University of Idaho
College of Natural Resources

CYANOTOXINS: WHAT THEY ARE AND WHY THEY MATTER

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ACKNOWLEDGEMENTS

- Graduate students (Sarah Burnet, Ted Harris)
- US Army Corps, Idaho EPSCoR, and NSF
- Undergraduate students/field assistants

Limnologist – study of inland water

At UI since 2007

- teach / research / train graduate students
- Interests – lake management/surface water protection/remediation
- Introduced species

Wide variety of projects

- Invertebrates (mysids/tadpole shrimp)
- *Didymo* (rock snot) mats,
- Algae in response to watershed inputs (CDA)
- Cyanobacteria (Willow Creek Reservoir / Fernan)

OUTLINE

- Cyanobacteria background/overview
- Toxins
- Toxins and human health
- Conditions that produce blooms
- Blooms and toxins

CYANOBACTERIA - BACKGROUND

- Source of our atmosphere approx. 3.5 bya
- Bacteria / algae characteristics

  -Chlorophyll a, evolve O_2

  -no cellulose in walls, no membrane-bound organelles, reproduction via fission, can fix nitrogen
- Occur in wide range of habitats and forms

CYANOBACTERIA - BACKGROUND

- Heterocysts – specialized cells to fix nitrogen
- Akinetes – resting cells
- Vacuoles – gas-filled vesicles to regulate buoyancy

CYANOBACTERIA – WHY DO WE CARE?

- Aesthetics (surface scums)
- Taste and odor issues
- Use O_2 when decomposing
- Produce suite of potent toxins

CYANOBACTERIA – WHO ARE THE PLAYERS?

Anabaena
Aphanizomenon
Microcystis

} (Annie – Fannie – Mike)

Lyngbya
Gleotrichia
Woronichinia

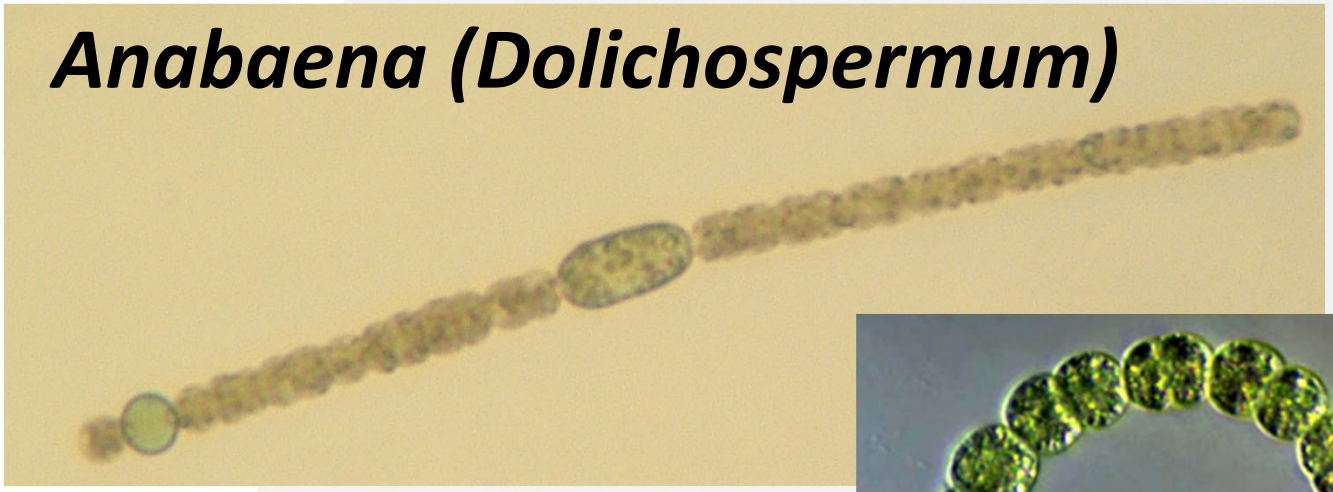
All have been found to occur in Idaho HABs

…and if those names weren't confusing enough

Recent name changes:

Anabaena* -- *Dolichospermum
Aphanizomenon* -- *Chrysosporum

Anabaena (Dolichospermum)

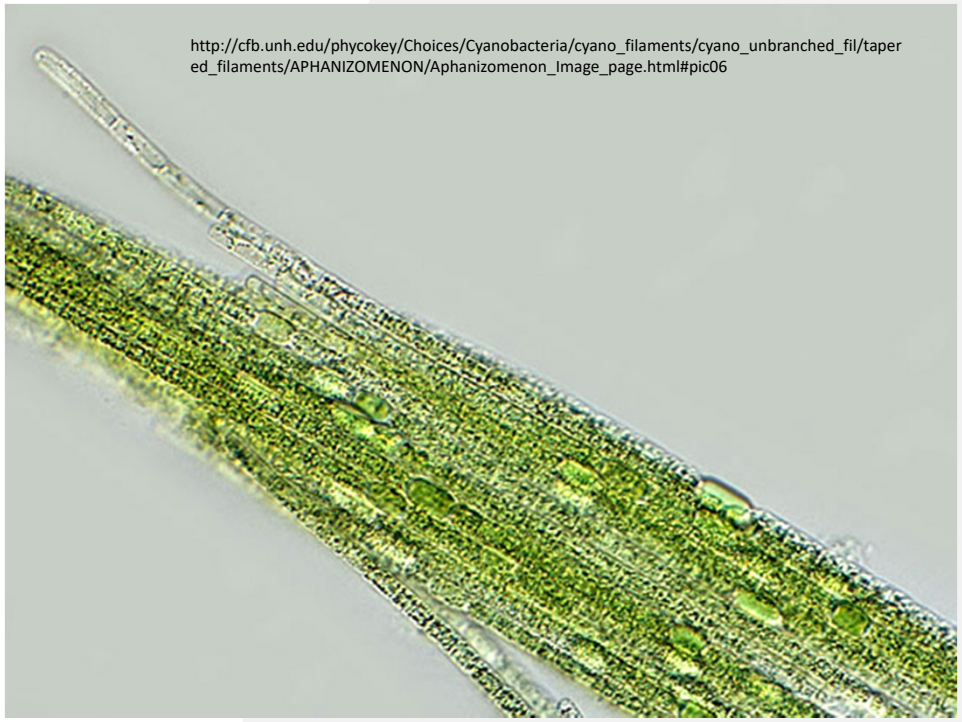


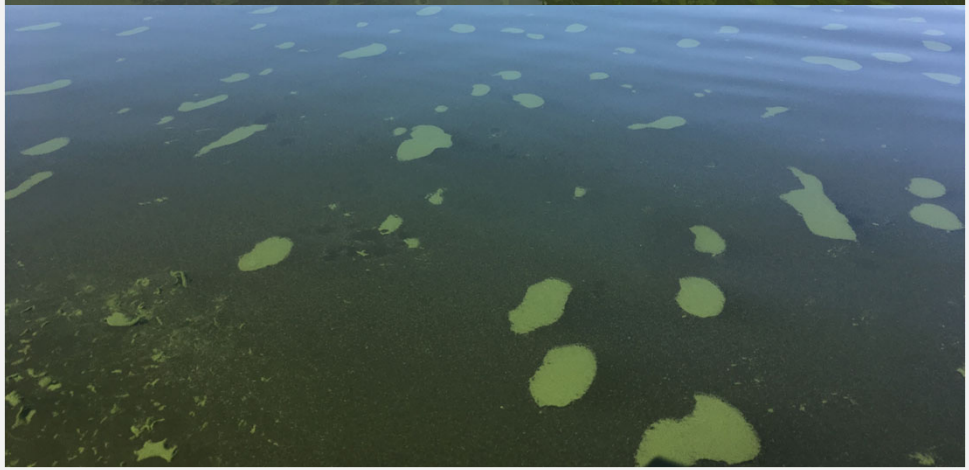
http://cfb.unh.edu/phycokey/Choices/Cyanobacteria/cyano_filaments/cyano_unbranched_fil/untapered_filaments/heterocysts/no_visible_sheath/ANABAENA/Anabaena_Image_page.html#pic12

Toxin – Anatoxin, microcystis

Spring bloom of *Anabaena (Dolichospermum)*

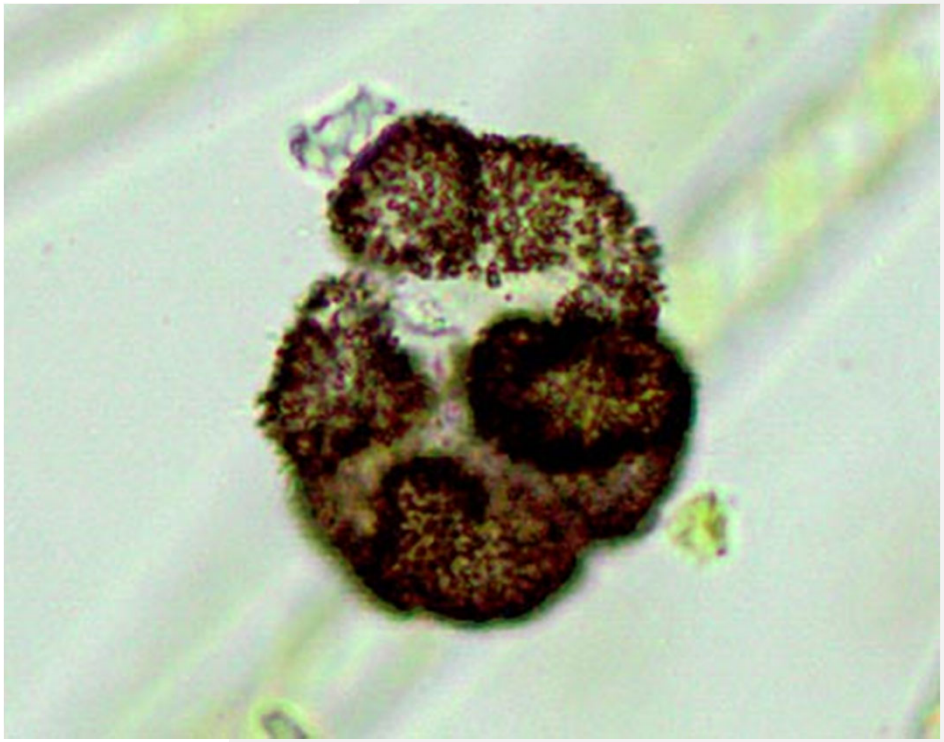
Aphanizomenon (Chrysosporum)

