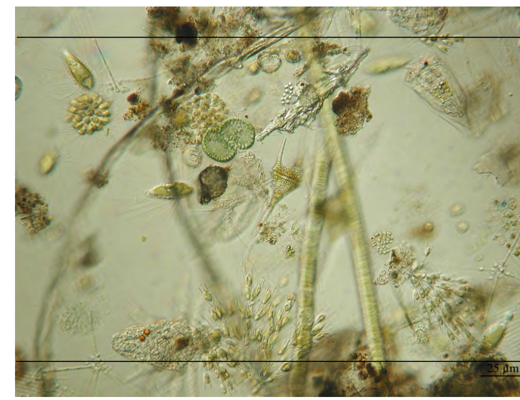
Cyanobacteria are bacteria

- Cyanobacteria
- ~~Blue-green algae~~

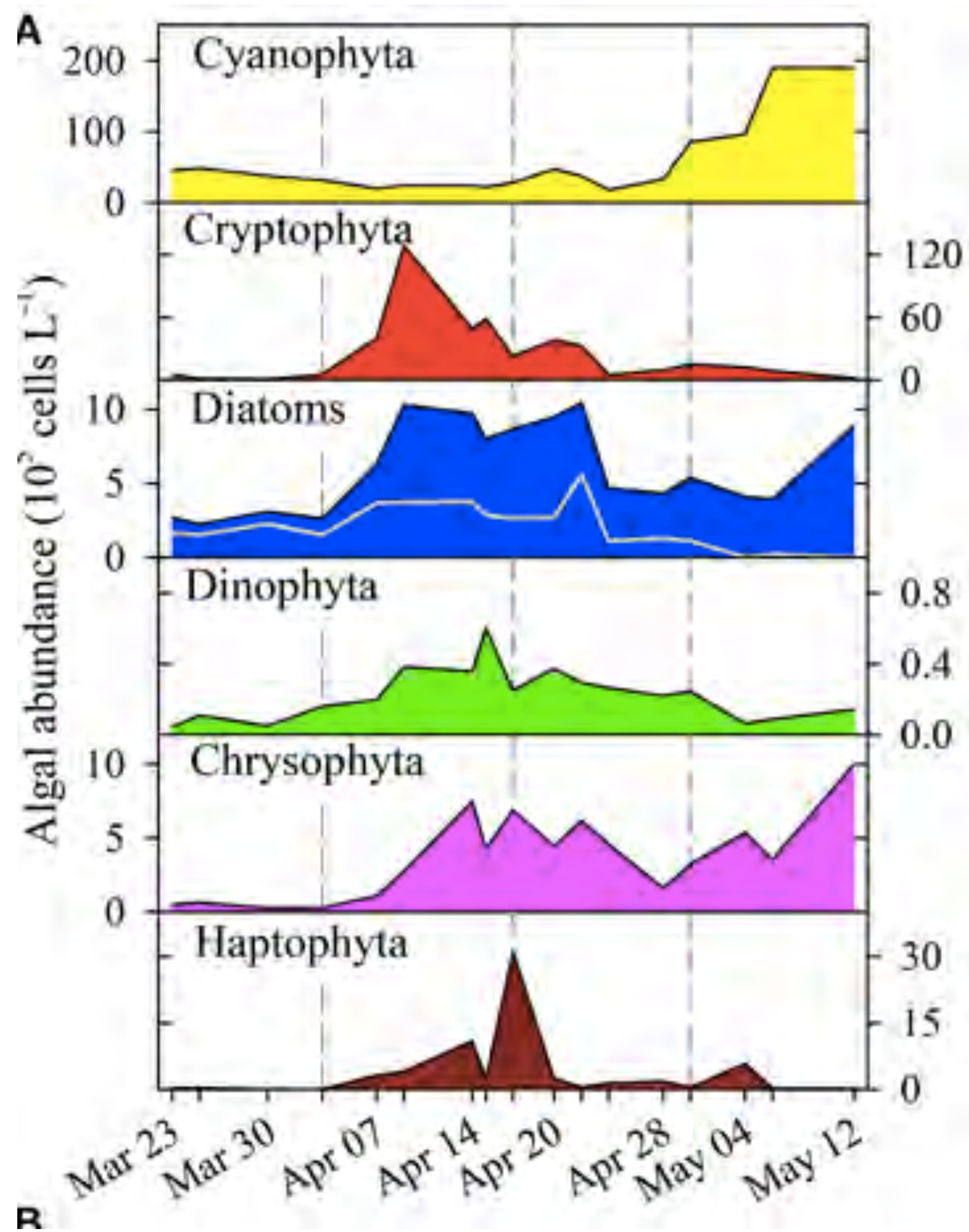
Phytoplankton community composition

- Seasonally somewhat predictable
- Known factors influence community composition
- Different species have different characteristics (traits), allowing them to succeed under different environmental conditions



Seasonal succession of different phytoplankton groups is a natural (and a typical) phenomenon

Lake Zurich, Switzerland

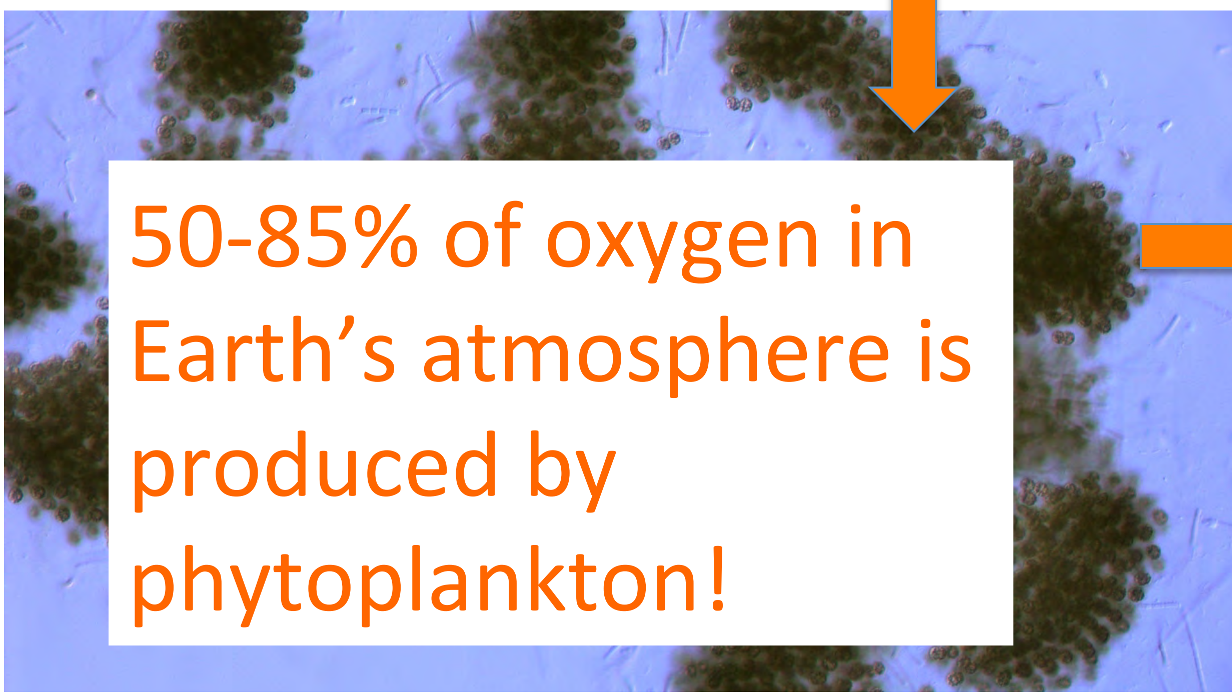


Posch et al. 2015, *Frontiers in Aquatic Microbiology*

What do phytoplankton, including cyanobacteria, do?
Answer: They do what plants do.

