# Climate Change: The Links to Global Expansion of Harmful Cyanobacterial Blooms

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

Urban, agricultural and industrial expansion

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Increasing nutrient (Nitrogen & Phosphorus) inputs

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Water use and hydrologic modification play key roles

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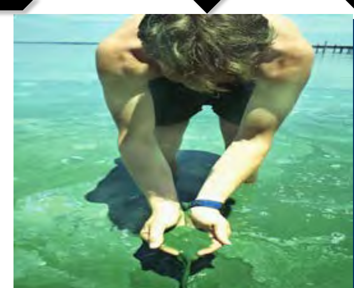
Climate (change) plays a key interactive role

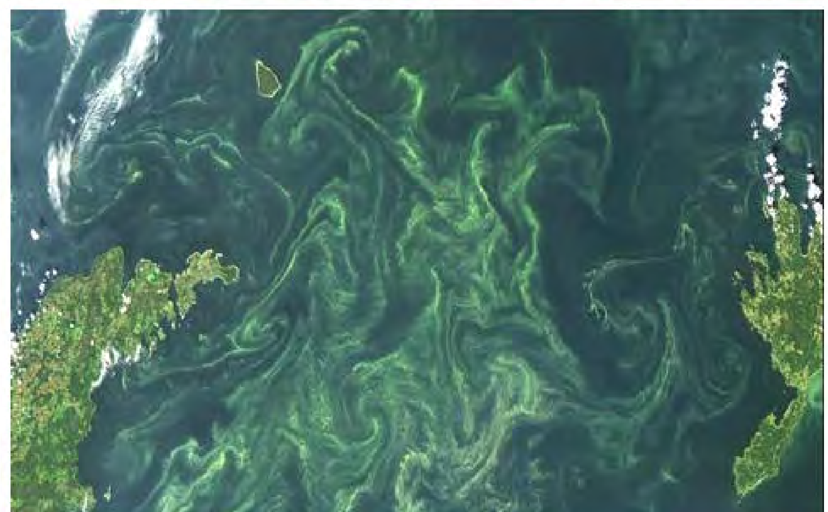
Blooms are intensifying and spreading




# Cyano Expansion in freshwater ecosystems is well-documented




# There are parallel scenarios in the marine environment

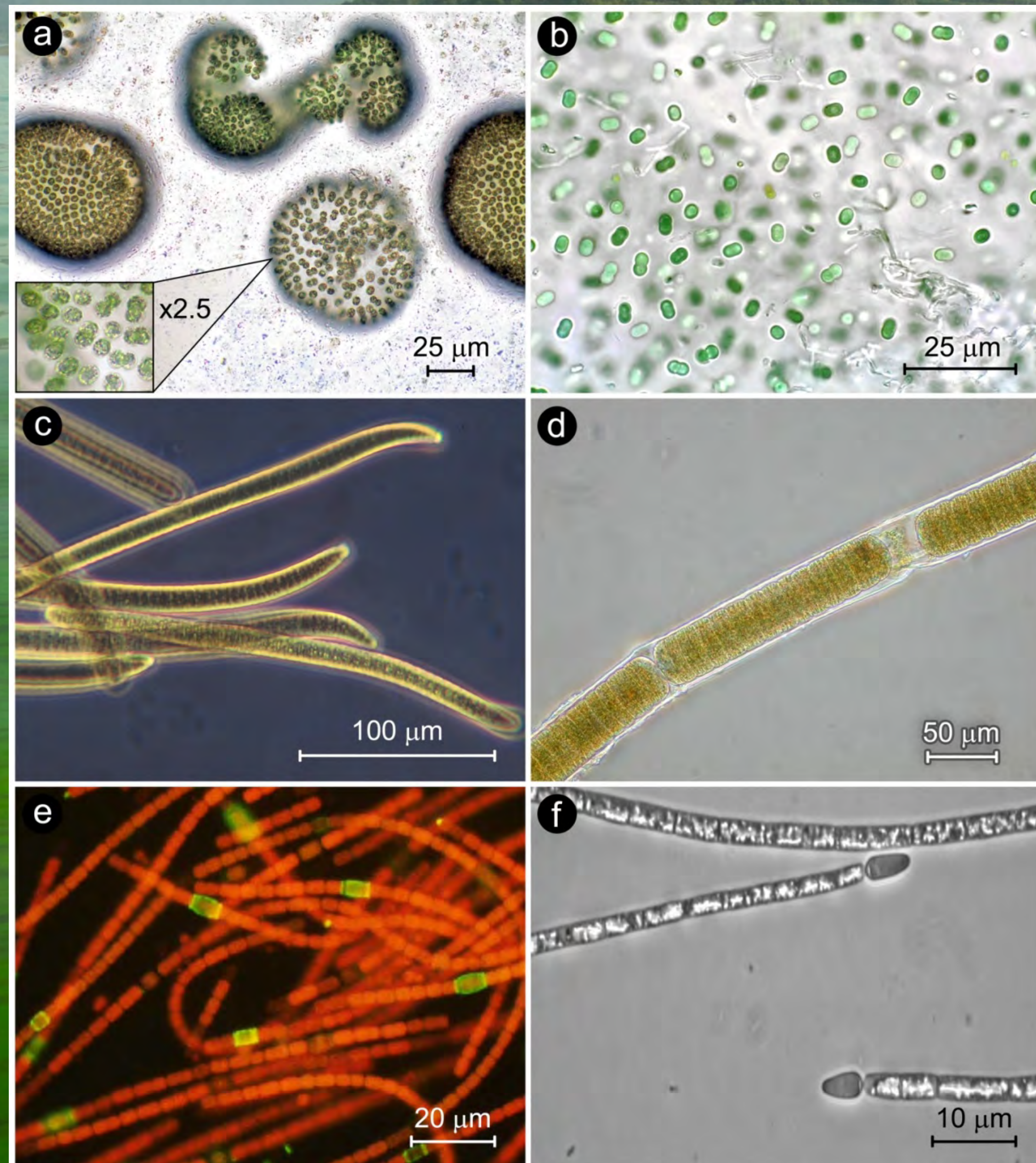


# The CyanoHAB Players

**Coccoid, solitary/colonial** (e.g. *Microcystis*), & picocyanos

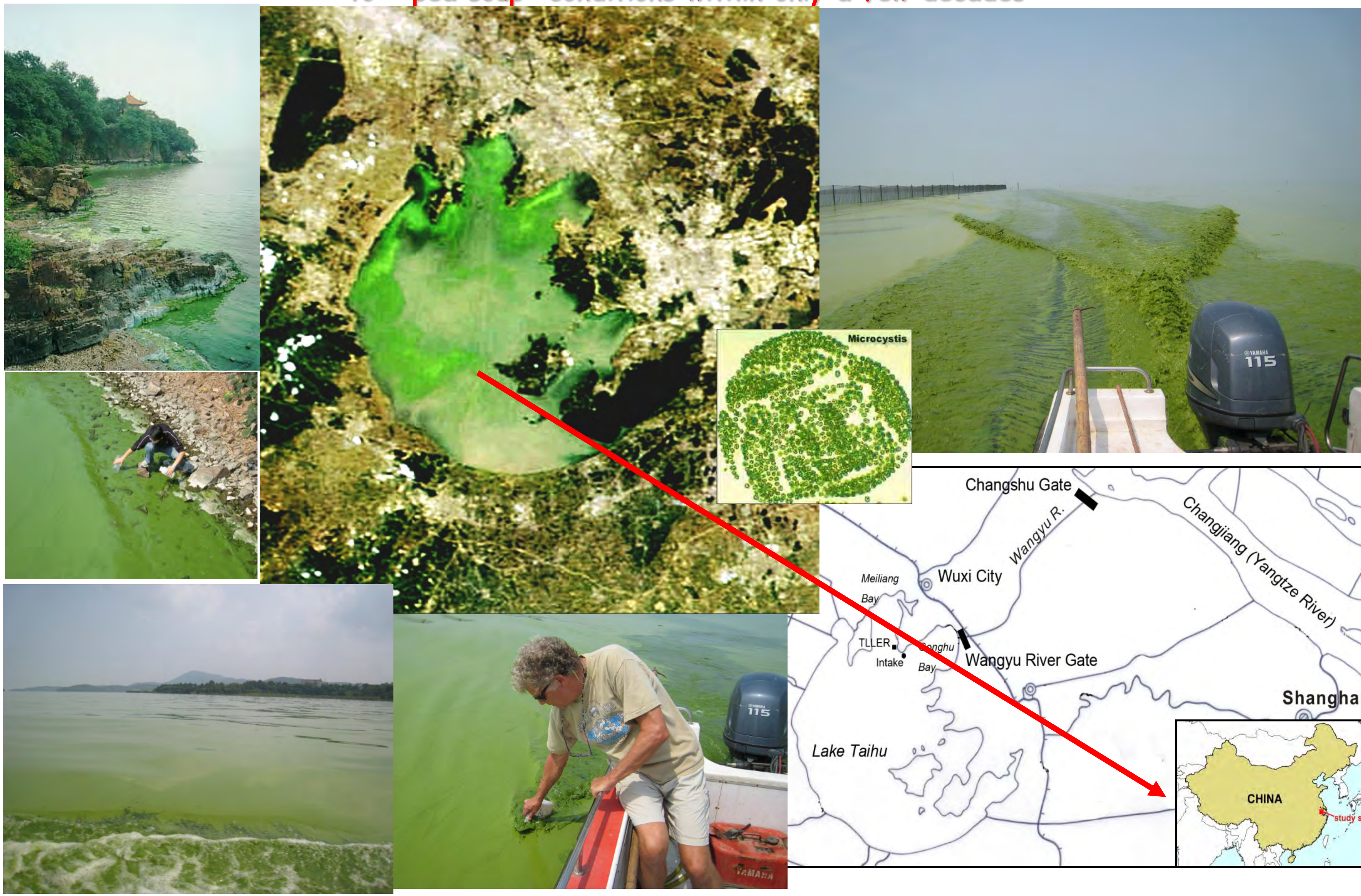
**Filamentous, non-heterocystous** (e.g. *Lyngbya*, *Oscillatoria*)

