CyanoHAB management and monitoring in waters experiencing human and climatically-induced environmental change: Implications for California

Hans W. Paerl, UNC-Chapel Hill Institute of Marine Sciences, Morehead City, NC, and many others!

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

Cyanobacterial Harmful Blooms (CHABs): 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

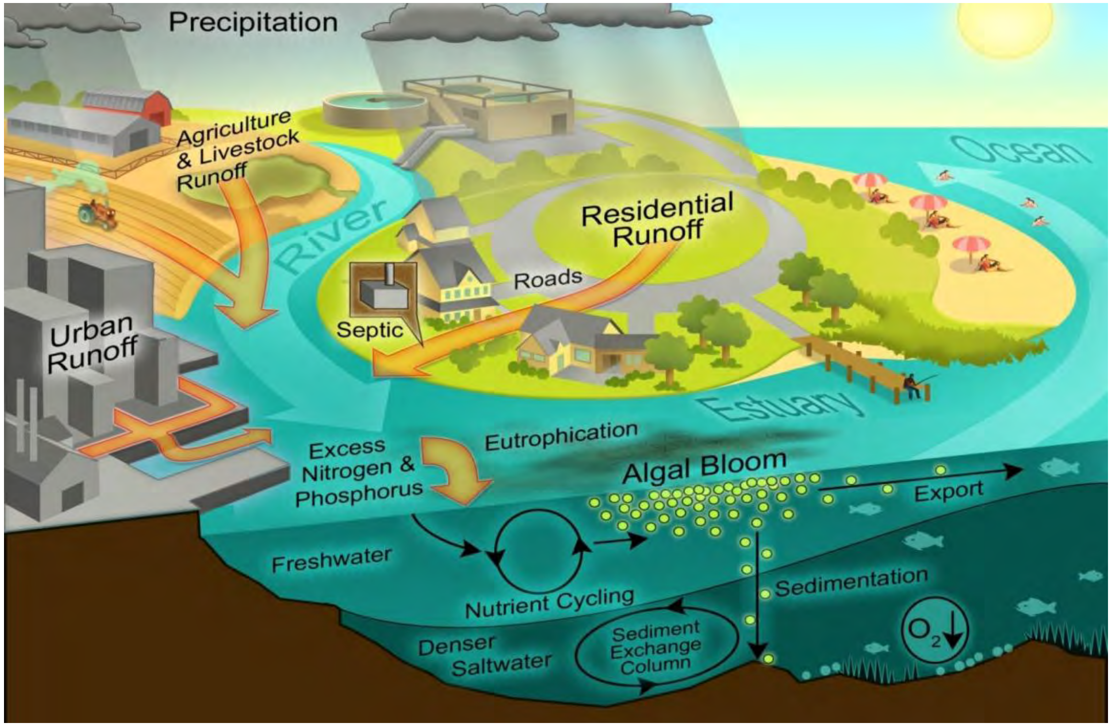
Blooms are intensifying and spreading

Emerging nutrient issues

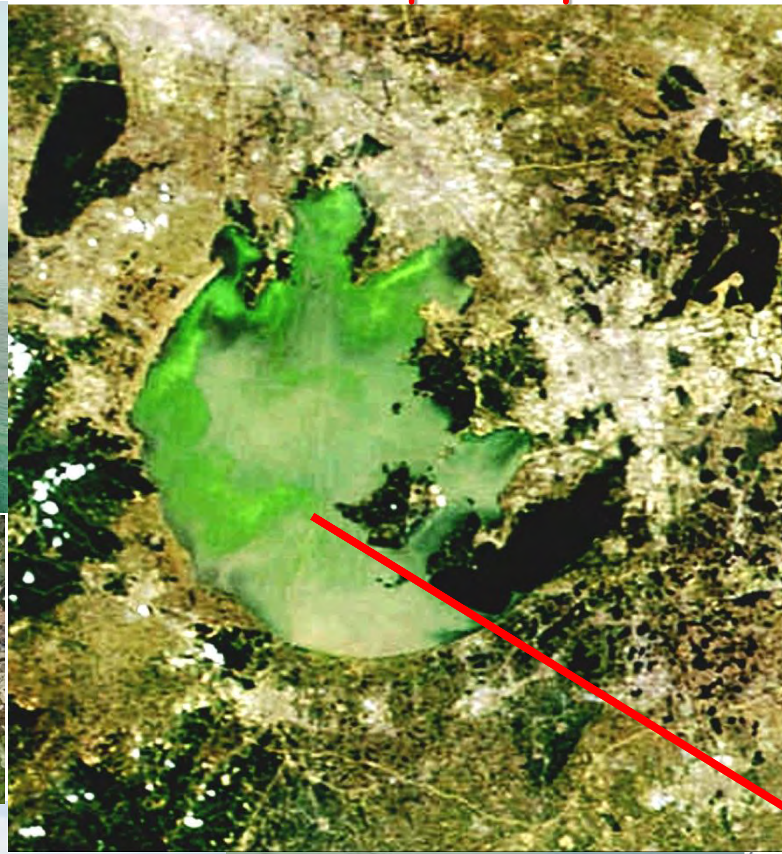
- Dogma: Primary production is controlled by P availability.

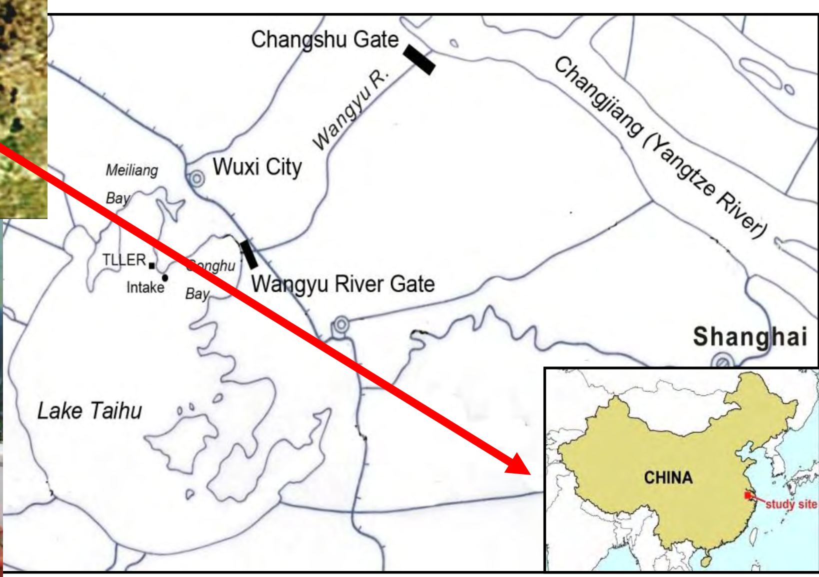
- However: Accelerating anthropogenic N & P loading has altered nutrient limitation and eutrophication dynamics

Results: Human-impacted systems reveal a complex picture and a challenge to nutrient management



