Controlling CyanoHABs in a world experiencing anthropogenic and climatic-induced change

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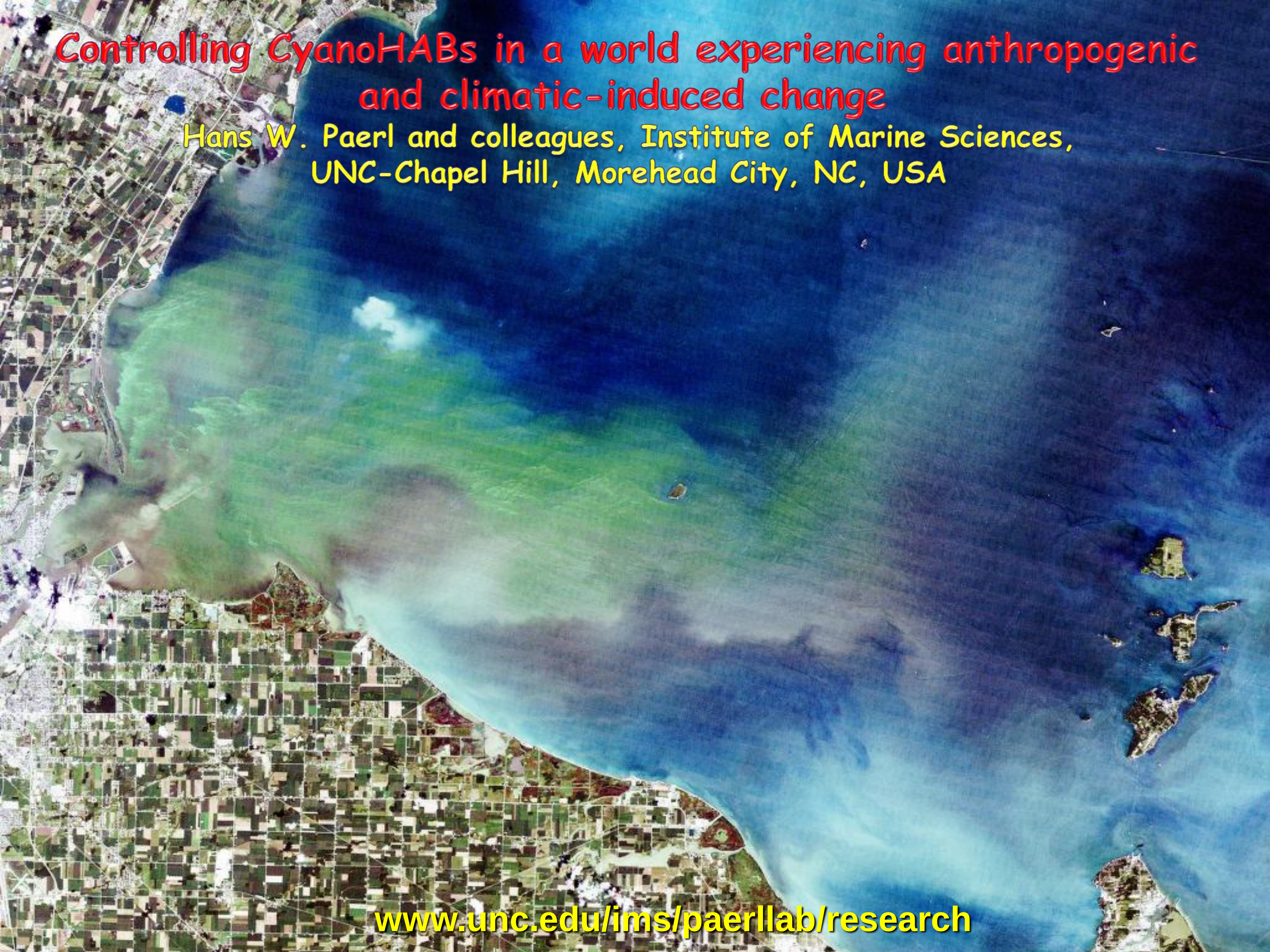


www.unc.edu/ims/paerllab/research

Cyanobacterial Harmful Blooms (CyanoHABs): Symptomatic of human and climatic alteration of aquatic environments

Urban, agricultural and industrial expansion

Increasing nutrient (Nitrogen & Phosphorus) inputs

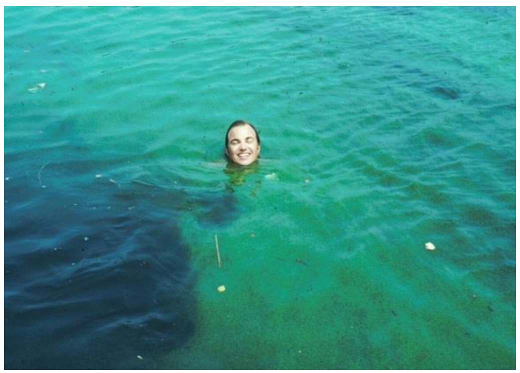
Water use and hydrologic modification play key roles

Climate (change) plays a key interactive role

Blooms are intensifying and spreading

Why the concern about HABs?

- Toxic to zooplankton, fish, shellfish, domestic animals and humans
- Cause hypoxia and anoxia, leading to fish kills
- Odor and taste problems
- loss of drinking water recreational, fishing use/sustainability




TUESDAY

FORT PIERCE TRIBUNE

It's back to class for St. Lucie students

Energy bill not a quick fix, says Bush at signing

Ewww! River's a 'mess'

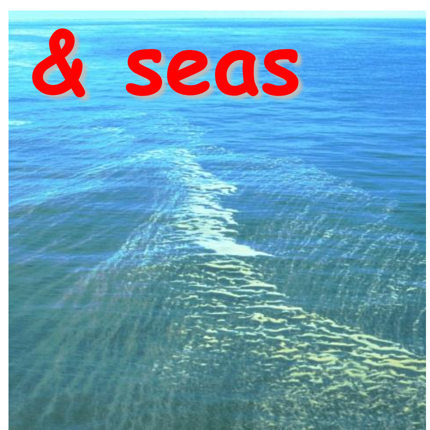
It's a global problem

- Freshwater Ecosystems

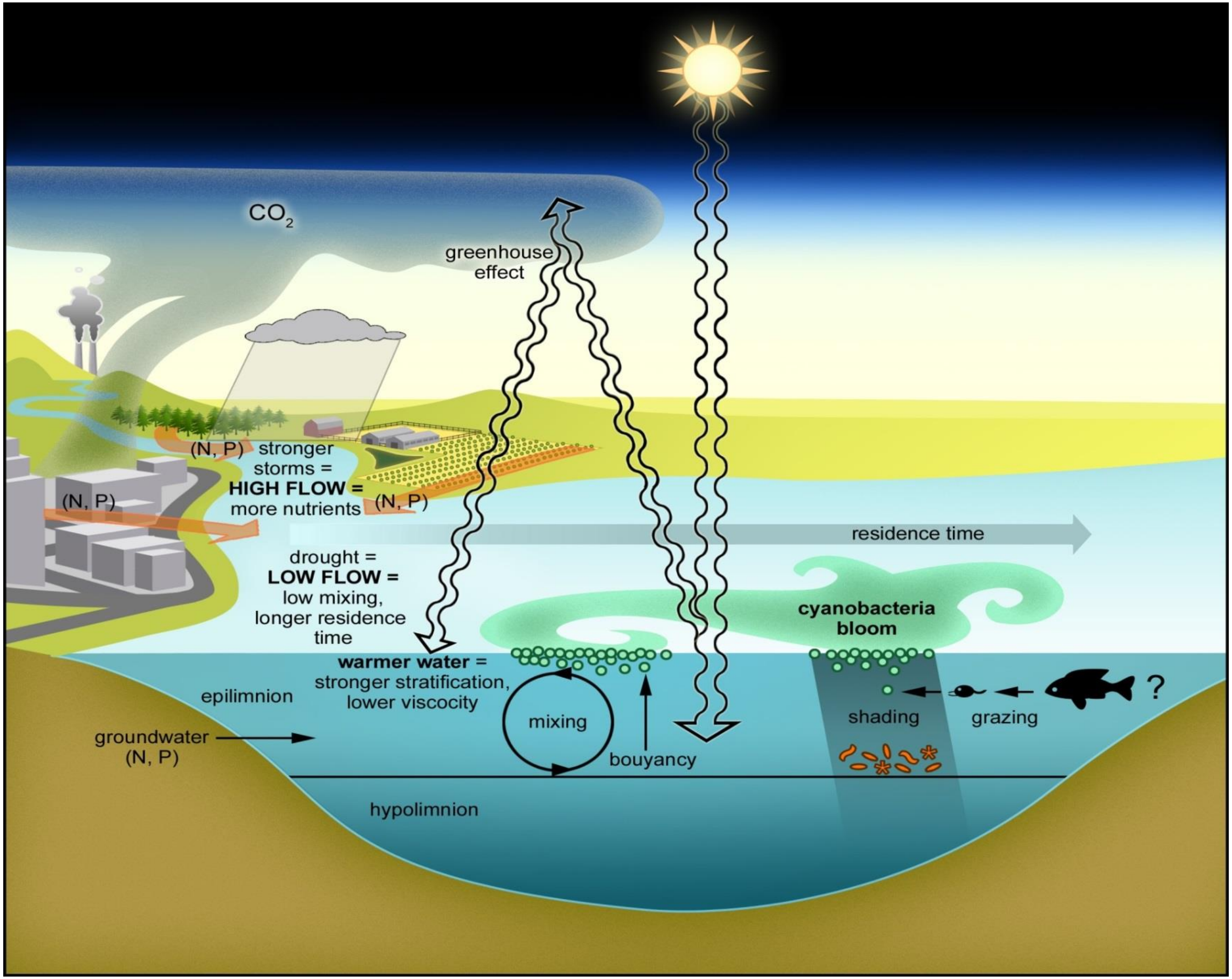
(lakes, reservoirs, streams, rivers)

- Estuaries

- Coastal waters & seas



What Controls CyanoHABS? Interacting Physical, Chemical & Biotic Factors



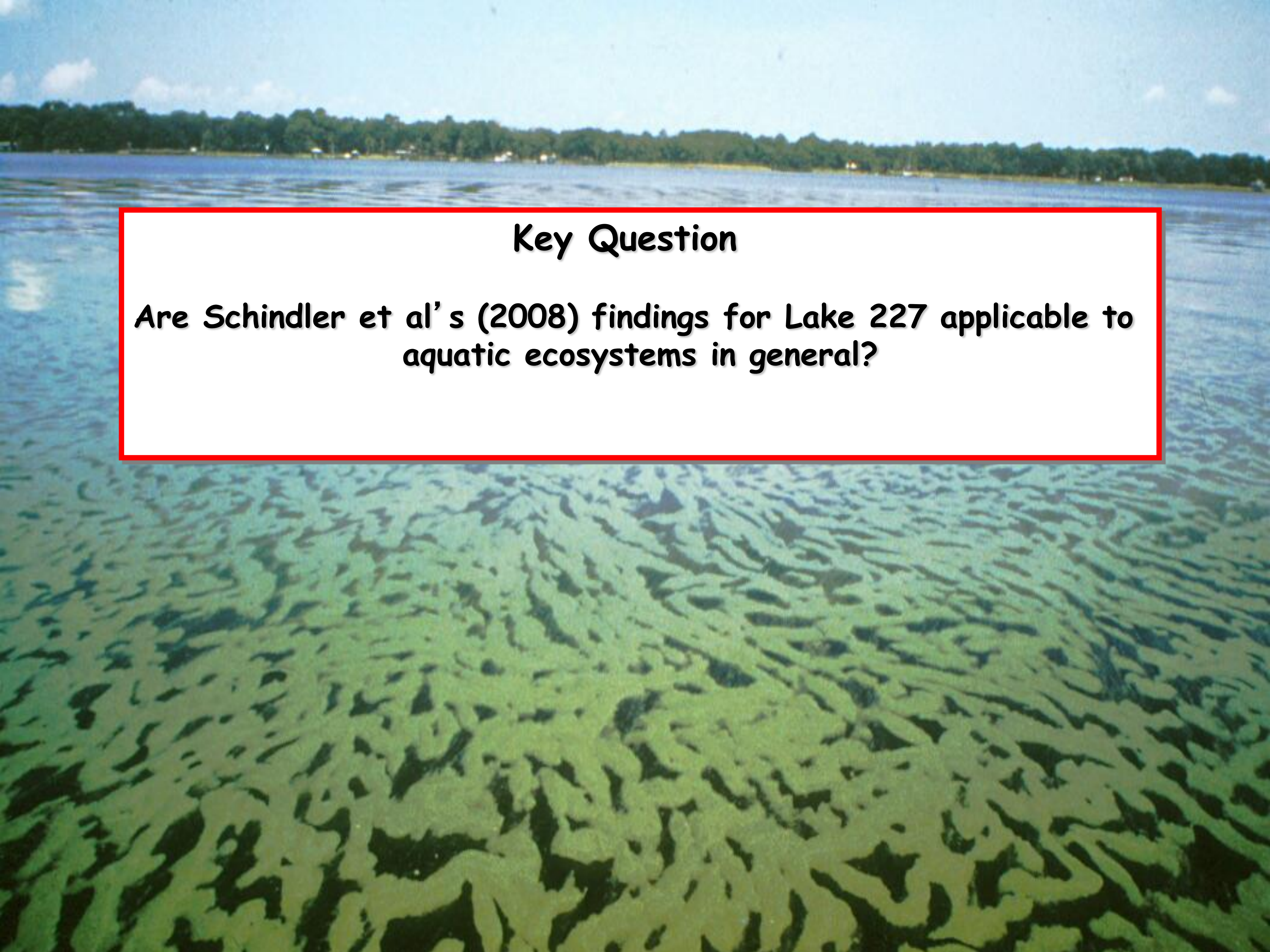
Nutrients: N and P inputs have long been recognized as playing a key role in bloom dynamics, but there's a controversy……..

"Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment"

Schindler et al. Proceedings of the National Academy of Science USA 105:11254-11258 (2008).

Conclusion by Schindler et al. (2008) (based on one lake: Lake 227) assumes that CyanoHAB N_2 fixation will supply ecosystem N needs Therefore, why worry about N? Argument extended to estuarine and coastal systems

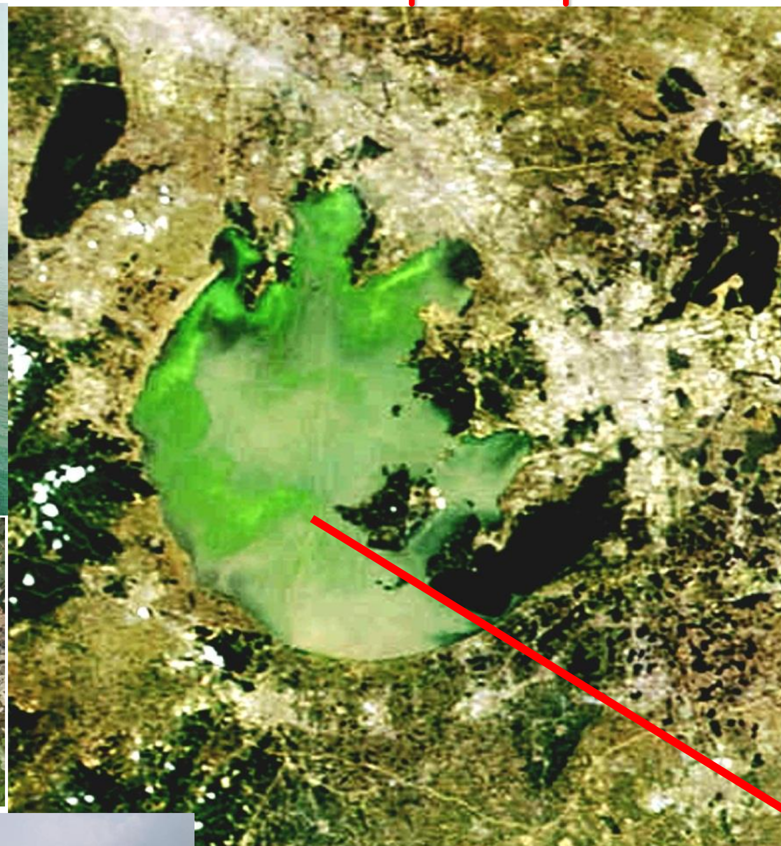
These assumption have been challenged
(Lewis and Wurtsbaugh 2008; Conley et al., 2009; Paerl 2009; Scott & McCarthy 2010: Lewis et al. 2011)

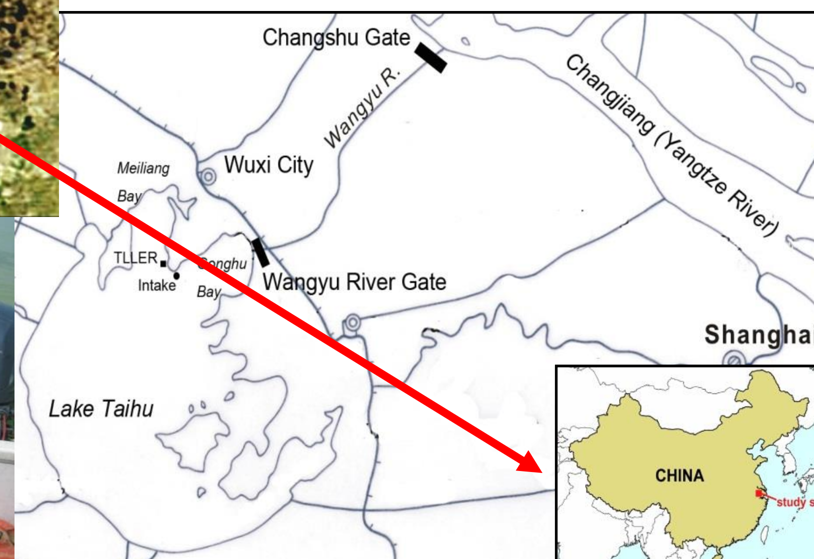


Key Question

Are Schindler et al's (2008) findings for Lake 227 applicable to aquatic ecosystems in general?

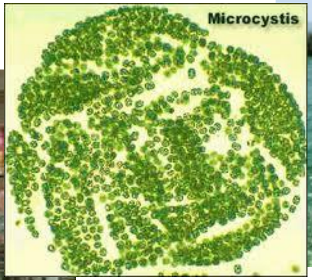
Lake Taihu 3rd largest lake in China. Nutrients (Lots!) associated with unprecendented human development in the Taihu Basin (Jiangsu Province). Results: Blooms have increased to "pea soup" conditions within only a few decades





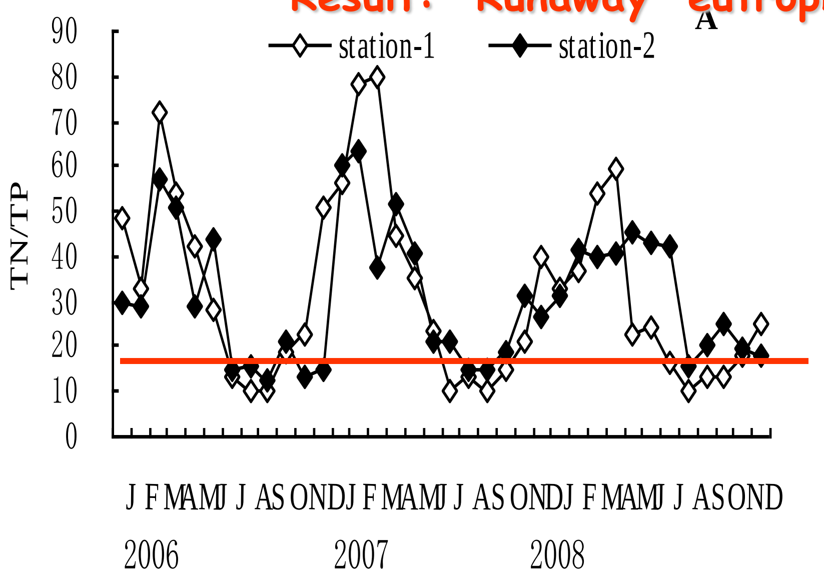
The water crises (2007- ?) in the Taihu Basin:

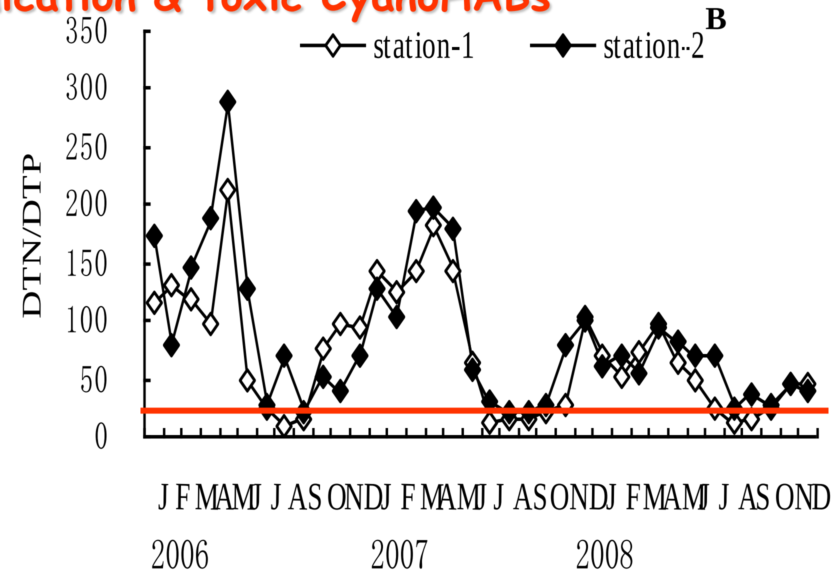
- Cessation drinking water use for >20 million (hepato- and neuro-toxins)
- Curtailed recreational use (contact dermatitis)
- Fisheries (commercial and recreational)
- Tourism???