Sunlight

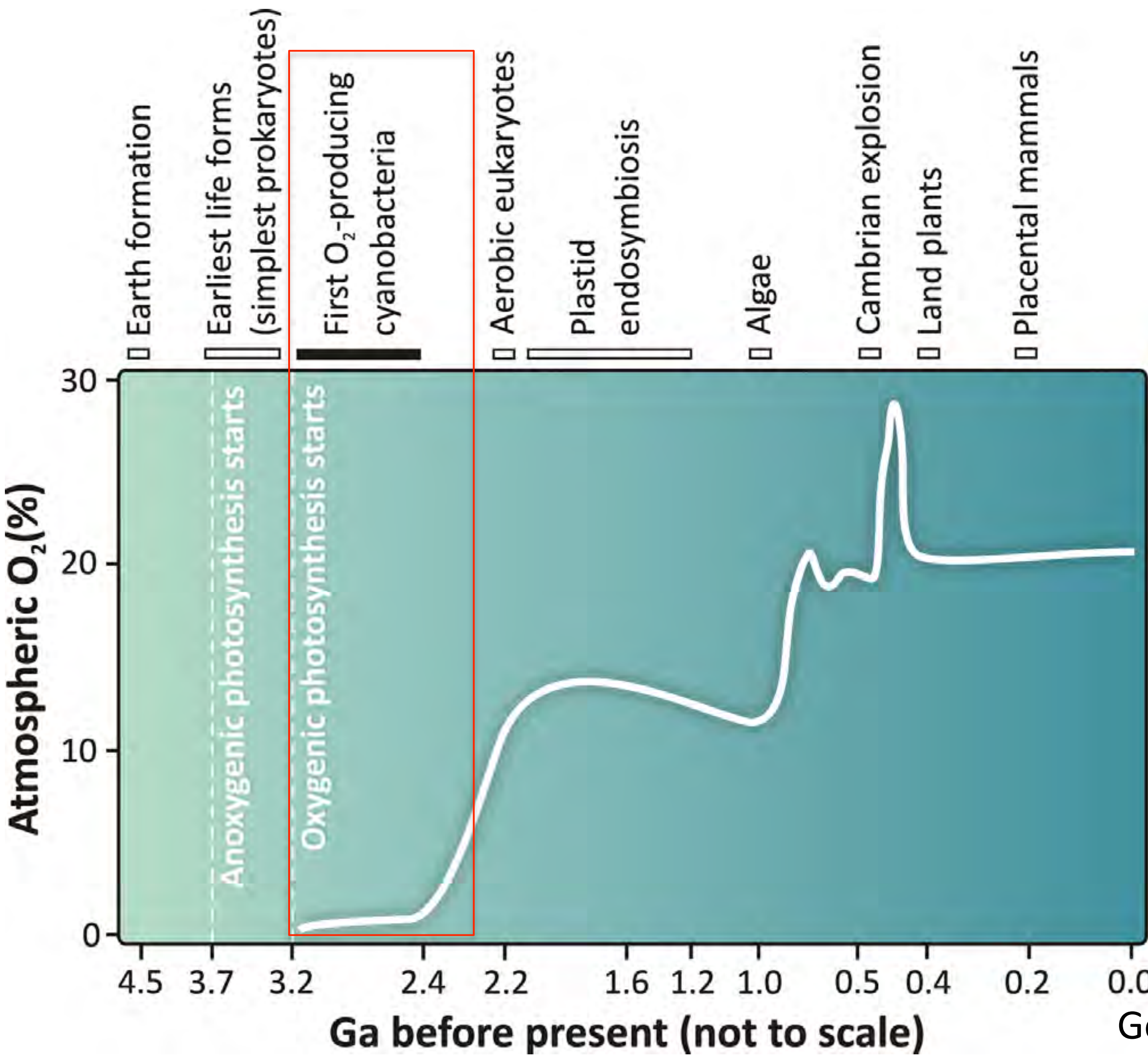
Carbon dioxide = CO_2



50-85% of oxygen in Earth's atmosphere is produced by phytoplankton!

Oxygen, O_2

Cyanobacteria produced the first oxygen on Earth



Cyanobacteria are ~3 billion years old

Govindjee and Shevela 2011
Frontiers in Plant Sci

Cyanobacterial “blooms”

- Mass accumulations of cyanobacteria
- Many species
- Bloom species composition and intensity often varies from year to year.
- Some are N_2-fixing (use atmospheric nitrogen as N source)
- Both marine and freshwater
- In freshwaters often considered a nuisance due to toxin production
- Toxicity varies among species and strains

The blooms

Klamath River, CA (2008)
Microcystis aeruginosa bloom

Baltic Sea
Nodularia spumigena bloom

Images: Moisander, unpubl.

Bloom under the microscope

Microcystis aeruginosa colonies from the Klamath River

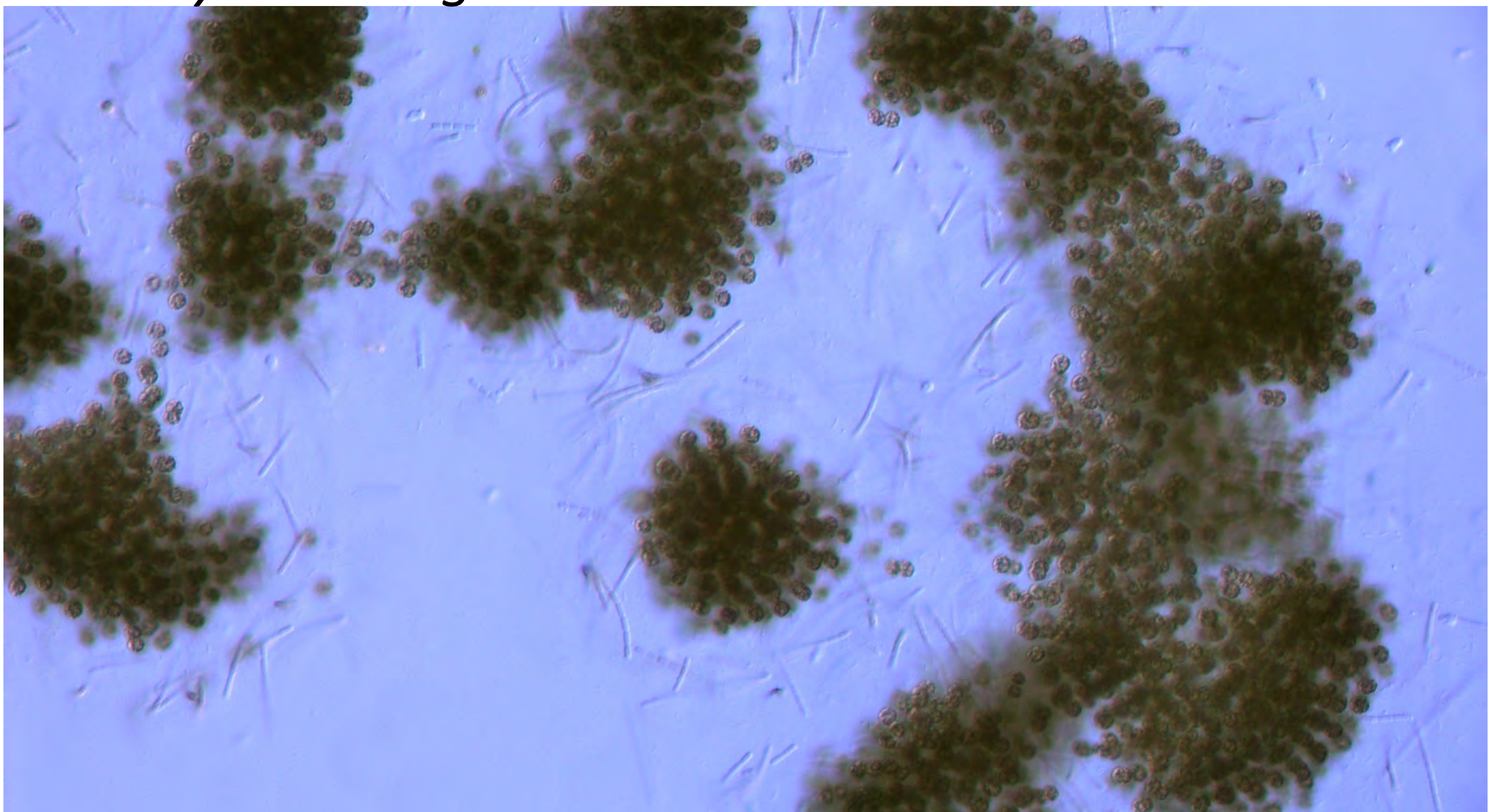


Image: Moisander, unpubl.

