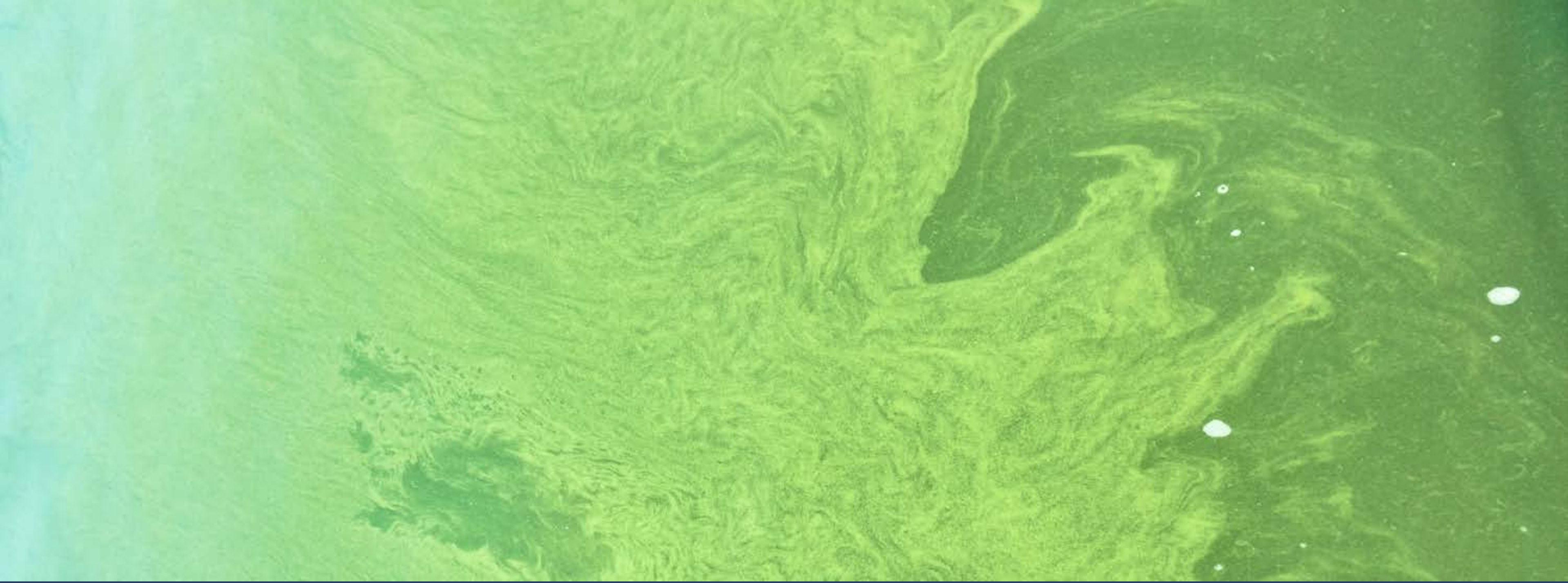


The role of nitrogen as a driver of harmful algal blooms

Silvia Newell

Co-authors: Justyna Hampel, Daniel Hoffman, Mark McCarthy, Justin Myers, Tim Davis, Tom Johengen, Duane Gossieux

Wright State University
Changing Lives

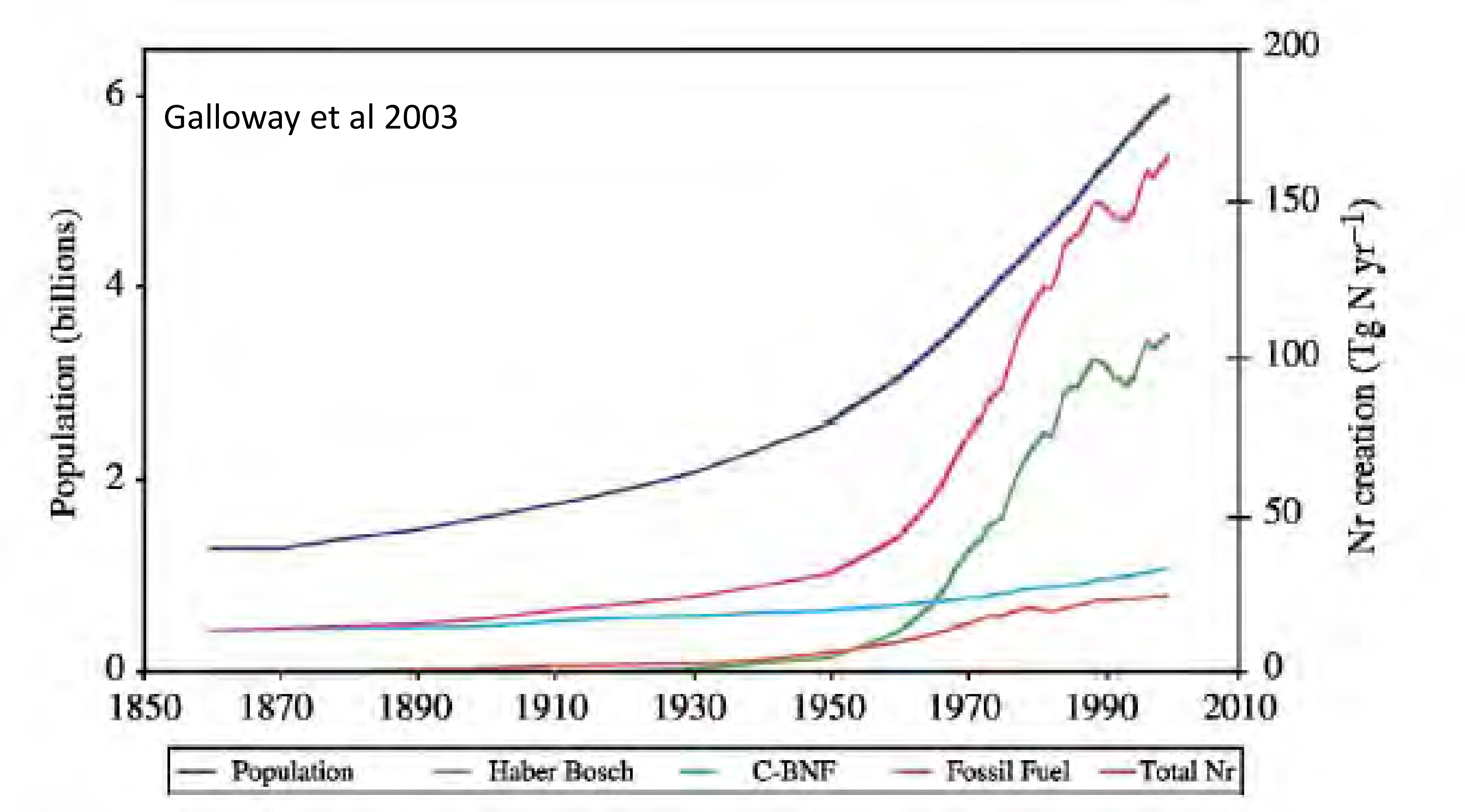
@NewellLab

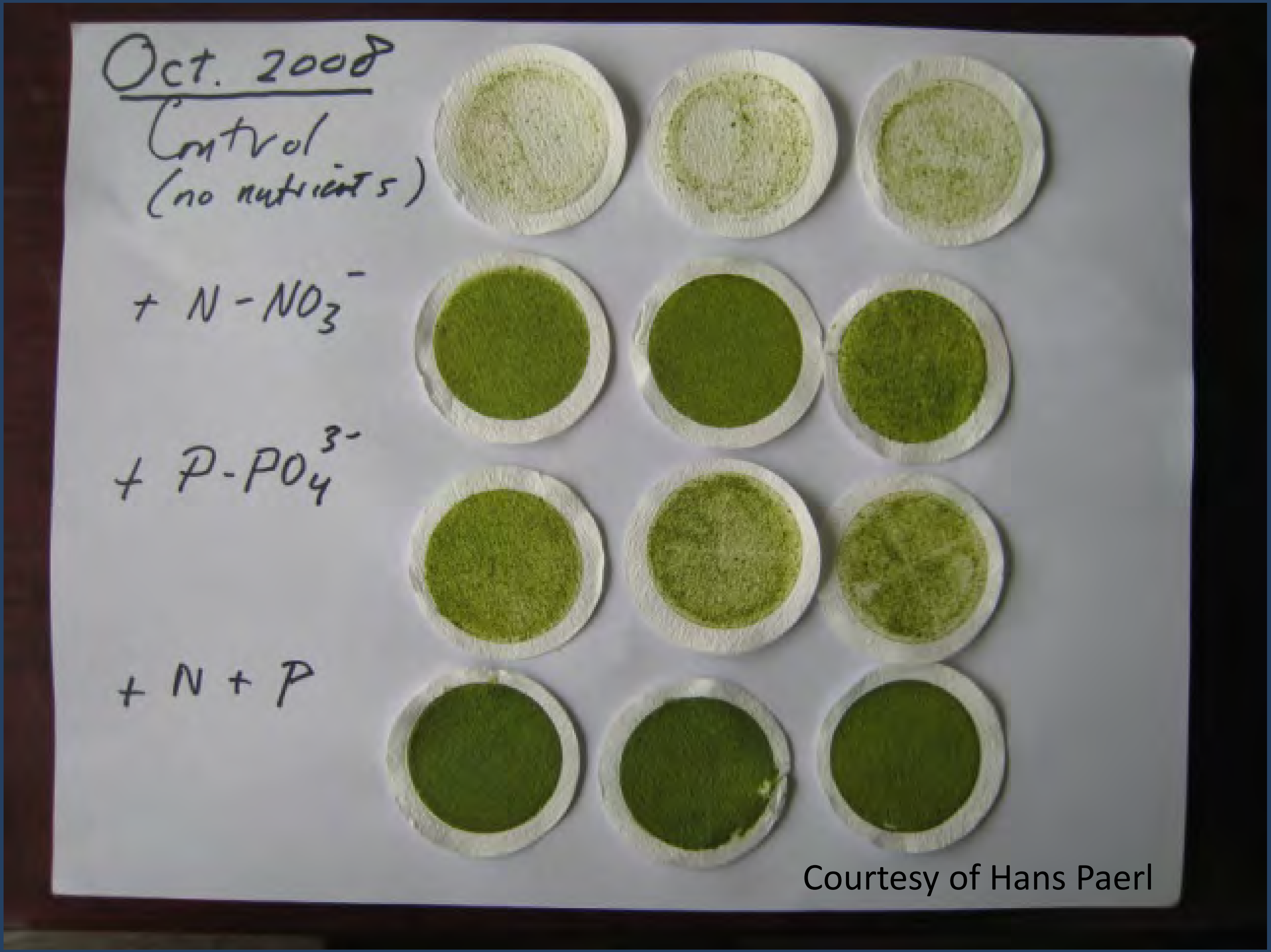
Ecosystem impacts from Nutrient loading

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

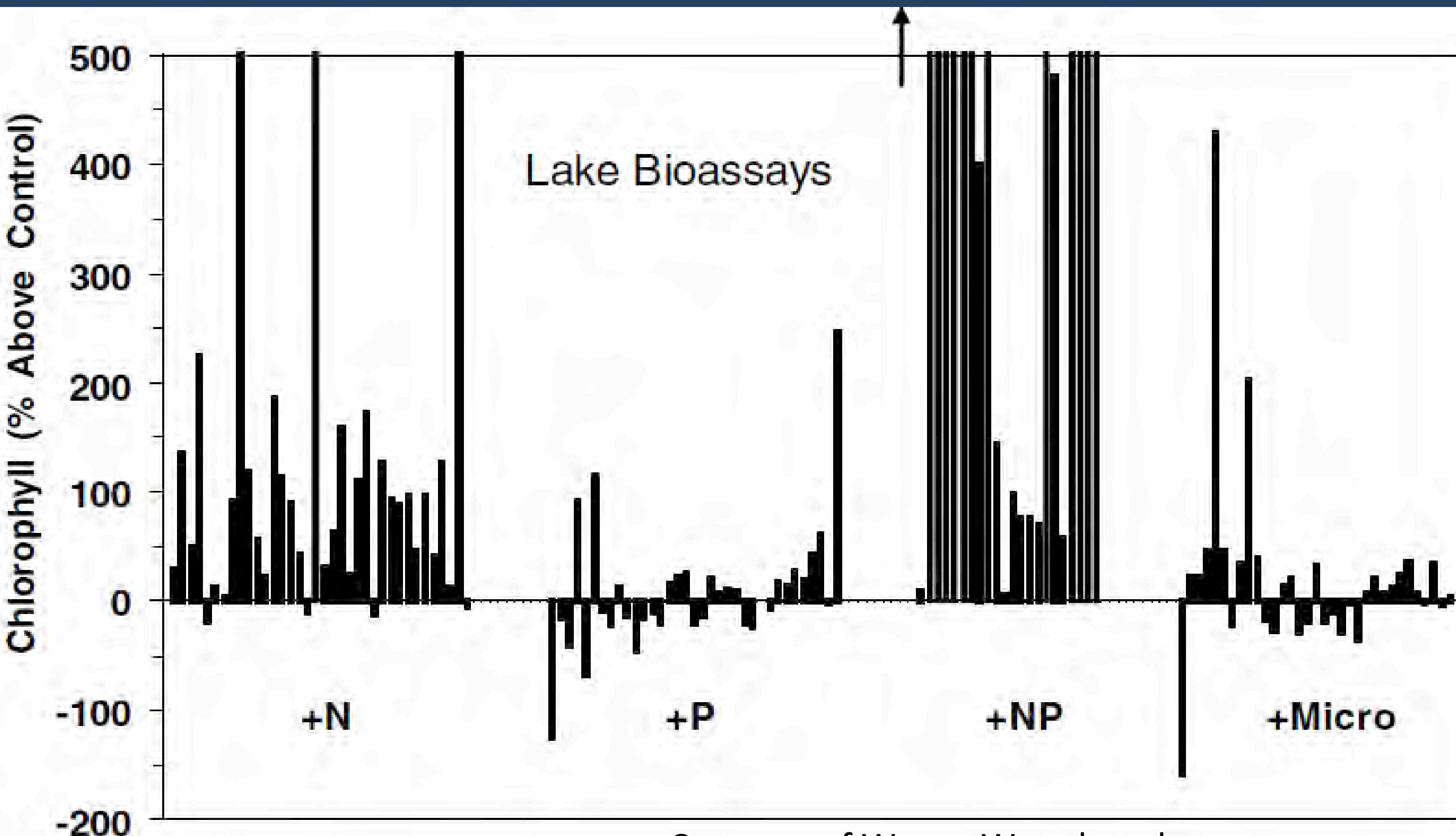
Daniel Hoffman

Anthropogenic N ≥ Biological N fixation

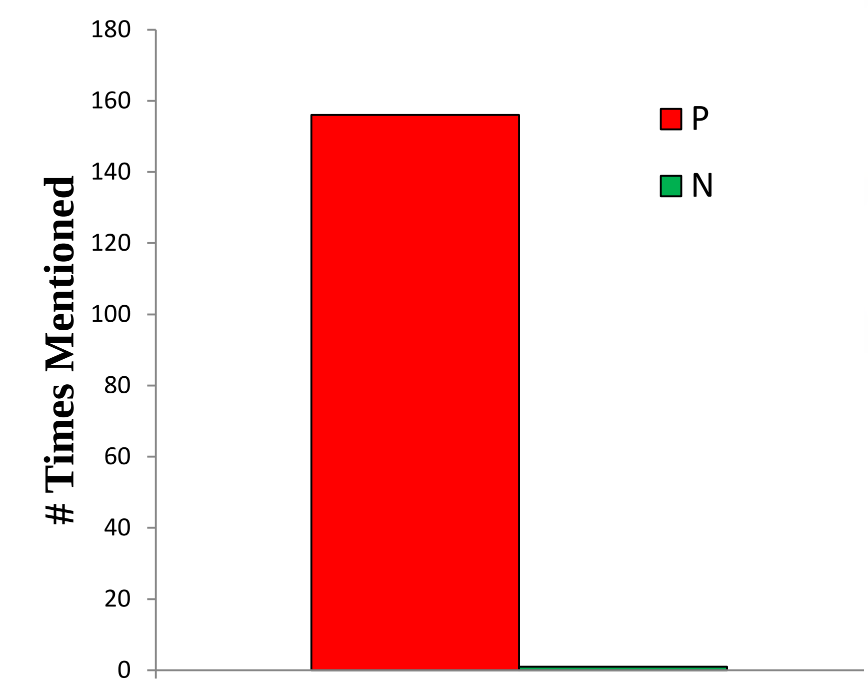



Oct. 2008
Control
(no nutrients)
+ N - NO_3^-
+ P - PO_4^{3-}
+ N + P
Courtesy of Hans Paerl

Nutrient Addition experiments



Courtesy of Wayne Wurtsbaugh



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Review

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

Donald Scavia [a,*], J. David Allan [b], Kristin K. Arend [c], Steven Bartell [d], Dmitry Beletsky [e], Nate S. Bosch [f], Stephen B. Brandt [g], Ruth D. Briland [h], Irem Daloğlu [b], Joseph V. DePinto [i], David M. Dolan [j], Mary Anne Evans [k], Troy M. Farmer [h], Daisuke Goto [l], Haejin Han [m], Tomas O. Höök [n], Roger Knight [o], Stuart A. Ludsin [h], Doran Mason [p], Anna M. Michalak [q], R. Peter Richards [r], James J. Roberts [s], Daniel K. Rucinski [b,i], Edward Rutherford [p], David J. Schwab [t], Timothy M. Sesterhenn [n], Hongyan Zhang [e], Yuntao Zhou [q,u]

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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.