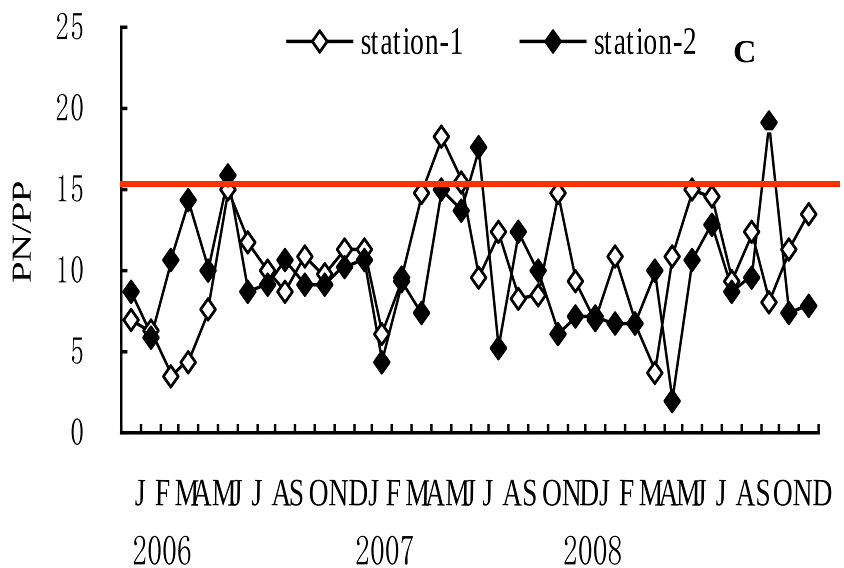


The nutrient "problem" in Taihu (and other hypertrophic lakes)

N & P inputs exceed what's needed for balanced algal growth.
Result: "Runaway" eutrophication & toxic CyanoHABs







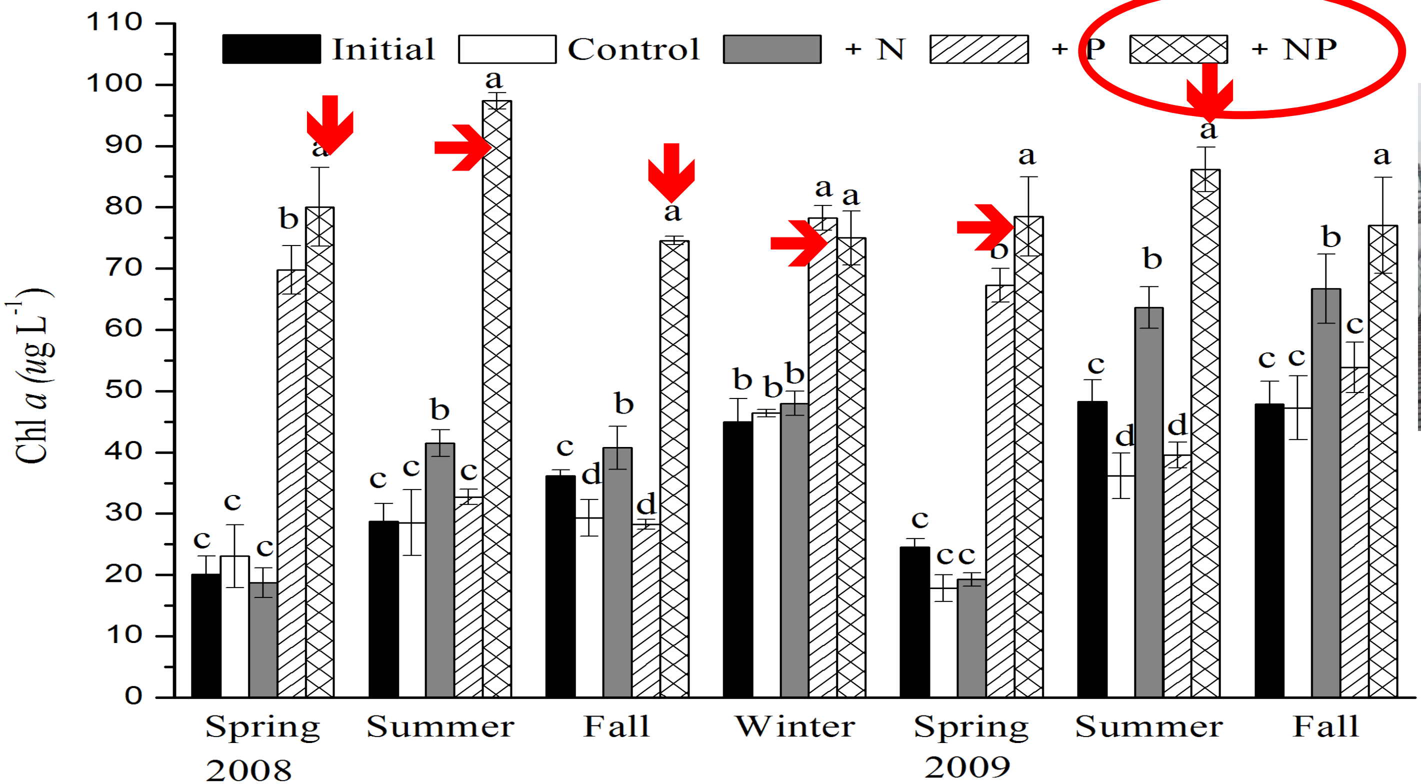
Nutrient (N&P) ratios in Taihu

Redfield (balanced growth)
~15:1 (N:P)

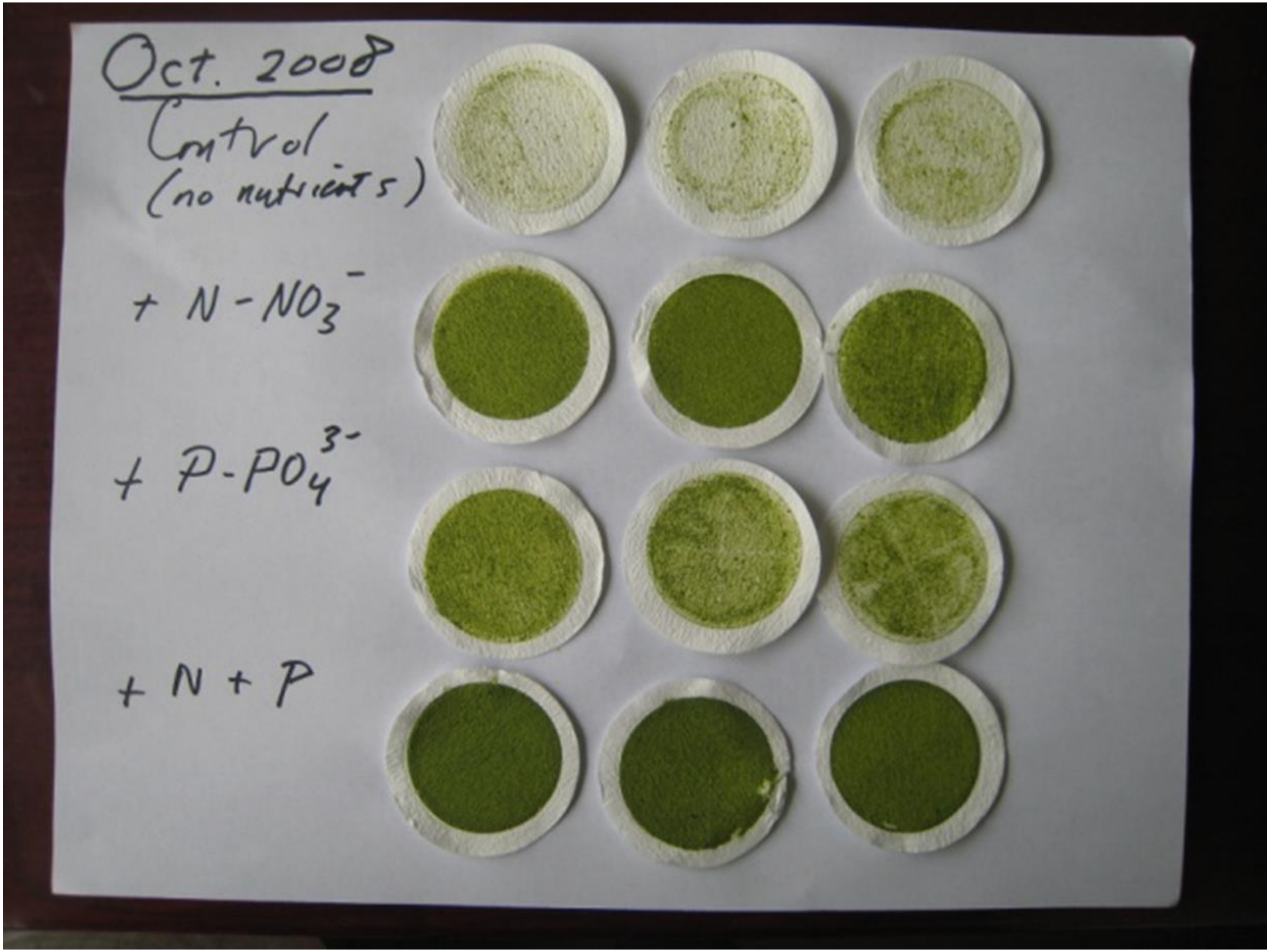
HYPOTHESIS
Dual (N & P) reductions will be needed to stem eutrophication and CyanoHABs

Xu et al., 2010

Effects of nutrient (N & P) additions on phytoplankton production (Chl *a*) in Lake Taihu, China: **Both N & P inputs matter!!**

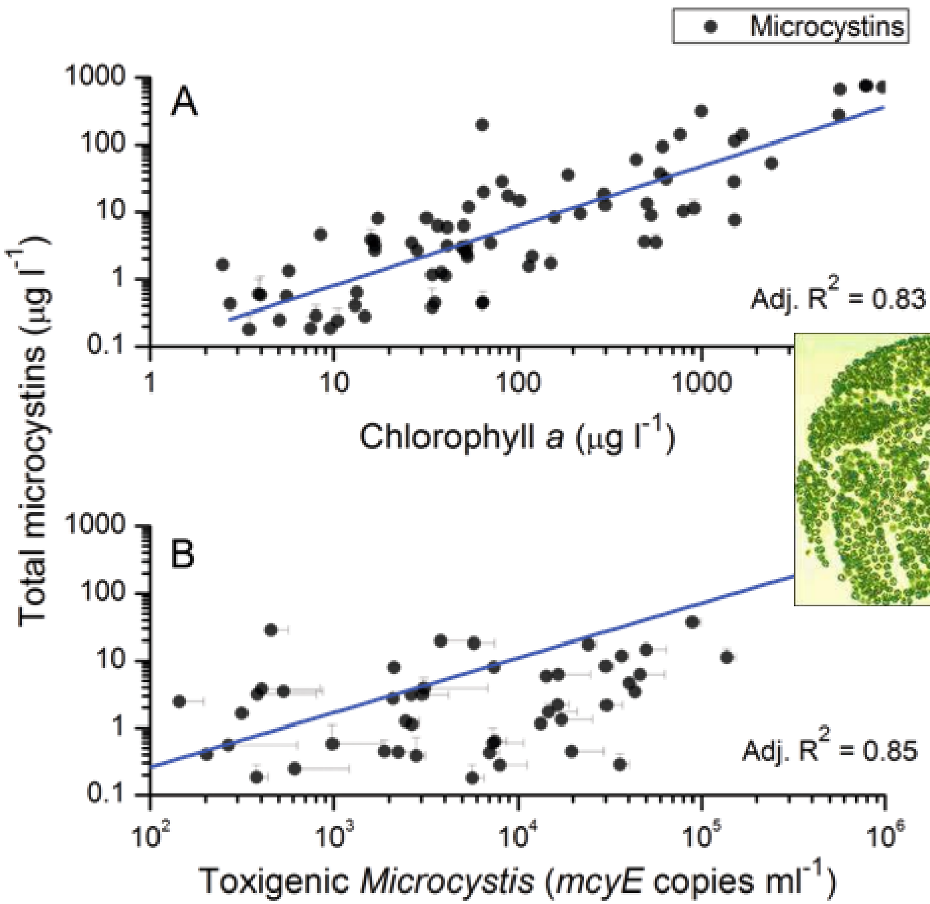


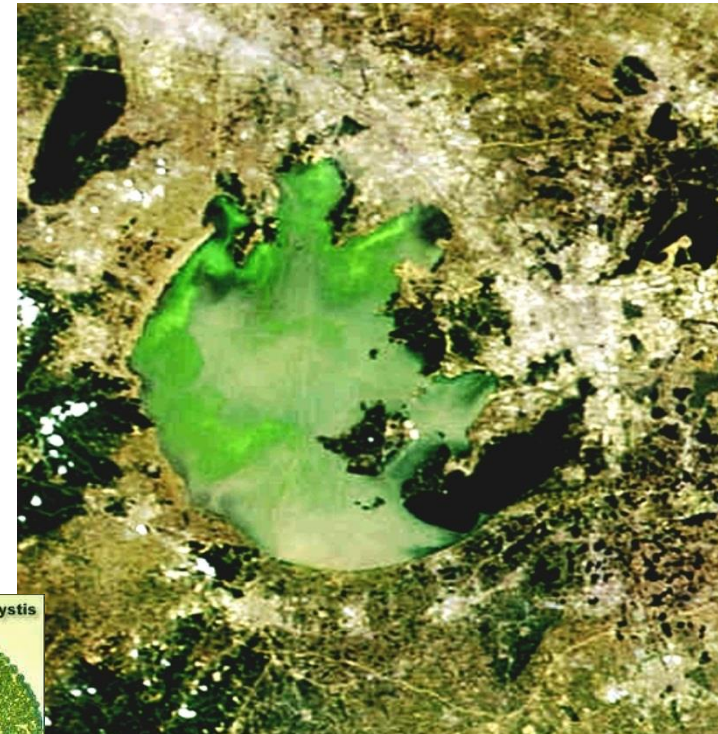
Xu et al. 2010; Paerl et al. 2011

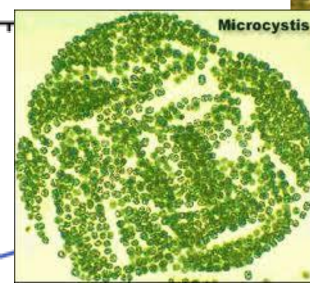


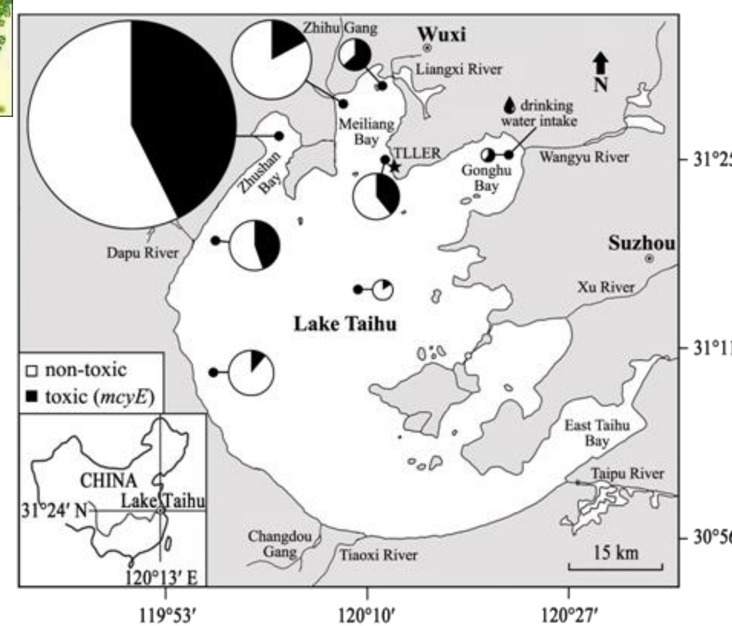
Oct. 2008
Control
(no nutrients)
+ N-NO3-
+ P-PO4 3-
+ N + P

CyanoHAB Toxicity
Related to nutrient inputs and biomass
Chlorophyll a is a sensitive, relevant and easy to use indicator



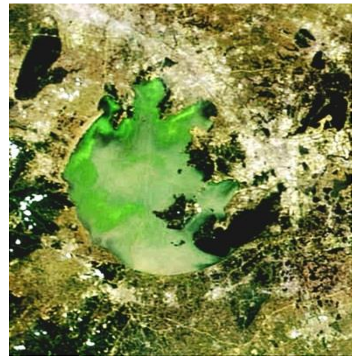


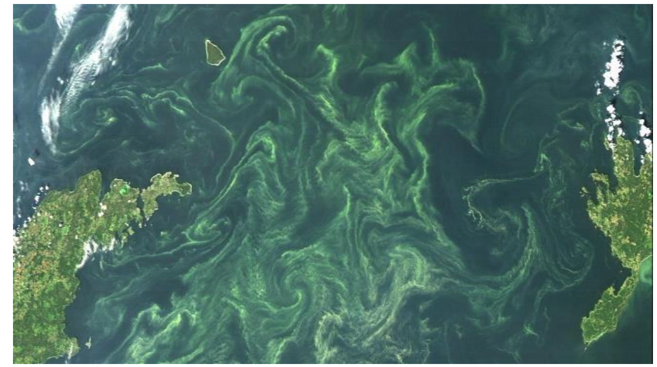




Otten et al., 2011, 2012; Wilhelm et al., 2011

Is Taihu a "looking glass" for hypertrophic shallow ecosystems worldwide?