**Filamentous, heterocystous** (e.g. *Anabaena*, *Nodularia*, *Cylindrospermopsis*)



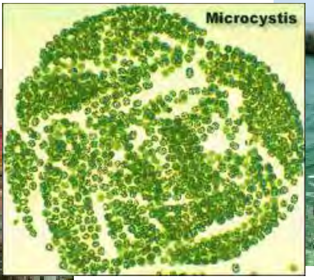
# First, the nutrient part of the story

Taihu, largest (2400 km$^2$) coastal plain lake in China, located in Yangtze R. Delta. Nutrients (Lots!) associated with development in the Taihu Basin. Results: Cyano 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

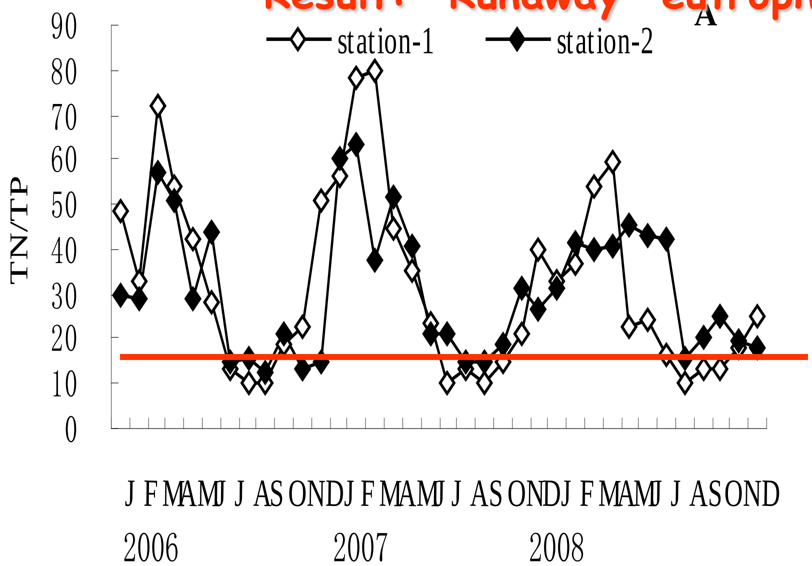


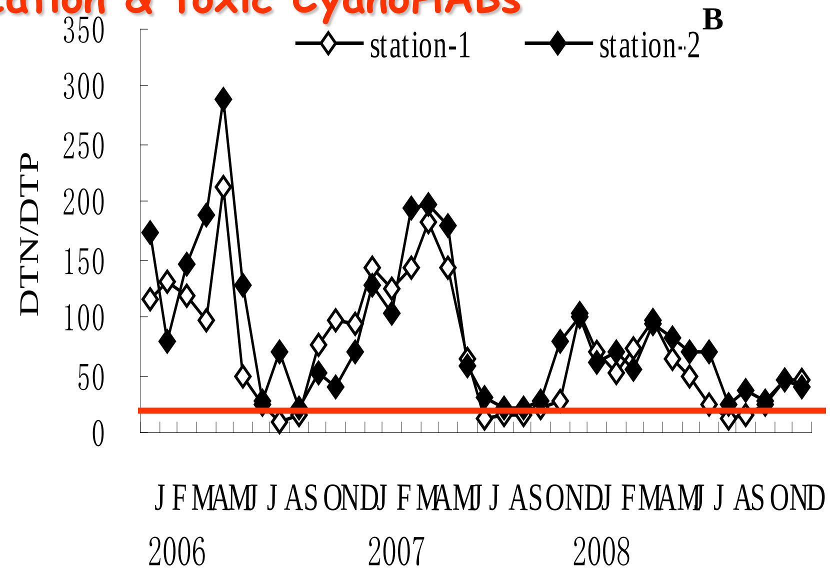


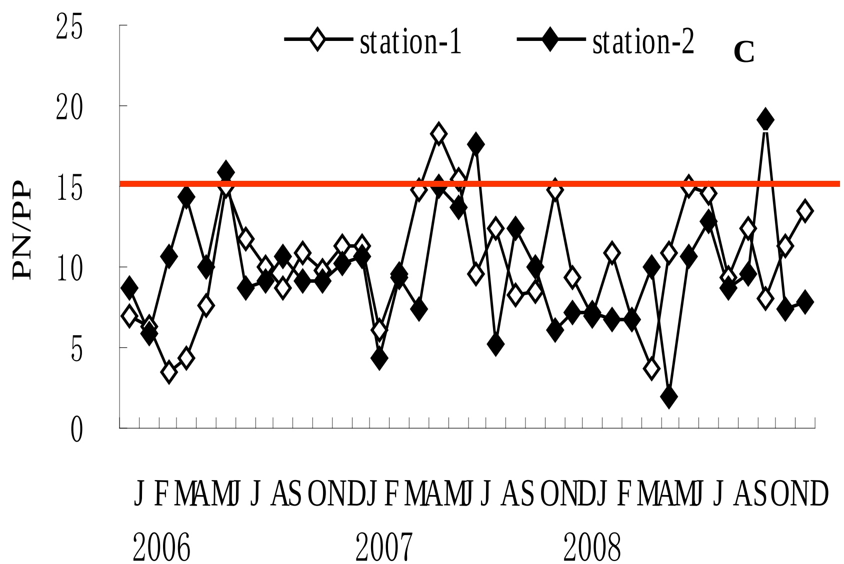
# The "nutrient problem" in Taihu

## N & P inputs seasonally exceed what's needed for balanced algal growth.

