HABs: Understanding nutrient drivers and low-tech mitigation strategies

Silvia Newell

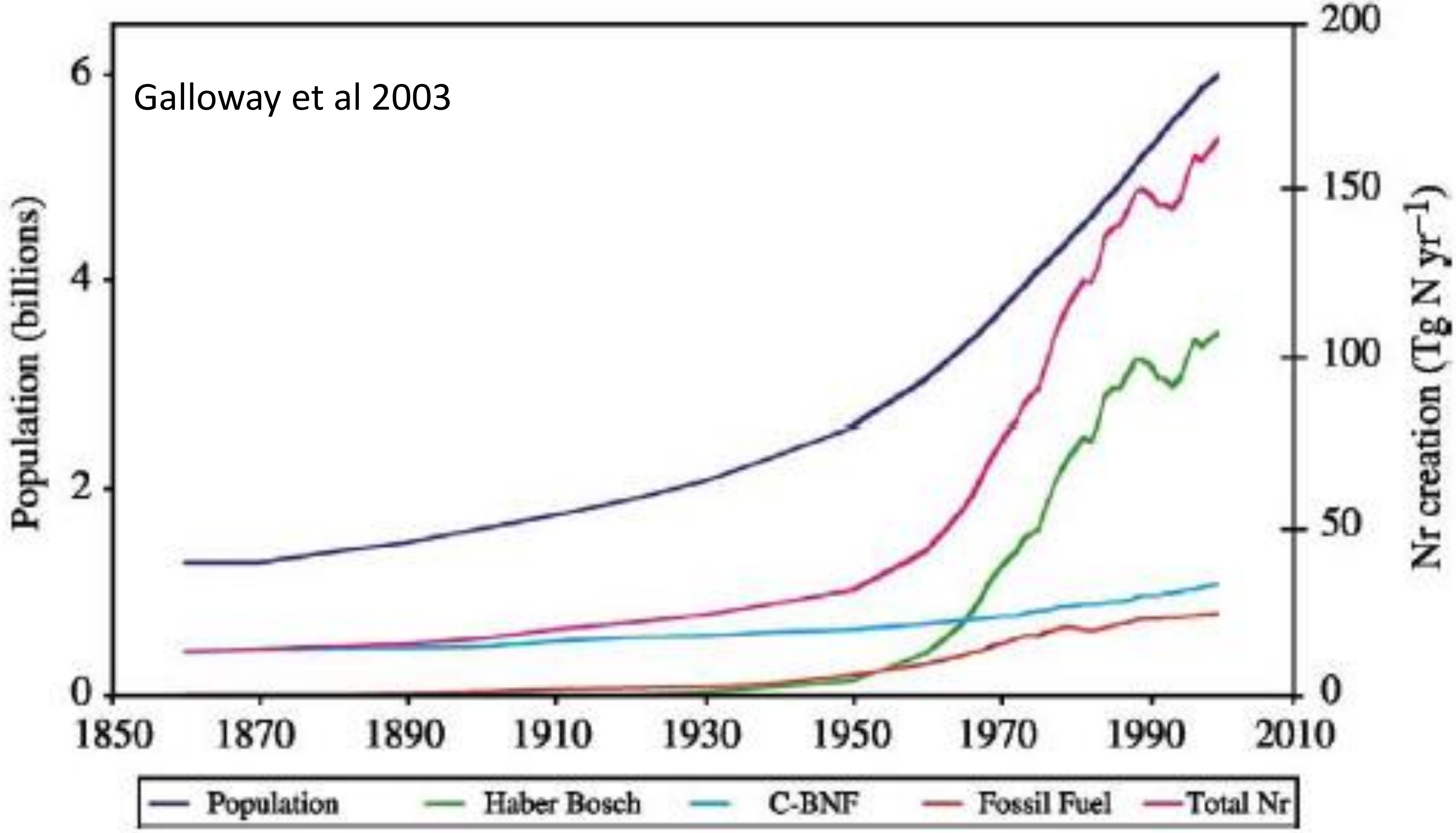
Sea Grant

NSF

WRIGHT STATE UNIVERSITY

CHANGING LIVES

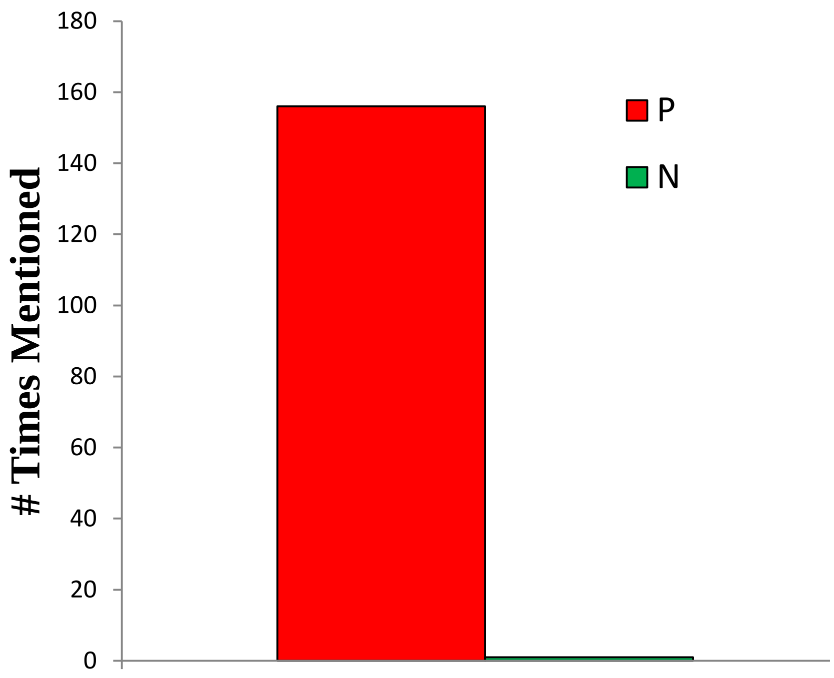
Anthropogenic N ≥ Biological N fixation



Ecosystem impacts from N-loading

- Harmful Algal Blooms
- Toxin production
- Fish Kills
- Oxygen depletion
- Greenhouse gas production

Daniel Hoffman



Almost 6 per page of text

Cyanobacteria = 16
Microcystis = 5

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Review

Assessing and addressing the re-eutrophication of Lake Erie: Central basin hypoxia

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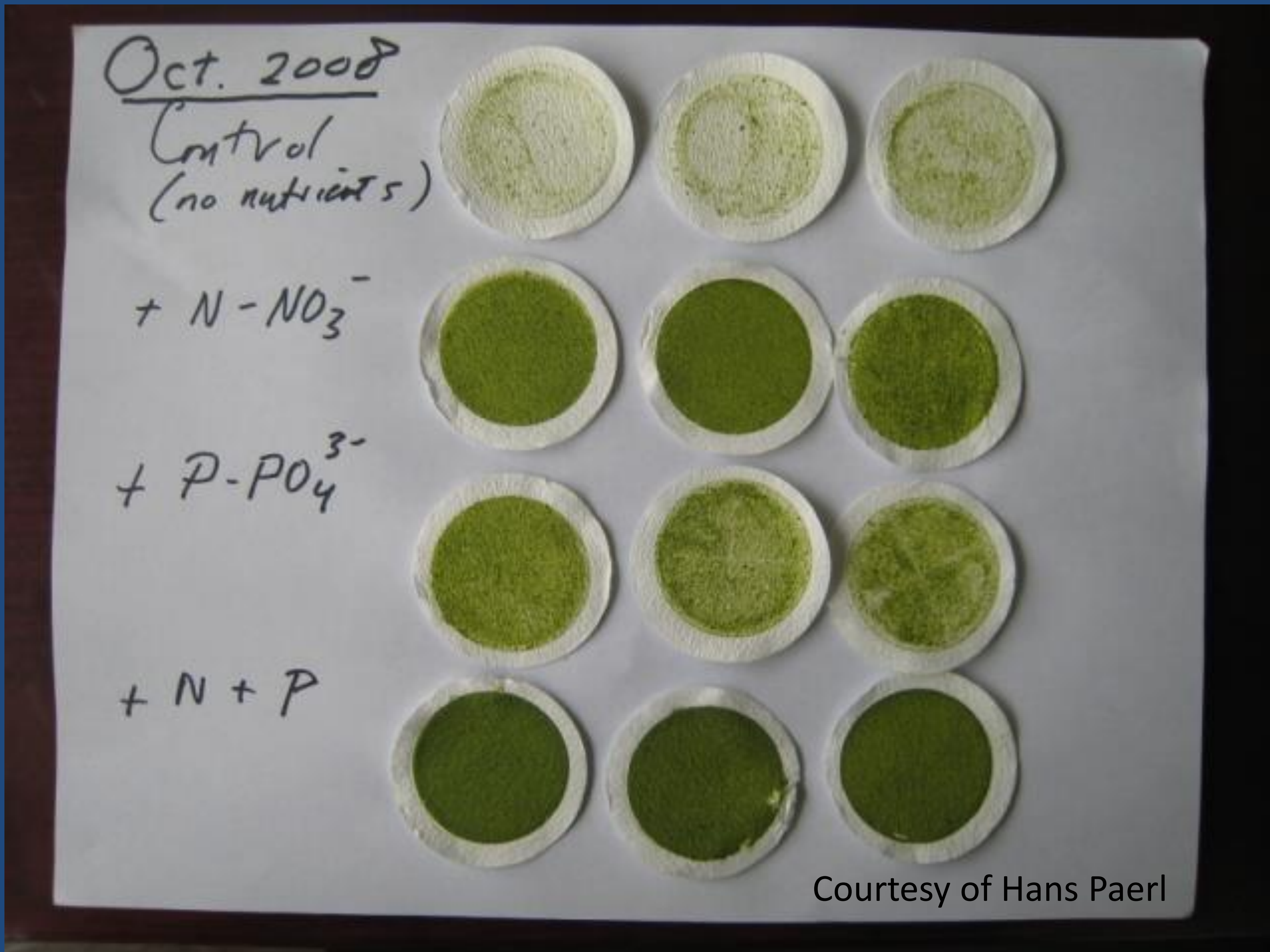
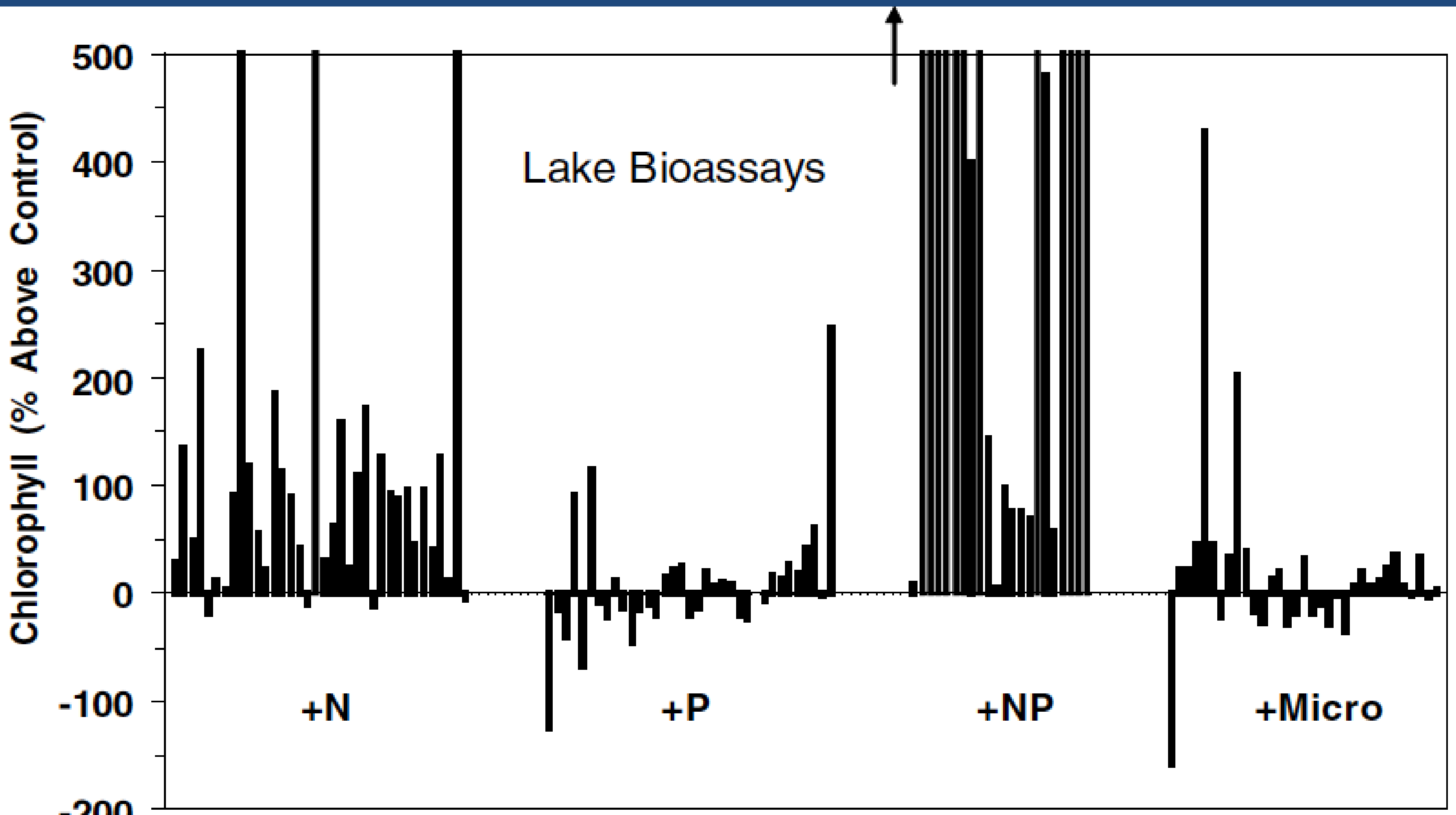
ABSTRACT