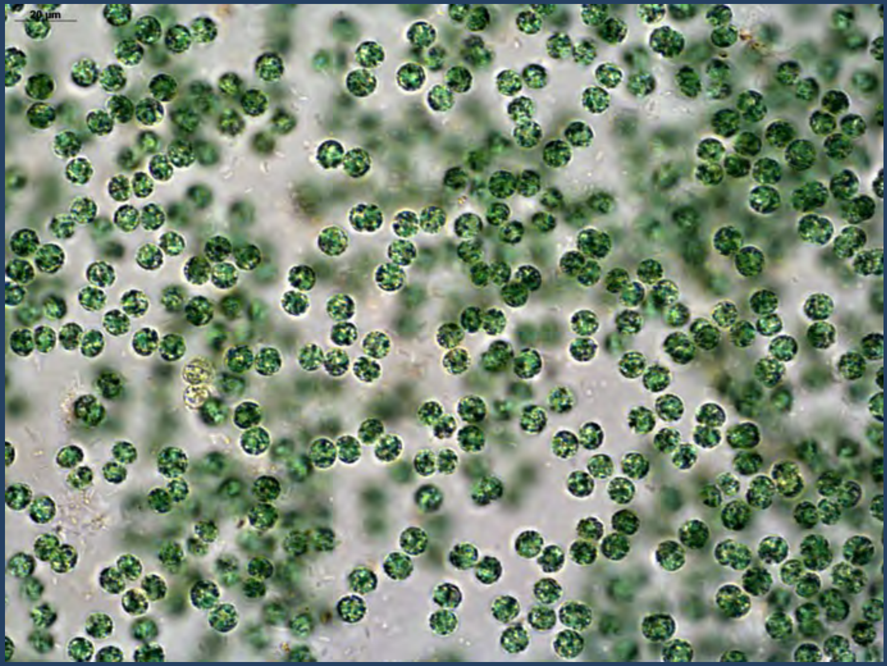
Almost 6 per page of text

Cyanobacteria = 16
Microcystis = 5

Community Dominance: Lake Erie cyanobacterial Harmful Algals Blooms

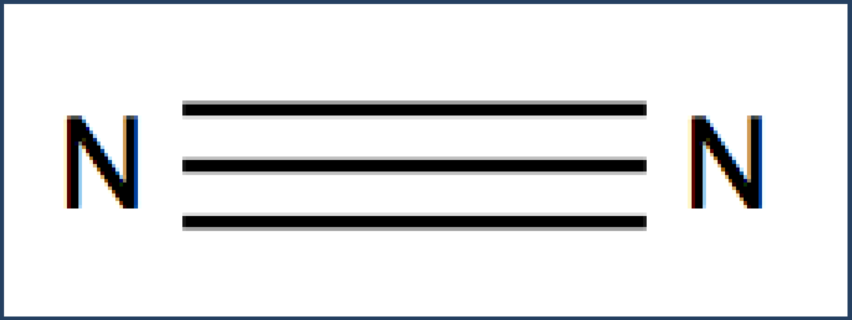
1960s and 1970s

1990s to Present



From http://cyanobacteria.myspecies.info

N Bioavailability



Triple bond -> difficult to break

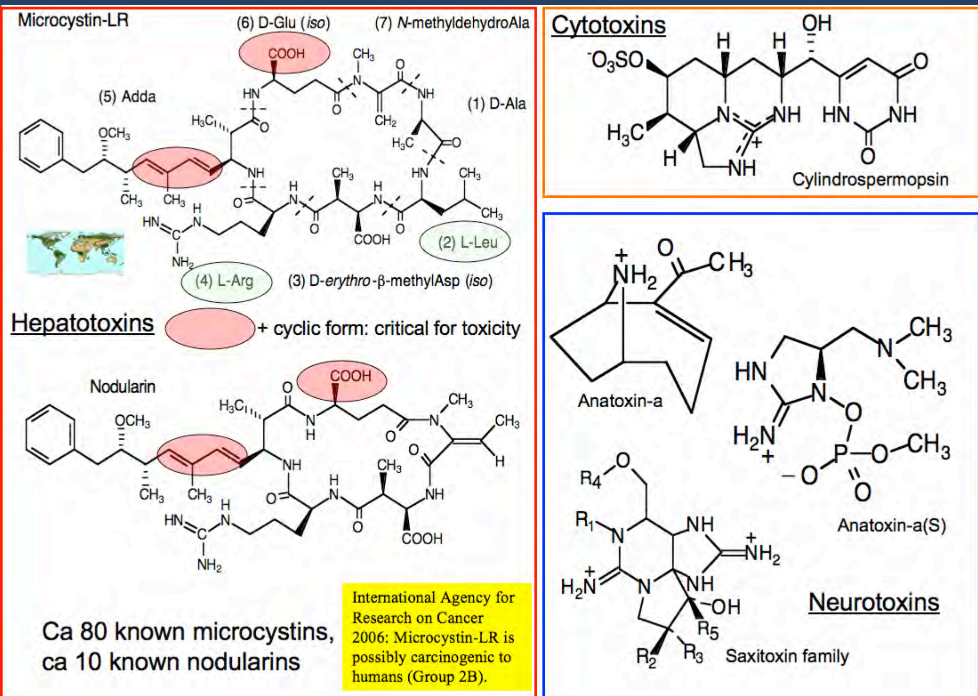
18 ATP required for each N_2 molecule

N_2: limited bioavailability

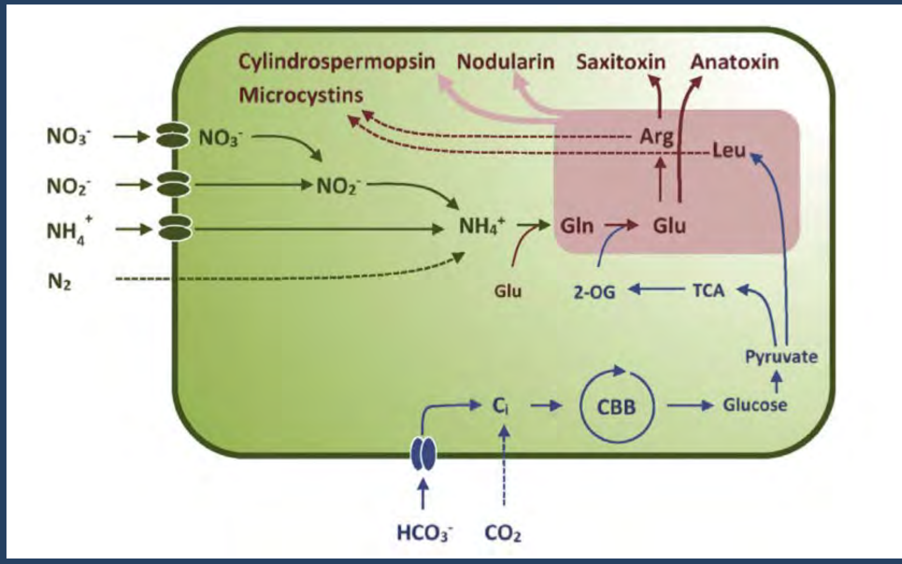
More useful forms:

NH_4^+, Urea, NO_3^-

N and Cyanobacteria Toxicity



© Jussi Meriluoto



Gobler et al. 2016

N and Cyanobacteria Toxicity

- Reduced N form additions to **non-N-fixing** cyanobacteria can increase toxicity.

(Davis et al. 2010, 2015; Chaffin et al. 2018)

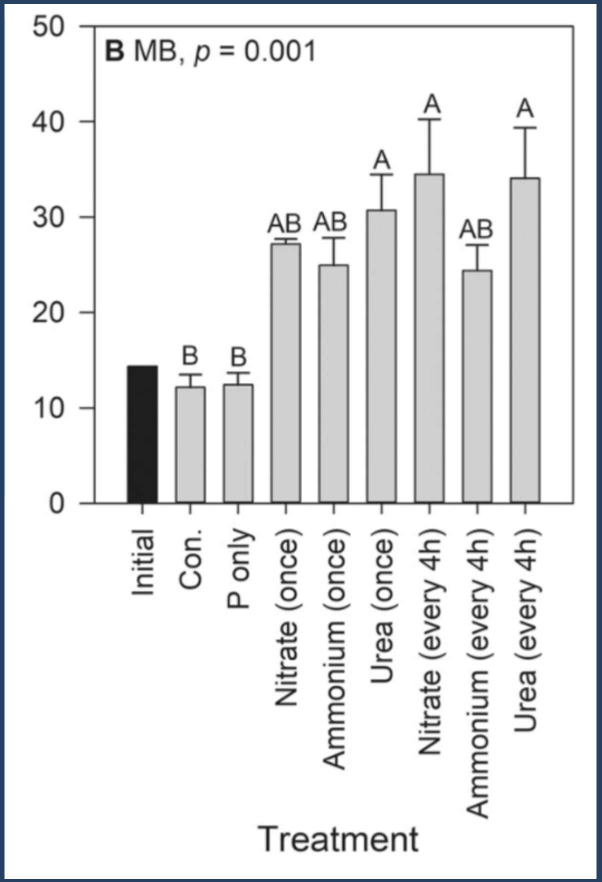
- Low NH_4^+ concentrations can inhibit toxin production

  (Kuniyoshi et al. 2010)

- NH_4^+ and urea uptake may lead to both increased *Microcystis* biomass and toxin production

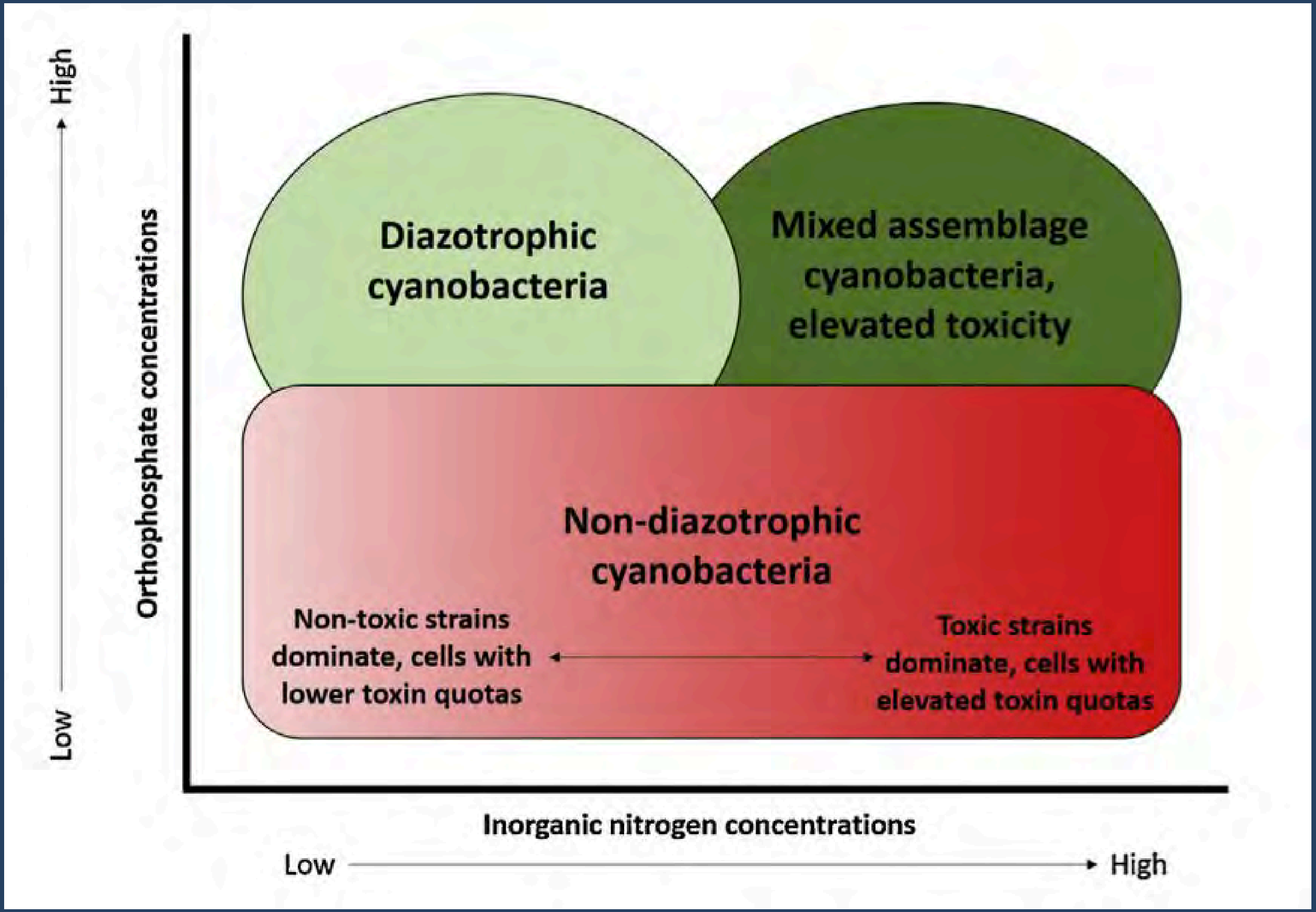
  (Harke et al. 2016)

Microcystins (µg/L)