## Result: "Runaway" eutrophication & toxic CyanoHABs




## Nutrient (N&P) ratios in Taihu

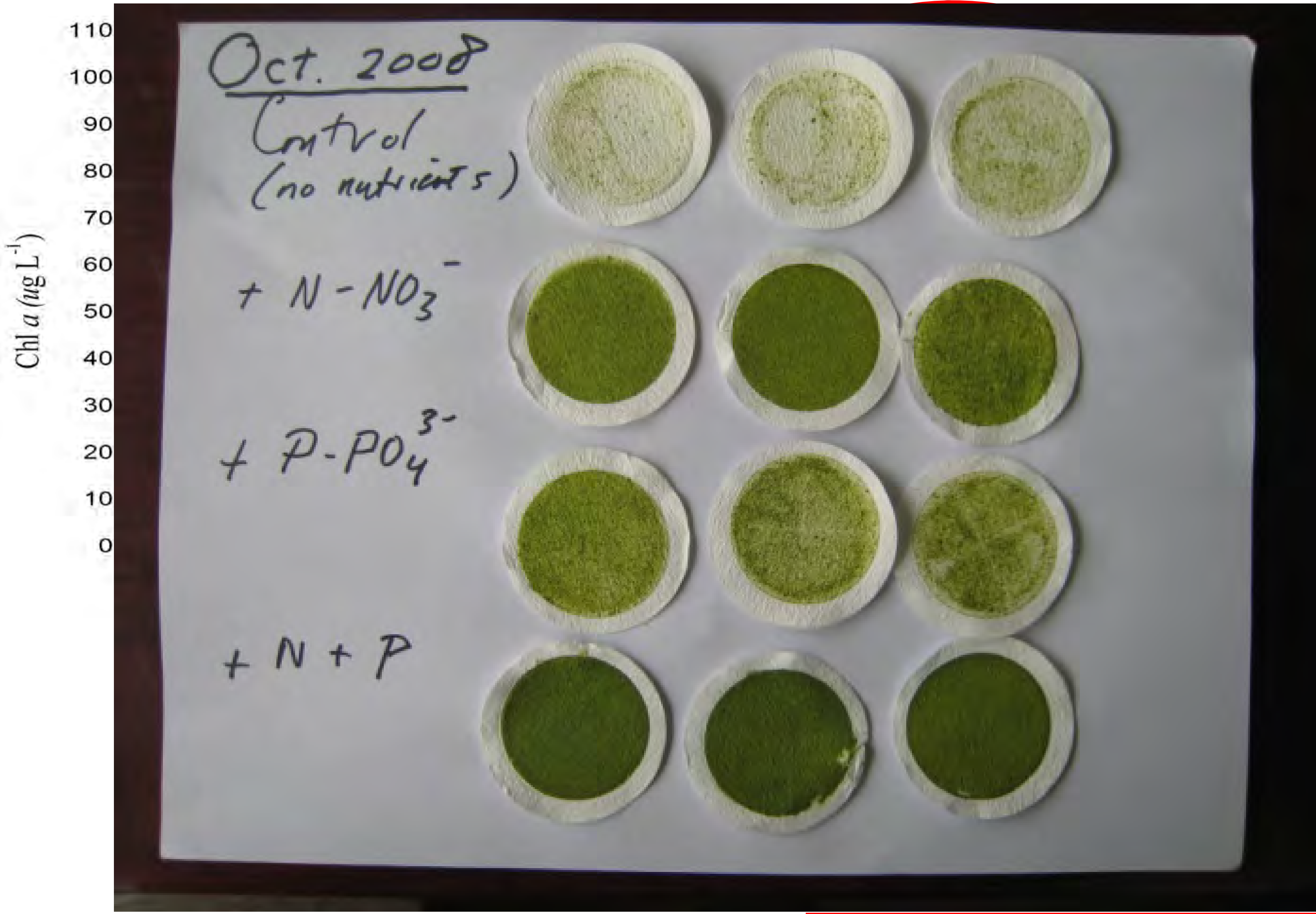
Redfield (balanced growth)
~15:1 (N:P)

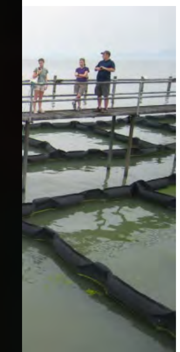
**HYPOTHESIS**

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

**Xu et al., 2010; Paerl et al., 2011**

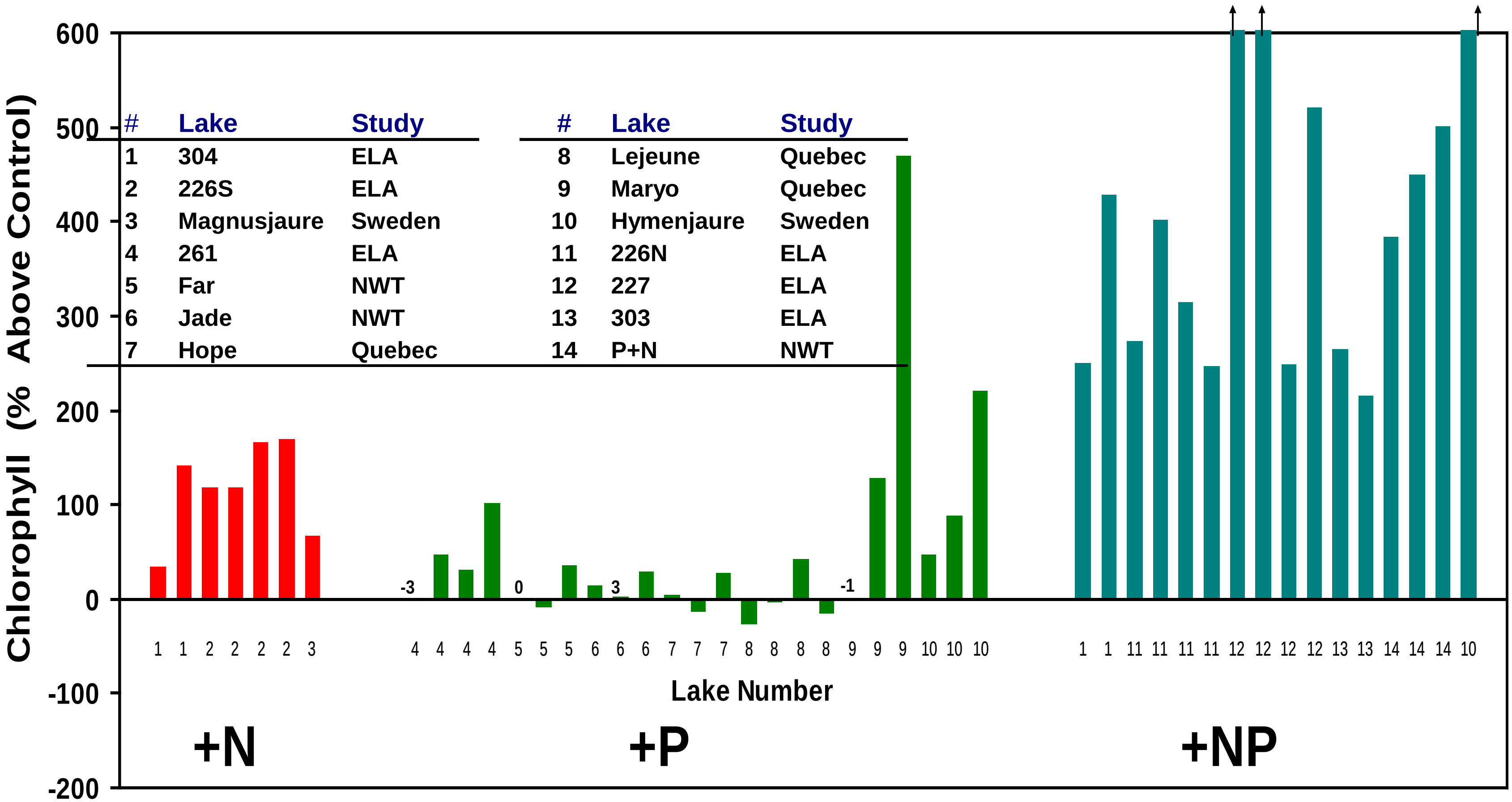
# Effects of nutrient (N & P) additions on phytoplankton production (Chl *a*) in Lake Taihu, China: **Both N & P inputs matter!!**



Xu et al. 2010; Paerl et al. 2011

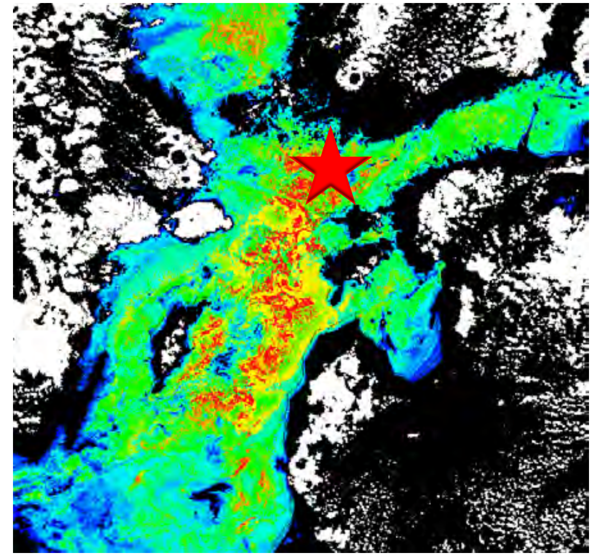
# Whole-Lake Fertilization Experiments (ELA, Quebec, NWT, Sweden)