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



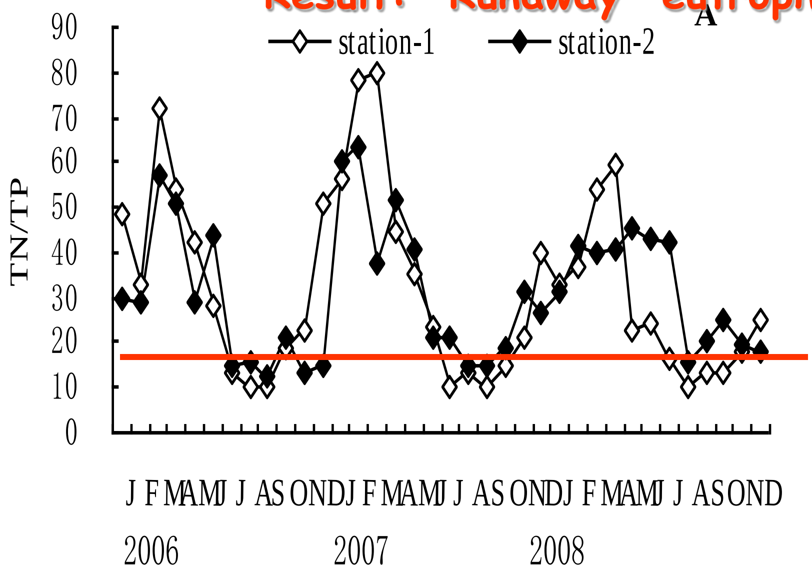


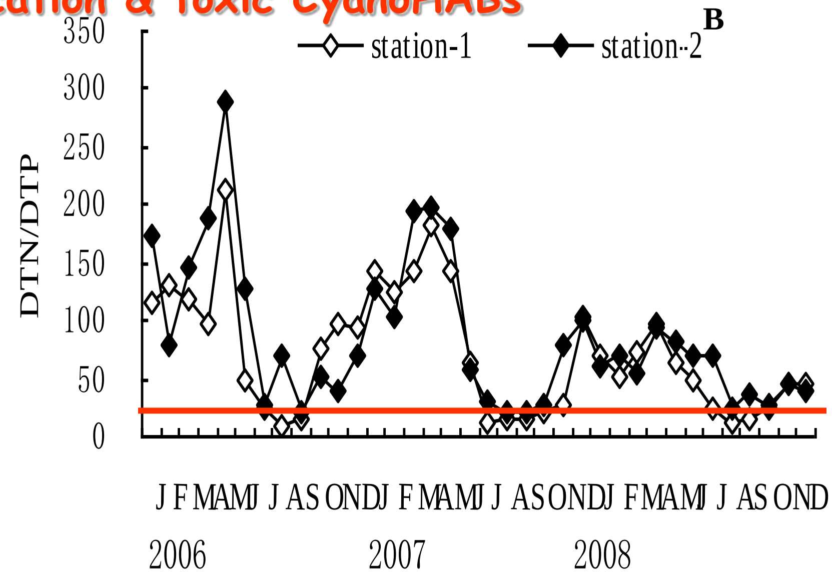
The water crises (2007- ?) in the Taihu Basin:

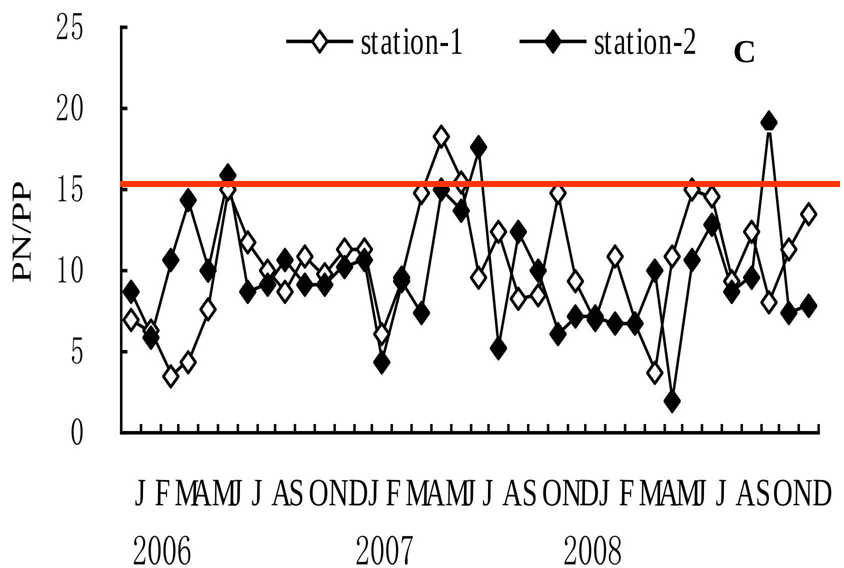
- Cessation drinking water use for >20 million (hepato- and neuro-toxins)
- Curtailed recreational use (contact dermatitis)
- Fisheries (commercial and recreational)
- Tourism???