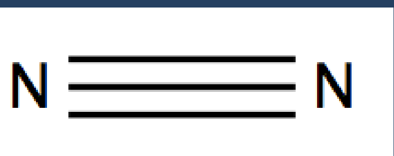
Chaffin et al. 2018

Implications for Community Shift



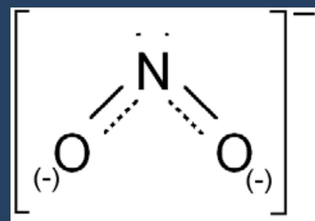
Gobler et al. 2016

Nitrogen



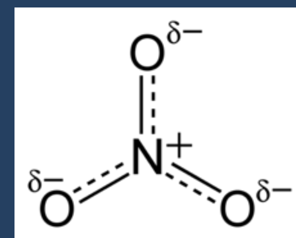
N_2

Dinitrogen Gas



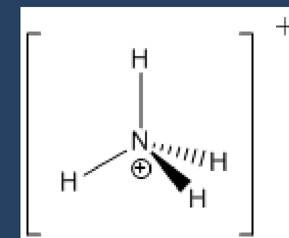
NO_2^-

Nitrite



NO_3^-

Nitrate

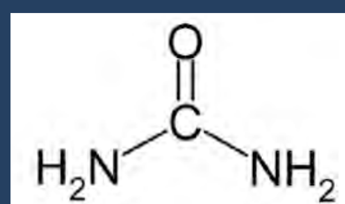


NH_3/NH_4^+

Ammonia/Ammonium

DON

Dissolved Organic N



Urea

N_2O

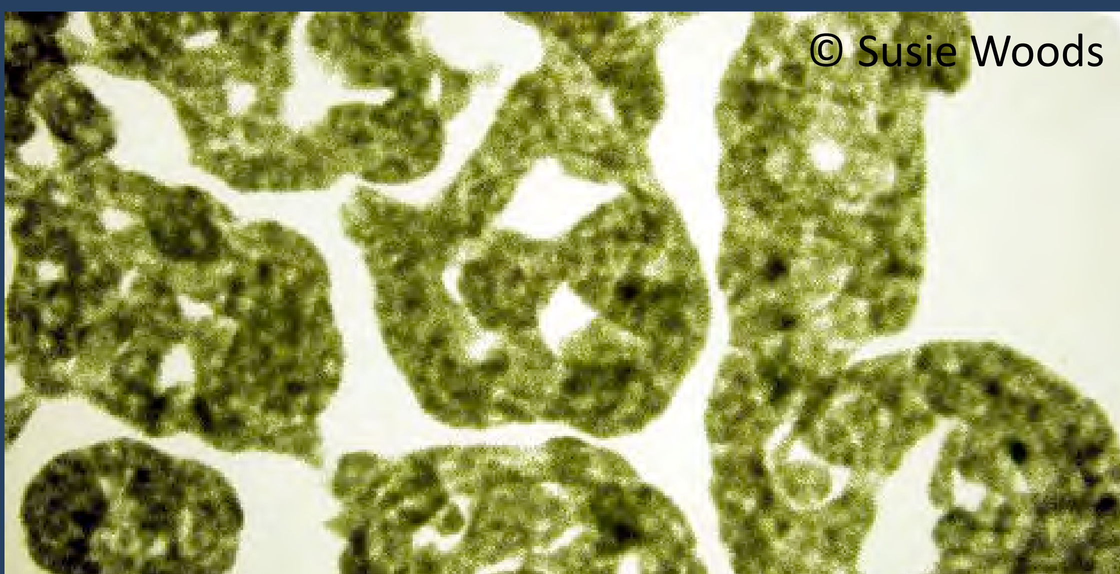
Nitrous Oxide

DIN

Dissolved Inorganic N

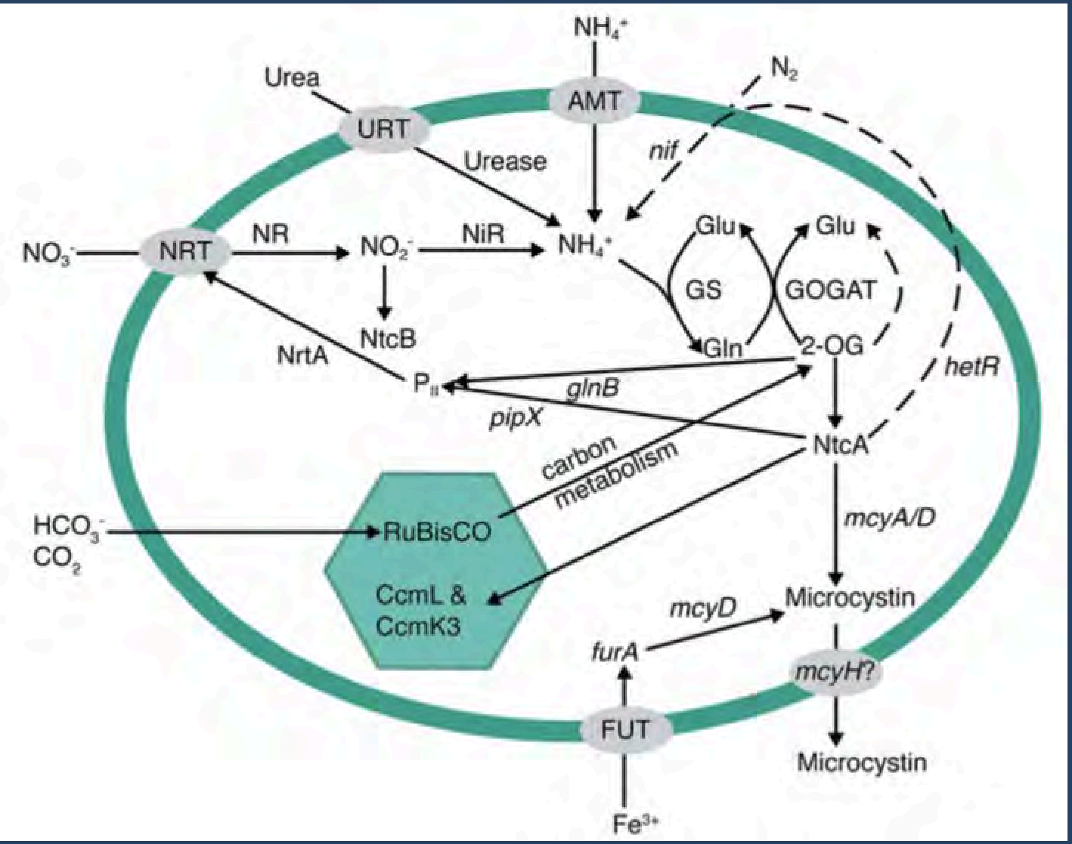
Ammonium: the common currency

Diatoms use and store nitrate efficiently

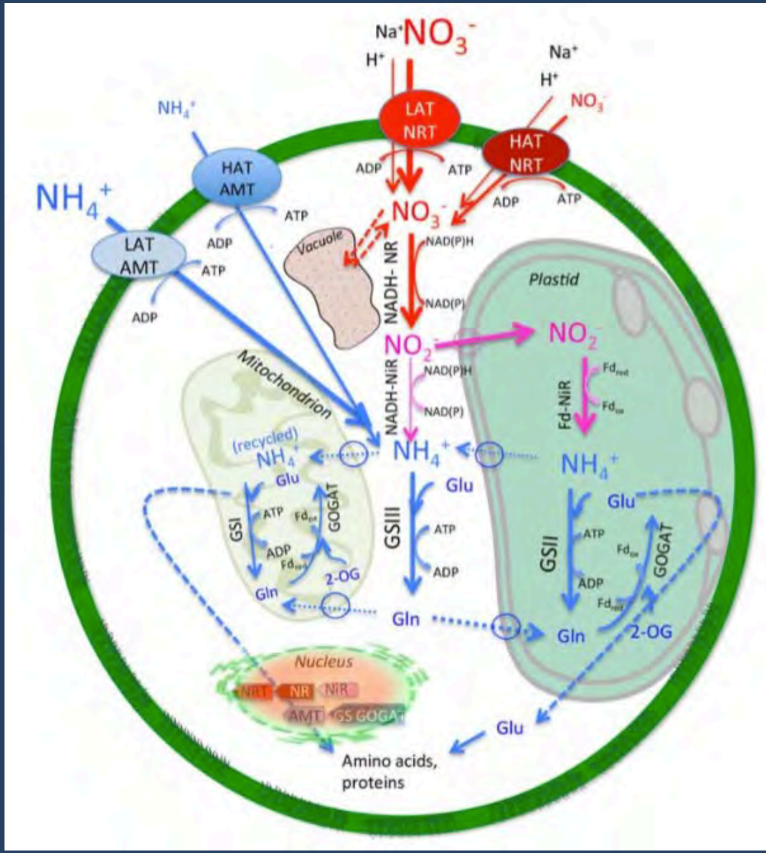


Most phytos greatly prefer *& Microcystis* has a very strong affinity for NH_4^+

N Assimilation in Phytoplankton



Beversdorf et al. 2015

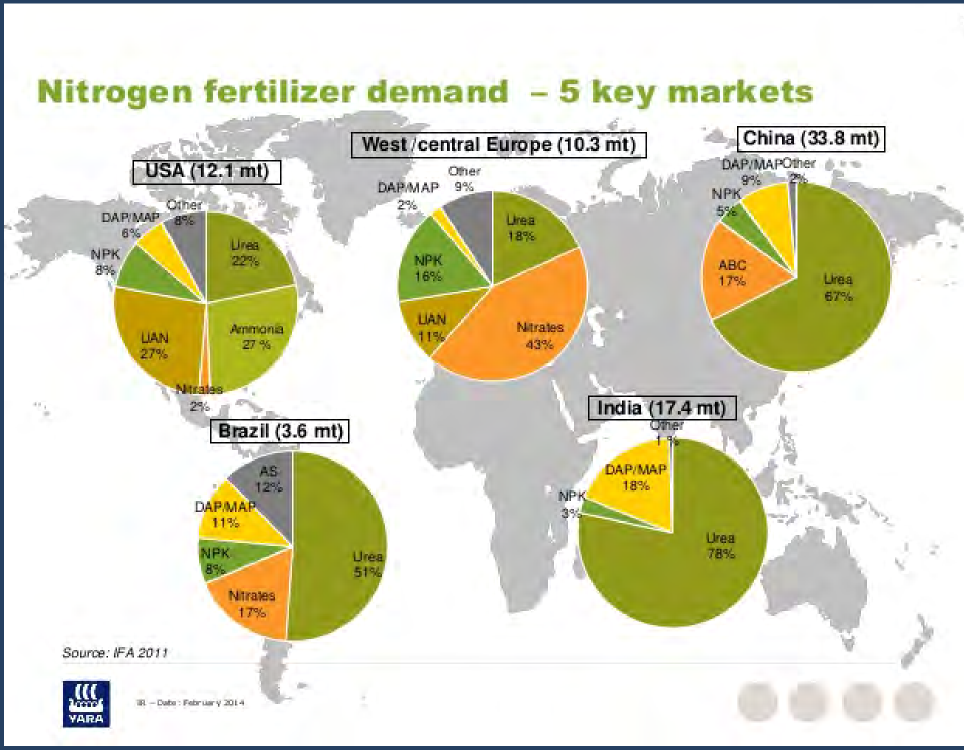


Glibert et al. 2015

N in Fertilizer

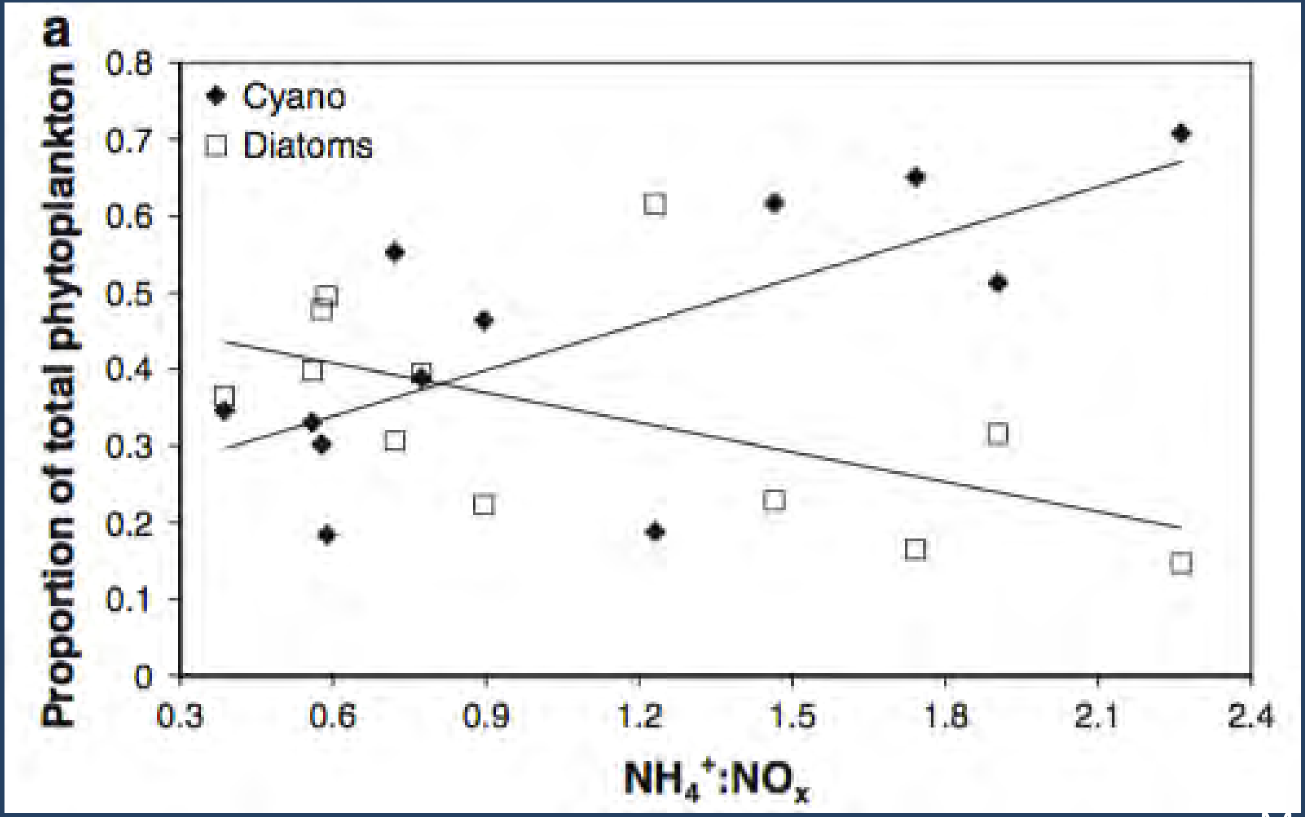
Global shift toward urea and/or anhydrous ammonia.

Urea = >50% of worldwide applications
(Glibert et al. 2006)



N Form and Community Structure

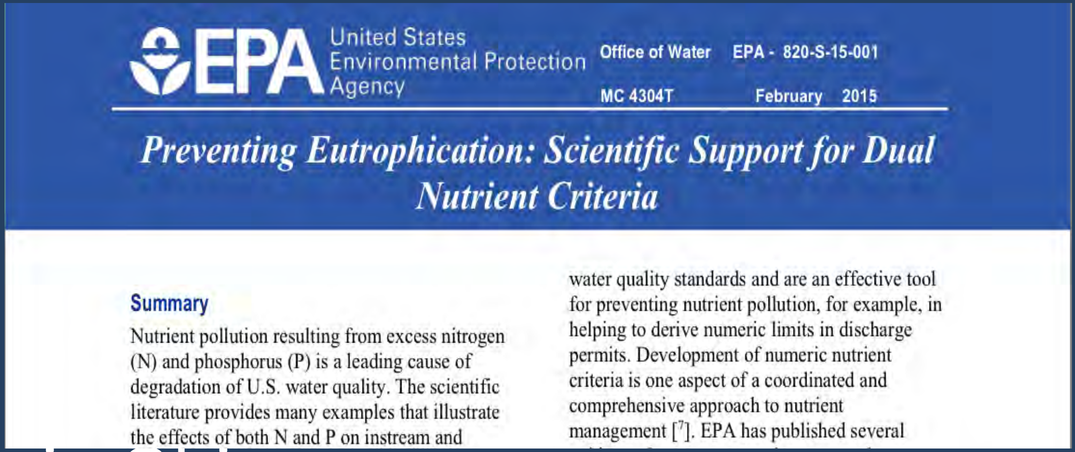
- NO_3^- : favors diatoms
- Reduced N (NH_4^+ and urea): favors cyanobacteria



McCarthy et al. 2009

(Limited) Regulations on N Inputs

- U.S. EPA Bulletin 820-S-15-001
  Advocates for <u>dual nutrient</u> control strategy



EPA United States Environmental Protection Agency

Office of Water EPA - 820-S-15-001

MC 4304T February 2015

Preventing Eutrophication: Scientific Support for Dual Nutrient Criteria

Summary

Nutrient pollution resulting from excess nitrogen (N) and phosphorus (P) is a leading cause of degradation of U.S. water quality. The scientific literature provides many examples that illustrate the effects of both N and P on instream and

water quality standards and are an effective tool for preventing nutrient pollution, for example, in helping to derive numeric limits in discharge permits. Development of numeric nutrient criteria is one aspect of a coordinated and comprehensive approach to nutrient management [7]. EPA has published several

- No N reduction targets in Ohio
  Proposed 40% reduction in P loading
  Great Lakes Water Quality Agreement – Annex IV

Case study: Lake Erie

Maumee River

Increasing CyanoHABs in Western Lake Erie linked to increase in SRP

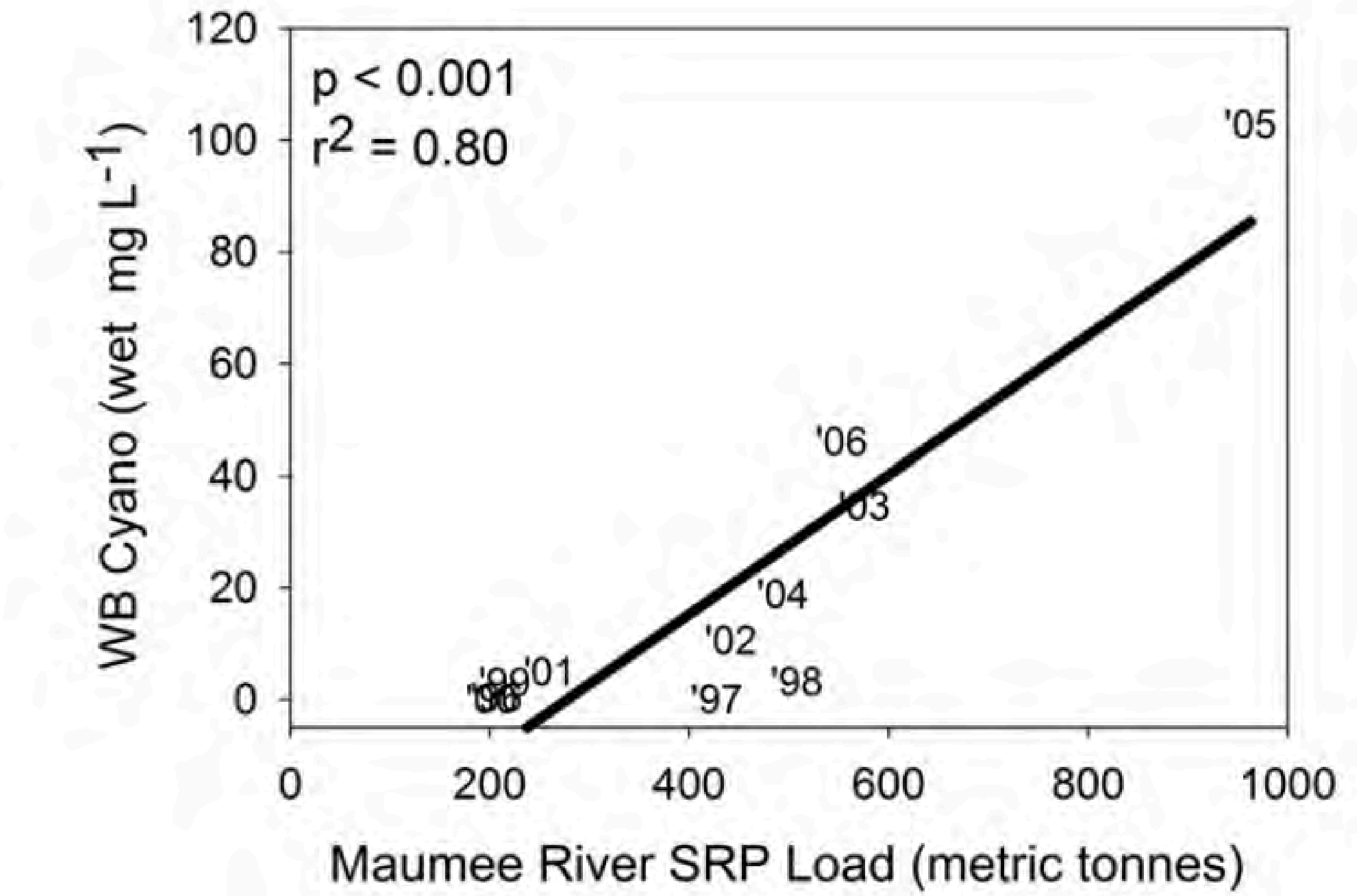
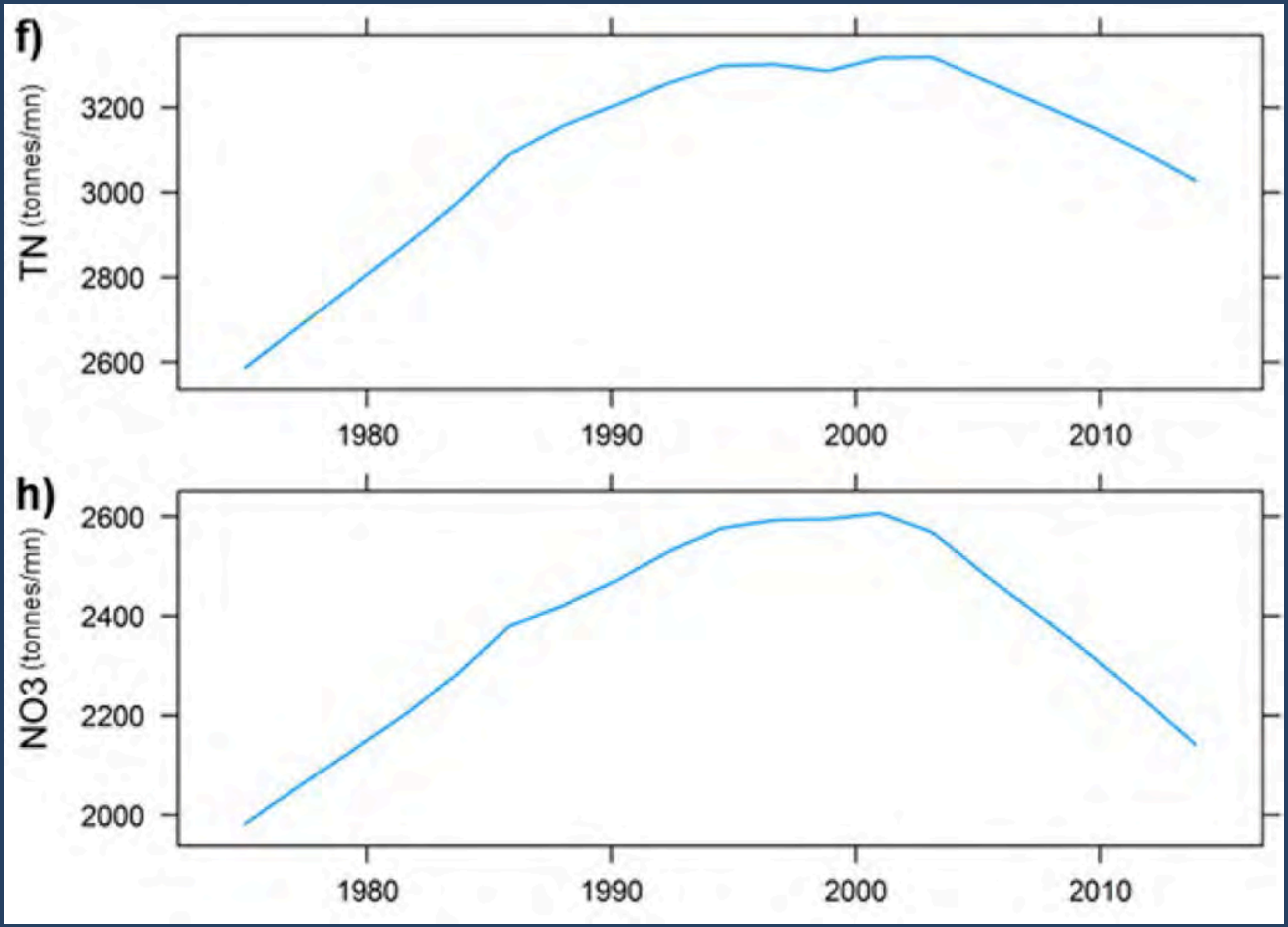


Fig. 4. Western basin (WB) median cyanobacteria wet-weight biomass (mg L^{-1}) (Cyano) as a function of Maumee River SRP load (metric tonnes) for water years 1996–2006.

Maumee N Loads to Western Lake Erie



Stow et al. 2015

N Inputs to Western Lake Erie

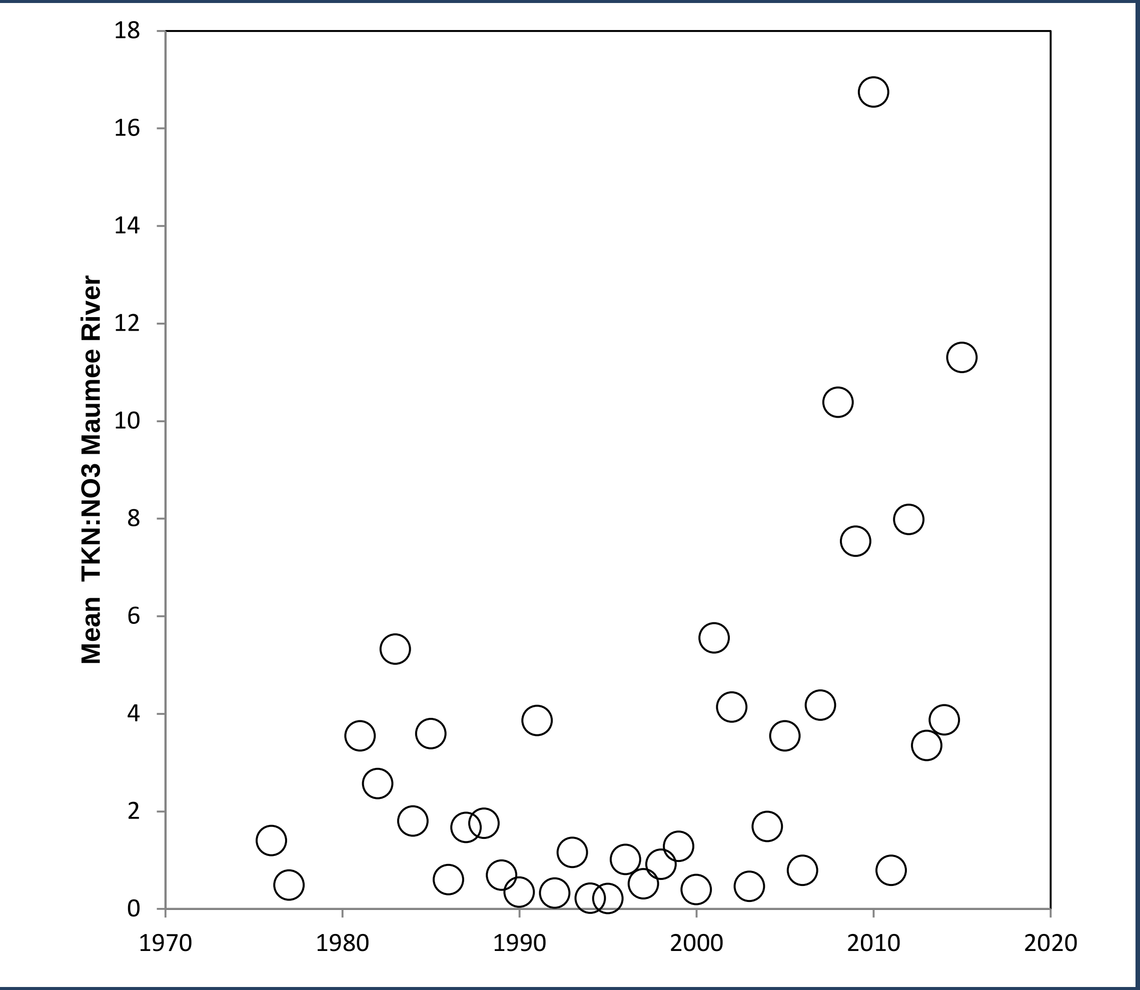
- Maumee River: largest Great Lakes watershed
- Kjeldahl N (NH_4^+ + organic N) load from Maumee River to Lake Erie

  = 9000 metric tons/yr

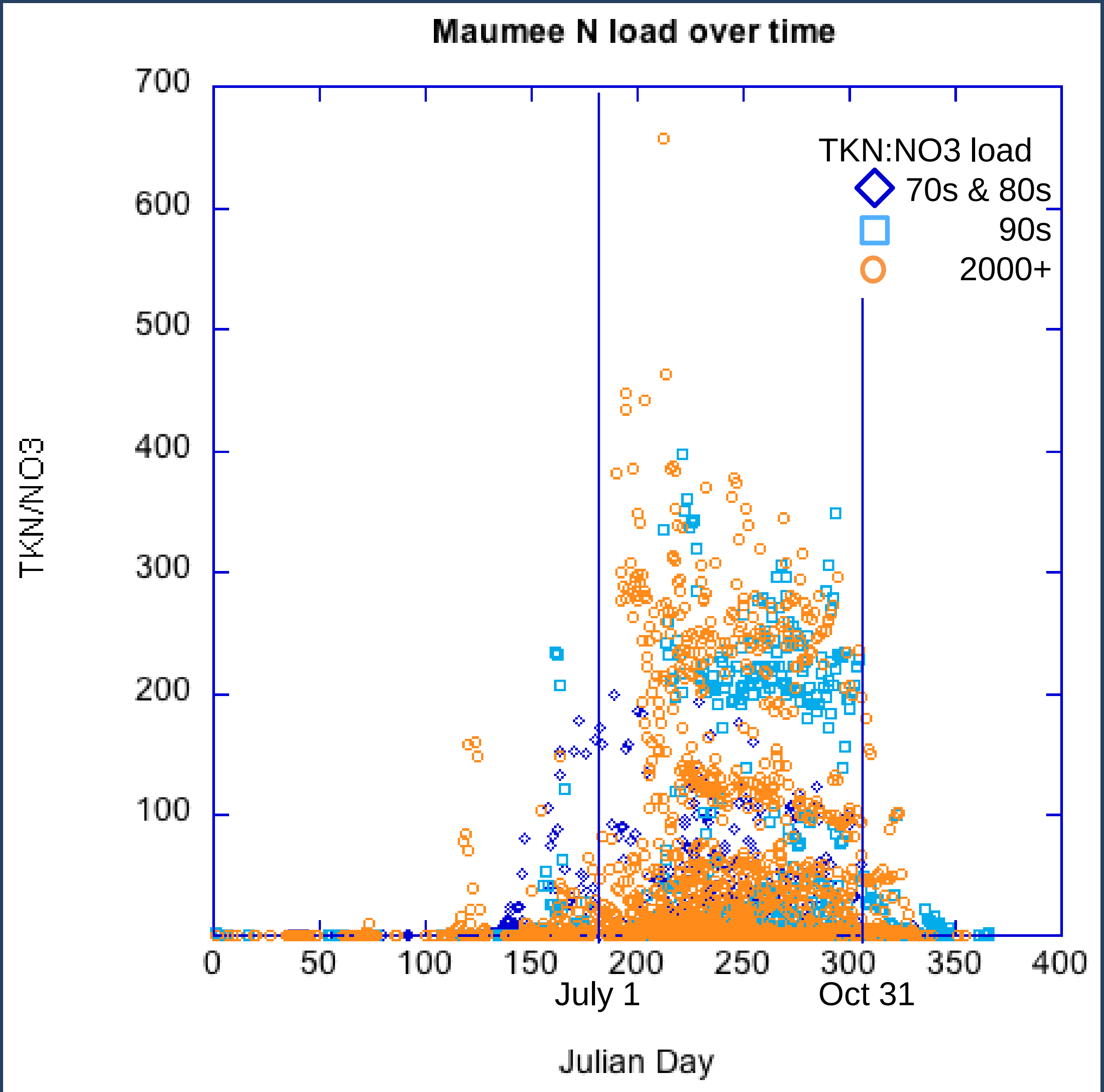
  ¼ of total N load

  (Richards et al. 2010)