Relieving phosphorus loading is a key management tool for controlling Lake Erie eutrophication. During the 1960s and 1970s, increased phosphorus inputs degraded water quality and reduced central basin hypolimnetic oxygen levels which, in turn, eliminated thermal habitat vital to cold-water organisms and contributed to the extirpation of important benthic macroinvertebrate prey species for fishes. In response to load reductions initiated in 1972, Lake Erie responded quickly with reduced water-column phosphorus concentrations, phytoplankton biomass, and bottom-water hypoxia (dissolved oxygen <2 mg/l). Since the mid-1990s, cyanobacteria blooms increased and extensive hypoxia and benthic algae returned. We synthesize recent research leading to guidance for addressing this re-eutrophication, with particular emphasis on central basin hypoxia. We document recent trends in key eutrophication-related properties, assess their likely ecological impacts, and develop load response curves to guide revised hypoxia-based loading targets called for in the 2012 Great Lakes Water Quality Agreement. Reducing central basin hypoxic area to levels observed in the early 1990s (ca. 2000 km^2) requires cutting total phosphorus loads by 46% from the 2003–2011 average or reducing dissolved reactive phosphorus loads by 78% from the 2005–2011 average. Reductions to these levels are also protective of fish habitat. We provide potential approaches for achieving those new loading targets, and suggest that recent load reduction recommendations focused on western basin cyanobacteria blooms may not be sufficient to reduce central basin hypoxia to 2000 km^2.



Courtesy of Hans Paerl

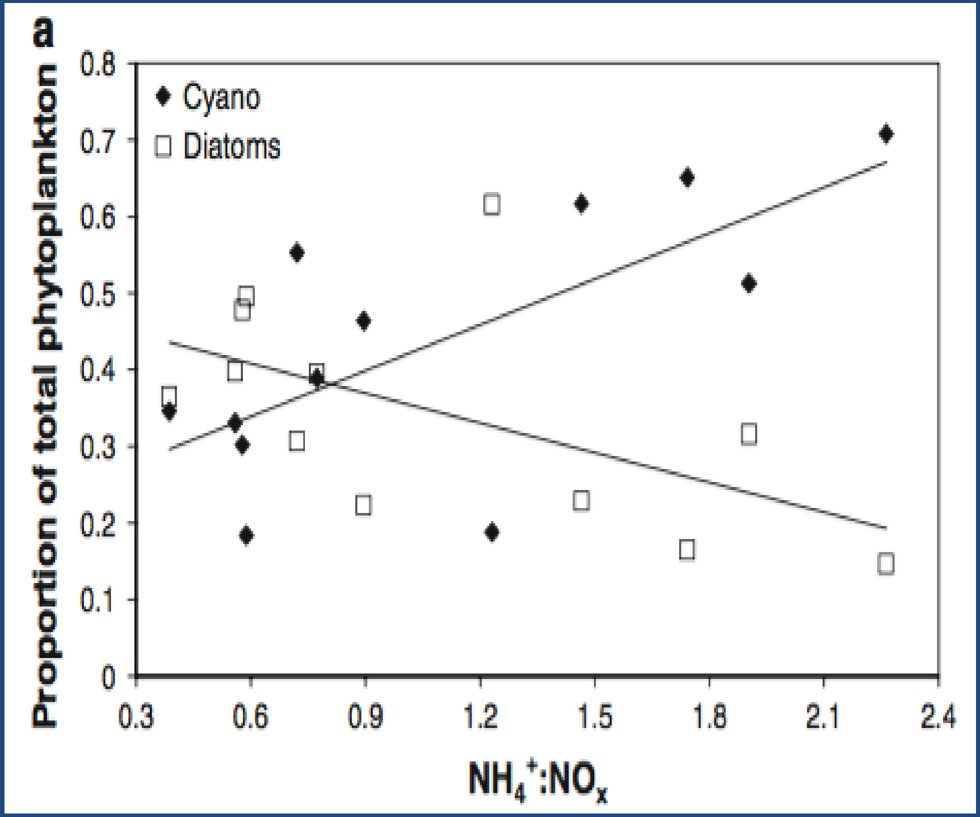
Nutrient Addition experiments



Courtesy of Wayne Wurtsbaugh

N Form and Community Structure

- NO_3^- : favors diatoms
- Reduced N (NH_4^+ and urea): favors cyanobacteria



McCarthy et al. 2009

N and Cyanobacterial Toxicity

- N additions to non-N-fixing cyanobacteria can increase toxicity.

  (Davis et al. 2010, 2015)

- Low NH_4^+ concentrations can inhibit toxin production

  (Kuniyoshi et al. 2010)

- Urea uptake may lead to both increased *Microcystis* biomass and toxin production

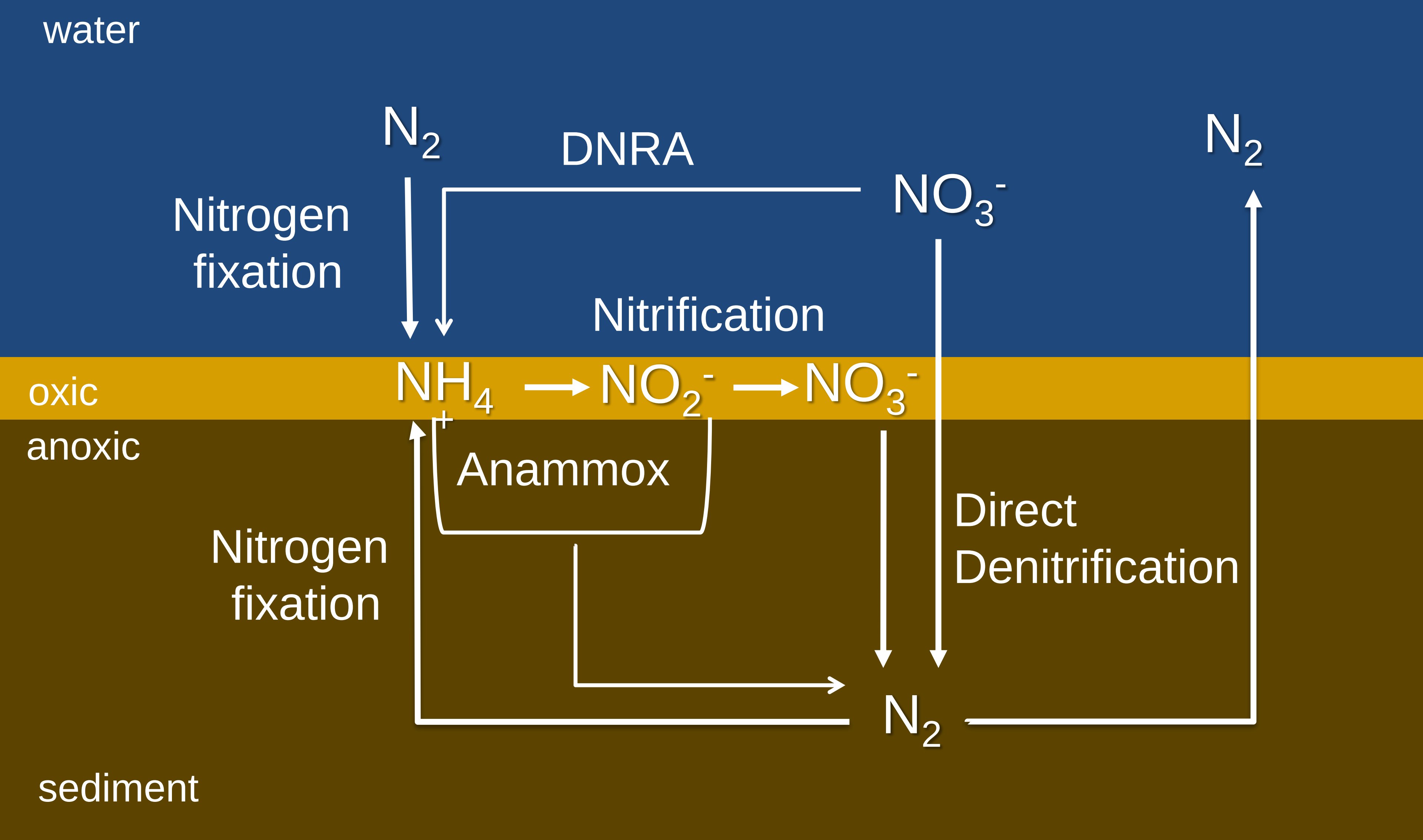
  (Finlay et al. 2010)

Table 5. The percentage of experiments in which N compounds significantly increased the density of the total phytoplankton community, total *Microcystis* community, non-toxic *Microcystis*, and toxic *Microcystis* relative to control treatments ($p < 0.05$) during nutrient amendment experiments. Percentages and number of significant treatments out of total number of experiments (in parentheses) shown

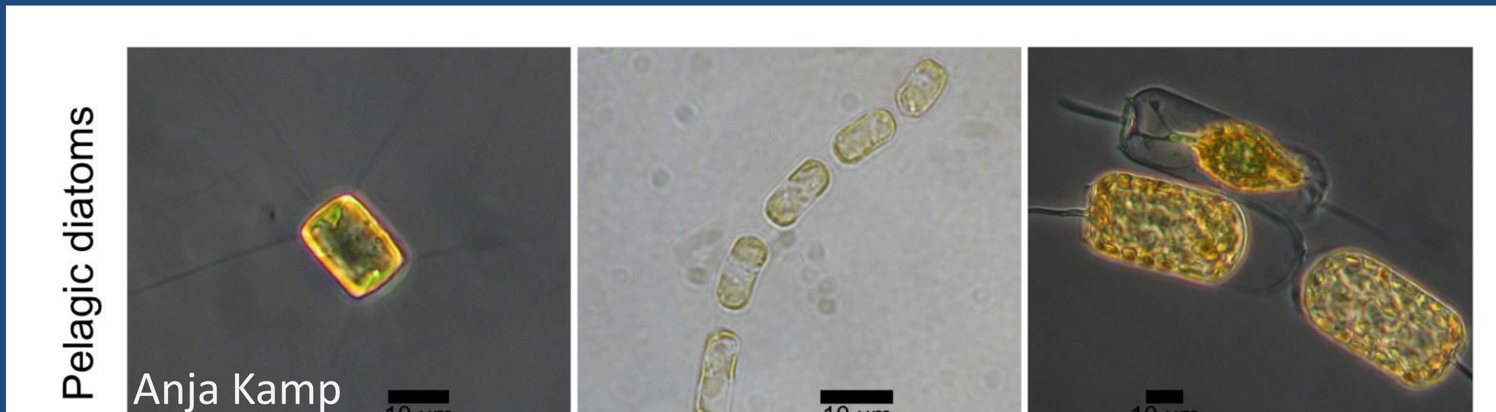
Compound	Experiments (%)			
	Total phytoplankton	Total *Microcystis*	Non-toxic *Microcystis*	Toxic *Microcystis*
Any N compound	83 (10/12)	67 (8/12)	50 (6/12)	75 (9/12)
Nitrate	50 (6/12)	42 (5/12)	25 (3/12)	58 (7/12)
Ammonium	25 (3/12)	17 (2/12)	17 (2/12)	42 (5/12)
Inorganic N	58 (7/12)	42 (5/12)	25 (3/12)	67 (8/12)
Urea	25 (3/12)	50 (6/12)	50 (6/12)	8 (1/12)
L-glutamine	33 (4/12)	25 (3/12)	33 (4/12)	0 (0/12)
Organic N	33 (4/12)	50 (6/12)	50 (6/12)	8 (1/12)
Orthophosphate	8 (1/12)	50 (6/12)	33 (4/12)	42 (5/12)