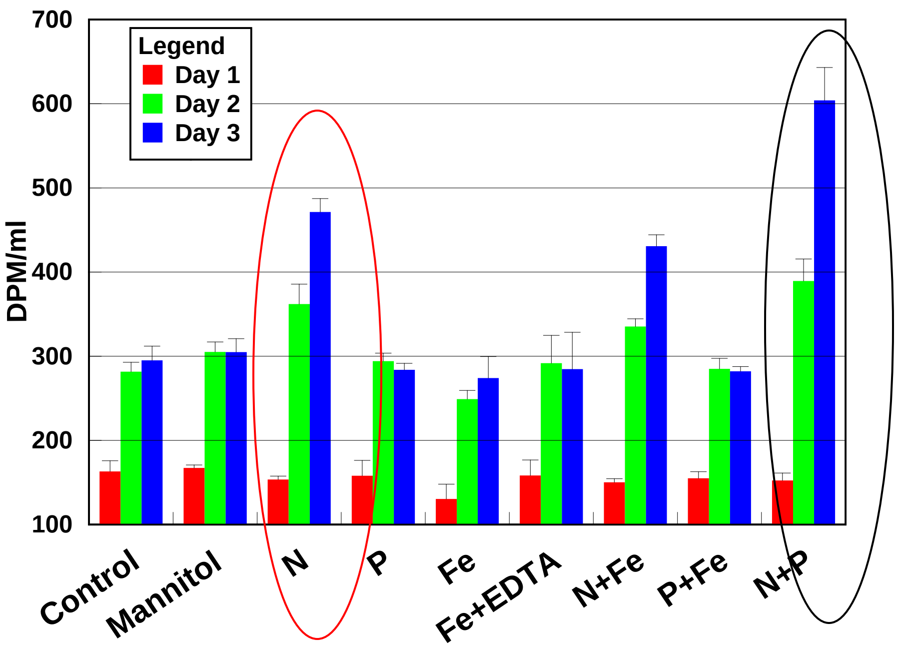

**Co-Limitation is Dominant**

Wurtsbaugh et al., 2012

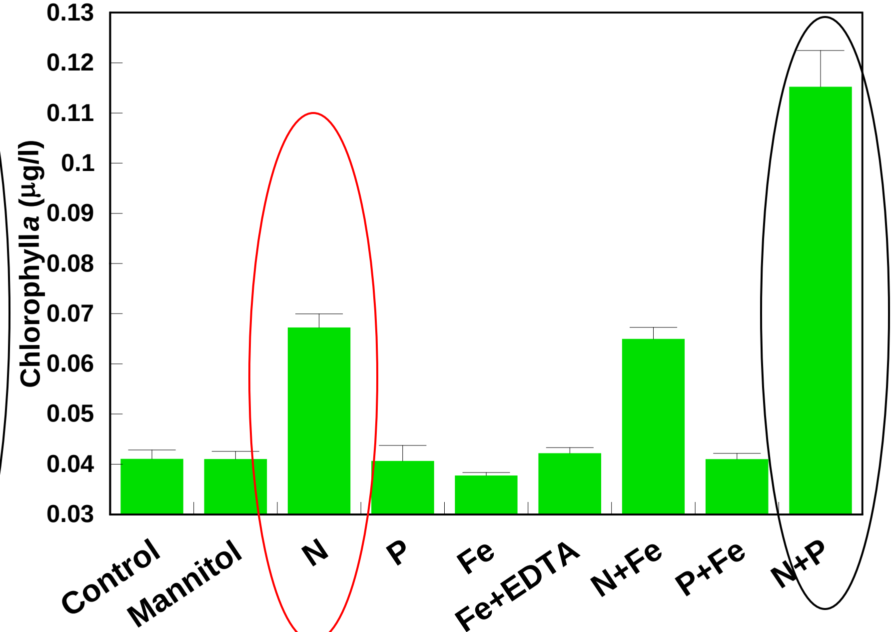
# The brackish Baltic Sea: N +P enrichment is often most stimulatory