Reduced N % of Maumee Load increasing



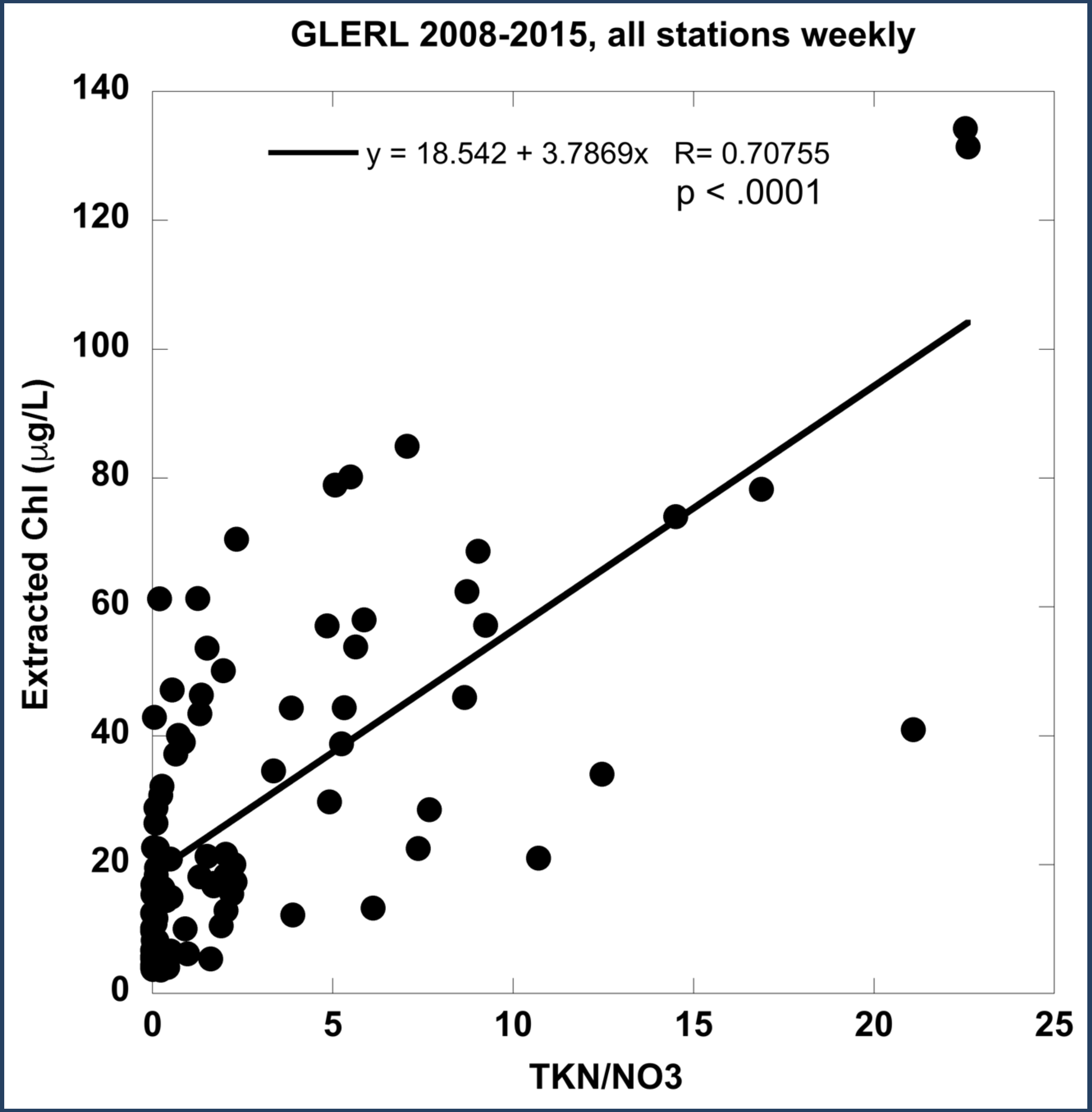
Newell et al., 2019



*Most values outside of summer are <1; y-axis scale starts at 1

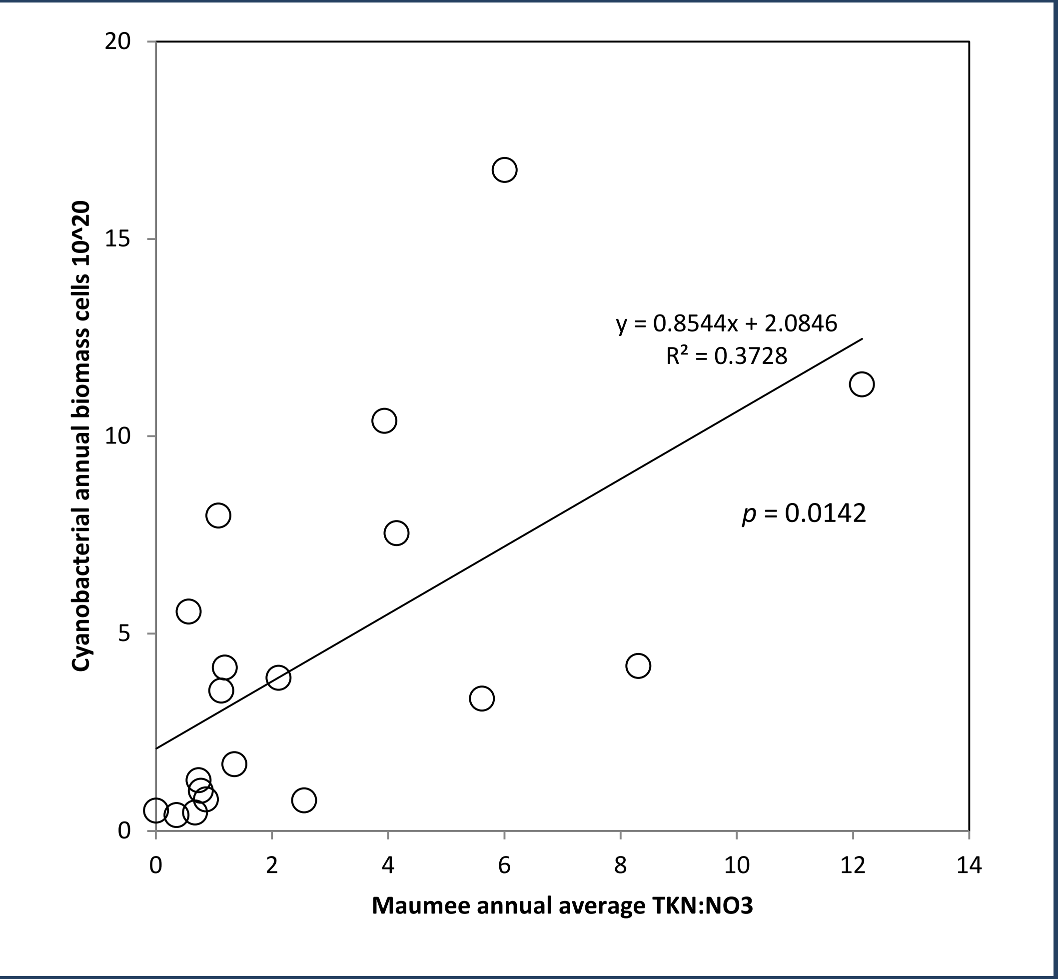
Newell et al., 2019

TKN/NO_3^- vs Chlorophyll concentrations



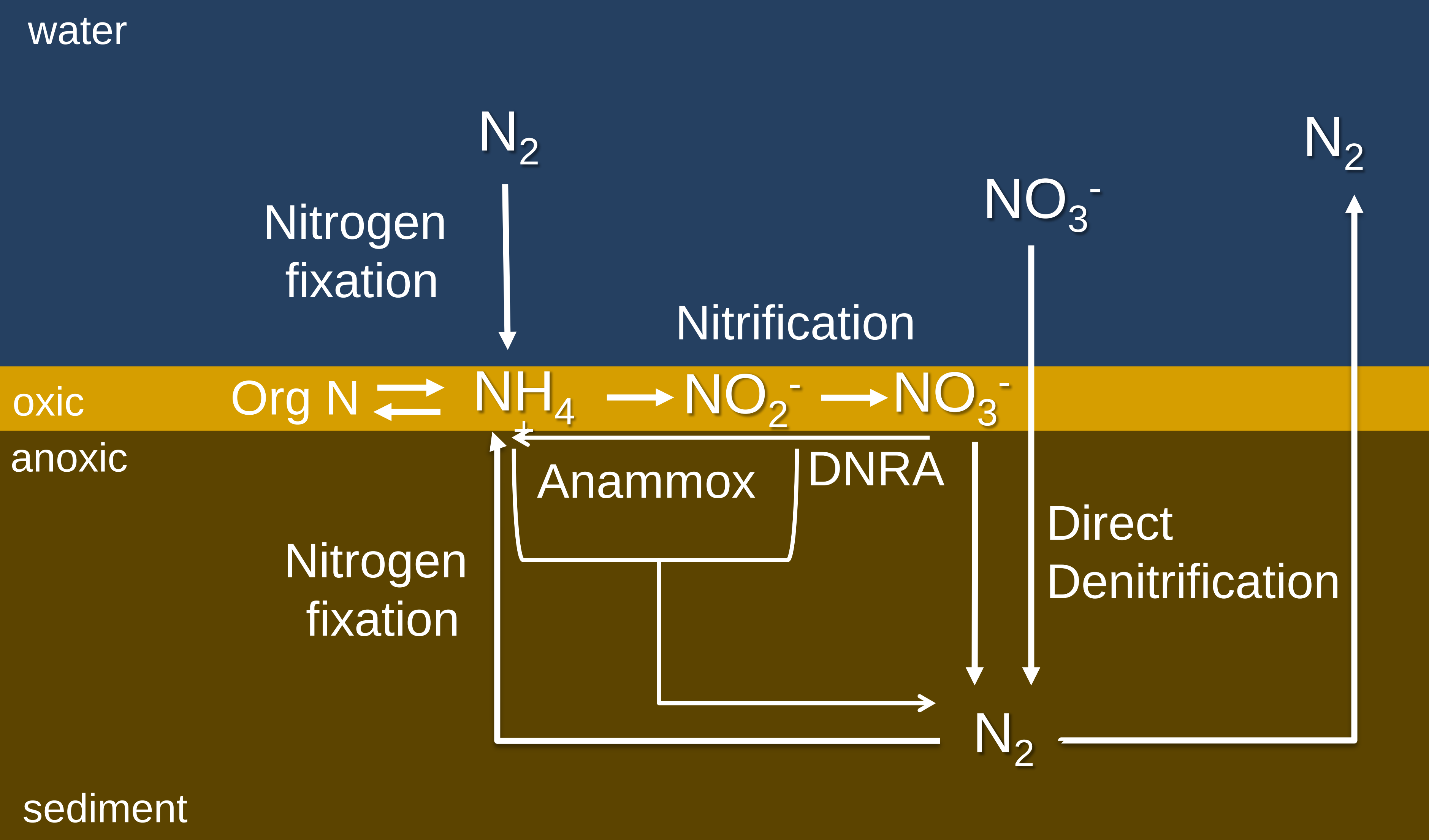
Newell et al., 2019

The proportion of reduced to oxidized N in the Maumee River load is significantly correlated to the increase in cyanobacterial bloom biomass in Western Lake Erie.



Newell et al., 2019

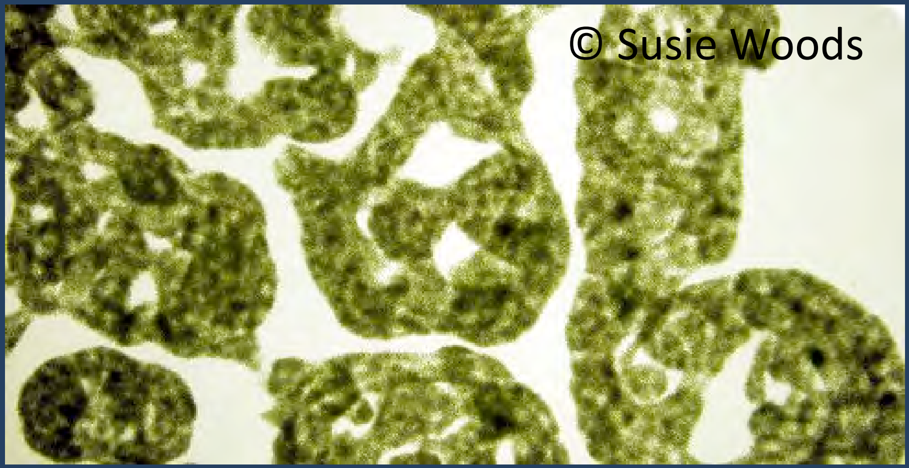
Nitrogen Cycle



Newell Lab research objectives

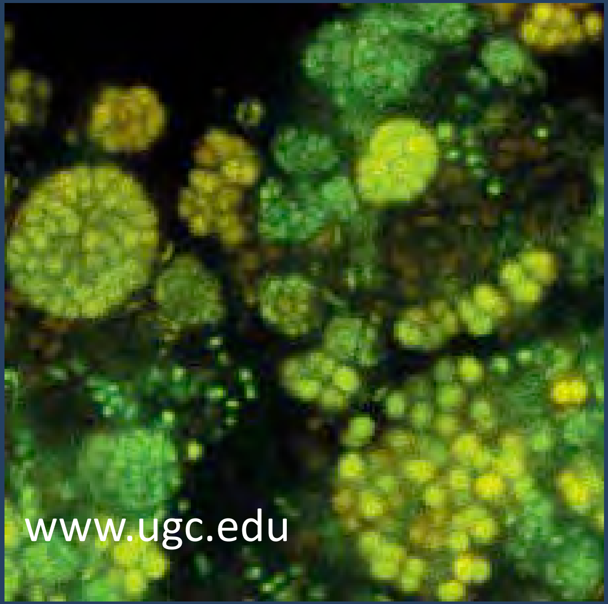
- To use a paired molecular-biogeochemical approach to disentangle the intricacies of the nitrogen cycle
- To understand the impact of human activities (primarily climate change and increased nitrogen loading) on the nitrogen cycle

Ammonium: the common currency



NH_4^+ half-saturation constant (K_m) for Microcystis is high: 0.5-37 µM

Nicklisch and Kohl 2007, Takeya et al. 2004



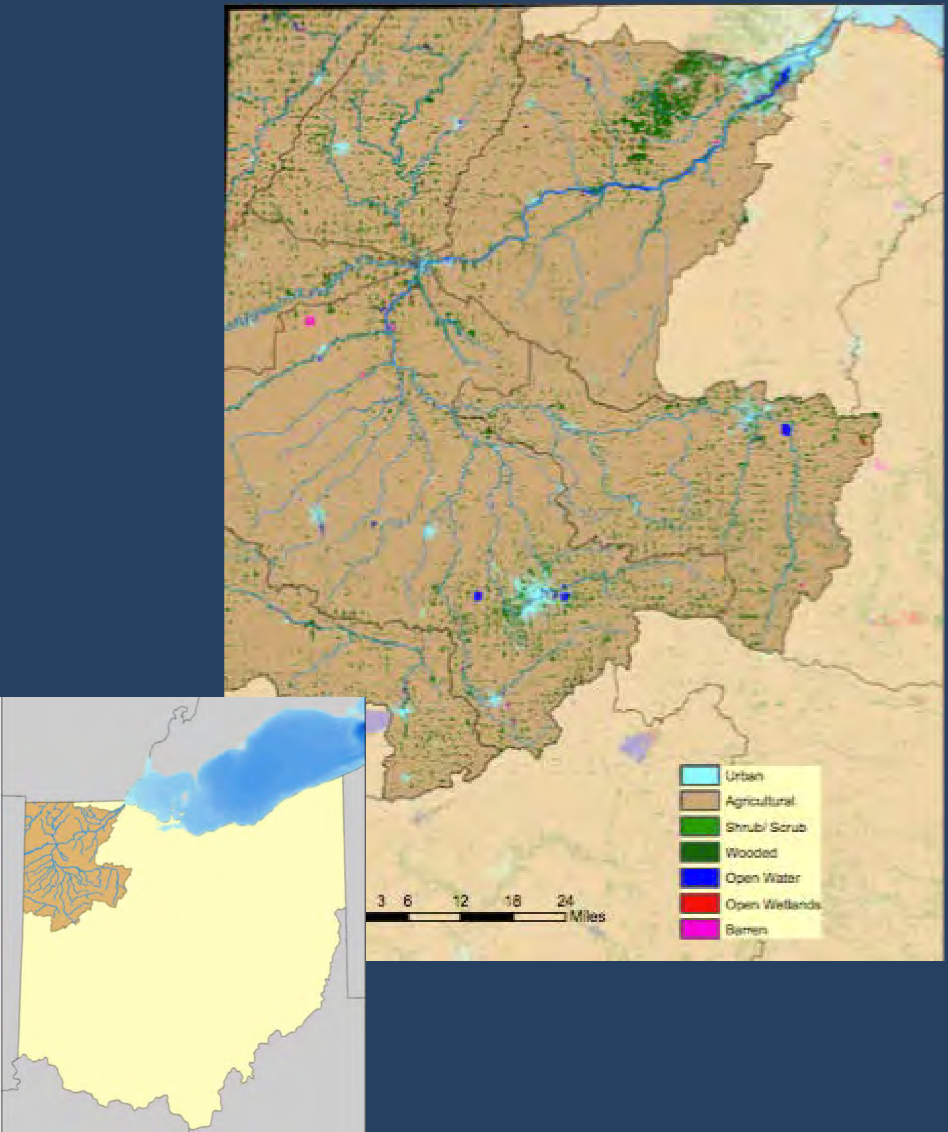
Ammonia-oxidizing bacteria can have a very high K_m (5-300 µM) but ammonia-oxidizing archaea have a very, very low K_m 0.05-0.15 µM

Internal N loading

Research Questions

- How quickly is NH_4^+ recycled?
- To what extent can NH_4^+ recycling support cyanobacterial bloom growth?
- When do phytoplankton become N-limited?