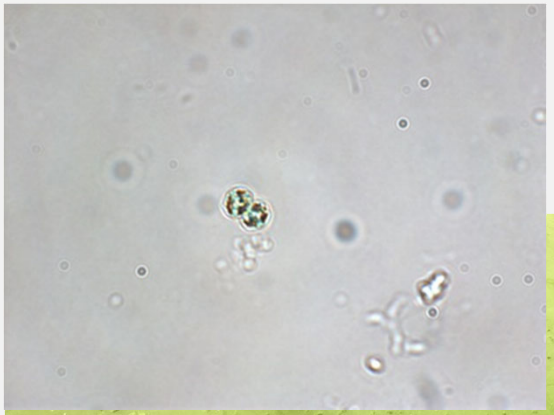


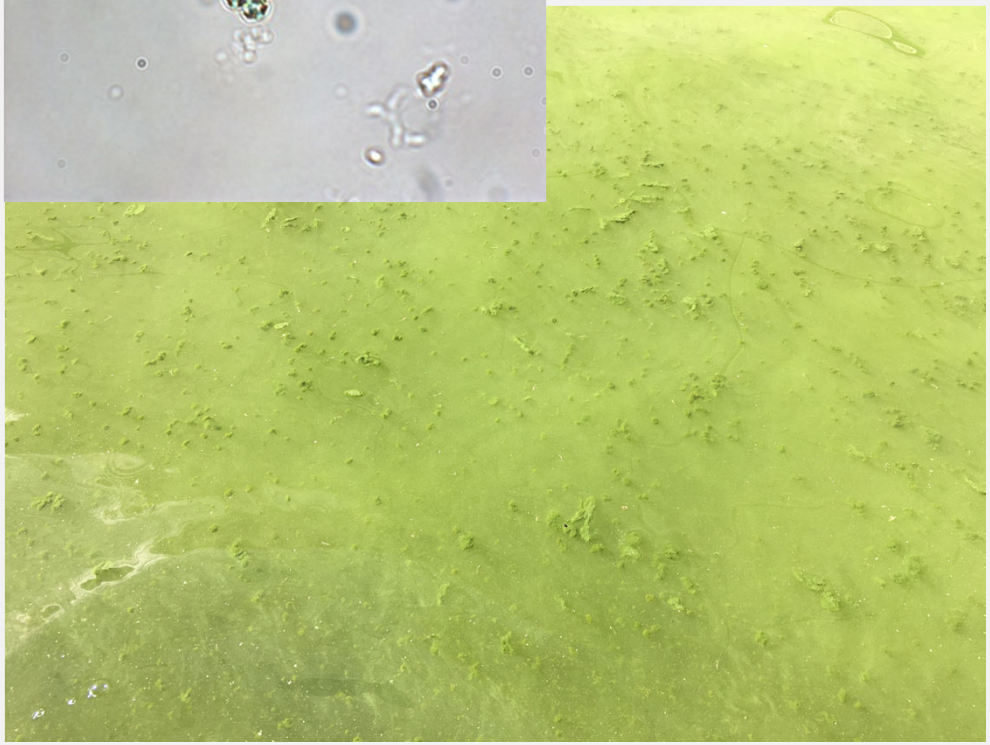


Toxin – cylindrospermopsin, saxitoxin-like

Microcystis

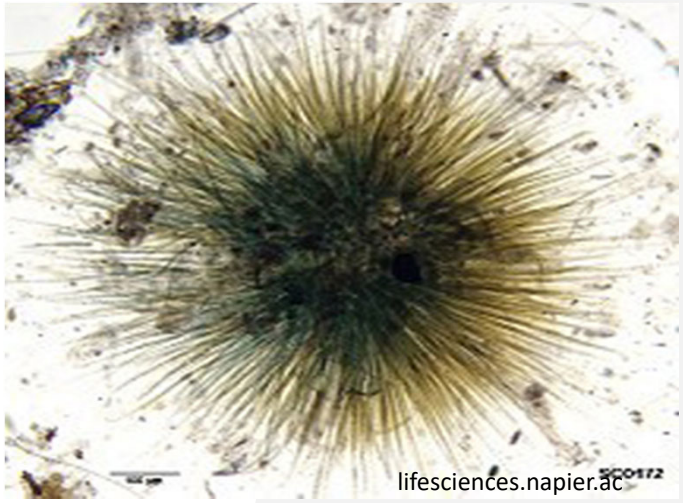




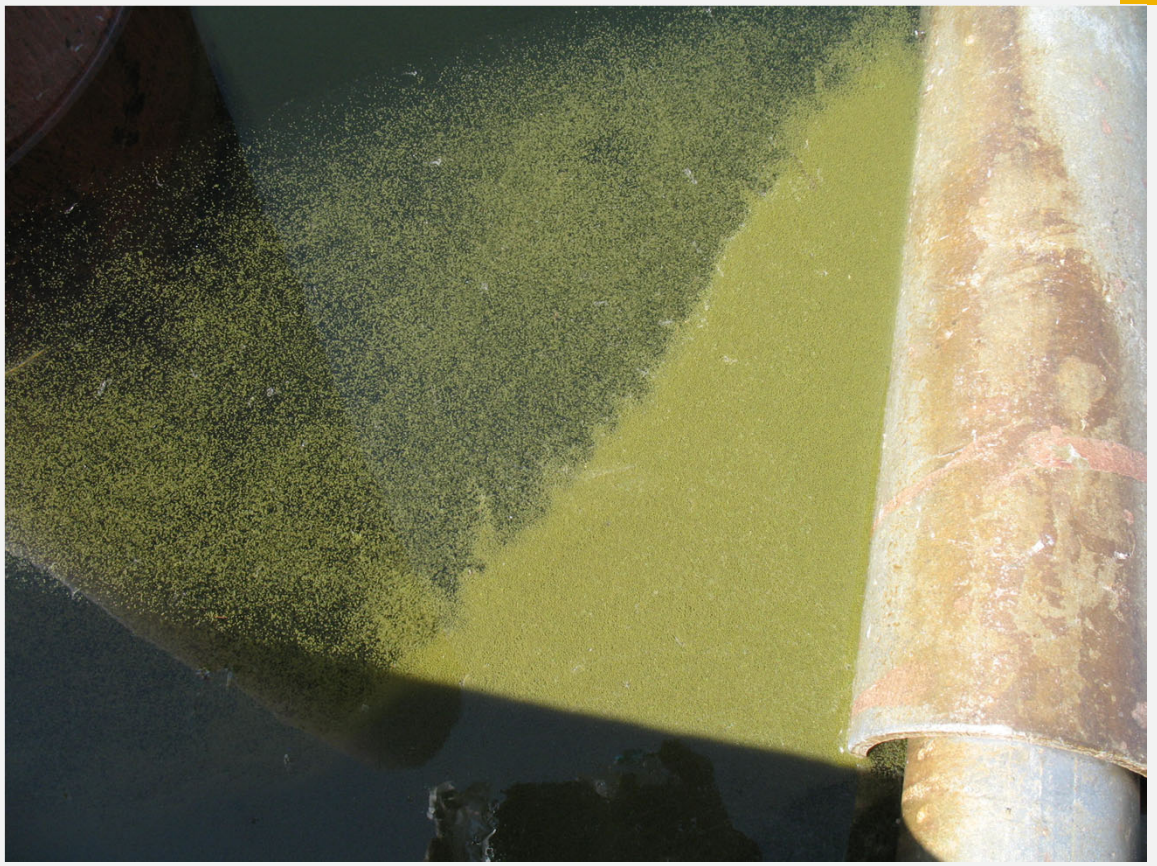


Stores nitrogen – does not fix
Toxin – microcystin, anatoxin

Gleotrichia



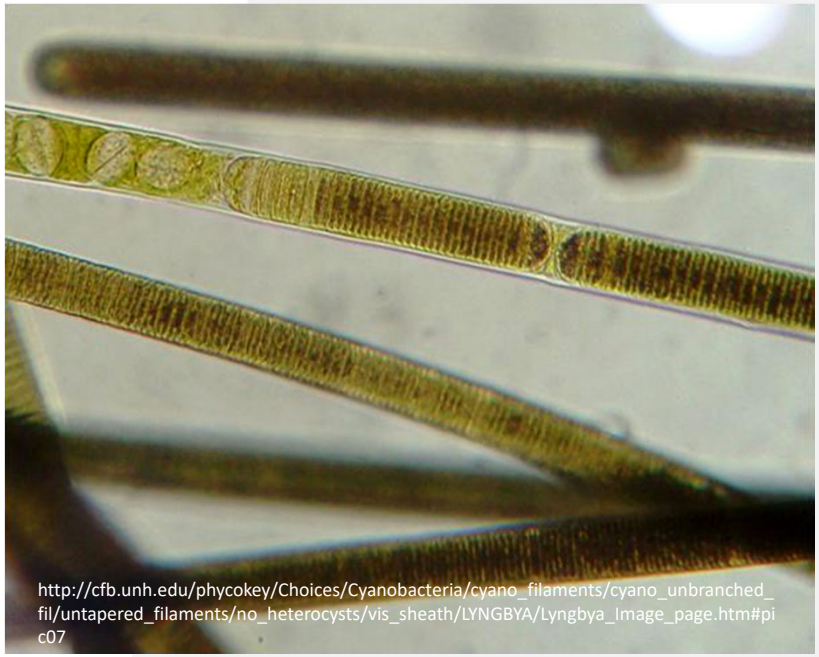
lifesciences.napier.ac.uk



Toxin – microcystin LR

Takes up P from sediments in early spring

Lyngbya



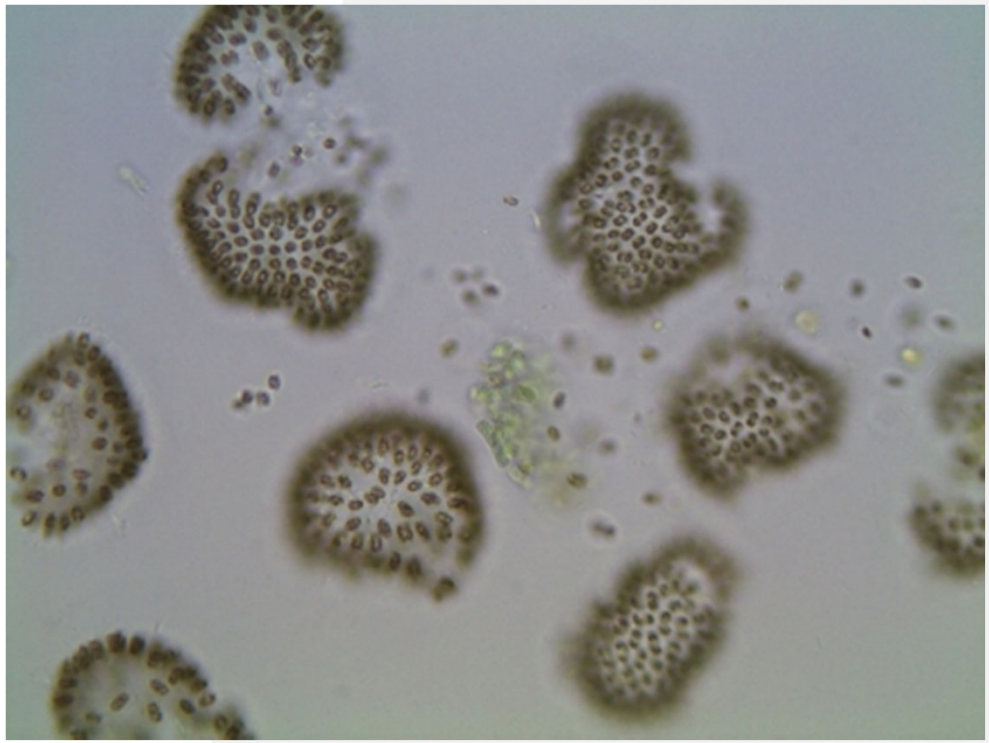
http://cfb.unh.edu/phycokey/Choices/Cyanobacteria/cyano_filaments/cyano_unbranched_fil/untapered_filaments/no_heterocysts/vis_sheath/LYNGBYA/Lyngbya_Image_page.htm#pic07

Entwisle et al. Posted at rbgsyd.nsw.gov.au

Fixes nitrogen without heterocysts – mainly at night when P/S is absent

Toxin – cylindrospermopsin, saxitoxin-like

Woronichinia



Toxin – anatoxin, microcystin

GENUS		
ANABAENA	ENTOPHYSALIS	PULVINULARIA
ANABAENOPSIS	EUCAPSIS	PSEUDANABAENA
APHANIZOMENON	FISCHERELLA	RAPHIDIOPSIS
APHANOCAPSA	GLOEOCAPSA	RHABDODERMA
APHANOTHECE	GLOEOTHECE	RHABDOGLOEA
ARTHROSPIRA	GLOEOTRICHIA	RIVULARIA
AULOSIRA	GOMPHOSPHAERIA	ROMERIA
BORZIA	HAPALOSIPHON	SCHIZOTHRIX
CALOTHRIX	HOMEOTHRIX	SCYTONEMA
CAMPTYLONEMOPSIS	LEMMERMANNIELLA	SNOWELLA
CAPSOSIRA	LYNGBYA	SPHAEROZYGA
CHAMAESIPHON	MASTIGOCLADUS	SPIRULINA
CHROOCOCCUS	MERISMOPEDIA	STICHOSIPHON
CHROOMONAS	MICROCHAETE	STIGONEMA
CRINALIUM	MICROCOLEUS	SYNECHOCOCCUS
COELOSPHAERIUM	MICROCYSTIS	SYNECHOCYSTIS
COLEODESMIUM	MICROCYSTIS culture	TOLYPOTHRIX
CYANOBIUM	NODULARIA	TRICHODESMIUM
CYANOTHECE	NOSTOC	TRICHORMUS
CYLINDROSPERMOPSIS	OSCILLATORIA	WOLLEA
CYLINDROSPERMUM	PLECTONEMA	WORONICHINIA
DACTYLOCOCCOPSIS	PLEUROCAPSA	
DERMOCARPA	PHORMIDIUM	
DICHOTHRIX	PLECTONEMA	

http://cfb.unh.edu/phycokey/Choices/Cyanobacteria/cyano_1page/cyano_key.html

Ecologically – cyanobacteria present carbon bottleneck

Large / colonial – difficult to ingest by zooplankton (large plankters starve)

Toxins have negative effects on zooplankton (although some not affected)

CYANOBACTERIA – TOXINS history

1000 yrs ago General Zhu Ge-Ling reported mortality in troops that drank water from a river in southern China that was green

1878 Australian lakes – livestock deaths

1980's – livestock wildlife deaths in N. Idaho

1993 Idaho – cattle deaths at Cascade

1996 Brazil 52 humans in dialysis unit with contaminated water

2013 New Mexico – 100 Elk – exposure via drinking trough

2014 Toledo, OH drinking water intake shutdown

2017 Lakeview, OR cattle deaths

2018 Salem, OR cyanotoxins in water

CYANOBACTERIA – TOXINS

- Endotoxins
- Cytotoxins
- Hepatotoxins
- Neurotoxins

CYANOBACTERIA – TOXINS

- Endotoxins – Lipopolysaccharides (LPS)

- assoc. with outer membrane
- skin rashes - dermatoxins

CYANOBACTERIA – TOXINS

- Cytotoxins – toxic to cells (necrosis)
  - breakdown of cell membrane

CYANOBACTERIA – TOXINS

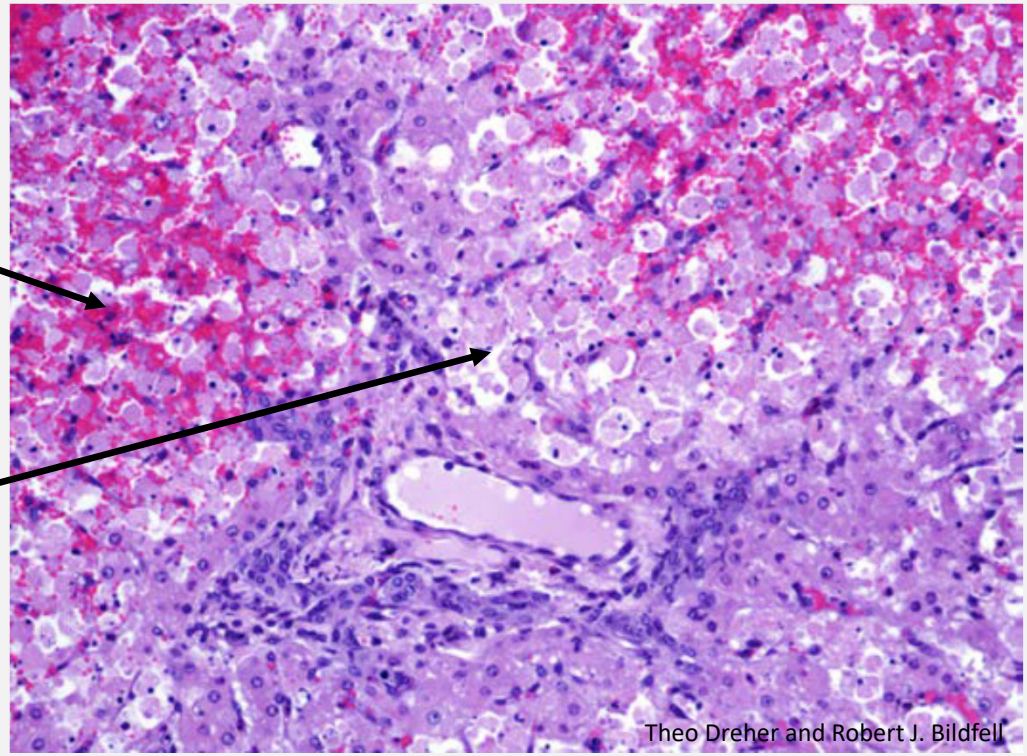
- Hepatotoxin – liver (hemorrhaging)