Davis et al. 2010

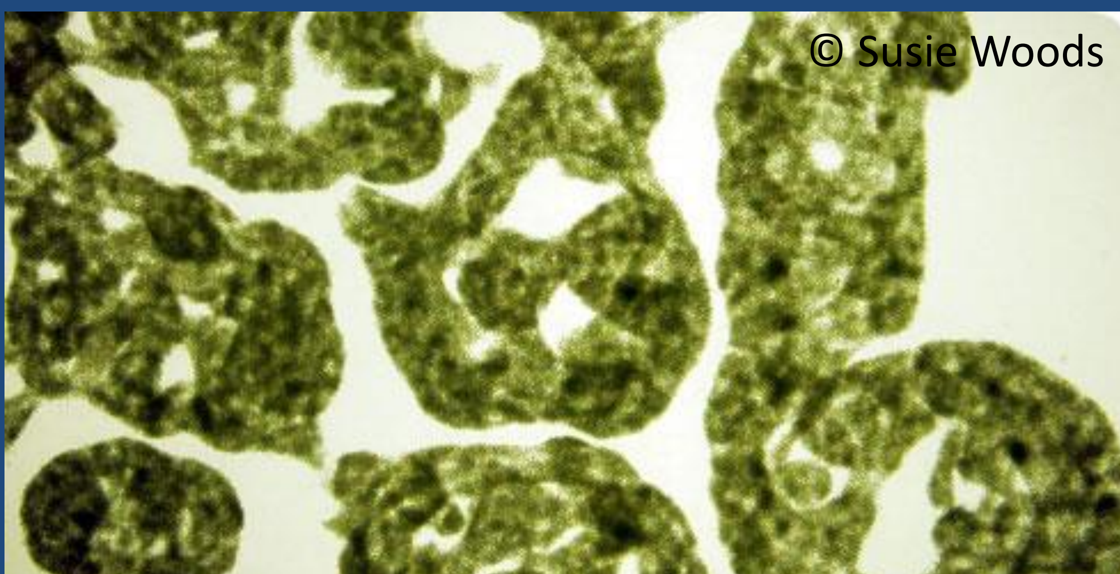
Nitrogen Cycle



Ammonium: the common currency



Diatoms use and store nitrate efficiently



But most phytos- including Microcystis- greatly prefer NH_4^+

Why is in situ NH_4^+ rarely measured accurately?

1. Rapid turnover (uptake/regeneration)

2. Insufficient sample handling

Most common nutrient sample handling method:
Sample bottle/carboy filled in the field, stored in a cooler, transported to lab, aliquoted out…

How long does it sit until being analyzed, or at least filtered?
What pore size is the filter?

In situ NH_4^+ is rarely measured accurately

Using actual data from Taihu Lake:

Scenario #1 --- Dark NH4 uptake = 0.000 μmol N L^{-1} h^{-1}
Dark NH4 regeneration = 1.442
Actual in situ {NH4} = 0.611 μM

An unfiltered water sample, stored in a dark cooler, would have:

{NH4} = 1.3 μM in just 30 minutes.
{NH4} = 3.5 μM in just 2 hours.
{NH4} = 6.4 μM in just 4 hours.
{NH4} = 35.2 μM in just 24 hours.

In situ NH_4^+ is rarely measured accurately

Using actual data from Taihu Lake:

Scenario #2 --- Dark NH4 uptake = 0.276 μmol N L^{-1} h^{-1}
Dark NH4 regeneration = 0.126
Actual in situ {NH4} = 0.258 μM

An unfiltered water sample, stored in a dark cooler, would have:

{NH4} = 0 μM in 103 minutes!!!

Why is in situ NH_4^+ rarely measured accurately?

Using actual data from Missisquoi Bay (McCarthy et al. 2013):

Scenario #1 --- Dark NH4 uptake = 0.118 μmol N L^{-1} h^{-1}

Dark NH4 regeneration = 0.259

Actual in situ {NH4} = 1 μM

An unfiltered water sample, stored in a dark cooler, would have:

{NH4} = 1.6 μM in just 4 hours.

{NH4} = 4.4 μM in just 24 hours.

{NH4} = 11.2 μM in just 72 hours.

Courtesy of M. McCarthy

Why is in situ NH_4^+ rarely measured accurately?

Using actual data from Missisquoi Bay (McCarthy et al. 2013):

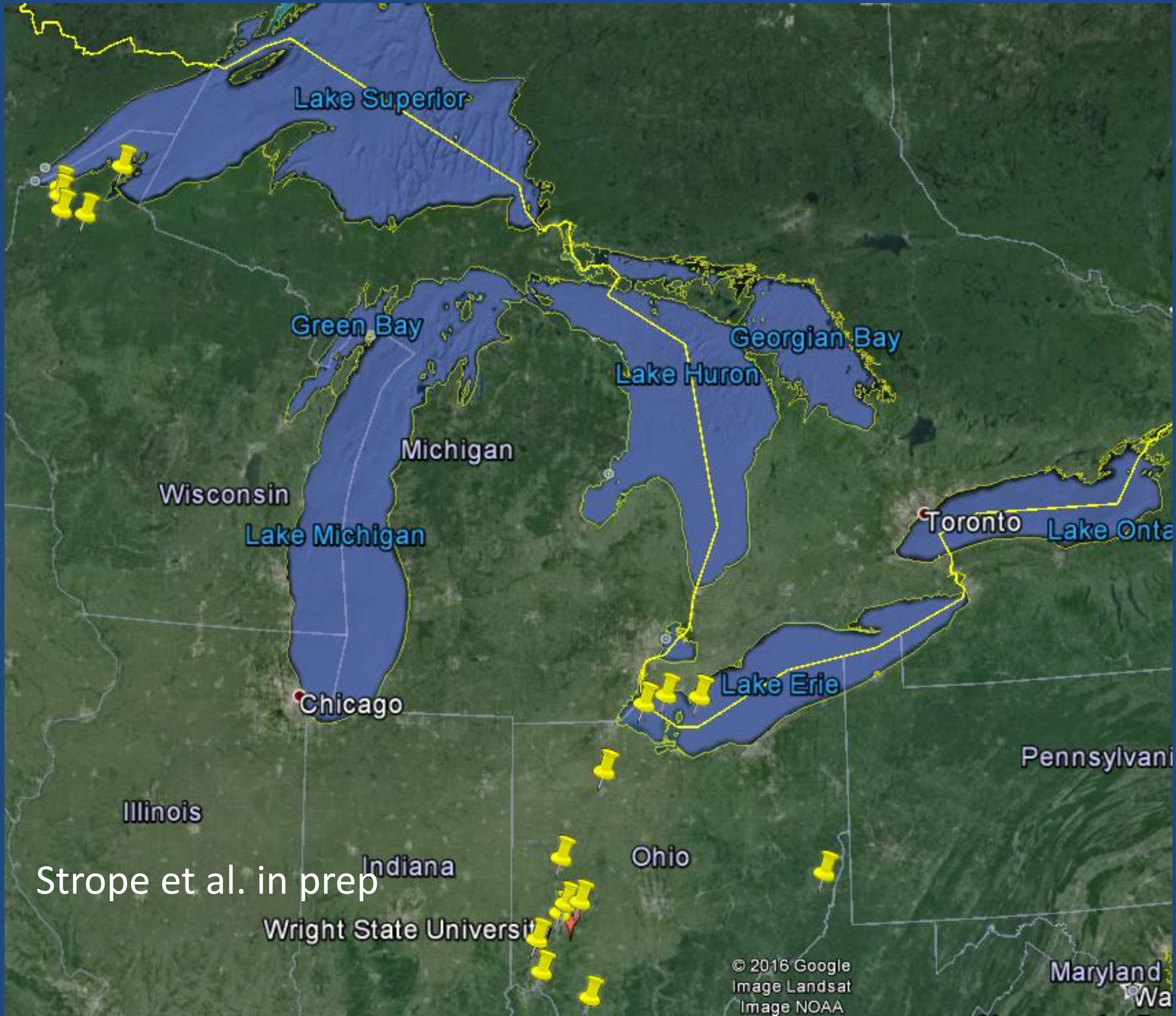
Scenario #2 --- Dark NH4 uptake = 0.213 μmol N L^{-1} h^{-1}
Dark NH4 regeneration = 0.105
Actual in situ {NH4} = 0.19 μM

An unfiltered water sample, stored in a dark cooler, would have:

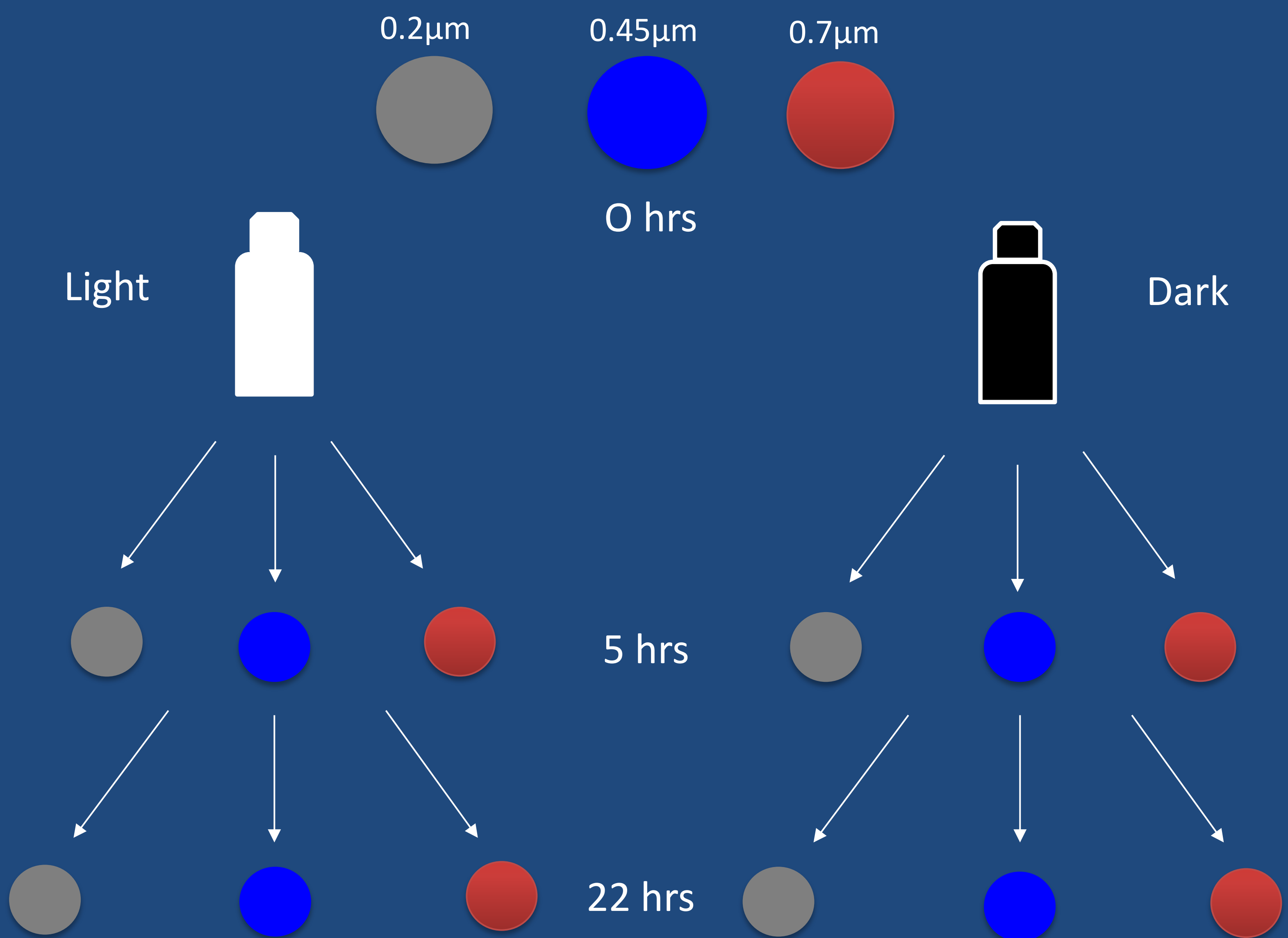
{NH4} = 0 μM in 105 minutes!!!