N Inputs to Western Lake Erie



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- Kjeldahl N (NH_4^+ + organic N) load from Maumee River to Lake Erie

  = 9000 metric tons/yr

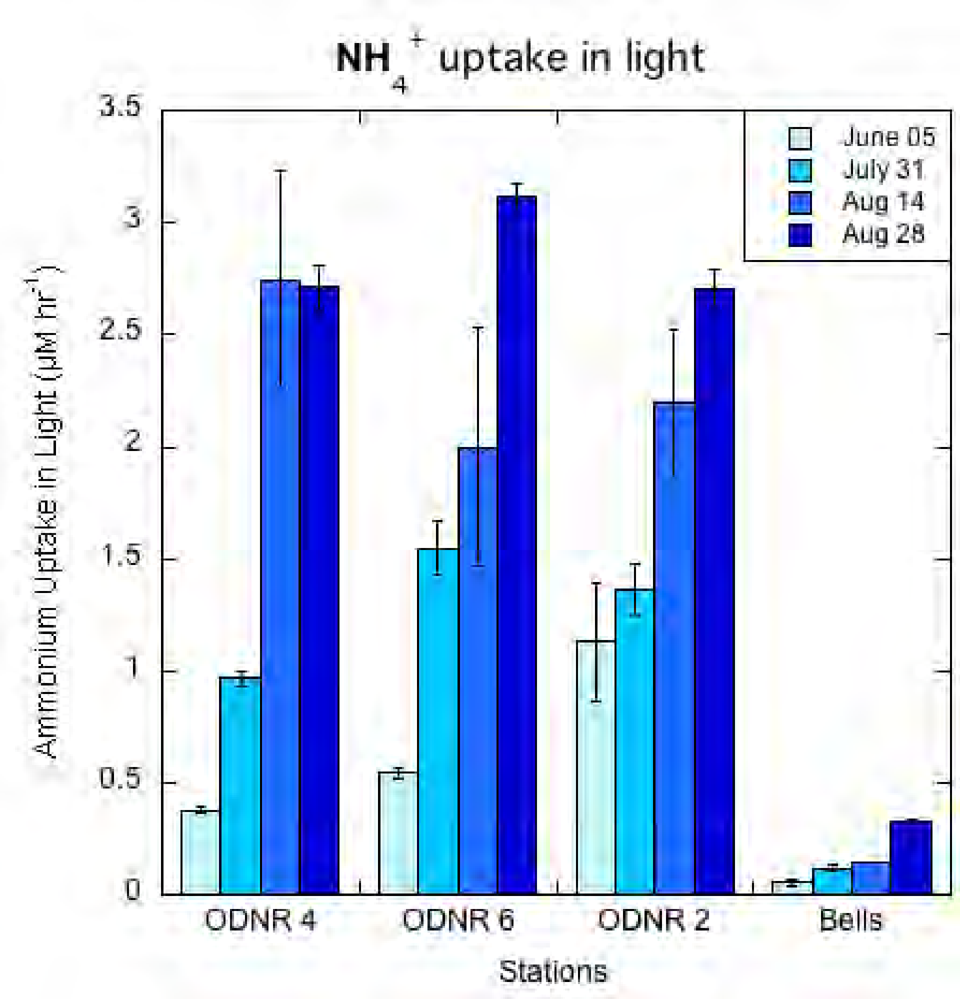
  ¼ of total N load

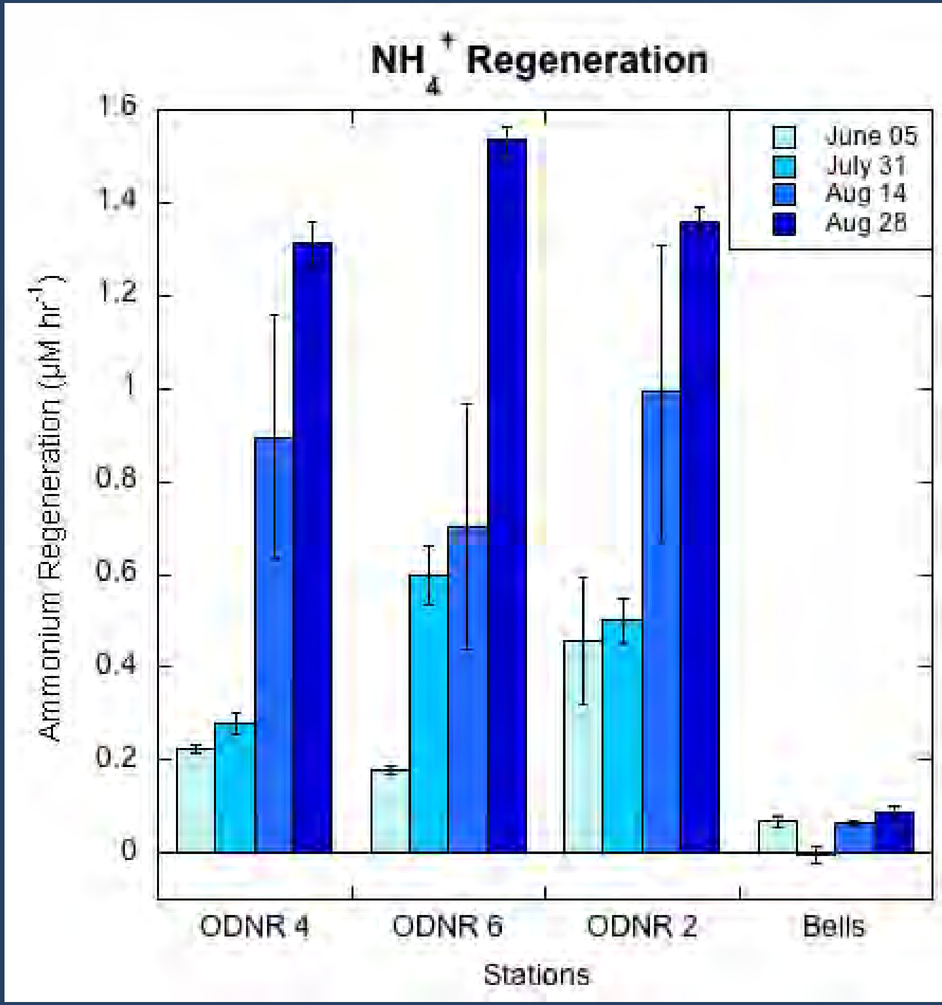
  (Richards et al. 2010)

Ammonium cycling drives harmful algal blooms in Sandusky Bay, Lake Erie

Justyna J. Hampel, Mark J. McCarthy, George S. Bullerjahn, Robert M. McKay, Michelle Neudeck, and Silvia E. Newell

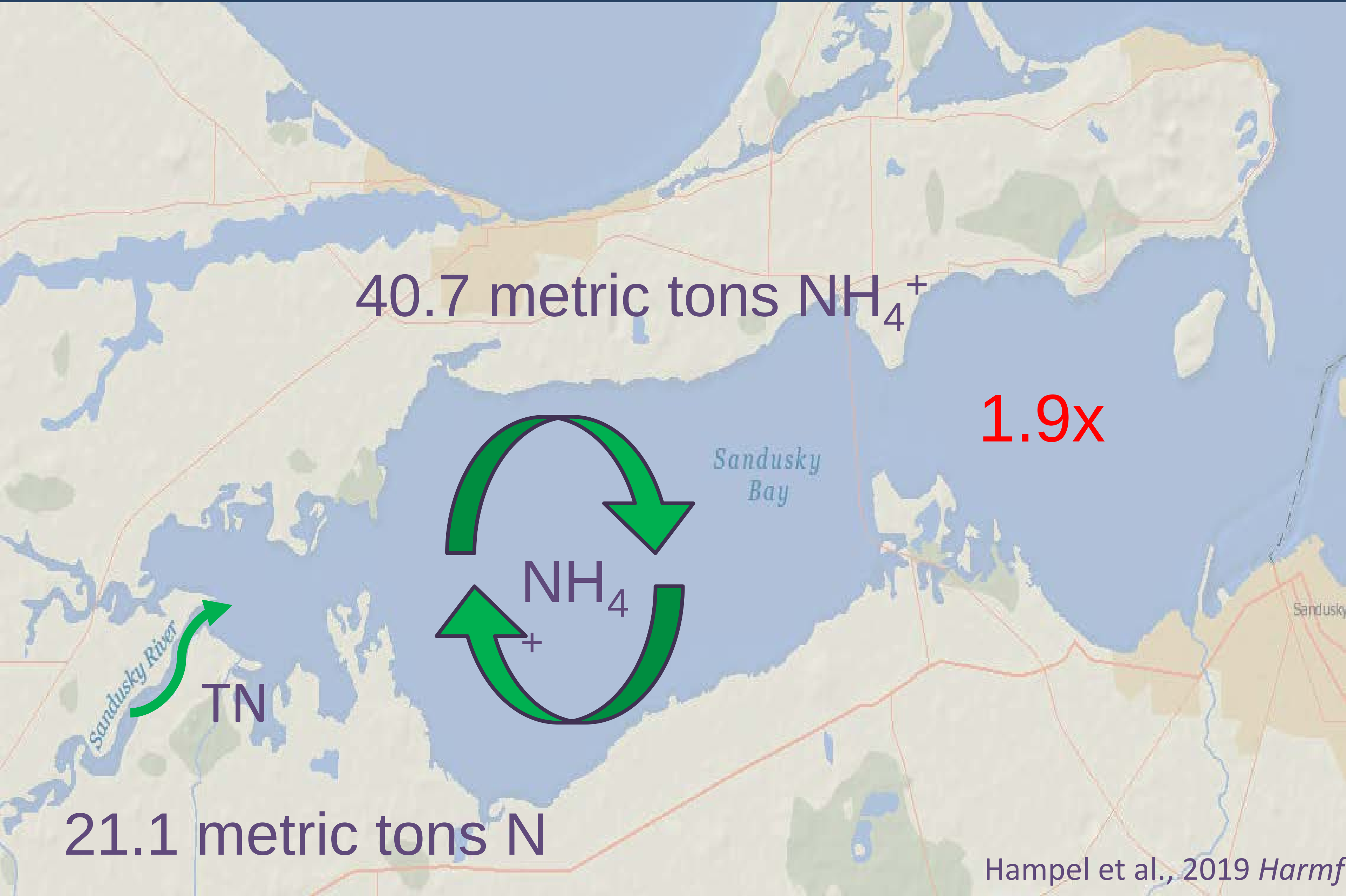
Sandusky Results: Potential Ammonium Uptake and Regeneration