Nutrient dynamics in Taihu

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







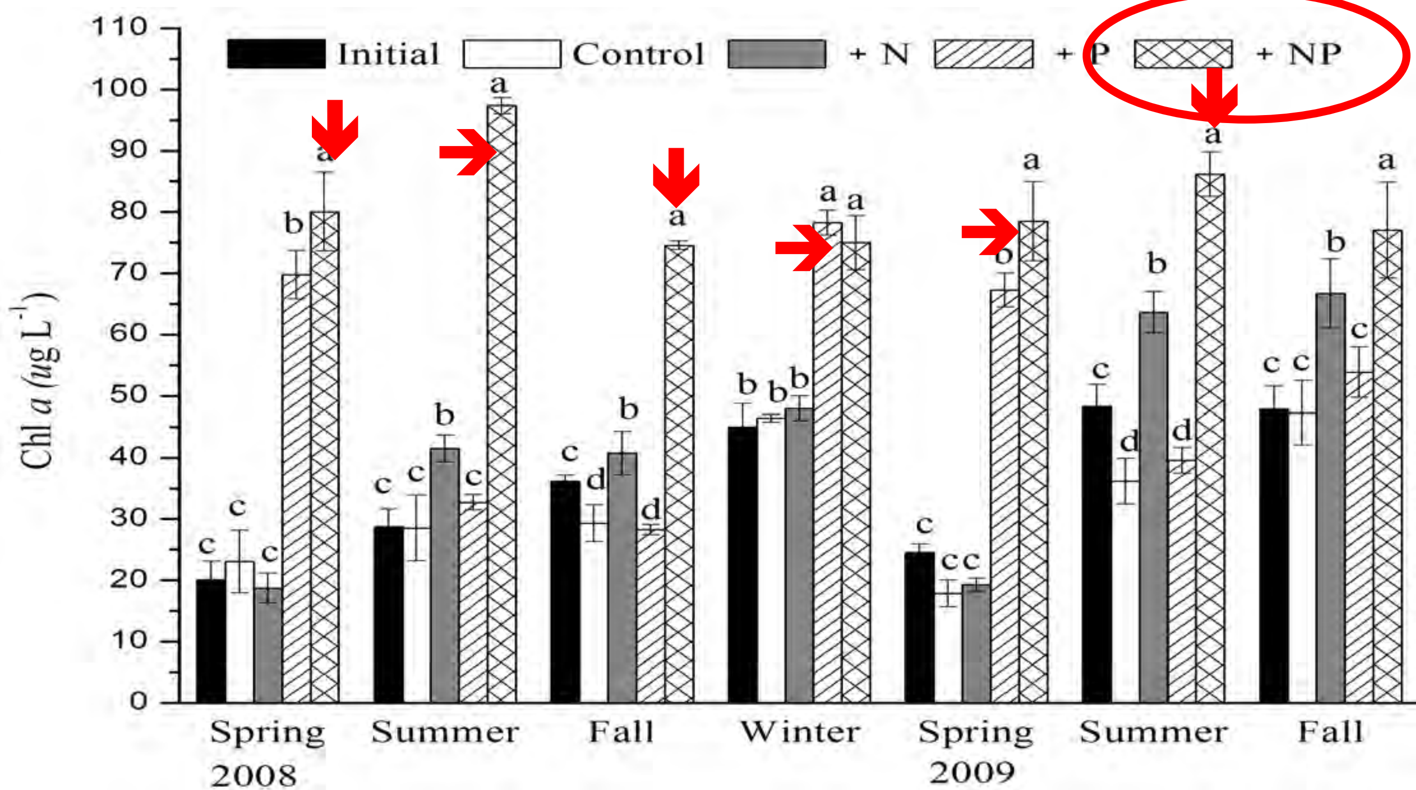
Nutrient (N&P) ratios in Taihu

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

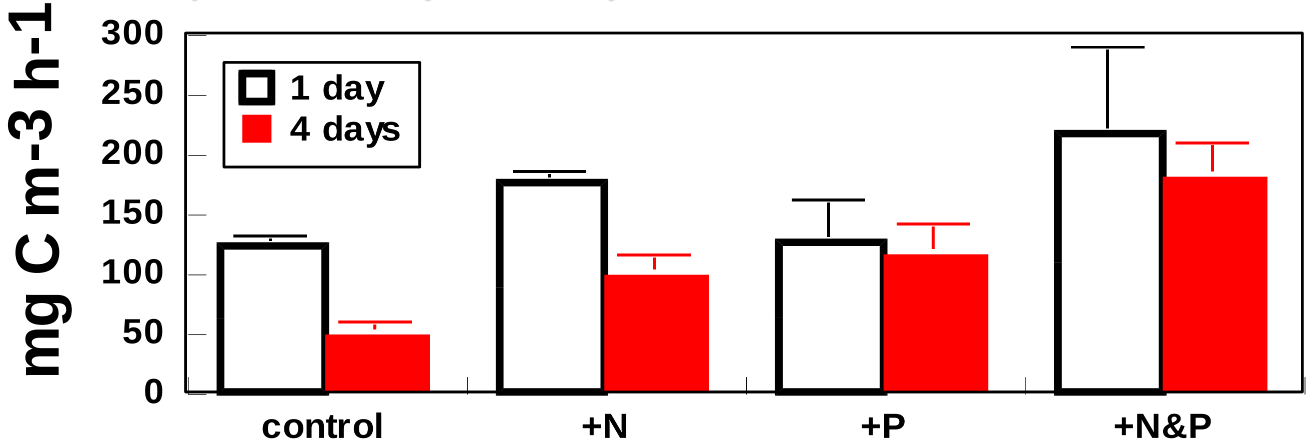

Oct. 2008
Control
(no nutrients)
$+ N-NO_3^-$
$+ P-PO_4^{3-}$
+ N + P

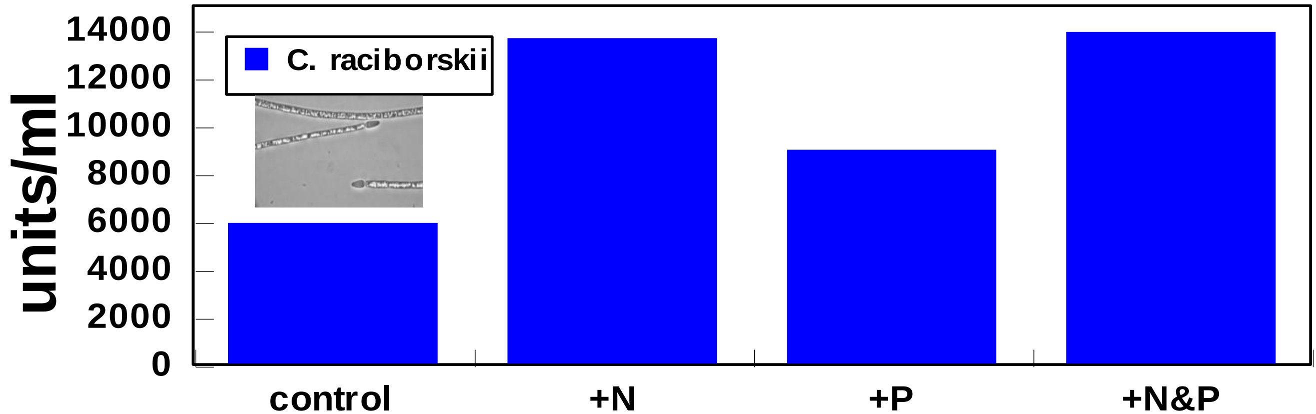
Taihu as "looking glass" for eutrophying shallow ecosystems elsewhere?

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 River system, FLorida: Nitrogen and Phosphorus Effects on CyanoHAB Growth and Bloom Potential (*Cylindrospermopsis raciborskii*)

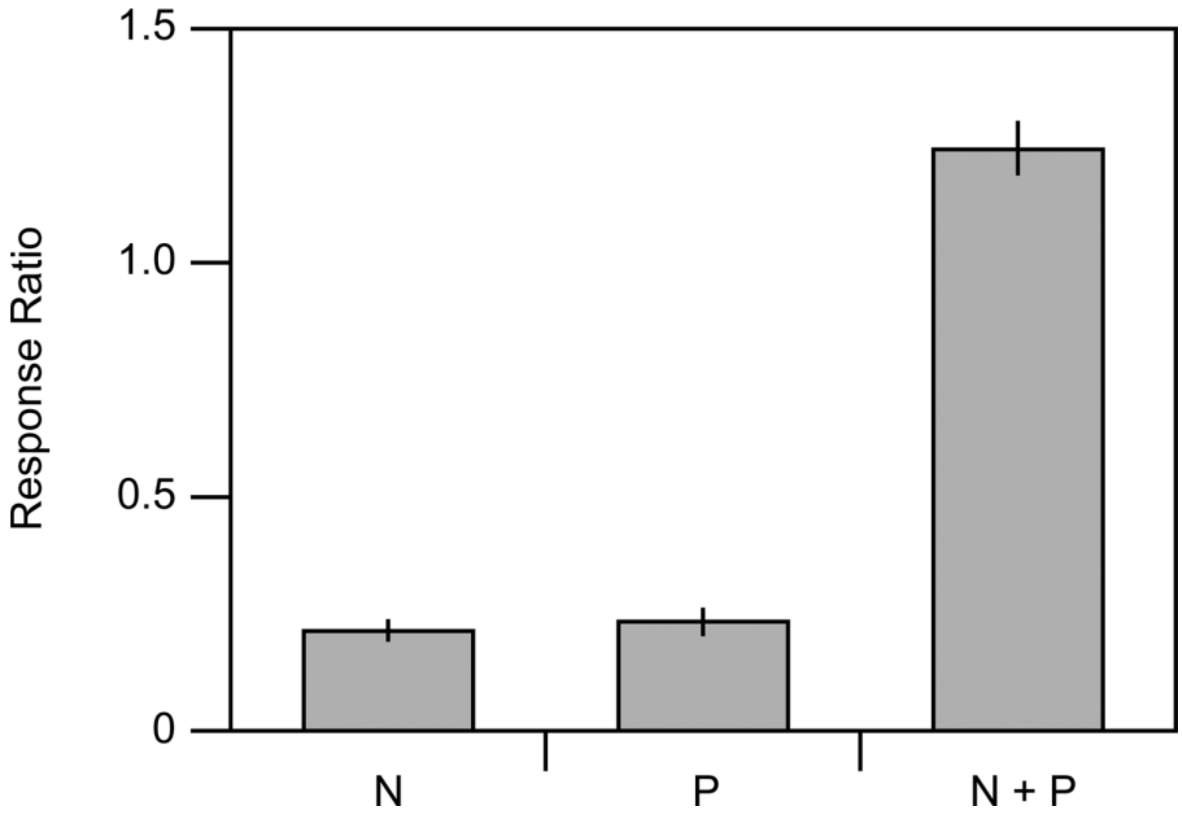




Take home message: *Cylindrospermopsis raciborskii* is opportunistic
Dual N & P input constraints will likely be needed to control it

Piehler et al, 2009

N & P limitation in lakes worldwide



Lakes: N= 55

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

Assumption: N_2 fixing cyanos can meet N demands in lakes, so why control N inputs? (Schindler et al., 2008). However, N_2 flux from shallow eutrophic lakes indicates net loss (negative net N_2 flux) of reactive N to the atmosphere.

Lake	Nitrogen Fixation	Denitrification	Net N_2 Flux
	N_2 Flux (g N m^{-2} yr^{-1})		
Lake 227 (ELA*), Canada	0.5	5 – 7	-6.5 to -4.5
Lake Mendota, Wisconsin, USA	1.0	1.2	-0.2
Lake Okeechobee, Florida, USA	0.8 – 3.5	0.3 – 3.0	-2.2 to 0.5
Lake Erken, Sweden	0.5	1.2	-0.7