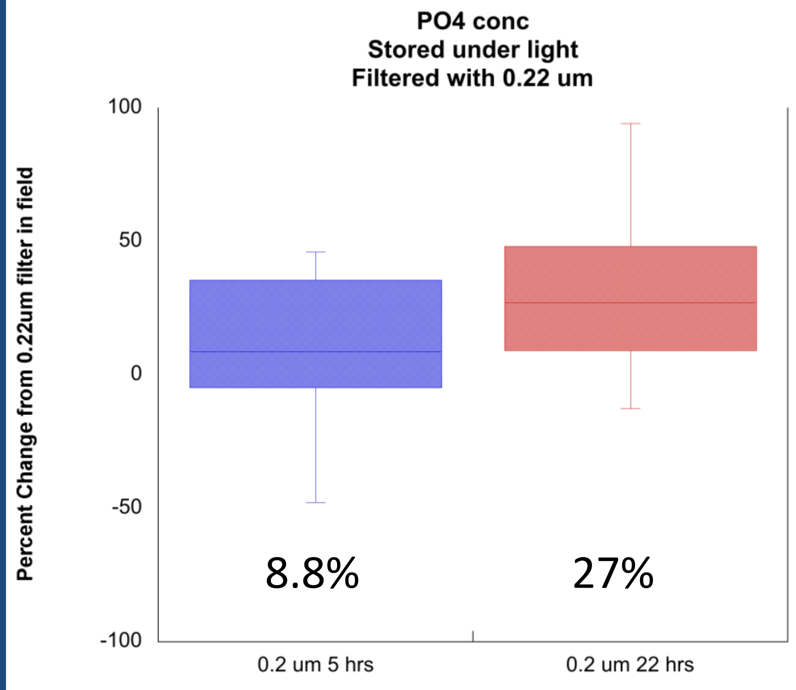
Courtesy of M. McCarthy

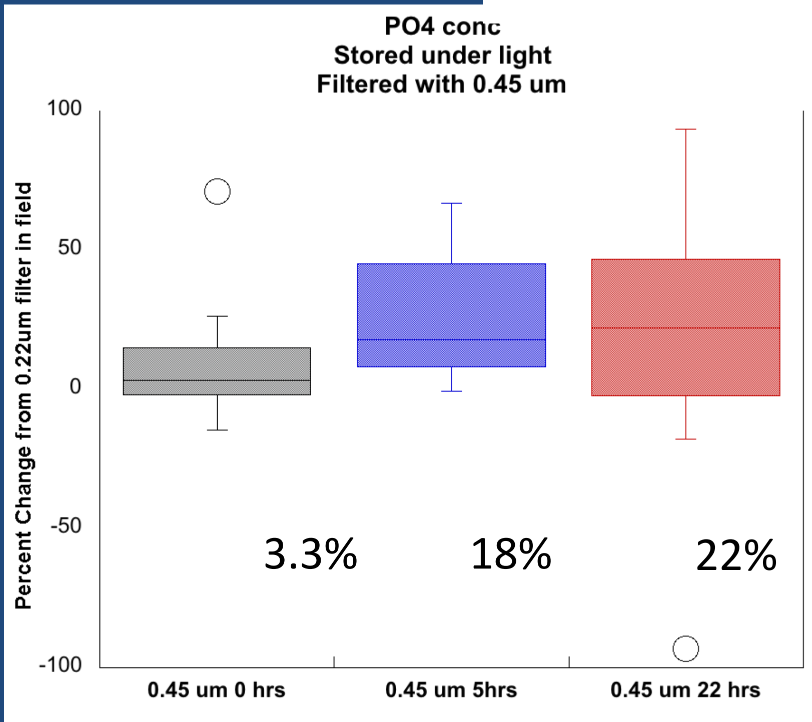
Does time to filter and filter size matter for NH_4^+ and SRP concentrations?

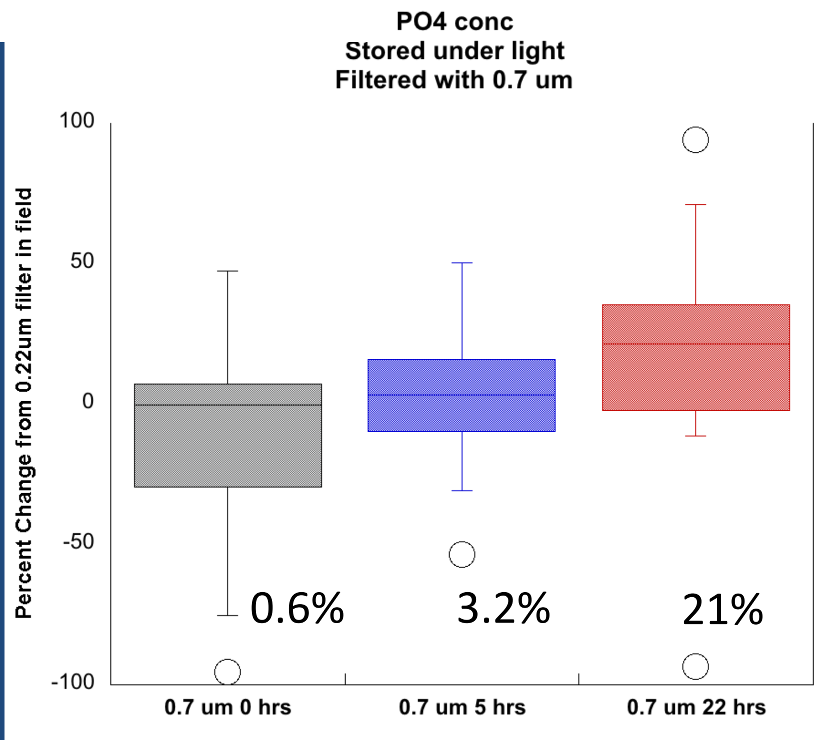


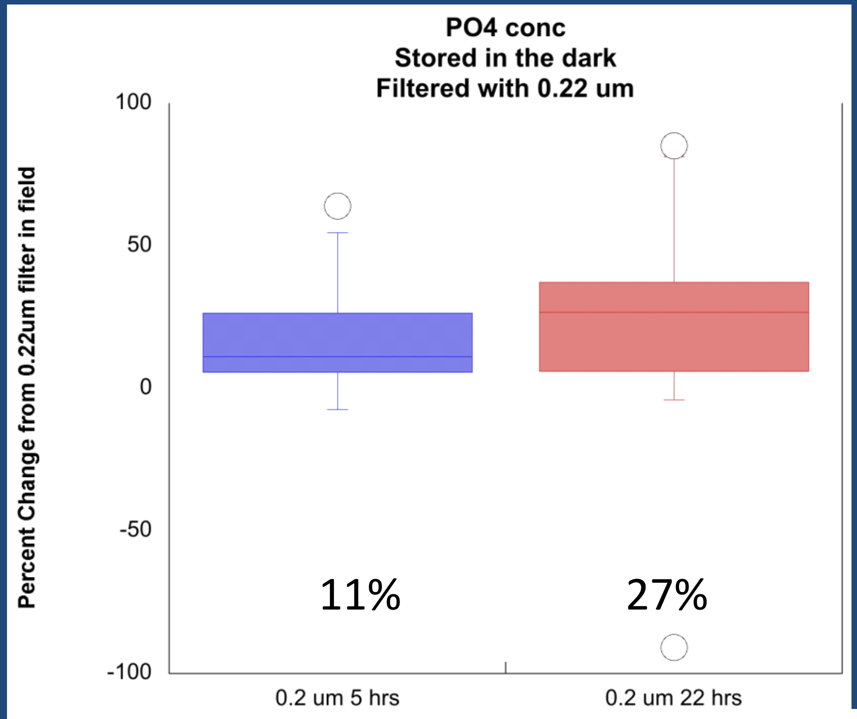
Strope et al. in prep

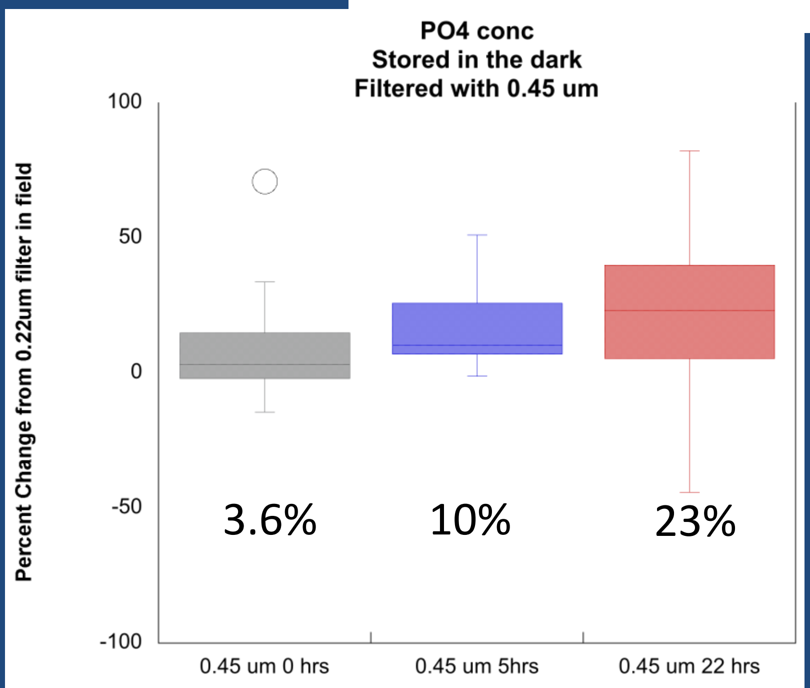

0.2µm
0.45µm
0.7µm
O hrs
Light
Dark
5 hrs
22 hrs

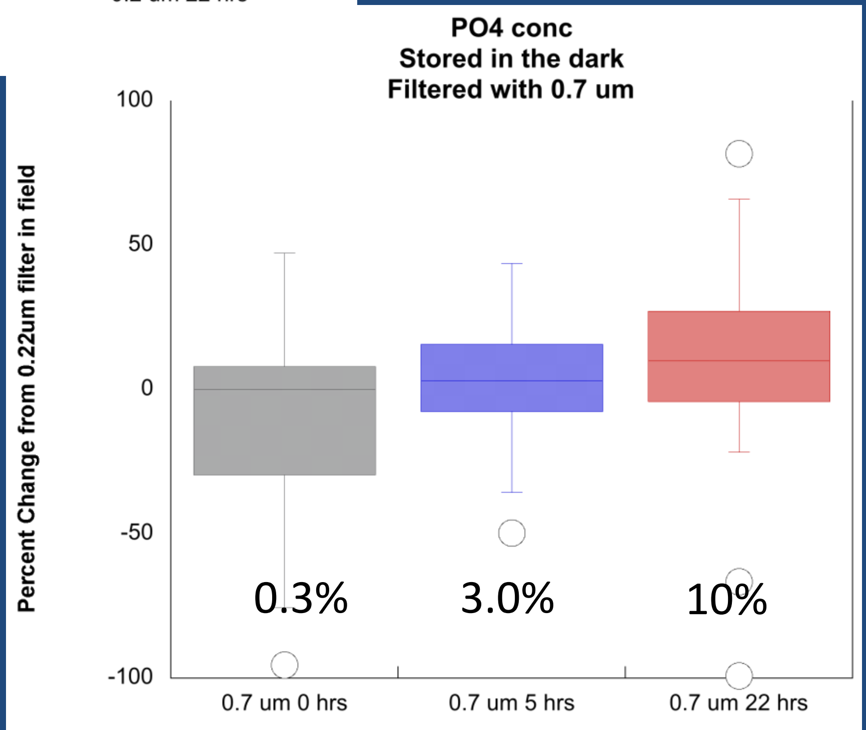

PO4 conc
Stored under light
Filtered with 0.22 um
Percent Change from 0.22um filter in field
100
50
0
-50
-100
8.8%
27%
0.2 um 5 hrs
0.2 um 22 hrs