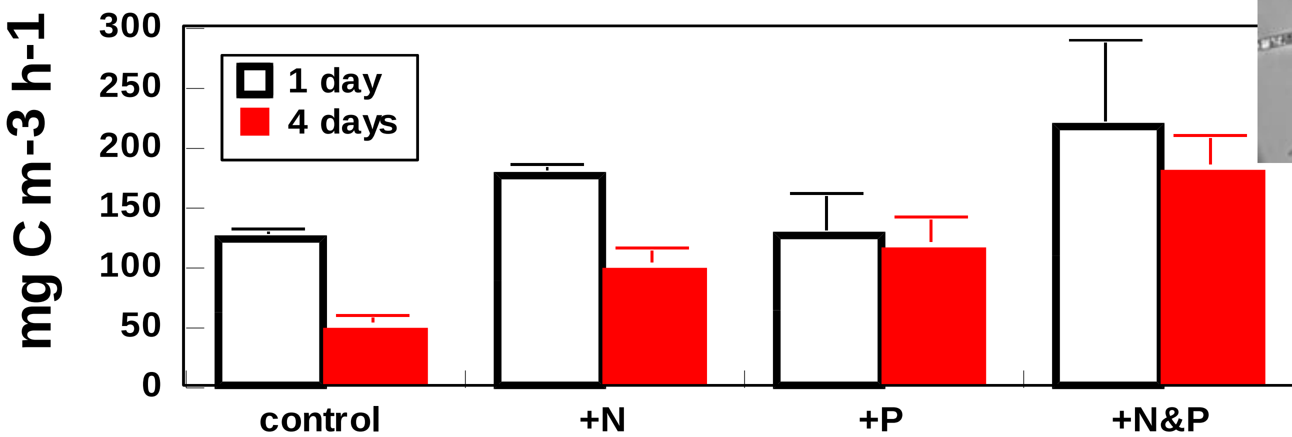


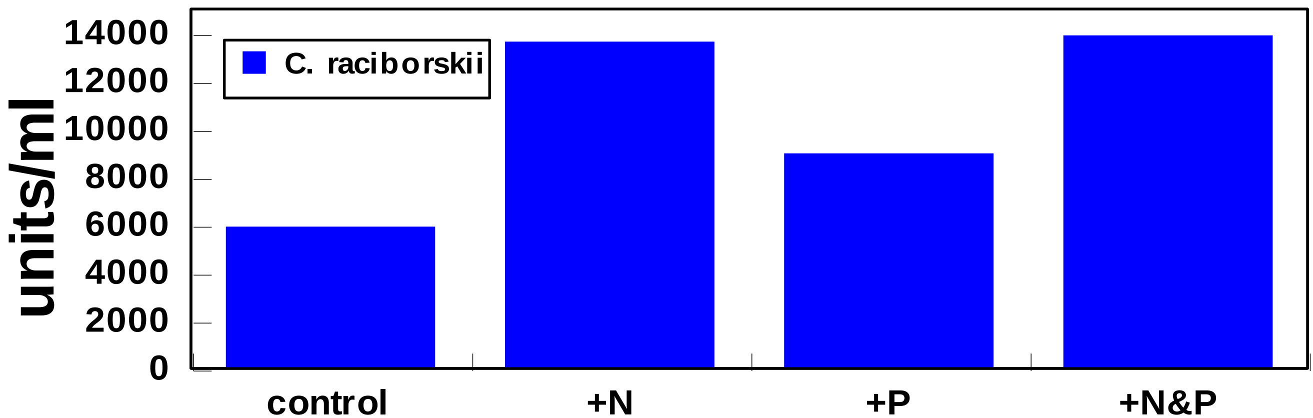


Florida lakes : *Cylindrospermopsis raciborskii*, rapidly-proliferating, toxic N_2 fixing cyanoHAB

- High P uptake and storage capacity
- High NH_4^+ uptake affinity (competes well for N)
  - N additions (NO_3^- + NH_4^+) often significantly increase growth (chl *a* and cell counts) and productivity
- N_2 fixer (can supply its own N needs)
- Tolerates low light intensities
  - Eutrophication/decreased transparency favors *Cylindro*
  - Often in water column with other cyanoHABs

St. Johns R. System, FLorida: Nitrogen <u>and</u> Phosphorus Effects on CyanoHAB Growth and Bloom Potential (*Cylindrospermopsis raciborskii*)

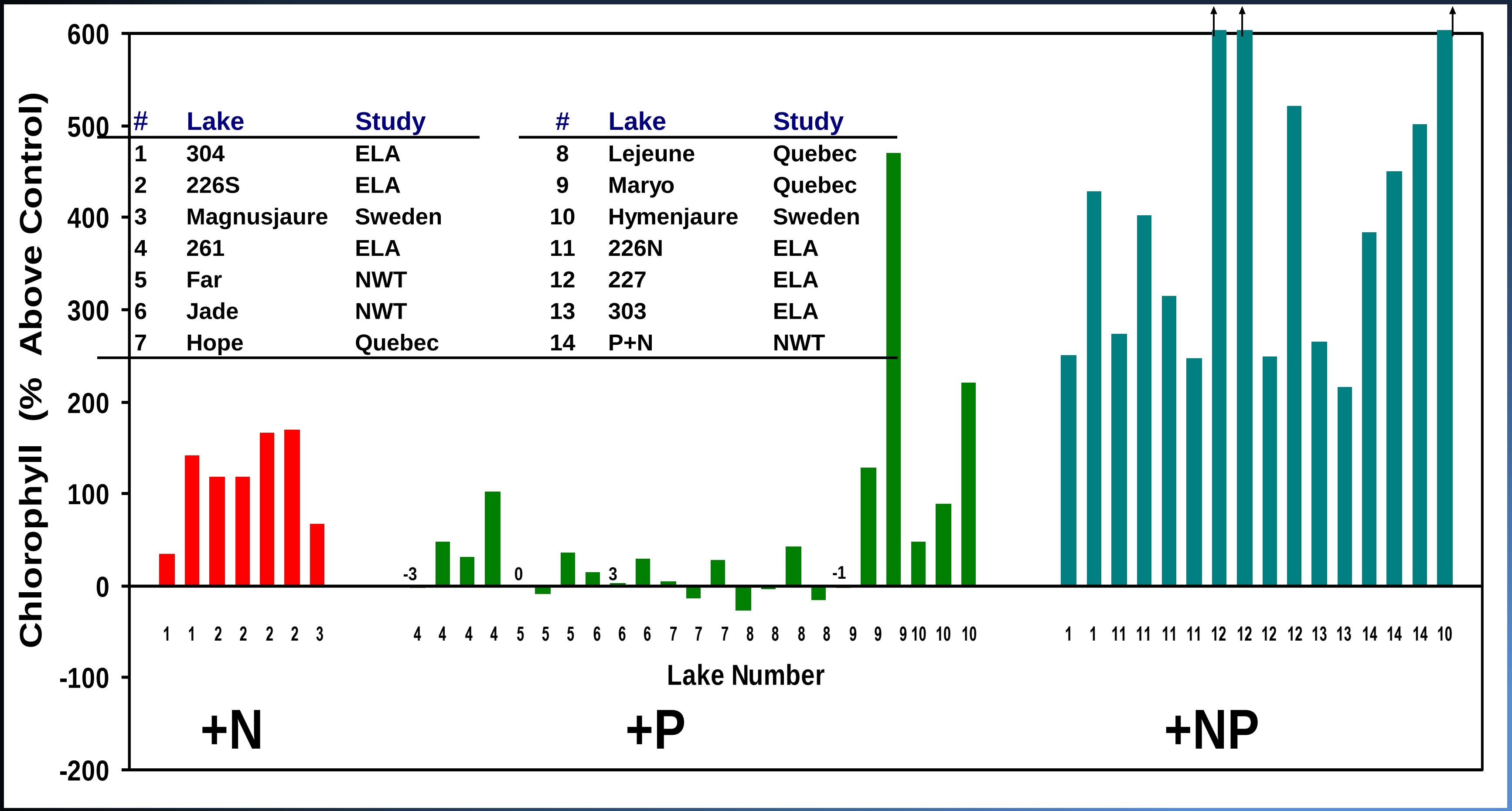




Take home message: *Cylindrospermopsis raciborskii* is opportunistic
Dual N & P input constraints will likely be needed to control it

Piehler et al, 2009

Whole-Lake Fertilization Experiments (Canada: ELA, Quebec, NWT, Sweden)



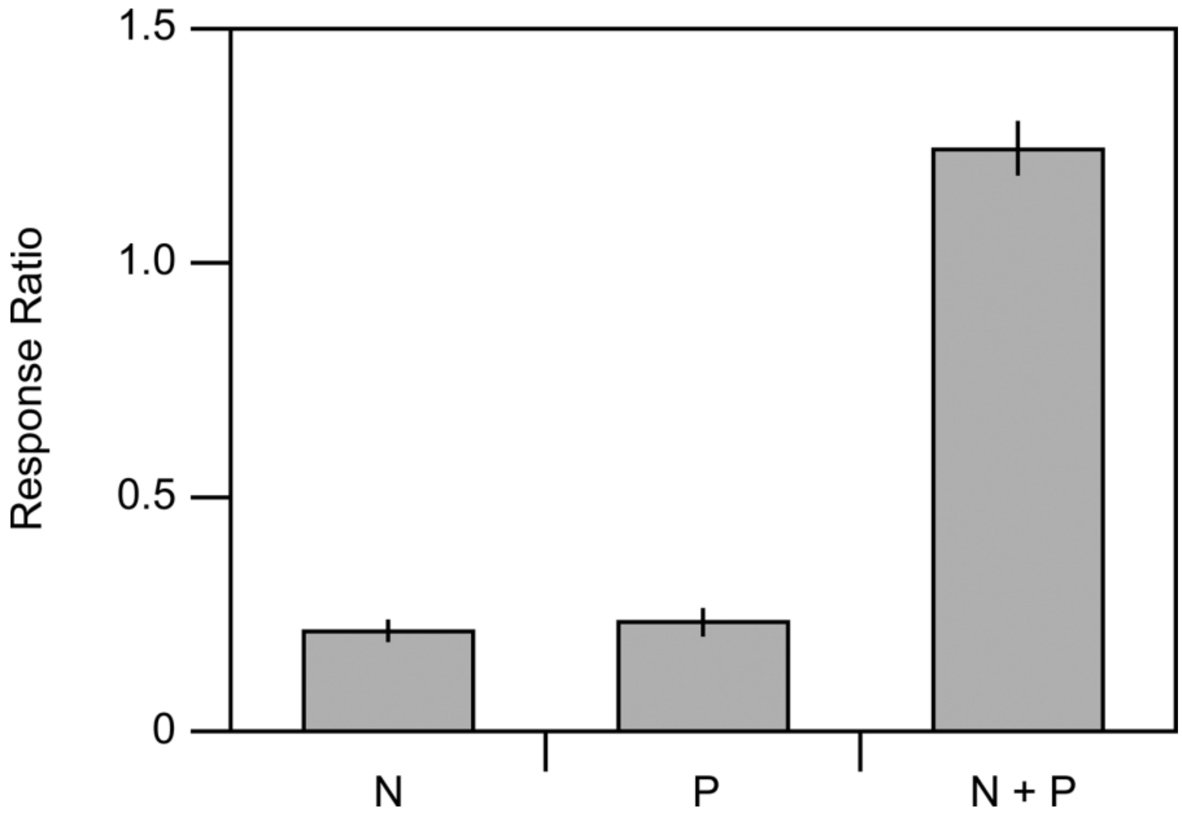
#	Lake	Study
1	304	ELA
2	226S	ELA
3	Magnusjaure	Sweden
4	261	ELA
5	Far	NWT
6	Jade	NWT
7	Hope	Quebec

#	Lake	Study
8	Lejeune	Quebec
9	Maryo	Quebec
10	Hymenjaure	Sweden
11	226N	ELA
12	227	ELA
13	303	ELA
14	P+N	NWT

Co-Limitation Dominant

Wurtsbaugh et al., 2012

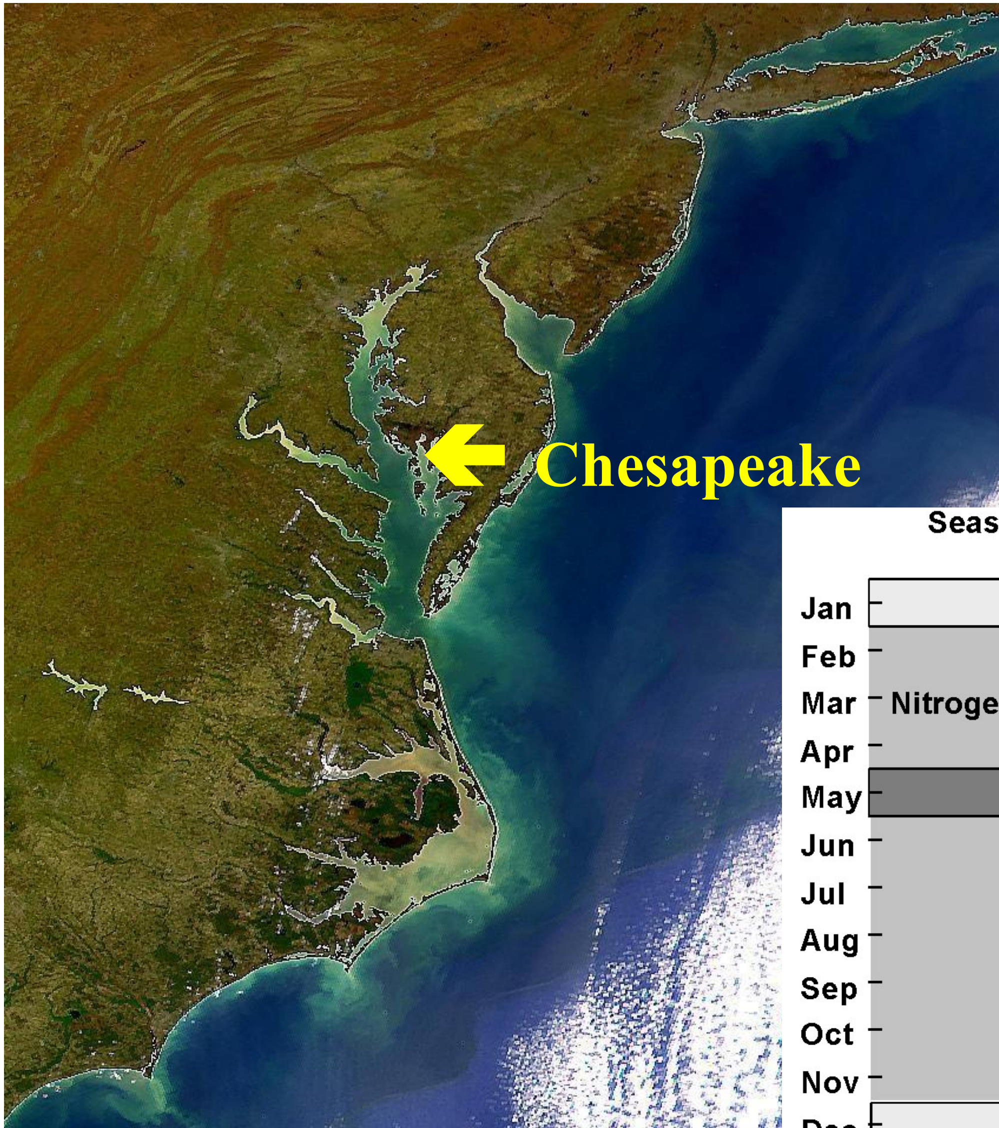
A summary of N & P limitation in lakes worldwide

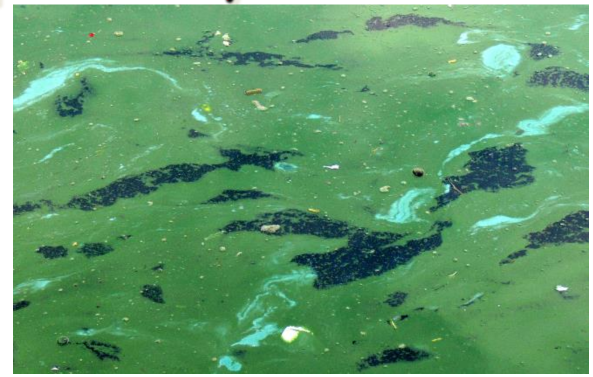


Lakes: N= 55

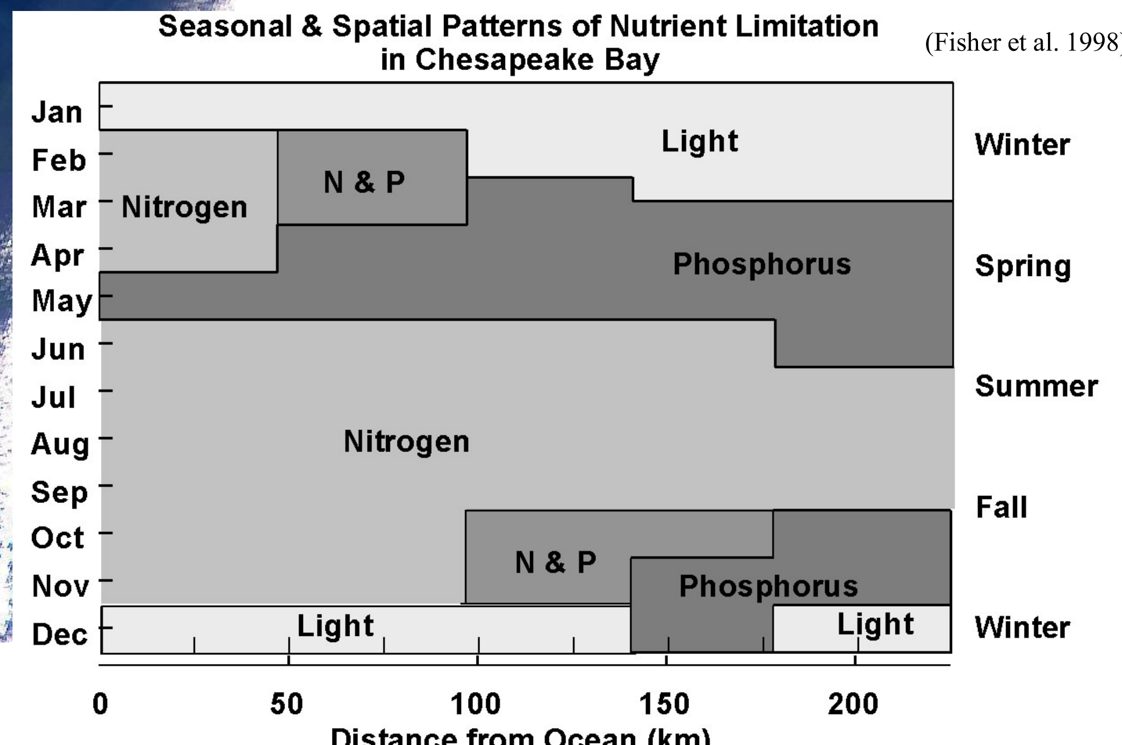
Lewis et al., ES&T 45:10300-10305 (2011)

Nutrient limitation along the freshwater to marine continuum
Estuaries with CyanoHABs: the Chesapeake Bay