**Baltic Sea 2000, Bioassay A**
**Primary Productivity**

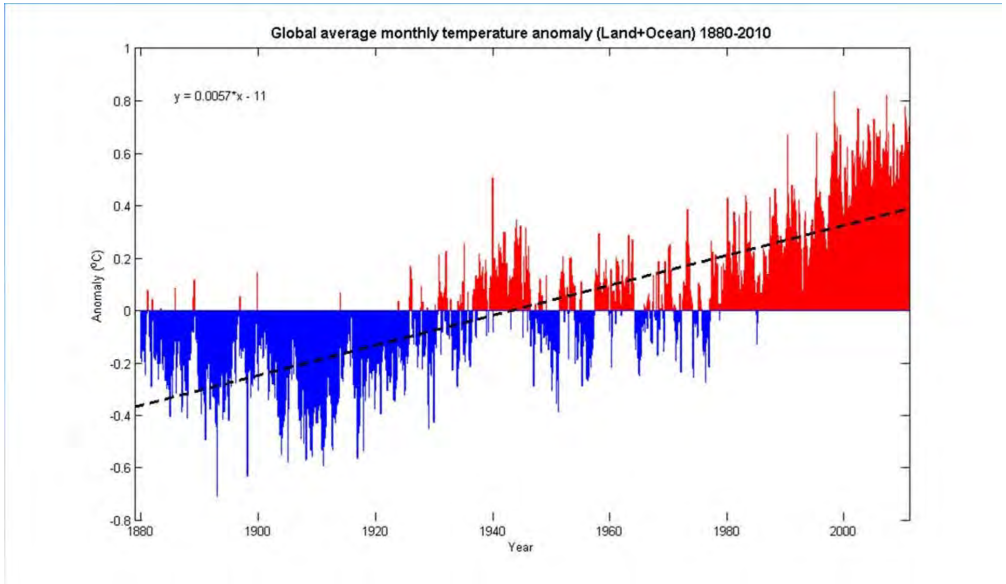



**Baltic Sea 2000, Bioassay A**
**Chlorophyll**



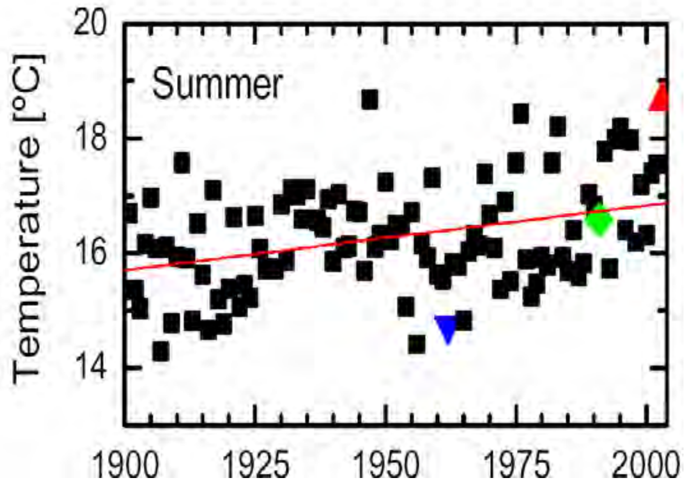

**Moisander et al. 1994; 2003**

# Interactive Impacts of Climate Change: Its Getting Warmer

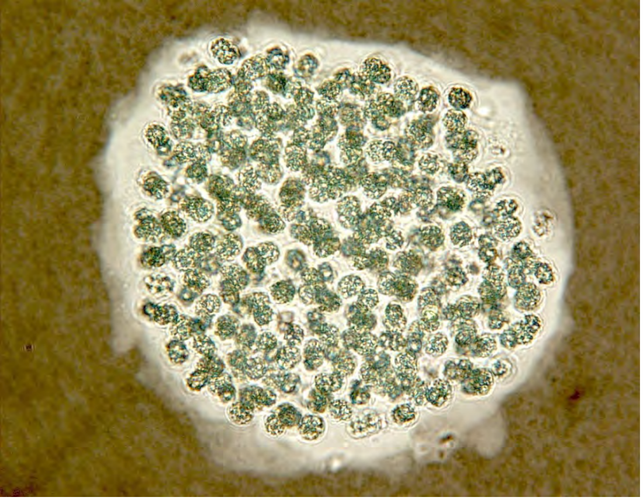



## Additional Evidence

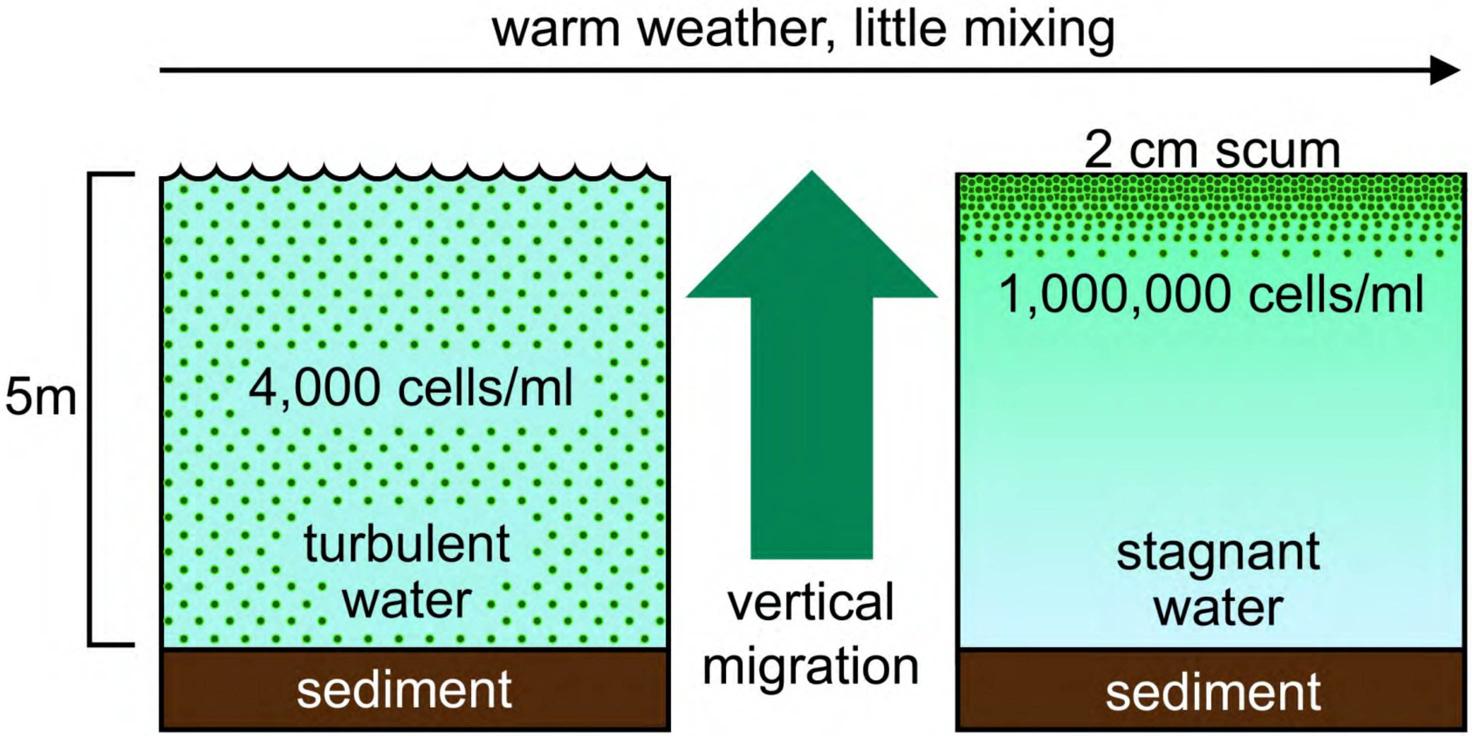
2003 was the hottest summer in 500 years in Europe!
2005, 2009, 2014 were the hottest years ever in N. America
2010 hottest year in central Asia




**Huisman et al. 2006**
**Mean epilimnetic Temp.**
**In Dutch lakes**



# Buoyant Cyanos favored by Stronger Stratification



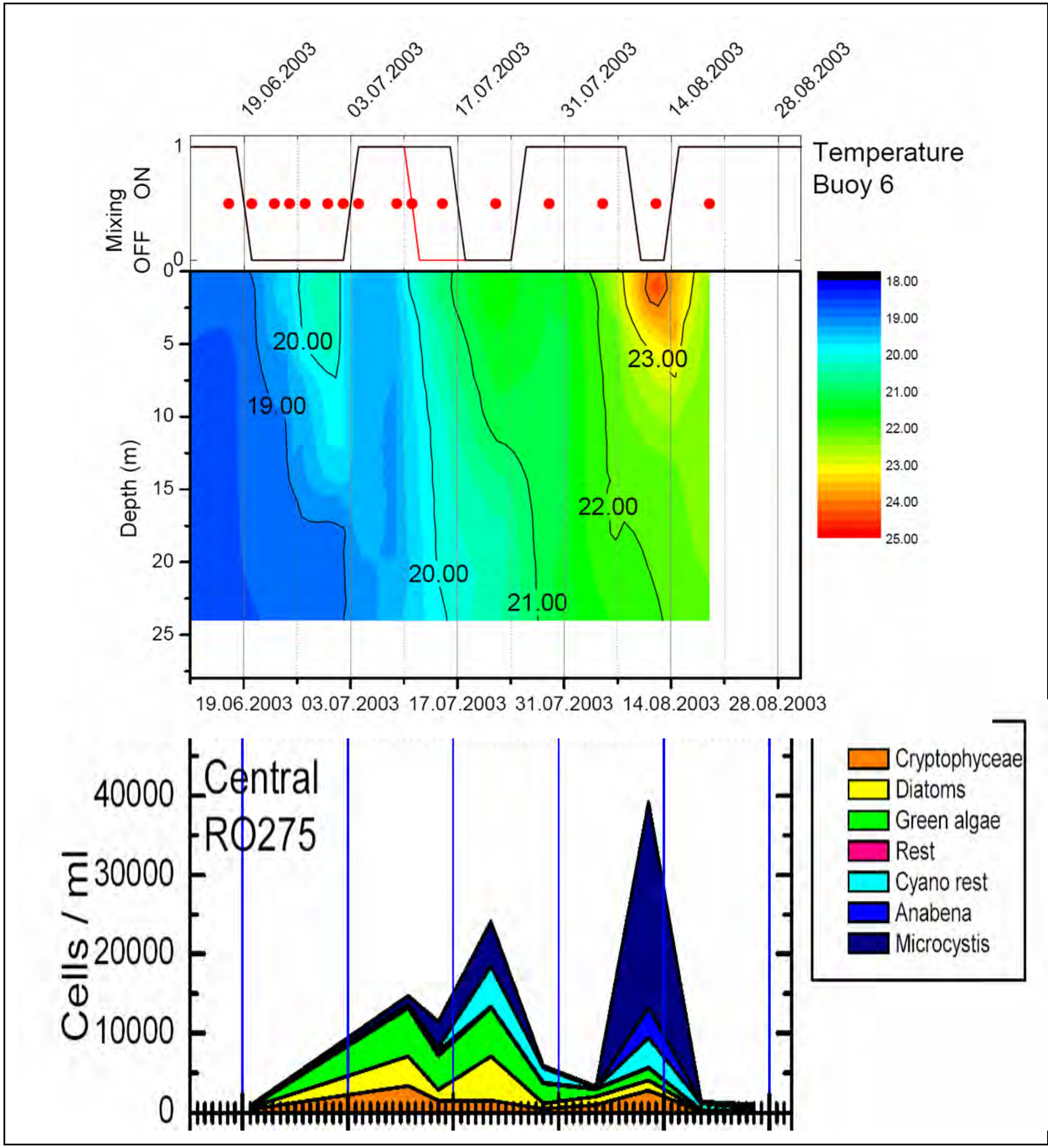

**Paerl and Huisman 2009**

# Mid August 2003:

## Lake Nieuwe Meer, Netherlands

## Heatwave & little mixing

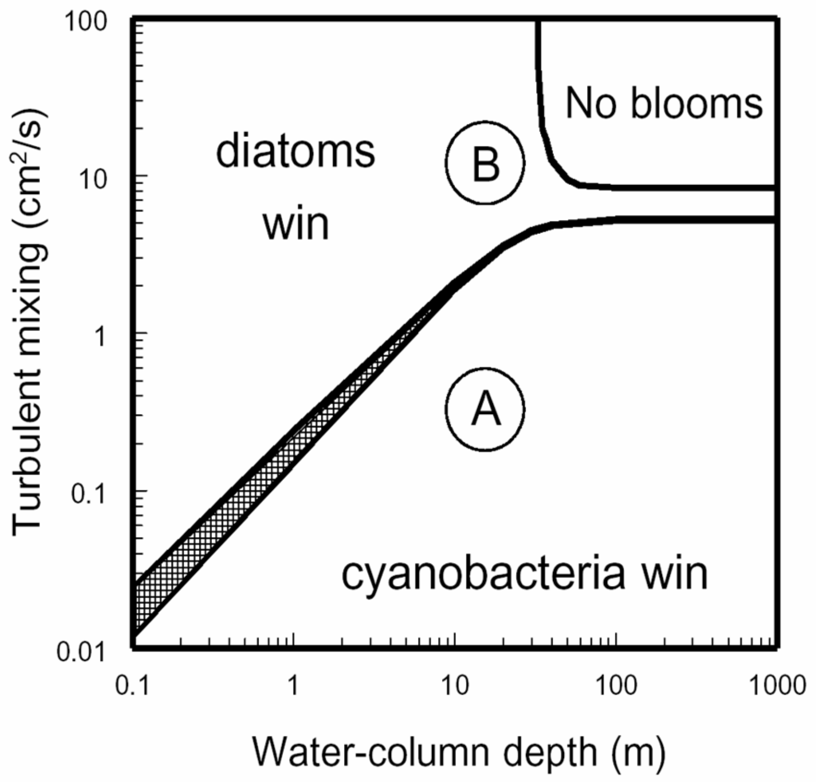
*Microcystis* benefits!