**Experimental Lakes Area*

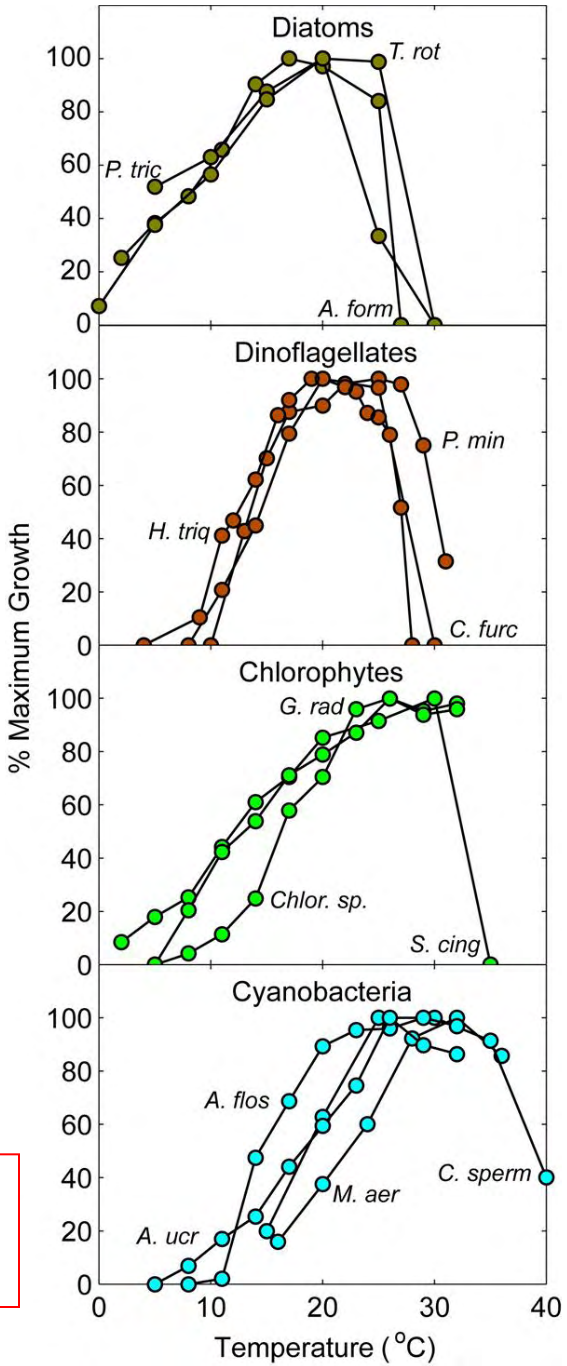
From: Paerl & Scott (2010) ES&T

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!!

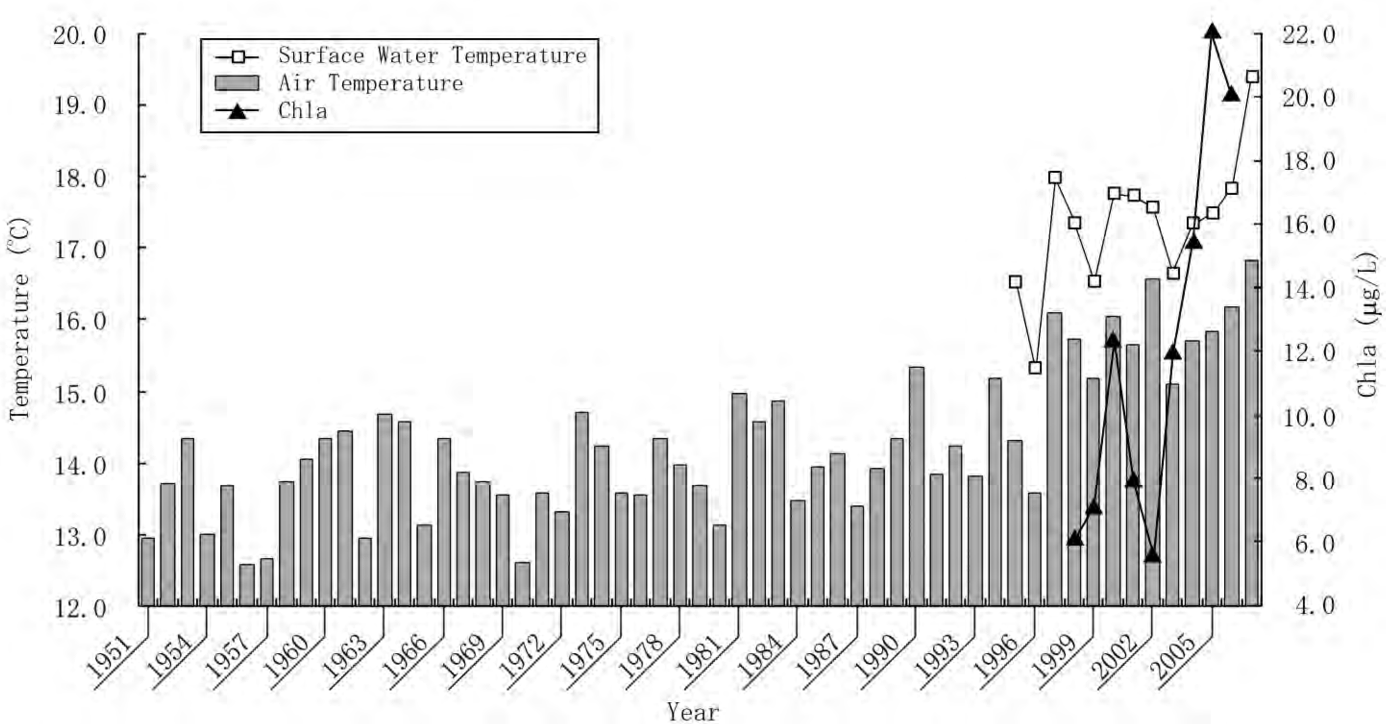
Confounding Impacts of Climate Change: Its Getting Warmer

The link to CyanoHABs………
Temperature affects growth rates



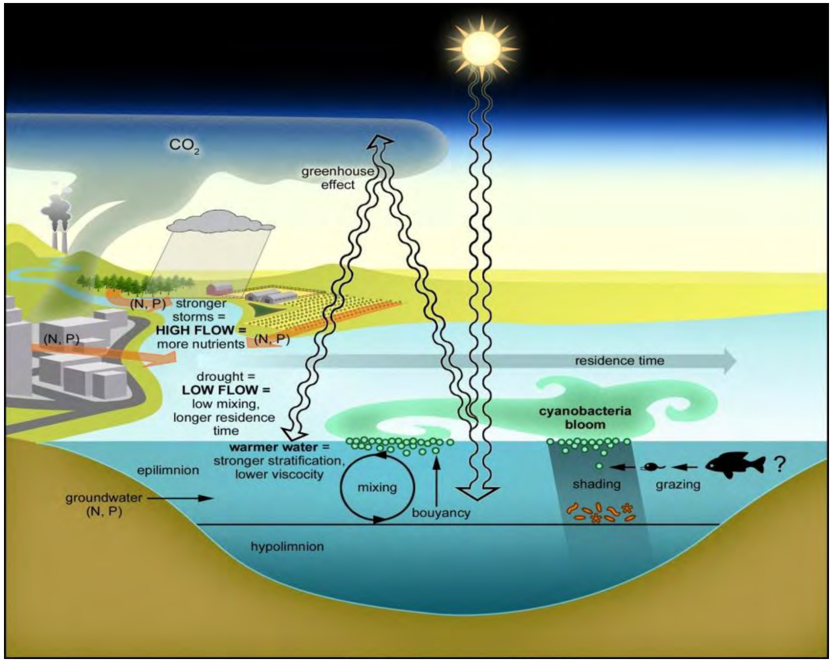
References: Kraweik 1982, Grzebyk & Berland 1996; Kudo et al., 2000, Litaker et al., 2002, Briand et al., 2004, Butterwick et al., 2005, Yamamoto & Nakahara 2005, Reynolds 2006

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



Conclusions

- N_2 Fixation does not meet ecosystem N demands; hence new N inputs can control eutrophication.
- Both N and P controls are needed to counter CyanoHAB proliferation (same true for CA)
- Developing nutrient input-bloom thresholds will need to take climate change (warming, changes in precip. patterns) into consideration