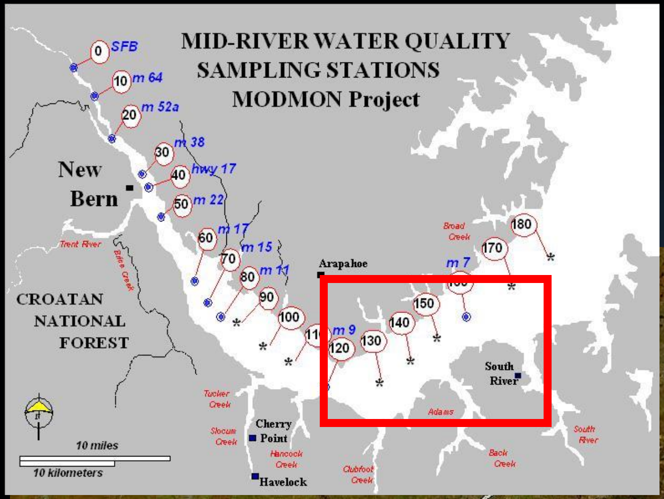


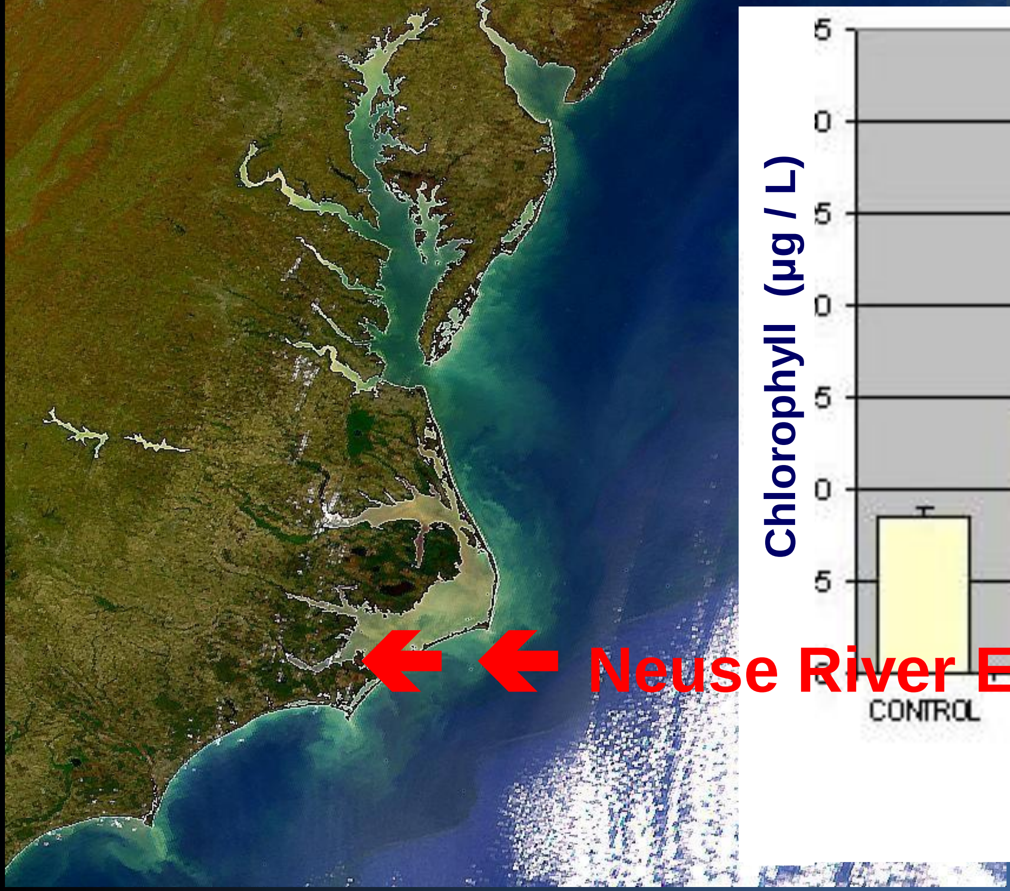


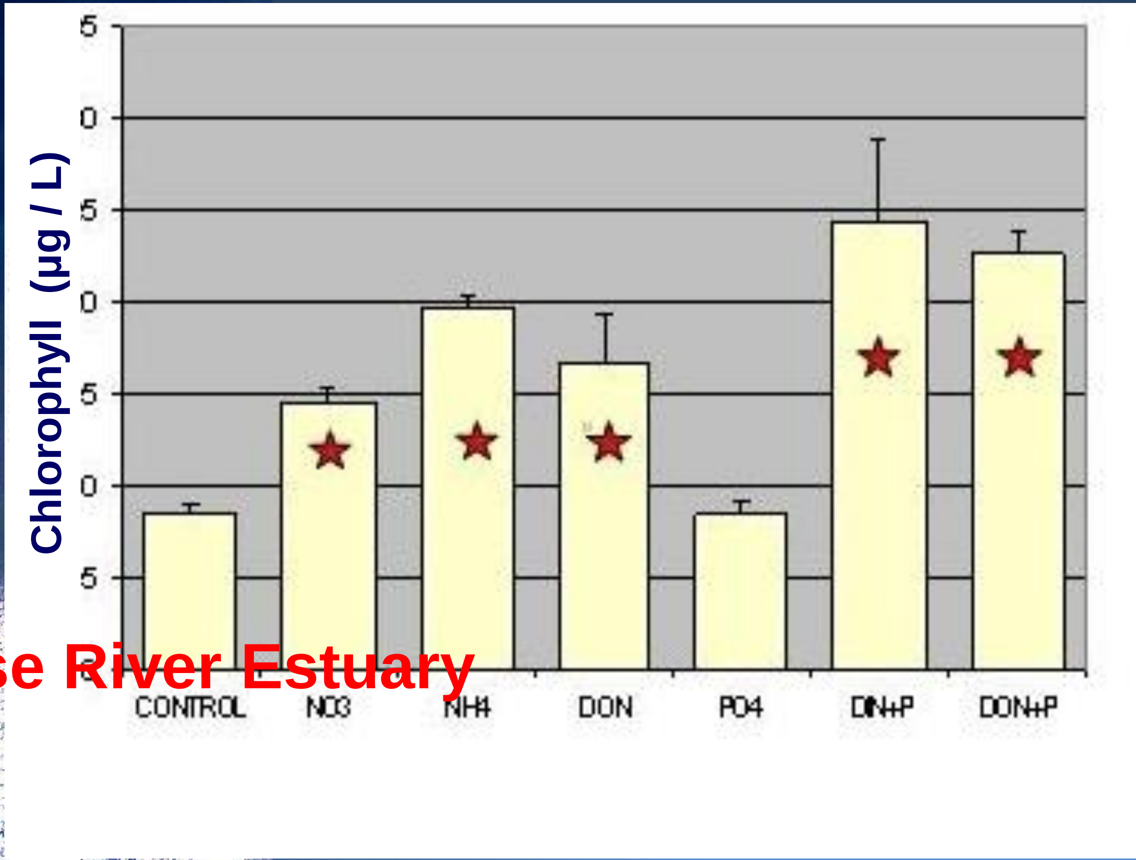
Fisher et al. 1998



Nutrient limitation in the Neuse R.Estuary,NC



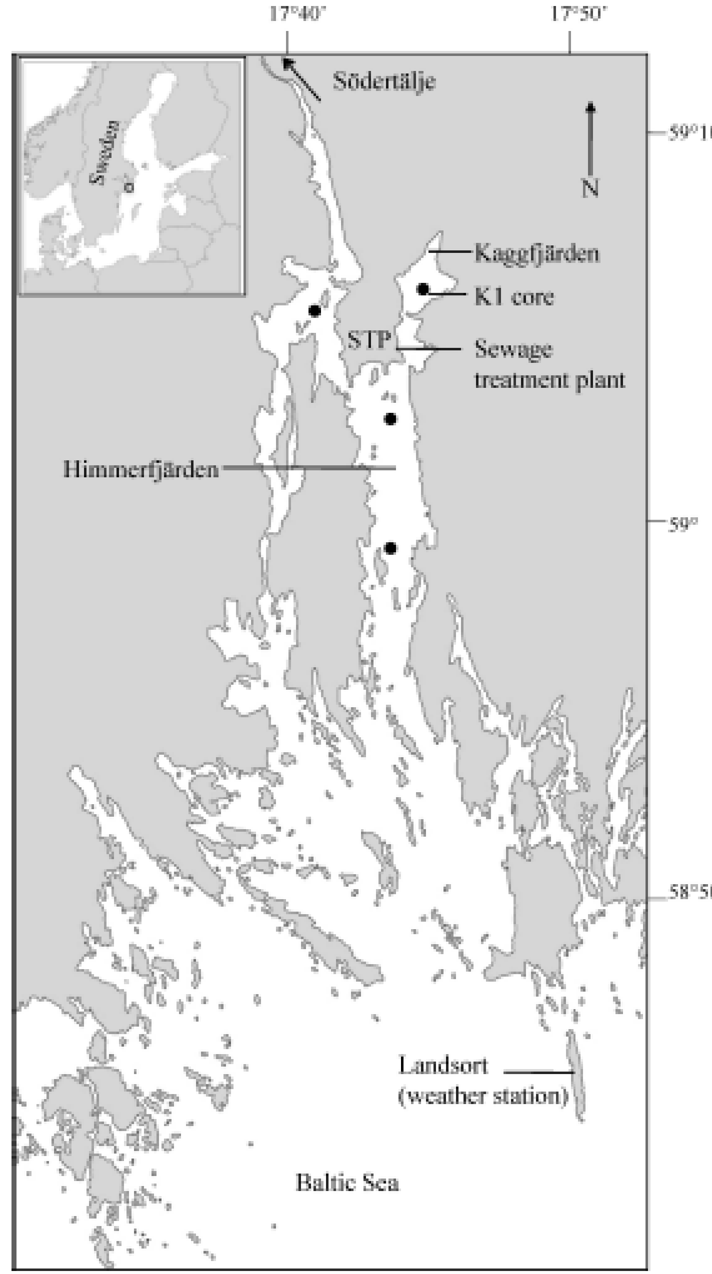




Paerl et al., 1995; Gallo 2006

Nutrient load and phytoplankton (dominated by cyanobacteria) growth response in Himmerfjärden (freshwater to brackish), Sweden

Courtesy: Ulf Larsson & Ragnar Elmgren
Stockholm University



The Himmerfjärden case: Baltic coastal area with large Sewage treatment plant,

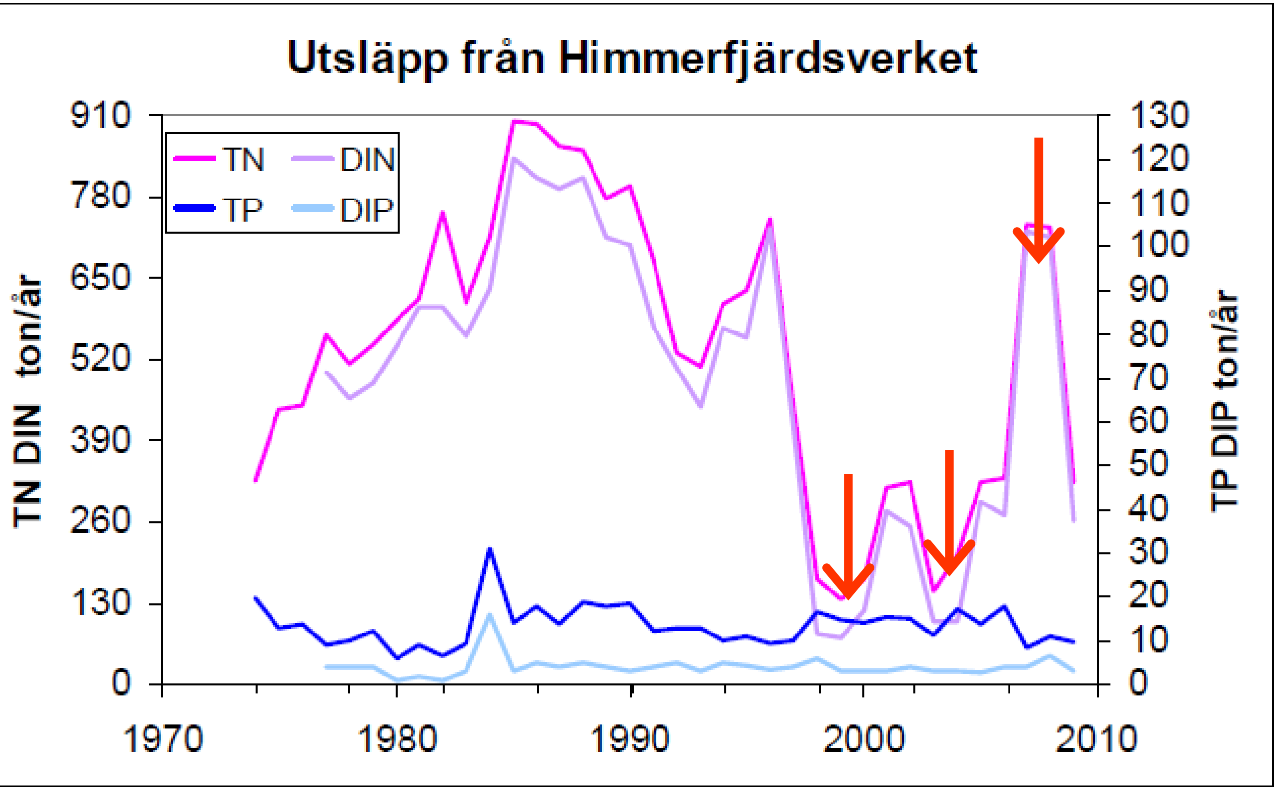
P removal since 1976

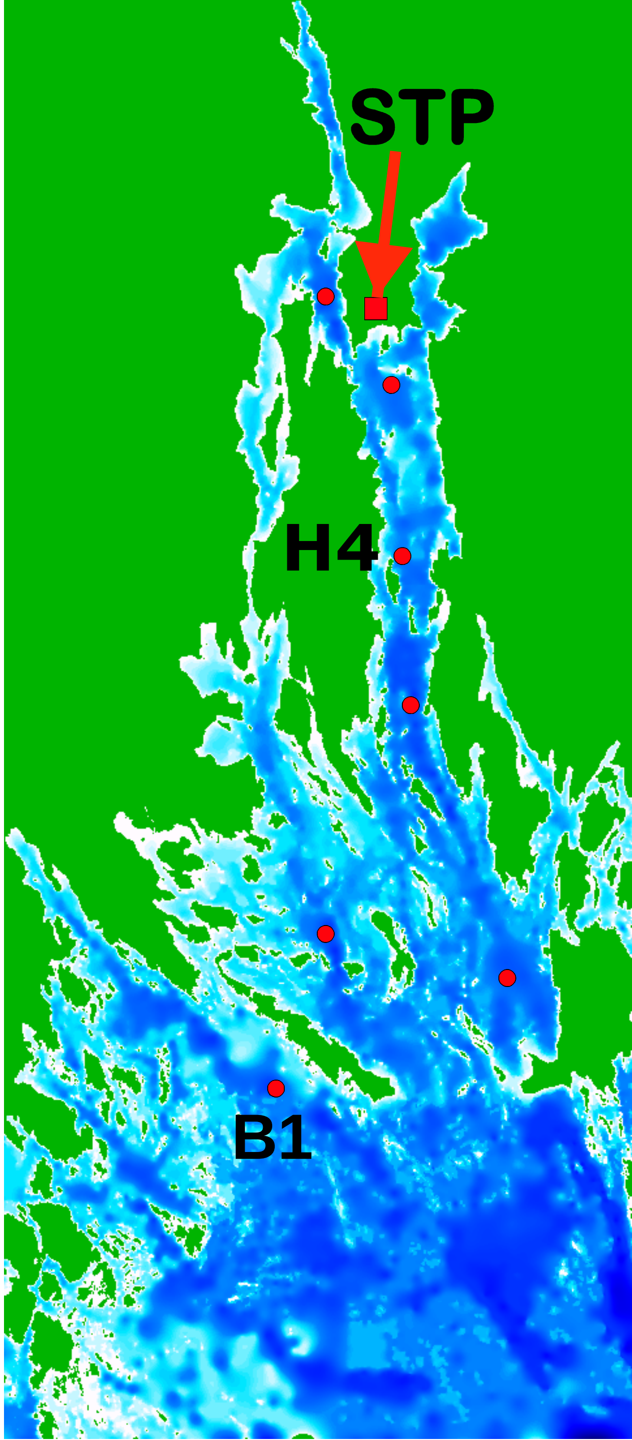
N removal started in 1993 (50%) & 2000 (80%).

No N removal 2004-2008

EFFECTS ON PHYTOPLANKTON (Chl a)?