2. Are cyanobacteria a very recent phenomenon?

- Cyanobacteria are billions of years old.
- Blooms have been around for a long time.
  - Sediment cores from the Baltic Sea: blooms in the system have been around at least 7,000 years (Bianchi et al. 2000 Limnol. Oceanogr.)

3. What is the story about toxins?

- Chemical compounds produced by the cells.
- A range of different kinds.

Toxins produced by cyanobacteria

***Toxin group* and Toxin**	**Primary target organ in mammals**	**Cyanobacterial genus**
Cyclic peptides		
Microcystins	Liver	*Microcystis, Dolichospermum, Planktothrix, Nostoc, Anabaenopsis*
Nodularin	Liver	*Nodularia*
Alkaloids		
Anatoxin-a, and –a(S)	Nerve synapse	*Dolichospermum, Aphanizomenon, Planktothrix*
Aplysiatoxin	Skin	*Lyngbya, Schizothrix, Planktothrix*
Cylindrospermopsins	Liver	*Cylindrospermopsis, Aphanizomenon, Umezakia*
Lyngbyatoxin-a	Skin, gi tract	*Lyngbya*
Saxitoxins	Nerve axons	*Dolichospermum, Aphanizomenon, Lyngbya, Cylindrospermopsis*
Lipopolysaccharides	Potential irritants	

According to Sivonen and Jones, 1999

Why do cyanobacteria produce toxins?

- Microcystin most studied – some **proposed roles, under debate**:
  - Intracellular physiological roles
  - Cell-cell communication
  - Helps under oxidative stress (binds to proteins and protects from degradation)
  - Grazing and parasite deterrant
  - Toxin genes are older than eukaryotes; the original role was likely physiological rather than serving as eukaryote deterrent

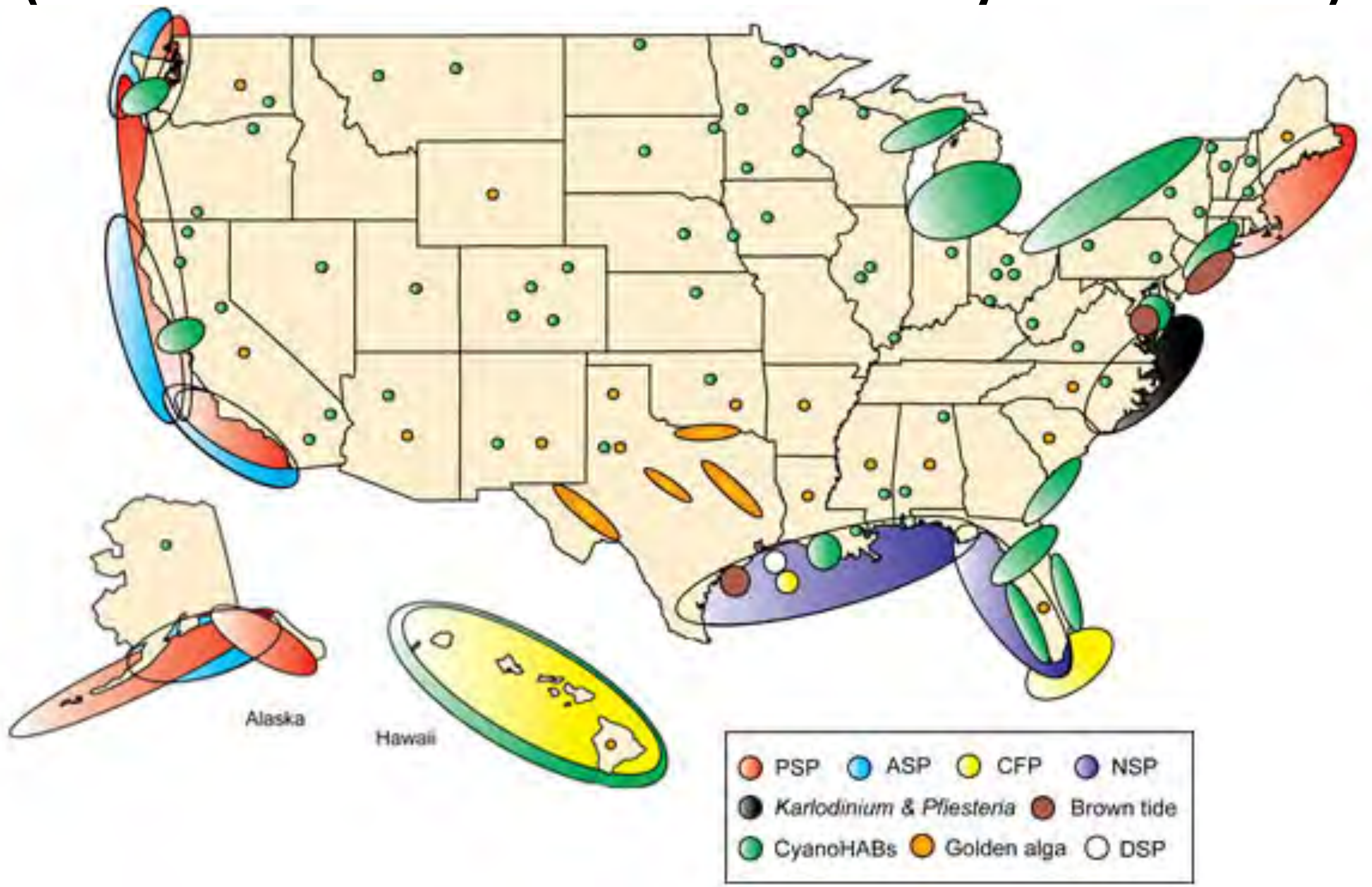
The known and proposed risks

- The most extreme case: Dialysis center in Brazil: 76 people died
  - microcystins and cylindrospermopsin in dialysis treatment water; intraveneous exposure to toxins
- Australia: Palm Island mystery disease, In 1979. Hepatoenteritis, affected ~150 people.
  - Cylindrospermopsin poisoning due to cell lysis in water treatment
- Some chronic exposure links to humans proposed
  - Link proposed to liver cancer in China (Ueno et al. 1996).
  - Recent study in Canada showed **no link** in Canadian populations (Labine et al. 2015).
- In Florida, surface water used as drinking water; cyanotoxins found at drinking water plants
- Contact irritation

The known and proposed risks

- Domestic animal deaths have been reported, some most likely go unreported (dogs, livestock)
  - Liver damage can be proof, but often confirmatory water sample lacking
  - Exposure to higher quantities more likely.
- Wild animals, example: sea otters in Northern California consumed shellfish that had been filter feeding in coastal waters where bloom containing river water entered the bay → sea otter liver damage → death

Where are U.S. CyanoHABs found? (Green dots = states with CyanoHABs)