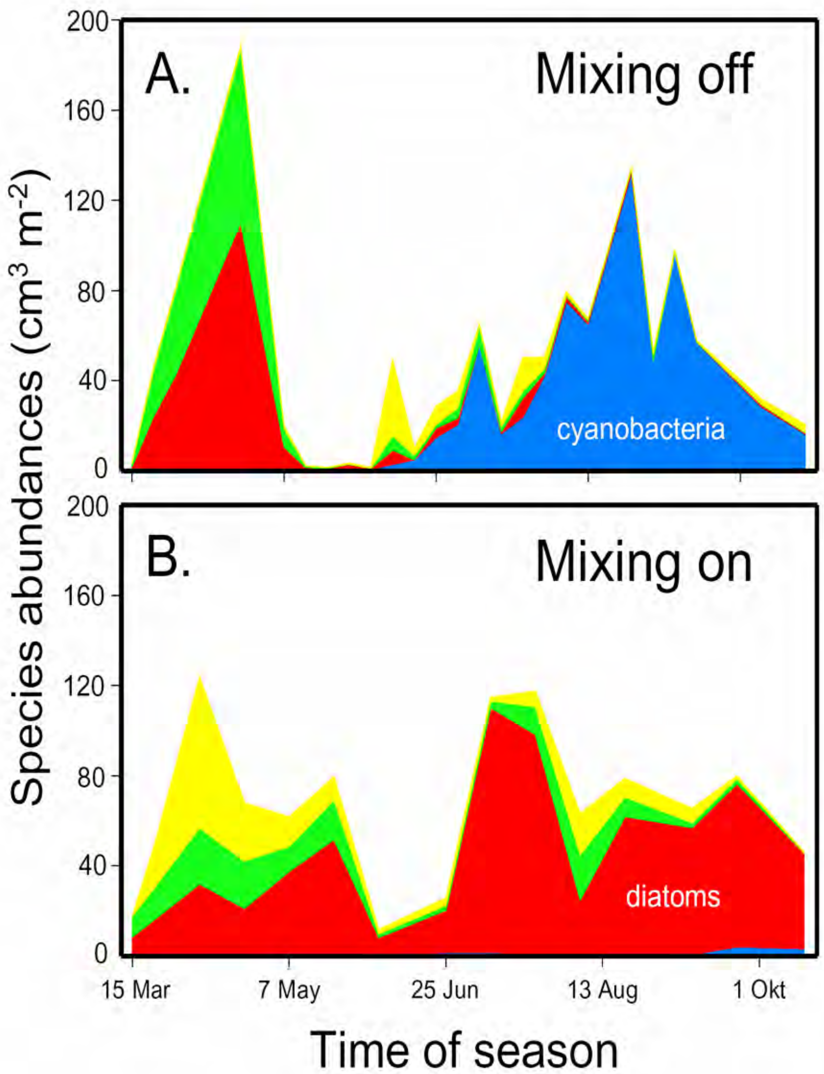

Jöhnk et al., 2008

# Testing the Model

## Theory

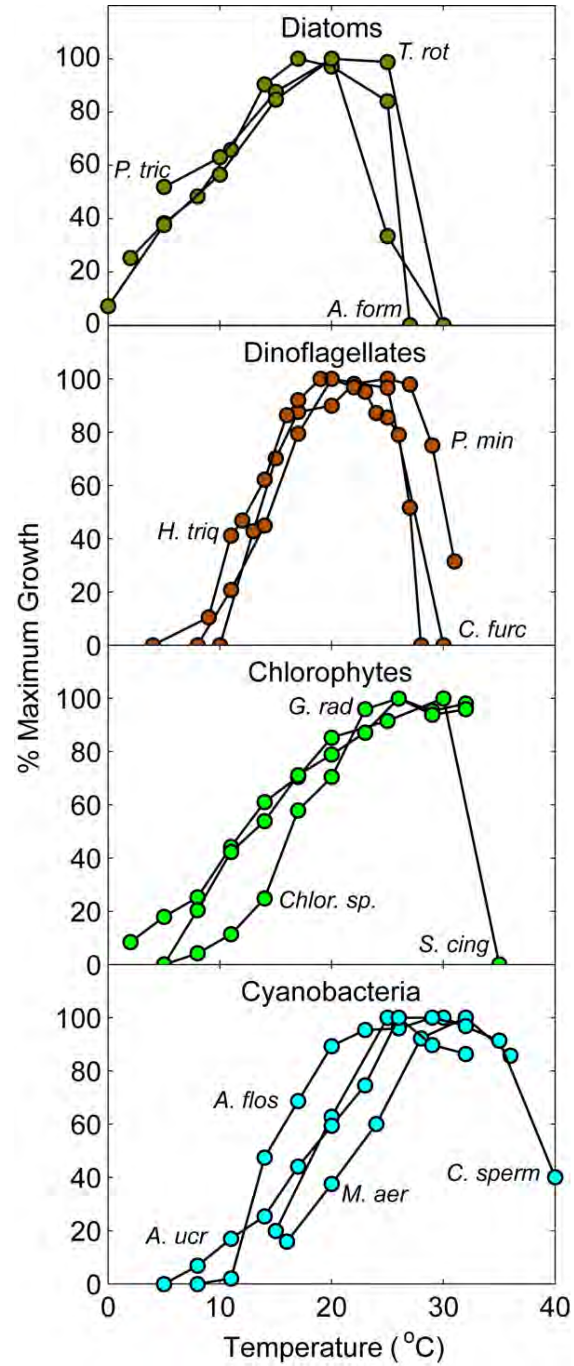



## Lake data



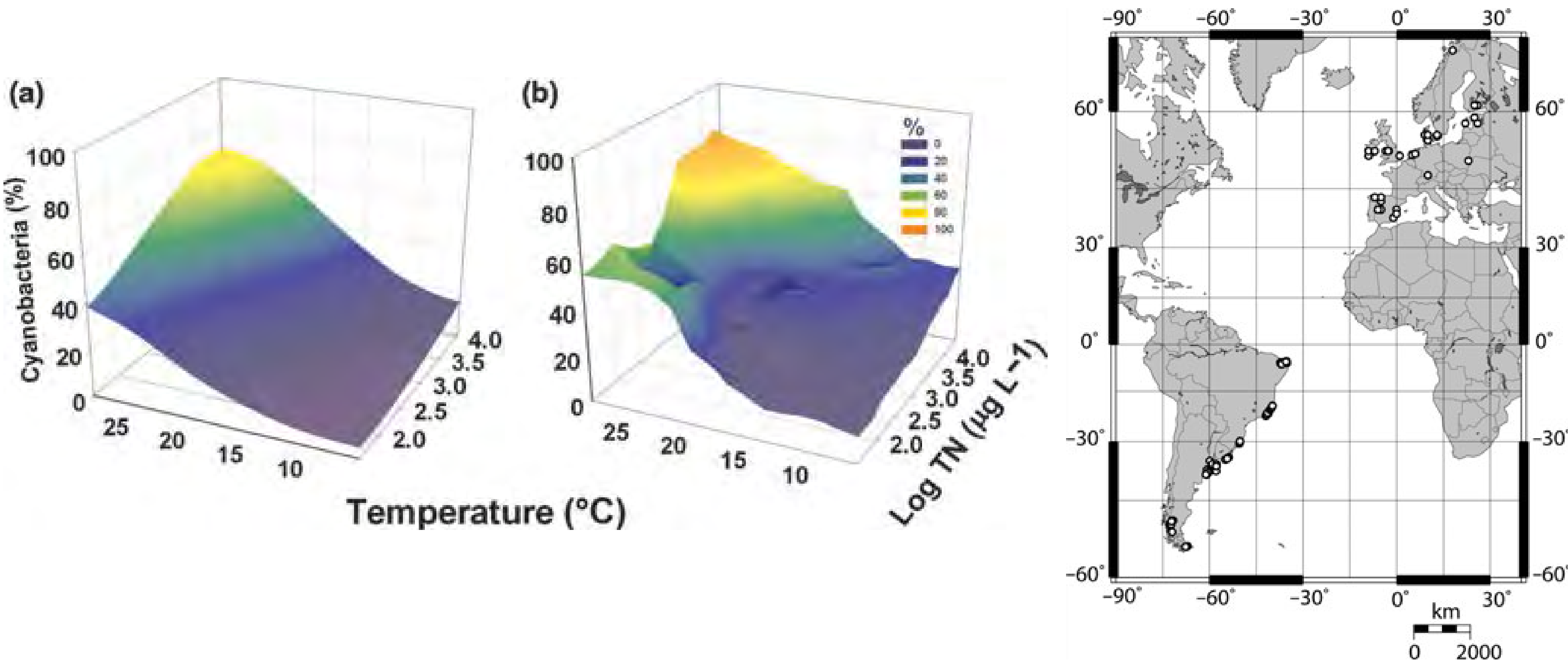

**Huisman et al., 2004**

# Temperature affects growth rates


Refs.: 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



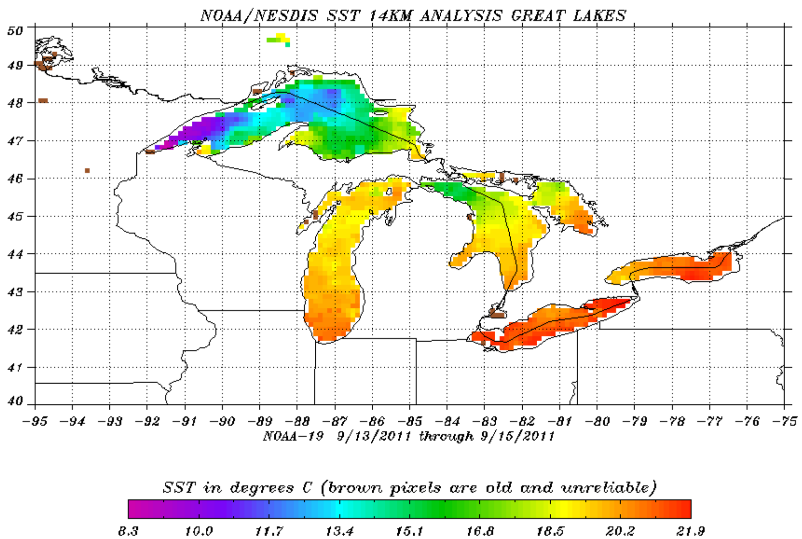

Percentage of cyanobacterial biovolume in phytoplankton communities as a function of water temperature and nutrients in 143 lakes along a climatic gradient in Europe and South America.