Plant loads , tonnes/ year

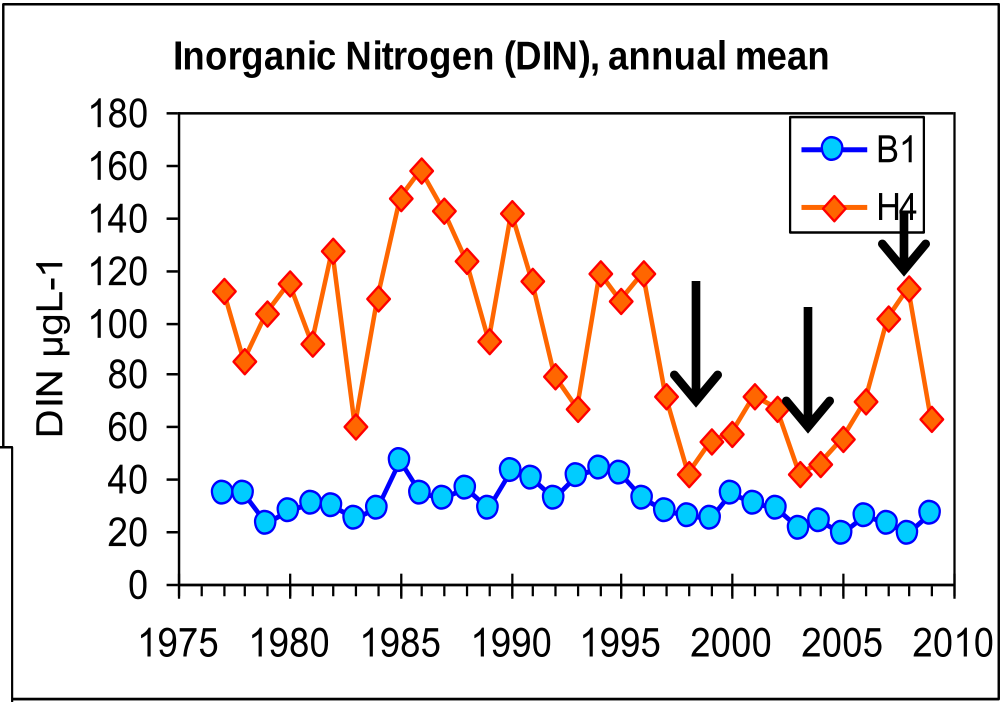


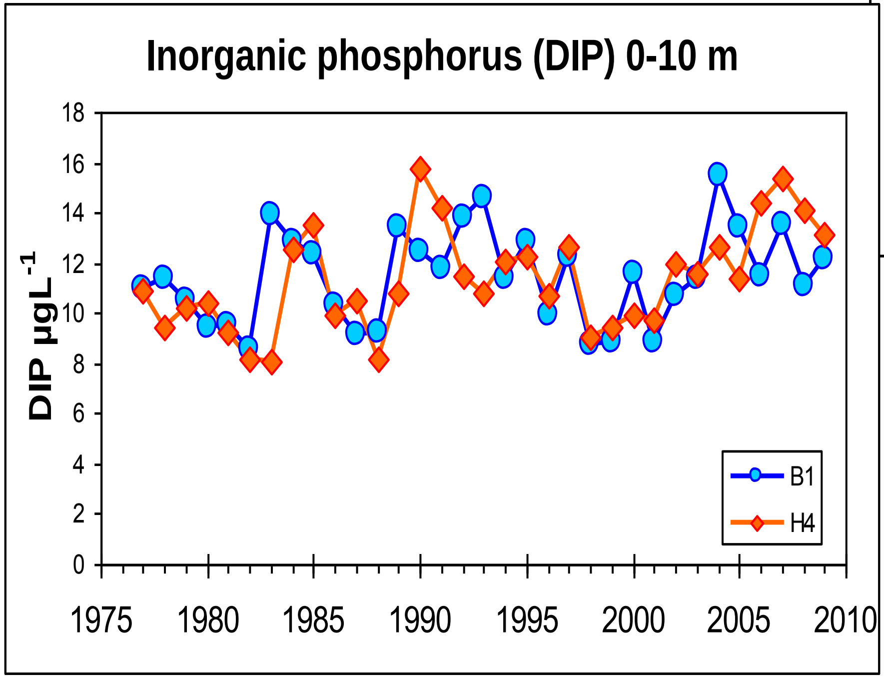


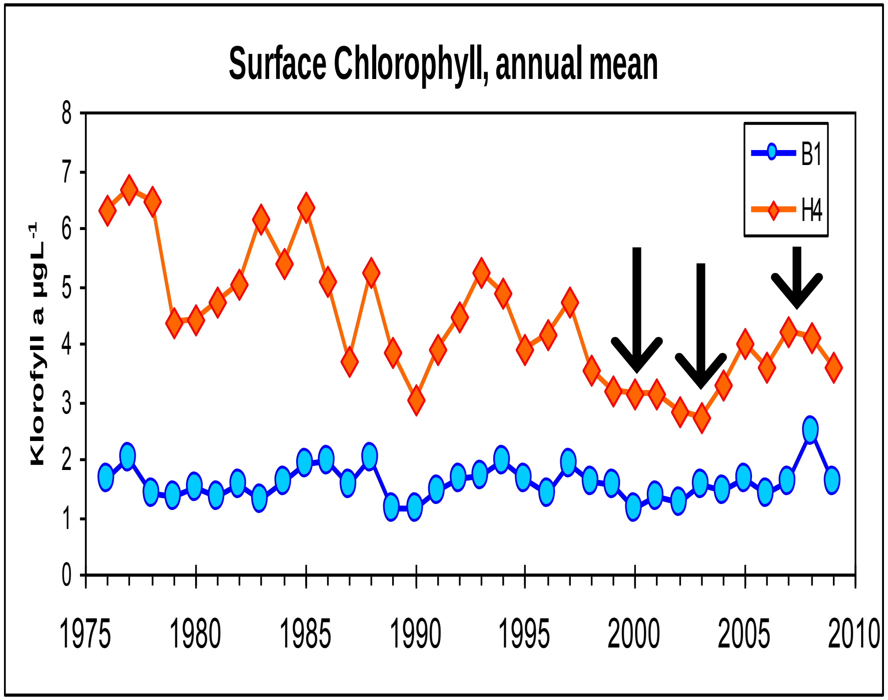
H4 =Eutrophicated station

B1= Reference station

The results: Reducing DIN inputs reduced Chl a



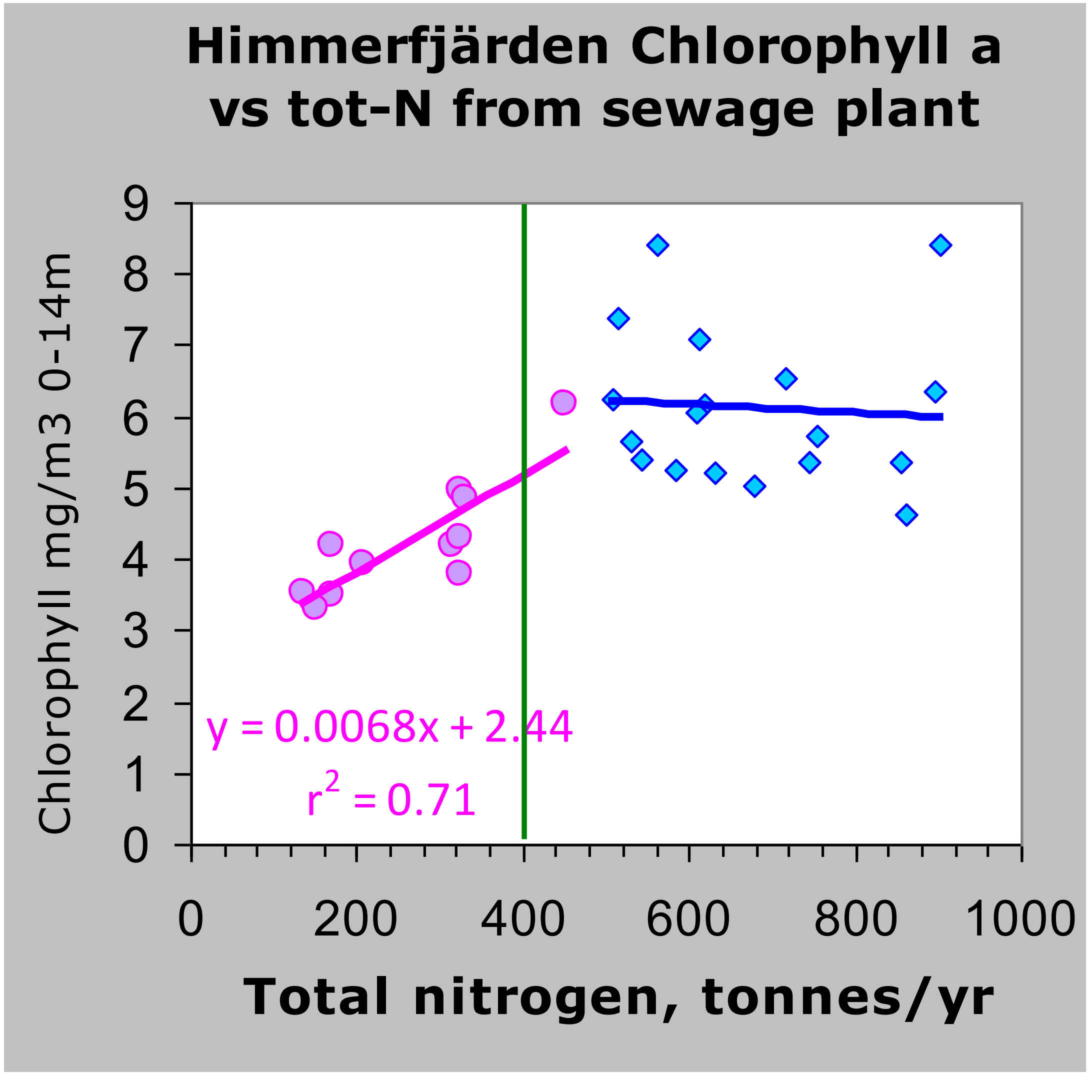




Larsson and Elmgren, 2012

Developing a N loading-bloom threshold

Stockholm University



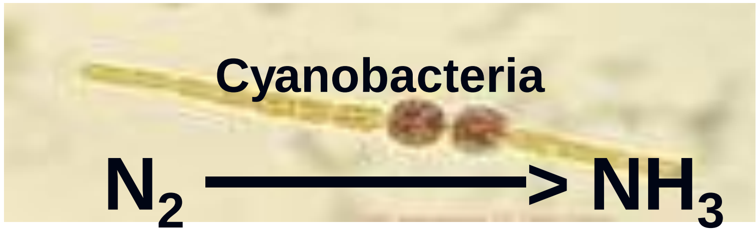
Lowering nitrogen discharge below 400 tonnes/yr clearly reduced local phytoplankton biomass.

Source:
Ulf Larsson, pers.comm.

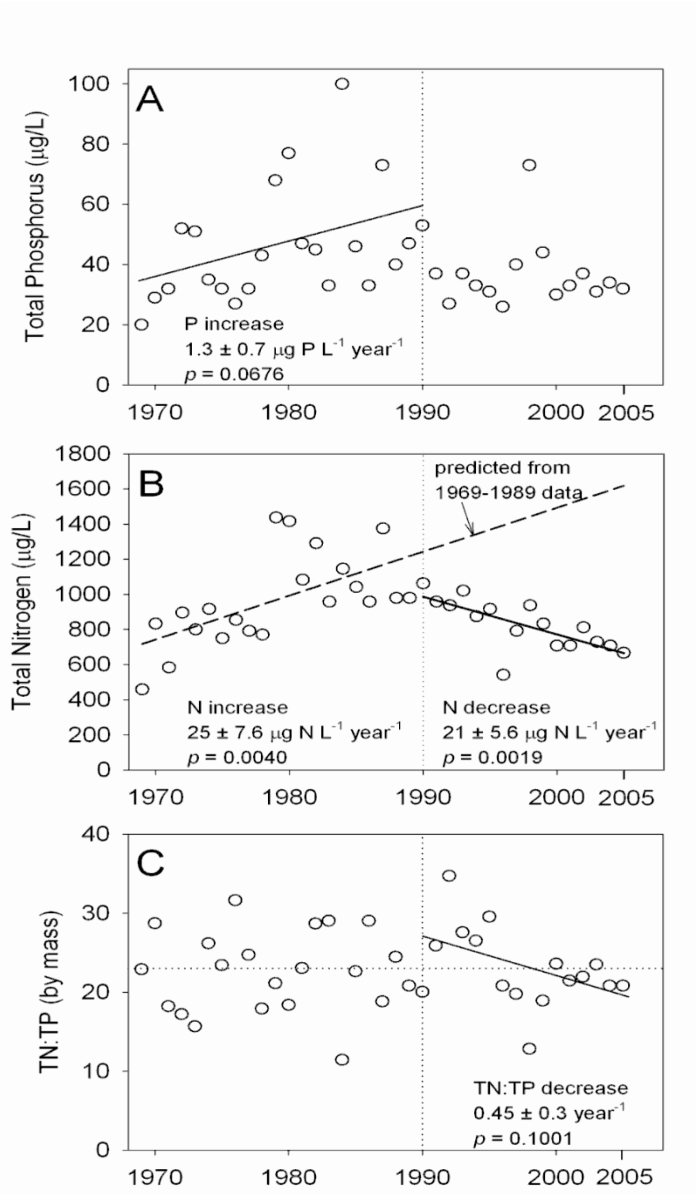
Lets go back to the ‘P only” paradigm from whole-lake experiments, suggesting that P alone controls algal biomass (Schindler et al., 2008)

The Argument:

If nitrogen is in short supply, nitrogen fixation by cyanobacteria will make up the nitrogen deficit:



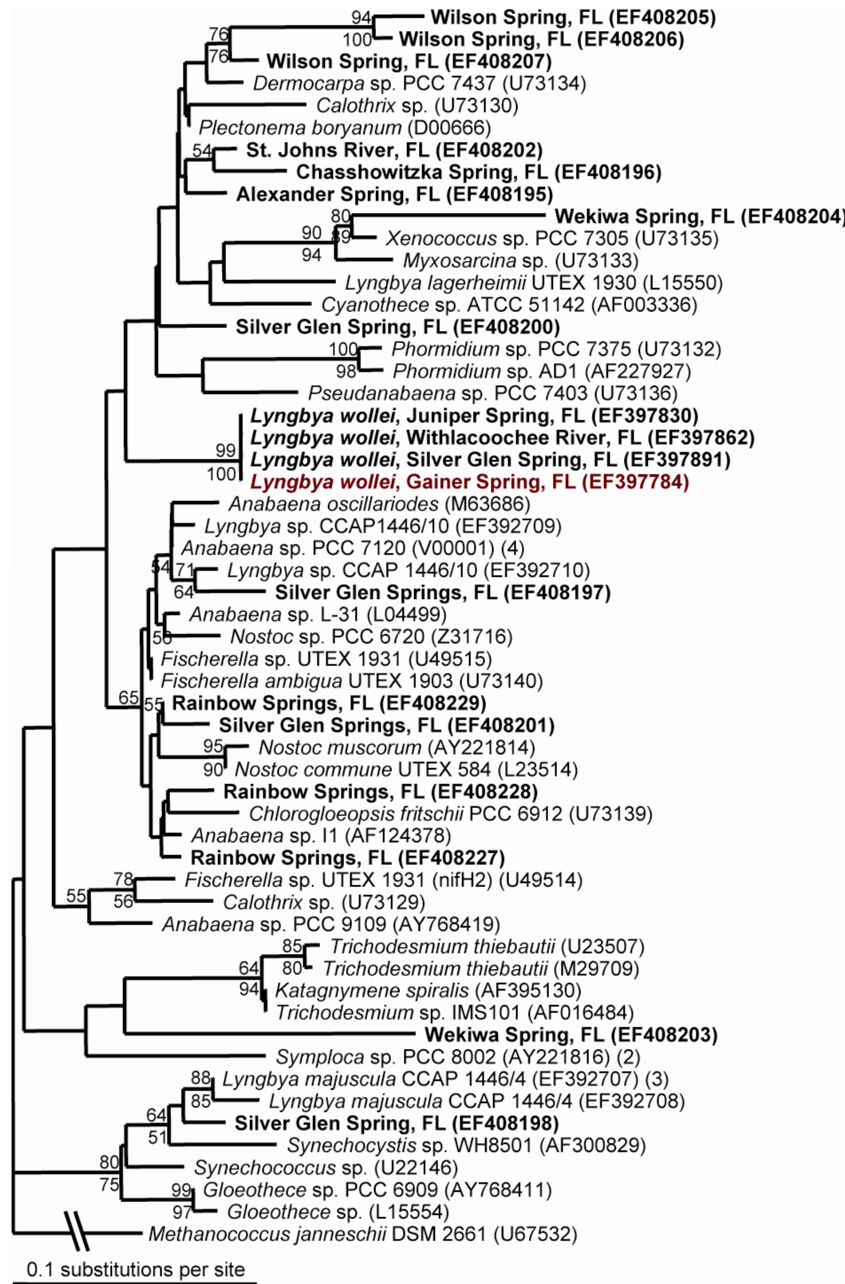
Lets look at the data for lake 227: What happened following N&P fertilization (1968-1989), then only P fertilization (1989 ➔)?



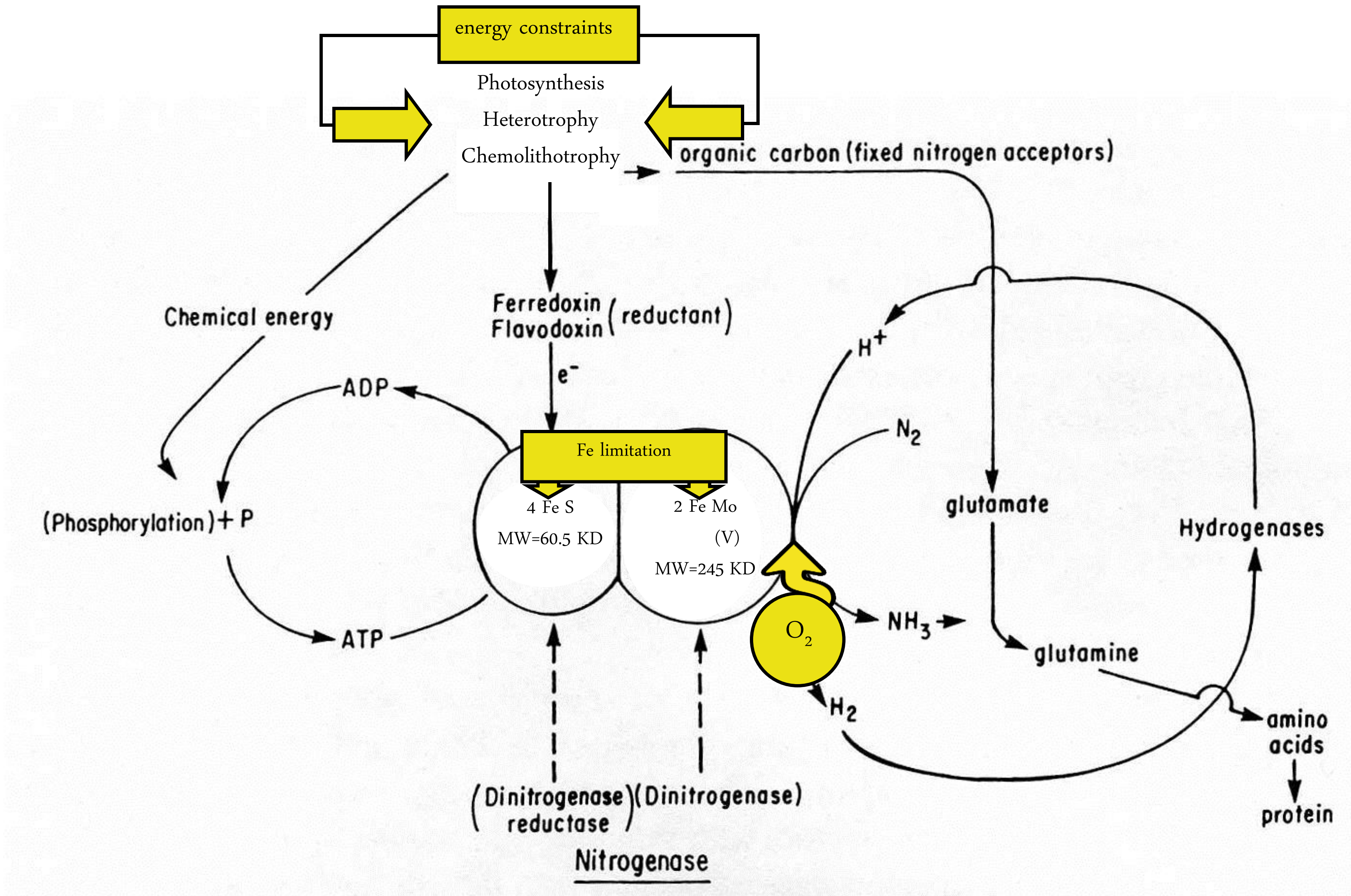
Following cessation of N fertilization, Total N, TN:TP, and phytoplankton biomass decreased. N_2 fixation could not keep up with ecosystem N demands
(Scott & McCarthy L&O 55:1265-1270 (2010)

WHY?????

Its not because there's a shortage of N2 fixing taxa



Controls on N_2 fixation: Its not just P or N:P…Other controls



Also, N_2 losses from shallow eutrophic systems exceed "new" N inputs via N_2 fixation

Annual estimates of ecosystem N_2 fixation, denitrification, and net ecosystem N_2 flux in lakes.

Location	**N_2 Fixation ($g\ N\ m^{-2}\ yr^{-1}$)**	**Denitrification ($g\ N\ m^{-2}\ yr^{-1}$)**	**Net N_2 Flux ($g\ N\ m^{-2}\ yr^{-1}$)[1]**
Lake 227 (ELA)[2]	0.5	5-7	-6.5 – -4.5
Lake Mendota[2]	1.0	1.2	-0.2
Lake Okeechobee[2]	0.8 – 3.5	0.3 – 3.0	-2.2 – 0.5
Lake Erken[2]	0.5	1.2	-0.7
Lake Elmdale	10.4[3]	18[4]	-7.6
Lake Fayetteville	10.6[3]	23[4]	-12.4
Lake Wedington	7.0[3]	12[4]	-5.0

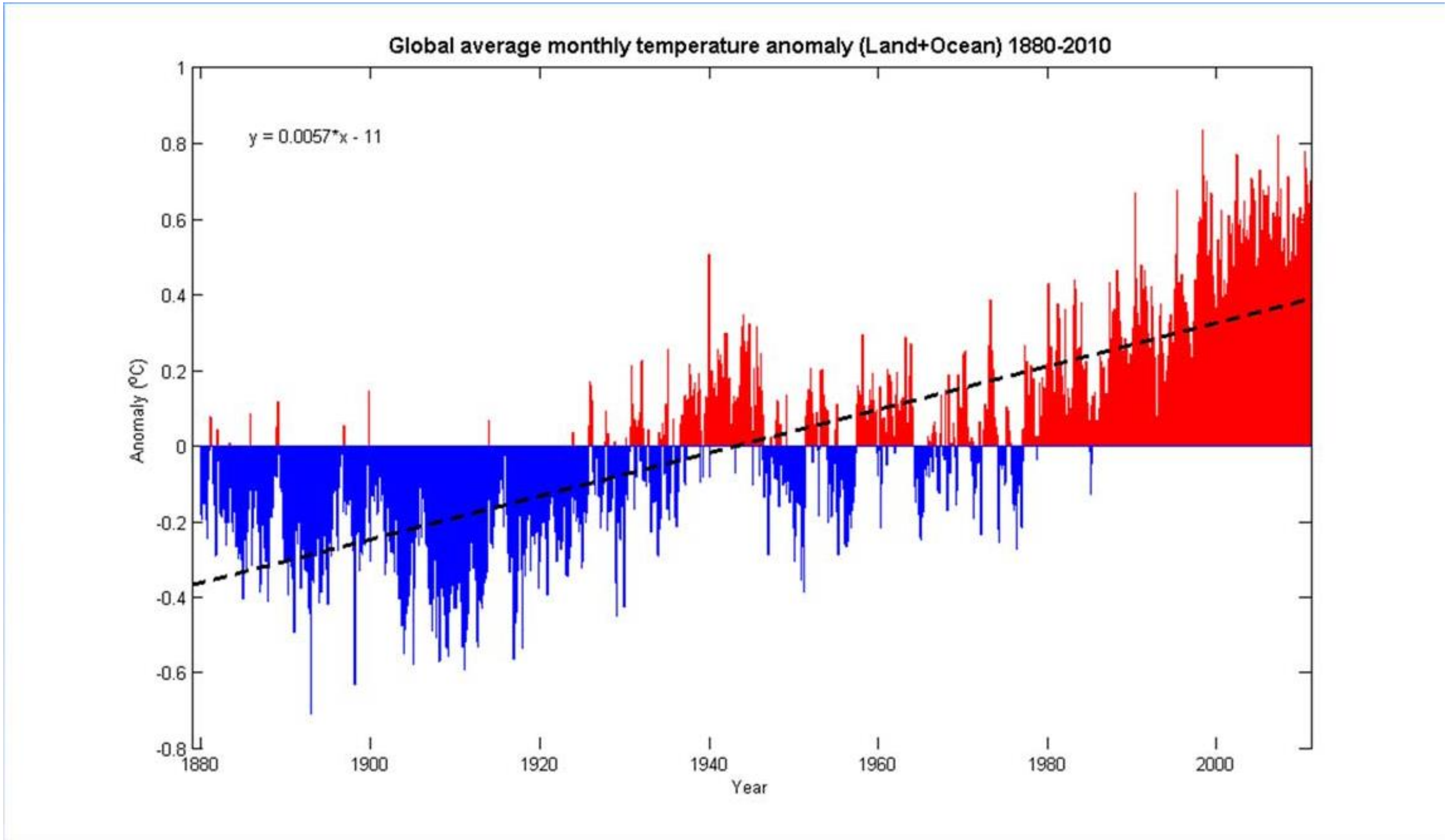
[1]Net negative N_2 flux represents reactive N loss, positive represents gain; [2]Paerl and Scott (2010); [3]J.T. Scott (unpublished data); [4]Grantz et al. (2012)

