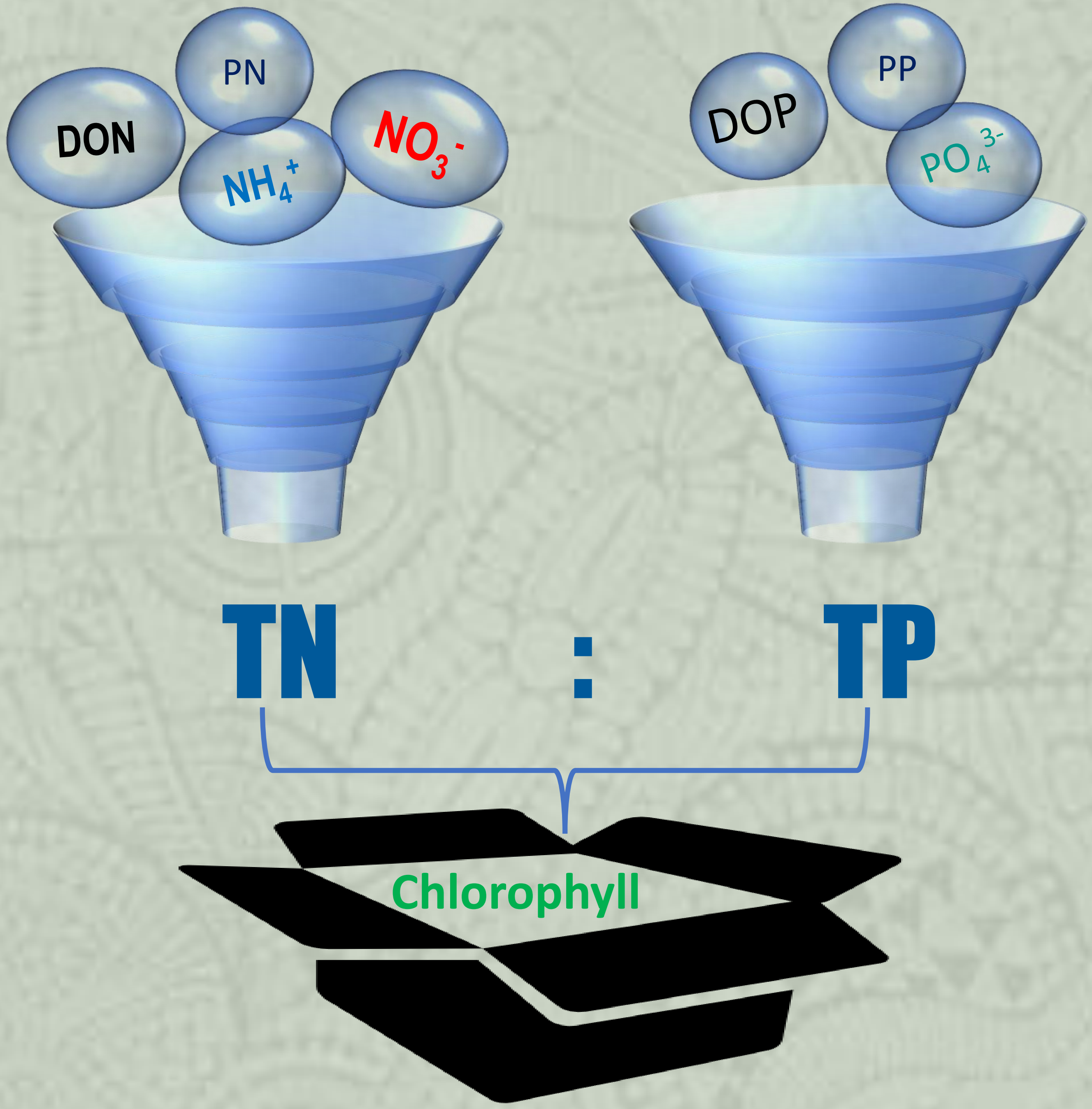
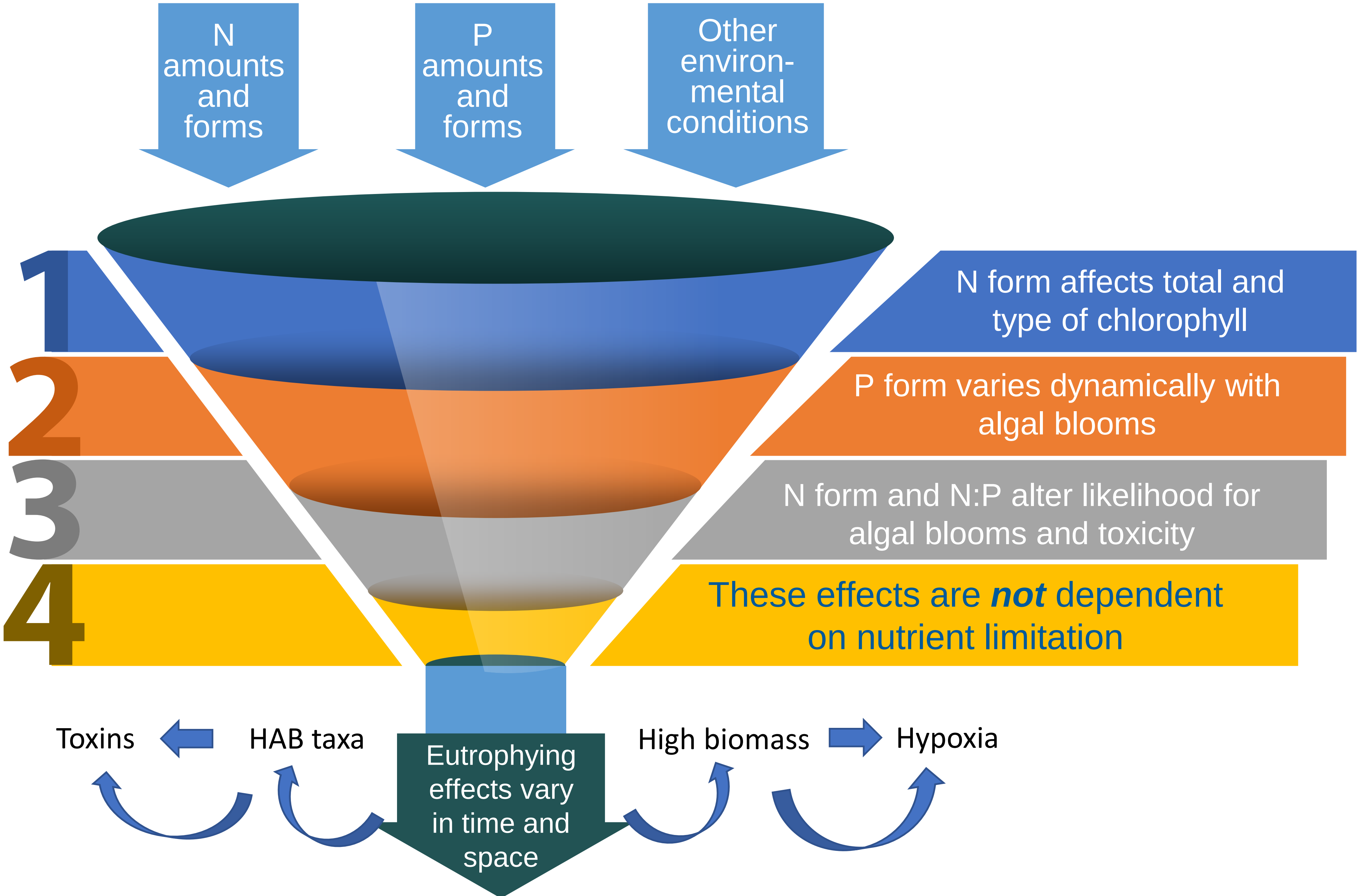
Biological responses to nutrient forms and proportions

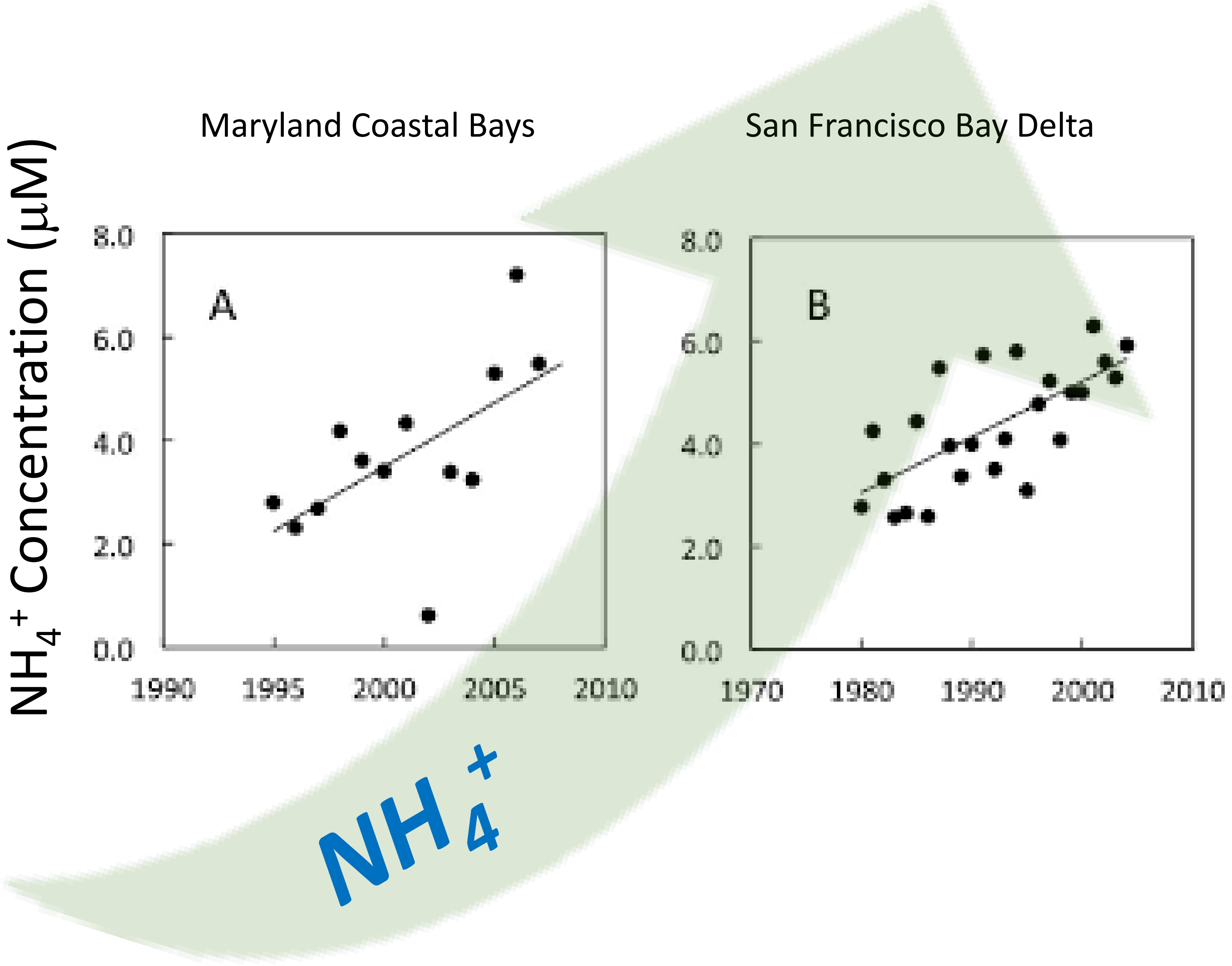
Pat Glibert

University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE

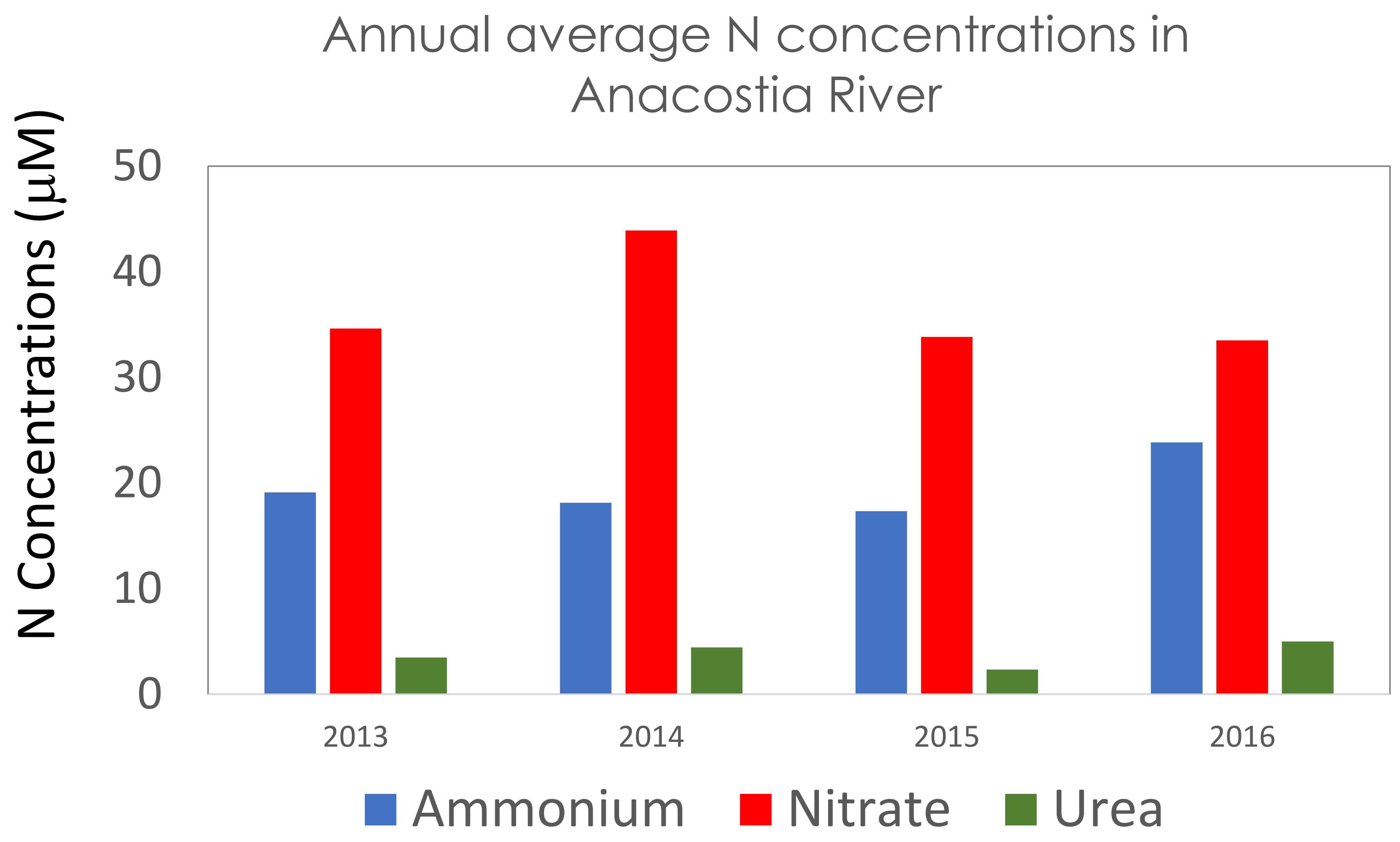


How do N and P speciation affect **total** chlorophyll– as well as the **type** of chlorophyll?


N amounts and forms
P amounts and forms
Other environ-mental conditions
1
N form affects total and type of chlorophyll
2
P form varies dynamically with algal blooms
3
N form and N:P alter likelihood for algal blooms and toxicity
4
These effects are ***not*** dependent on nutrient limitation
Toxins
HAB taxa
Eutrophying effects vary in time and space
High biomass
Hypoxia

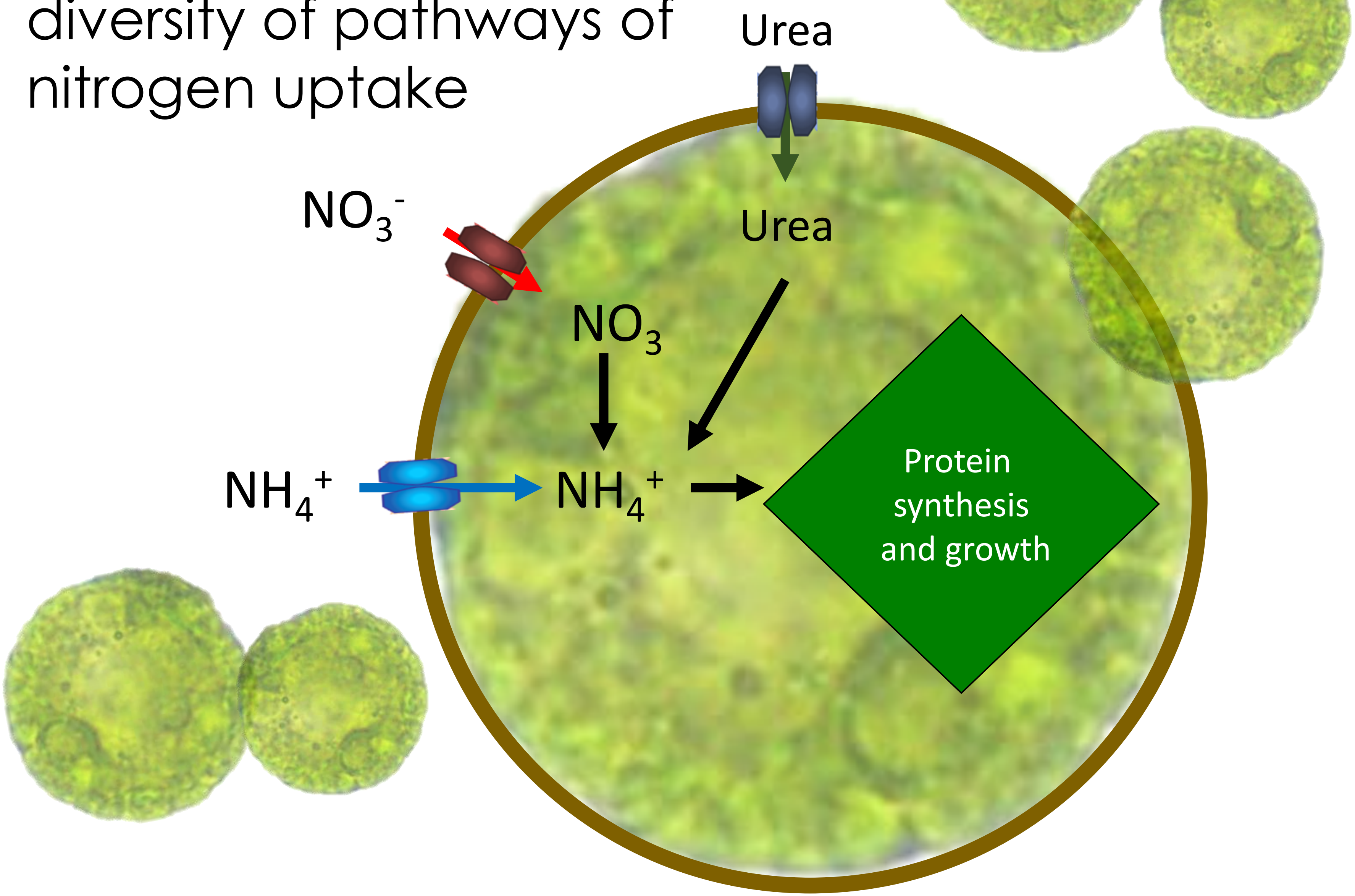


Glibert et al. L&O 2016



Annual average N concentrations in Anacostia River
N Concentrations (µM)
50
40
30
20
10
0
2013
2014
2015
2016
Ammonium
Nitrate
Urea

Algae have a range of nitrogen sources and a diversity of pathways of nitrogen uptake



Dogma:

"There should be no selective effect ... that might distinguish between the potential performance of any pair of planktonic algae, so long as the resource concentrations are able to saturate the growth demand..."