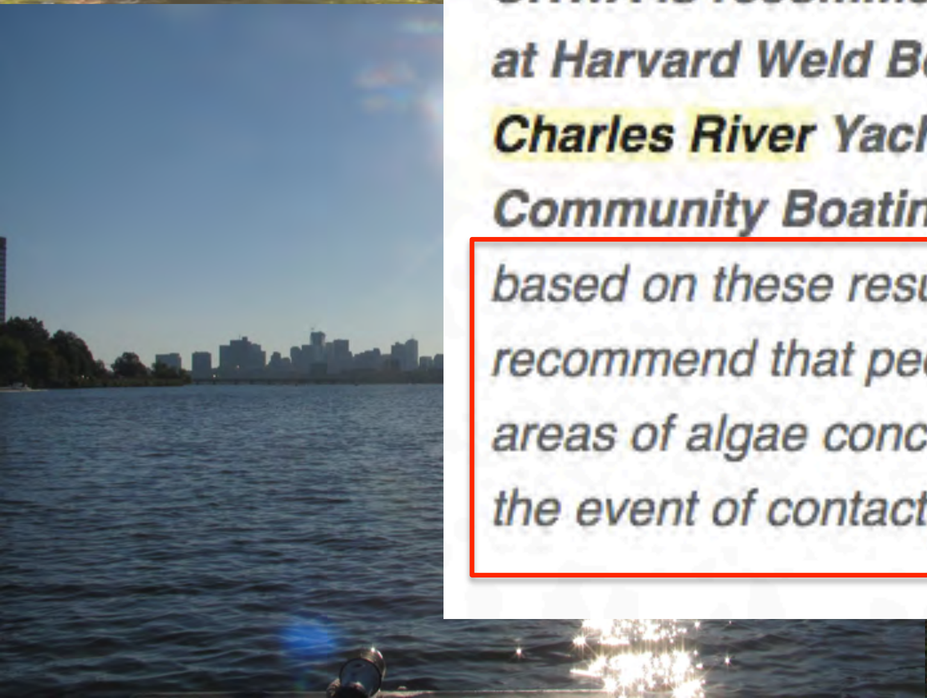


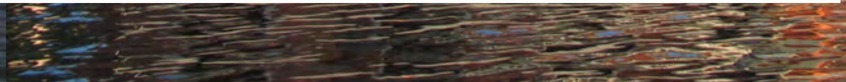
U.S. National Office for Harmful Algal Blooms, Woods Hole Oceanographic Institution

One example from Massachusetts:

Water Quality Forecast for Thursday, August 13, 2015 at 9:30 am:

*In accordance with the MA Dept. of Public Health cyanobacteria (blue-green algae) advisory has been posted for the area of the Charles River below the Anderson Memorial Bridge (near Harvard Square), **CRWA is recommending that yellow flags be flown at Harvard Weld Boathouse, Riverside Boat Club, Charles River Yacht Club, Union Boat Club, Community Boating, & CRCK at Kendall Square,** based on these results. Public health officials recommend that people and pets avoid contact in areas of algae concentration and rinse thoroughly in the event of contact.*





Regulatory limits for cyanotoxins

Massachusetts: posting limit for recreational waters: 70,000 cells/mL
Or >14 ug toxin/L (recreational advisory threshold)

WHO Recreational Exposure Guidelines			
Relative Probability of Acute Health Effects	Cyanobacteria (cells/mL)	Microcystin-LR (µg/L)	Chlorophyll-a (µg/L)
Low	< 20,000	<10	<10
Moderate	20,000-100,000	10-20	10-50
High	100,000-10,000,000	20-2,000	50-5,000
Very High	> 10,000,000	>2,000	>5,000

USEPA 10 Day Drinking Water Health Advisory		
Cyanotoxin	Bottle-fed infants and pre-school children	School-age children and adults
Microcystins	0.3 µg/L	1.6 µg/L
Cylindrospermopsin	0.7 µg/L	3 µg/L

Recreational advisories

- Limits and procedures vary by state
  - Cell counts vs. visual scums vs. toxin concentrations
- Range from advisory to closure
- Not all states post recreational advisories

4. What can we do to reduce blooms?

What causes blooms? Taxon-specific differences. Many environmental factors play roles.

- Temperature – warm is beneficial
- Nutrients (N, P) – varies
- Light intensity and quality - varies
- Salinity – variable tolerance
- DOM – can promote
- pH/pCO_2 - flexibility
- Mixing – stratification beneficial
- Residence time – low flow beneficial

→Combinations of the above

→ Prediction is still difficult

→ Relative influence on toxic and nontoxic strains poorly understood

Images: Moisander, unpubl.

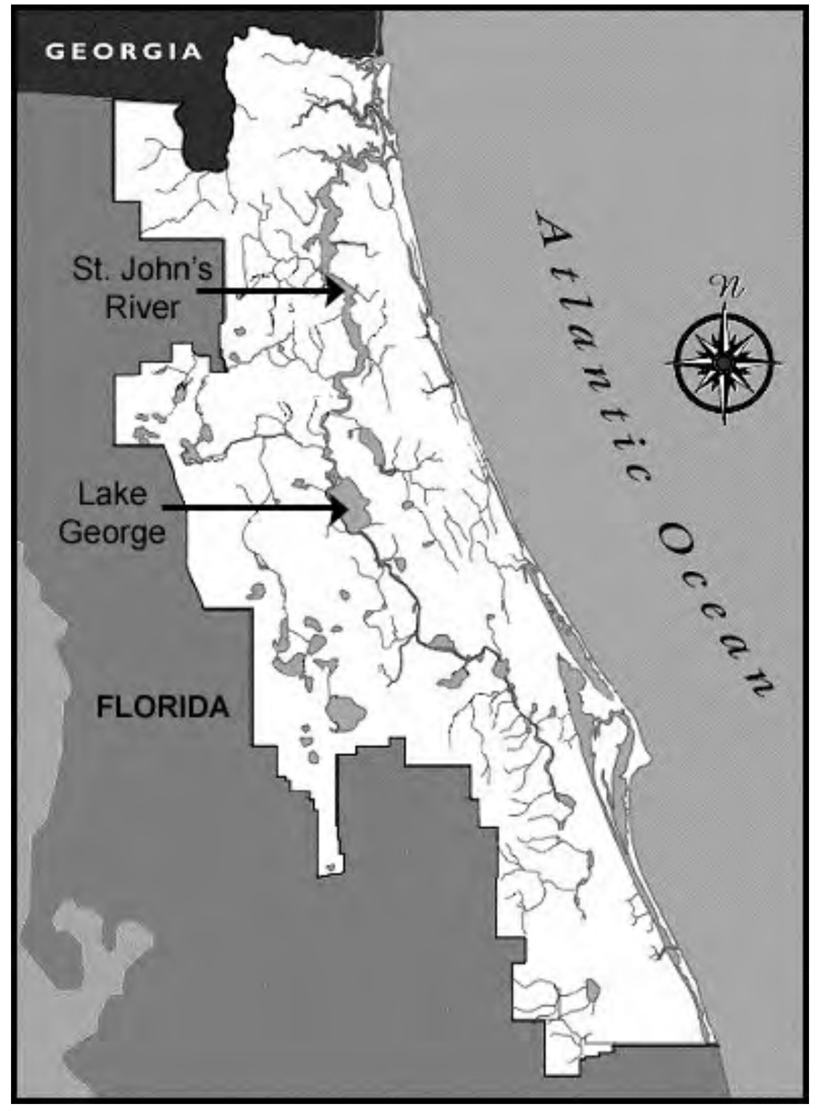
What makes them good competitors in phytoplankton?

- Average temperatures are rising
- High nutrient availability
- Increased turbidity (murky waters)
- Organic matter load can promote them too
- They can regulate their vertical position in the water column
  - Better access to light, nutrients

Community development influenced by specifics of each system

Case study: St. Johns River, Florida

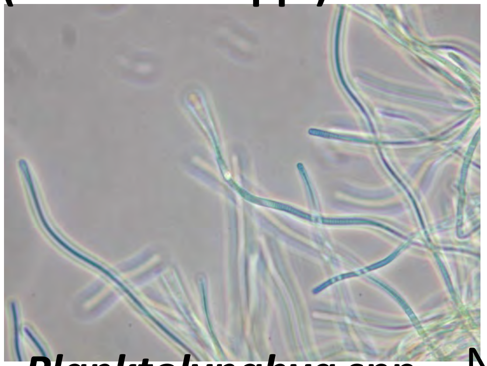
- Blooms most dense in the late summer
- 300 miles long, slow-flowing river
- How does nutrient availability influence bloom species composition?



Recent shift in the cyanobacterial community composition in the St. Johns River Estuary, FL

“Native”

***Dolichospermum* spp.** N_2 fixer
(*Anabaena* spp.)



***Planktolyngbya* spp.** Non-N_2 fixer

“Invasive”

Cylindrospermopsis raciborskii
N_2 fixer

Images: Moisander, unpubl.