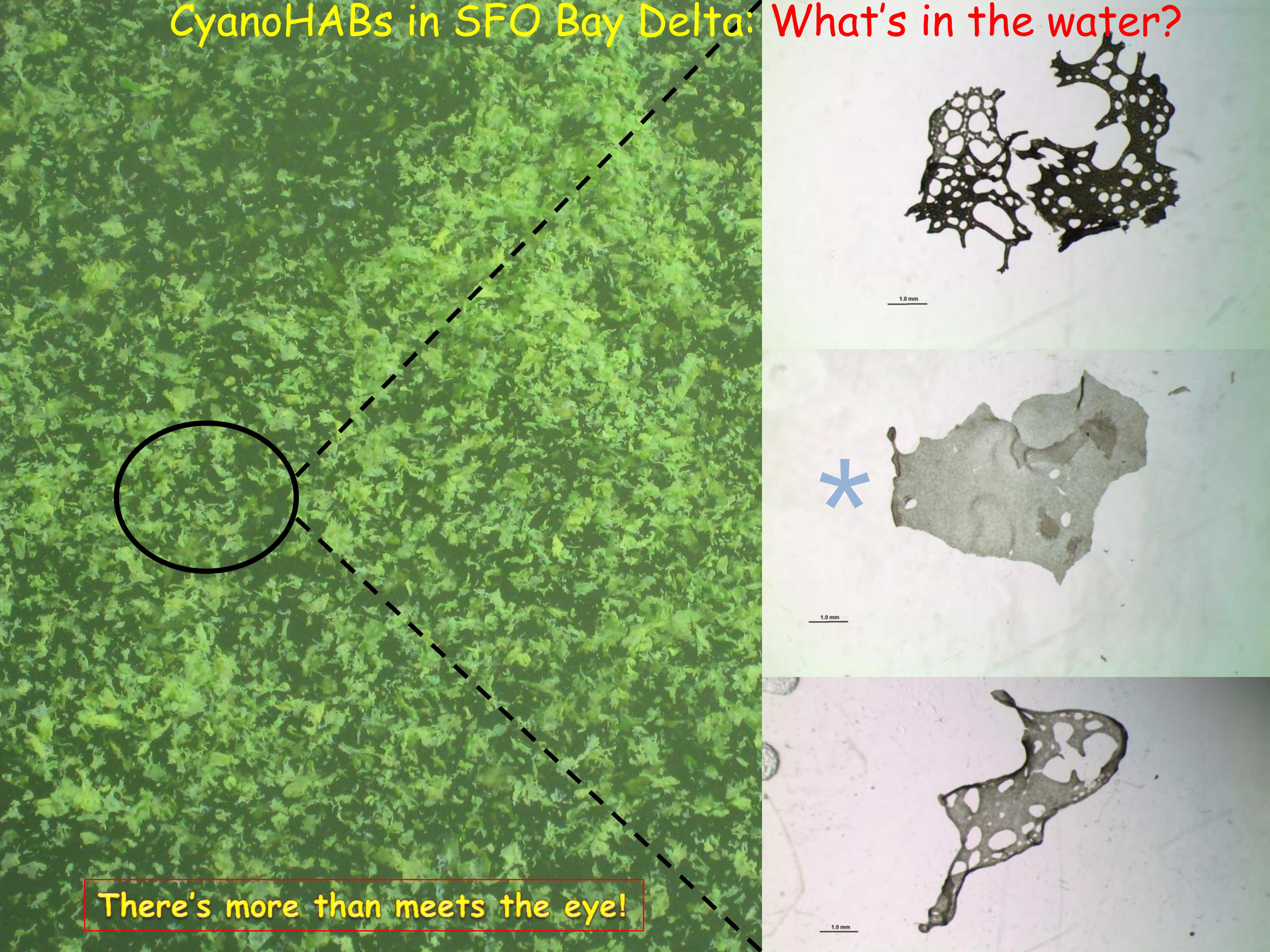


Assessments toxigenic *Microcystis* assemblages in:

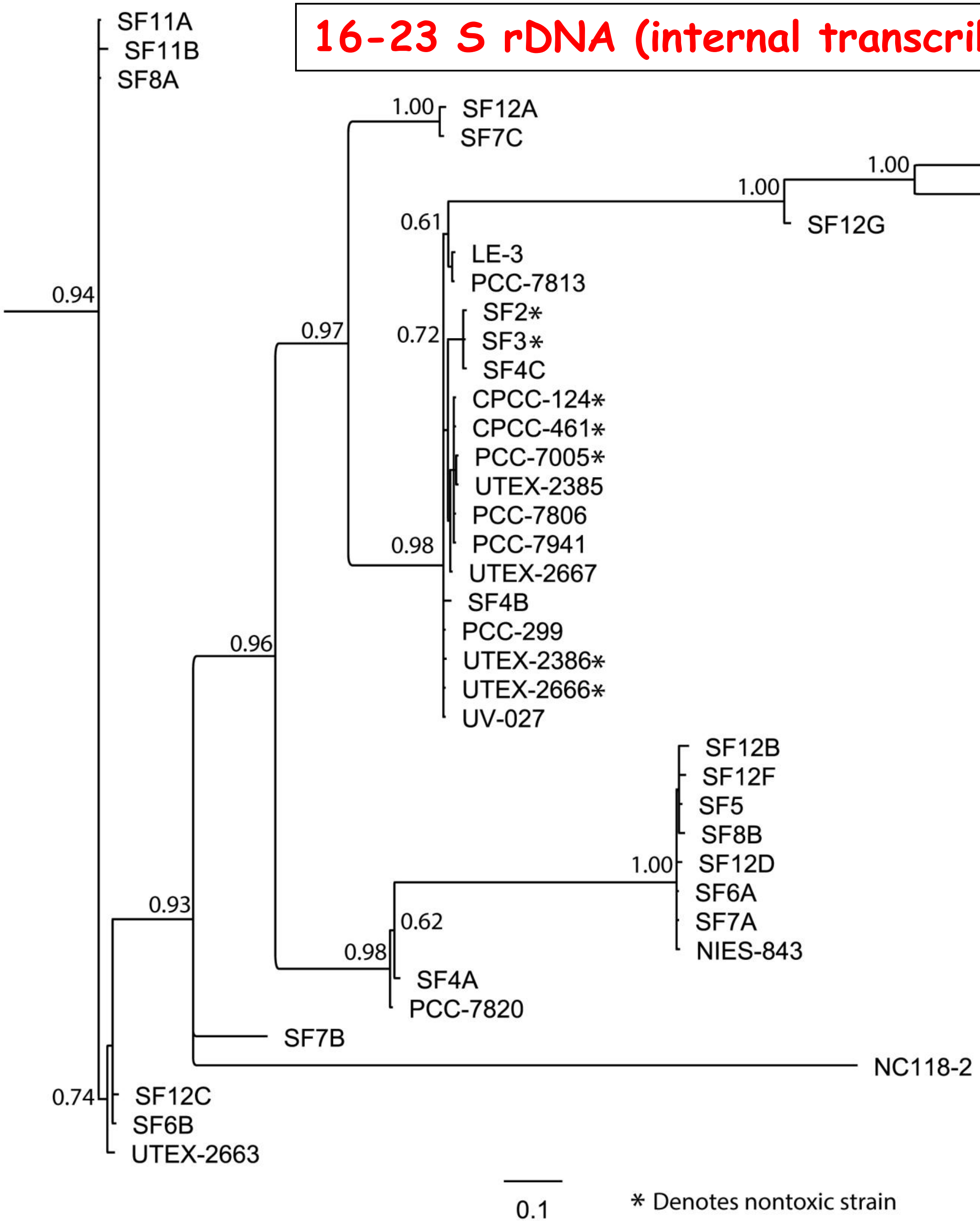
San Francisco Estuary Delta & Lake Taihu, China

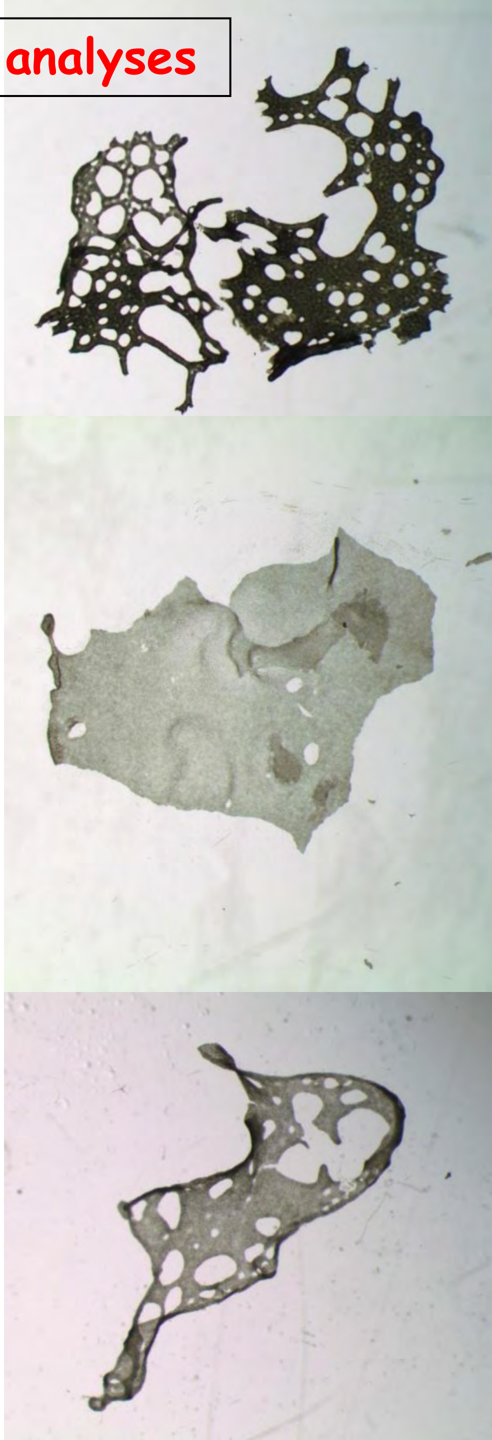
Timothy G. Otten and Hans W. Paerl
University of North Carolina at Chapel Hill
Institute of Marine Sciences

CyanoHABs in SFO Bay Delta: What's in the water?