Reynolds 1999

i.e., at saturation, nutrients are not "regulating"
(other than ecosystem effects of too much biomass)

Dogma:

"There should be no selective effect ... that might distinguish between the potential performance of any part of planktonic algae, so long as the resource concentrations are able to saturate the growth demand..."

Reynolds 1999

i.e., at saturation, nutrients are not "regulating"
(other than ecosystem effects of too much biomass)

Dogma: If the use of the resource needing more manipulation [e.g.,NO_3^-]..., in order to achieve the same product formation[moles] product per second), then the cell doubling time will be significantly increased since more [moles] of the product of the resource manipulation will be required to double cell mass...

Raven et al. (1992)

i.e., growth rate on NH_4 should be faster than on NO_3

Dogma:

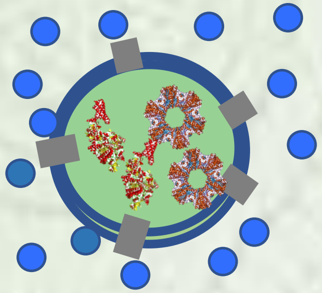
If the use of the resource needing more manipulation [e.g.,NO3-]..., in order to achieve the same product formation[moles] product per second), then the cell doubling time will be significantly increased since more [moles] of the product of the resource manipulation will be required to double cell mass...

Raven et al. (1992)

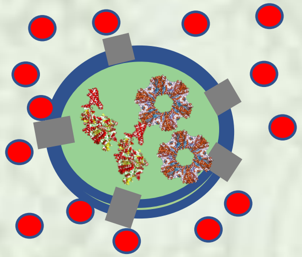
i.e., growth rate on NH_4 should be faster than on NO_3

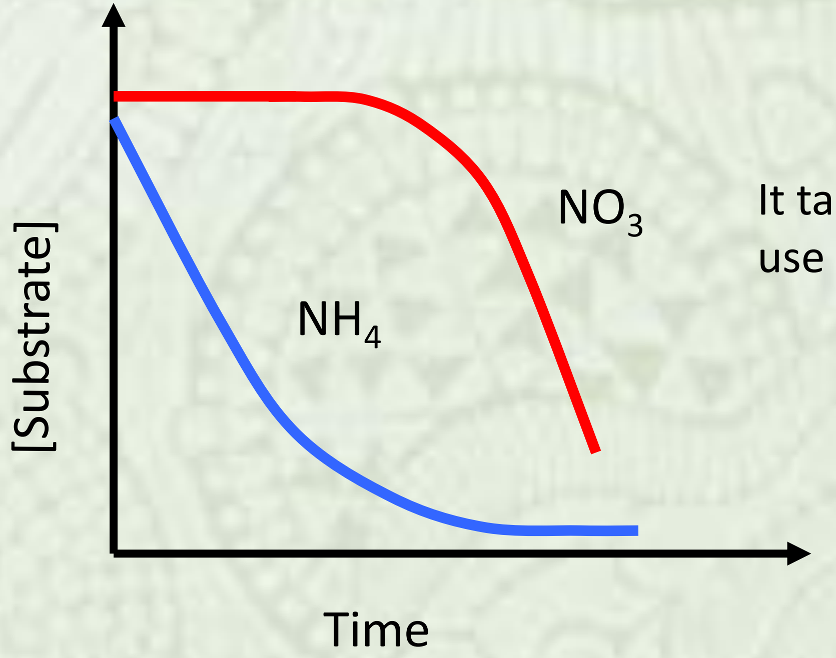
NH_4 is classically considered the "preferred" form of N

NH_4^+



NO_3^-

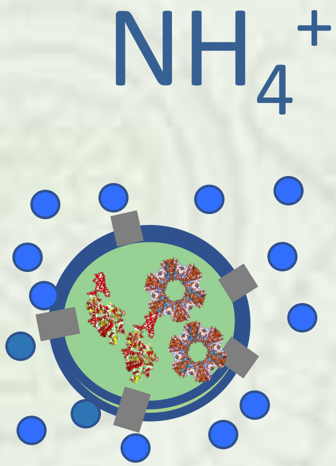


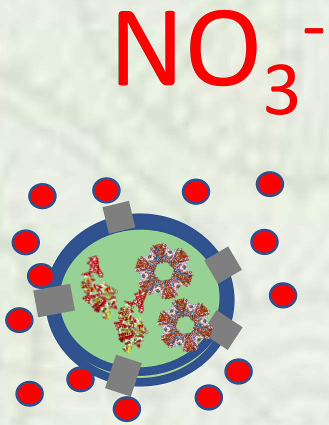


It takes more energy to use NO_3

Glibert et al. L&O 2016

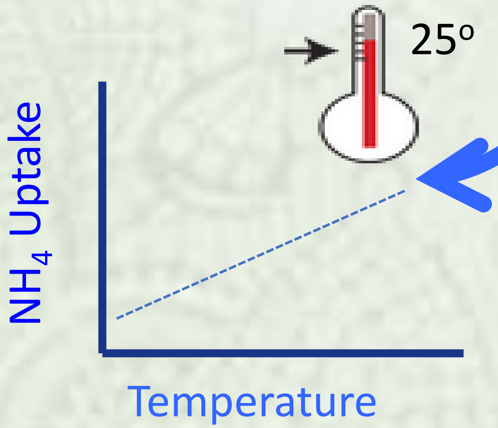
The regulation of NH_4^+ and NO_3^- assimilation is very different

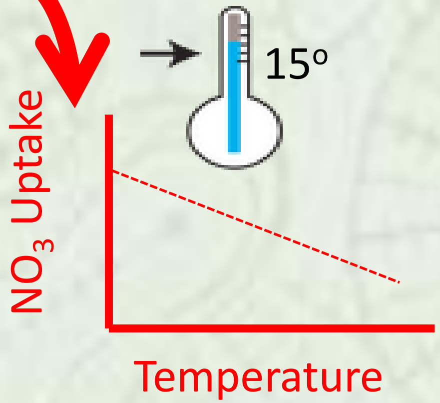




More NO_3^- at LOW temps

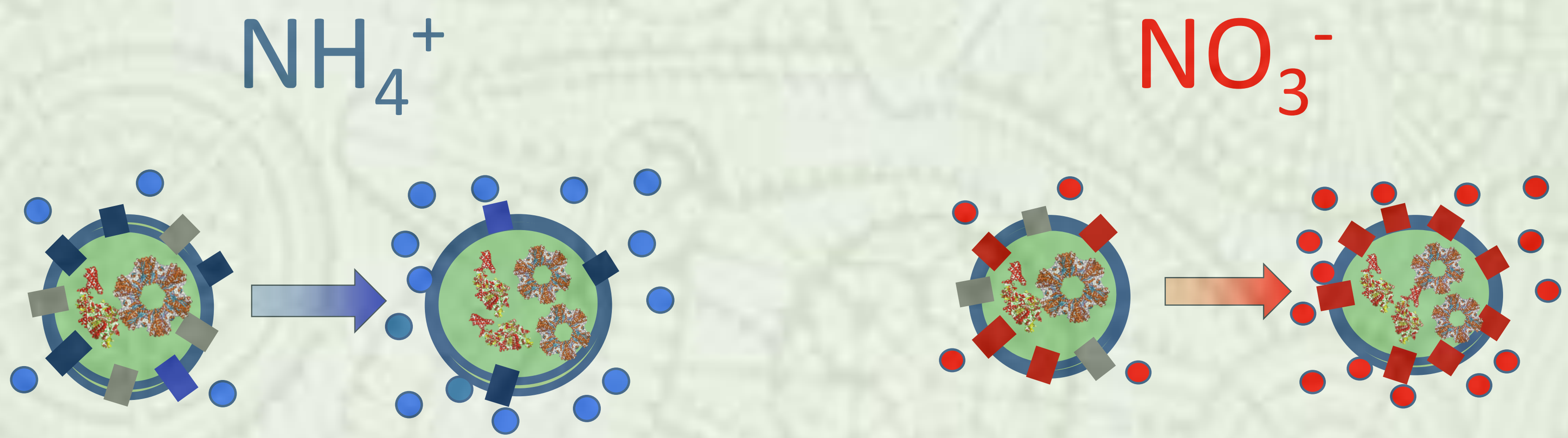
More NH_4^+ at WARM temps



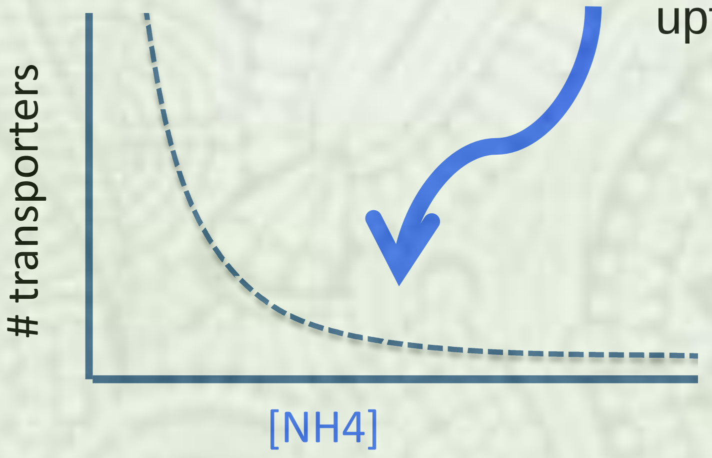


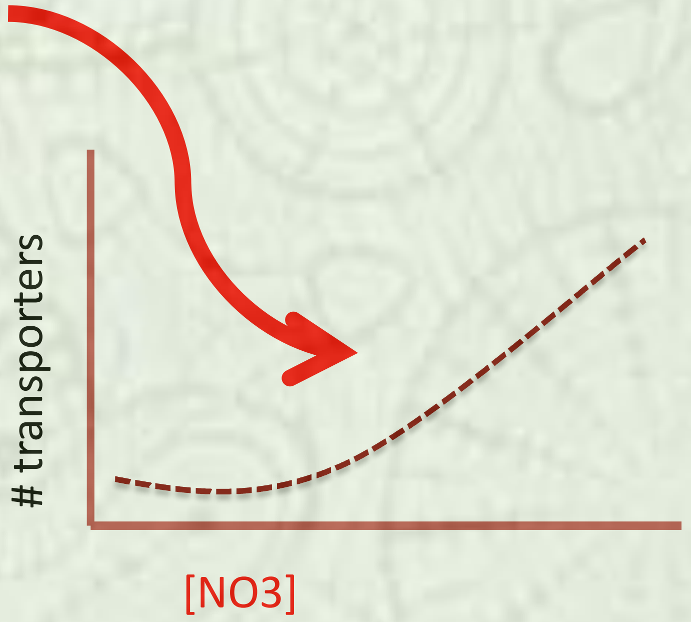
Glibert et al. L&O 2016

The regulation of NH_4^+ and NO_3^- assimilation is very different



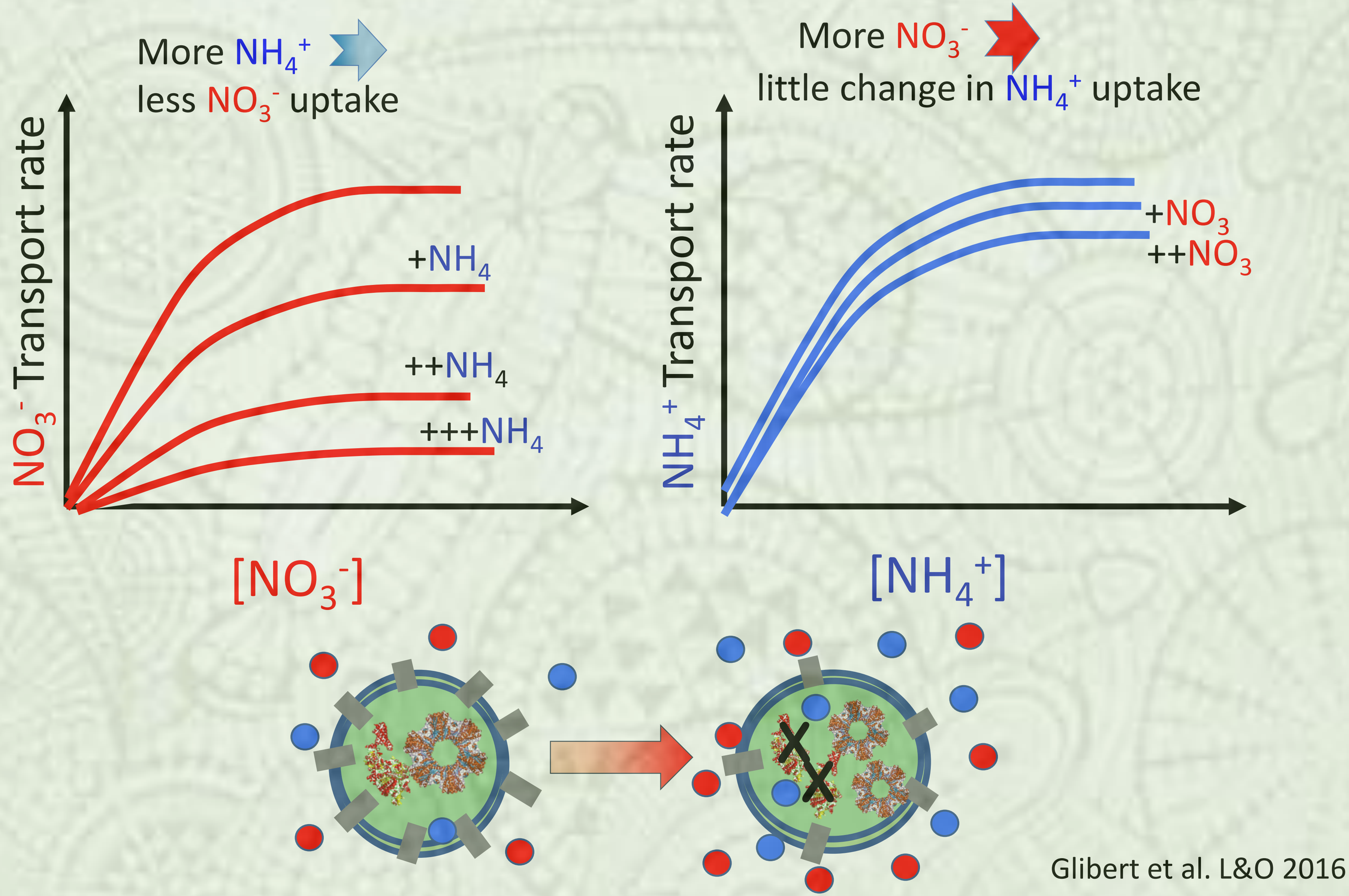
More NO_3^-, more uptake capacity;
More NH_4^+, capacity for uptake decreases





Glibert et al. L&O 2016

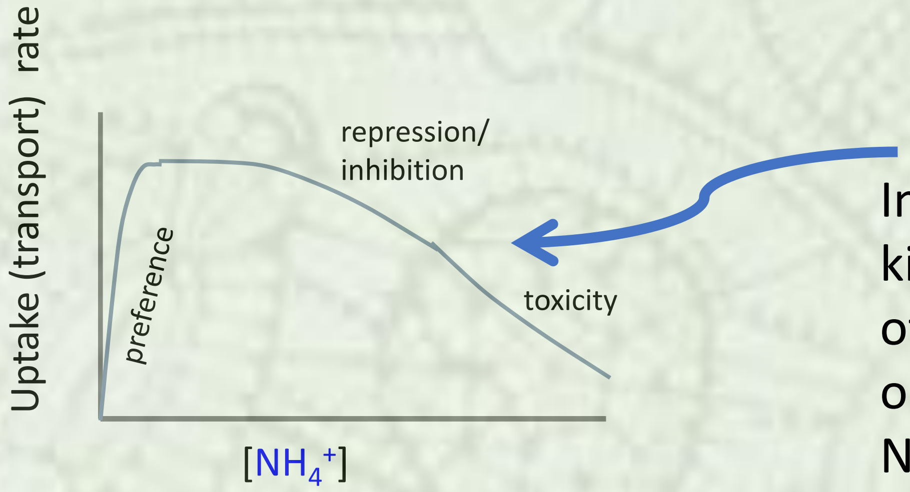
The regulation of NH_4^+ and NO_3^- assimilation is very different