Cylindrospermopsis raciborskii

Fixes N_2

First appeared in Florida in 1980’s

Produces several toxins

Toxins detected in drinking water treatment plants in Florida

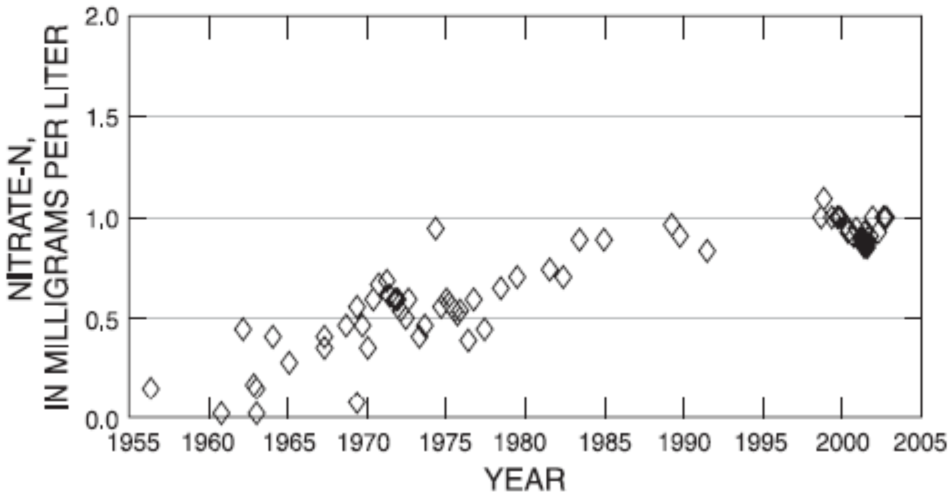
Abundances reported to be increasing in temperate systems worldwide.

Thought to compete well under lower light levels, reported to have a high affinity to phosphate.

N_2 fixation 101

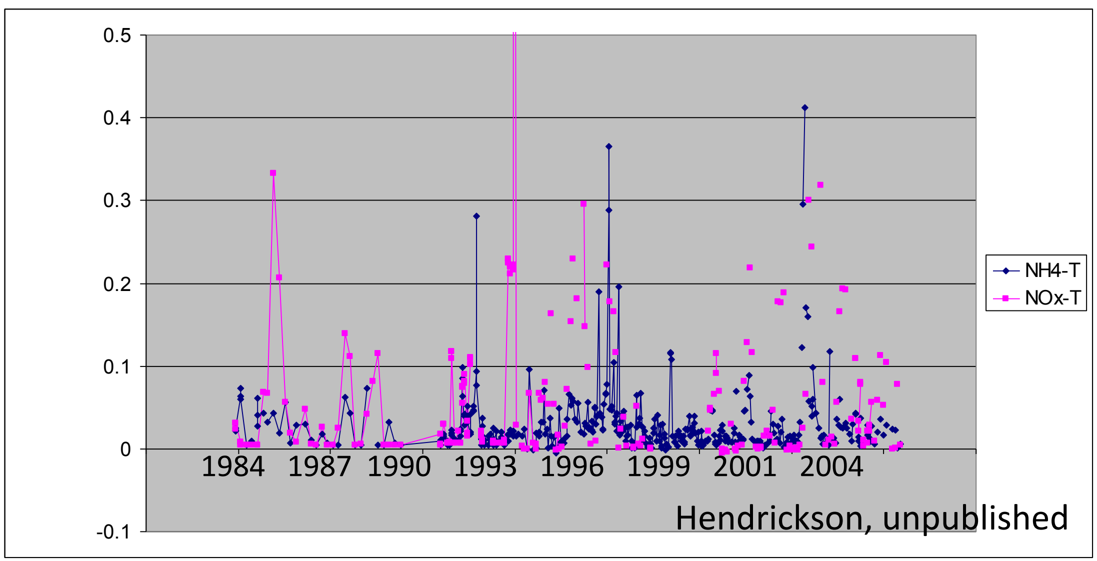
- Many bloom formers can fix N_2
  - *Dolichospermum, Aphanizomenon, Cylindrospermopsis*
- Use atmospheric nitrogen as N source
- A benefit for the organisms if nitrate, ammonium limiting
- Traditional thinking: diazotrophs outcompeted by eukaryotic phytoplankton or non-N_2 fixing cyanobacteria if nitrate, ammonium available
- (N_2 fixation requires a lot of energy)

A potential reason for *Cylindrospermopsis* invasion:



Cohen 2007

Nitrate at a St. J. watershed site



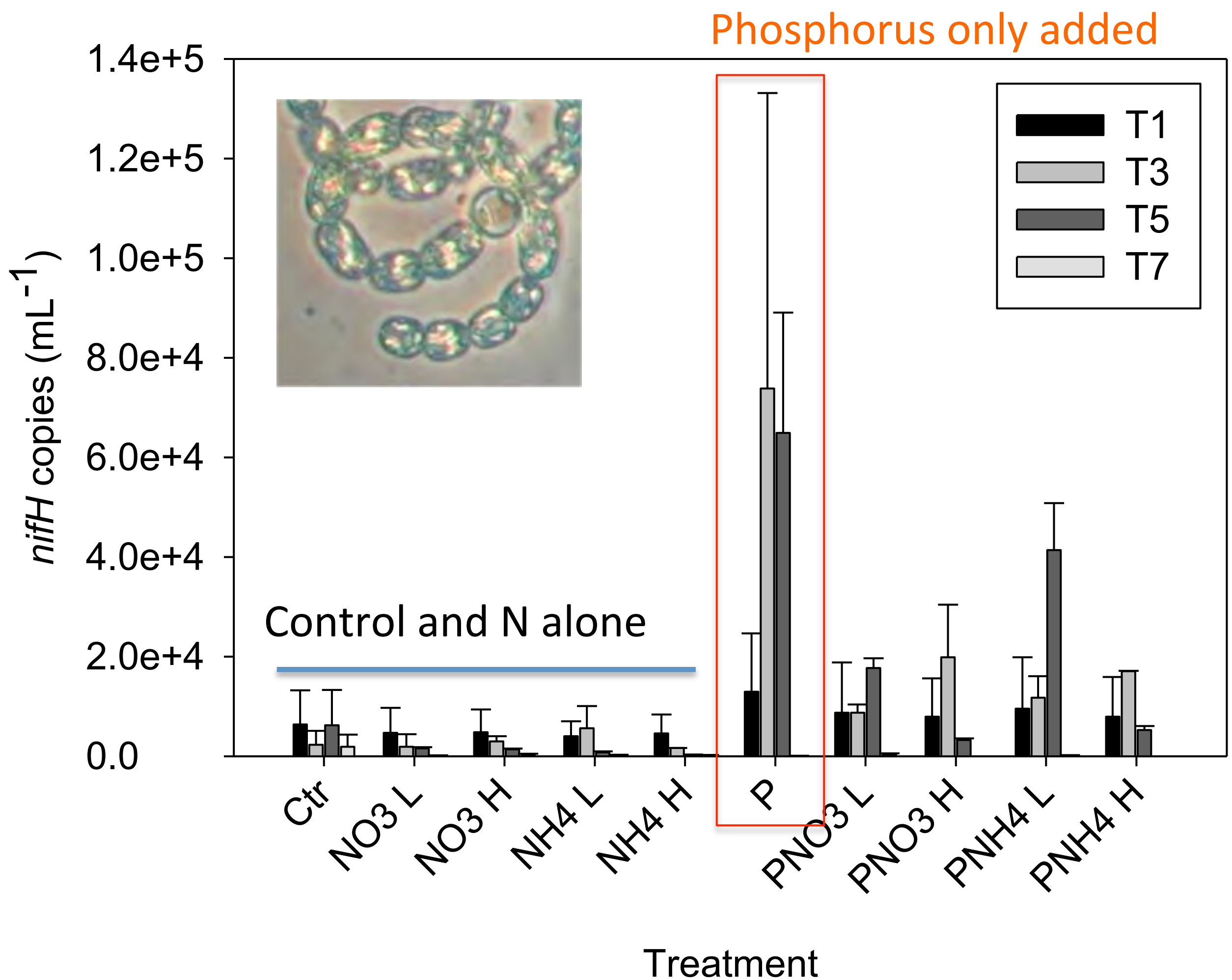
Dissolved inorganic nitrogen in St. Johns River

St. Johns River: long-term increases, high short-term pulses in NITROGEN

St. Johns River,
Nutrient manipulation
experiments

Image: Moisander, unpubl.