Conclusions: 1. N_2 fixation does NOT meet ecosystem N demands

2. More N inputs will accelerate eutrophication

3. We Gotta get serious about controlling N!!

Confounding Impacts of Climate Change: Its Getting Warmer

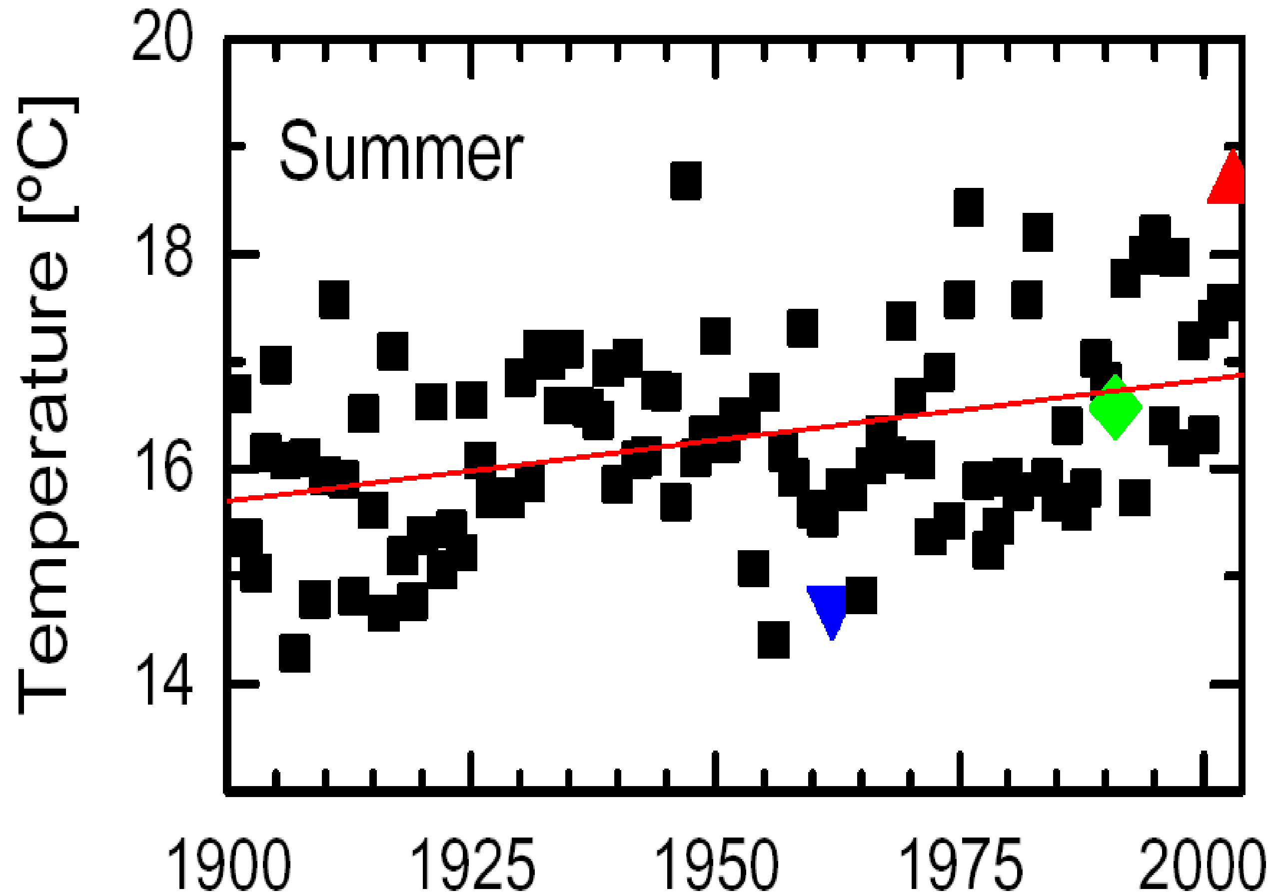



Positive proof of global warming.
1800's
1900's
1950
1970
1980
1990

Additional Evidence

2003 was the hottest summer in 500 years in Europe!
2005, 2009, 2012 were the hottest years ever in N. America
2010 hottest year in central Asia

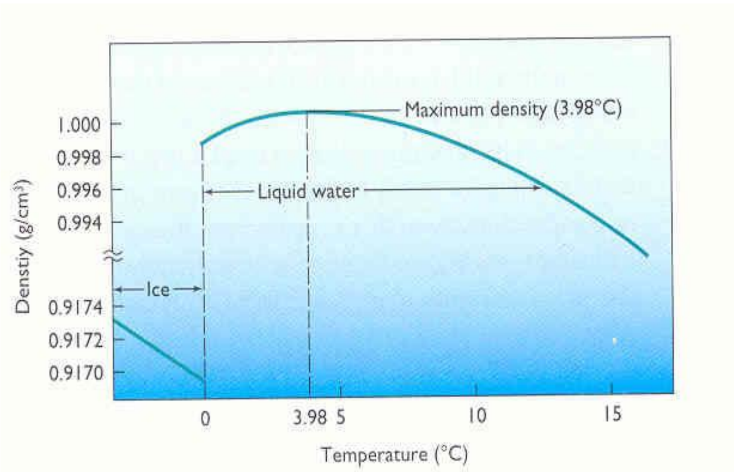
Below is the mean summer surface water temperature in a range of Dutch lakes



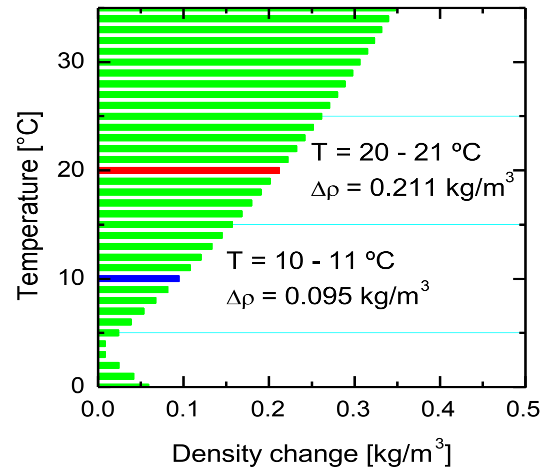
Huisman et al. 2006; KNMI, De Bilt, the Netherlands

Temperature affects stratification

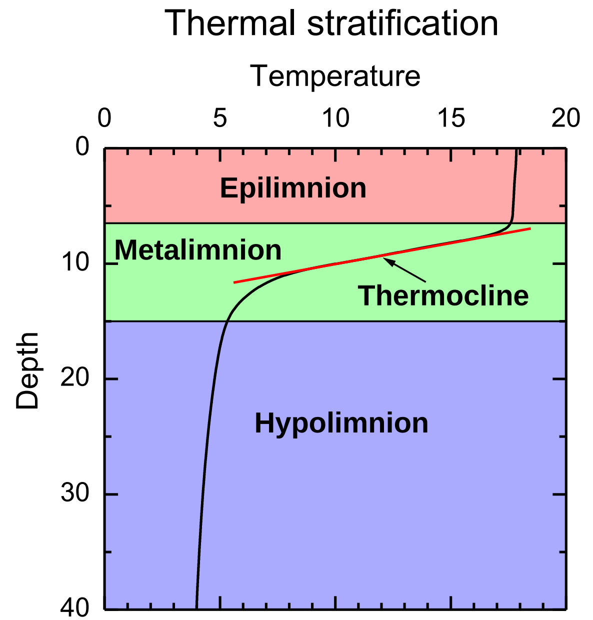
density profile of water

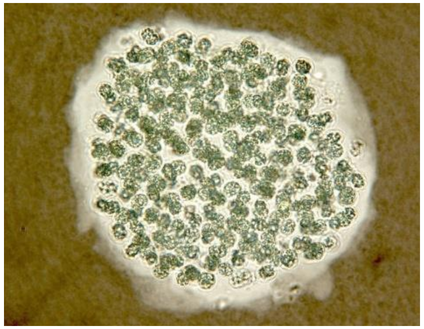


➔ density change per 1 °C

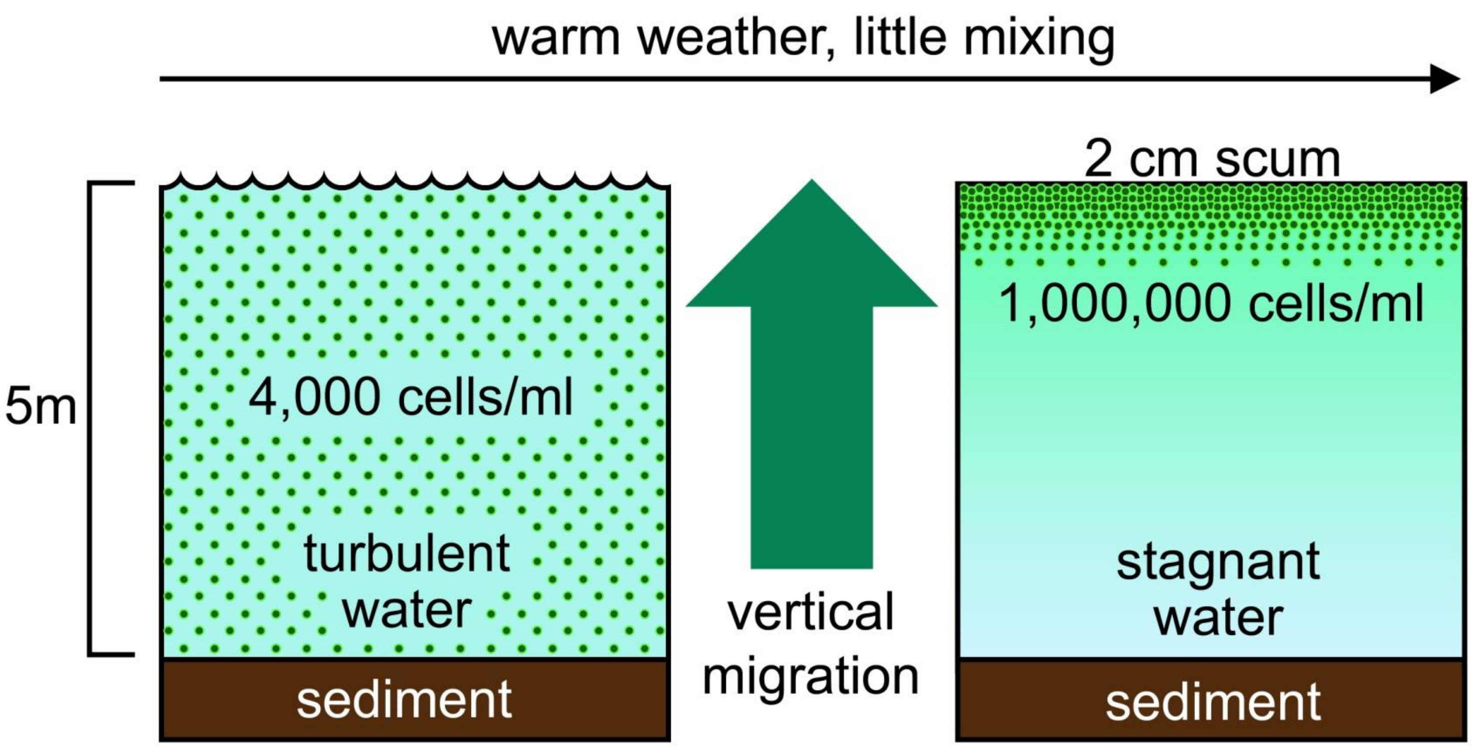


➔ At higher temperature, stratification is stronger !





Buoyant Cyanos favored by Stronger Stratification



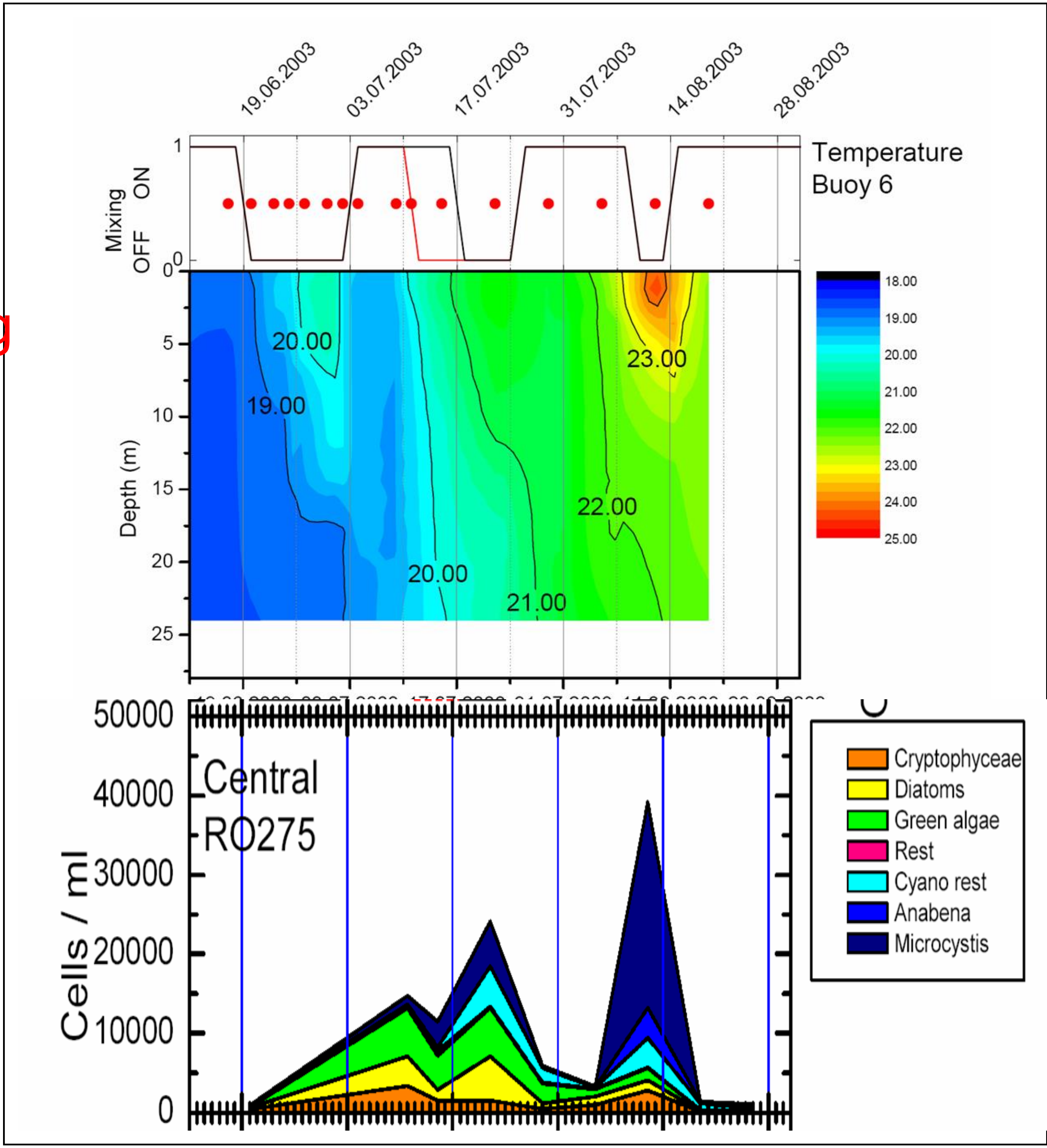
Paerl and Huisman 2009

Mid August 2003:

Nieuwe Meer, Holland

Heatwave & little mixing

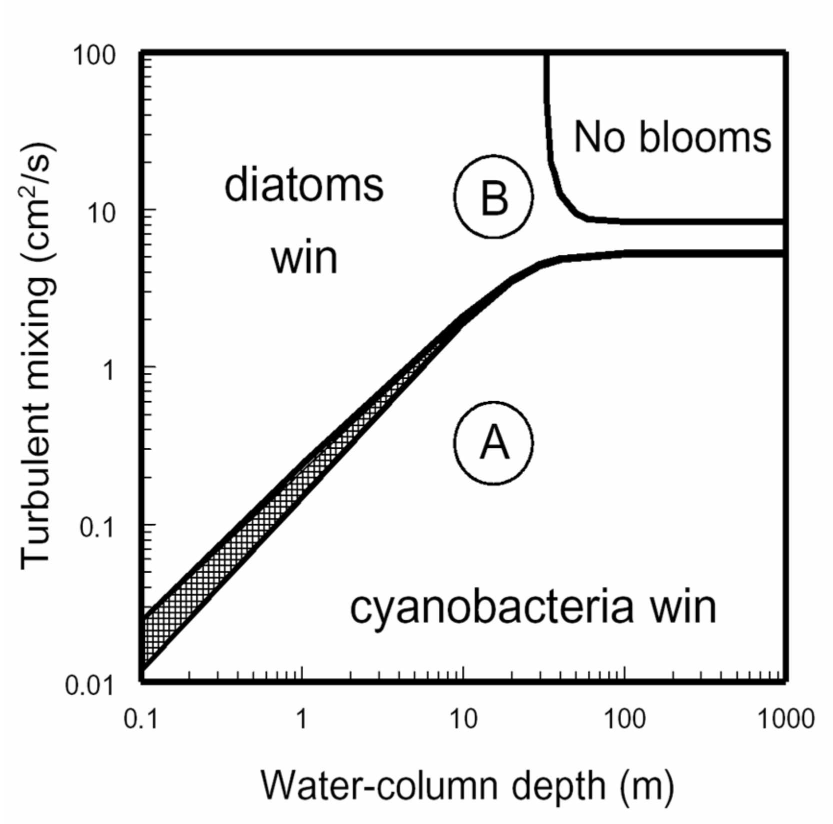
Microcystis benefits!