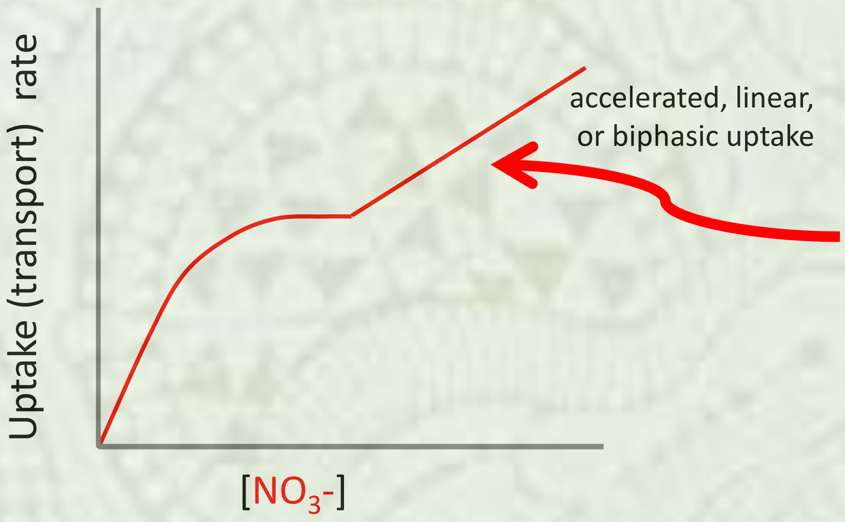
Glibert et al. L&O 2016

The regulation of NH_4^+ and NO_3^- uptake is very different

This can result in very different types of kinetics of uptake

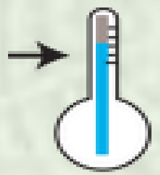


Inhibition kinetics are often observed for NH_4^+ uptake

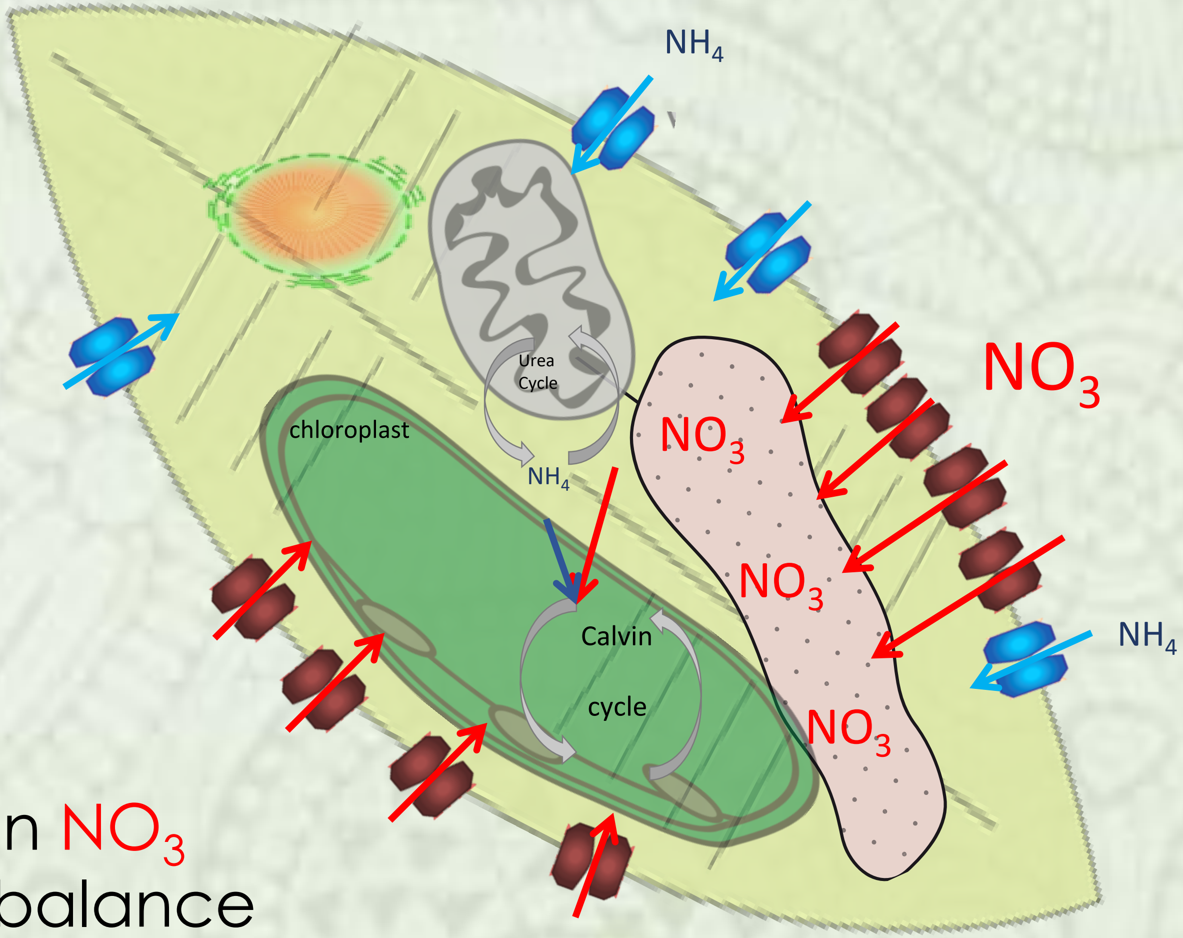


Nonsaturable (linear) NO_3^- uptake is commonly observed

Diatoms



Diatoms have a large capacity to take up and assimilate NO_3^-

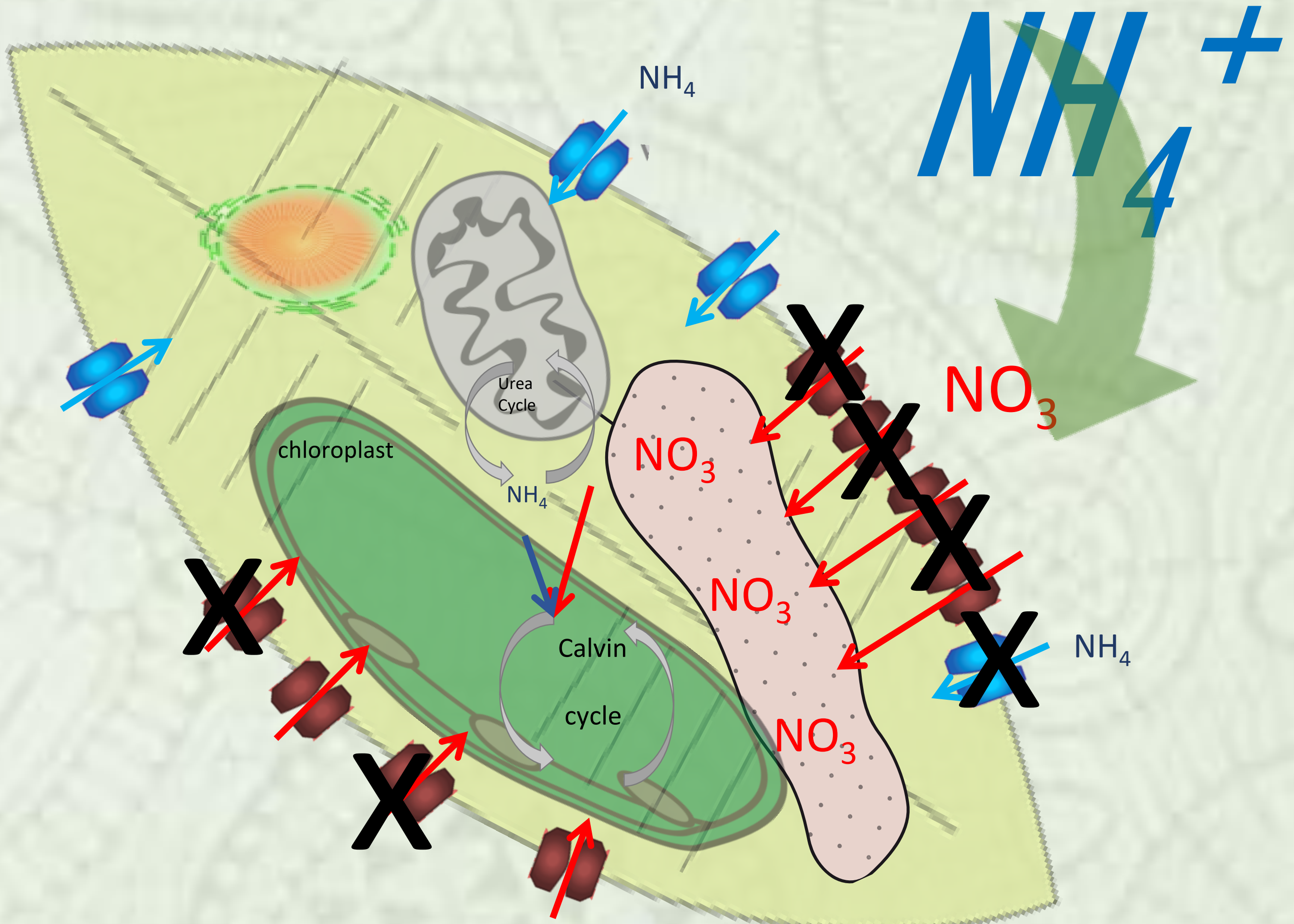


Why?

They depend on NO_3 for cell energy balance

Glibert et al. L&O 2016

Diatoms



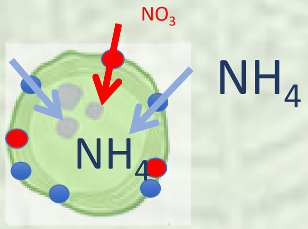
Diatoms have a large capacity to take up and assimilate NO_3^-

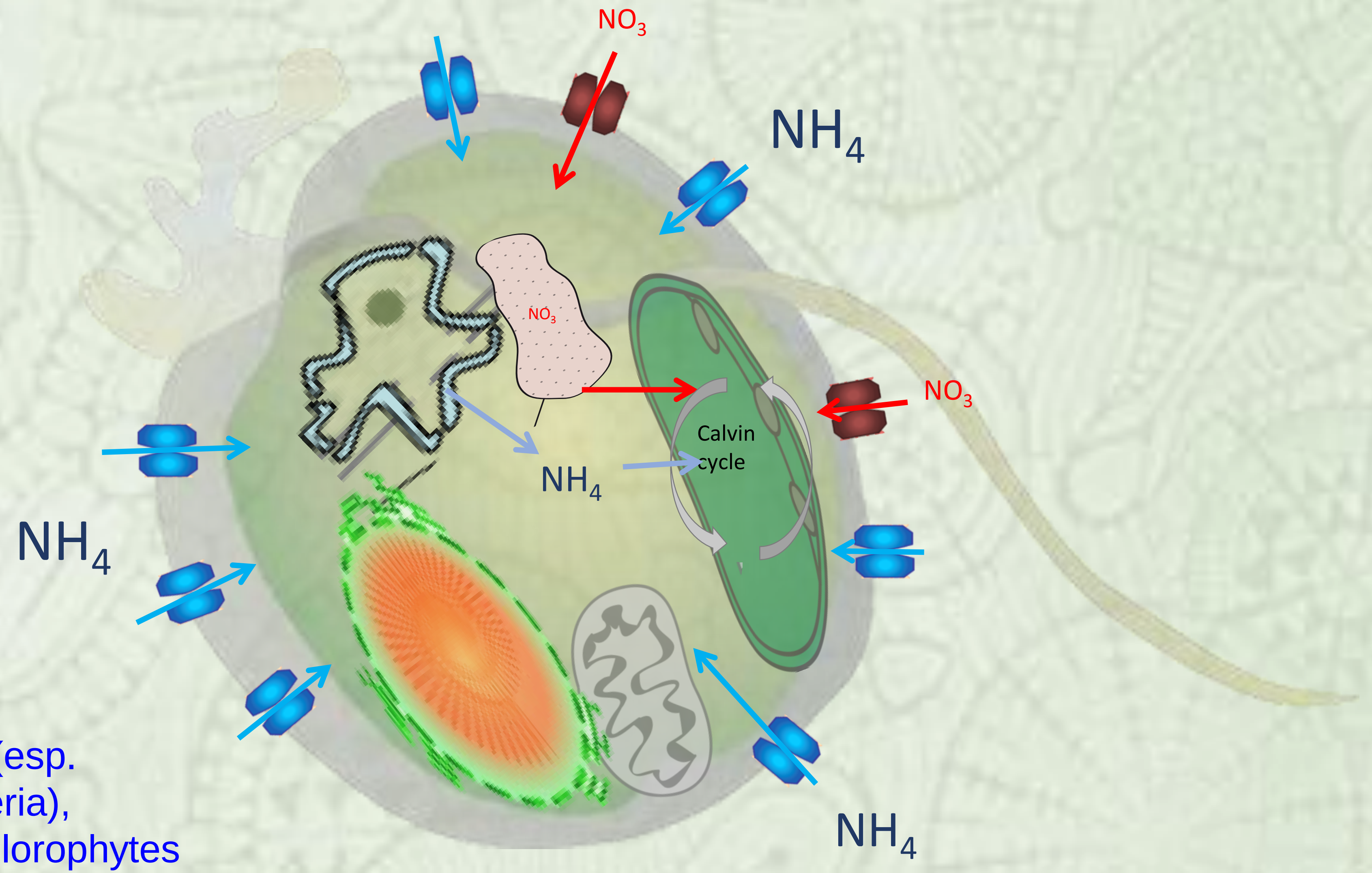
This mechanism can be repressed by NH_4 especially in cool waters (winter/spring)

Glibert et al. L&O 2016

Dinoflagellates

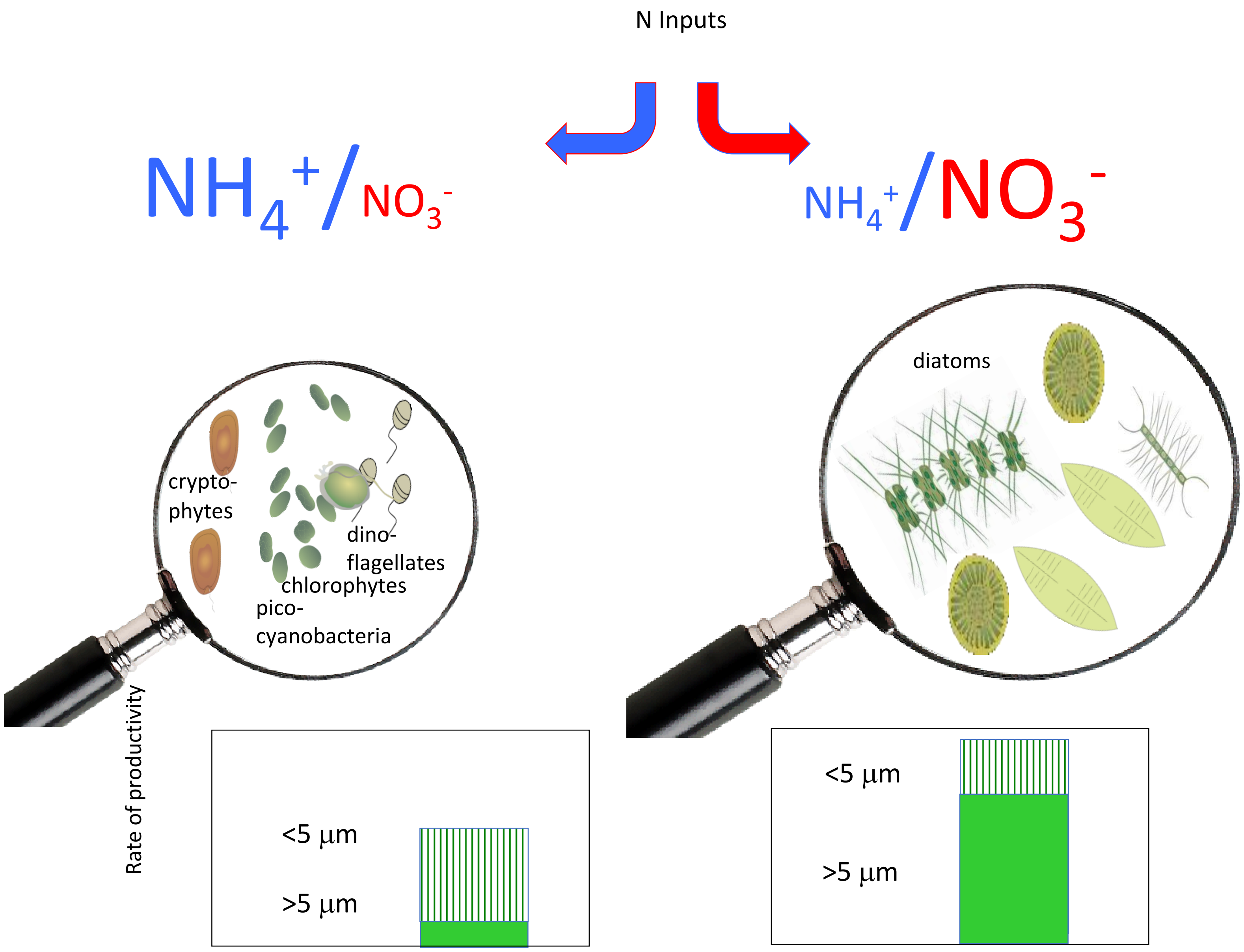
Picocyanobacteria





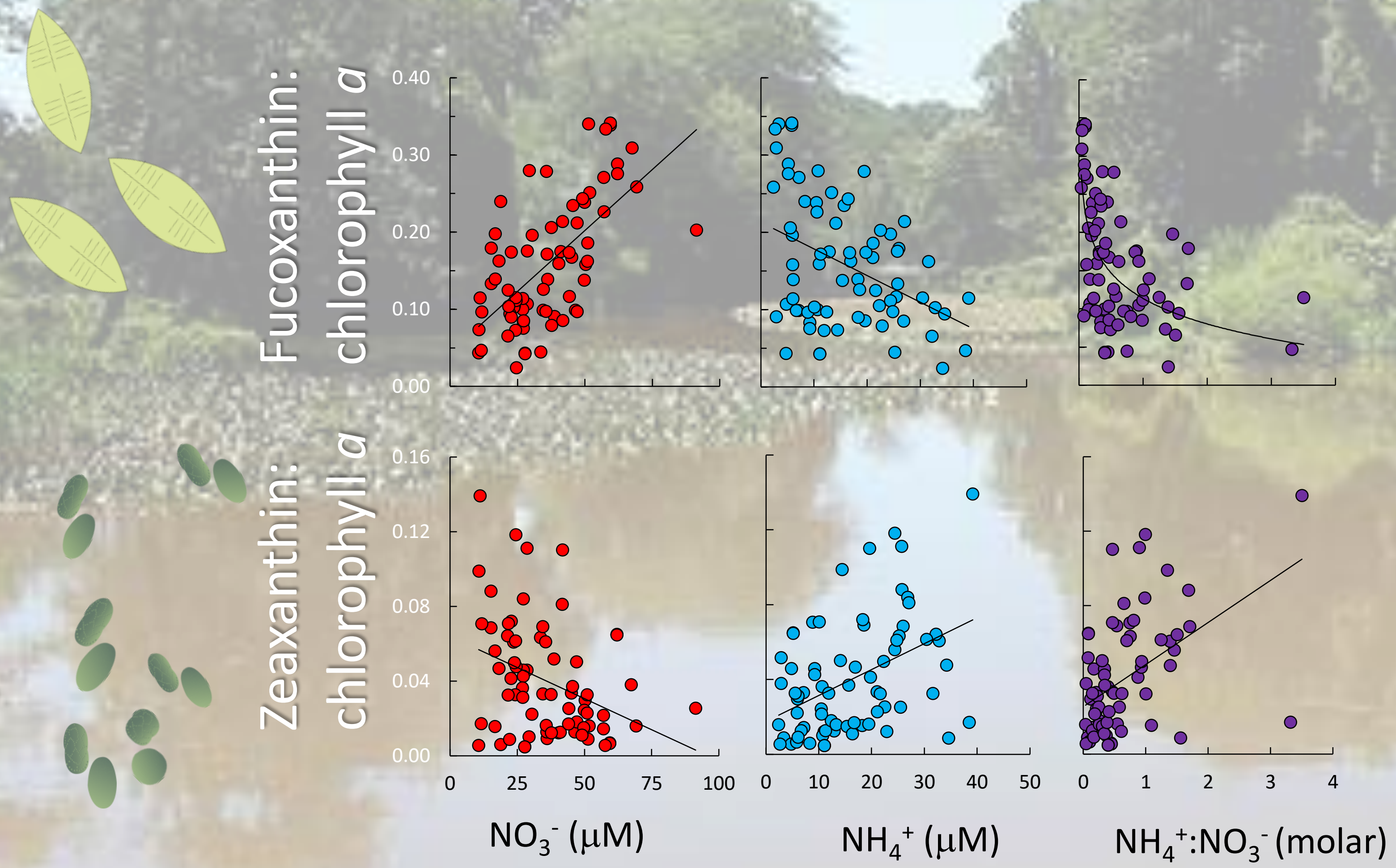
Cyanobacteria (esp. picocyanobacteria), dinoflagellates and chlorophytes have a large capacity to take up and assimilate NH4