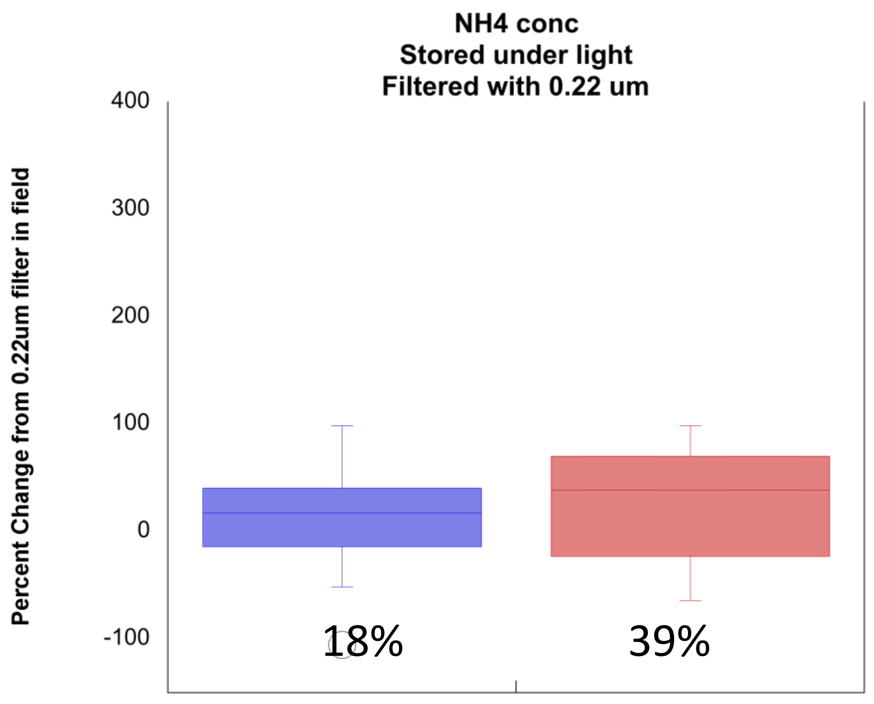

PO4 conc
Stored under light
Filtered with 0.45 um
Percent Change from 0.22um filter in field
100
50
0
-50
-100
3.3%
18%
22%
0.45 um 0 hrs
0.45 um 5hrs
0.45 um 22 hrs

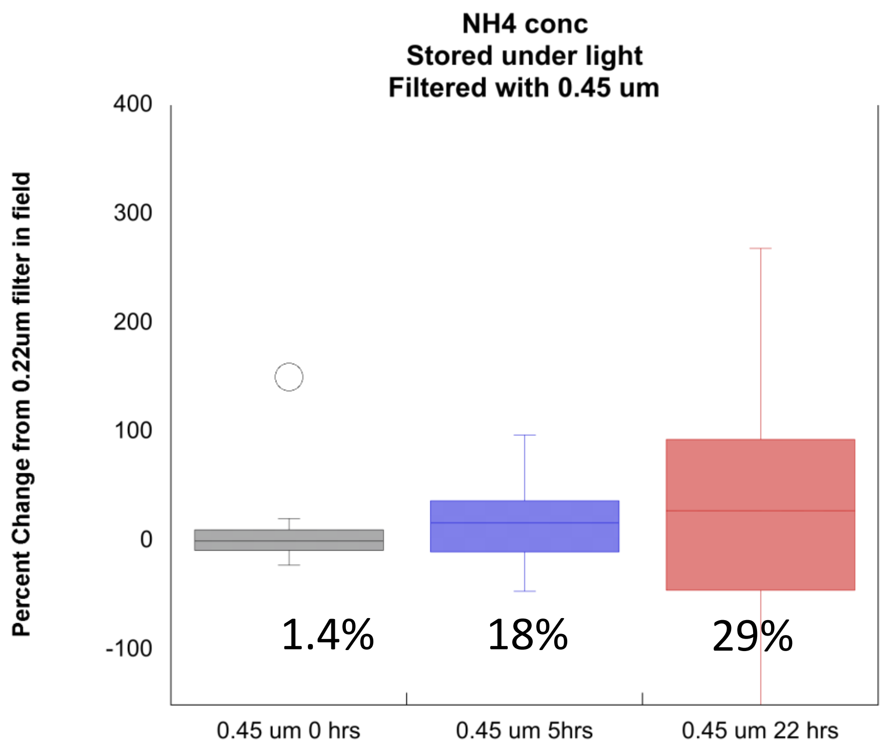

PO4 conc
Stored under light
Filtered with 0.7 um
Percent Change from 0.22um filter in field
100
50
0
-50
-100
0.6%
3.2%
21%
0.7 um 0 hrs
0.7 um 5 hrs
0.7 um 22 hrs

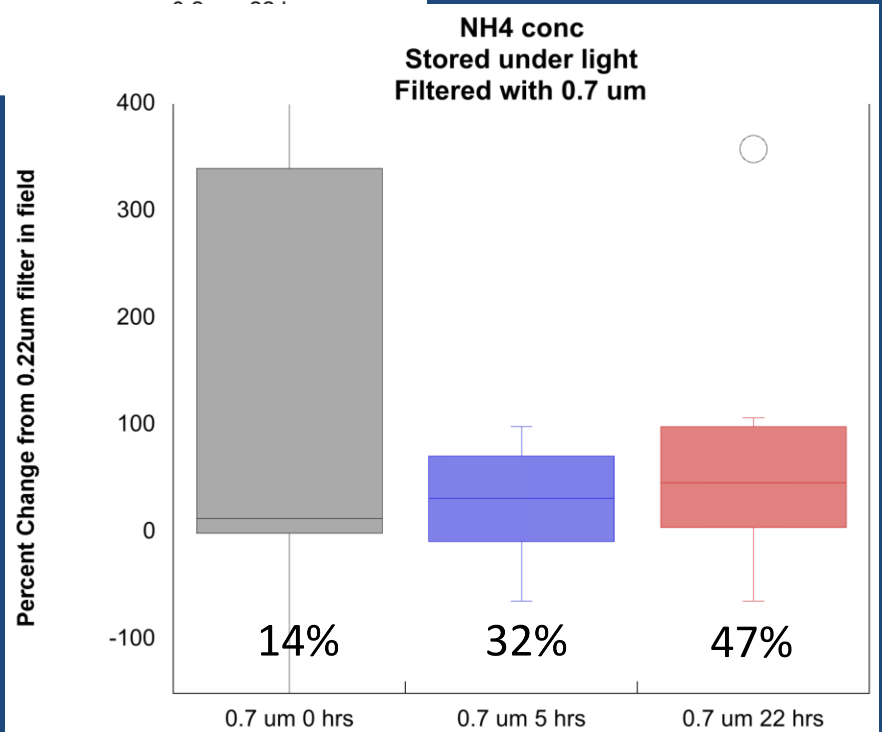

PO4 conc
Stored in the dark
Filtered with 0.22 um
Percent Change from 0.22um filter in field
100
50
0
-50
-100
11%
27%
0.2 um 5 hrs
0.2 um 22 hrs

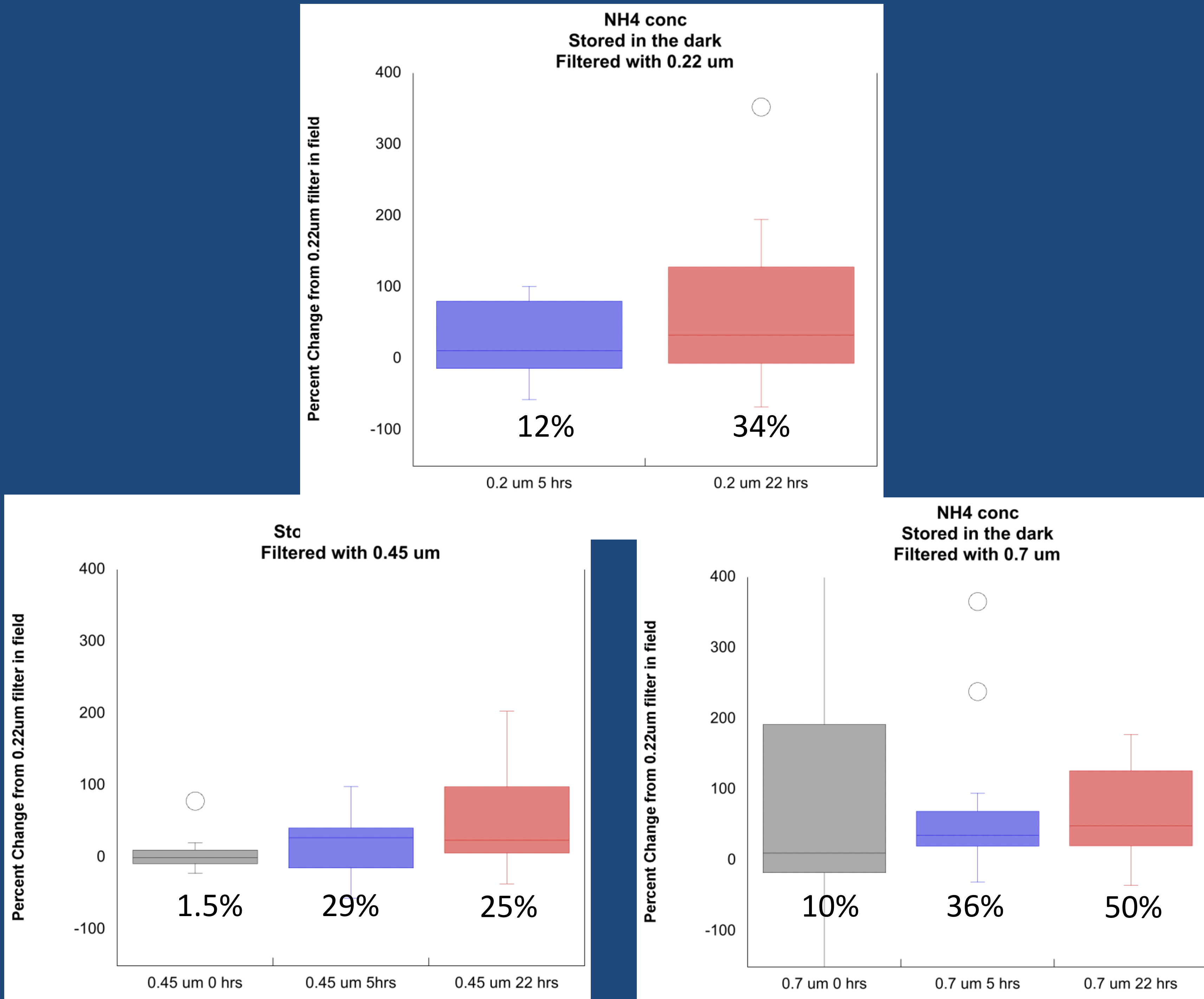

PO4 conc
Stored in the dark
Filtered with 0.45 um
Percent Change from 0.22um filter in field
100
50
0
-50
-100
3.6%
10%
23%
0.45 um 0 hrs
0.45 um 5hrs
0.45 um 22 hrs