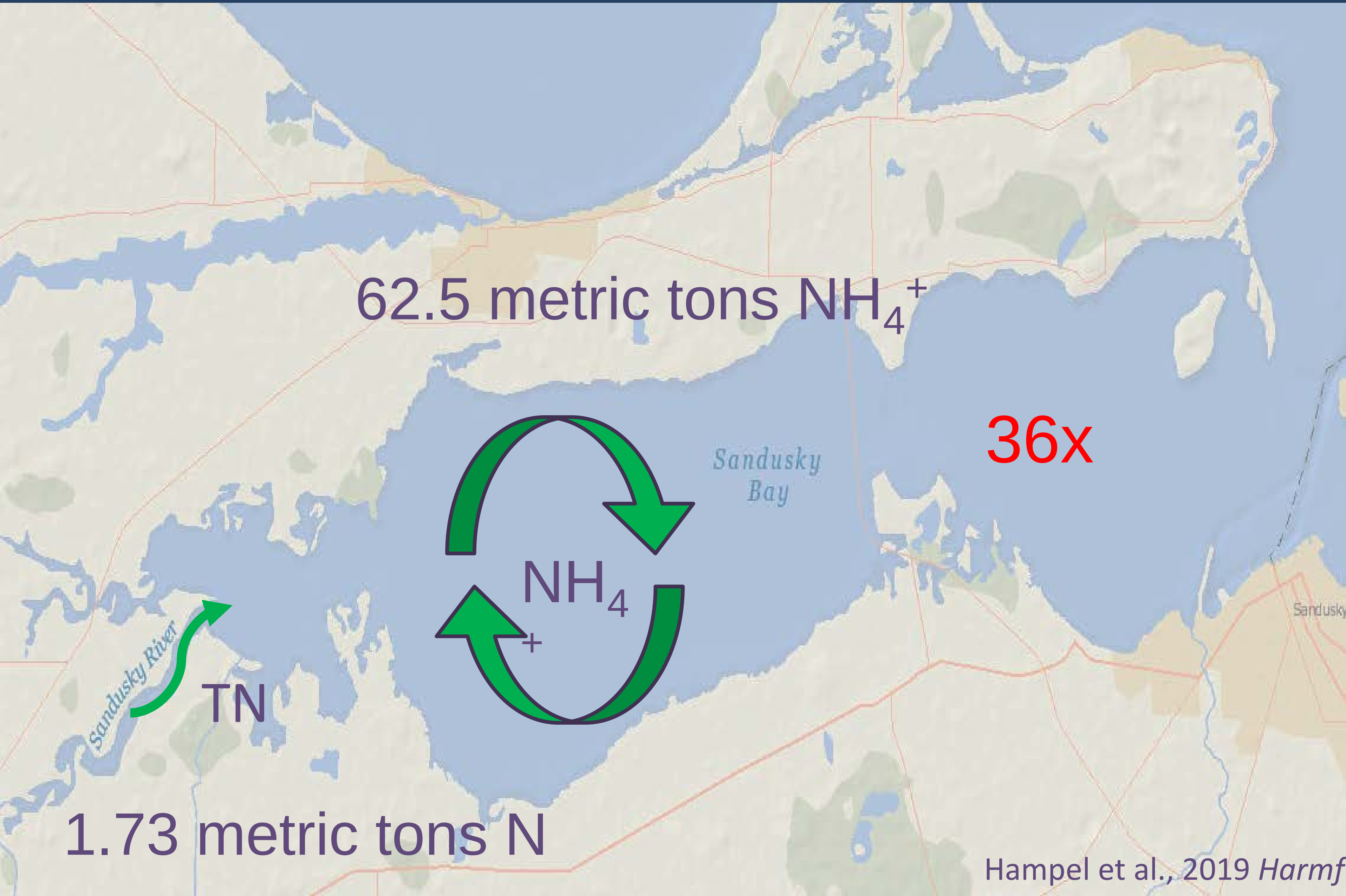
Hampel et al. 2019

June 5th, 2017



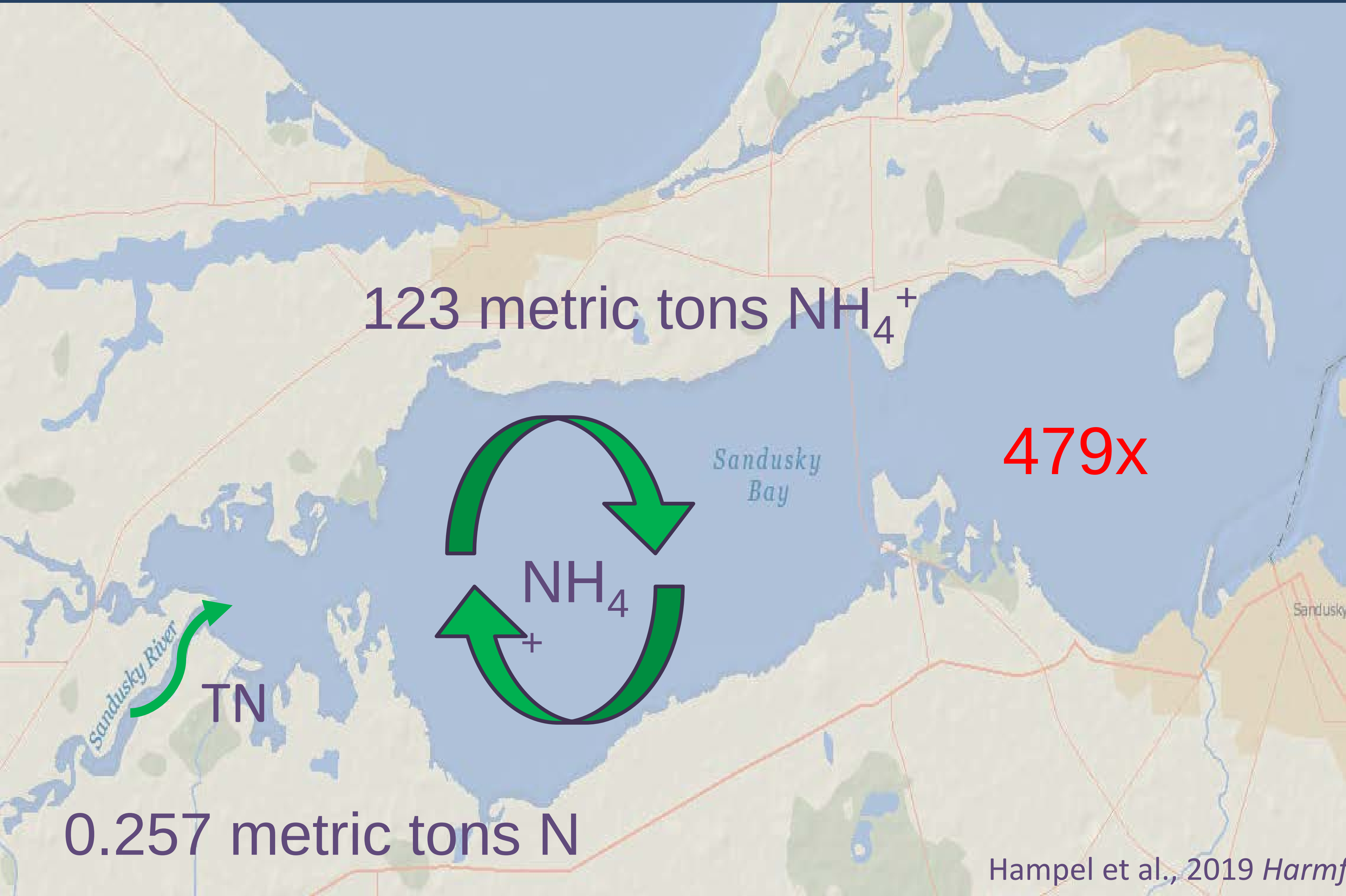
Hampel et al., 2019 *Harmf*

July 31st, 2017

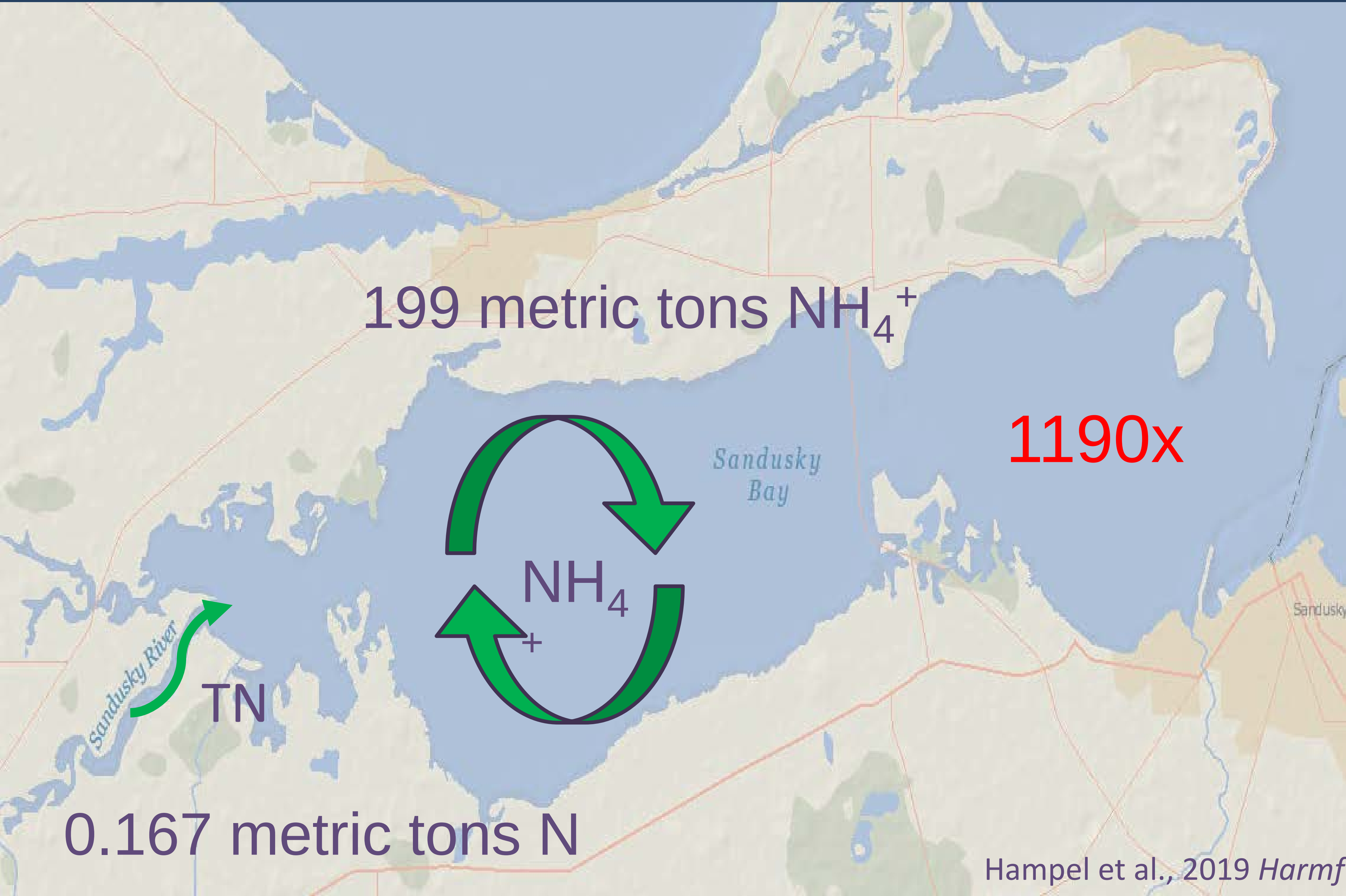


Hampel et al., 2019 *Harmf*

August 14th, 2017



August 28^{th}, 2017



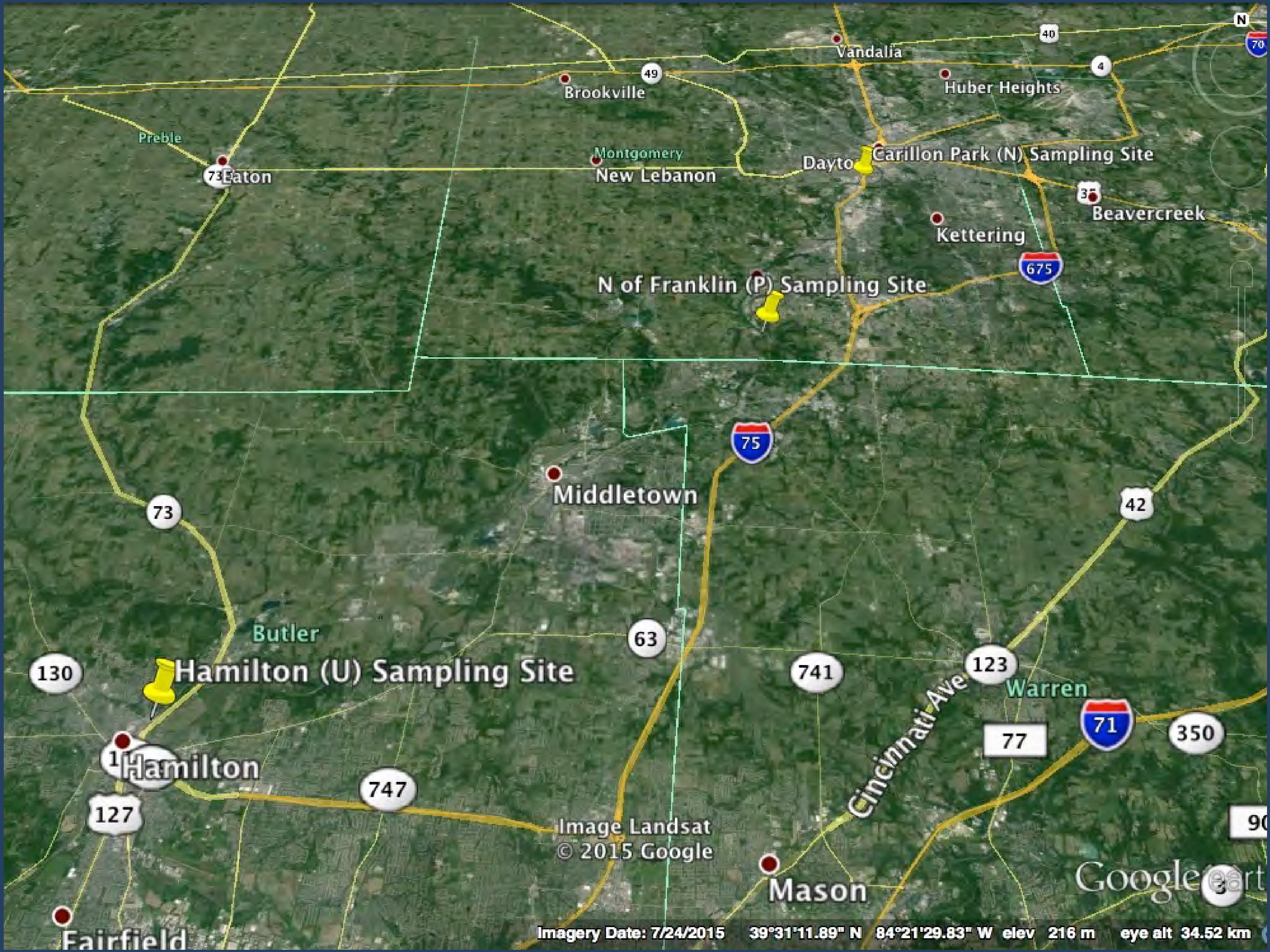
Hampel et al., 2019 *Harmf*

Sandusky Bay: Ammonium Regeneration

- Regeneration in the bay increases throughout the summer suggesting that toward the end of summer the bloom relies heavily on regenerated NH_4^+.
  - With undetectable DIN in the water column, regeneration sustains the bloom

- When extrapolated to the whole bay volume, daily NH_4^+ regeneration exceeded daily TN loadings at all sampling events.
  - Useful tool for N management practices and nutrient regulations.


Eutrophication in the Great Miami River:
To What Extent Can Sediment Nitrogen Loss
Compensate for Nutrient Over-enrichment?
Lee Slone, M.Sc. student – WSU
Slone et al. 2018
Slone et al., 2018



Vandalia
Huber Heights
Brookville
Preble
Eaton
Montgomery
New Lebanon
Dayto
Carillon Park (N) Sampling Site
Beavercreek
Kettering
N of Franklin (P) Sampling Site
675
75
Middletown
73
42
Butler
63
130
Hamilton (U) Sampling Site
741
123
Cincinnati Ave
Warren
77
71
350
Hamilton
747
127
Image Landsat
© 2015 Google
Mason
Fairfield
Imagery Date: 7/24/2015 39°31'11.89" N 84°21'29.83" W elev 216 m eye alt 34.52 km

Collect intact sediment cores and near-bottom water for continuous-flow incubations to measure SWI N fluxes and transformations.

Photos courtesy of Nate Christopher at Fondriest Env.


LGMR 9.3.15
Site 1 Core C1

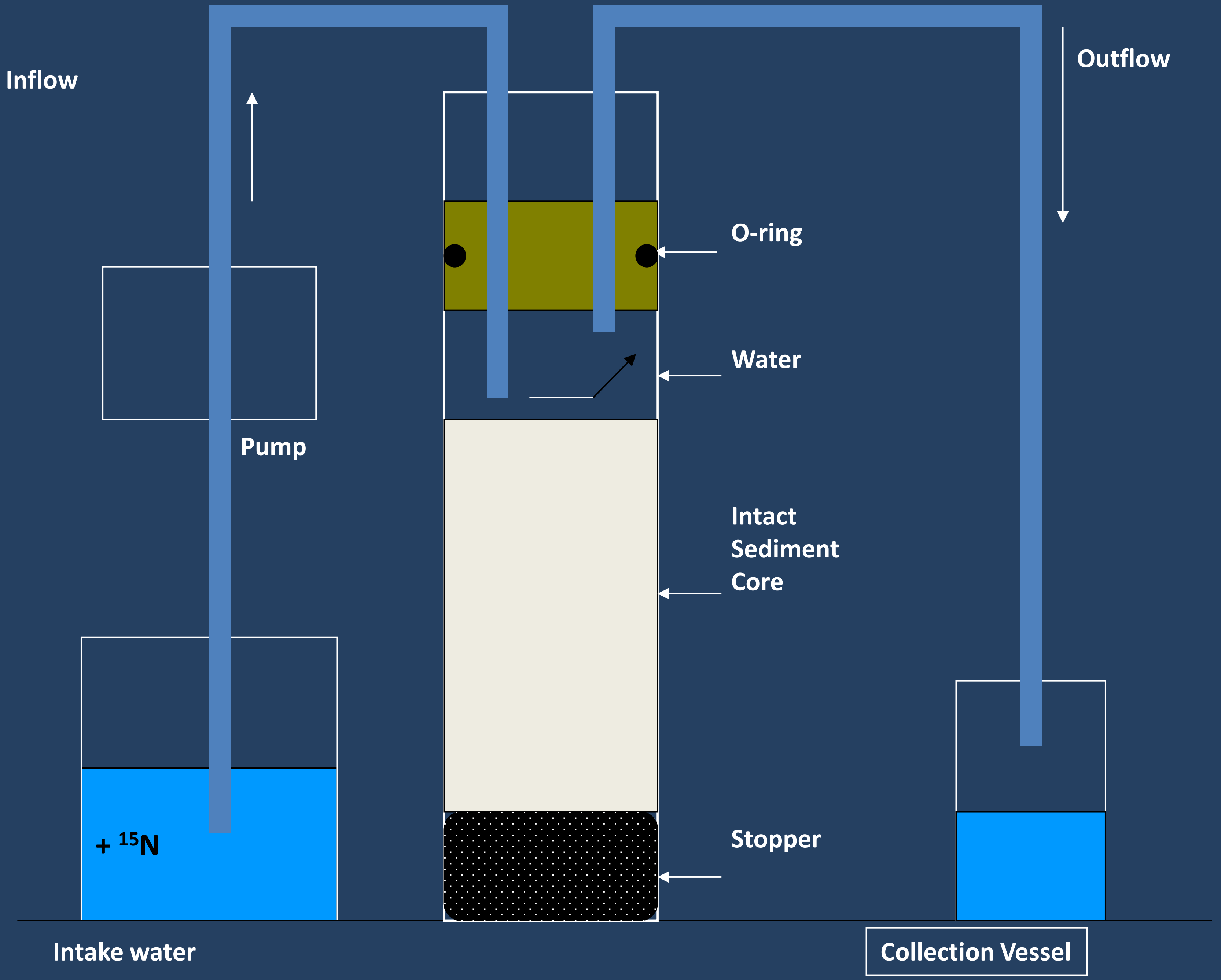

LGMR 9.3.15
Site 2 CORE A1


Site 3:
above dam
Site 4:
below dam


LGMR 8.27.15
Site 5 CORE A1


LGMR 8.27.15
Site 6 CORE C2

Lee Slone


Inflow
Outflow
O-ring
Water
Pump
Intact
Sediment
Core
Stopper
+ 15N
Intake water
Collection Vessel

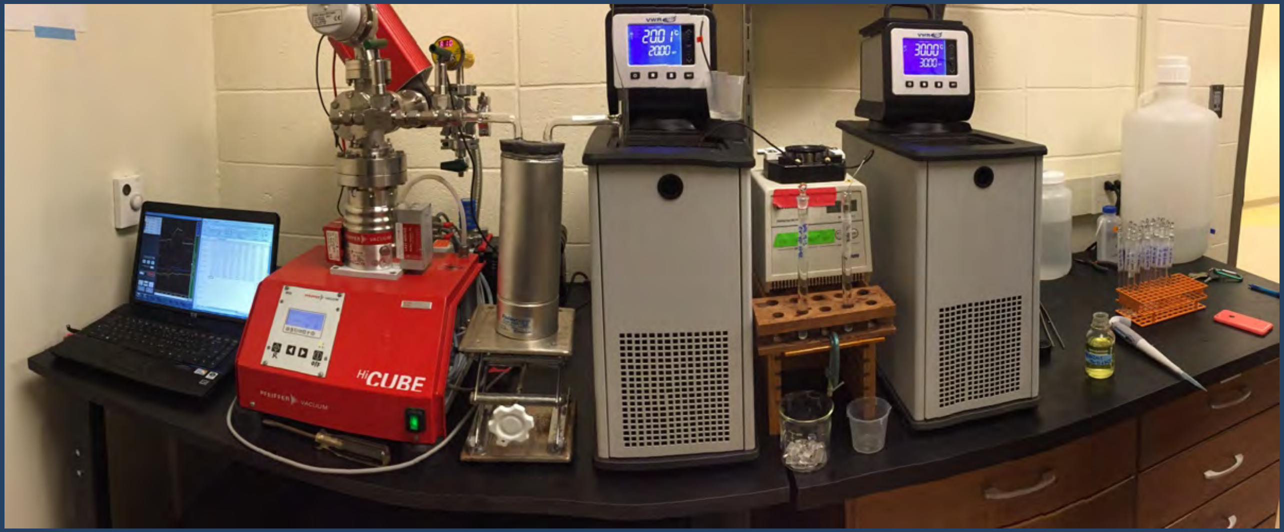
Denitrification

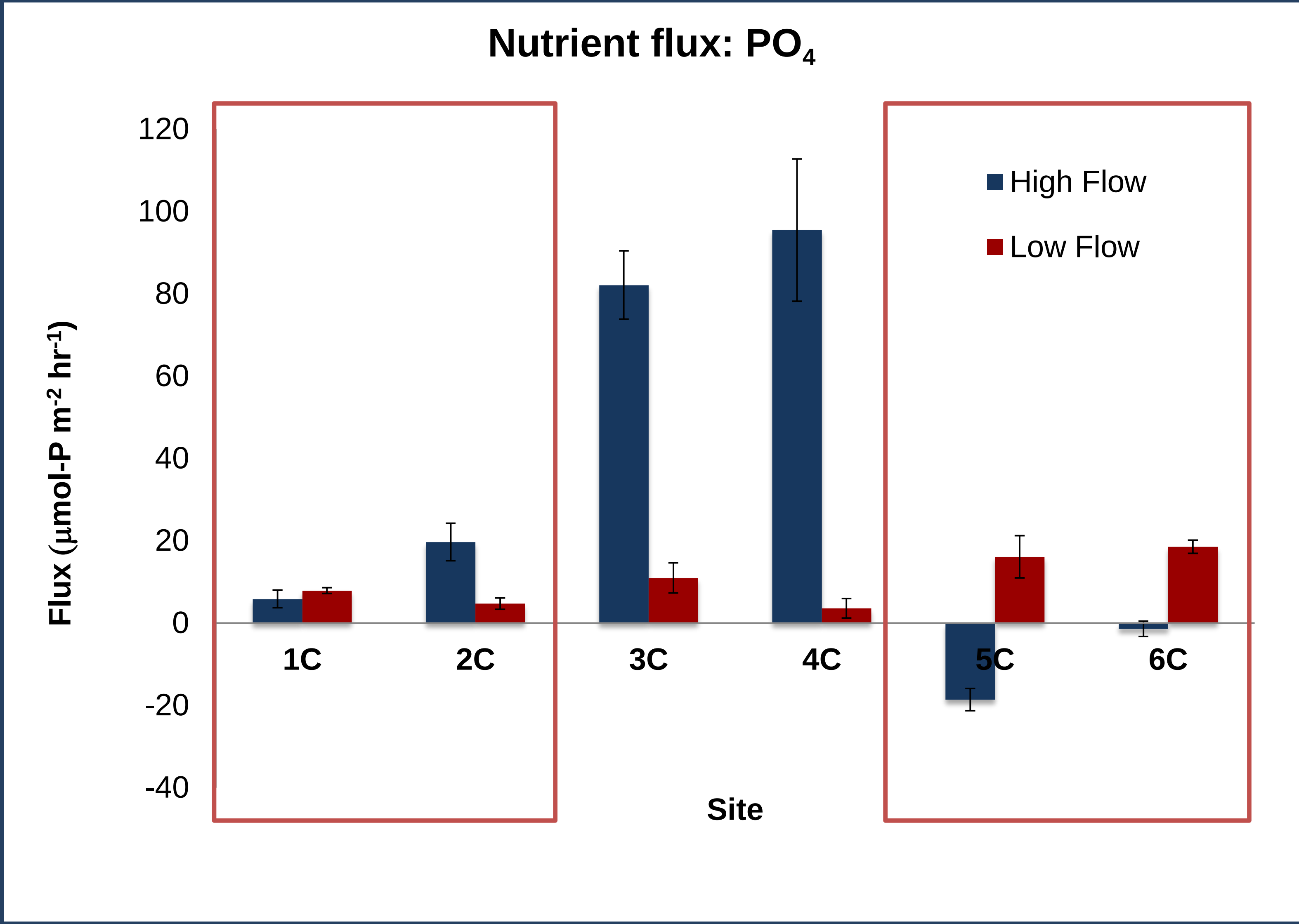
$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

- Requires anoxia
- Pathway ends at N_2O more often under low oxygen
- Removes excess N from ecosystem
- Critical ecosystem service in eutrophic systems!

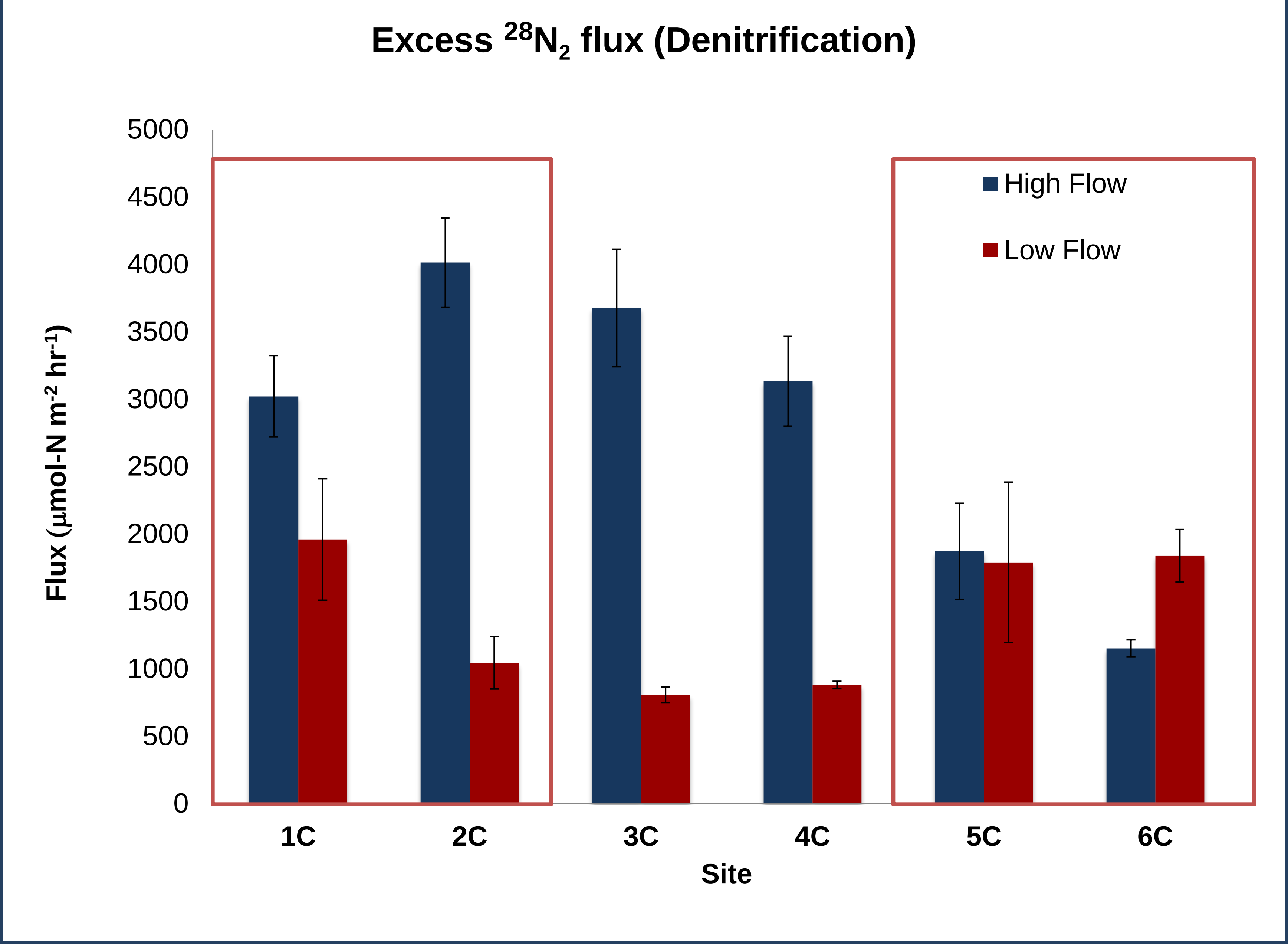
Dissolved gas fluxes

- Dissolved gases ($^{28}N_2$, $^{29}N_2$, $^{30}N_2$, O_2, Ar)
- MIMS (Kana et al. 1994, An et al. 2001)