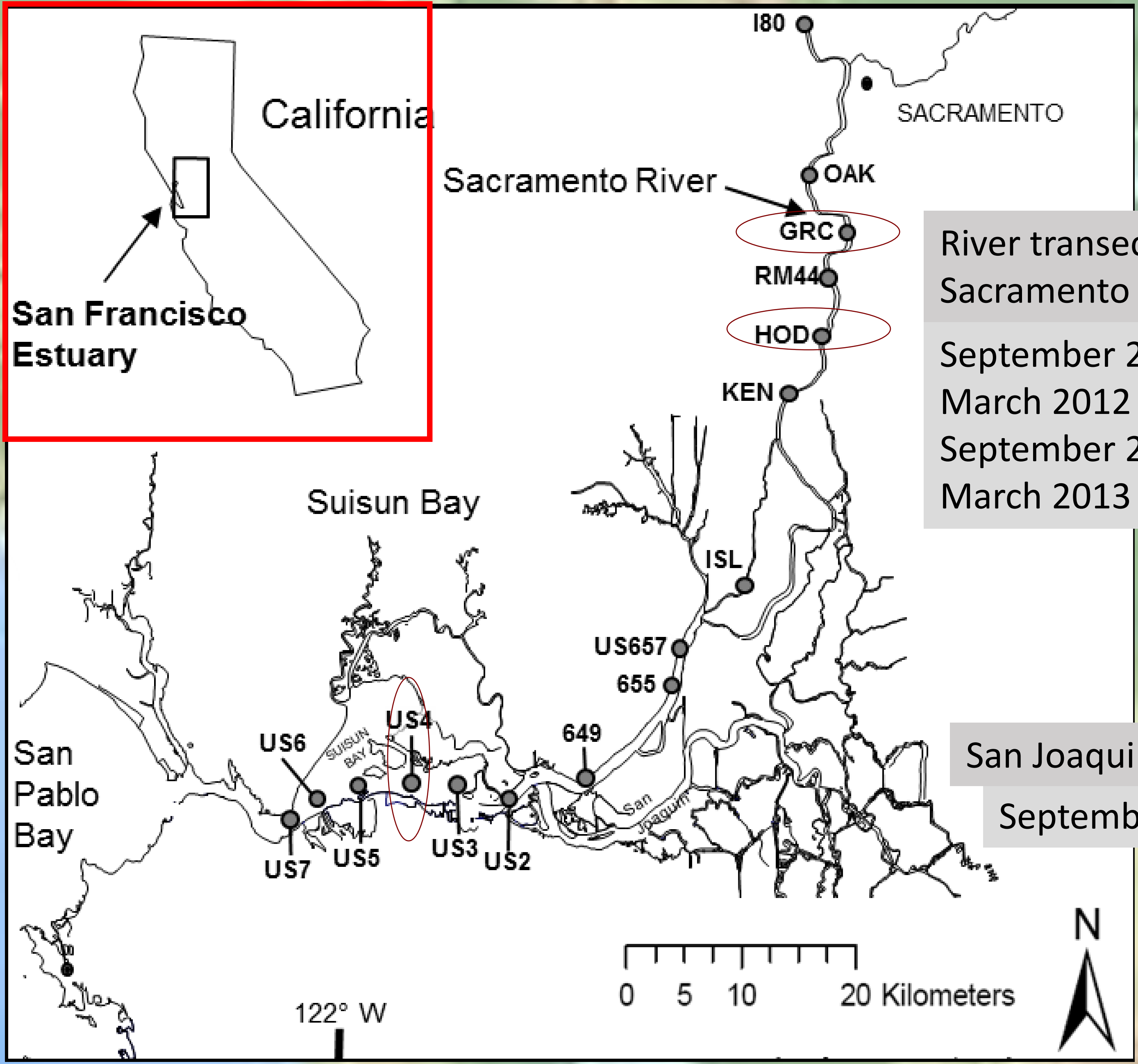
Glibert et al. L&O 2016



N Inputs
NH_4^+/NO_3^-
NH_4^+/NO_3^-
crypto-
phytes
dino-
flagellates
chlorophytes
pico-
cyanobacteria
diatoms
Rate of productivity
<5 µm
>5 µm
<5 µm
>5 µm

Results from the Anacostia River





River transects:
Sacramento to Suisun

September 2011
March 2012
September 2012
March 2013

San Joaquin sampling

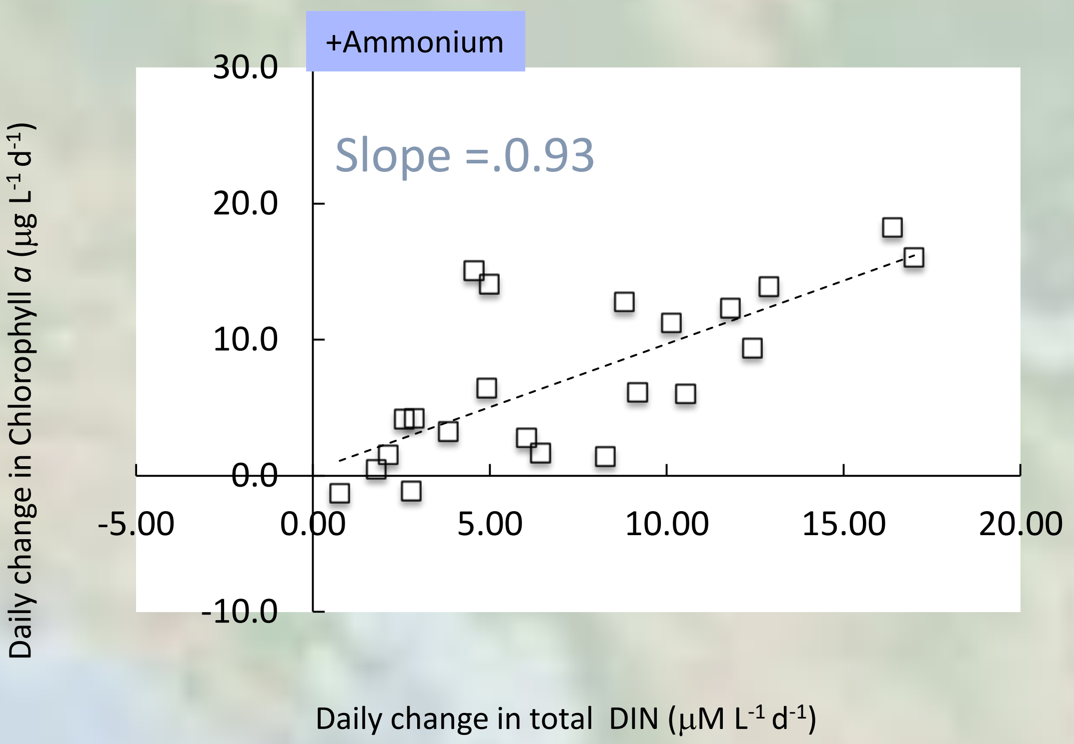
September 2013

Sample collection

Enrich with different forms of N (same concentration)

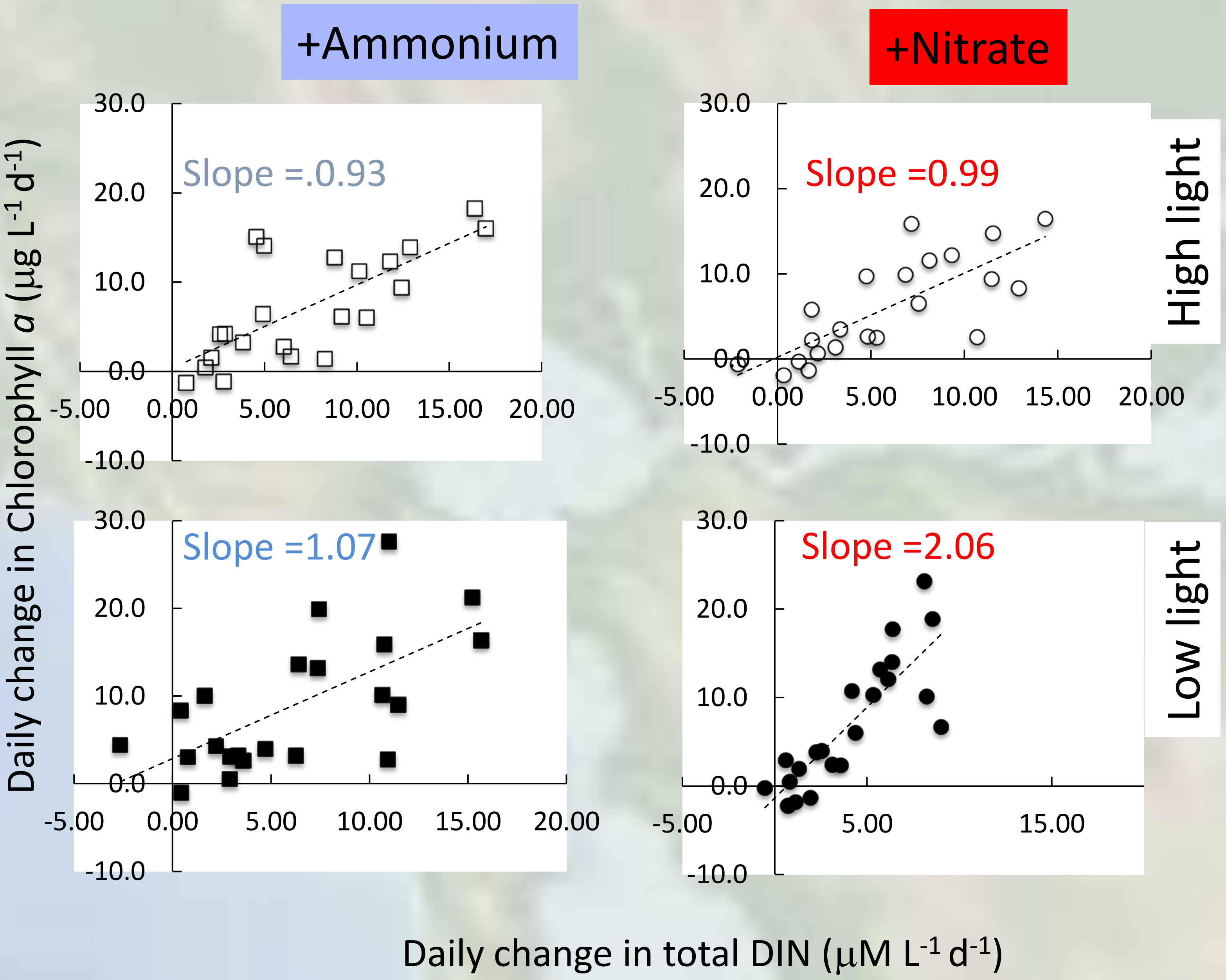
Measure processes and biomass changes on daily basis for ~5 days

Data from all sites, seasons compared by treatment



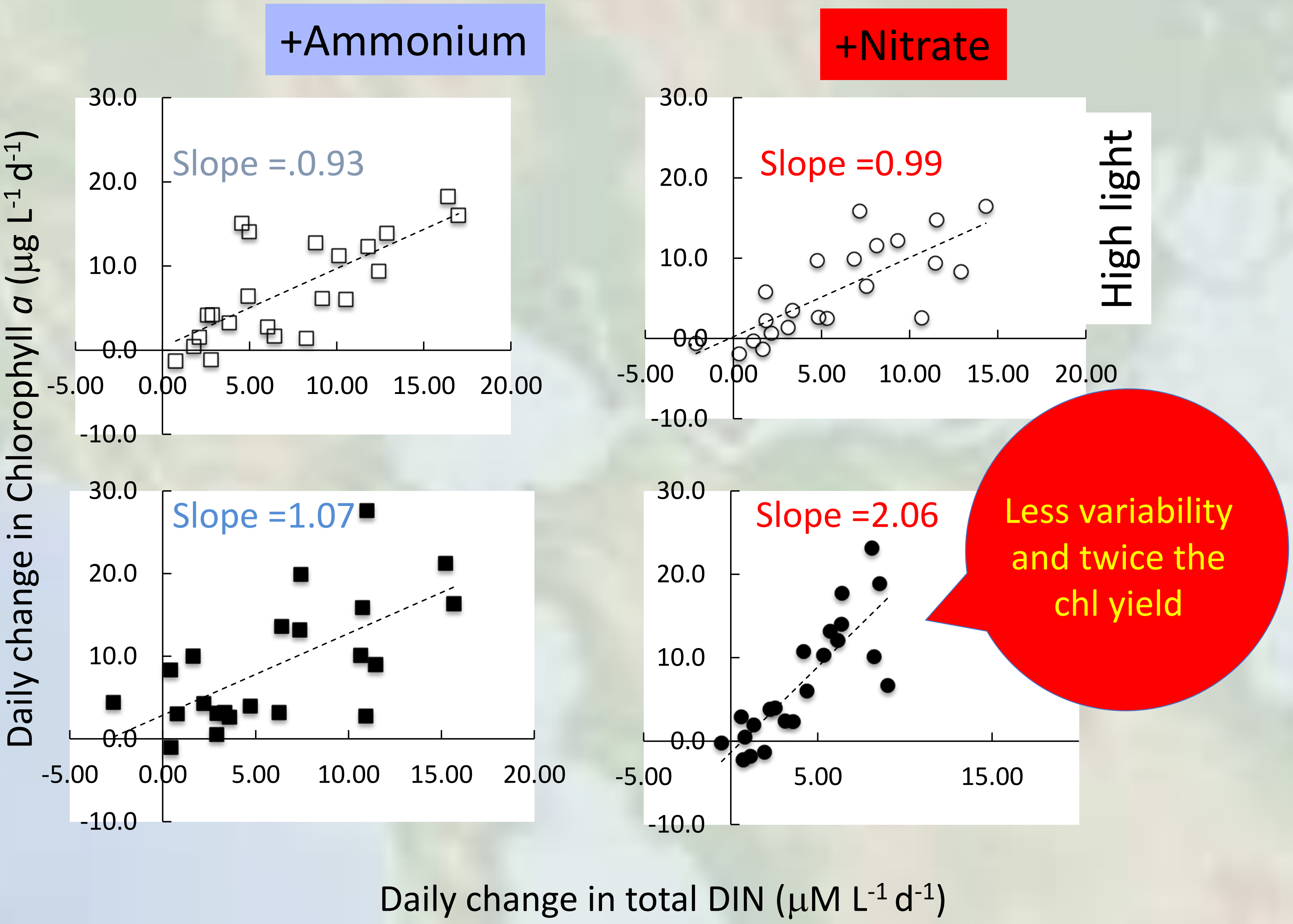
Note- nutrient changes are shown with inverse sign

Glibert et al. 2014c



Note- nutrient changes are shown with inverse sign

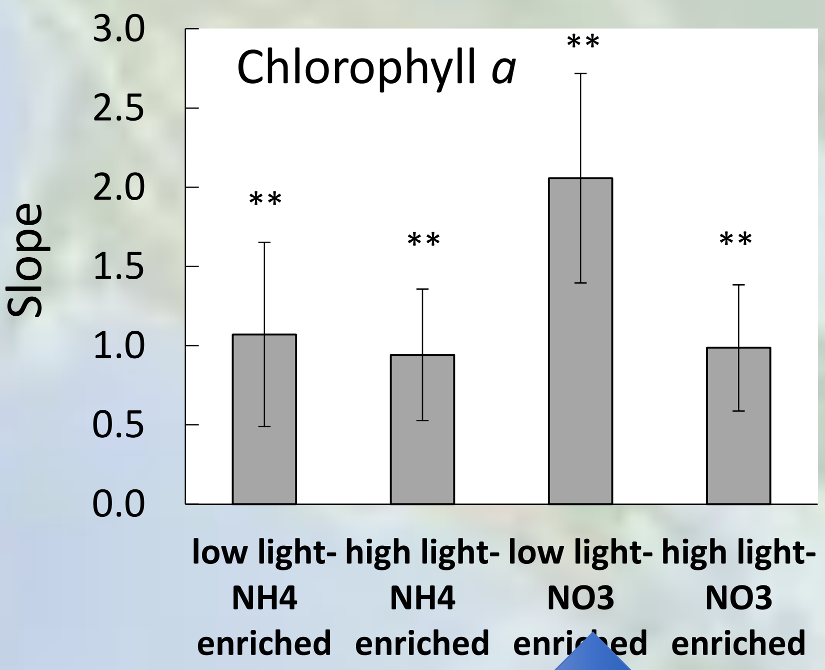
Glibert et al. 2014c

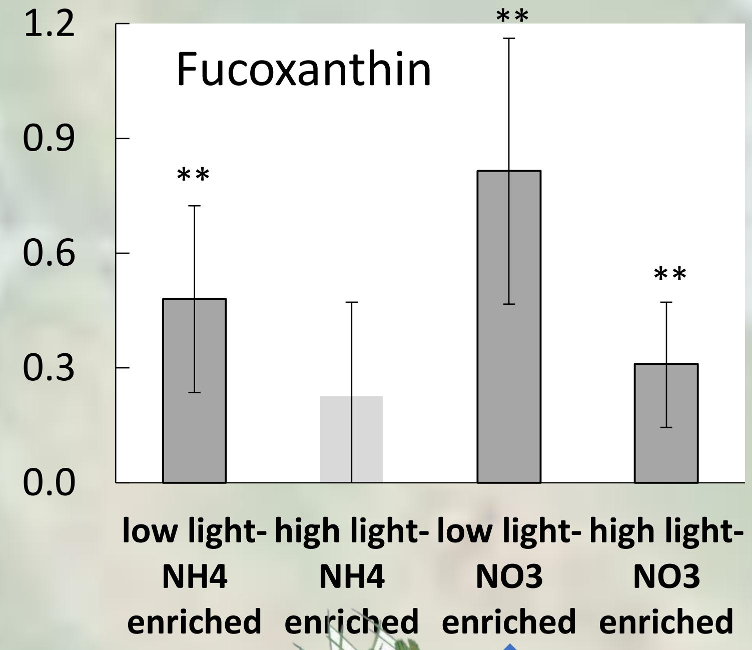


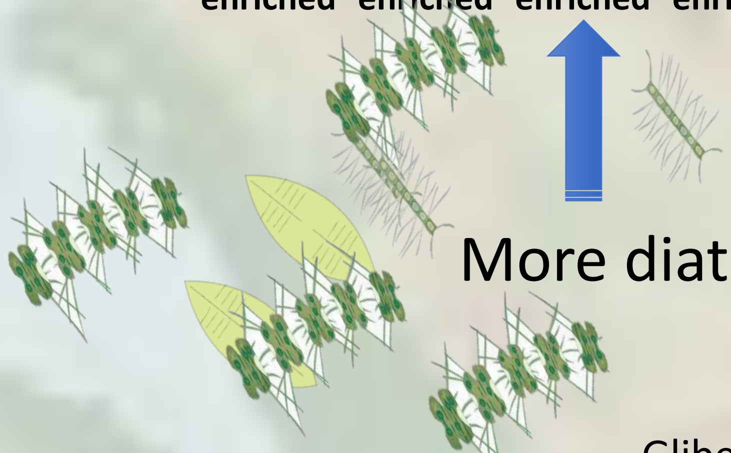
Note- nutrient changes are shown with inverse sign

Glibert et al. 2014c

More diatoms produced under NO_3^- enrichment (and low light)





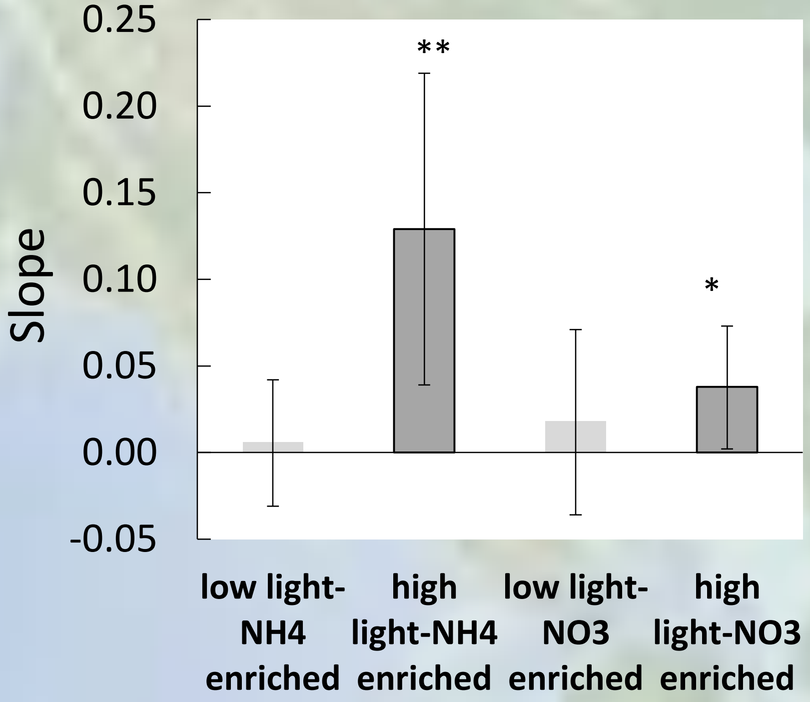


More diatoms !