PO4 conc
Stored in the dark
Filtered with 0.7 um
Percent Change from 0.22um filter in field
100
50
0
-50
-100
0.3%
3.0%
10%
0.7 um 0 hrs
0.7 um 5 hrs
0.7 um 22 hrs

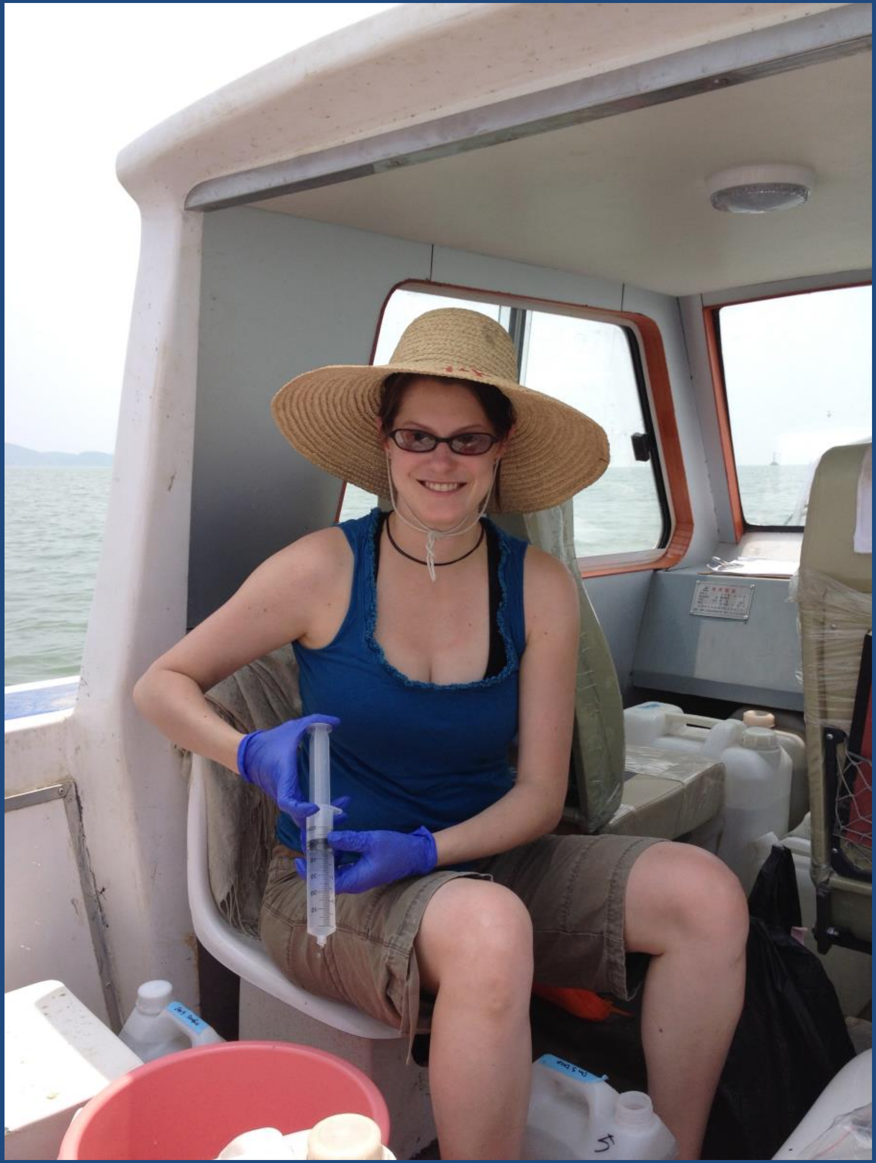

NH4 conc
Stored under light
Filtered with 0.22 um
Percent Change from 0.22um filter in field
400
300
200
100
0
-100
18%
39%


NH4 conc
Stored under light
Filtered with 0.45 um
Percent Change from 0.22um filter in field
400
300
200
100
0
-100
1.4%
18%
29%
0.45 um 0 hrs
0.45 um 5hrs
0.45 um 22 hrs


NH4 conc
Stored under light
Filtered with 0.7 um
Percent Change from 0.22um filter in field
400
300
200
100
0
-100
14%
32%
47%
0.7 um 0 hrs
0.7 um 5 hrs
0.7 um 22 hrs


NH4 conc
Stored in the dark
Filtered with 0.22 um
Percent Change from 0.22um filter in field
400
300
200
100
0
-100
12%
34%
0.2 um 5 hrs
0.2 um 22 hrs
Sto
Filtered with 0.45 um
Percent Change from 0.22um filter in field
400
300
200
100
0
-100
1.5%
29%
25%
0.45 um 0 hrs
0.45 um 5hrs
0.45 um 22 hrs
NH4 conc
Stored in the dark
Filtered with 0.7 um
Percent Change from 0.22um filter in field
400
300
200
100
0
-100
10%
36%
50%
0.7 um 0 hrs
0.7 um 5 hrs
0.7 um 22 hrs

Take Home:
Filter field samples for ammonium to 0.2 um (or at least 0.45 um) in the field!



Objective

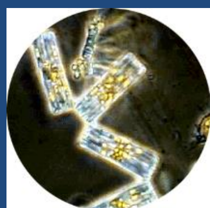
Determine how much ammonium is regenerated in the water column relative to the sediments and external N inputs

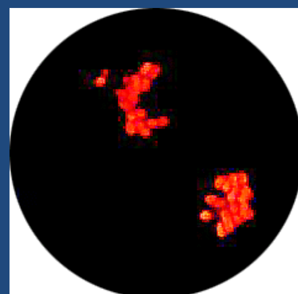
NH_4^+ Uptake and Regeneration

Methods:

- Additions of ^{15}N-labeled NH_4^+
- Light and dark incubations
- Sampling immediately after isotope amendment and following 24 hour incubation
- Total pool (^{14}N+^{15}N) NH_4^+ analysis
- Quantification of ^{15}N-labeled NH_4^+ uptake and regeneration

Bacteria and phytoplankton





Zooplankton/Mixotrophs

Uptake

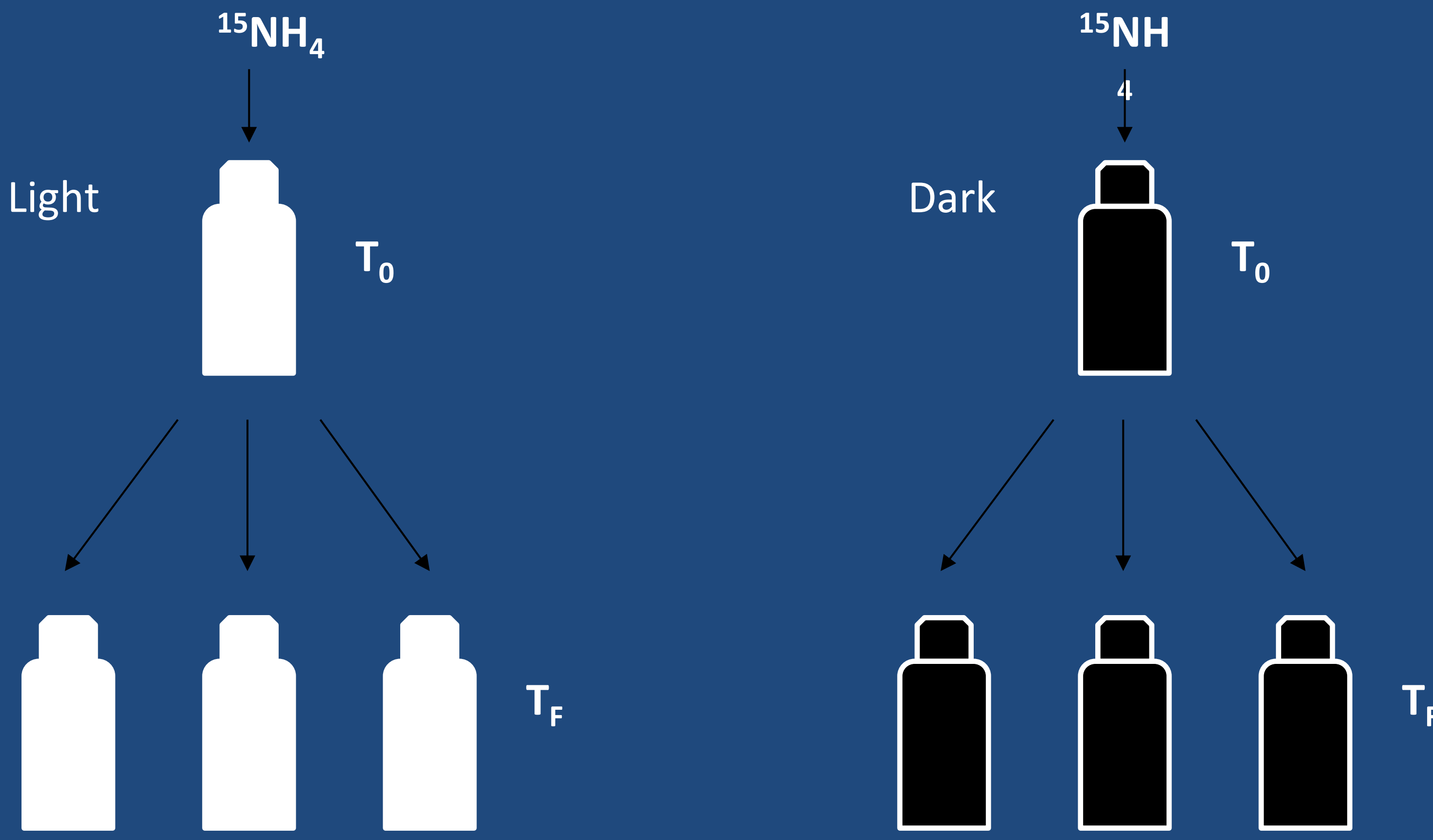
Regeneration

$^{15}NH_4^+$

$^{14}NH_4^+$

NH_4^+ pool becomes diluted (“lighter”)