  - breakdown of cell membrane
  - no antidote

Necrosis in liver cells

Hemorrhage

Necrosis and vacuolation



CYANOBACTERIA – TOXINS

- **Neurotoxins – central nervous system**

  - **Affect 4 major components**
  - ion channels, acetylcholine receptors, synaptic vesicle peptides, and acetylcholine esterase
  - **Respiratory paralysis** (rapid)

Chemical structure of cyanotoxins (modified from Chorus 1999, USEPA 2019)			
Structure	Cyanotoxin	Primary target organ in mammals	Cyanobacteria genera
Cyclic peptides	Microcystins	Liver	*Microcystis*, *Anabaena*, *Planktothrix* (Oscillatoria), *Nostoc*, *Hapalosiphon*, *Anabaenopsis*
	Nodularins	Liver	*Nodularia*
Alkaloids	Anatoxin-a	Central Nervous System Nerve synapse	*Anabaena*, *Planktothrix* (Oscillatoria), *Aphanizomenon*
	Anatoxin-a(S)	Nerve synapse	*Anabaena*
	Cylindrospermopsins	Liver / kidney / lymphoid tissue	*Cylindrospermopsis*, *Aphanizomenon*, *Umezakia*
	Lyngbyatoxin-a	Skin, gastro-intestinal tract	*Lyngbya*
	Saxitoxin	Nerve synapse	*Anabaena*, *Aphanizomenon*, *Lyngbya*, *Cylindrospermopsis*
	Lipopolysaccharides (LPS)	Potential irritant; affects any exposed tissue	All
Polyketides	Aplysiatoxins	Skin	*Lyngbya*, *Schizothrix*, *Planktothrix* (Oscillatoria)
Amino Acid	BMAA	Nervous System	All

Note – on previous slide – those toxins and species highlighted in yellow have been found in Idaho

HUMAN HEALTH EFFECTS

- Rashes
- Hay fever-like reactions
- Flu-like symptoms / nausea
- Gastrointestinal upset (vomiting, diarrhea)
- Death
- Chronic exposure – ↑ cancer rates, ALS etc.

HUMAN HEALTH EFFECTS

- Need to be careful about cause and effect

- BMAA – beta-Methylamino-L-alanine
  - Research suggests linkage to Amyotrophic Lateral Sclerosis (ALS), Parkinsonism Dementia Complex (PDC)

HUMAN HEALTH EFFECTS

Torbick et al. 2017. Assessing Cyanobacterial Harmful Algal Blooms as Risk Factors for Amyotrophic Lateral Sclerosis. Neurotox Res (2018) 33:199–212

Caller, et al. 2012. Spatial clustering of Amyotrophic lateral sclerosis and the potential role of BMAA. Amyotrophic Lateral Sclerosis 13:25–32.

Caller, et al. 2009. A cluster of Amyotrophic lateral sclerosis in New Hampshire: A possible role for toxic cyanobacteria blooms. Amyotrophic Lateral Sclerosis 10:101–08.

HUMAN HEALTH EFFECTS

Chernoff et al. 2017. A critical review of the postulated role of the nonessential amino acid, β-N-methylamino-L-alanine, in neurodegenerative disease in humans. Journal of Toxicology and Environmental Health, Part B, DOI: 10.1080/10937404.2017.1297592

- call attention to 'issues' in previous studies

- mainly cautionary about cause / effect, not enough data to conclusively establish linkages

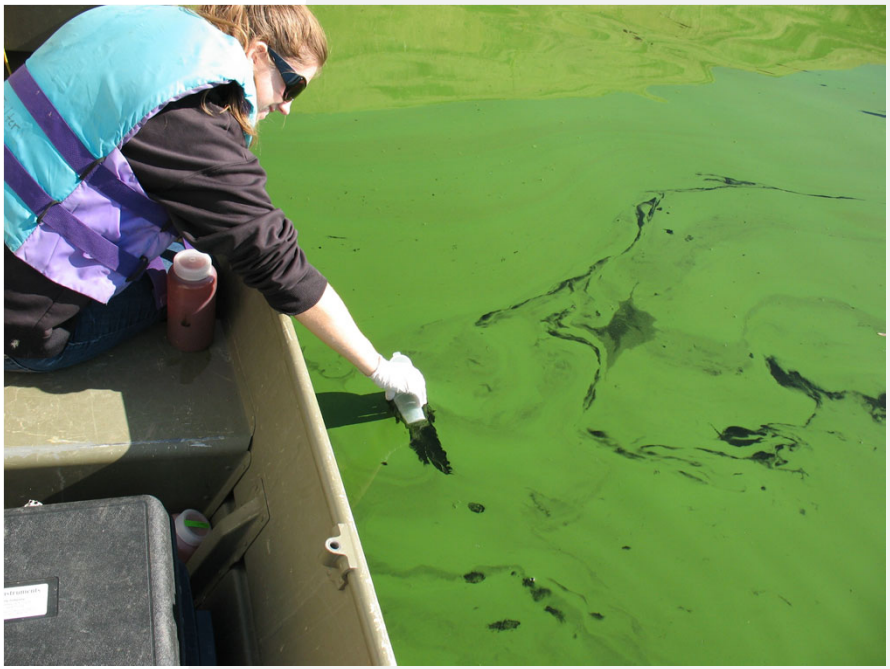
HUMAN HEALTH EFFECTS

Many confounding factors obscure direct link between cyanotoxins and human illness (esp. at chronic level)

Most incidences are retrospective analyses

Potential for serious health consequences

CONDITIONS THAT PRODUCE BLOOMS



CONDITIONS THAT PRODUCE BLOOMS

- Some indication of increase of incidence
- Warm stagnant water
- Nutrient imbalances

Trophic state (continuum)

Oligo- **Meso-** **Eutrophic**

Eutrophication

- **presence of excess nutrients that stimulate aquatic plant growth** (Schindler et al. 2008)

Natural trajectory of lakes

- Oligotrophy to eutrophy

"Natural eutrophication"

Tens of thousands of years…

Cultural eutrophication

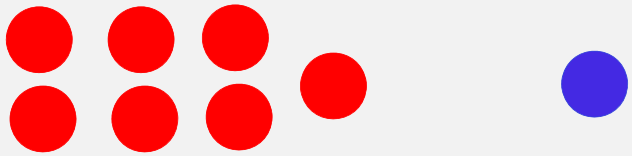
- accelerated natural process via human activities
-
-

Most concerned about:

Nitrogen and Phosphorus

N:P

7:1 = balanced

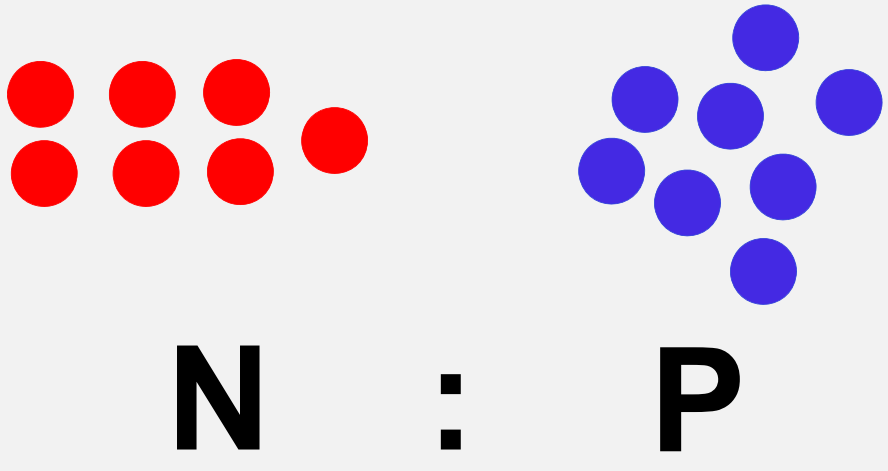


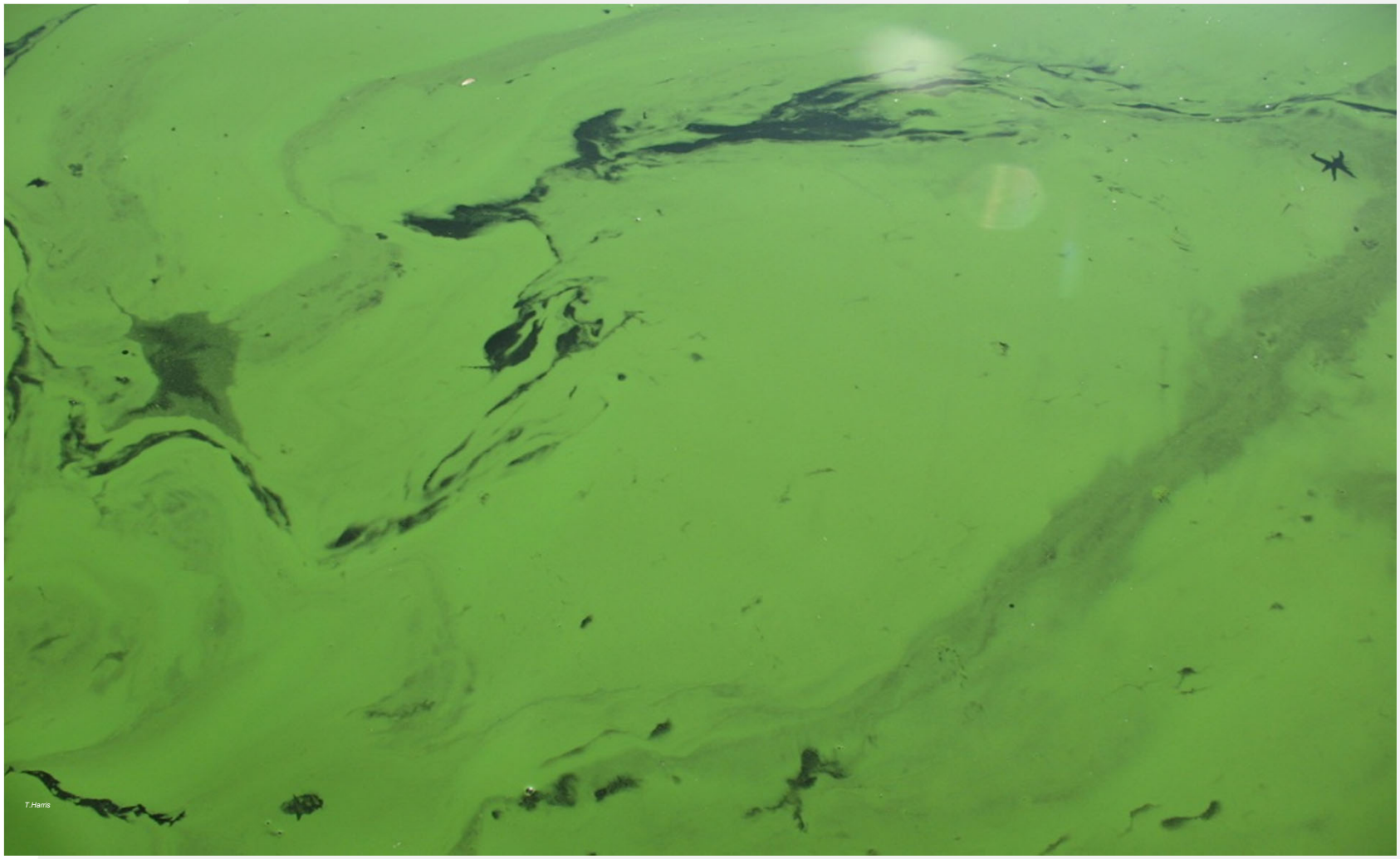
N:P ratio

- **Theoretically**
  N:P > 7 = P-limited - OK

N:P ratio

- Theoretically
  N:P > 7 = P-limited - OK
  N:P < 7 = N-limited - problems



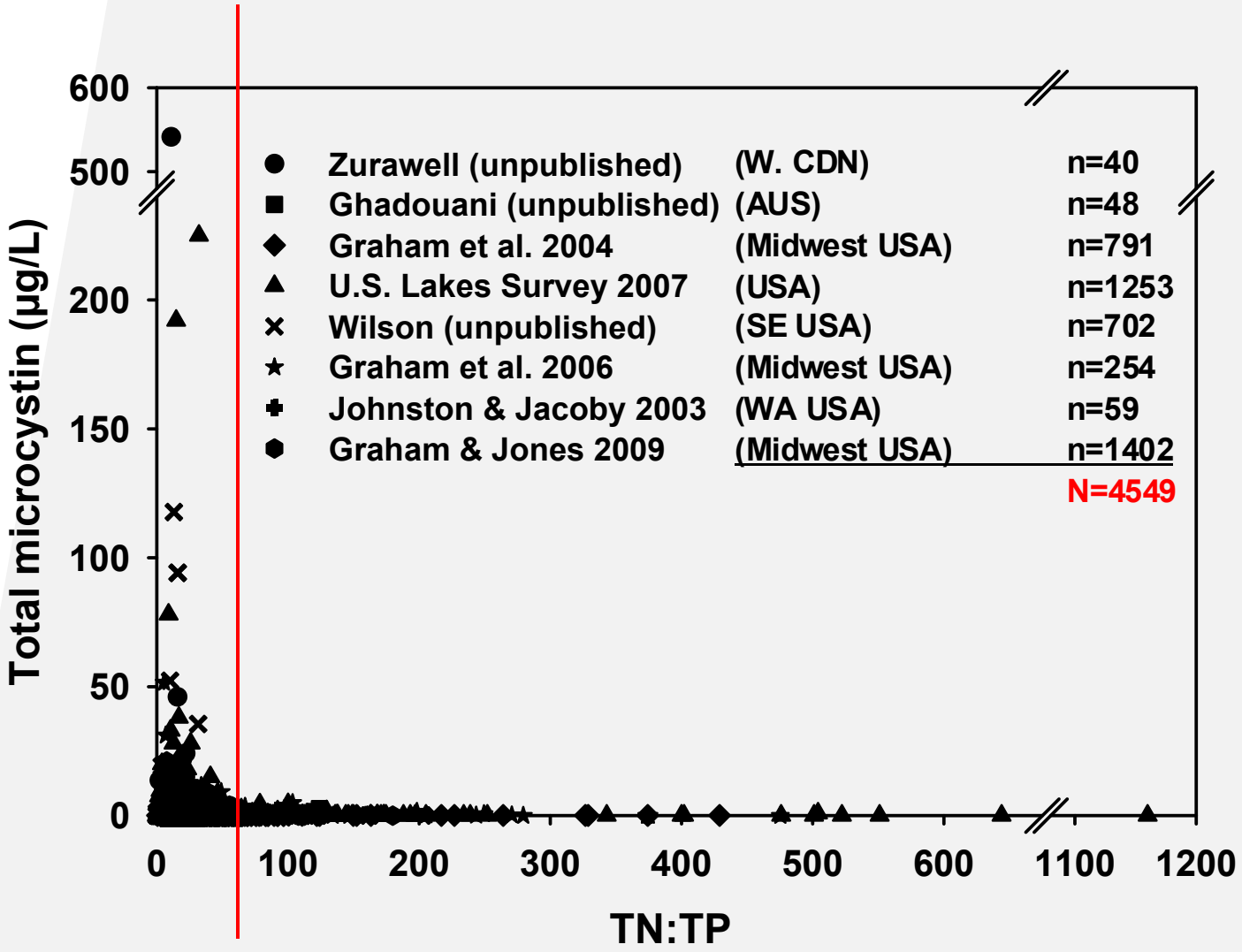

T.Harris

Low N:P ratio

- Favors cyanobacteria
- Ability to fix N from atmosphere
- Can overcome N-limitation

N:P ratio

- In reality, cyanobacteria blooms and toxins occur when N:P is 75:1 or less


Total microcystin (µg/L)
600
500
200
150
100
50
0
0
100
200
300
400
500
600
1100
1200
TN:TP
Zurawell (unpublished) (W. CDN) n=40
Ghadouani (unpublished) (AUS) n=48
Graham et al. 2004 (Midwest USA) n=791
U.S. Lakes Survey 2007 (USA) n=1253
Wilson (unpublished) (SE USA) n=702
Graham et al. 2006 (Midwest USA) n=254
Johnston & Jacoby 2003 (WA USA) n=59
Graham & Jones 2009 (Midwest USA) n=1402
N=4549

Need dual approach

i. Reduce anthropogenic load

ii. In-lake management

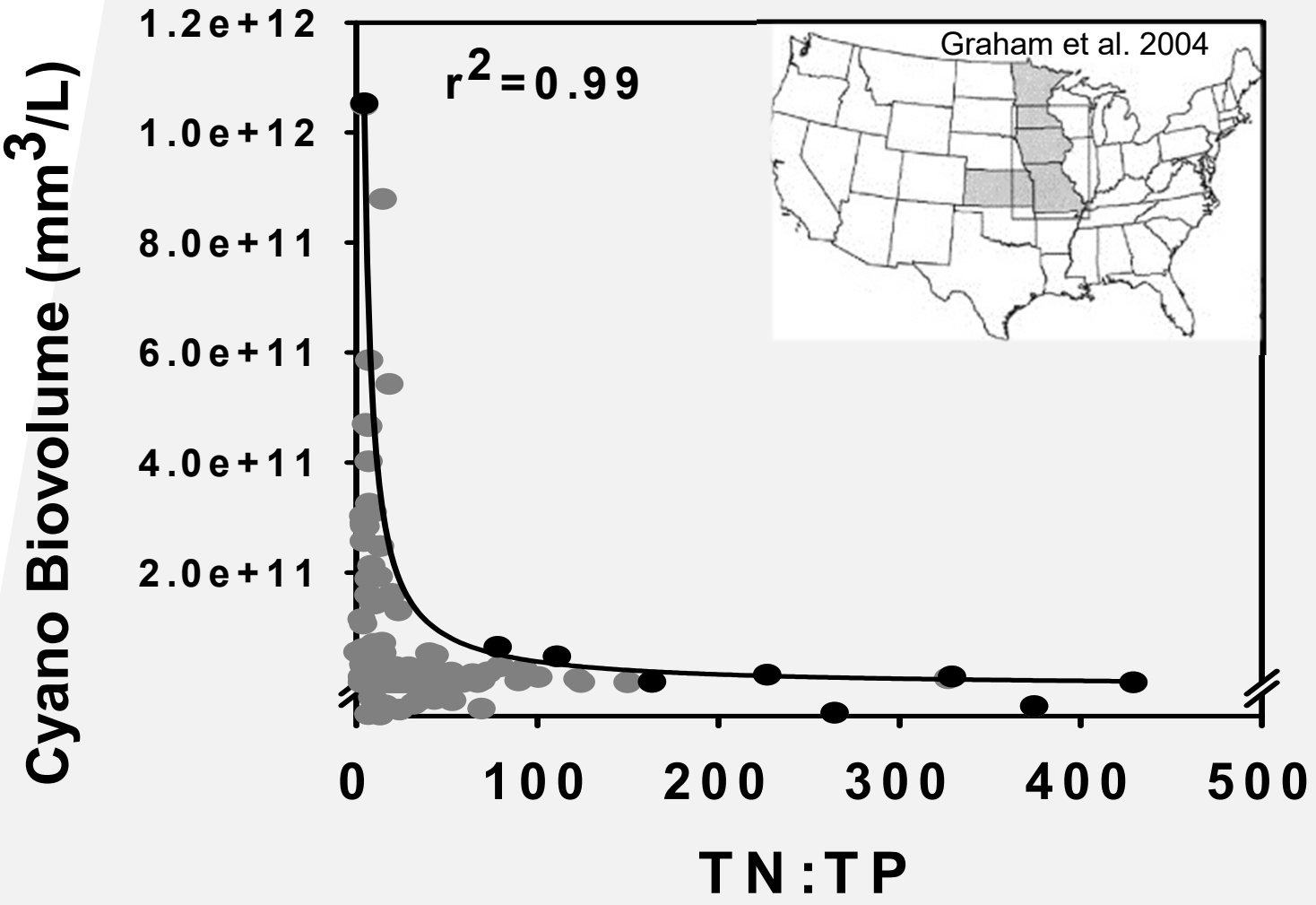
drop out P

or add N

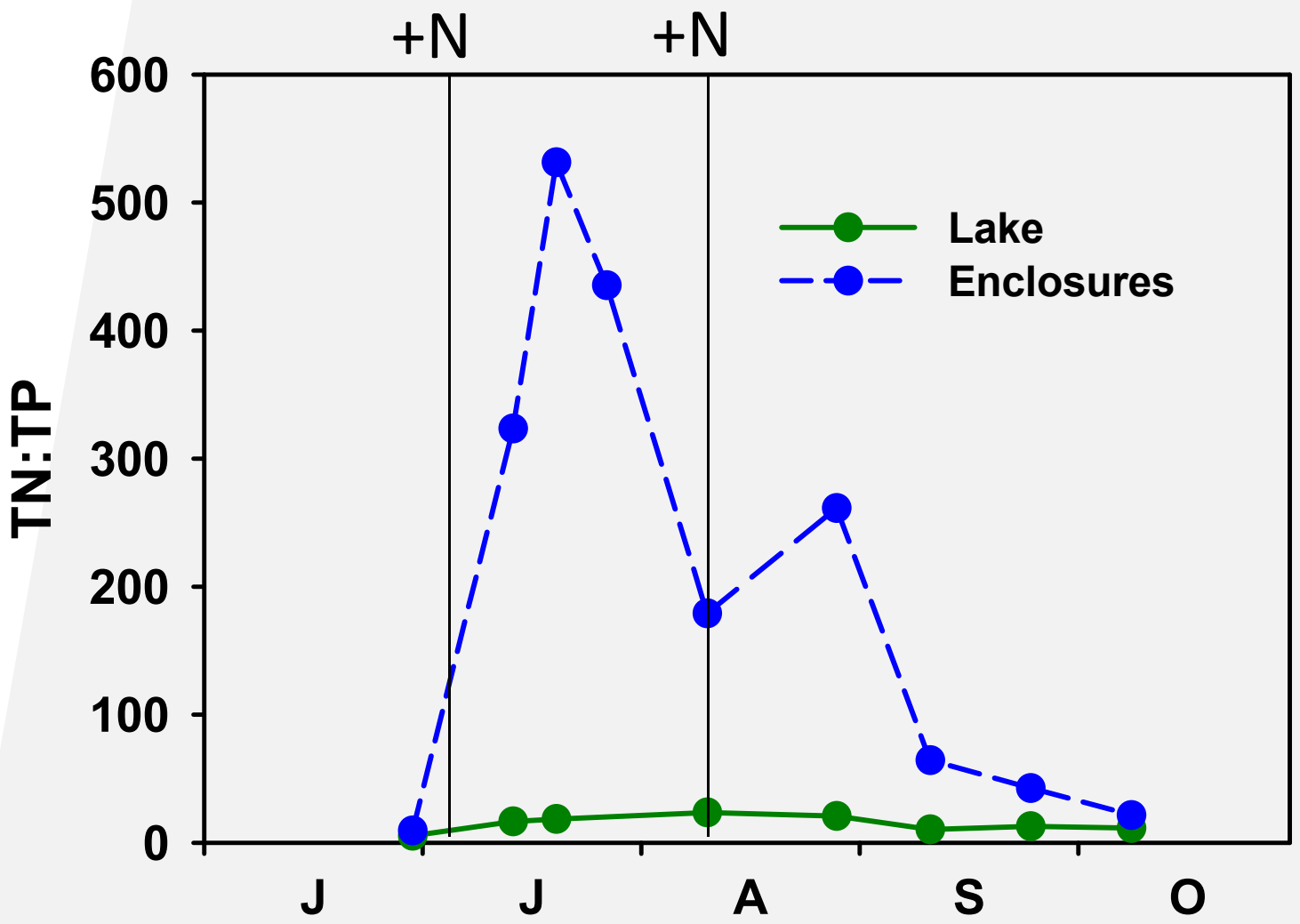
Add N – a nutrient

- considered a pollutant under CWA

- consider only for systems that are firmly in eutrophic state


Cyano Biovolume (mm3/L)
1.2e+12
1.0e+12
8.0e+11
6.0e+11
4.0e+11
2.0e+11
r2=0.99
Graham et al. 2004
0
100
200
300
400
500
TN:TP