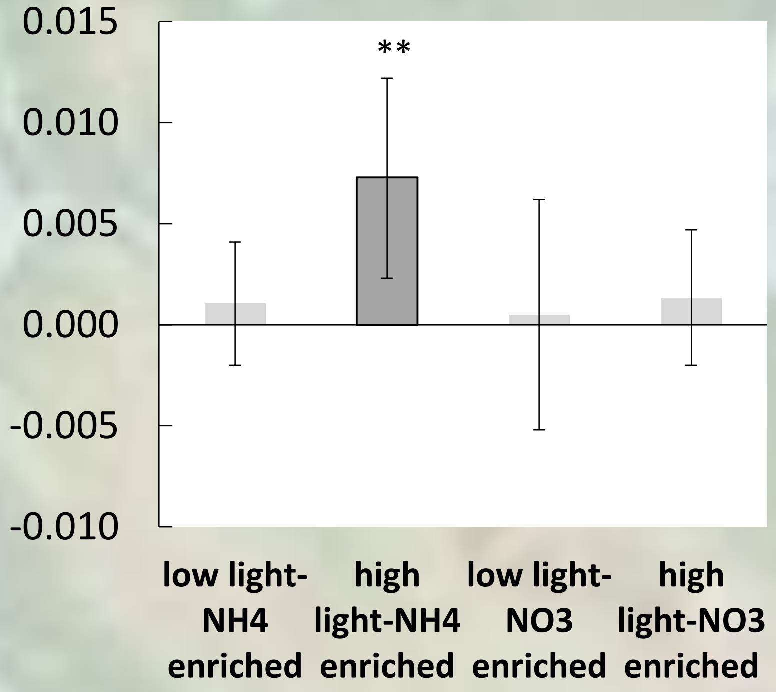
Glibert et al. 2014c

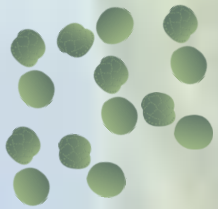
More chlorophytes and cyanobacteria produced under NH_4^+ enrichment (and high light)

Chlorophyll *b*



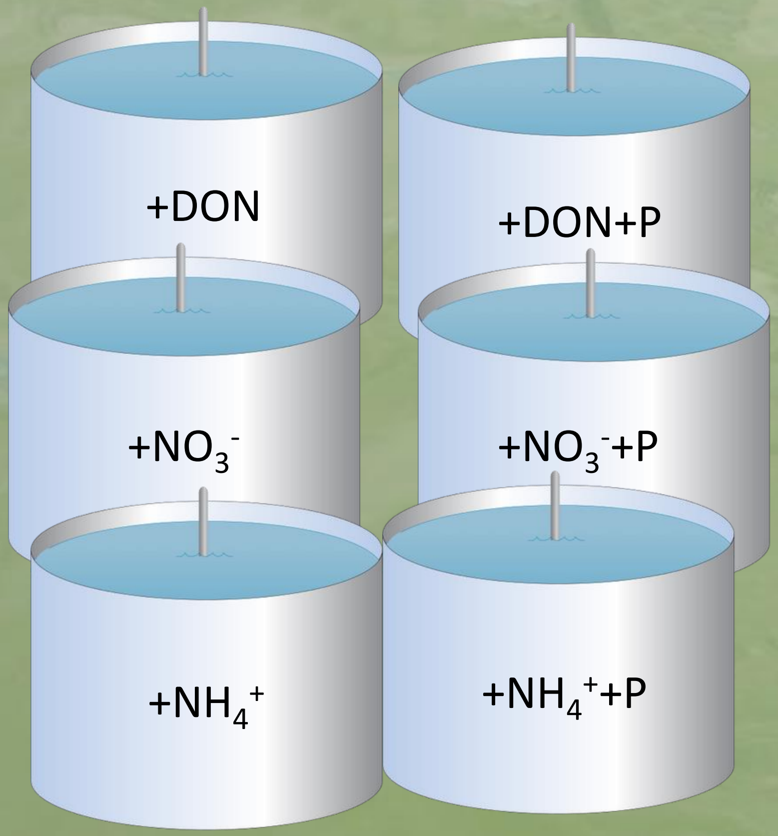
Zeaxanthin



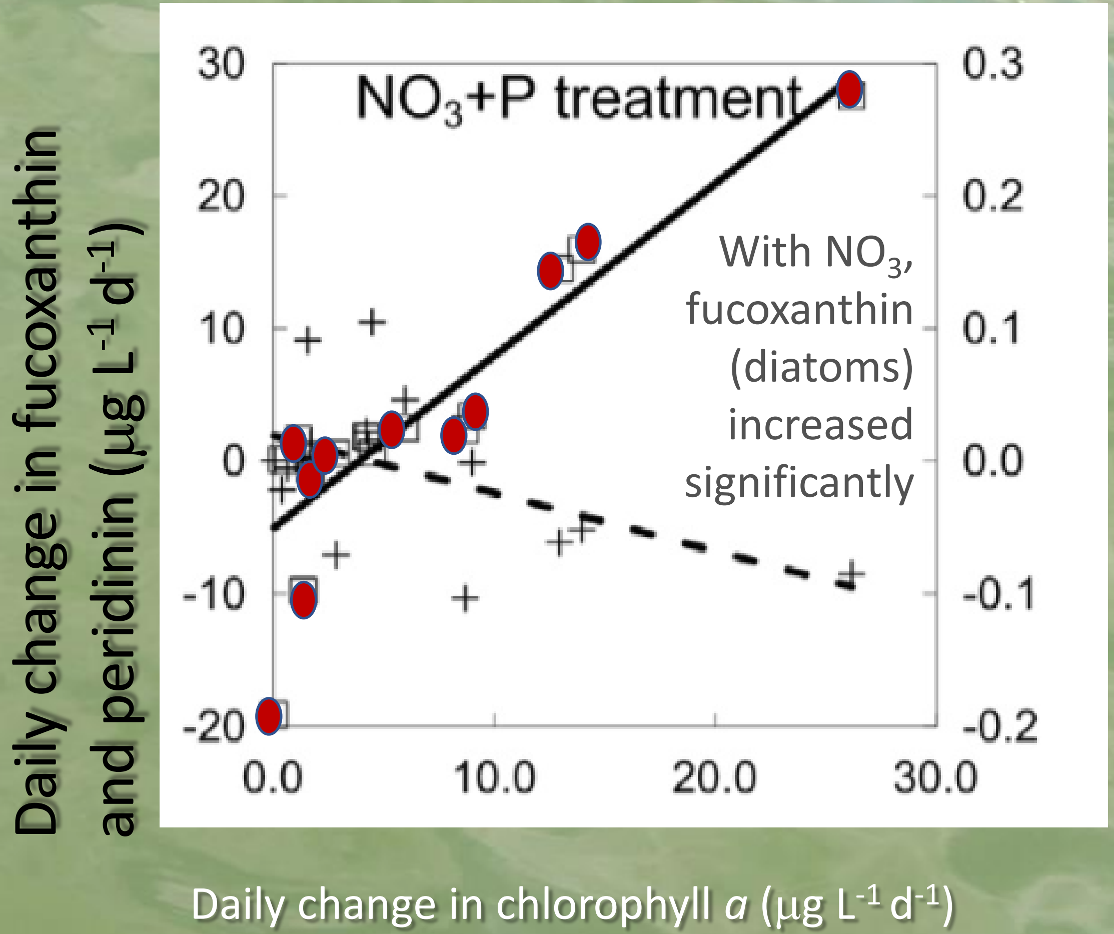


More cyanobacteria!

Glibert et al. 2014c

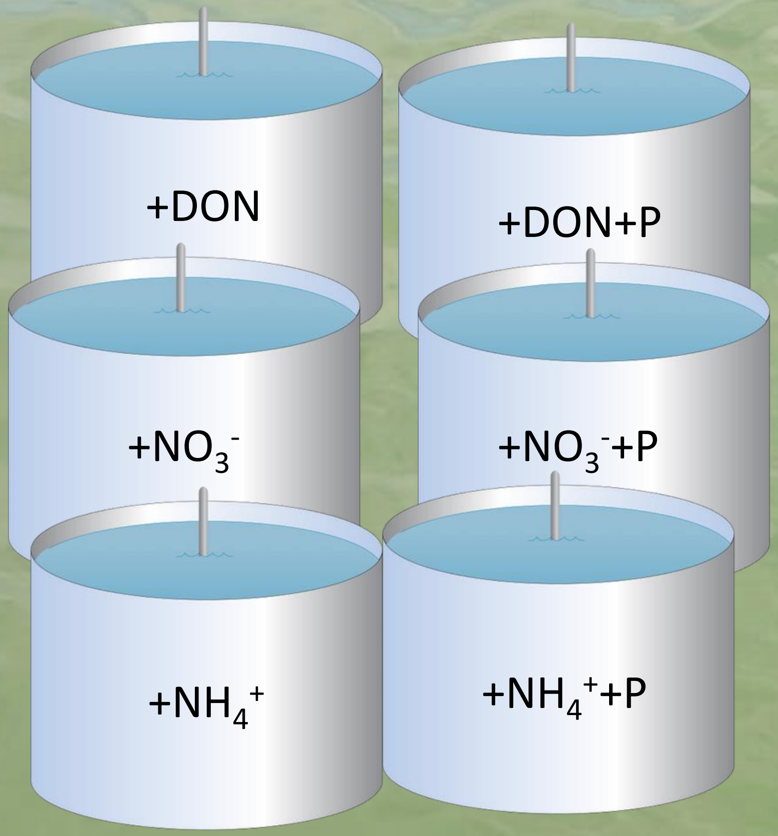


1000 Liter mesocosms- 5 day experiments
Experiments run over multiple seasons and years



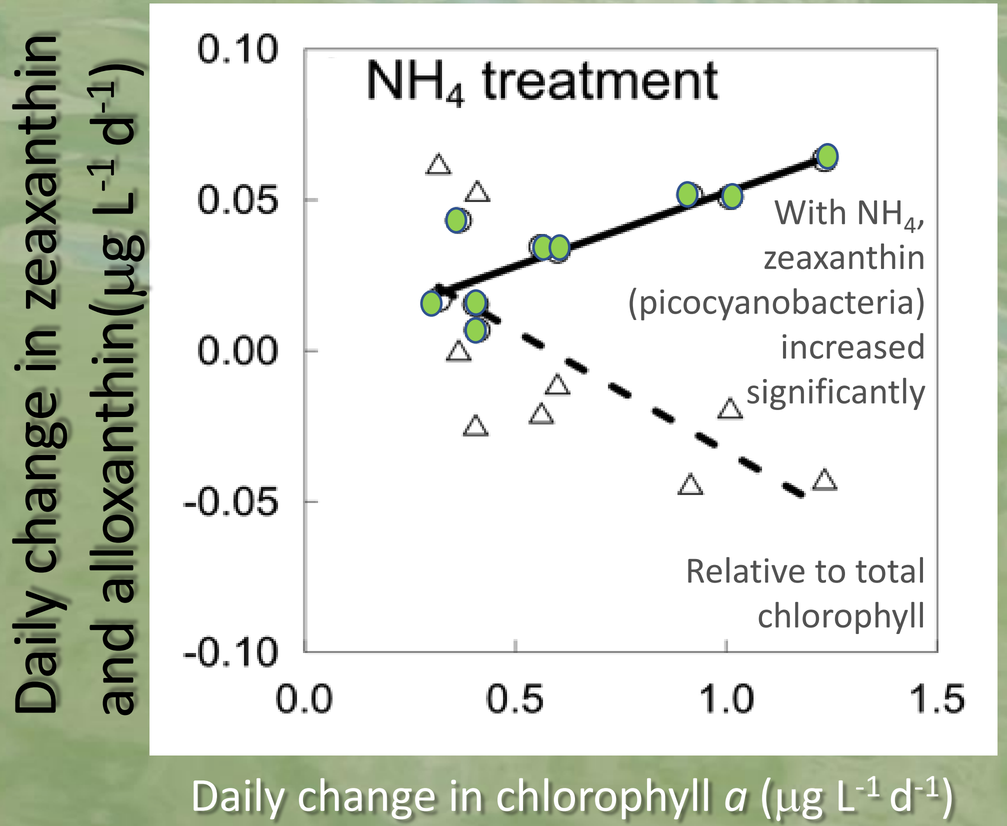
Comparable results from Florida Bay

Shangguan et al.2017 JEMBE



1000 Liter mesocosms

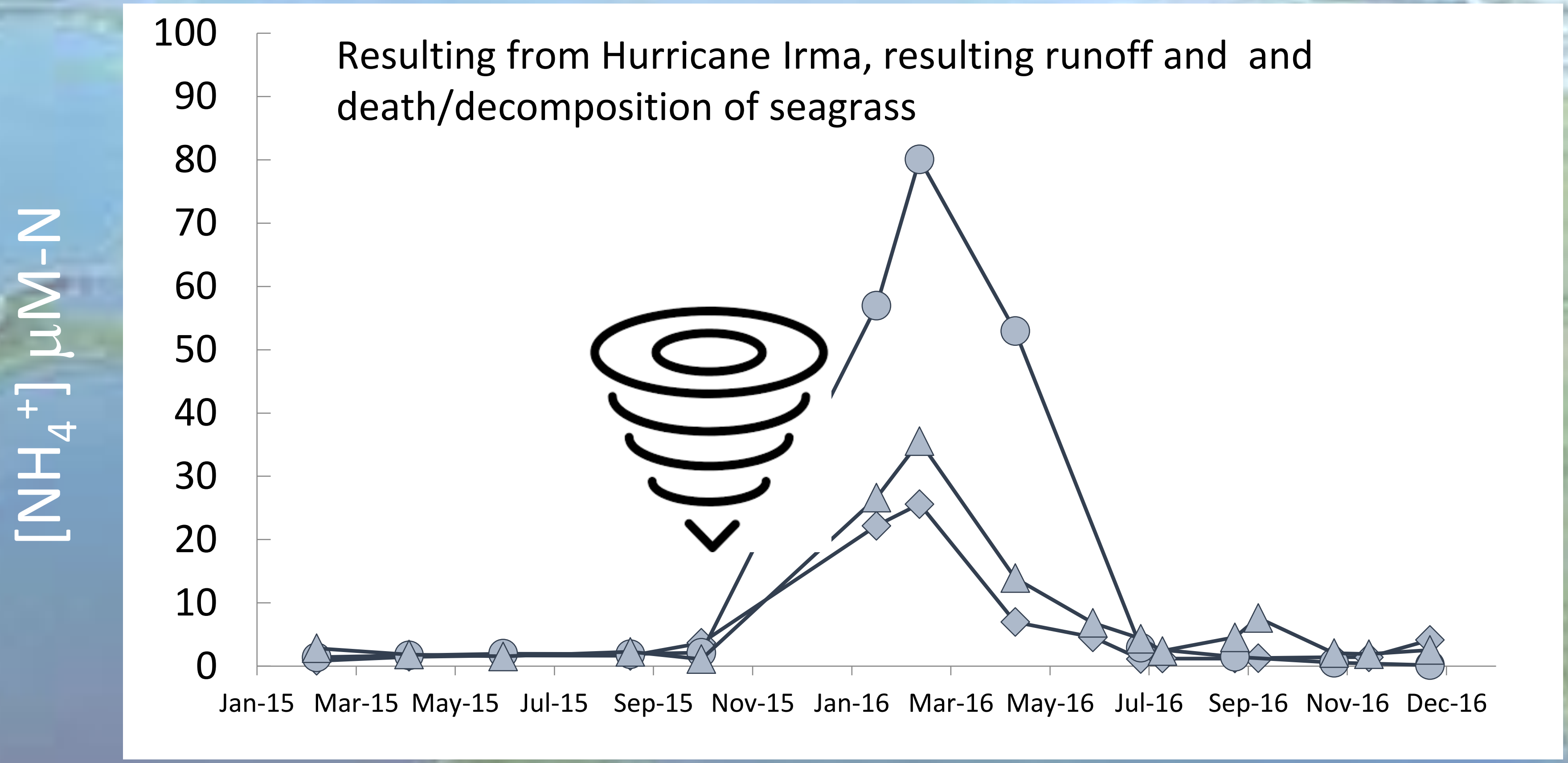
Experiments run over multiple seasons and years