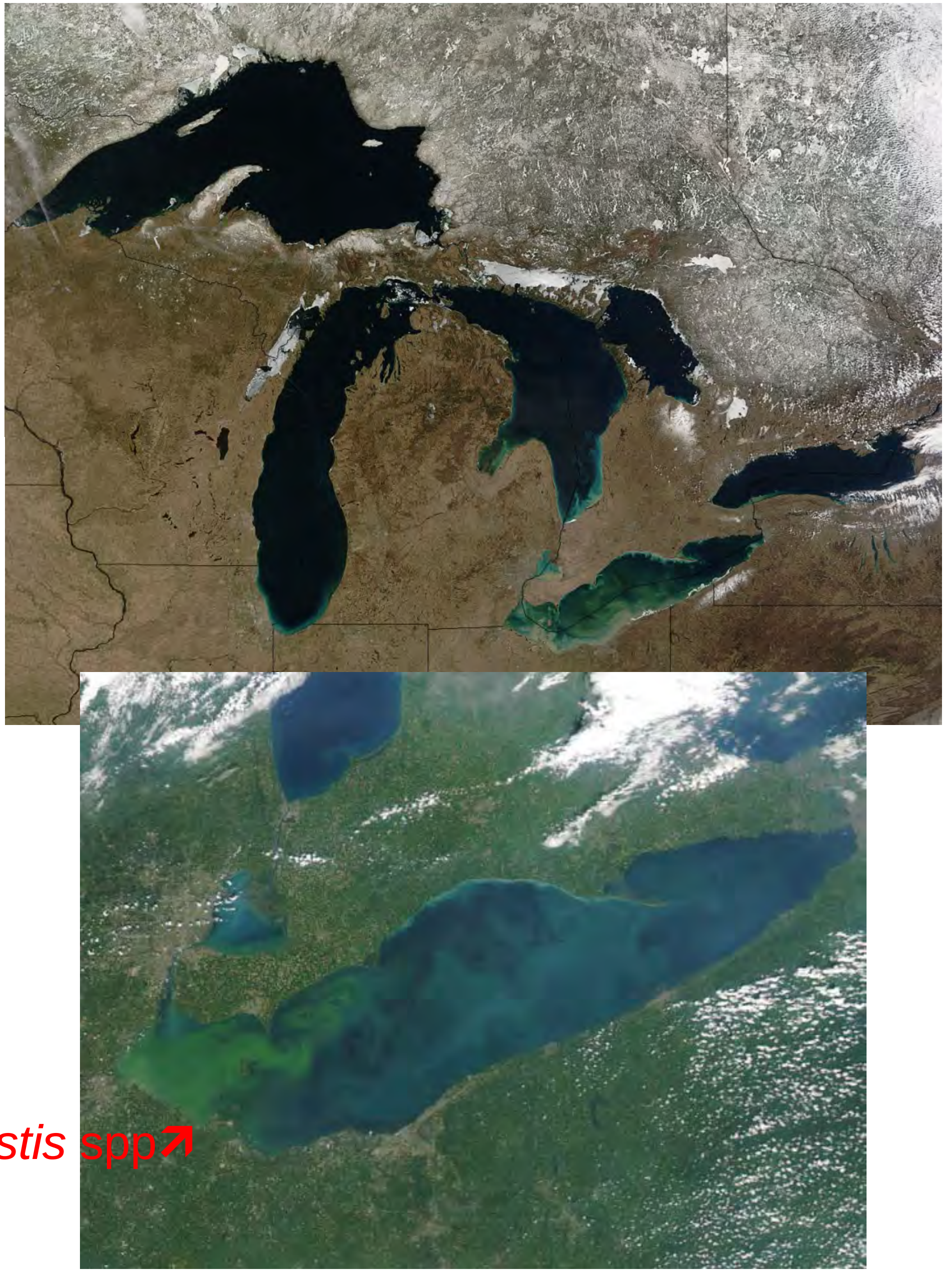
(a) Combined effects of temperature and nutrients as captured by a logistic regression model

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

**From Kosten et al. (2011). Global Change Biology DOI: 10.1111/j.1365-2486.2011.02488.x**

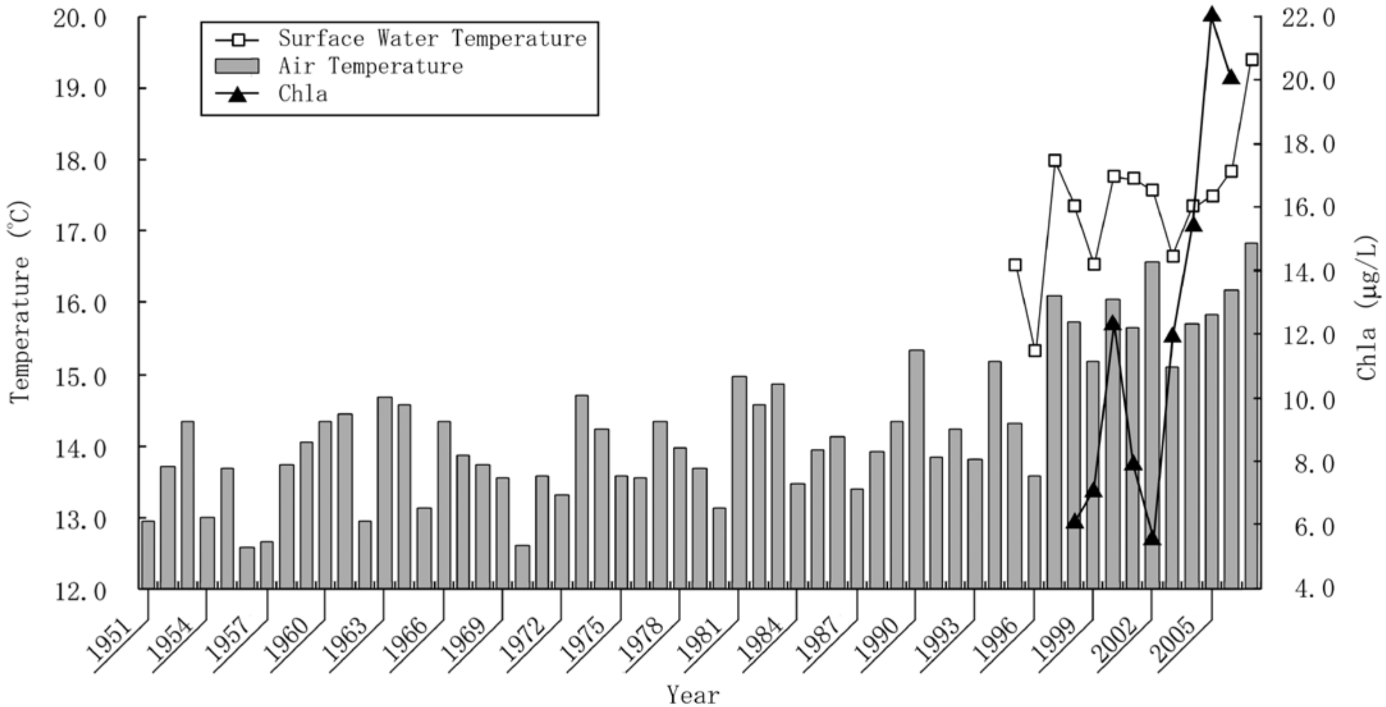
Cyanobacterial resurgence in Lake Erie (Laurentian Great Lakes): Combined effect of eutrophication and warming?