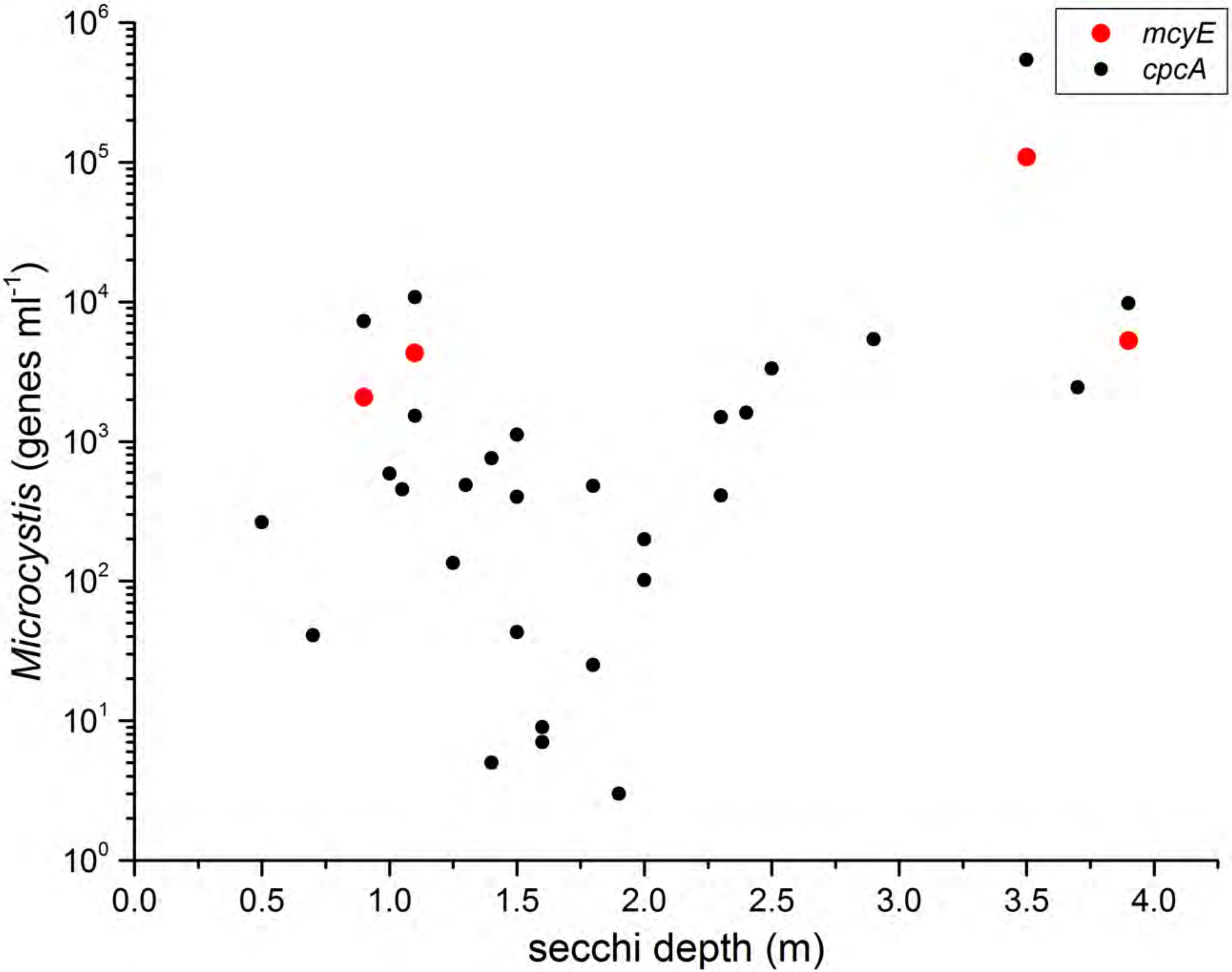


16-23 S rDNA (internal transcribed spacer) analyses

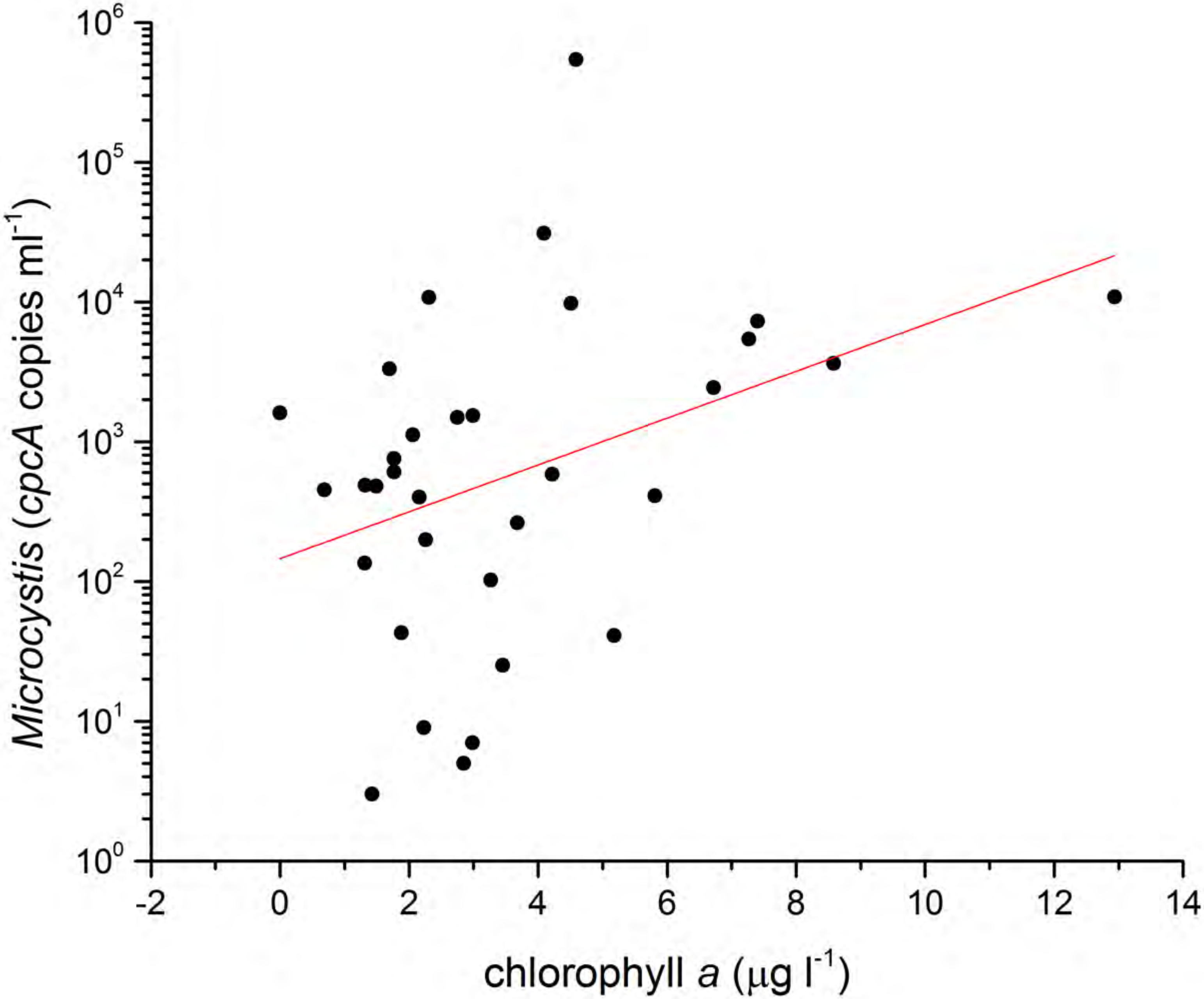




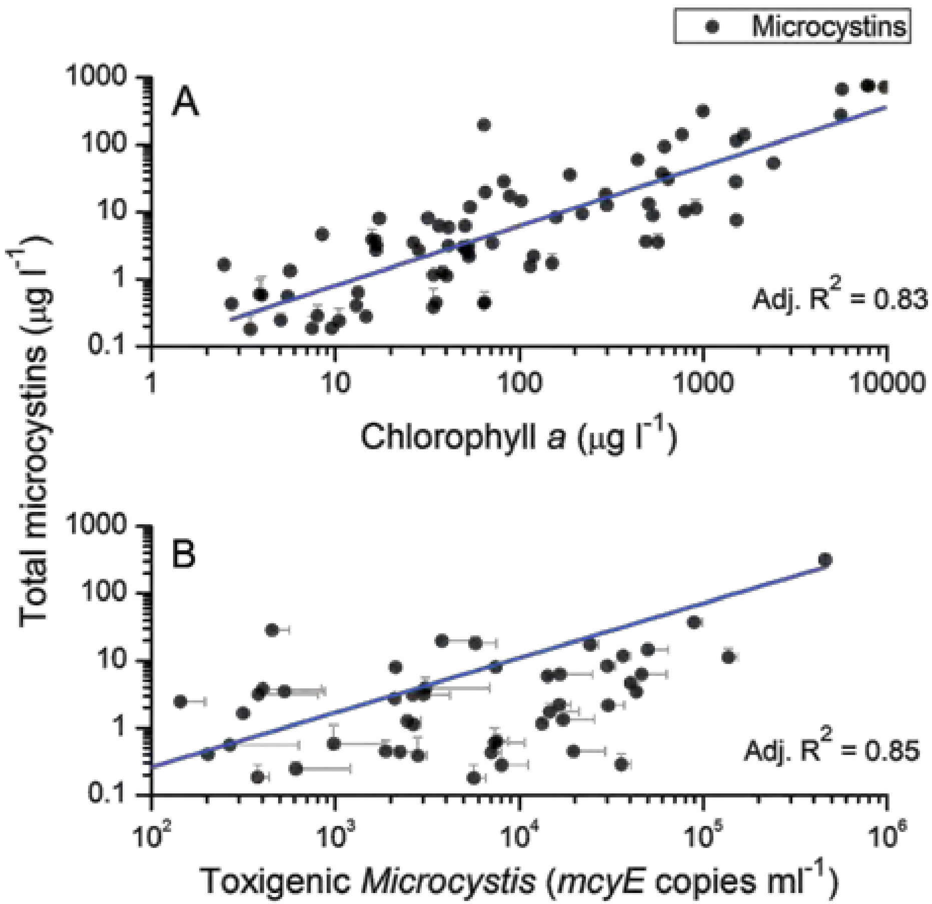
Is there a link to clarity (light availability)?

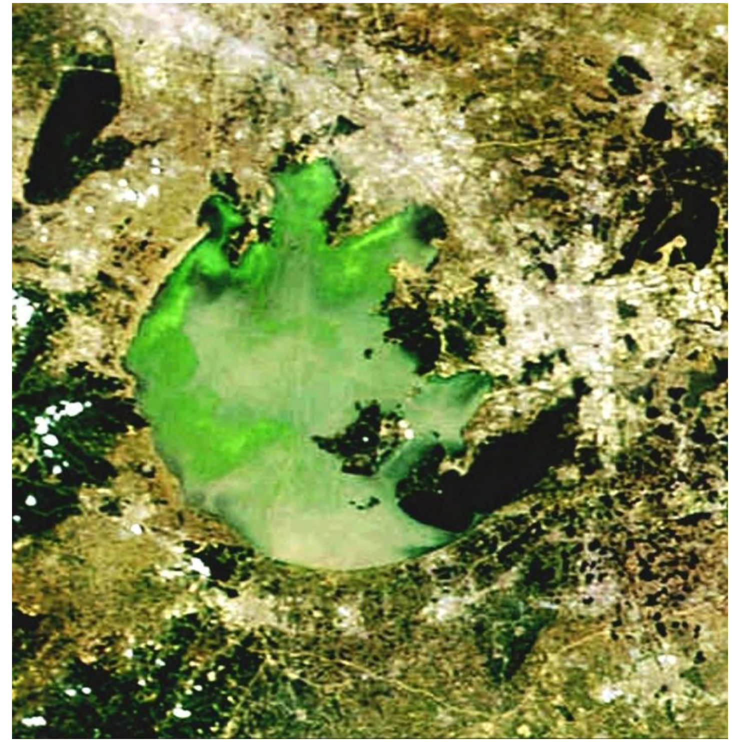


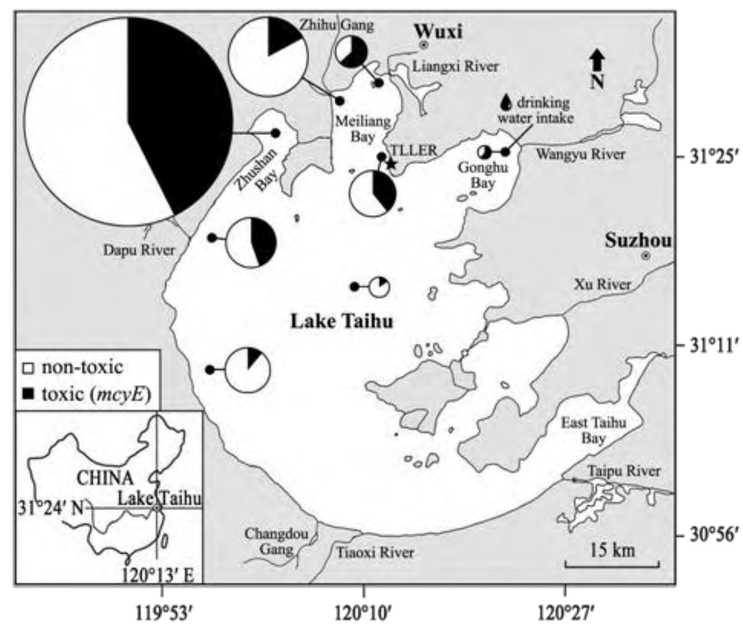
The link to biomass (as Chl *a*)



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

Conclusions

- *Microcystis* community = numerous strains, many of which capable of producing several microcystin congeners
- Morphology is a poor indicator of species/strain or toxicity
- Once toxic genotypes are identified, there are relationships between toxic ones and standard biomass indicators
- Light intensity may be an important factor driving toxic ecotypes

Some observations: needs for standardized, integrative sampling protocols

Often only the “worst” area of lake is sampled (e.g., wind blown surface scum) and tested. This is used to determine maximum public health risk.

These data do not accurately portray toxin status of the lake and cannot be paired meaningfully with physiochemical data to determine factors promoting toxin-producing CyanoHABs..

The “one-size-fits-all” approach to sampling, testing and lake closings does not broadly apply across CA lakes & reservoirs….. Varying drivers of toxicity, differing sensitivities to CyanoHABs, and water uses vary.

Management Considerations

Time and money are not best spent identifying CyanoHAB taxa beyond the genus level.

No single species should be universally considered "safe" (e.g., *Aphanizomenon flos-aquae*).

The list of harmful secondary metabolites produced by cyanobacteria continues to expand. Water quality managers (especially from rural or small operations) may not be able to afford routine testing for a multitude of toxins.

Also, seemingly nontoxic populations may produce other harmful compounds which cannot be currently assayed.