NH_4^+ Uptake and Regeneration



NH_4^+ Uptake and Regeneration

- Total pool ($^{14}N+^{15}N$) NH_4^+ analysis

  Lachat Quikchem 8500

- Measurement of ^{15}N-$NH4^+$

  OX-MIMS Method (Yin et al. 201

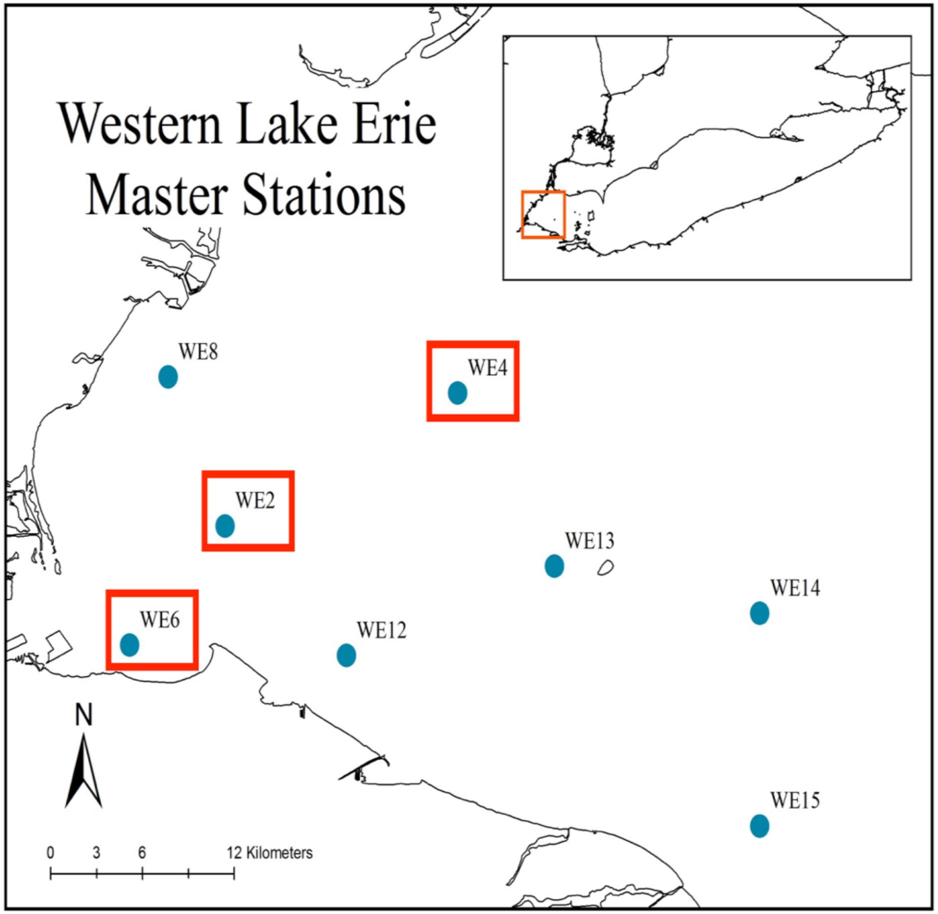
KIBrO

NH_4^+ + KIBrO → N_2

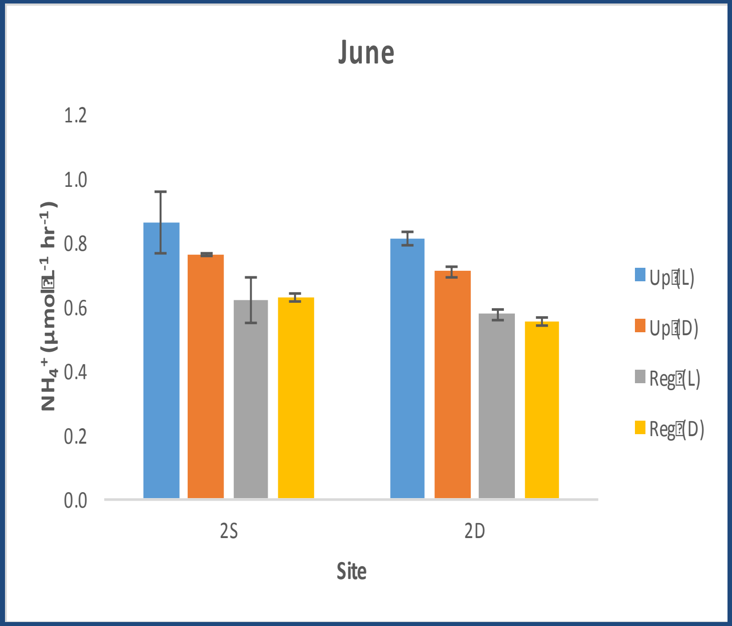
Membrane inlet mass spectrometry for dissolved gas analysis (^{29}N and ^{30}N-labeled N_2)

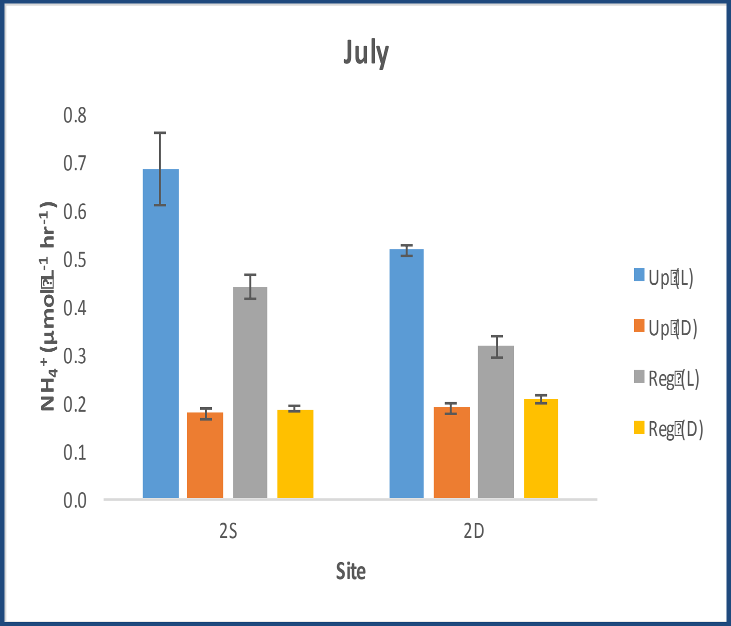
- Uptake and regeneration rates calculated following the method of Blackburn et al. (1979)

Sample Sites

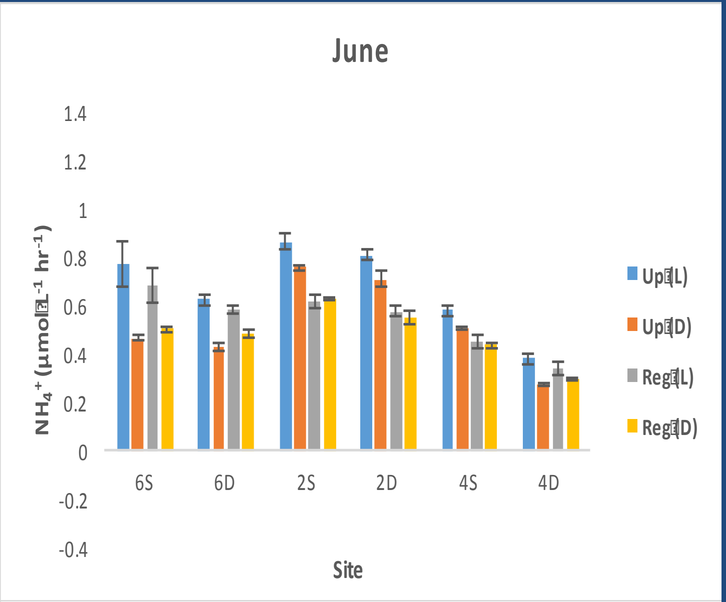


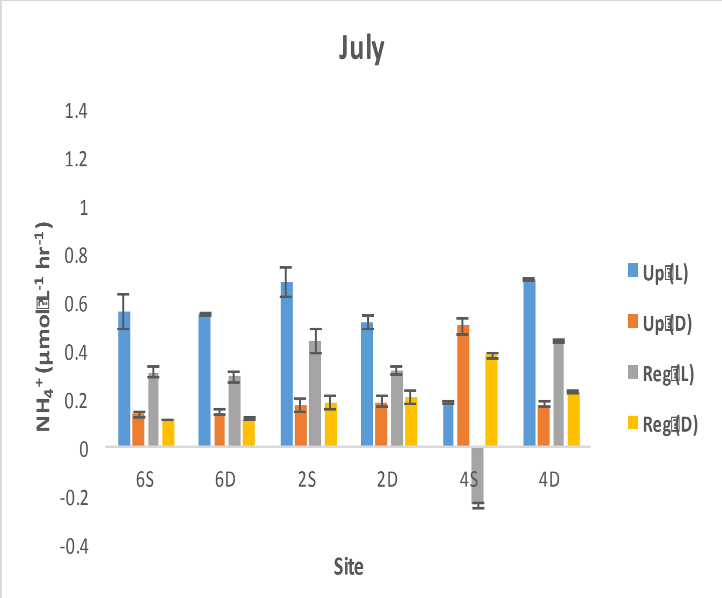
NH_4^+ Uptake/Regeneration

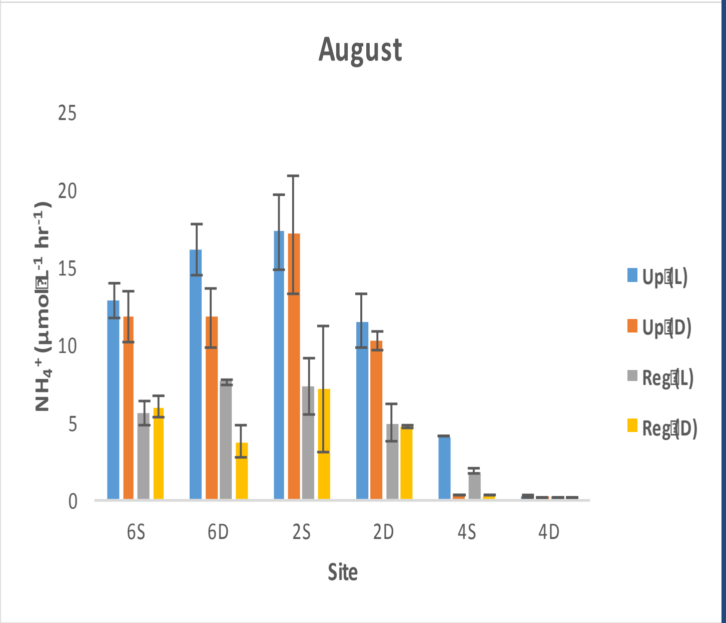


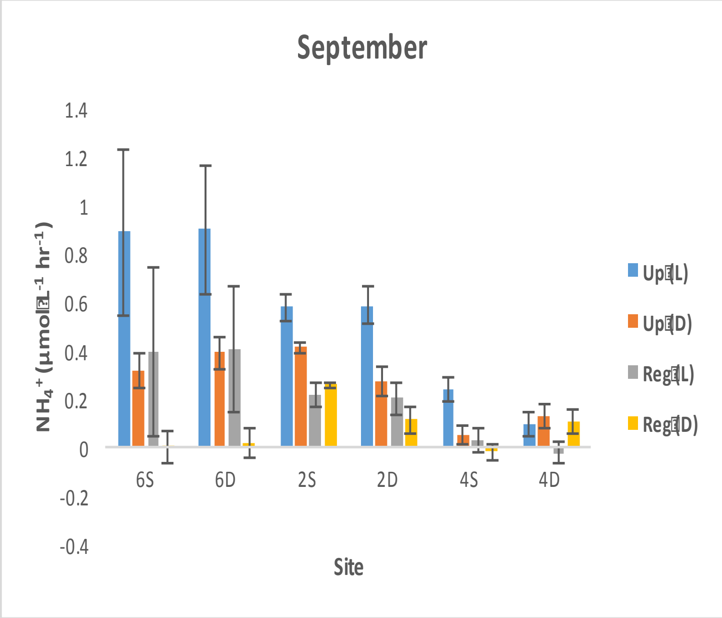


NH_4^+ Uptake/Regeneration







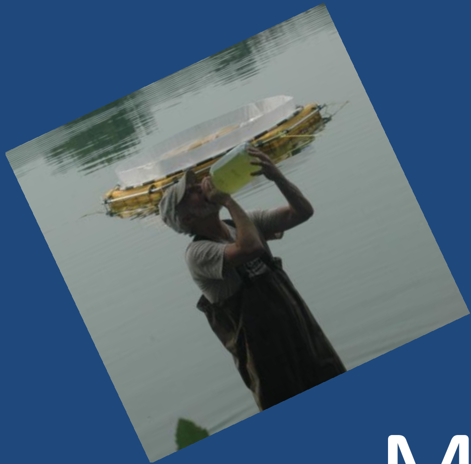


June

July

August

September



Mitigating Freshwater Cyanobacteria Blooms

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[3]Department of Anthropology, University of Maryland, College Park, MD, USA
[4]Horn Point Laboratory, University of Maryland Center for Environmental Sciences, Cambridge, MD, USA
[5]GEMSTONE Program, University of Maryland, College Park, MD, USA