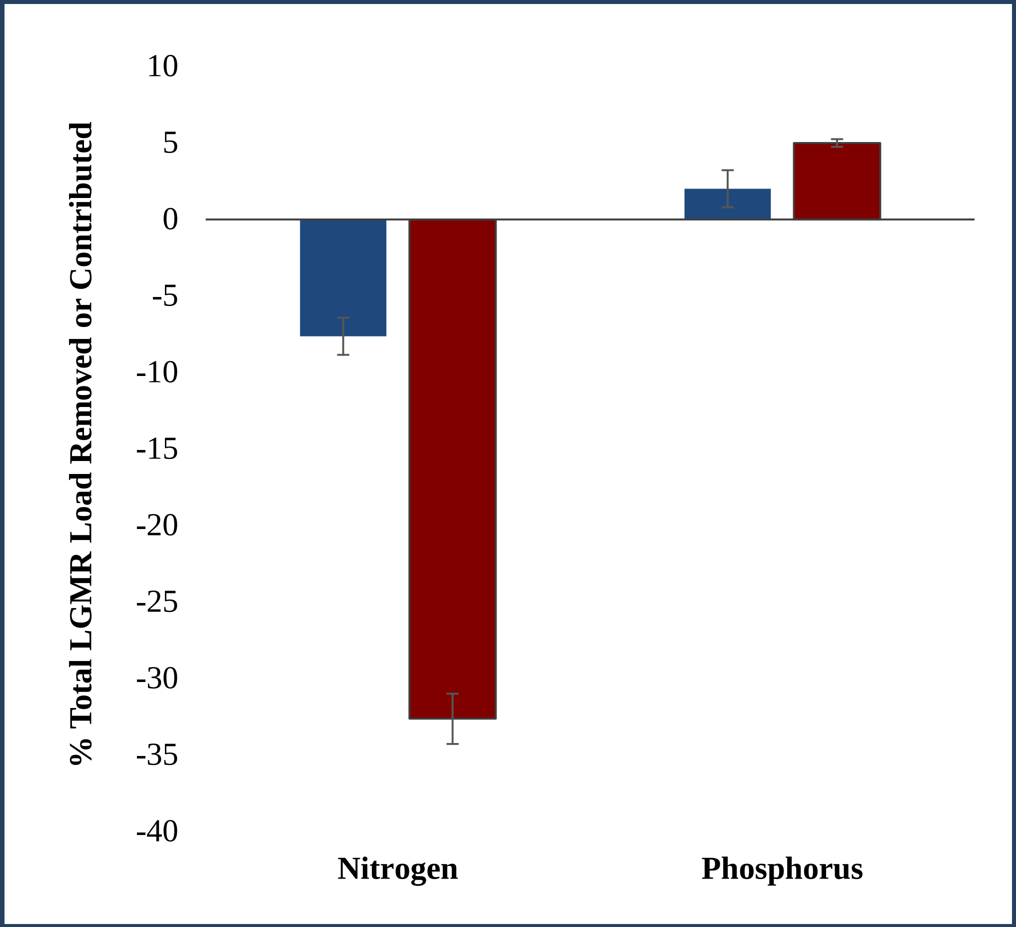


Slone et al., 2018



Slone et al., 2018

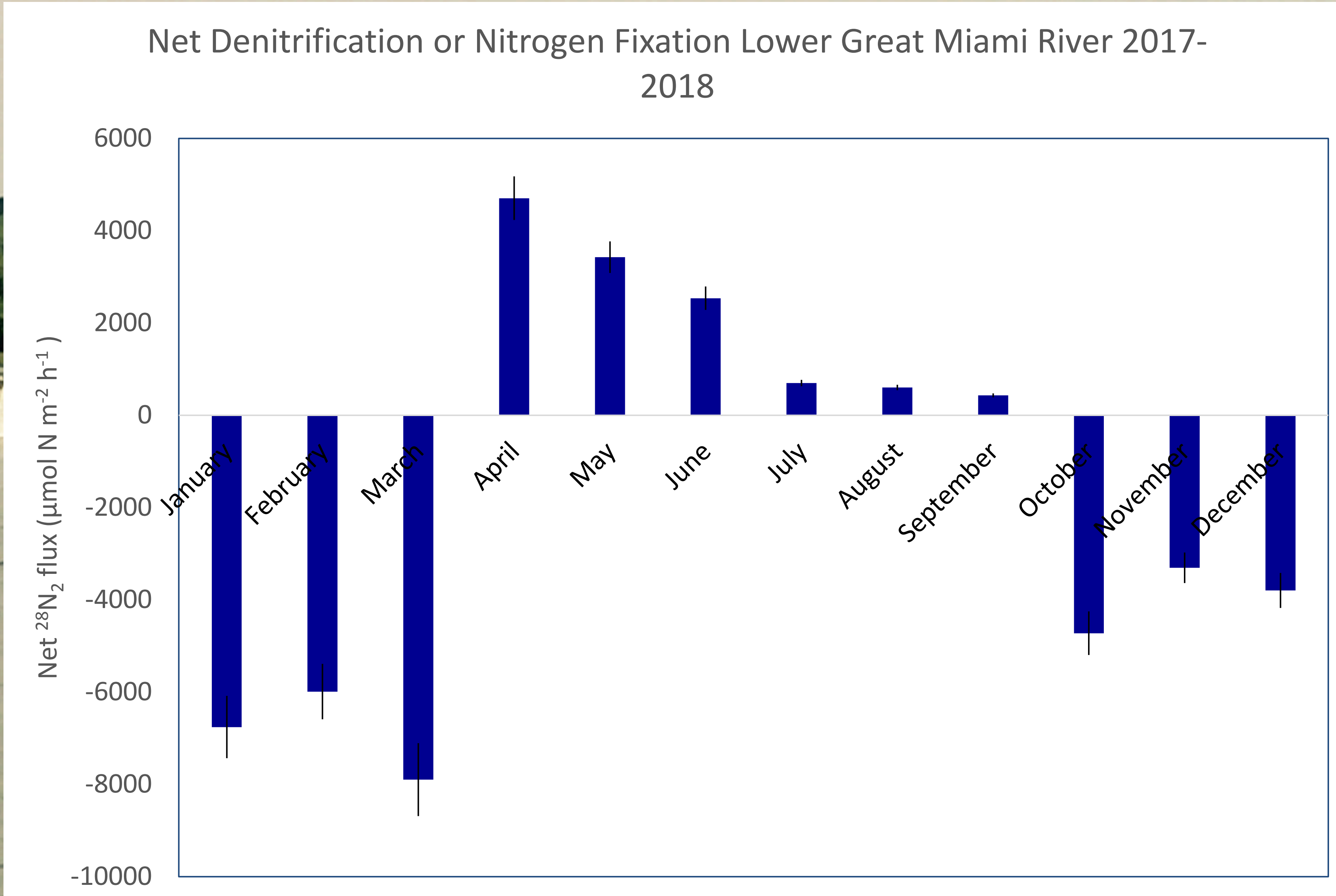
Impact on River Nutrient Load



Slone et al., 2018

LGMR Conclusions

- Denitrification removed nitrate at very high rates during high river flow, but N removal was still exceeded by external inputs (to a lesser extent during low flow).
- Sediments were a source of bioavailable ammonium, potentially contributing to local algal blooms, but were a strong nitrate sink and overall net N sink.
- River sediments were a P source, contributing an additional 2 - 6 % to the external P load from the agricultural and urban watershed.
- These results support calls for a dual nutrient (N & P) management approach to control eutrophication in inland waters and coastal marine systems.



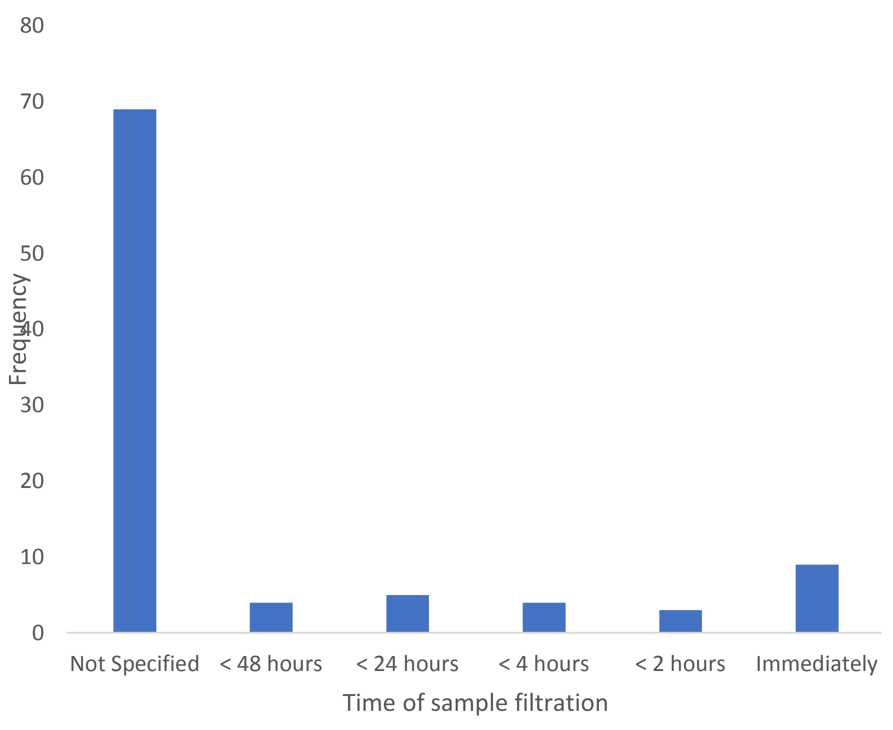
Slone et al. 2018

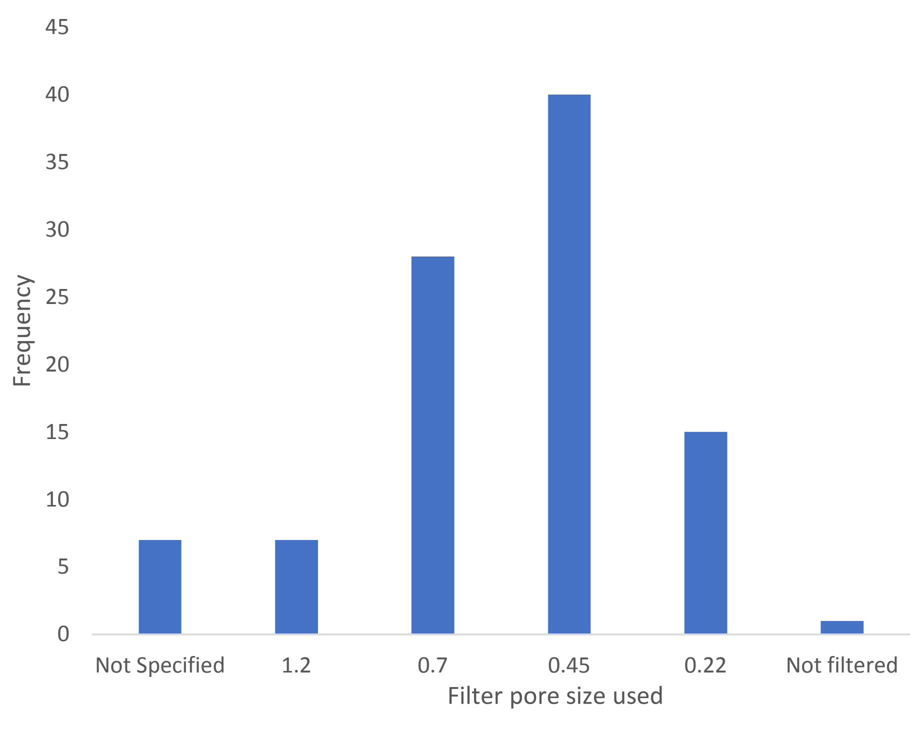
Slone et al., 2018

Nutrient sample collection

- Megan Reed et al.

Journal article survey of nutrient sampling methods





Reed et al., L&O Methods, in review

Why does accurate nutrient data matter?

- Using data from Hampel et al 2018:

  Uptake: 0.759 µmol L^{-1} h^{-1}

  Regeneration: 0.337 µmol L^{-1} h^{-1}

  Ambient concentration of ammonium (NH_4^+) : 0.33 µM

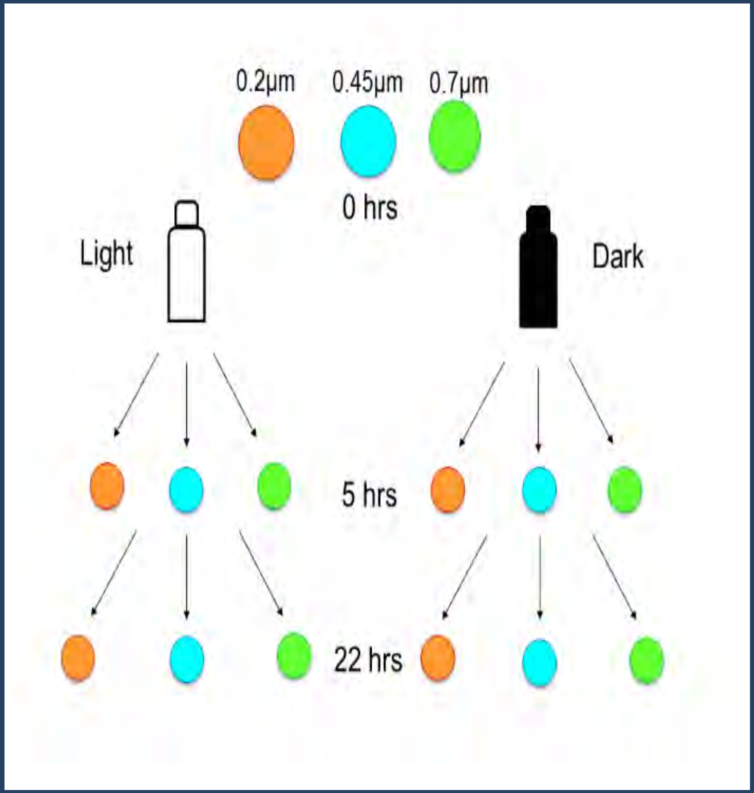
  An unfiltered water sample stored in the dark would have:

  [NH_4^+]: 0.119 µM after 30 minutes

  [NH_4^+]: 0 µM after only 47 minutes!