Comparable results from Florida Bay

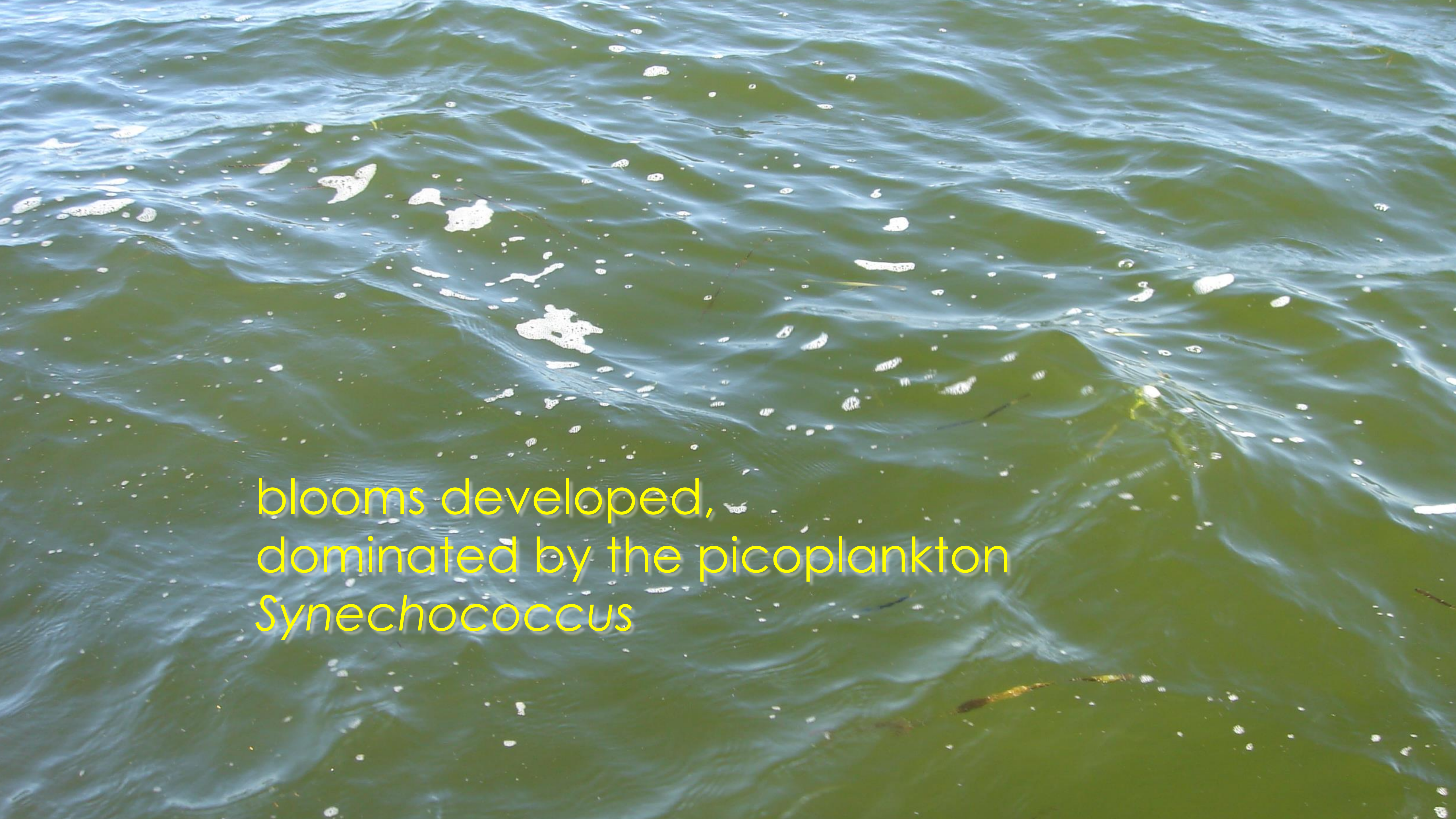
Shangguan et al.2017 JEMBE

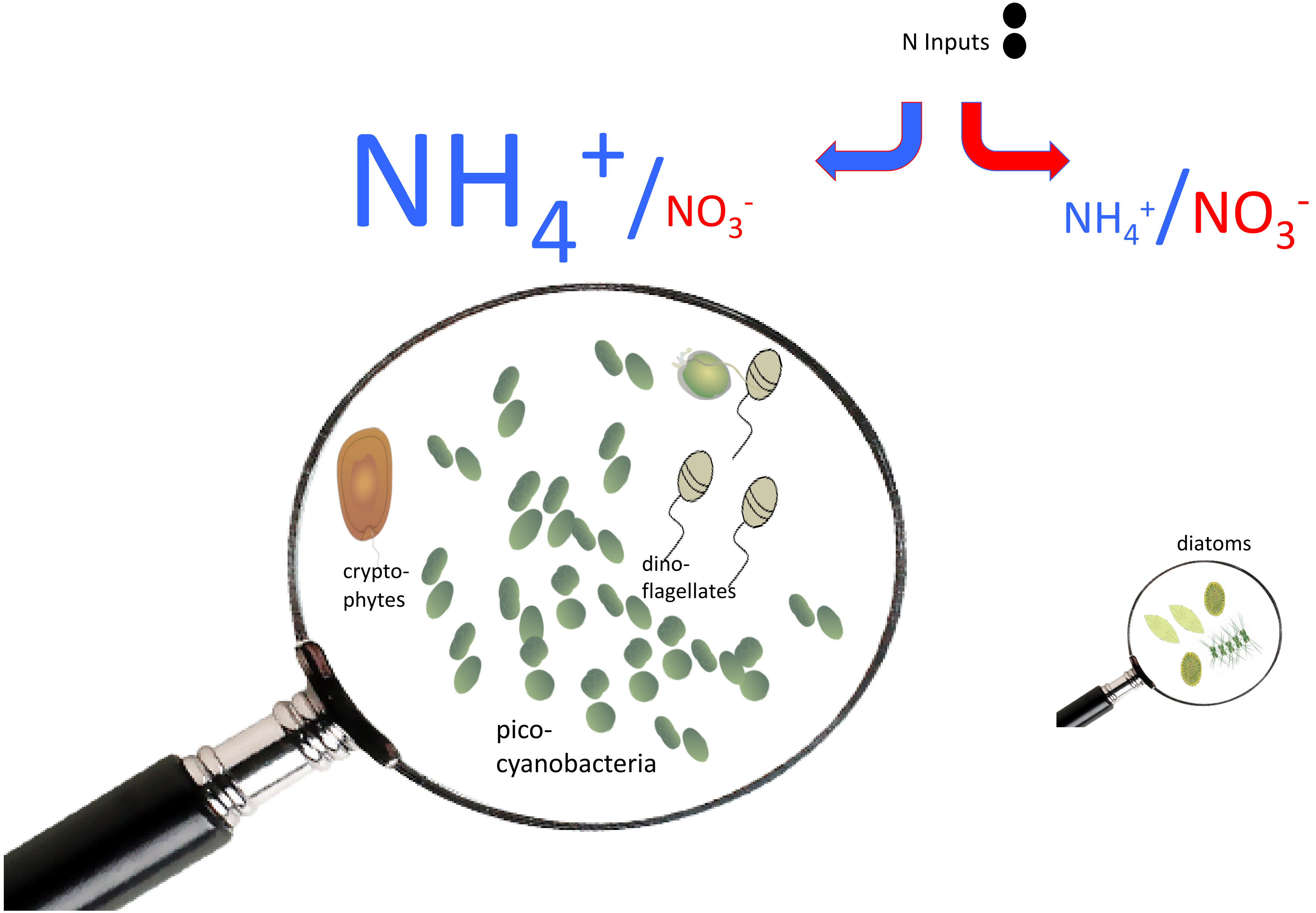
A natural enrichment experiment in Florida Bay: Extremely high concentrations of NH_4^+



2015-2016

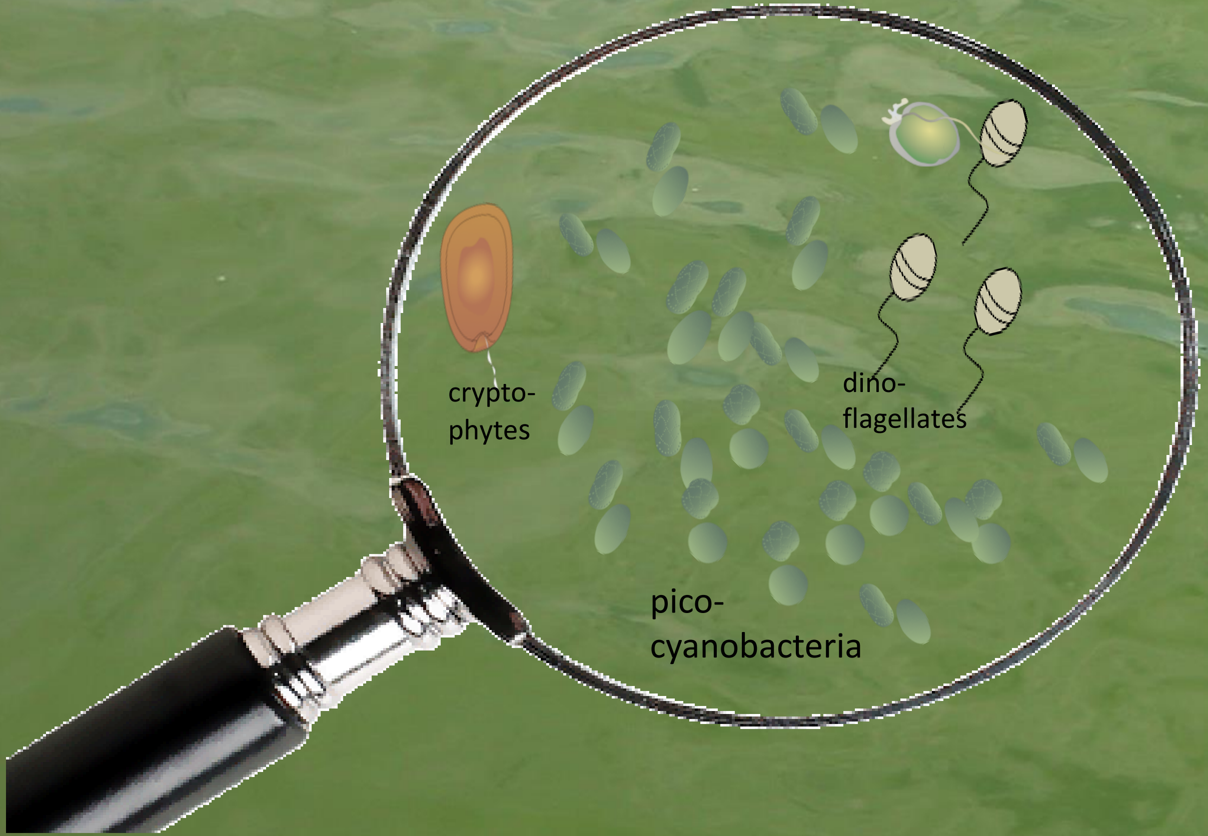
Florida Bay

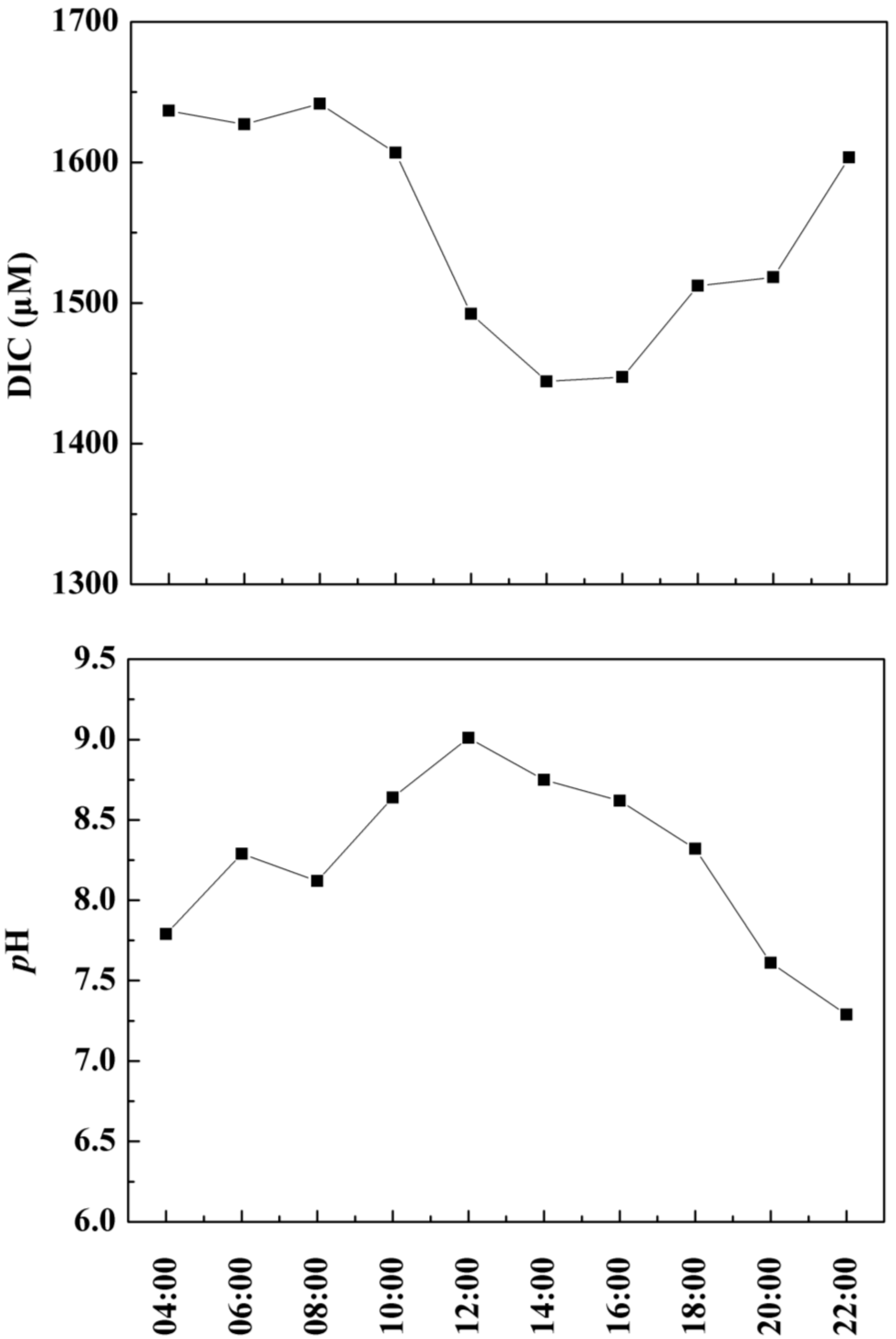

blooms developed,
dominated by the picoplankton
Synechococcus



N Inputs
NH_4^+/NO_3^-
NH_4^+/NO_3^-
crypto-
phytes
dino-
flagellates
pico-
cyanobacteria
diatoms

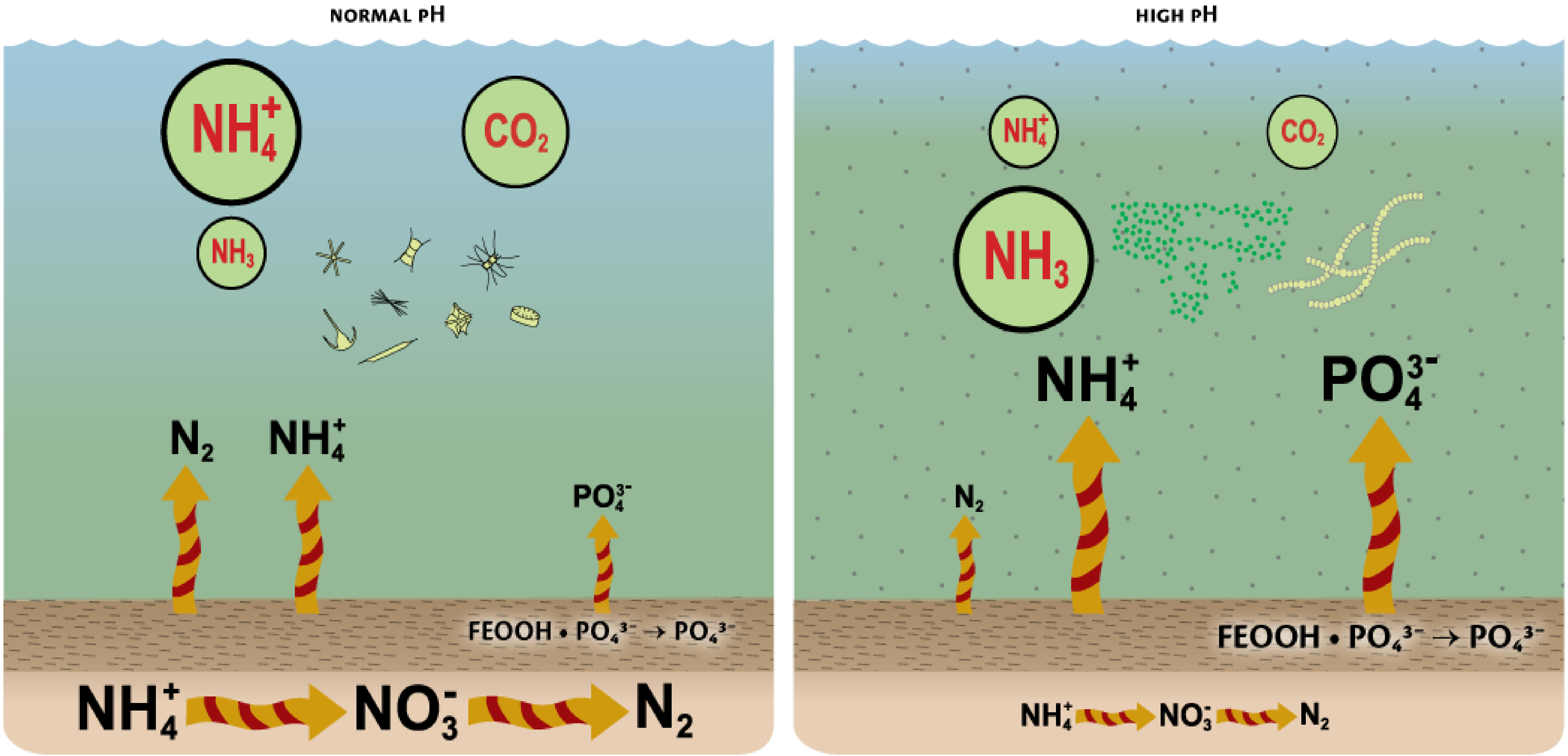
Algal blooms alter pH through daily DIC drawdown