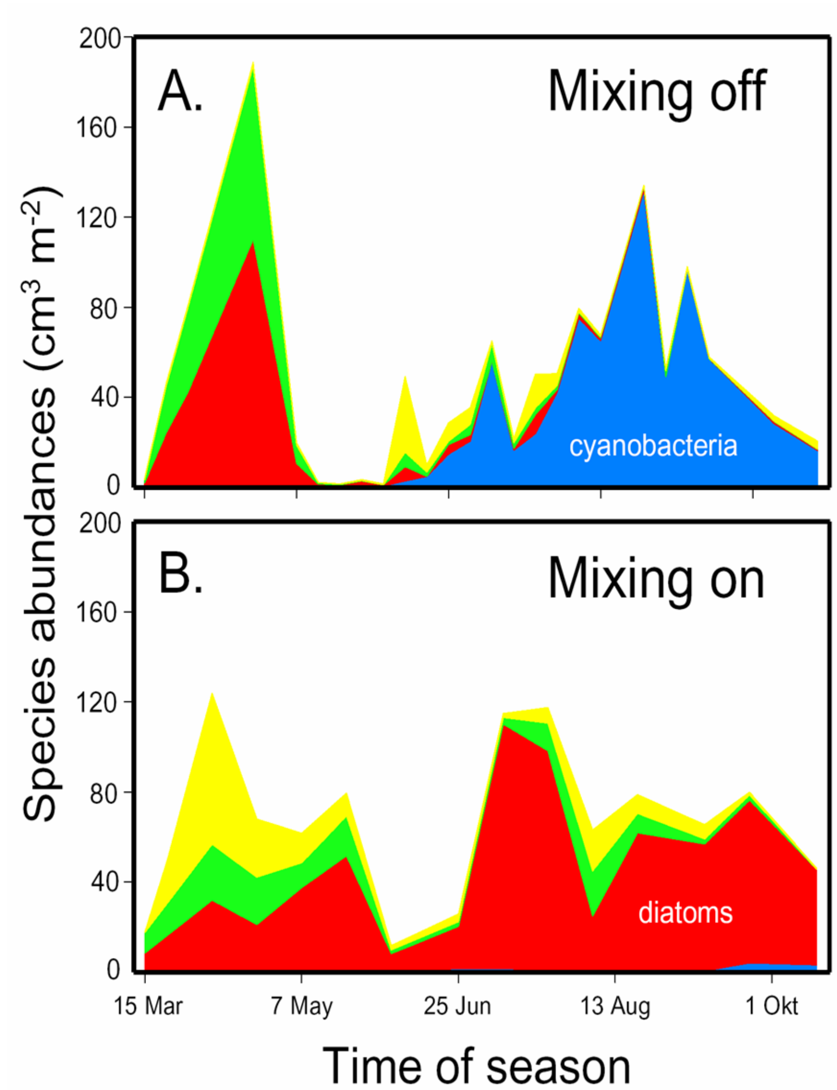
Jöhnk et al., 2008

Testing the Model

Theory

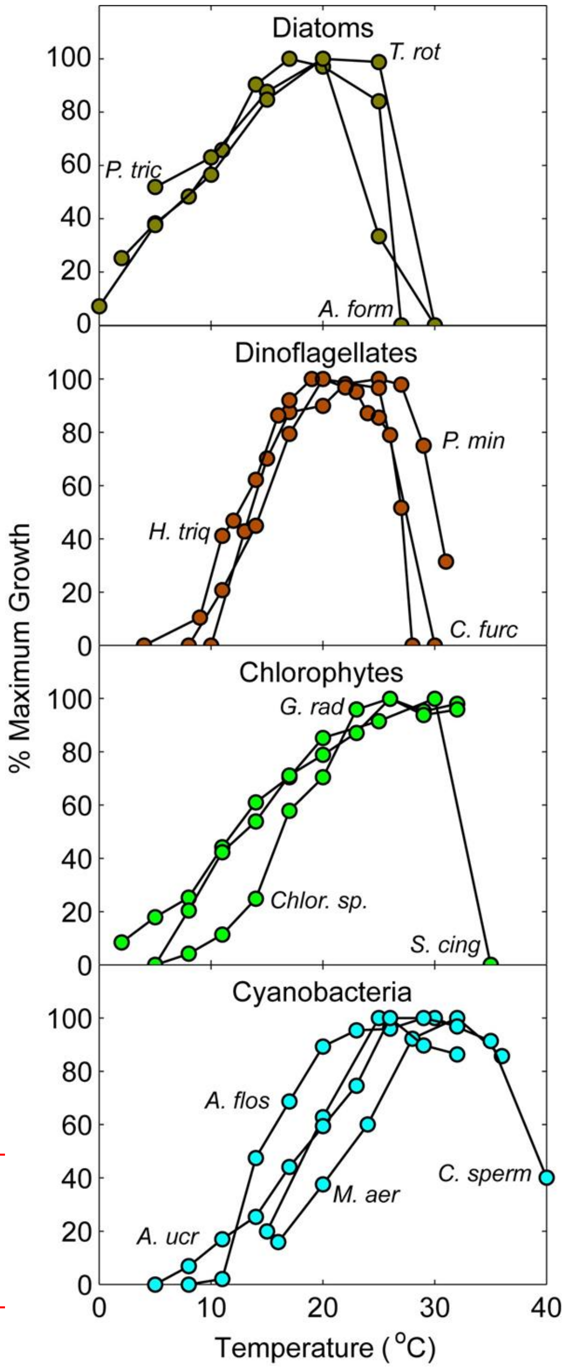


Lake data



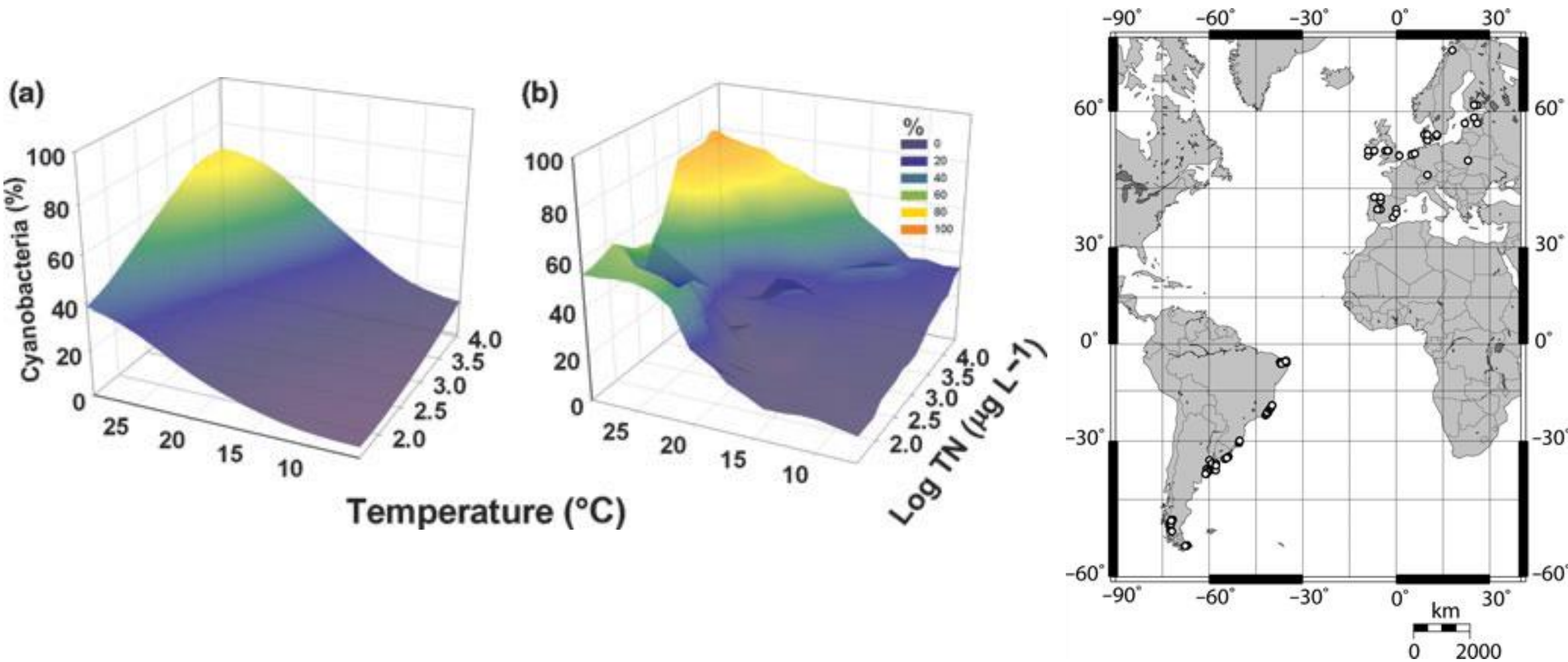
Huisman et al., 2004

The link to CyanoHABs………
Temperature affects growth rates



References: Kraweik 1982, Grzebyk & Berland 1996; Kudo et al., 2000, Litaker et al., 2002, Briand et al., 2004, Butterwick et al., 2005, Yamamoto & Nakahara 2005, Reynolds 2006

Cyanobacterial dominance along temperature & nutrient gradients in 143 lakes



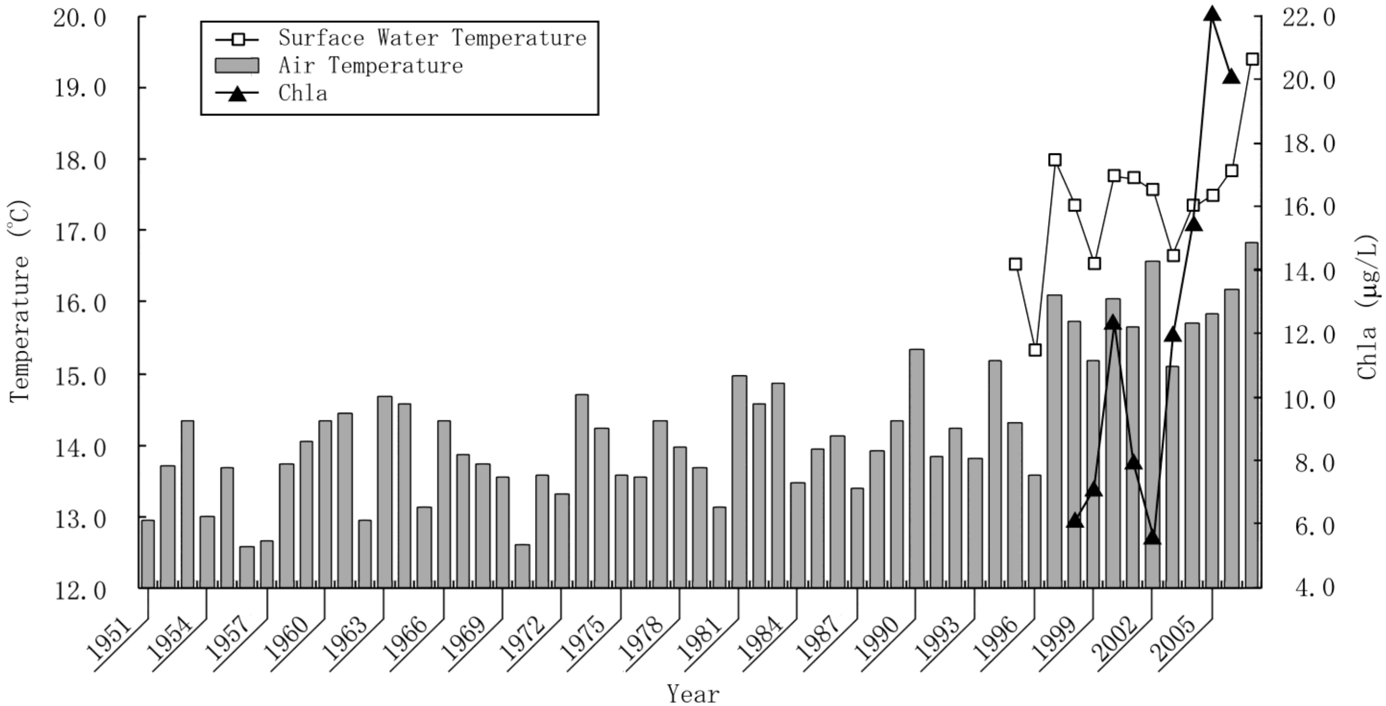
Percentage of cyanobacterial biovolume in phytoplankton communities as a function of water temperature and nutrients in 143 lakes along a climatic gradient in Europe and South America.

(a) Combined effects of temperature and nutrients as captured by a logistic regression model

(b) Response surface obtained from interpolation of the raw data using inverse distance weighting.

From Kosten et al. (2012). Global Change Biology

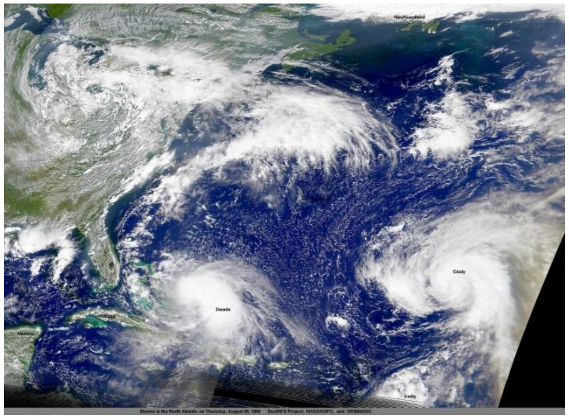
Temperature increases and longer-lasting, more intense cyanobacterial blooms in Taihu. Is warming changing CyanoHAB thresholds?



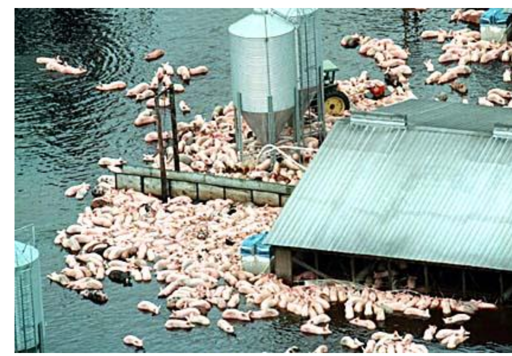
Hydrologically: Things are getting more extreme

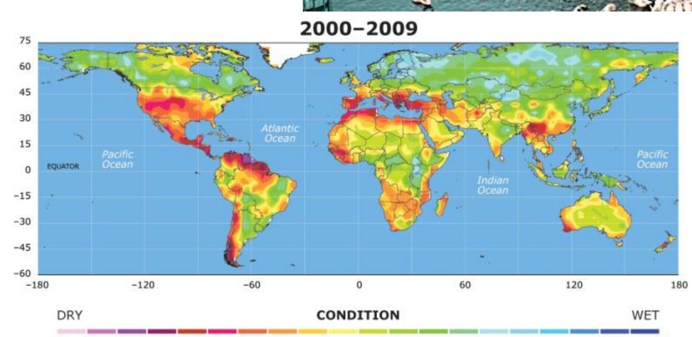
- **Storms, droughts more intense, extensive & frequent**

Melillo et al., 2014. 3rd National Climate Assessment, US Global Change Research Program

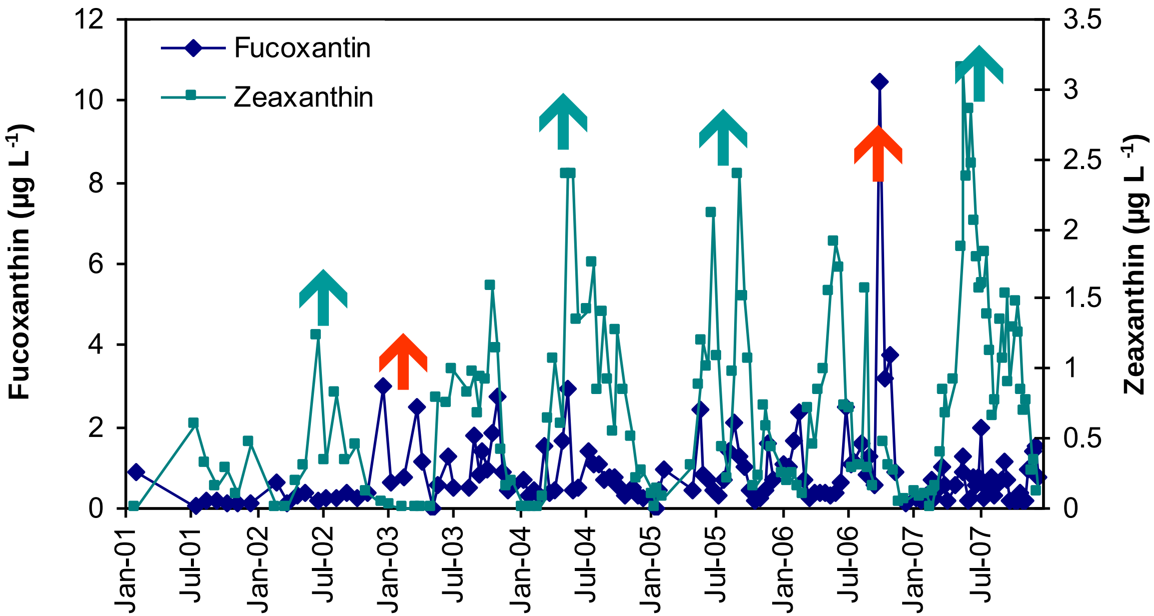


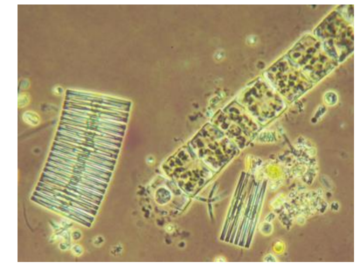


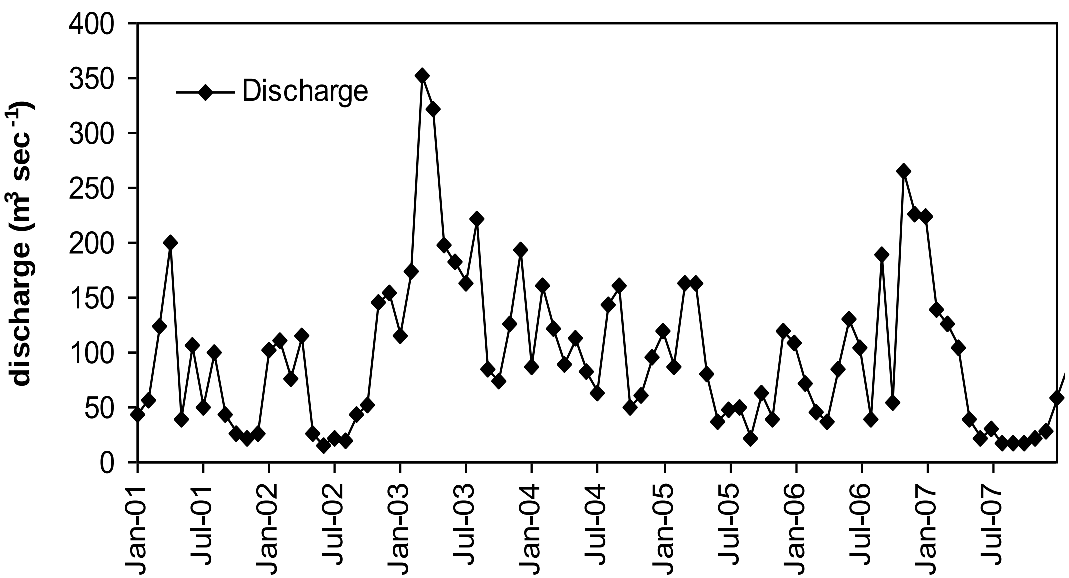


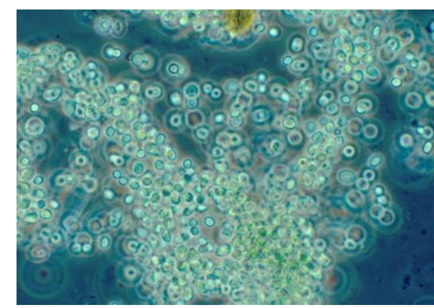
Hydrology (flushing) interacts with temperature to determine diatom (fucoxanthin) and cyanobacterial (zeaxanthin) dominance in Neuse R. Estuary





Diatoms like it cool & fast





Cyanos like it hot & slow

Paerl et al. 2009

What's being done to "fix" Taihu?

- Need for dual nutrient reduction strategy recognized
- Wastewater collection and treatment
- Creating buffer zones
- Dredging sediments
- Diversion of Yangtze R. water (to enhance flushing)
- Algal Collection techniques
- Precipitation/flocculation

Since 2007, Wuxi has built 68 new wastewater plants, treating 1,513,000 ton/day, upgraded all wastewater treatment levels for BOD, starting P but not (yet) N removal.