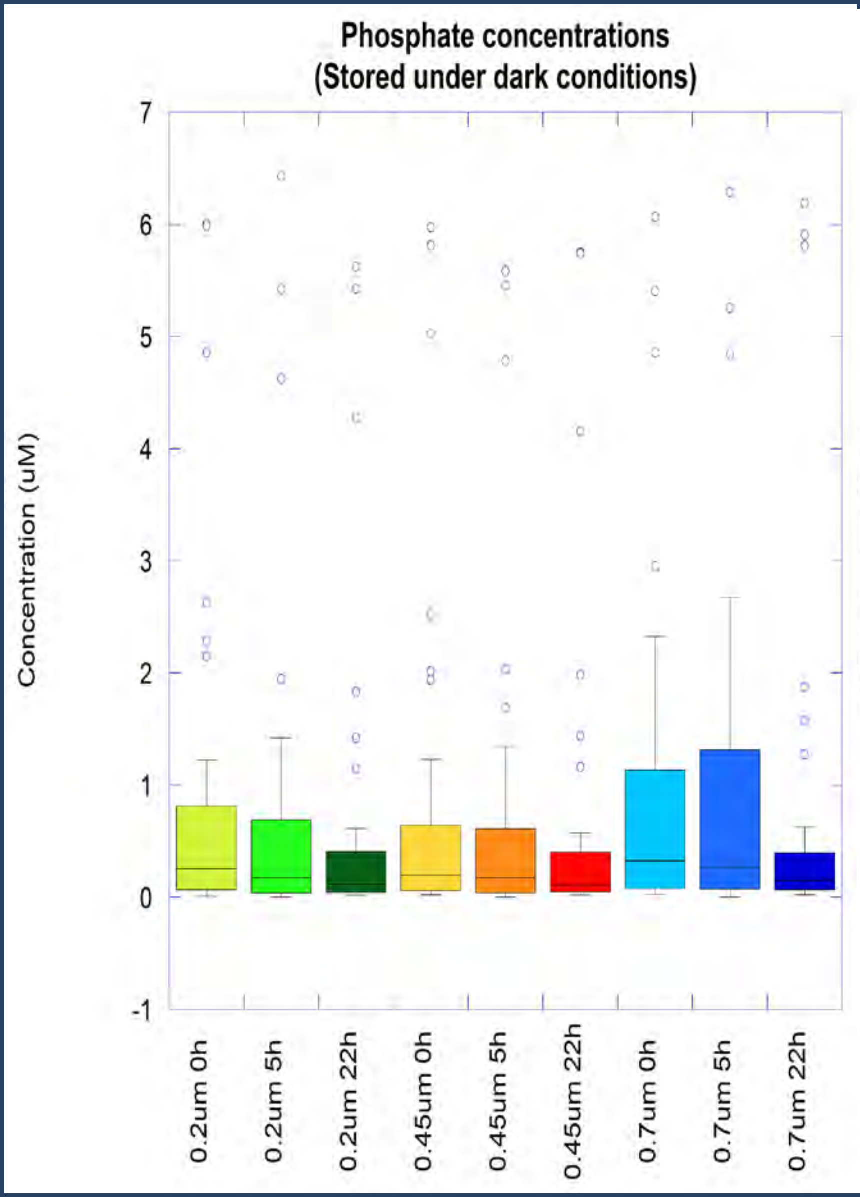
Methods- Study site

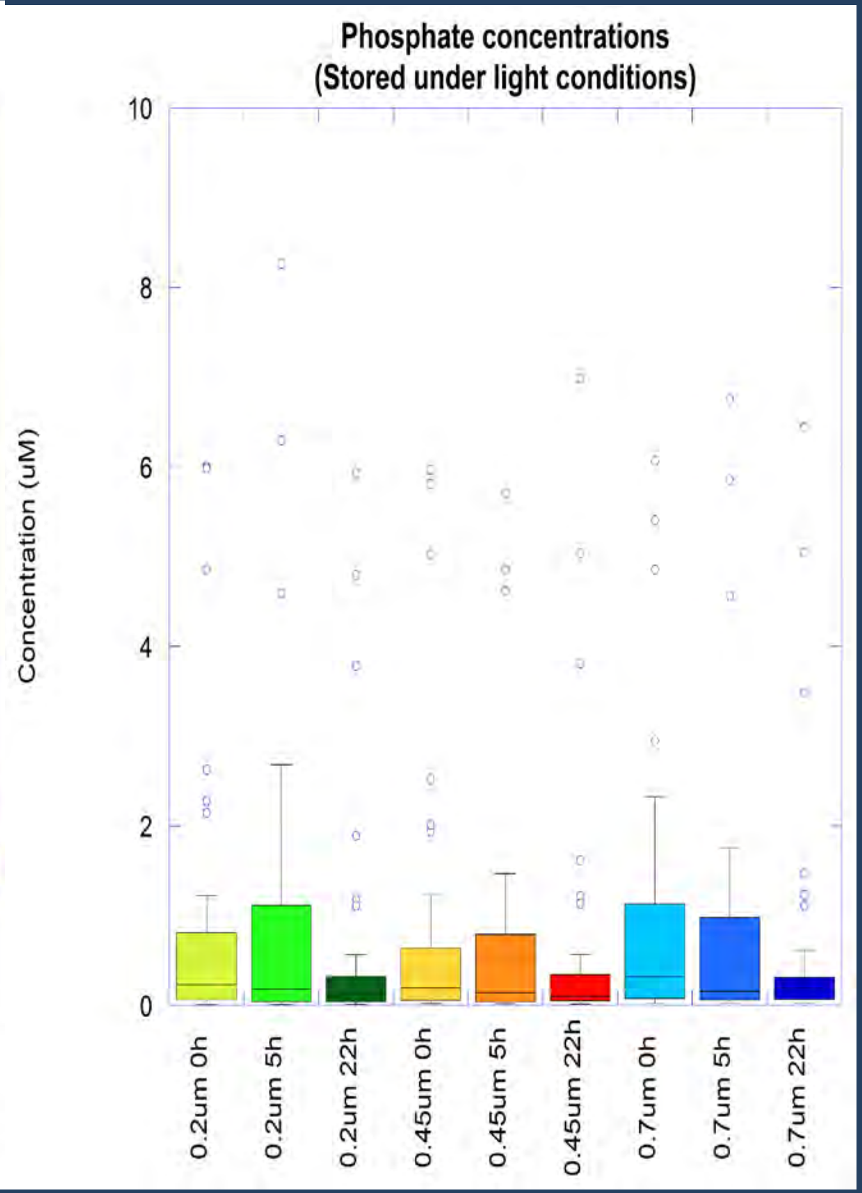
Sample collection



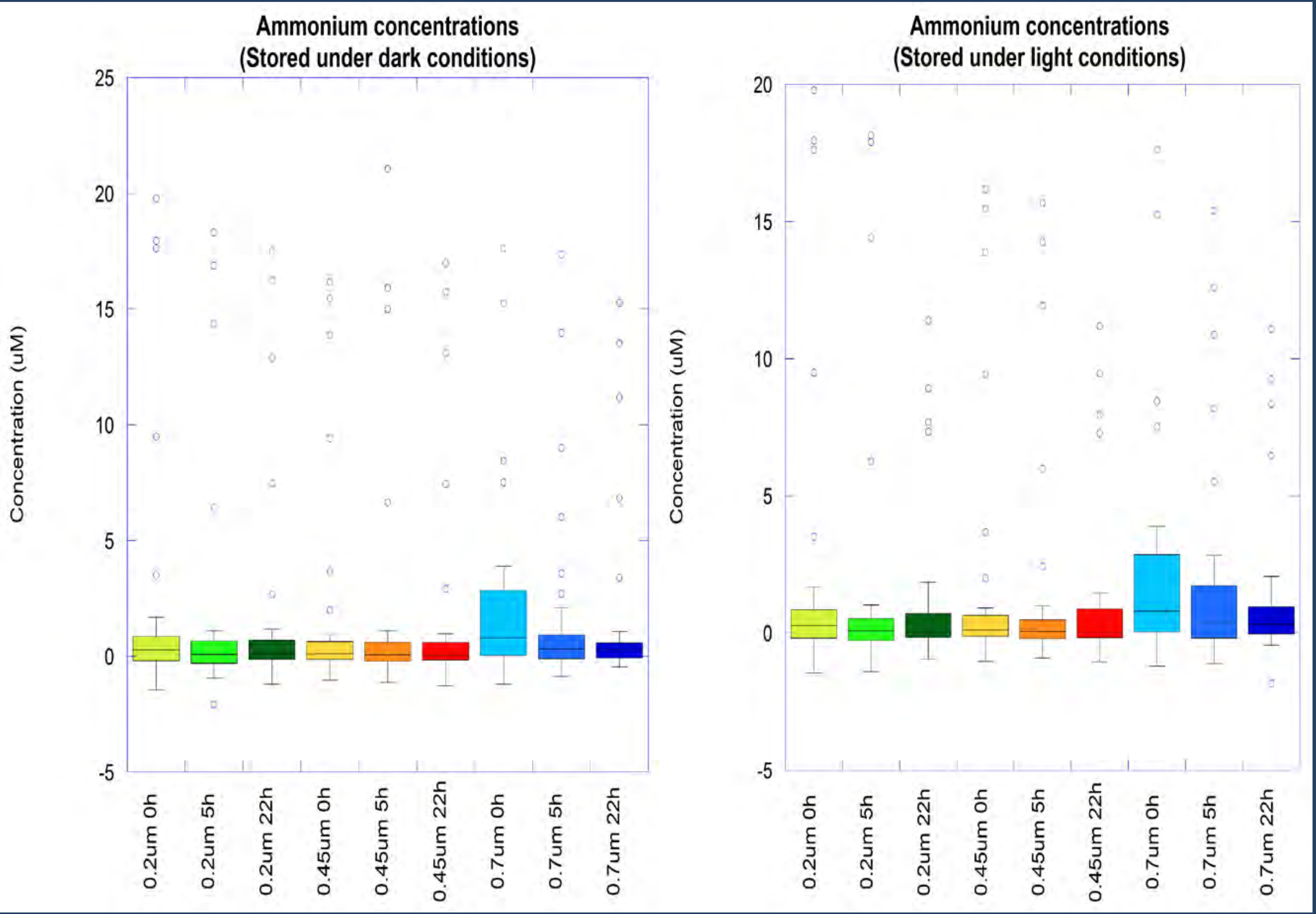
Reed et al., L&O Methods, in review

Results- Phosphate concentrations

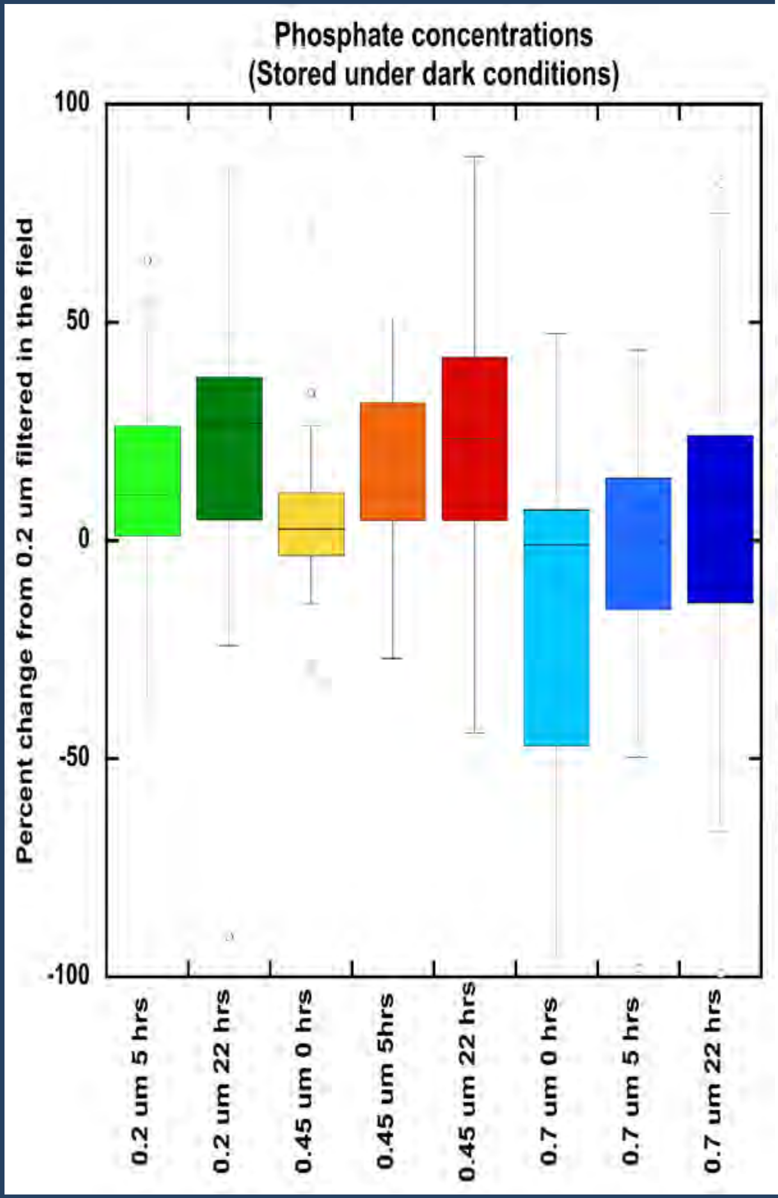


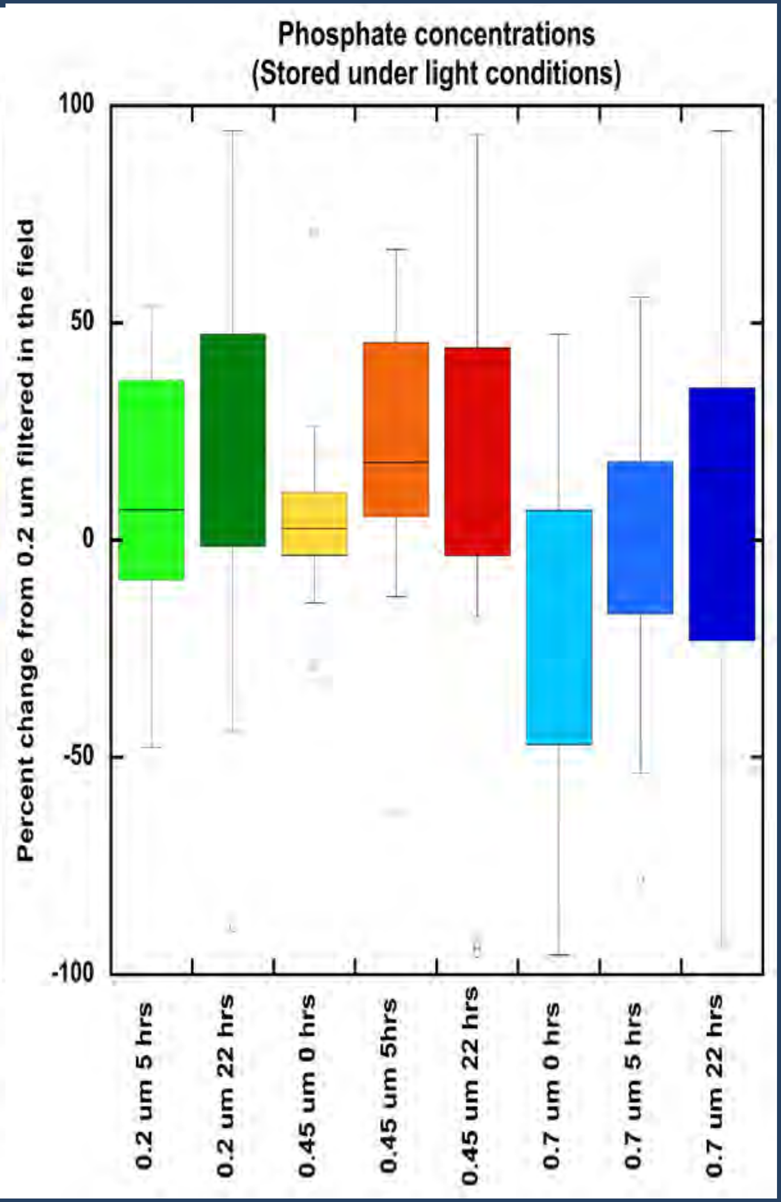


Ammonium concentrations

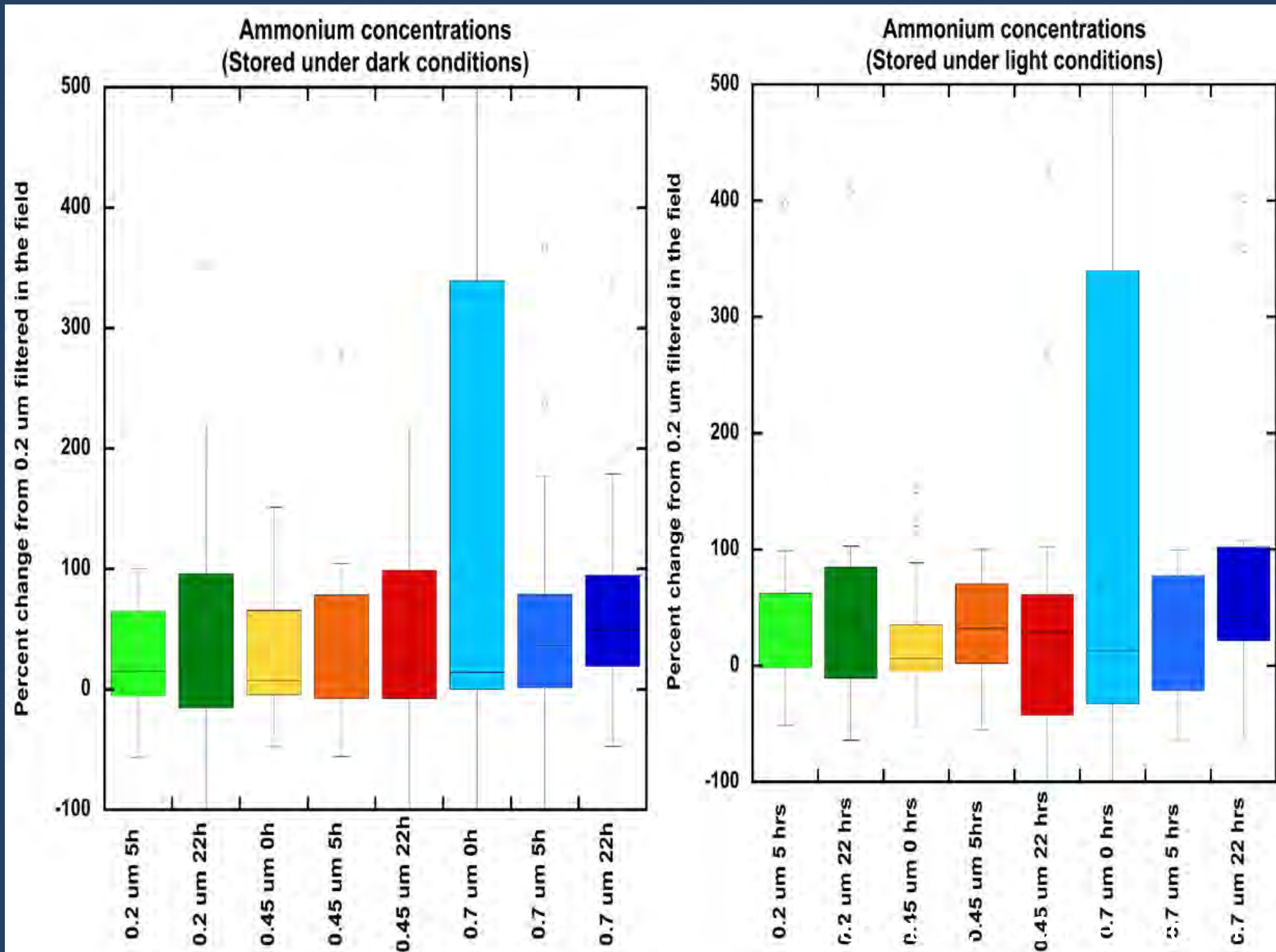


Percent change of phosphate concentrations

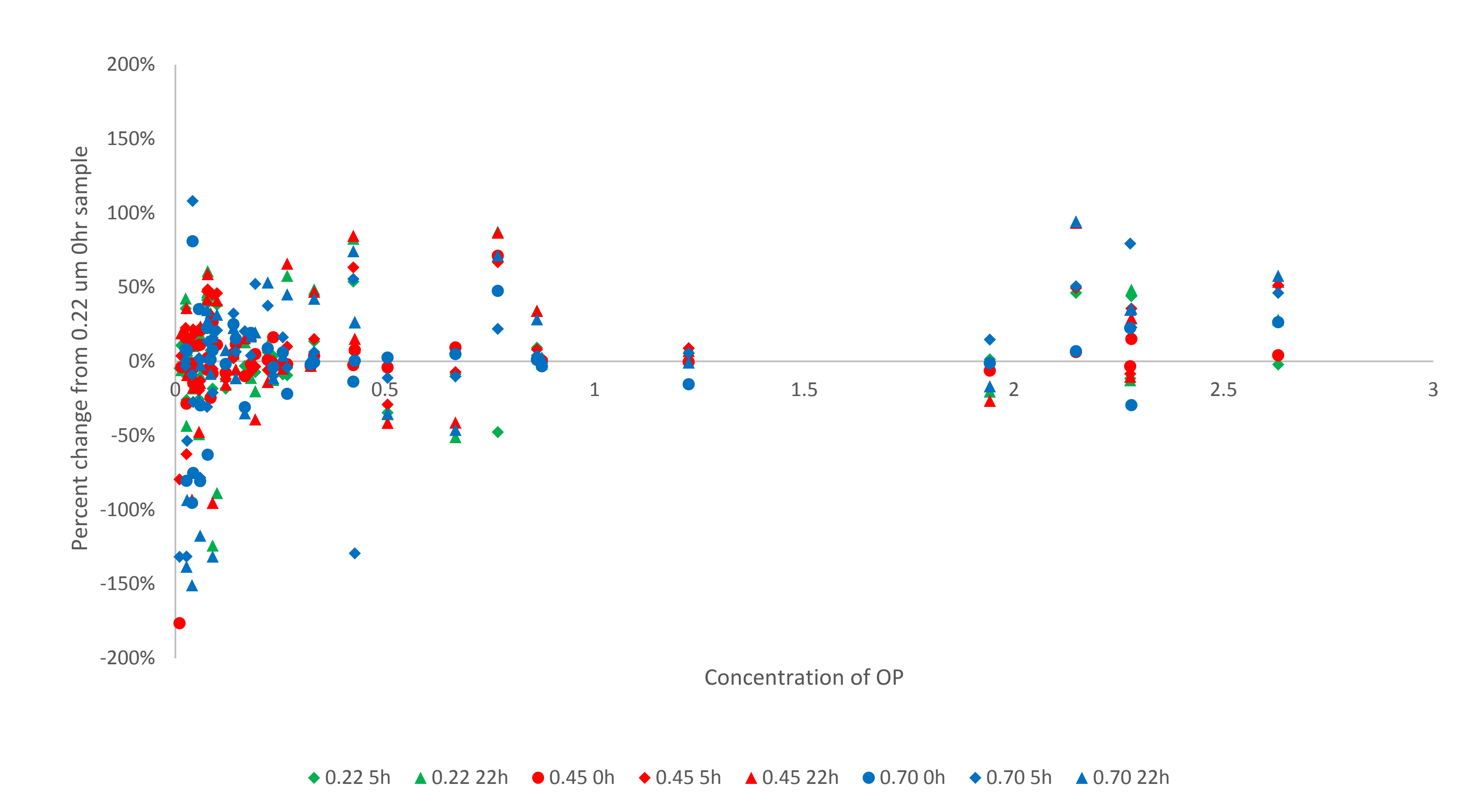




Percent change of ammonium concentrations

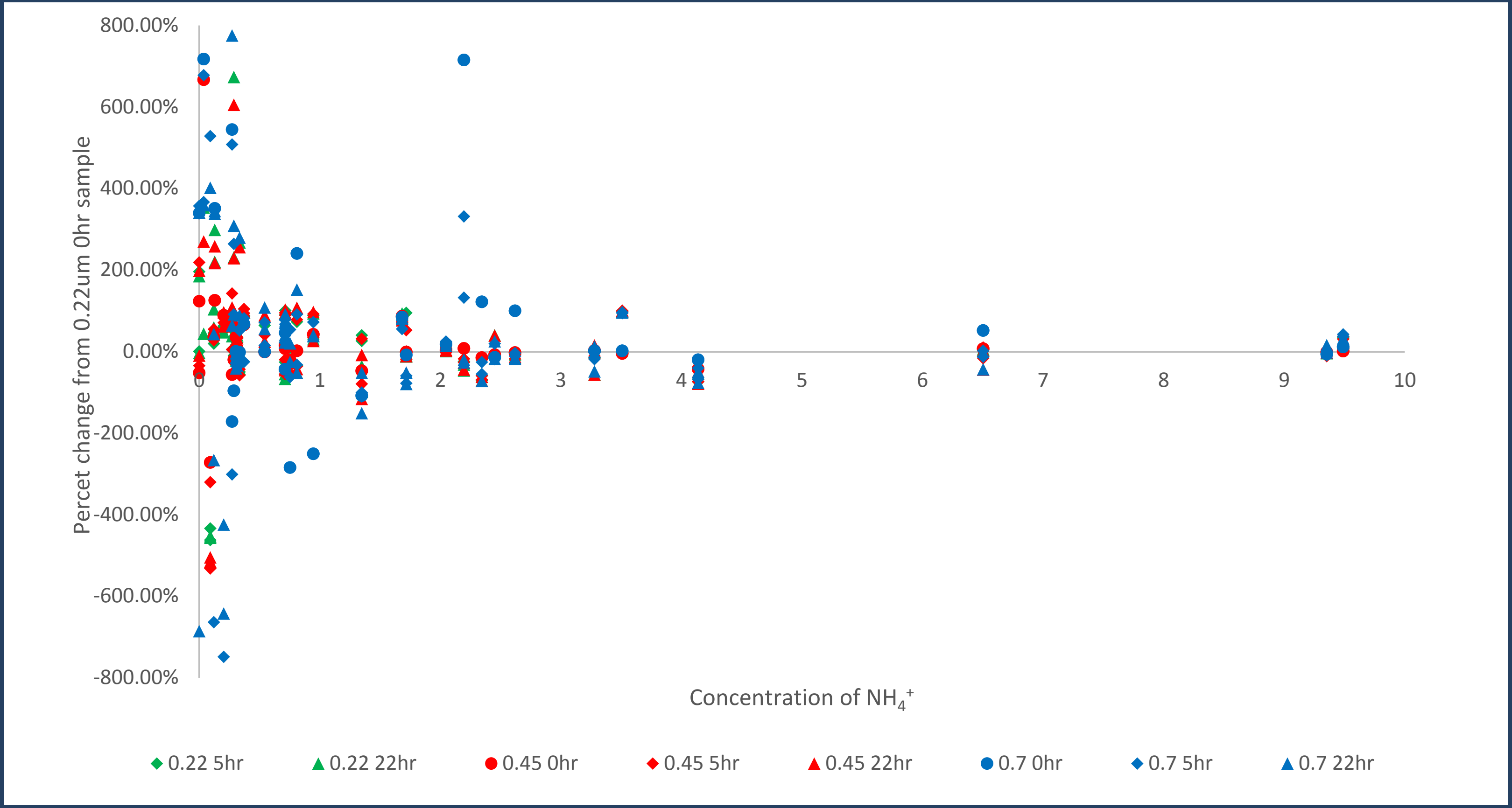


Concentration of P against percent change from 0.22 µM sample filtered in the field



Reed et al., L&O Methods, in review

Concentration of N against percent change from 0.22 µM sample filtered in the field



Reed et al., L&O Methods, in review

Sample Collection Conclusions

- Failing to filter samples in the field can lead to significant changes in the concentration compared to the ambient value
- Filtering in the field with 0.70 um filters has the most significant impact on nutrient concentration
- More specific filtering methods should be considered in order to ensure the accuracy of reporting nutrient monitoring data

Thank you!

- Zhang Lu
- Xu Hai
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- Liu Kaijun
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- Hammerschmidt Lab
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- Sue Watson/Env. Canada
- Miami Conservancy District