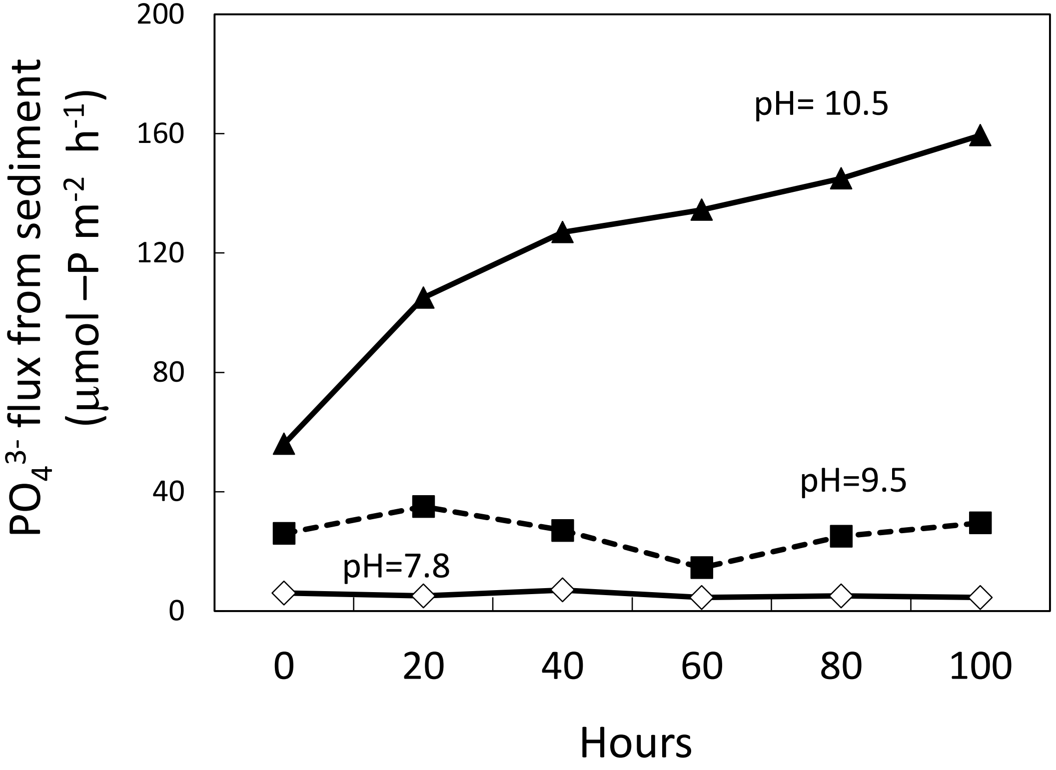
Yang et al. 2017

pH alters nutrient efflux

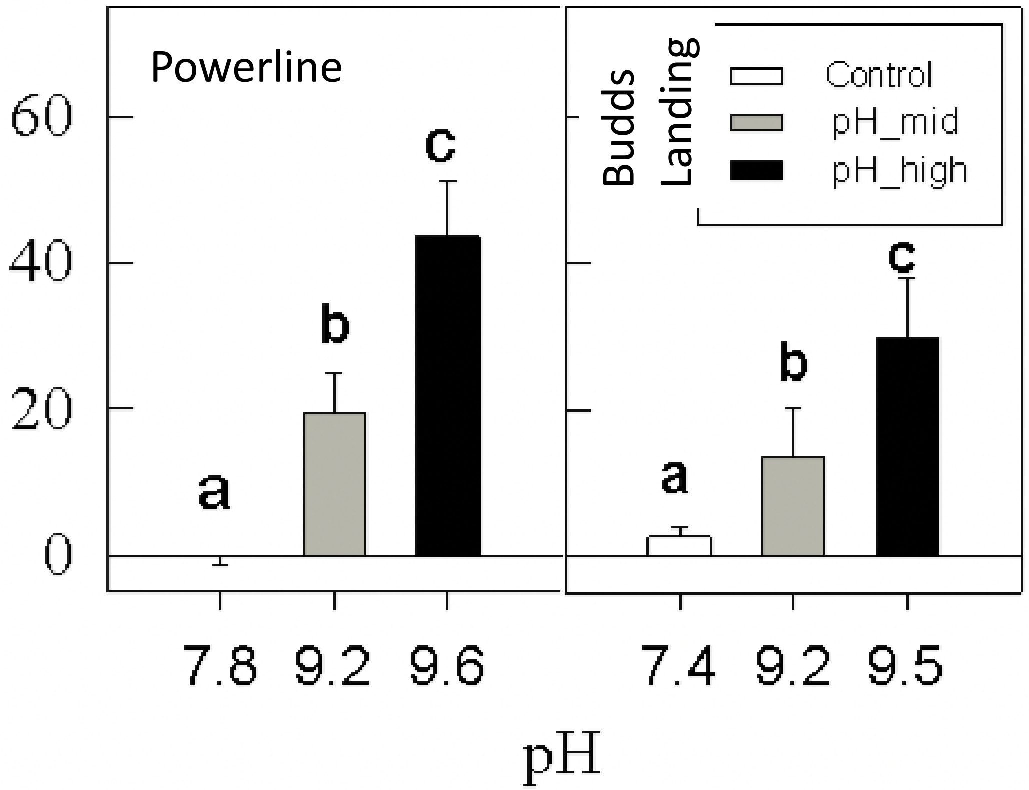


Glibert et al. 2011

Exchanges between bound P and soluble reactive P can be ***fast***



Bailey et al. 2006



Gao et al. 2012

As we target P for nutrient reduction, the result is large increases in N:P

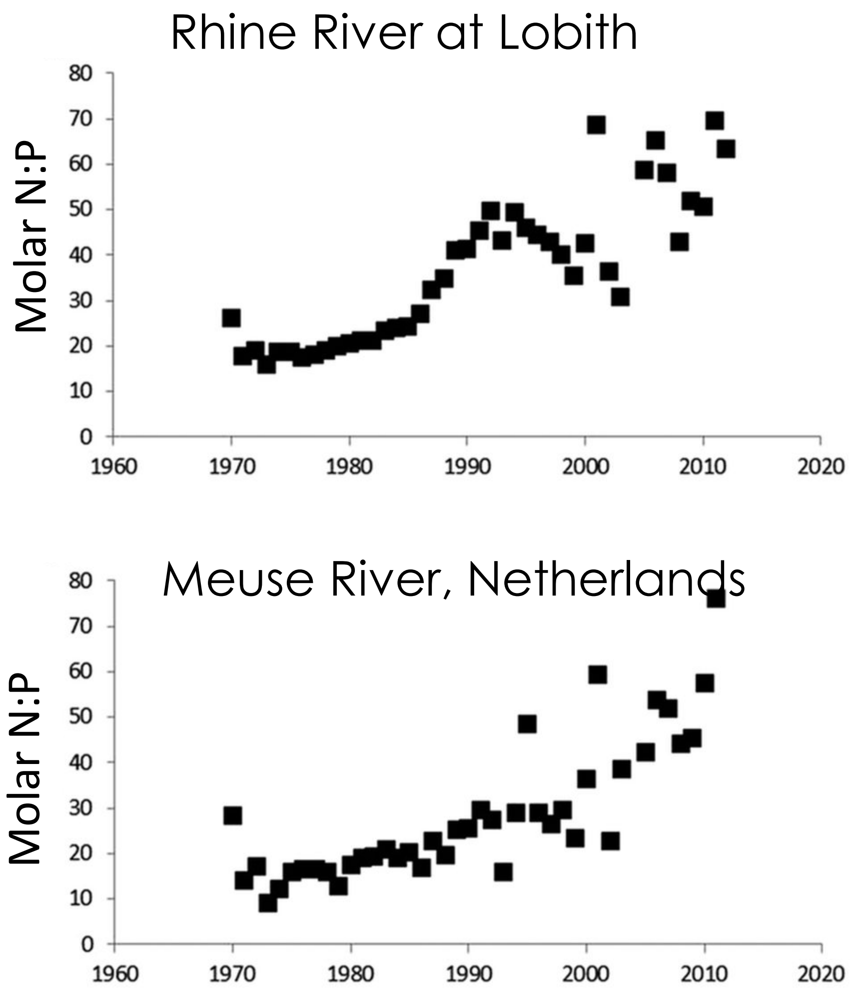
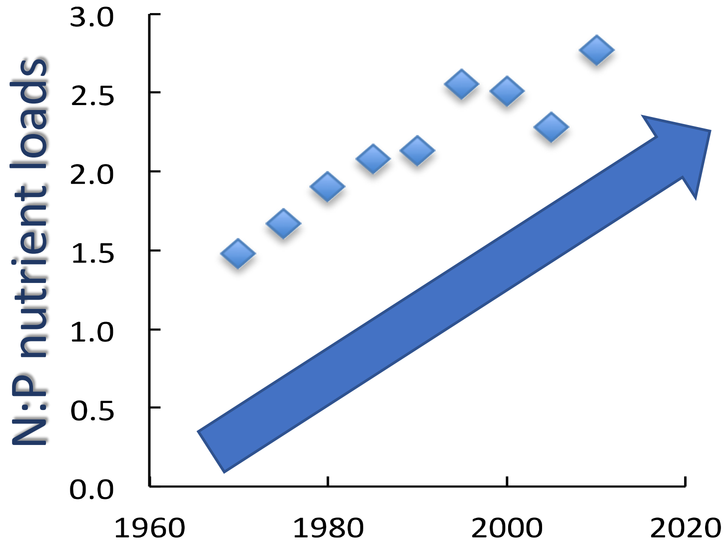
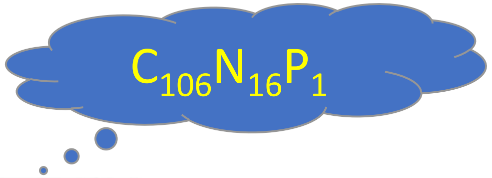


Figure from Bouwman et al. 2017

Map from Marcus et al. 2013



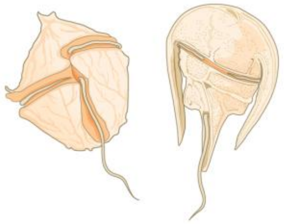


Numerous “strategies” for coping with imbalanced nutrient proportions:

Cells may substitute P-rich lipids

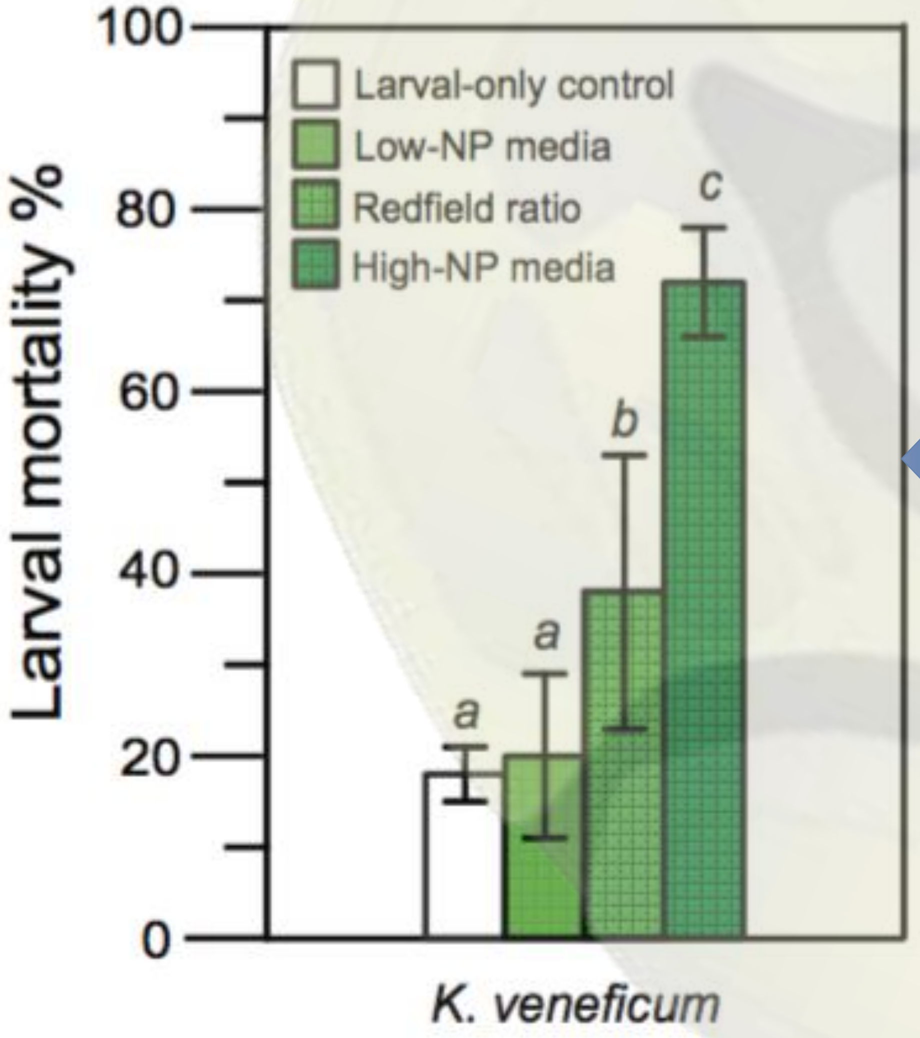
Cells may access alternate substrates- such as organic nutrients ***or particulates***

Cells may dissipate the excess nutrient- some of these compounds are C, or N-rich toxins



Glibert and Burkholder 2011.

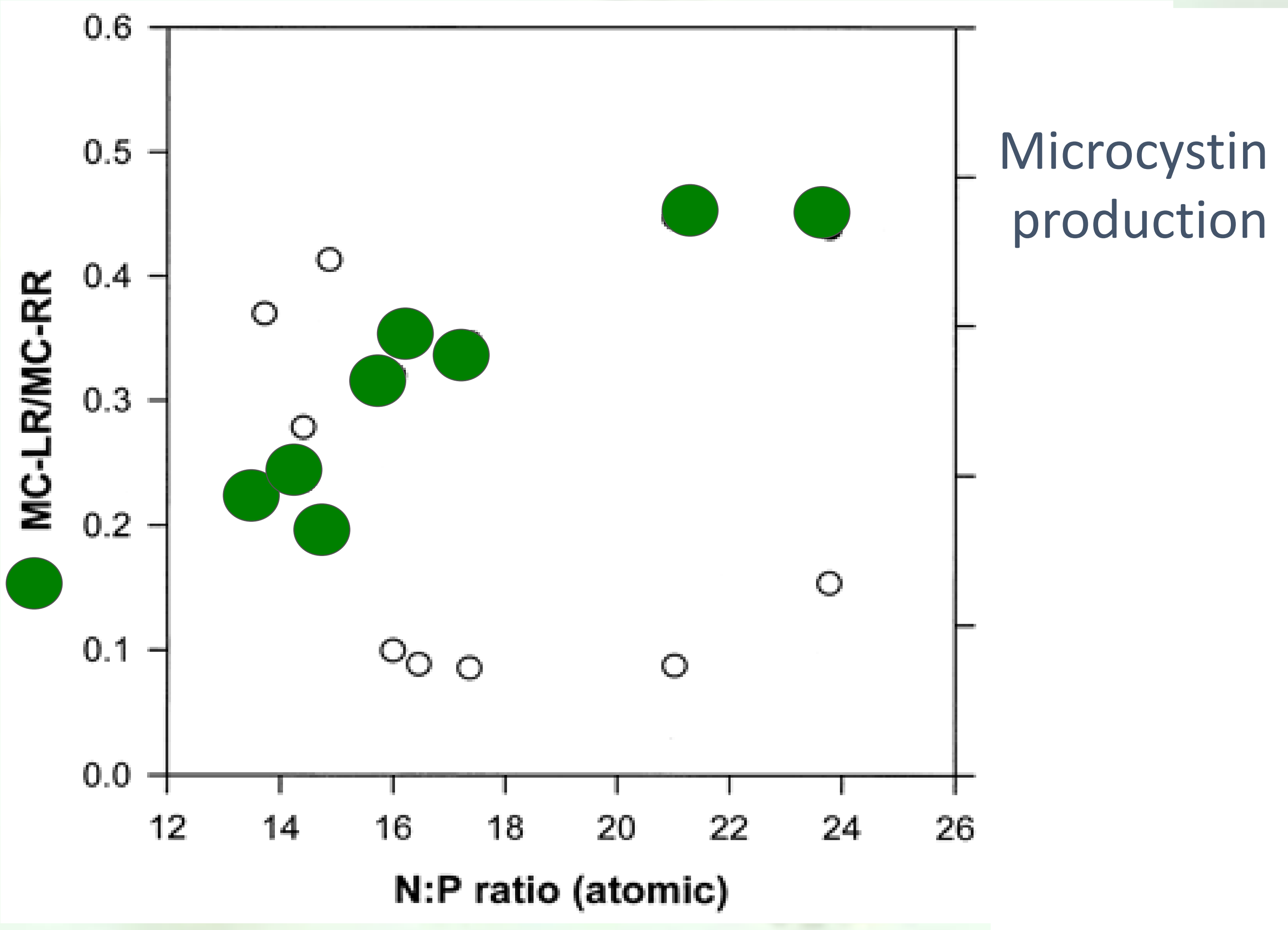
Rise of the mixotrophs (and HABs!)



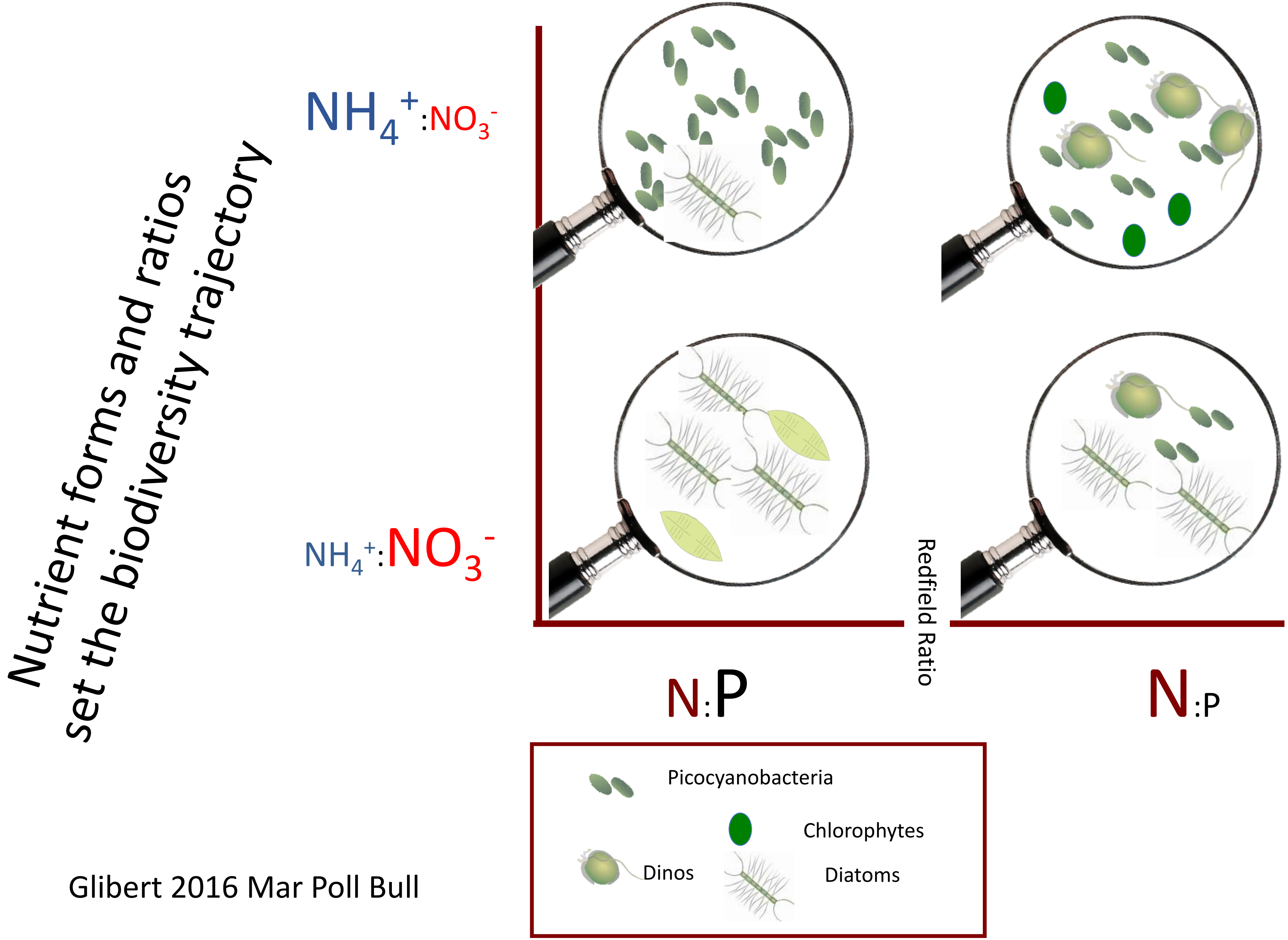
The mixotroph *Karlodinium veneficum* is more toxic at high N:P
(oyster larvae bioassay)

Lin et al.2017 Aq. Microb. Ecol.