Mesocosms


+N
+N
600
500
400
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200
100
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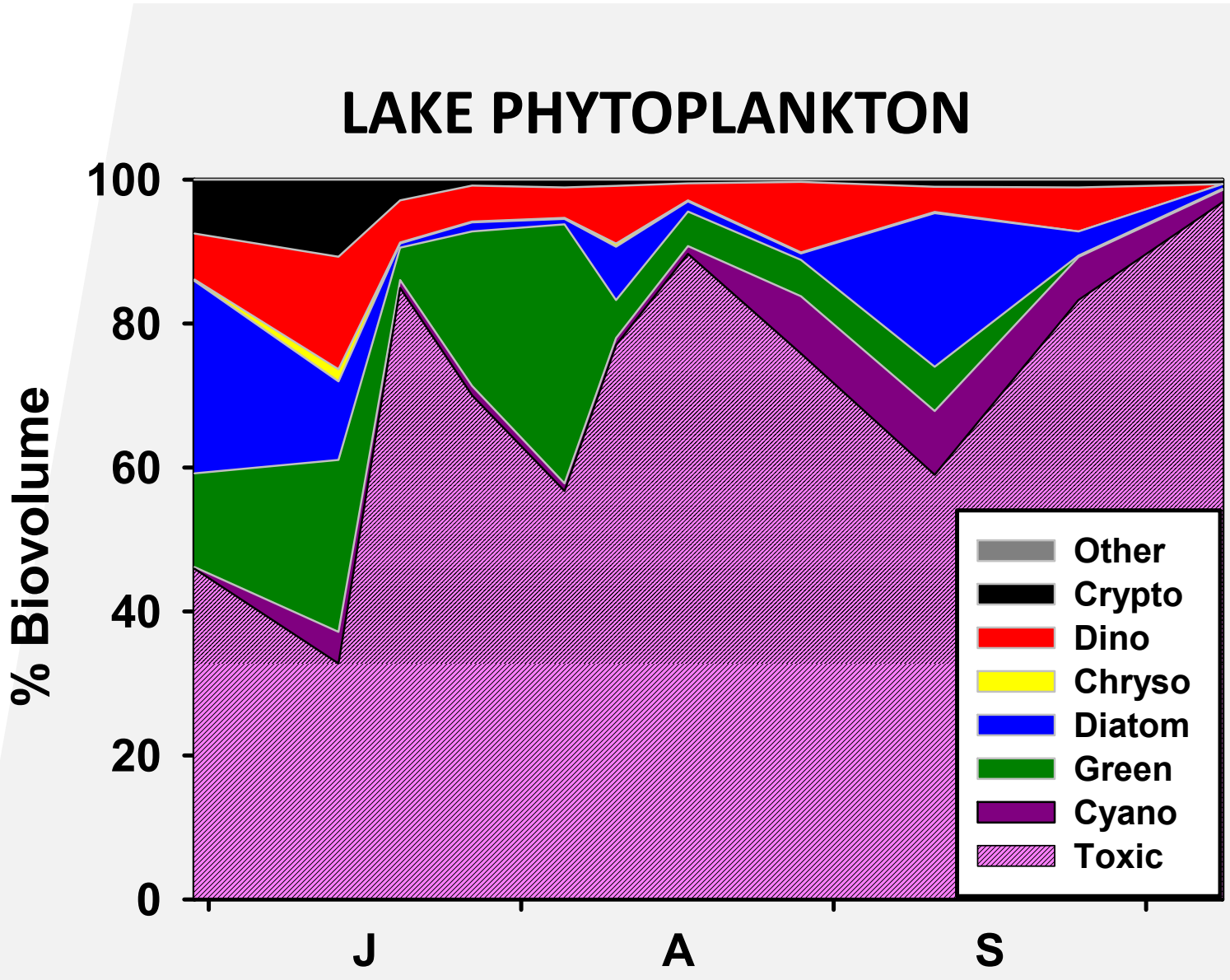
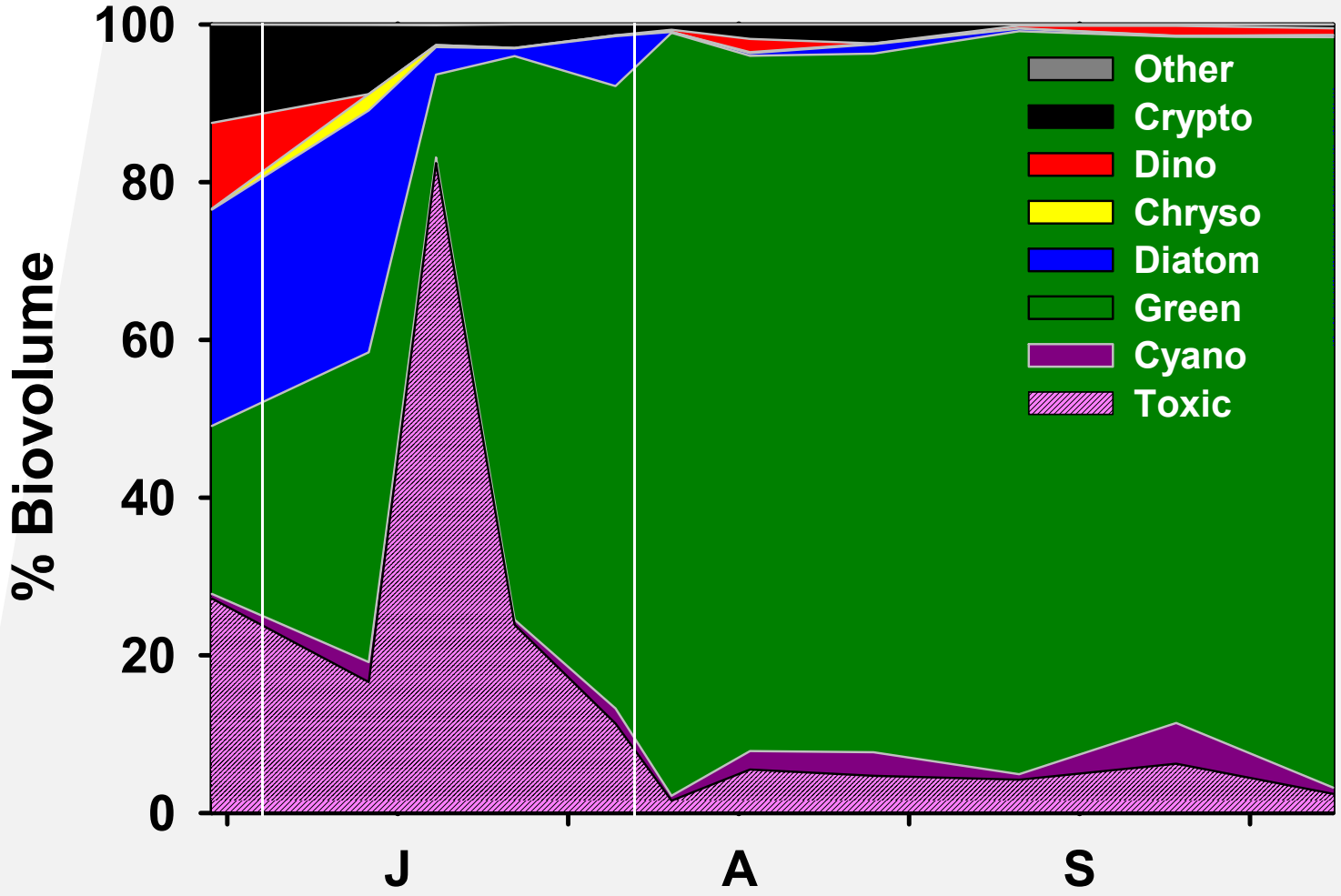
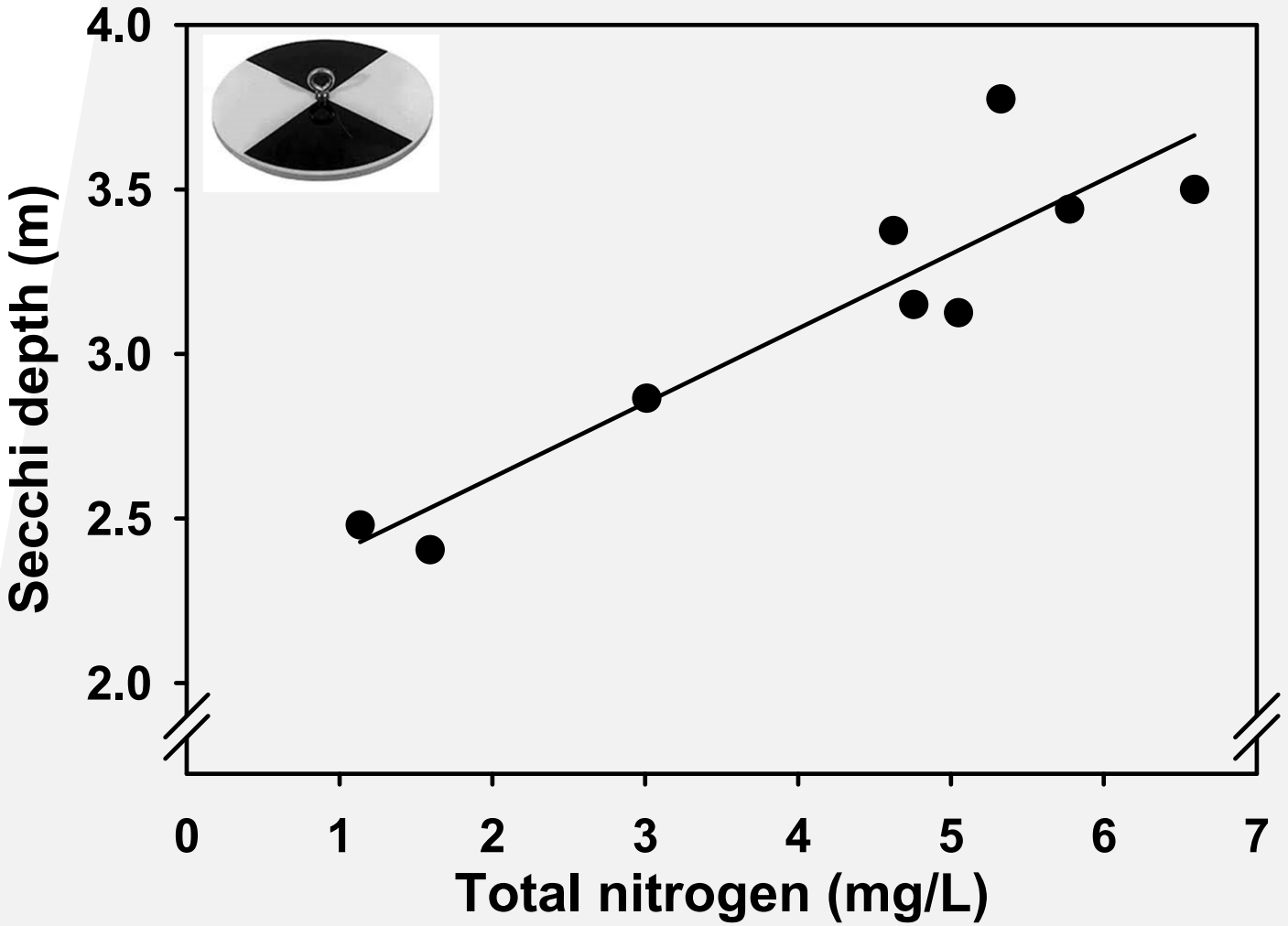
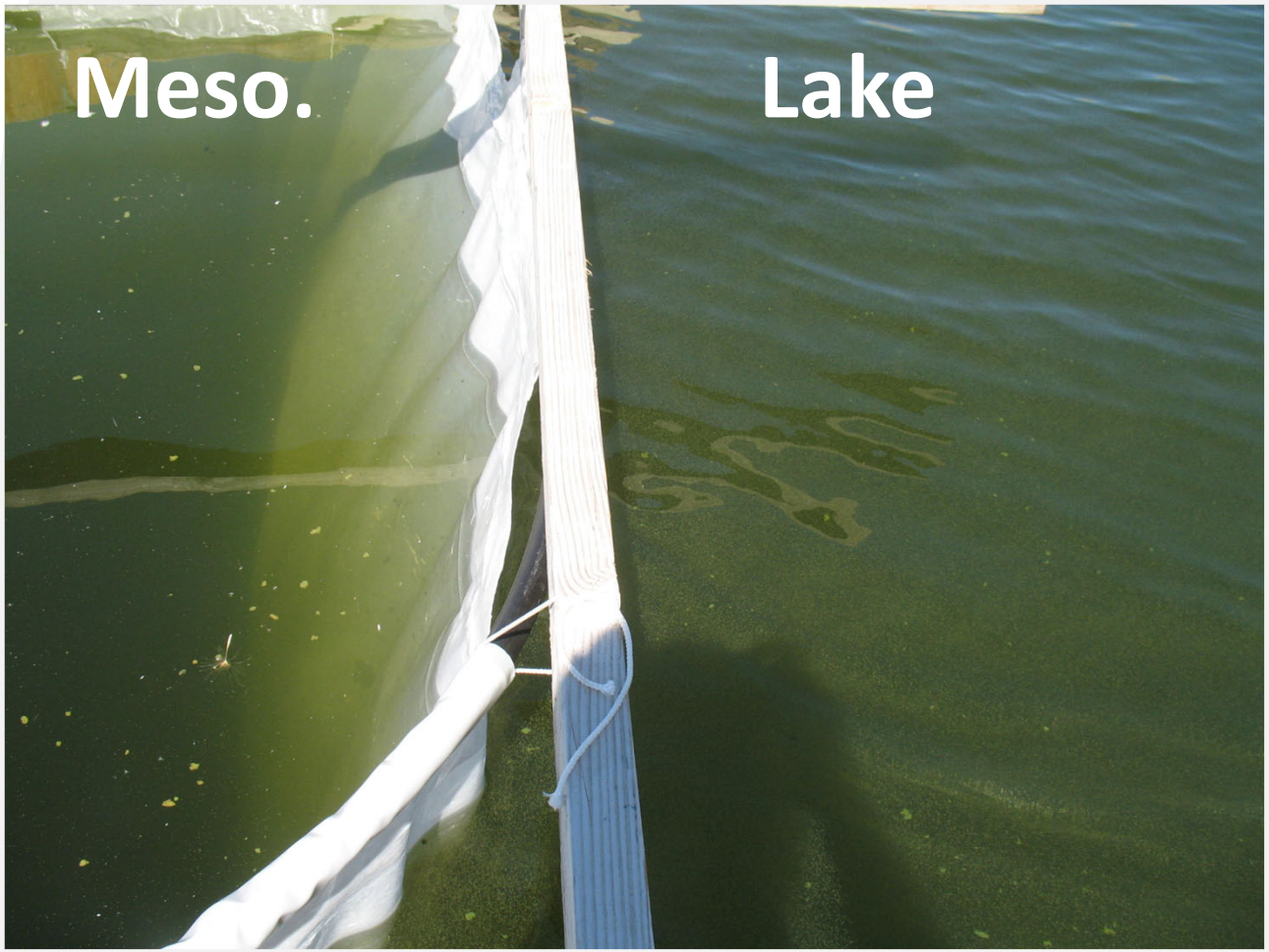
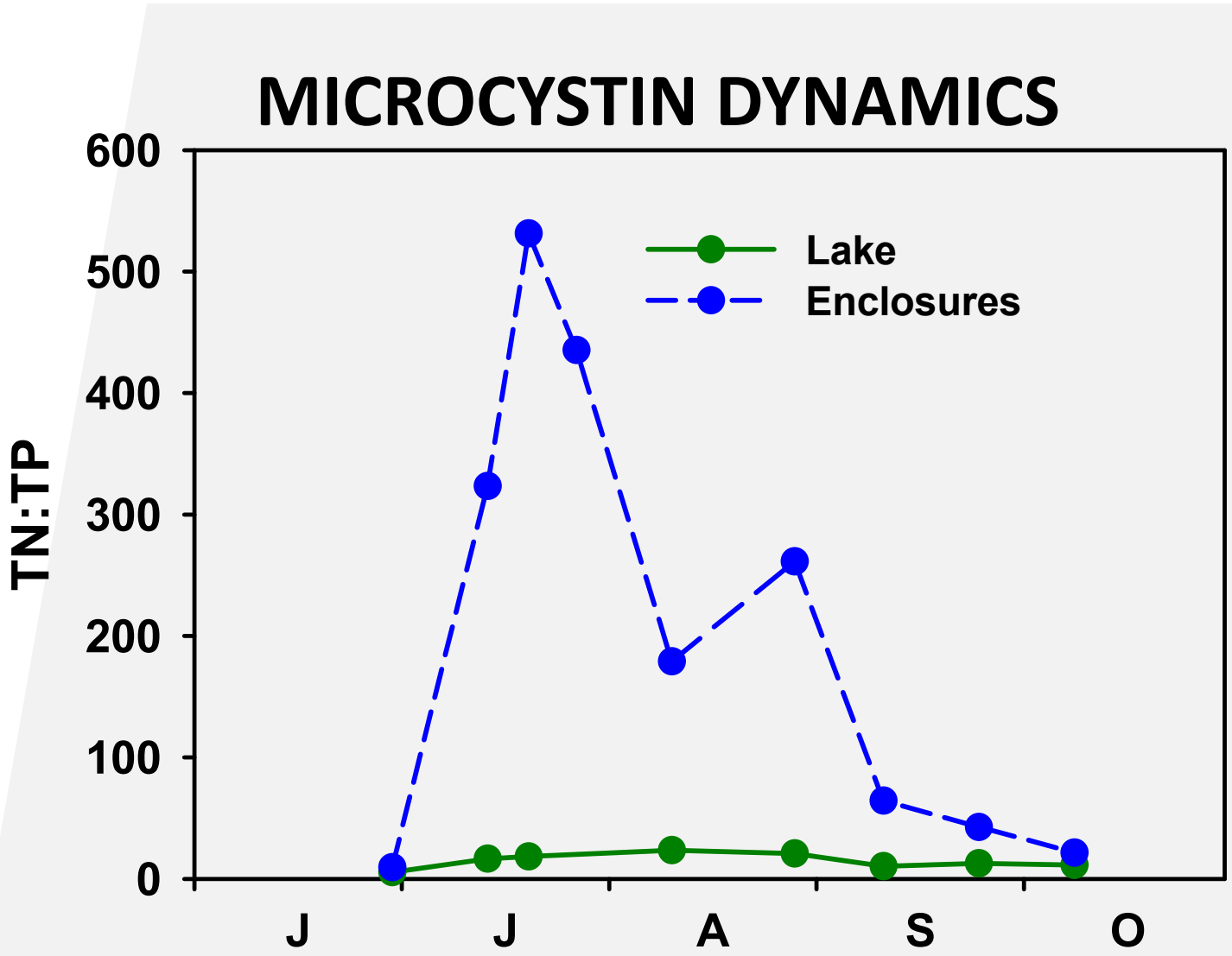
TN:TP
Lake
Enclosures
J
J
A
S
O