Dolichospermum sp. (*Anabaena* sp.) abundance (*nifH* copies mL^{-1})



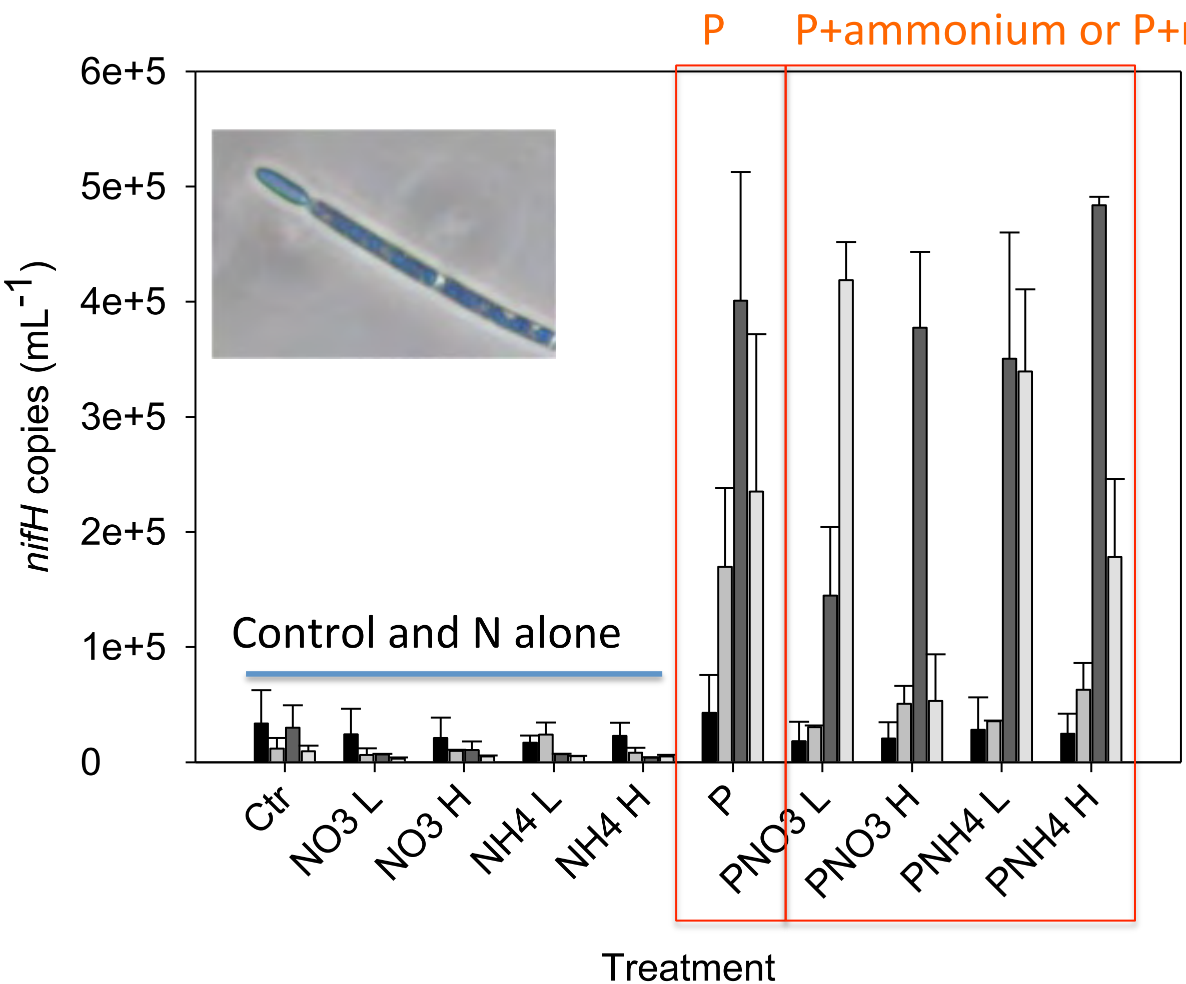
Growth was P limited.

Phosphorus added alone stimulated growth the most.

P added with N: growth was reduced.

Moisander et al. 2012, FEMS Micr. Ecol.

Cylindrospermopsis raciborskii abundance (*nifH* copies mL^{-1})



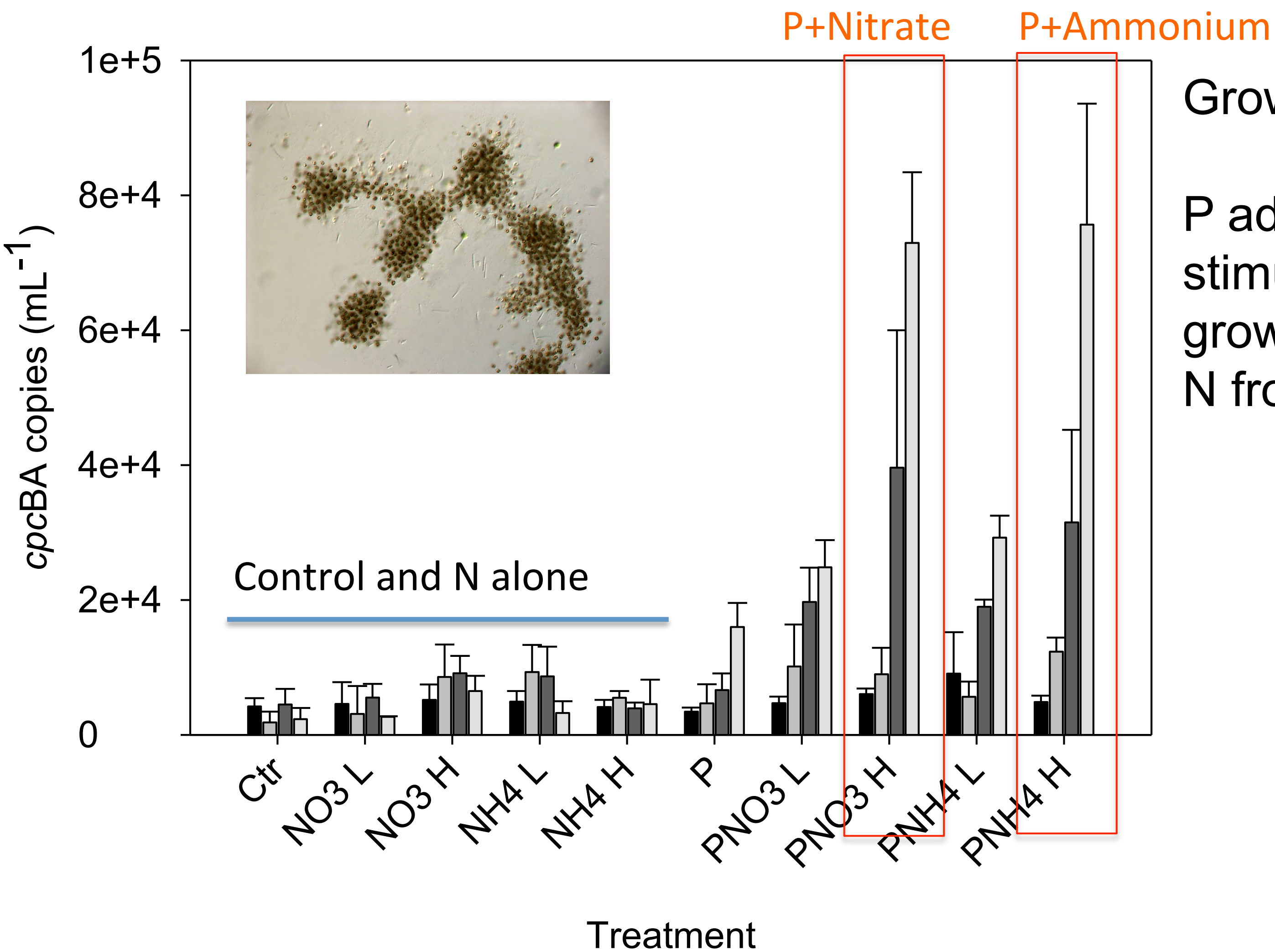
Growth was P limited.