Microcystis produces more toxin at high N:P

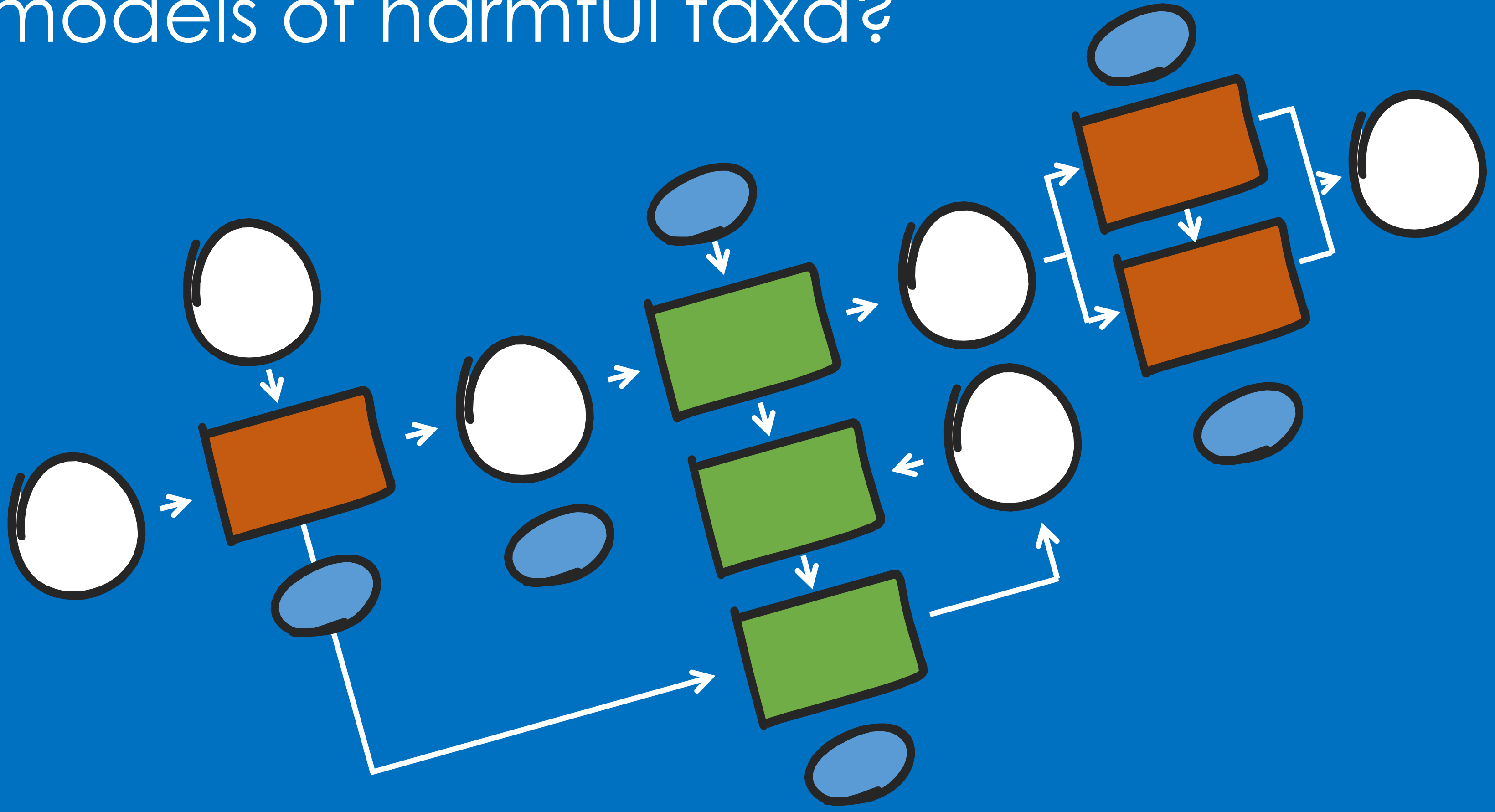


Oh et al. 2000 AEM

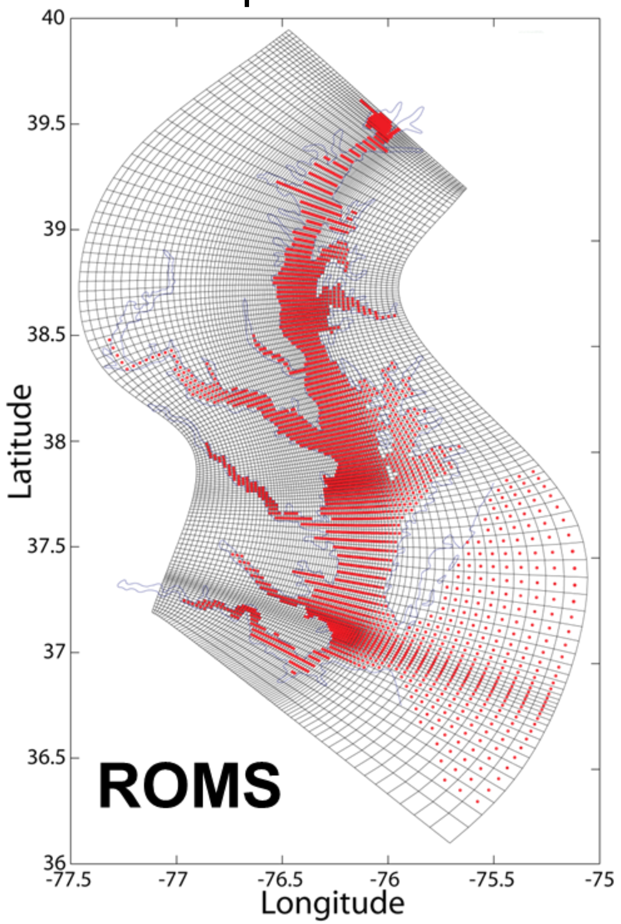


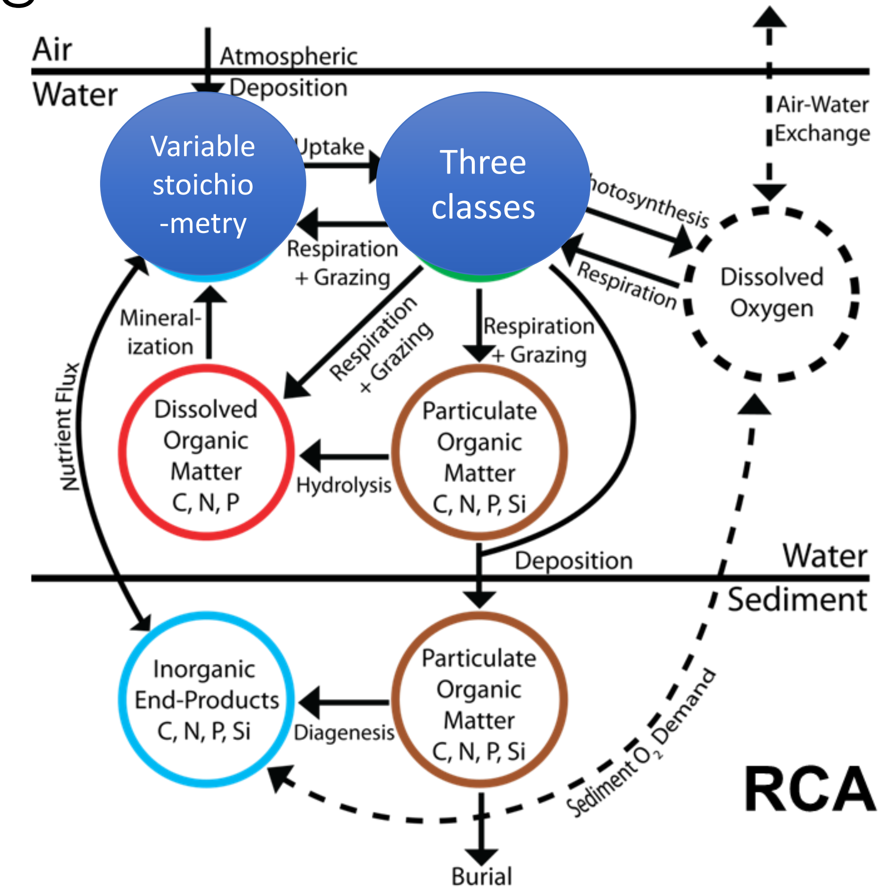
Glibert 2016 Mar Poll Bull

How can we incorporate nutrient proportions and forms in models of harmful taxa?



Building spatially explicit HAB models, developed on a biogeochemical framework





- Forced by freshwater from 8 major tributaries
- Resolution = 80 cells east-west, 120 cells north-south 20 vertical layers, 68,000 Cells

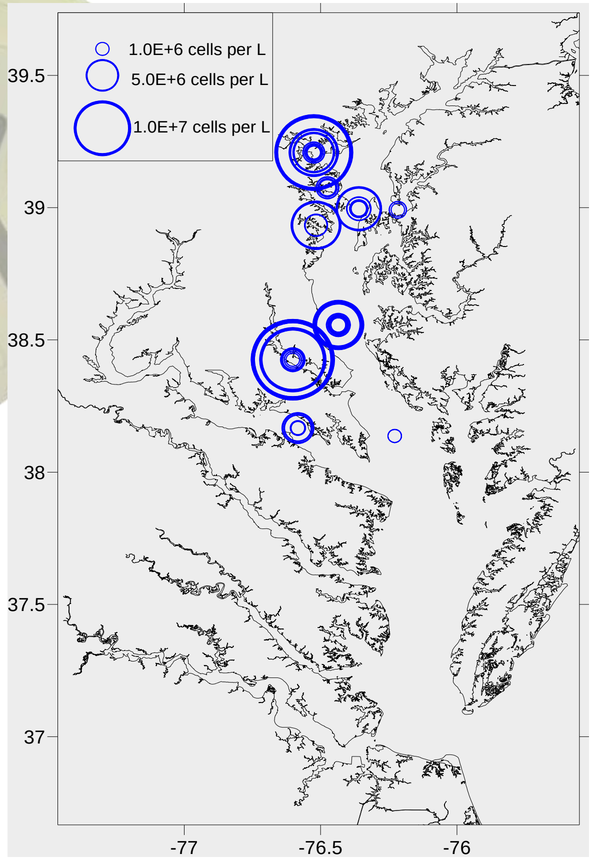
- 23 state variables
- Coupled sediment biogeochemical model
- External loads from 8 tributaries, point sources, atmospheric deposition
- Calibrated to water-column concentrations, sediment and water-column metabolic rates

Building on years of application of this model for predicting hypoxia

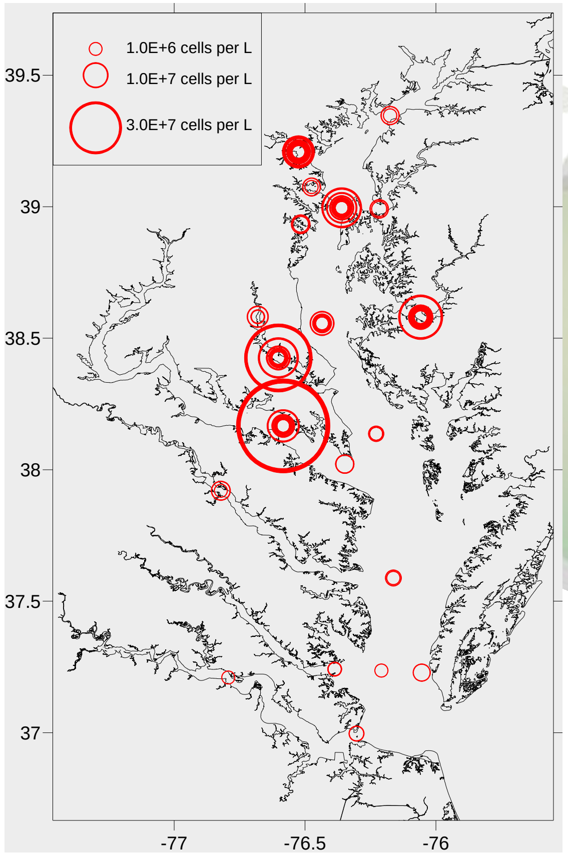
Karlodinium and *Prorocentrum* are common in the mid-upper reaches of Chesapeake Bay forming visible blooms and contributing to fish kills and other ecological problems

These species are found in the mid to upper Bay regions

Karlodinium



Prorocentrum

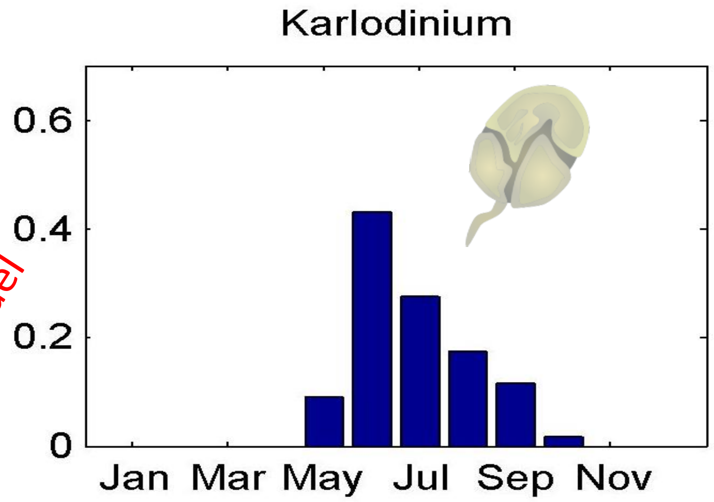


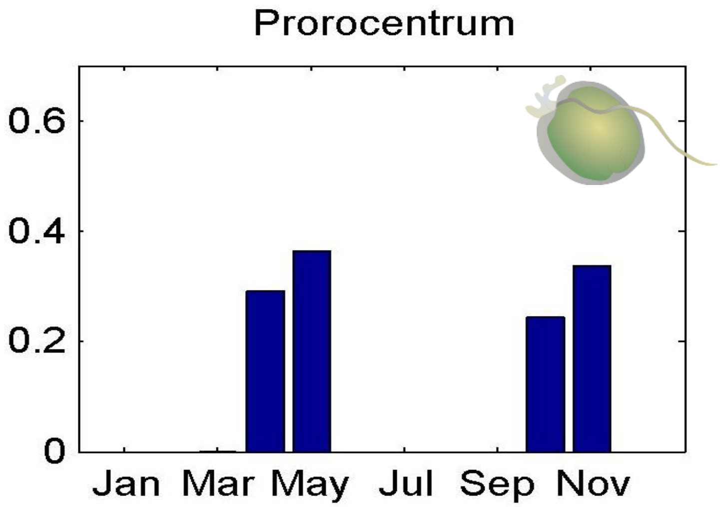
Li et al. 2014

Physical conditions and nutrient ratios alone yield good correspondence seasonally with analyses based on long term records (overestimate of fall *P. minimum*)

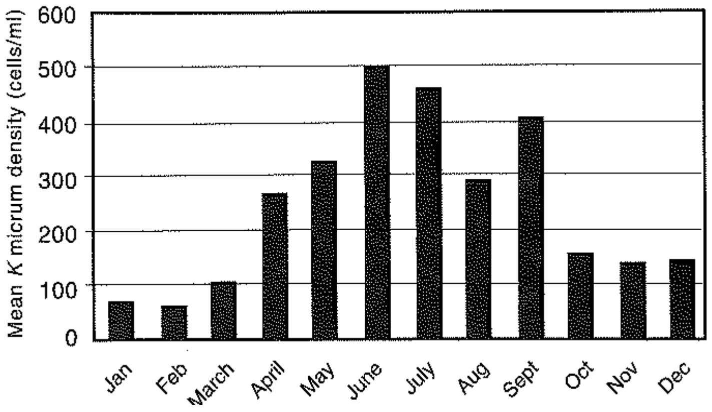
Compare model output with available data for past 2 decades

Habitat model

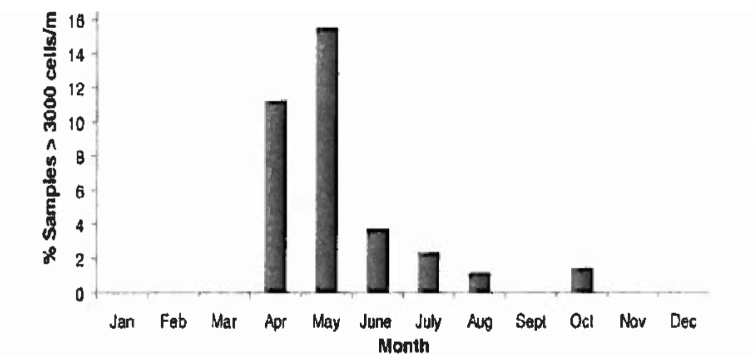




Long term data



Goshorn 2004



Tango 2005

Summary

1

NH_4^+ can be repressive at high concentrations while being a preferred N substrate under low concentrations

2

NH_4^+ and **NO_3^-** are assimilated differently– leading to different algal assemblages and total chlorophyll.[similar conclusions with other N substrates]

3

Algal accumulations affect pH, in turn affecting **PP-PO_4^{3-}** dynamics

4

Nutrient speciation affects phytoplankton dynamics-from limitation to excess, with implications for HABs

Total nutrient load sets the total amount of productivity of a system

BUT

The relative proportions of nutrients sets the ***QUALITY*** (who is there and how they are doing)… a finely tuned interplay of organisms driven by their organismal needs, their efficiency at acquiring what they need, how they balance what they don't, and the effects on growth and nutrient recycling

"Changed balances and ratios of nutrients at huge scales may have major impact on the distributions of plants, animals, and microbes at smaller scales"

Sterner and Elser 2002

Acknowledgements

Frances Wilkerson
Dick Dugdale

John Raven

Alex Parker

Chris Dupont

Peter Leavitt
Vanessa Swarbrick

JoAnn Burkholder

ECOHAB

Todd Kana

Ming Li
Fan Zhang
Yini Shangguan
Michelle Lin

Nitrogen Limited	If we	↑	nitrogen	then	↑	biomass
	If we	↑	phosphorus	then	—	biomass
Phosphorus Limited	If we	↑	nitrogen	then	—	biomass
	If we	↑	phosphorus	then	↑	biomass