建成覆盖所有城镇的68座污水处理厂，
日处理能力达到151.3万吨。
投资7.8亿元对现有污水处理厂全面进行
提标改造。

（无锡市太湖办顾刚提供）

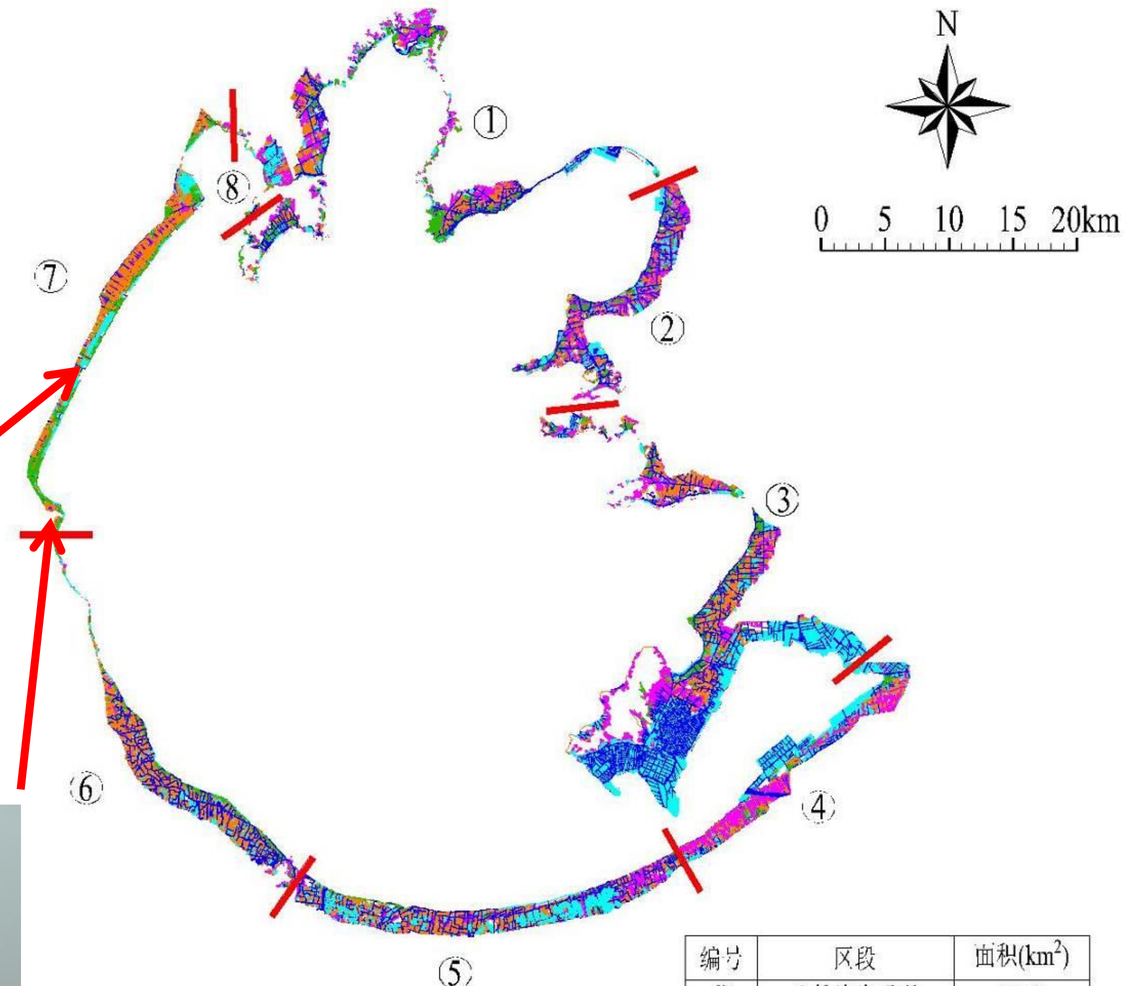
Using vegetative buffers to retain storm water nutrients






（Qin et al., 2012）

Construction of buffer zones and wetlands around the lake



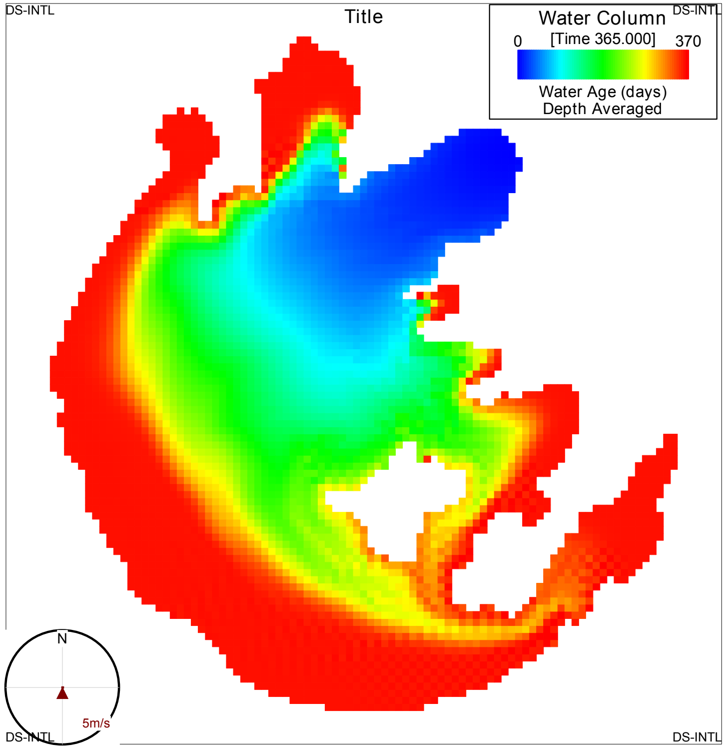
图例	土地利用	面积(km^2)
	城镇农村及工交建设用地	72.98
	林地、果园	42.26
	农田	192.61
	河流沟渠	29.68
	水库、坑塘	114.78

编号	区段	面积(km^2)
①	无锡滨湖区段	66.61
②	苏州高新区段	44.39
③	苏州吴中区段	142.55
④	苏州吴江市段	44.68
⑤	湖州吴兴区段	60.81
⑥	湖州长兴县段	44.50
⑦	无锡宜兴市段	41.38
⑧	常州武进区段	7.39
合计		452.31

(叶春提供）


More...
Map
Zhenjiang
镇江市
Changzhou
常州市
Nantong
南通市
Pump station
无锡市
Entrance
Suzhou
苏州市
Exit
Jiaxing
嘉兴市
Water diversions in Lake Taihu
©2008 Google - Imagery ©2008 TerraMetrics, Map data ©2008 Mapabc, AND, Europa Technologies

Yangtze River water diversion through Taihu: Cure or Curse?



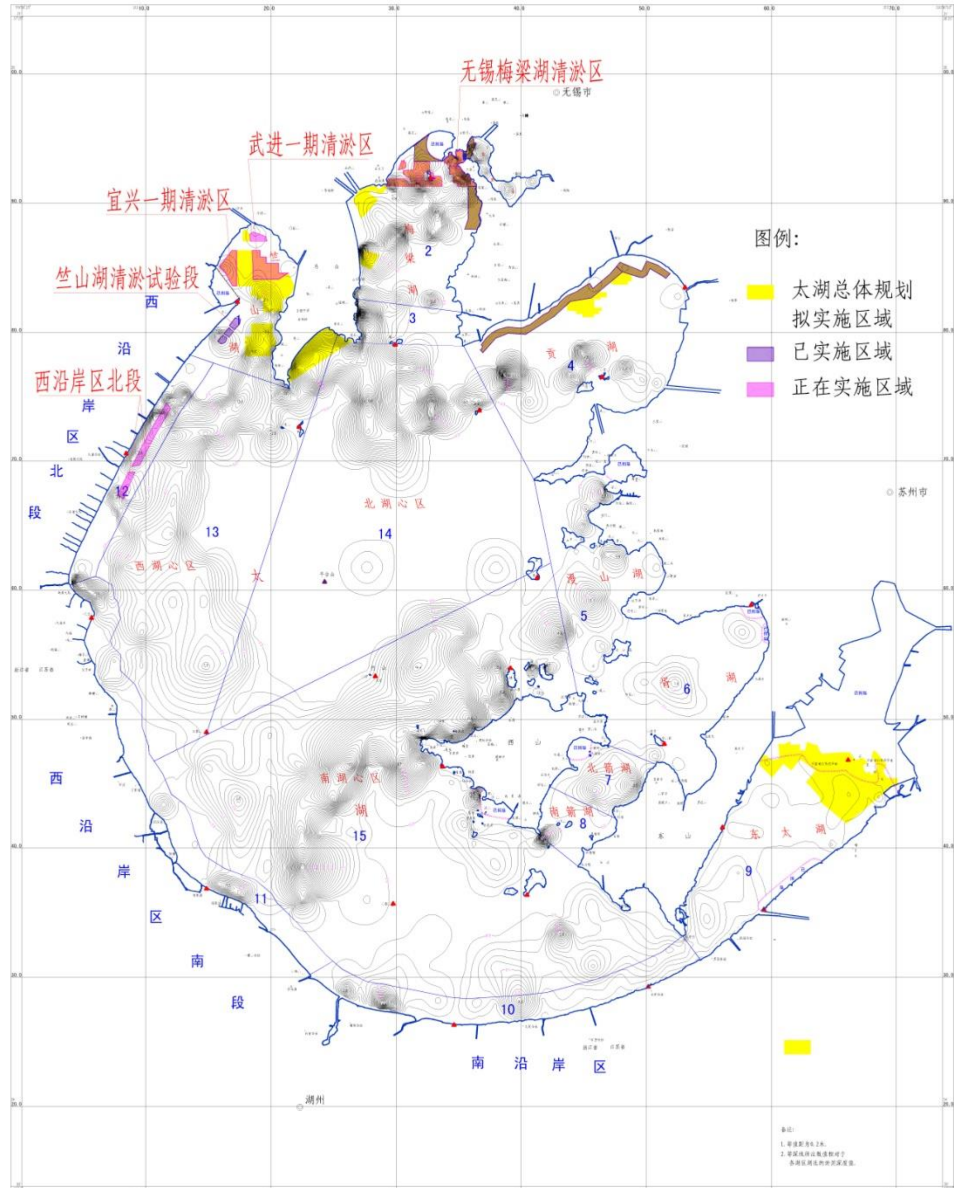
- **The heavily polluted lake regions (i.e. Meiliang Bay, Zhushan Bay and west littoral) are not remedied by the water transfer route and volume.**
- **Water residence time is reduced from ~ 320 days to ~ 220 days at best. This has no significant impact on reducing bloom potentials.**
- **The diversion may makes things worse…input from the heavily polluted Yangtze River adds ~15% to the N and P loads to the lake, potentially exacerbating eutrophication and blooms.**

HOHAI UNIVERSITY
www.hhu.edu.cn

Courtesy: Yiping Li--Hohai University, Nanjing, China

Polluted sediment dredging

✓40 km2 in north-western area and 1200 cubic meters (Lake area 2,300 km2). This has actually made the situation worse by releasing a legacy of nutrients and other pollutants, AND dredged sediments are deposited in catchments surrounding the lake Basin



(省水利厅提供)

CyanoHAB collection and removal

❖Between 2007 and 2012, 3500,000 tons of algal scum had been removed. However, this is <1% of what was produced!!

Flocculation and precipitation of CyanoHABs

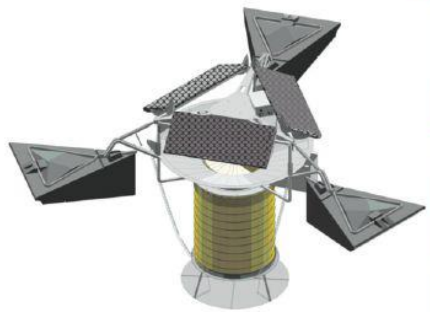
❖Trials indicate that sediment resuspension overwhelms "sediment capping" (i.e., can't hide the problem). ❖Costs prohibitive. ❖Doesn't solve the excess nutrient problem

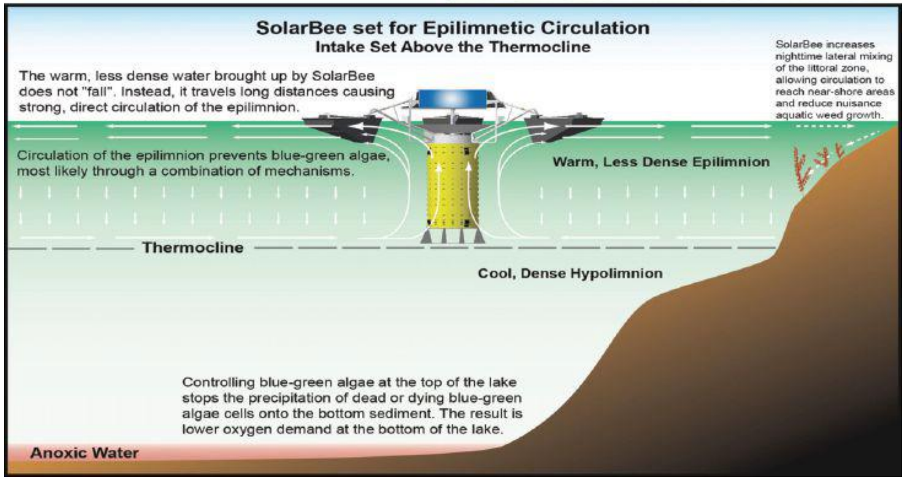
Bottom Line: Need to reduce BOTH N and P inputs, no matter what other "fixes" are proposed

Other physical-chemical approaches

Altering circulation

Solar-Powered, Long-Distance Circulation

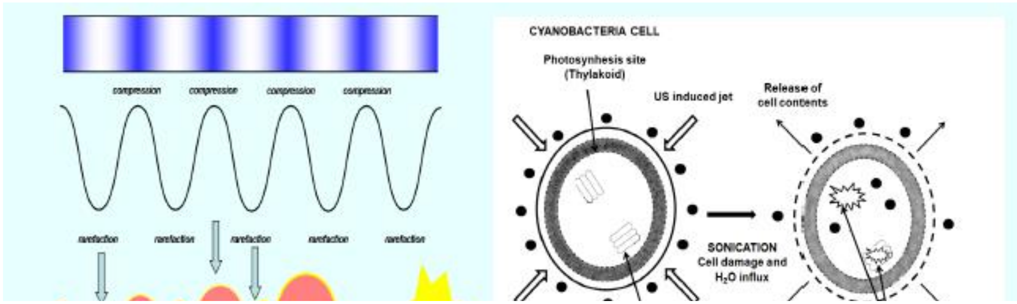




- May discourage formation of some buoyant cyanoHABs in confined waters
- May also increase primary production (by obviating light limitation)
- Nutrient transport and circulation??

Hudnell 2013

Effects of ultrasound on cyanobacterial biomass



Note: cell content leaks out upon lysis

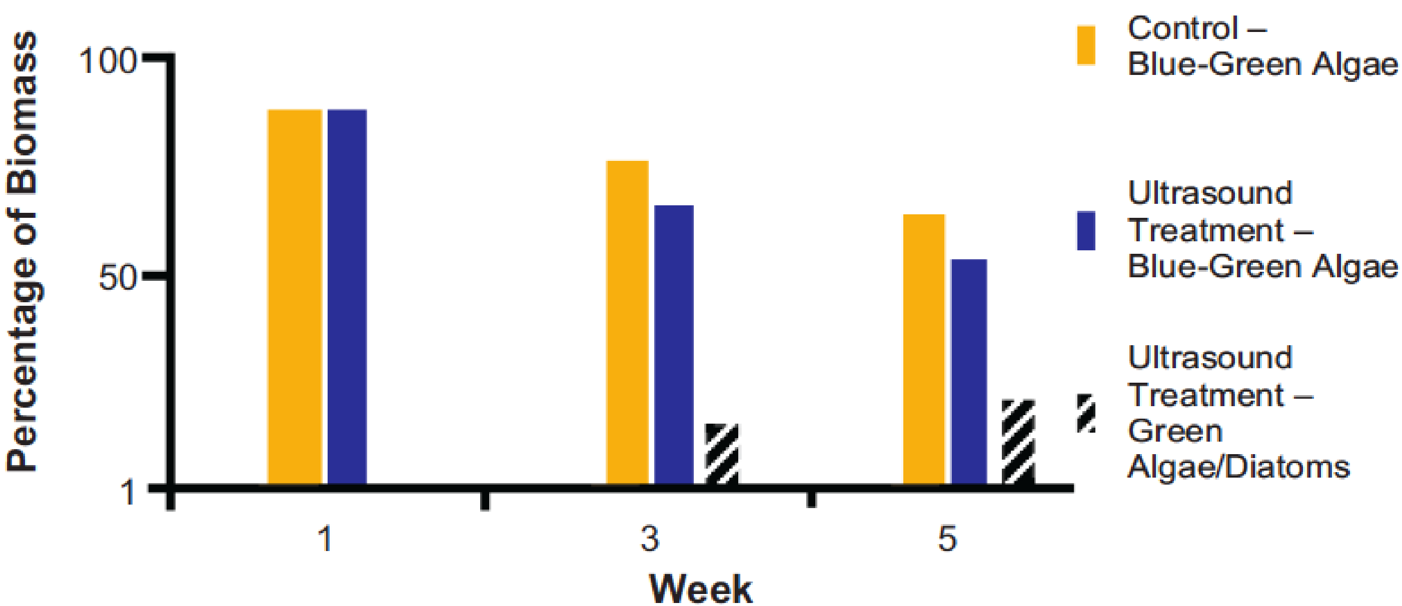
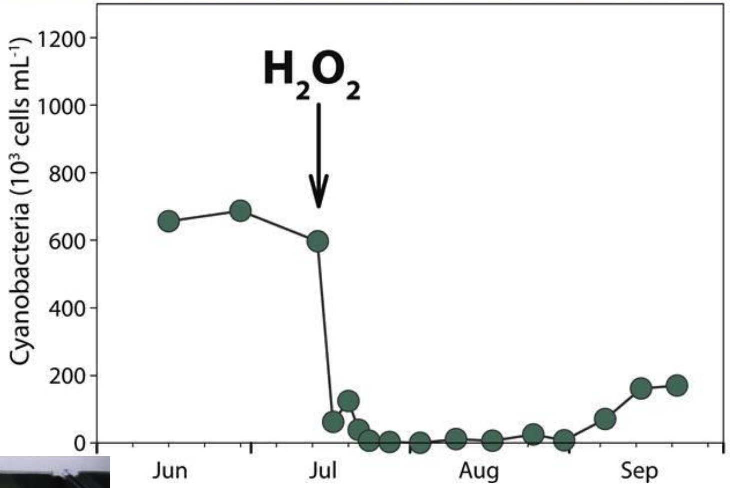
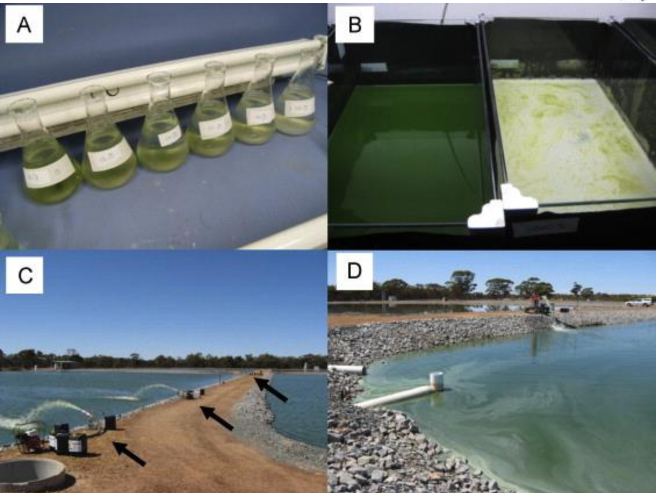


Figure 2. *Changes in algal composition in control and ultrasound-treated ponds.*

Zimba et al., 2008; Wu et al., 2012

Hydrogen Peroxide Treatment



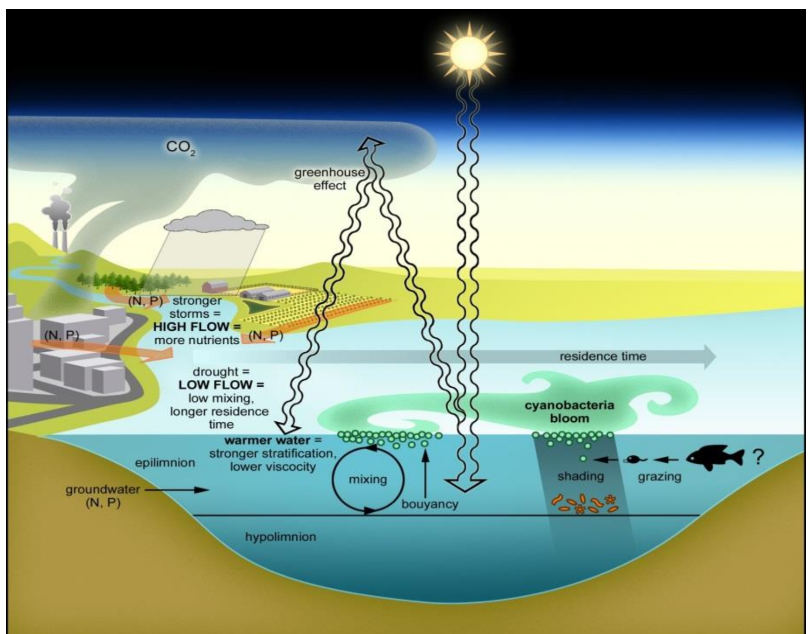


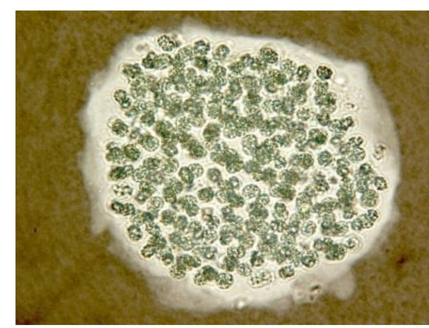
Kills cells (in confined systems) but releases toxins

Matthijs et al., 2012; Barrington et al., 2013

Management ramifications

- In most cases, both N & P reductions are needed (no matter what other physical/chemical approaches are used)
- Nutrient-bloom threshold are system-specific
- Nutrient-bloom thresholds may be changing
  - May need to reduce N and P inputs even more in a warmer world
- Nutrient input restrictions year-round
  - Cyanos are favored by higher temperatures, longer warm seasons





Thanks!!

www.unc.edu/ims/paerllab/research/cyanohabs/

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