Phosphorus added alone stimulated growth to the same degree as P+NO_3^- or P+NH_4^+:

Presence of **N with P did not inhibit growth**

Moisander et al. 2012, *FEMS Micr. Ecol.*

Microcystis aeruginosa abundance (*cpc*BA copies mL^{-1})

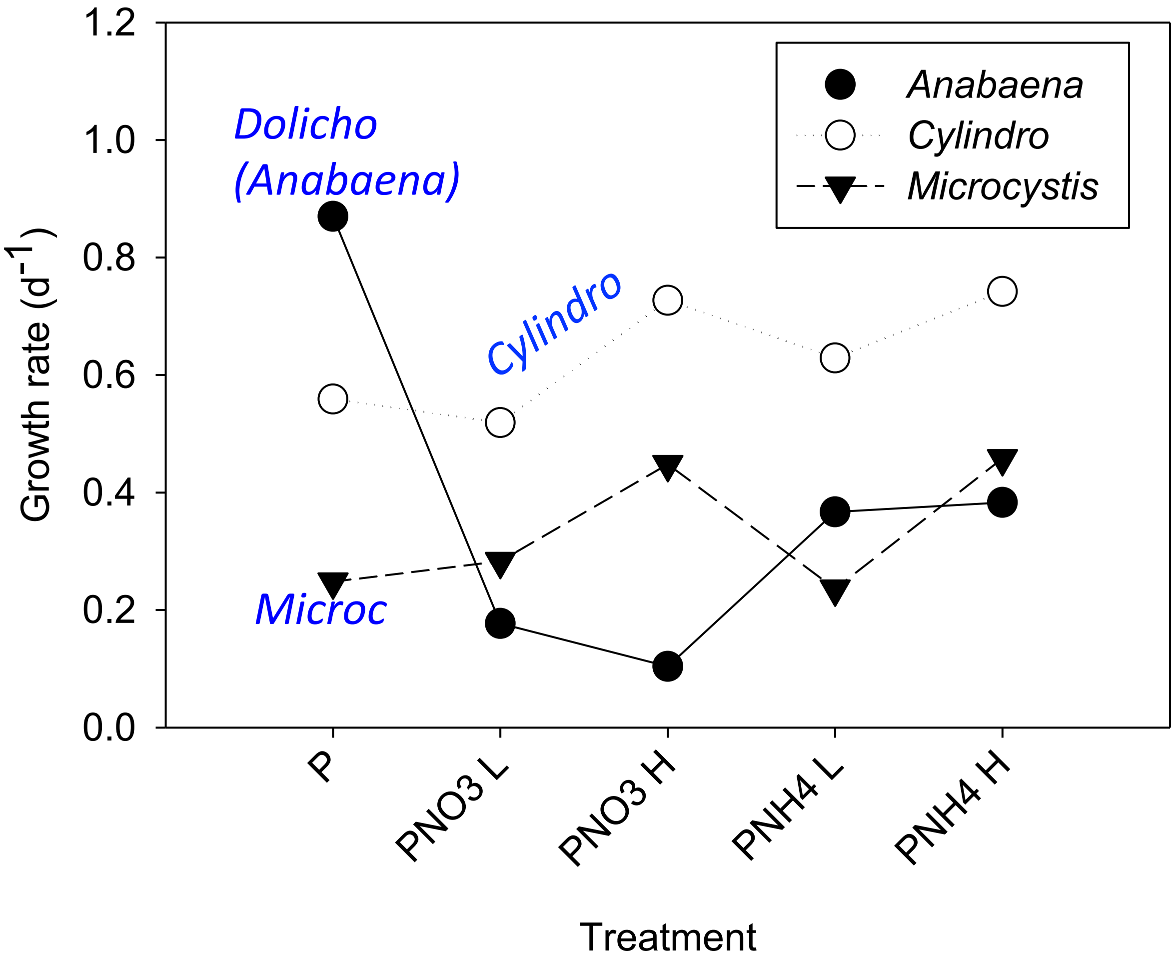


Growth was N+P limited.

P added alone stimulated growth, but slowly → N from diazotrophs?

Moisander et al. 2012, *FEMS Micr. Ecol.*

Growth rates with P or P+N in *Dolichospermum*, *Cylindrospermopsis*, and *Microcystis*



Moisander et al. 2012, *FEMS Micr. Ecol.*

New reason for the success and "invasiveness" of *Cylindrospermopsis?*

- Facultative diazotrophy
  - Ability to quickly switch between N_2 fixing and non-fixing modes
- N limited systems with increasing and variable N enrichment should be susceptible to *Cylindrospermopsis* blooms

Should we focus our efforts on nitrogen or phosphorus?

- Both.
- Potential HAB species can thrive under limitation for each, and some have flexible strategies.
- Nutrient loads can also promote overall eutrophication, leading to increased turbidity and anoxia and hypoxia, which can also indirectly promote blooms
- →Reduce both N and P loads to watersheds

The logical focus: nutrient loading

- Determine focus areas by hydrologic assessment and measurements in the system in question
  - Point sources
  - Non-point source load reduction include
    - Storm water management
    - Recreational activities – public outreach
    - Buffer zones, wetland preservation

Common sense practices include

- Maintain septic systems
- Use phosphorus free detergents
- Do not over-fertilize lawns
- Pick up pet waste
- Boating: bring your waste home
- Maintain vegetation around waters edge (buffer zones)

Biomanipulation and engineering solutions

- Artificially enhance mixing
  - Oxygenators
    - Reduces internal loading
    - Interferes with vertical migration
- Remove nutrients
  - Floating islands
- Reduce internal loading
  - Cover the bottom of the pond with a cover that prevents nutrients being released from sediments

Biomanipulation: Fish removal

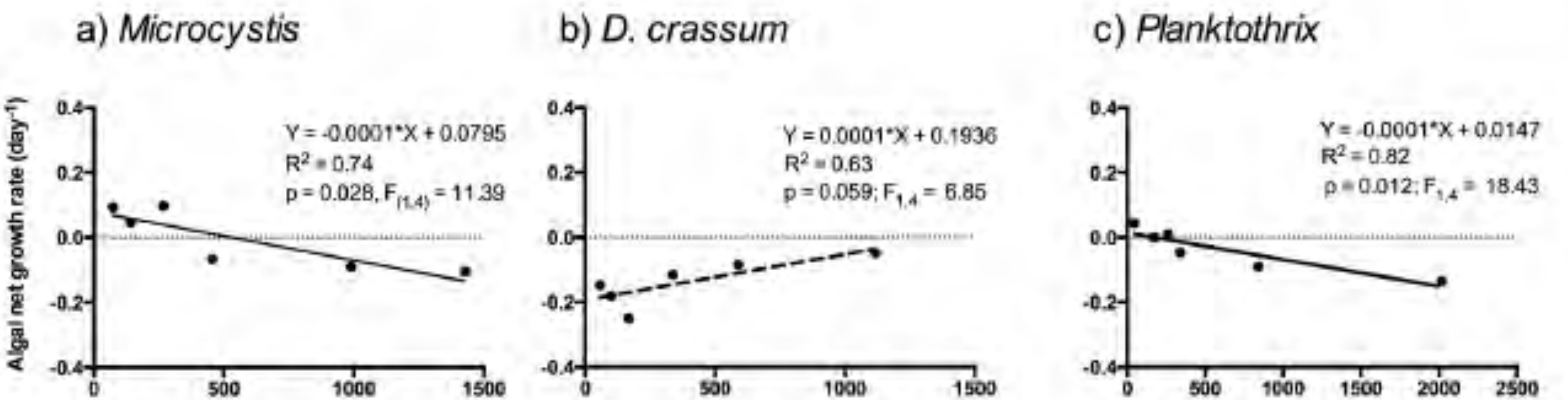
- Removal of planktivorous fish
  - Removes predators of large zooplankton
  - The idea is that the zooplankton will more effectively graze cyanobacteria

Does it work?