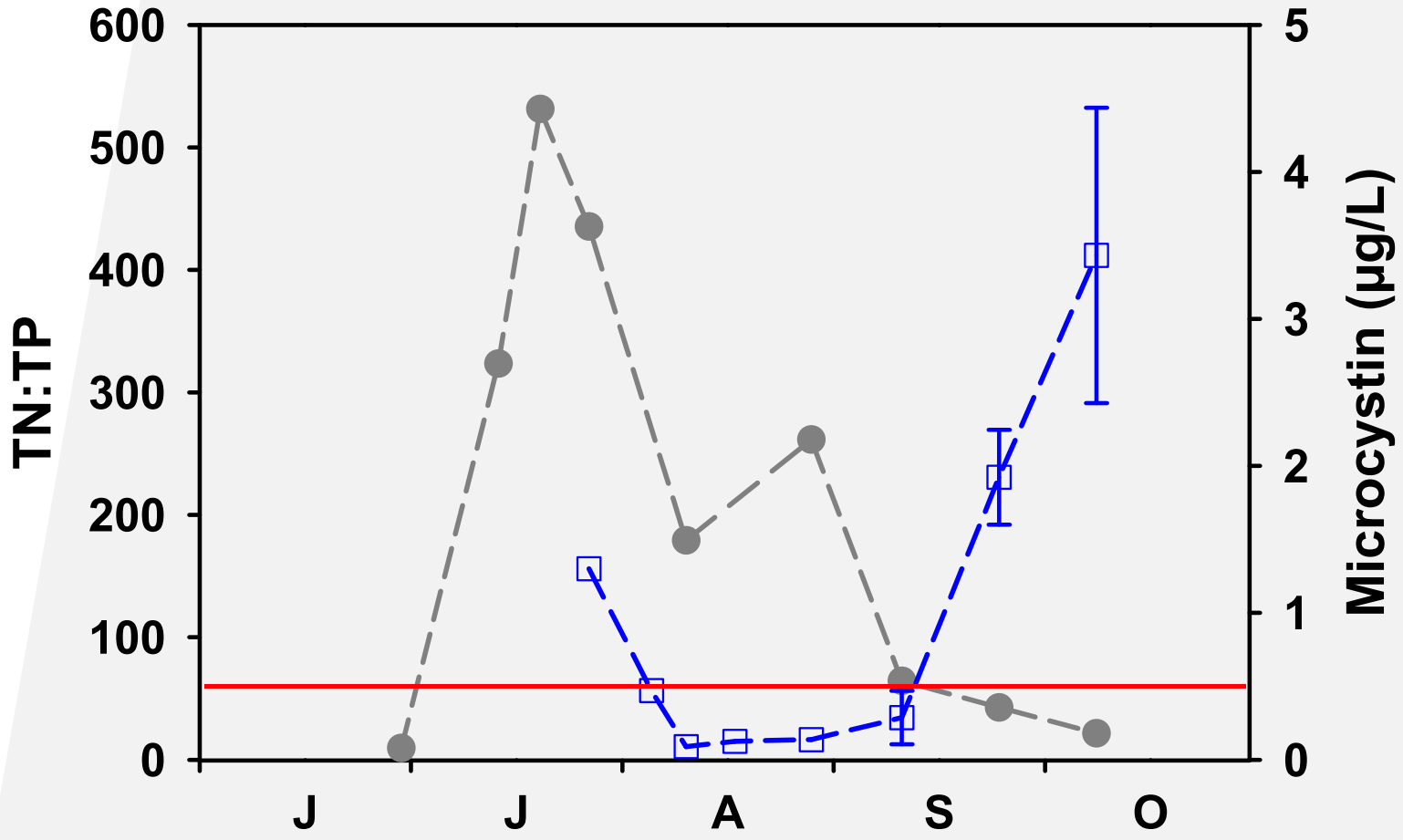

LAKE PHYTOPLANKTON
% Biovolume
100
80
60
40
20
0
J
A
S
Other
Crypto
Dino
Chryso
Diatom
Green
Cyano
Toxic


MESOCOSM PHYTOPLANKTON
% Biovolume
100
80
60
40
20
0
J
A
S
Other
Crypto
Dino
Chryso
Diatom
Green
Cyano
Toxic


4.0
3.5
3.0
2.5
2.0
Secchi depth (m)
0
1
2
3
4
5
6
7
Total nitrogen (mg/L)