Need for management based on cell counts, but in order to do so we need standardized toxin data that can inform the development of action levels based on these cell concentrations.

A Hierachical Approach to Evaluating Toxic CyanoHABs

History of CyanoHAB occurences?

↓

What spatiotemporal trends are known? Their frequency, magnitude and duration will dictate what sampling strategy to implement

↓

Chl a and microscopic analyses (biomass and composition?)
Are the likely offenders benthic (e.g., Lyngbya sp.) or pelagic?

↓

Toxin Analyses/quantification

↓

DNA analyses (e.g., colony PCR to identify specific toxin-producers)

↓

Combined, this information can be used to create a tailored monitoring approach. Ideally, these data can be used to establish maximum toxin cell quotas and manage purely on the basis of cell density.

Additional Considerations

- collect bloom samples in uniform manner & analyze them using the same methods

- If done on a large enough spatio-temporal scale, establish maximum toxin cell quotas

- Once this is established, the number of "full work-ups" can be reduced using cell densities as a proxy for the probable toxin content. Incorporate "safety factor" in this framework to account for anomalies

- With that in hand, primarily sample for microscopic ID, cell counts and Chl a, transparency and occasionally check for toxins to verify that they are within the expected (and acceptable) limits.

NSF-ENG/CBET 0826819: Ensuring Sustainability of Lake Taihu, China

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

Thanks to:
A. Joyner
T. Otten
B. Peierls
B. Qin
M. Piehler
K. Rossignol
S. Wilhelm
H. Xu
G. Zhu
TLLER "crew"

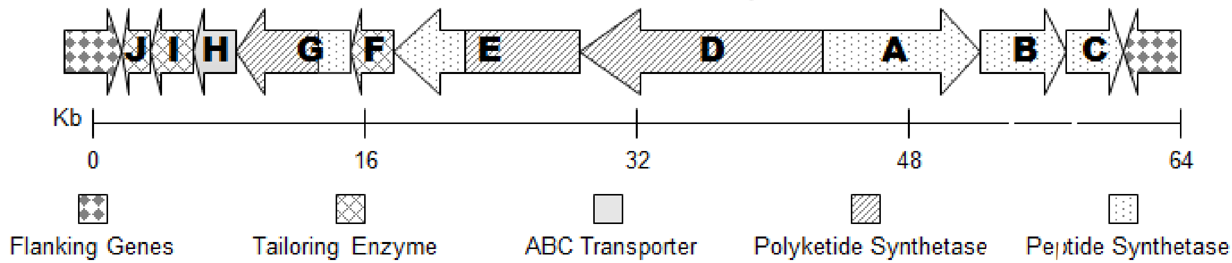
NSF

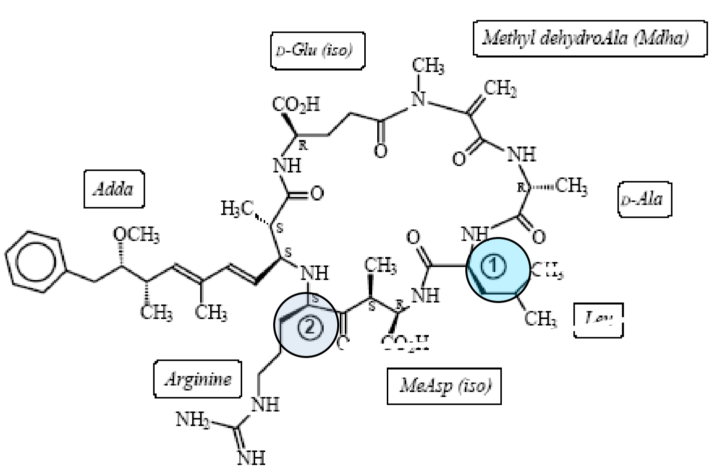
This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # 82667701

Additional support: Nanjing Instit. of Geography and Limnology, Chinese Academy of Sciences NIGLAS

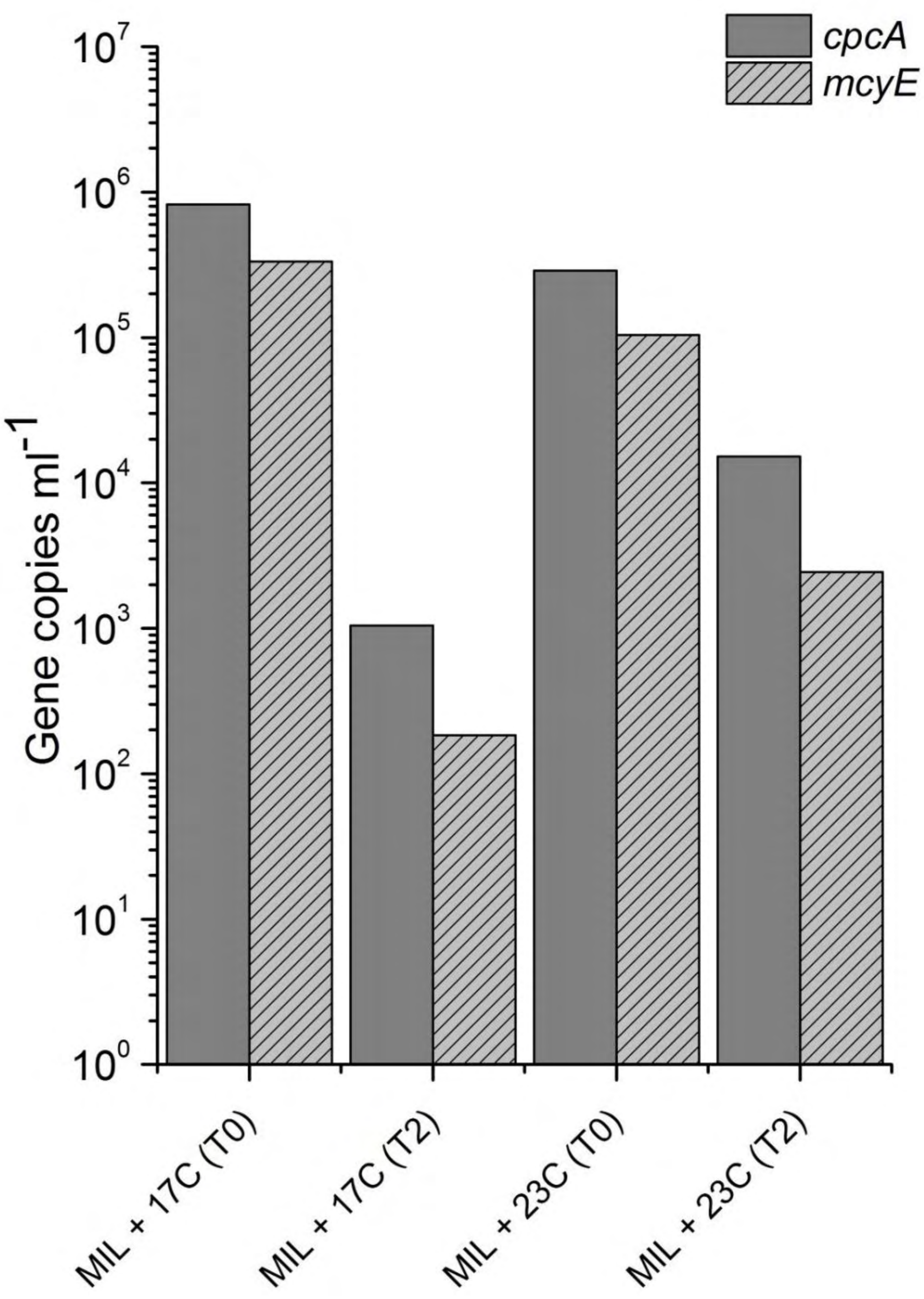
Variable microcystin congeners

- Majority of all 3 morphotypes ("flake", "web" and "hybrid") were *mcyB +*
- MC general structure cyclo-D-Ala-X-D-MeAsp-Z-Adda-D-Glu-Mdha, where X and Z are variable L-amino acids





*Over 80 MC congeners identified to date


cpcA
mcyE
Gene copies ml^{-1}
10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^7
MIL + 17C (T0)
MIL + 17C (T2)
MIL + 23C (T0)
MIL + 23C (T2)

Effects of different nitrogen sources on Taihu's CyanoHAB potential