Effectiveness of fish removal: Evidence is mixed.

Cyanobacterial abundance response was taxon specific when *Daphnia* zooplankton abundance increased:

Lake Ringsjön, Sweden



Zooplankton biomass (ug/L)

Urrutia-Cordero et al. 2016 *PLoS One*

Some cyanobacteria are not effectively consumed

- Use fish instead as planktivores?
- Only few fish species digest cyanobacterial blooms
  - Study with Tilapia suggested potential for using it in top–down control (Lu et al. 2006, *Hydrobiologia*)
  - Controlling the stock needs careful management

Inhibition by plant-based humics

- Evidence that plant based humic compounds have an inhibitory effect in the presence of UV light (taxon specific influence observed)
  - Oxygen radicals released → inhibitory
- Sources from wetlands naturally
  - could also be added (e.g. barley straw)

Increase flow in the system or open it to high salt

- Netherlands
- Peel-Harvey, Australia

Temperature

- Is increasing due to climate change caused by human activities
- Higher temperatures increase relative fitness of bloom-forming cyanobacteria
- Solution?

Solutions

- There is no one-size-fits all solution
- Any mitigation should address system – specific issues including
  - What species are present?
  - What causes the blooms in the specific system?
  - Are the blooms toxic?
- Can address the cause or be a short-term band aid

Cyanobacteria Monitoring Collaborative by the Environmental Protection Agency

http://cyanos.org/

GET INVOLVED

Check out bloomWatch, cyanoScope, and cyanoMonitoring to find ways you can start monitoring cyanobacteria.

bloomWatch App

Crowdsourcing to find and report potential cyanobacteria blooms

Engaging the public to report when and where potential cyanobacteria blooms appear.

LEARN MORE

cyanoScope

Mapping cyanobacteria one slide at a time

Engaging trained citizen scientists and professional water quality managers to understand where and when cyanobacteria species occur.

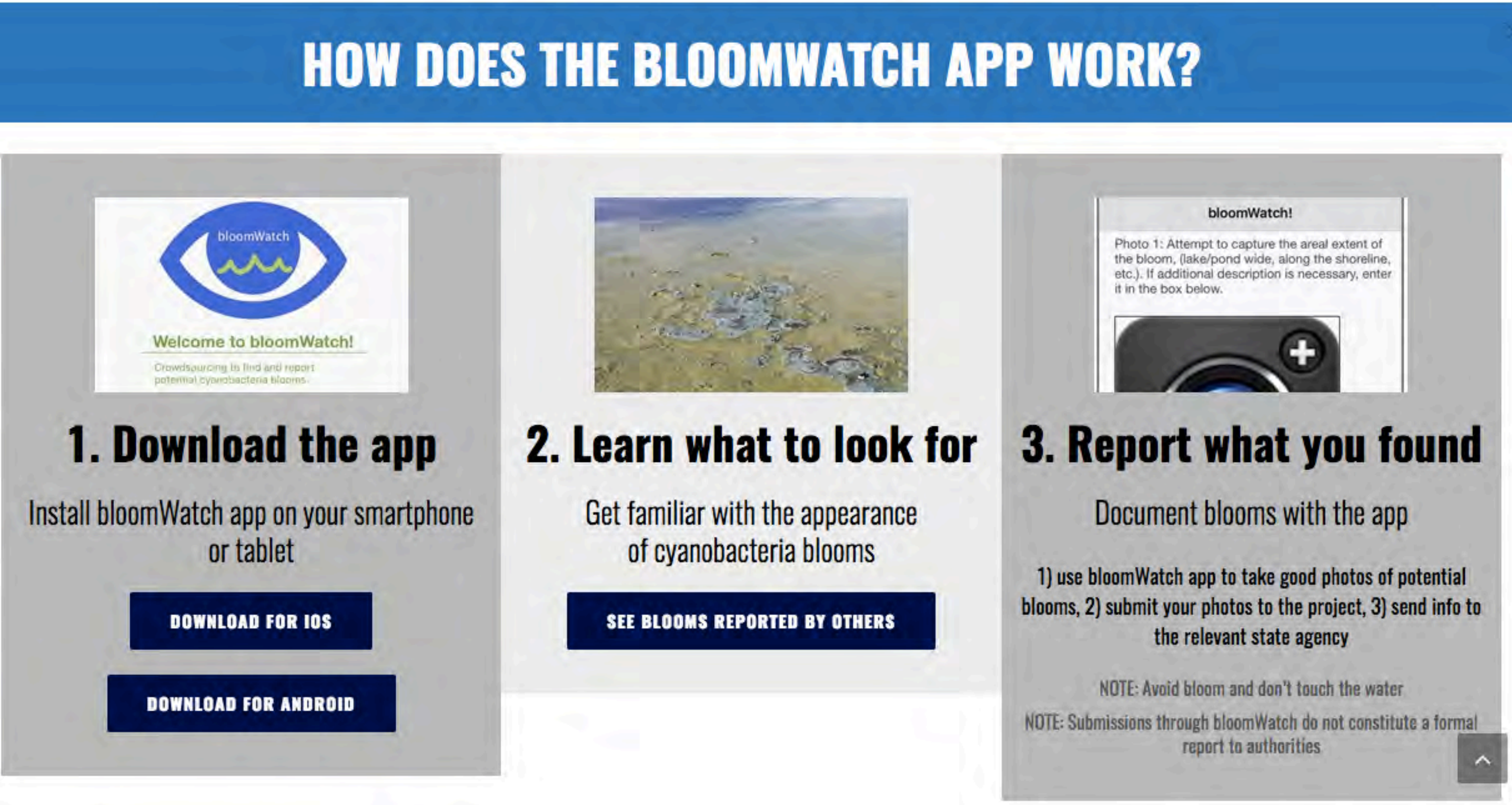
LEARN MORE

cyanoMonitoring

Monitoring cyanobacteria populations over time

Engaging professionals and trained citizen scientists to track seasonal patterns of cyanobacteria.

LEARN MORE



http://cyanos.org/bloomwatch/#bloomwatch_how

HOW DOES CYANOSCOPE WORK?

Collect cyanobacteria

1) collect cyanobacteria with a net tow, 2) prepare your microscope slides, 3) identify the dominant cyanobacteria in your sample

For information on training and equipment write to:

INFO@CYANOSCOPE.ORG

For help identifying the cyanobacteria in your sample:

THE ``DIRTY DOZEN`` CYANOS

Submit your images

1) take pictures of the dominant cyanobacteria in your sample, 2) upload the images and relevant info on iNaturalist.org

NOTE: Be sure include basic information about where and when the sample was collected.

NOTE: If not sure what cyanobacteria you have, that's fine! Go ahead and upload your image.

To submit your images, sign in or register at:

CYANOSCOPE ON INATURALIST.ORG

Interact online

1) the iNaturalist community can help confirm the identity of cyanobacteria, 2) you can view and comment on images submitted by others, 3) everyone can explore patterns of the appearance of cyanobacteria

To view and comment on images, sign in or register at:

CYANOSCOPE ON INATURALIST.ORG

Take home

- Cyanobacteria are an integral part of phytoplankton.
- Cyanobacteria are >2 billion years old: way, way, older than us…
- Rising temperatures, increasing availability of nutrients, increased water column stratification, water shortages, increased turbidity, all potentially promote blooms.
- The effects are taxon-specific.
- There is no one-size-fits-all mitigation solution.

Acknowledgements

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  - Hans Paerl, Paerl lab, Michael Piehler (UNC-CH)
  - Funding: NSF-DEB and UMass Dartmouth
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