Meso.
Lake


MICROCYSTIN DYNAMICS
TN:TP
600
500
400
300
200
100
0
J
J
A
S
O
Lake
Enclosures

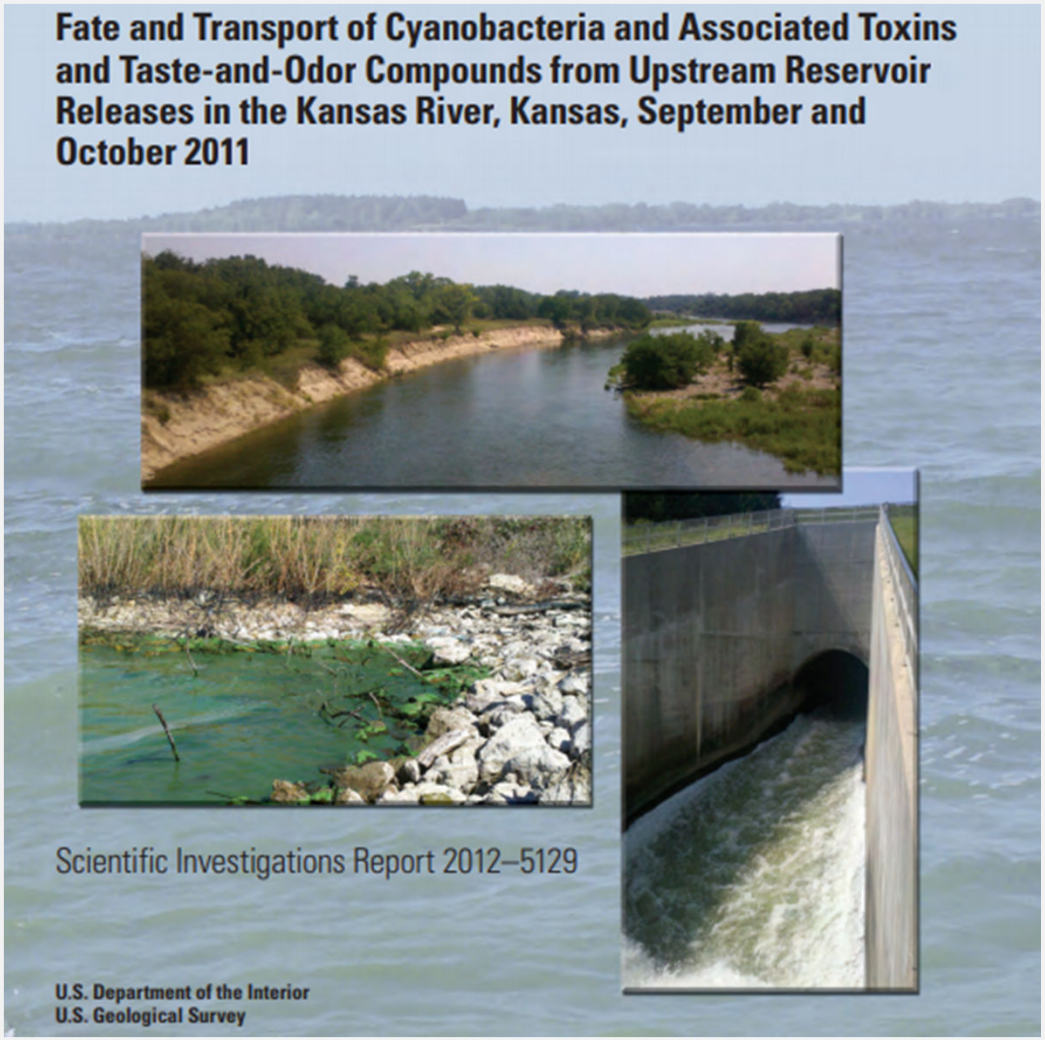

600
500
400
300
200
100
0
TN:TP
5
4
3
2
1
0
Microcystin (µg/L)
J
J
A
S
O

IN-LAKE ADDITIONS OF N ARE SUCCESSFUL

- Dworshak Reservoir, ID
- Kootenay Lake, BC
- Various other BC lakes, rivers

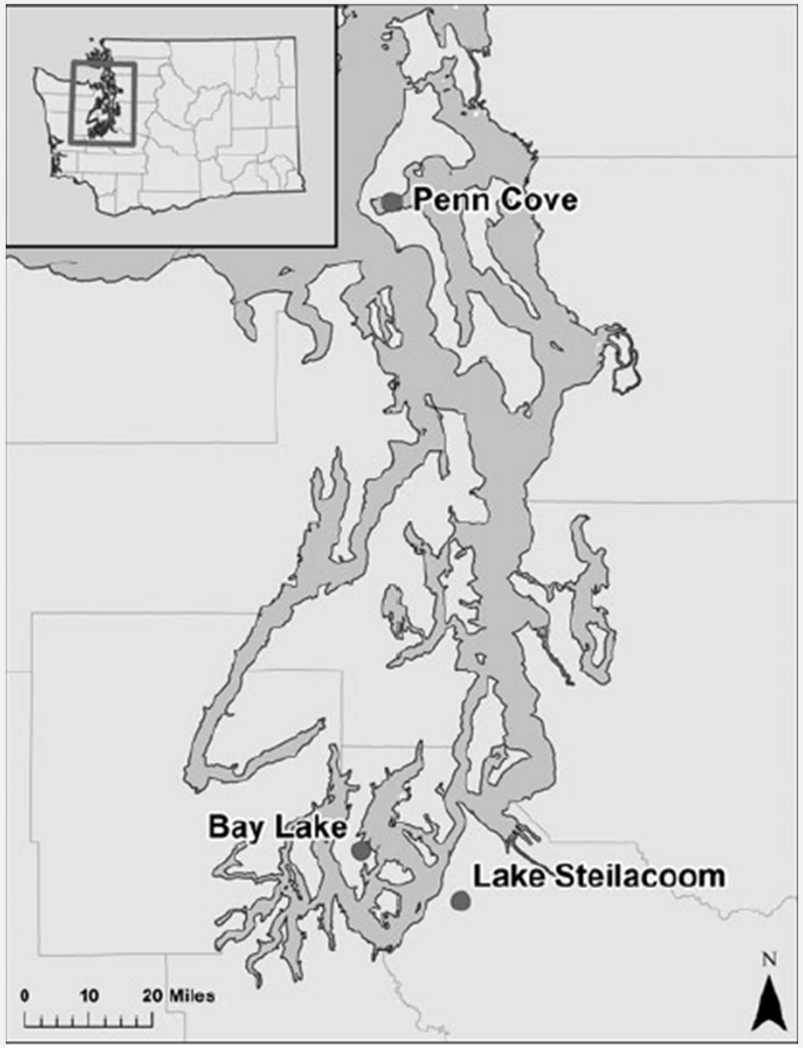
CYANOBACTERIA / TOXINS IN LONG-RANGE TRANSPORT, AND IN IRRIGATION WATERS

Toxins measured 173 miles downstream

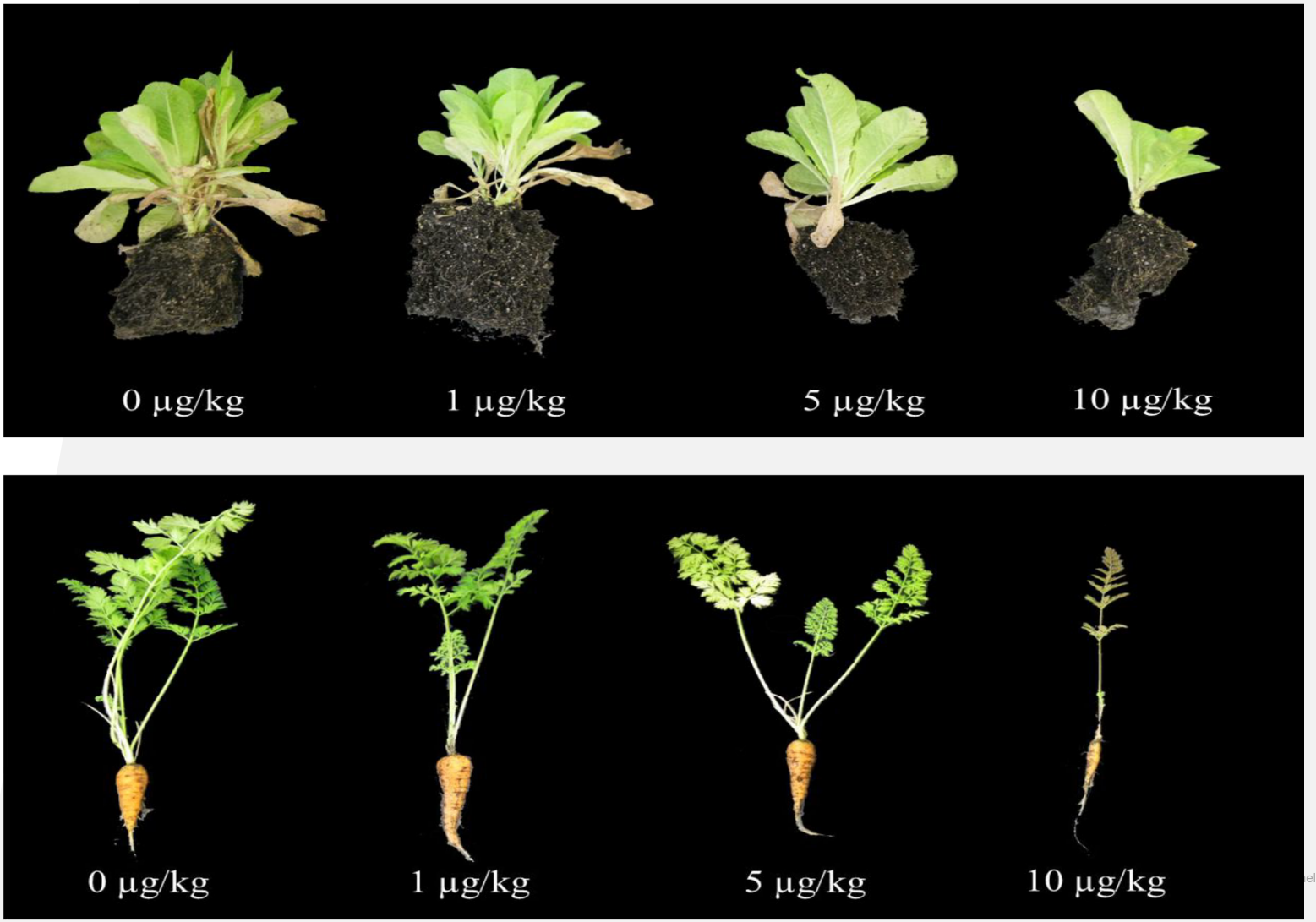


Graham et al. 2012

Pacific blue mussels (*Mytilus trossulus*) exposed to freshwater discharges from lakes with CyanoHABs were found to contain toxins.



(Preece et al., 2015a, 2015b)



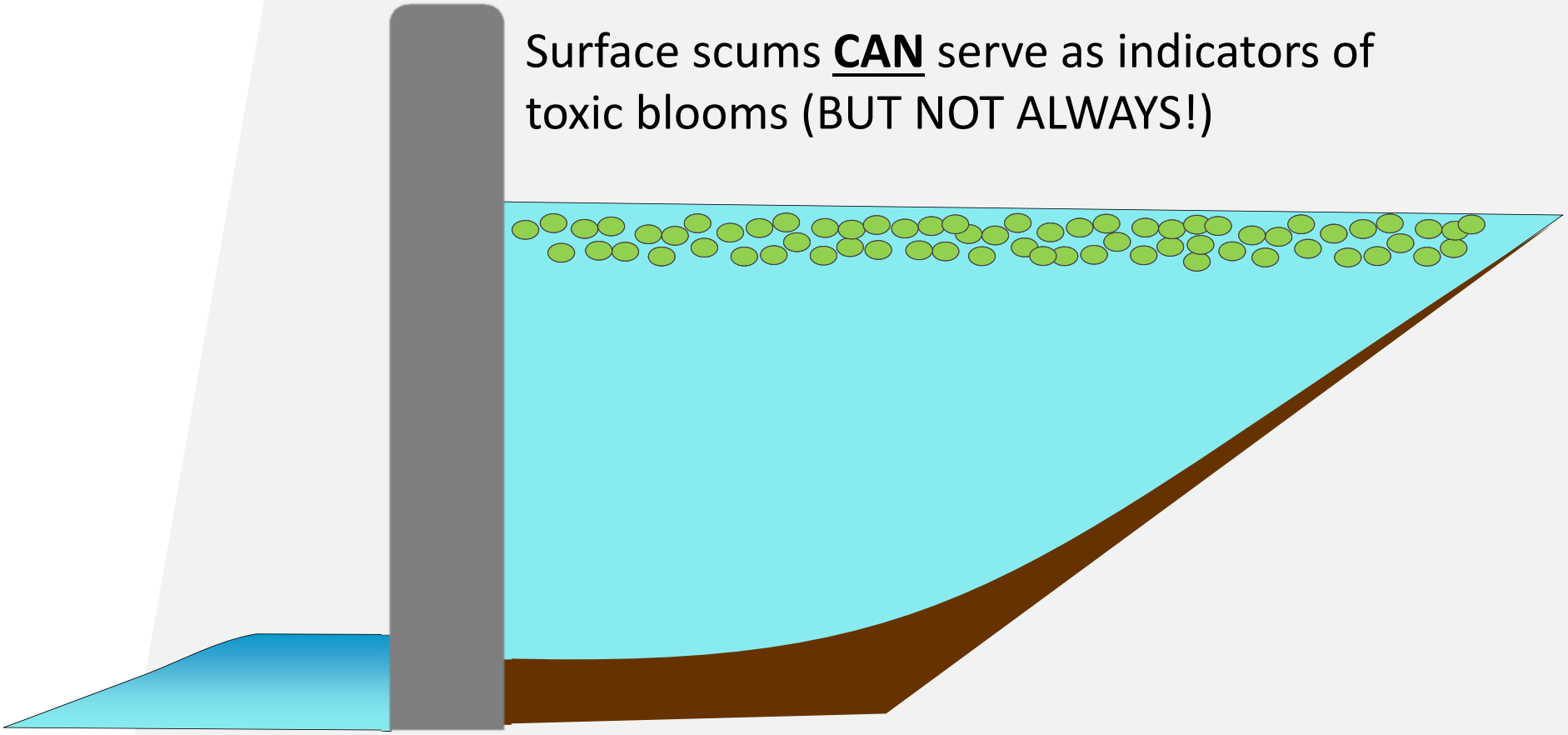
(Lee et al. 2017)

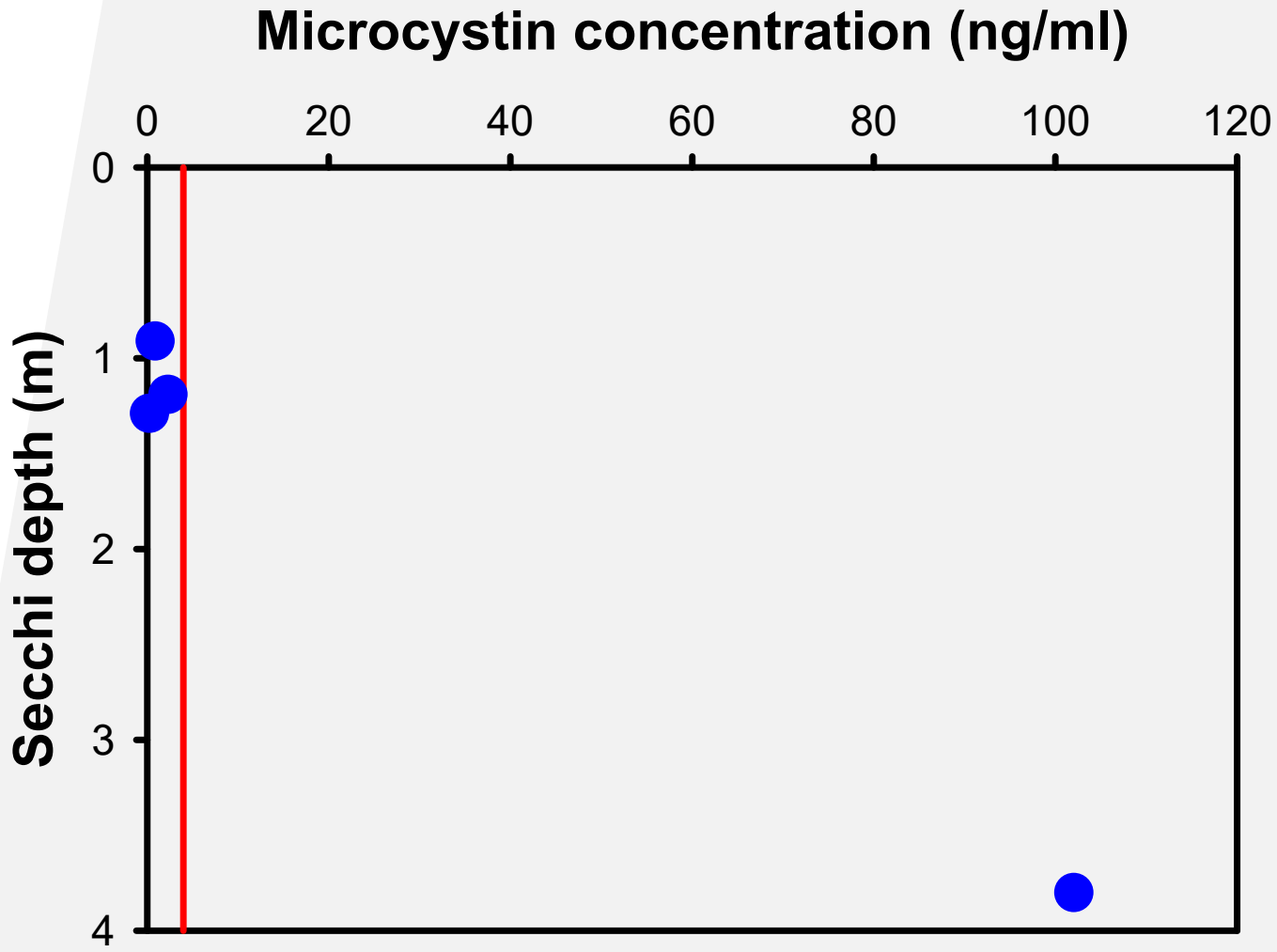
SPATIAL AND VERTICAL DISTRIBUTION OF CYANOBACTERIA

2016-06-17 06:44:33

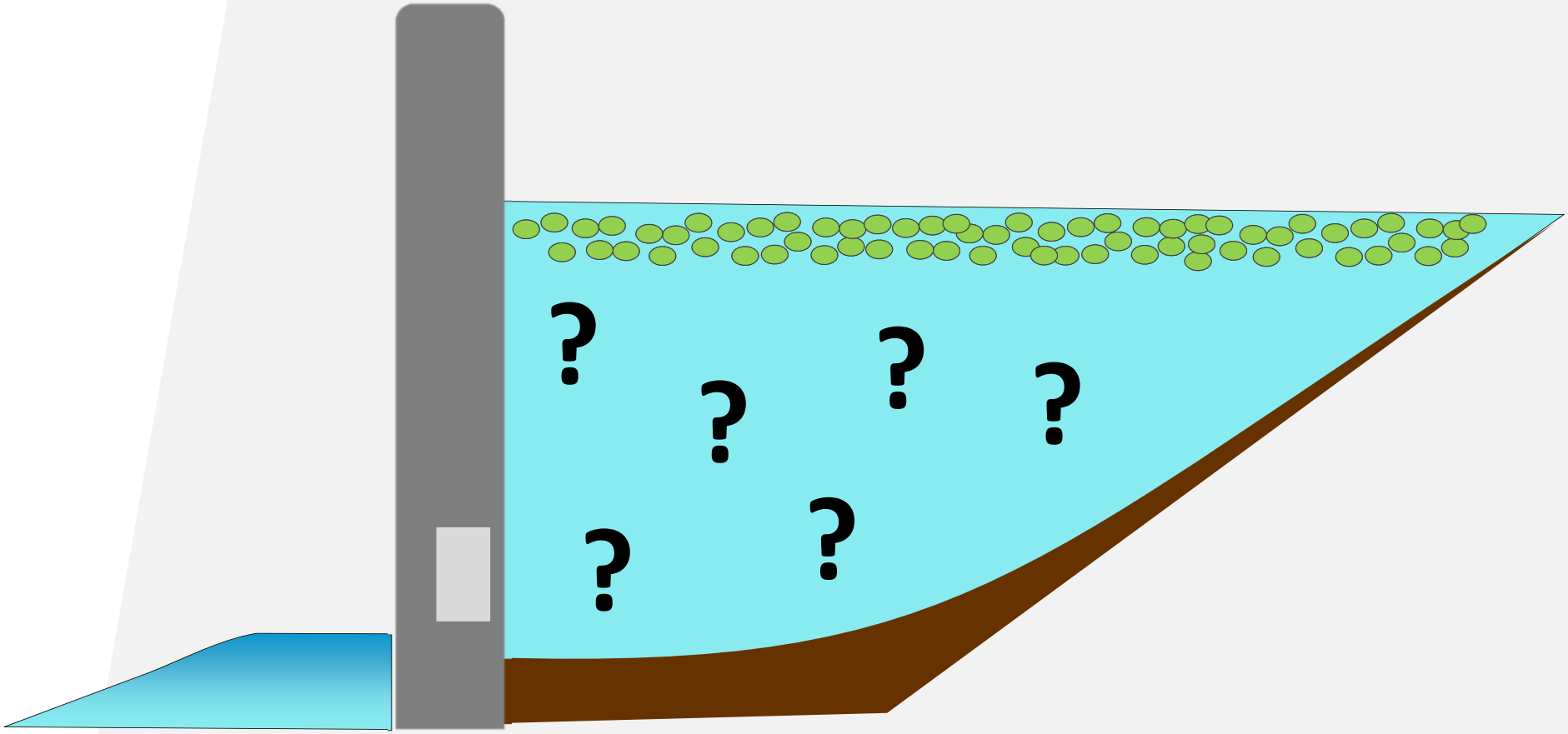
Best practices for toxin monitoring

Surface scums **CAN** serve as indicators of toxic blooms (BUT NOT ALWAYS!)