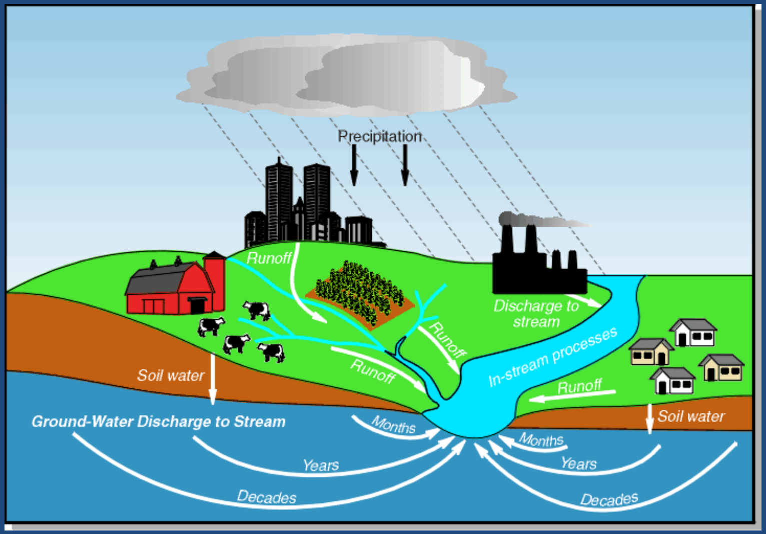
NOAA HAB-PCM Grant NA10NOS4780154

Microcystis Blooms on MD's Eastern Shore, USA

- Dog mortalities in 24-48 h in 2009 at Higgins Mill Pond; [microcystin] = 2.2 x 10^4 µg/L. Continued blooms today.
- Summer blooms in Lake Williston in 2009-2012, some exceeding WHO levels for recreational use.
- Reasons for blooms: Large nutrient input, warm temperatures, little water mixing

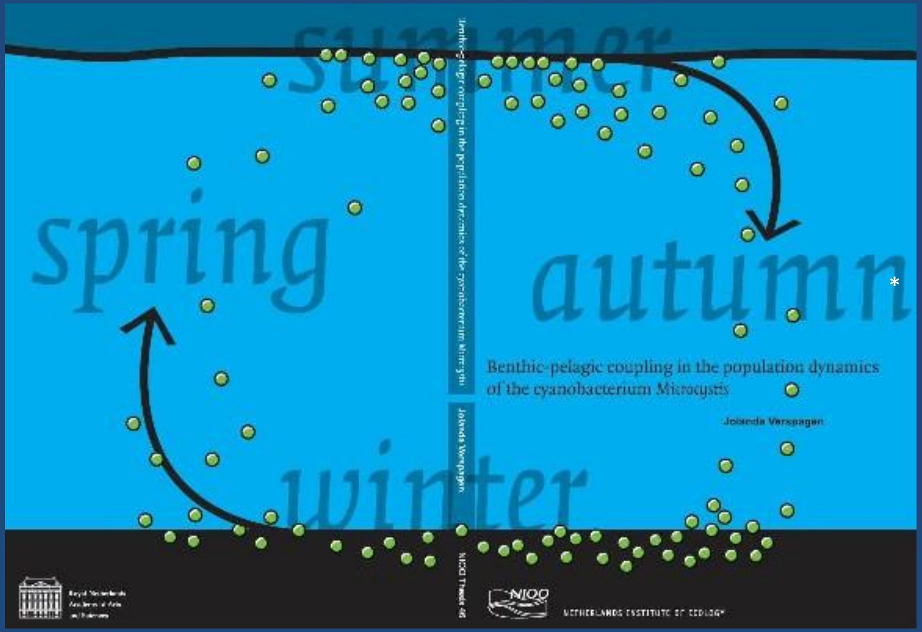
So fixing the problem?

- Reduce nutrients coming into lakes & ponds
  - Difficult:
    - Legacy groundwater NO_3
    - Continued excess fertilizer & litter applications
    - Very high soil P content
    - Expensive & requires behavior change
    - Little political will
- So must mitigate as well as prevent blooms



Mitigation Options?

- Bloom population overwinters by sinking to bottom & re-growth next year
- Try to delay and shrink blooms
- Barley Straw + white-rot fungi (*Trametes versicolor* and *Ceriporiopsis subvermispora*)

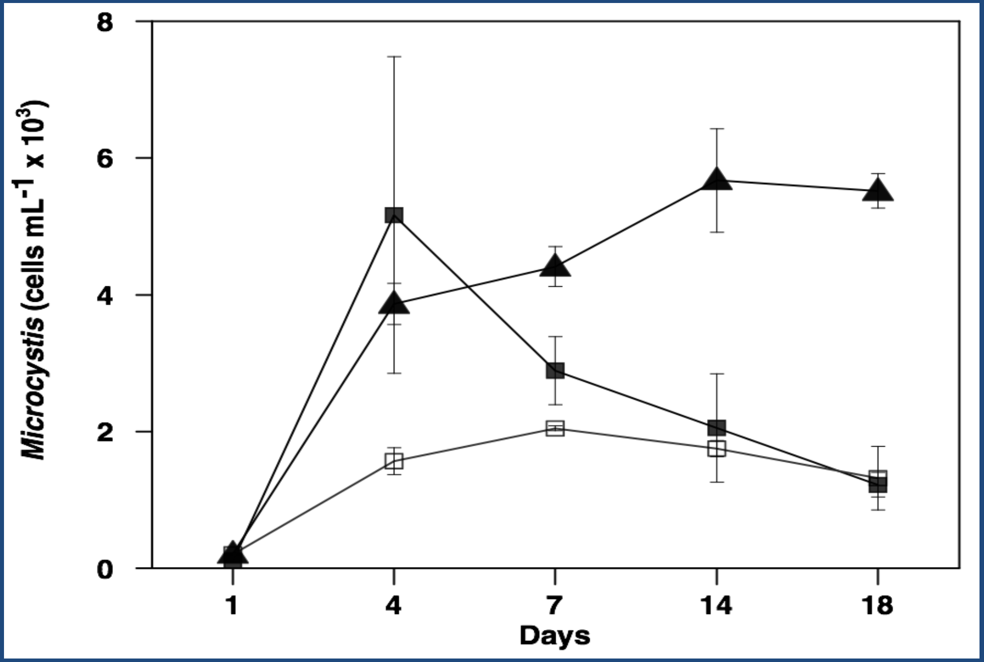


home.medewerker.uva.nl

http://www.haloarchaea.com/resources/cyanobacterialBloom2013/index.html*

Lake Williston; Sellner et al.

Growth depression in *M. aeruginosa* LE-3 after exposure to 0.01% (v/v) fungal-enriched barley straw extract from the field.

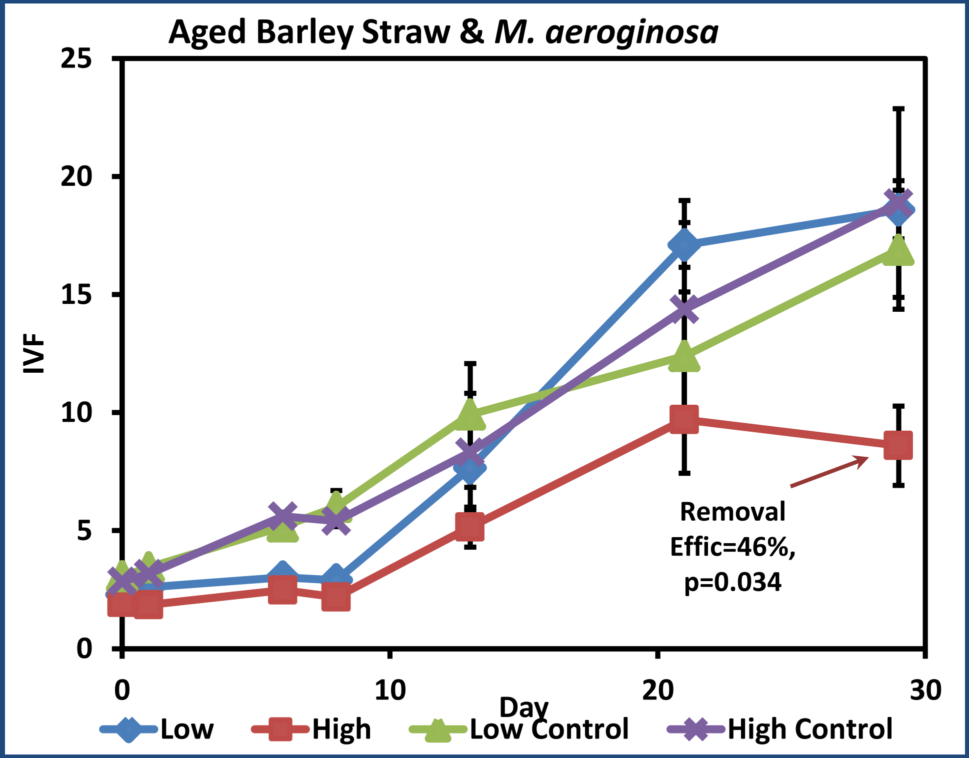


The extract was from barley bales in the field under light (full sun, □) and dark (▪) exposures; growth in control, no extract cultures depicted with ▲.

Barley Straw Deployment

Lake Williston: Barley Straw additions

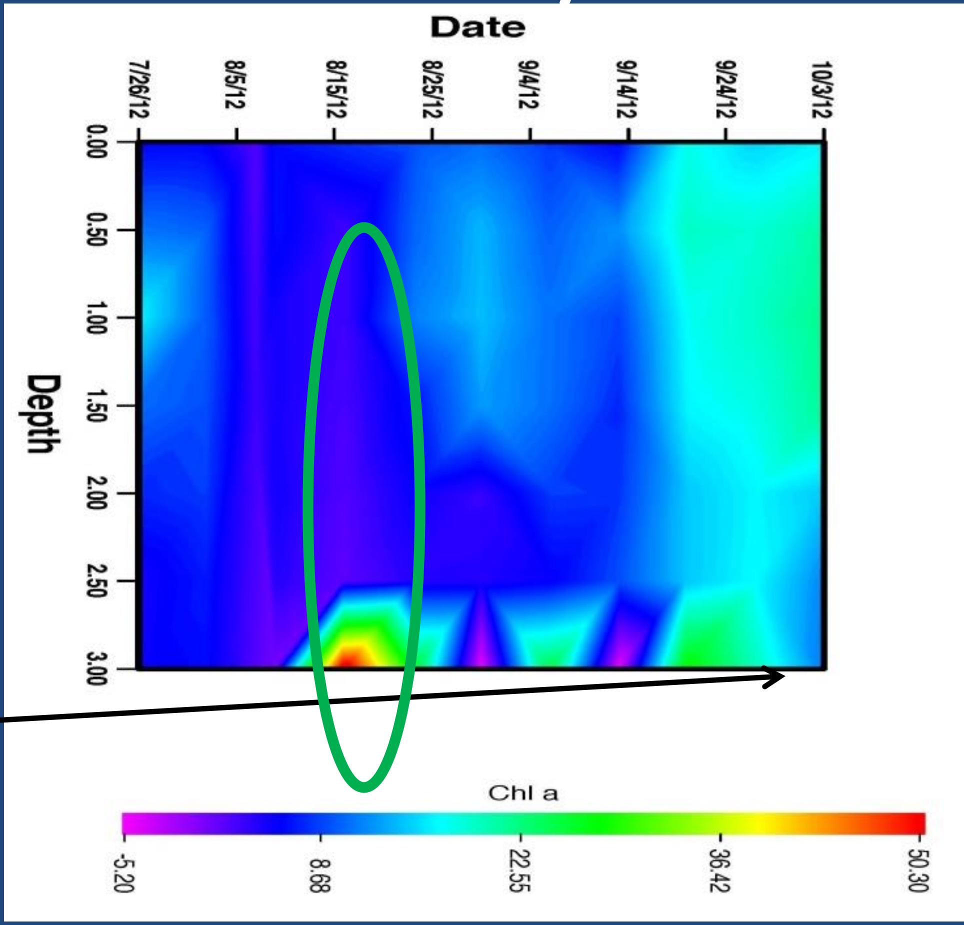
- Tried 1st 2 + addition of barley straw



- Bloom concentration significantly reduced by 46%!

Lake Williston: Bloom delayed

- Bloom was not observed until late August (last day of GSA Camp operations)
- Over-wintering population in 2012-2013 smaller
- Add new barley straw in spring 2013



Barley Straw recap

- Barley straw + white-rot fungi was effective at reducing cyanobacterial abundance by half
- Barley straw does not target diatoms
- Barley straw is cheap ($4/bale)
- Barley straw works best on small lakes (<5 acres), so could be a good solution for local parks or private lakes in Ohio

So THANK YOU!

- Barley straw works!
- So good, we're now trying it on Poplar Island & Carroll Creek (Frederick, MD)
- May try it in farm & home owner ponds across state

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