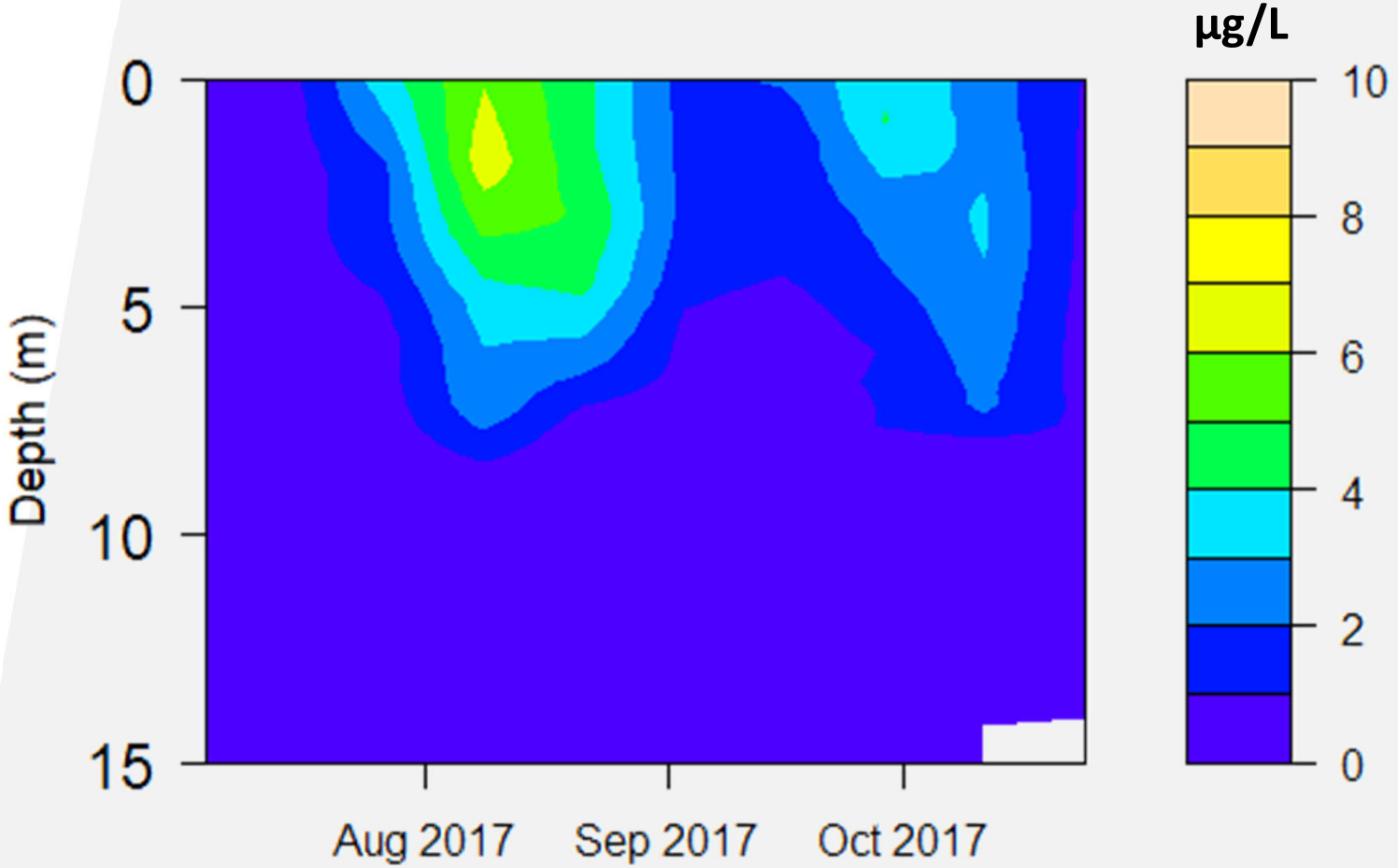



Microcystin concentration (ng/ml)
0
20
40
60
80
100
120
Secchi depth (m)
0
1
2
3
4

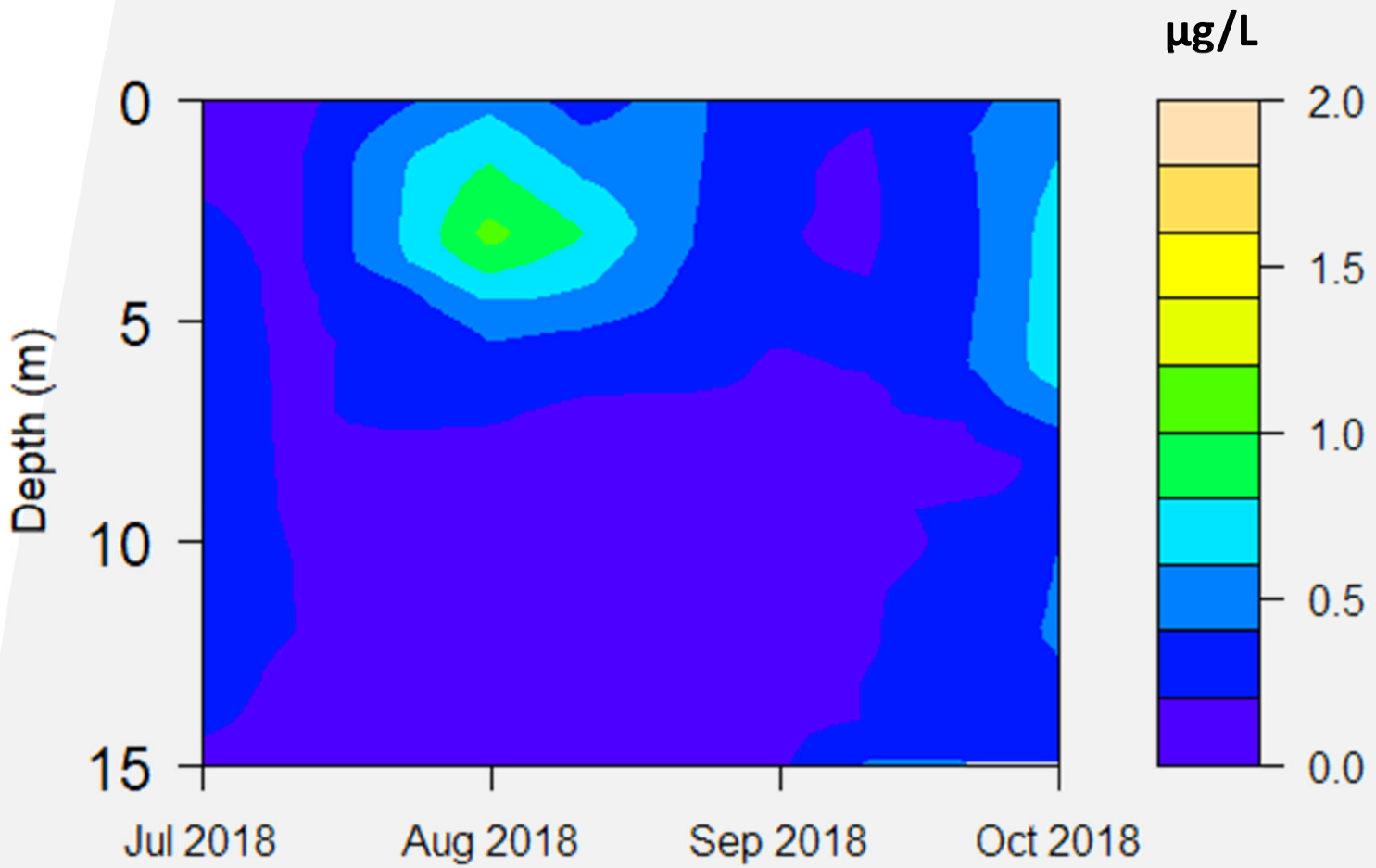
What is depth distribution of blooms and toxins?



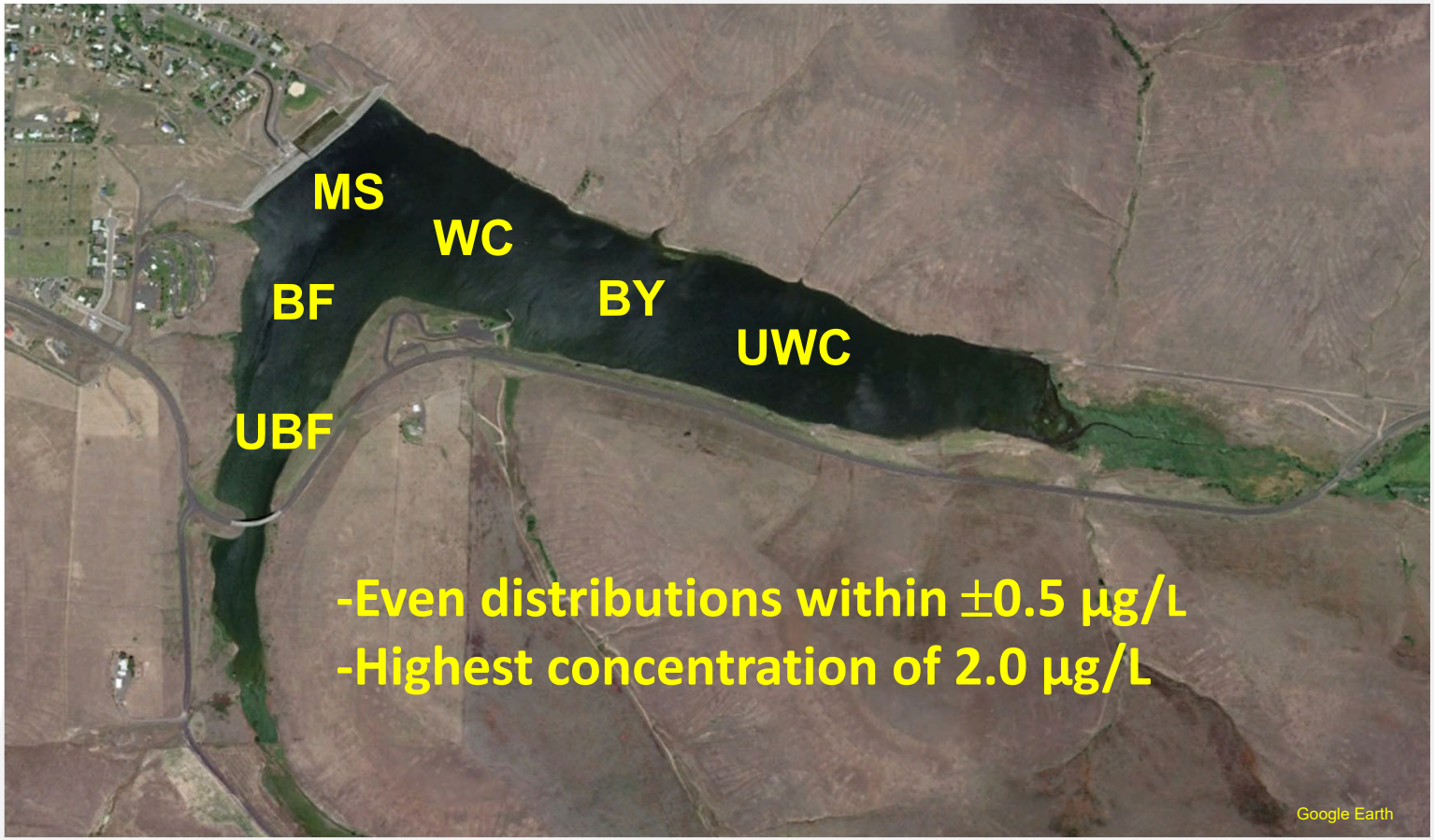
2017 toxin results



2018 toxin results



Toxin concentrations across surface (2018)



SPATIAL AND VERTICAL DISTRIBUTION OF CYANOBACTERIA

Toxins occur at depth

Scums good indicator of toxins (but not always)

Scums are highly mobile

Err on side of caution – sample scum

Questions?