**Courtesy NOAA/NESDIS & NASA/SeaWiFS**

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

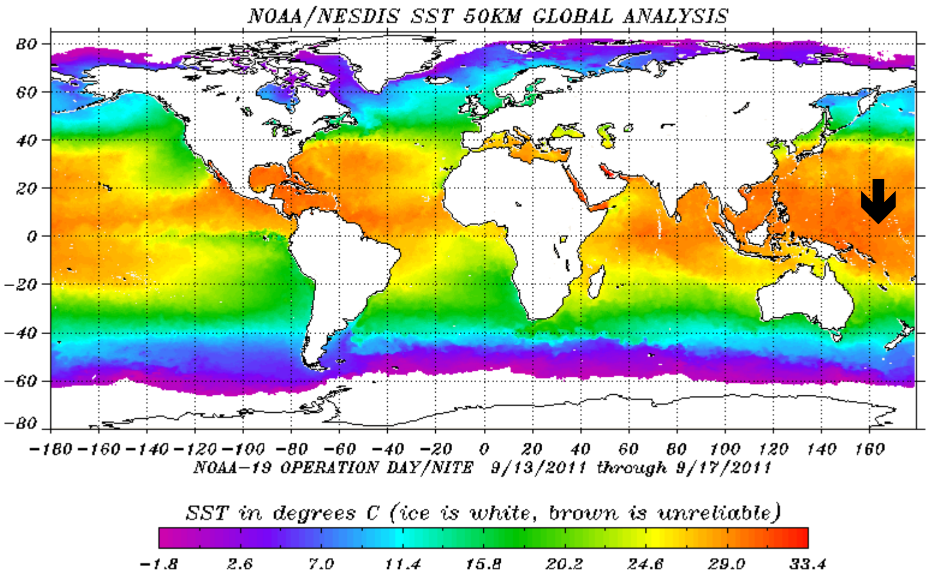


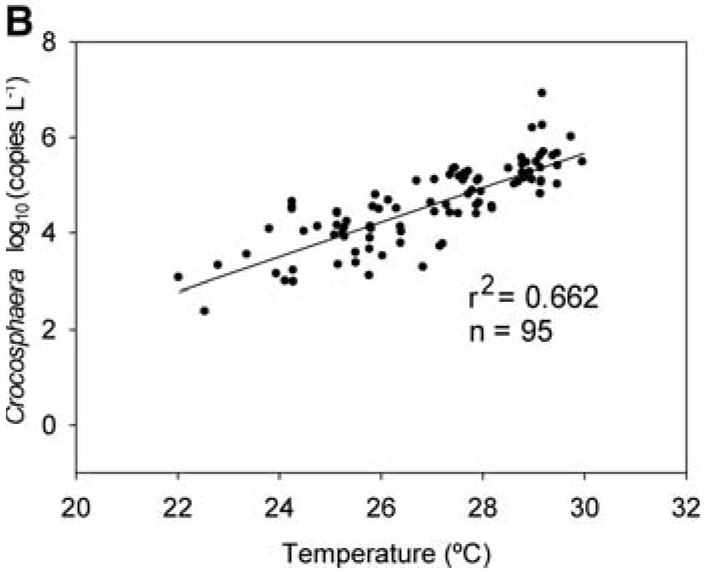

# What's the evidence that warming promotes cyanobacterial production & dominance in the marine environment?

St Johns River Estuary, Florida, USA

Baltic Sea, N. Europe

# Marine cyanobacterial diazotrophic picoplankton abundance vs. temperature

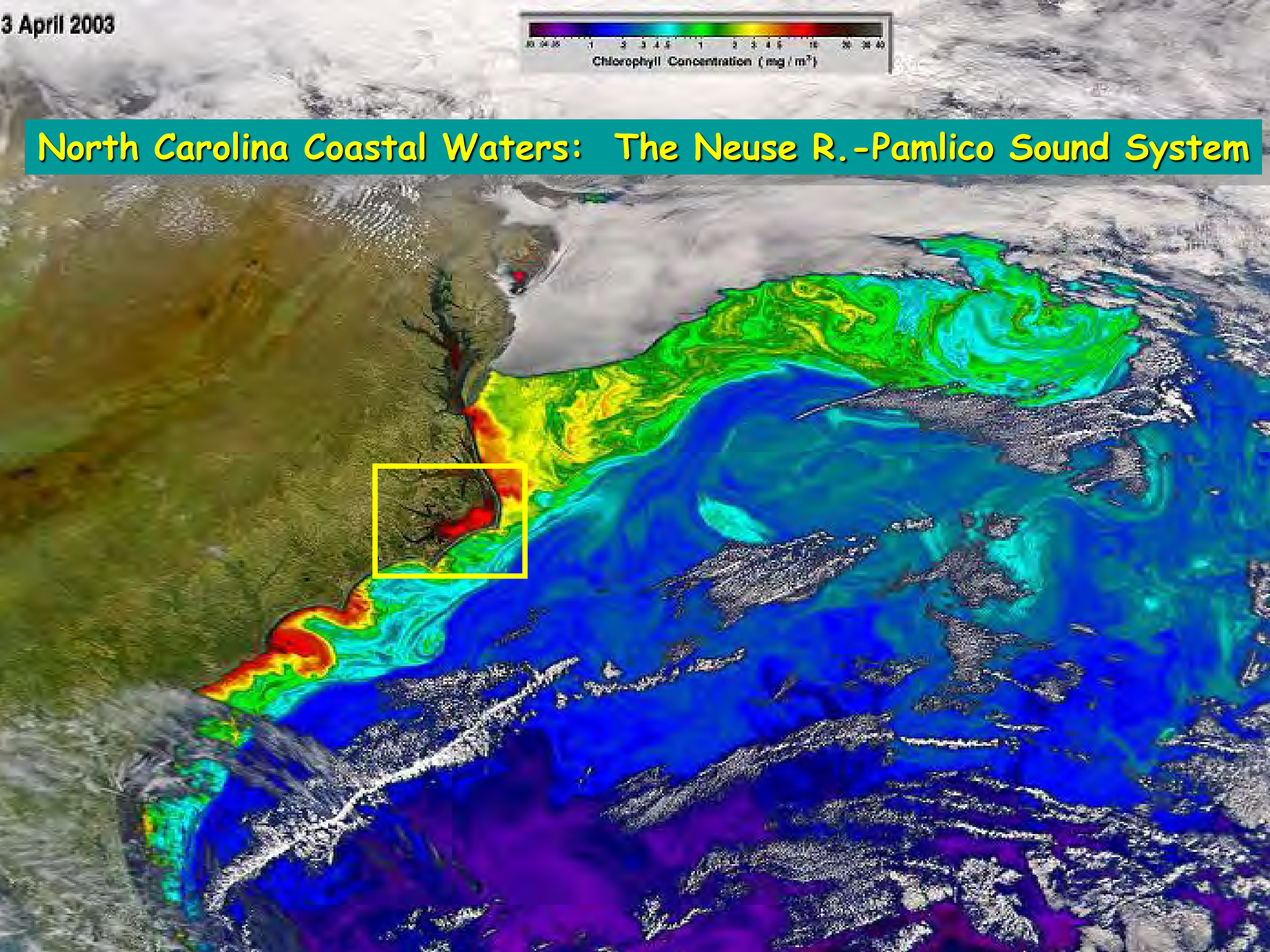


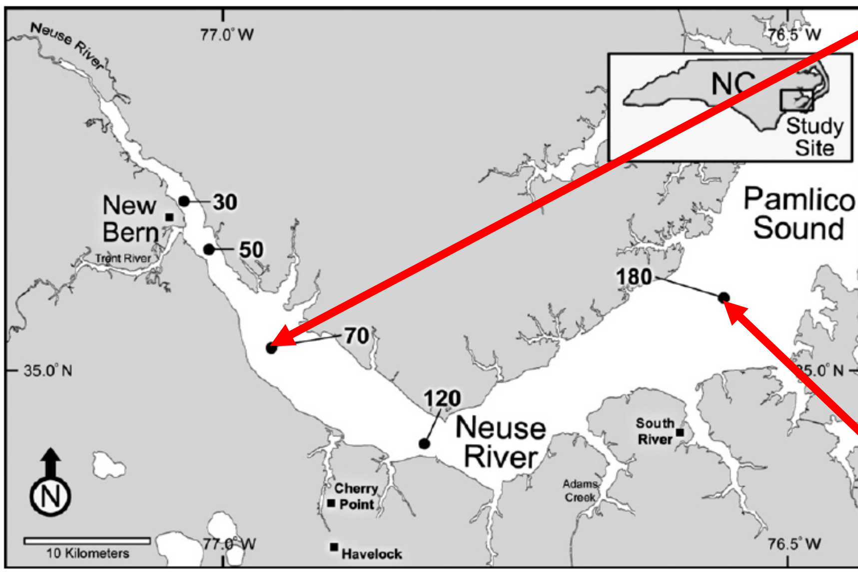

**Relationship of unicellular diazotroph abundances [log10 (nifH copies per liter)] and temperature for Crocosphaera. f = 5.13 – 0.1754x + 0.0638x2 – 0.0124x3..**

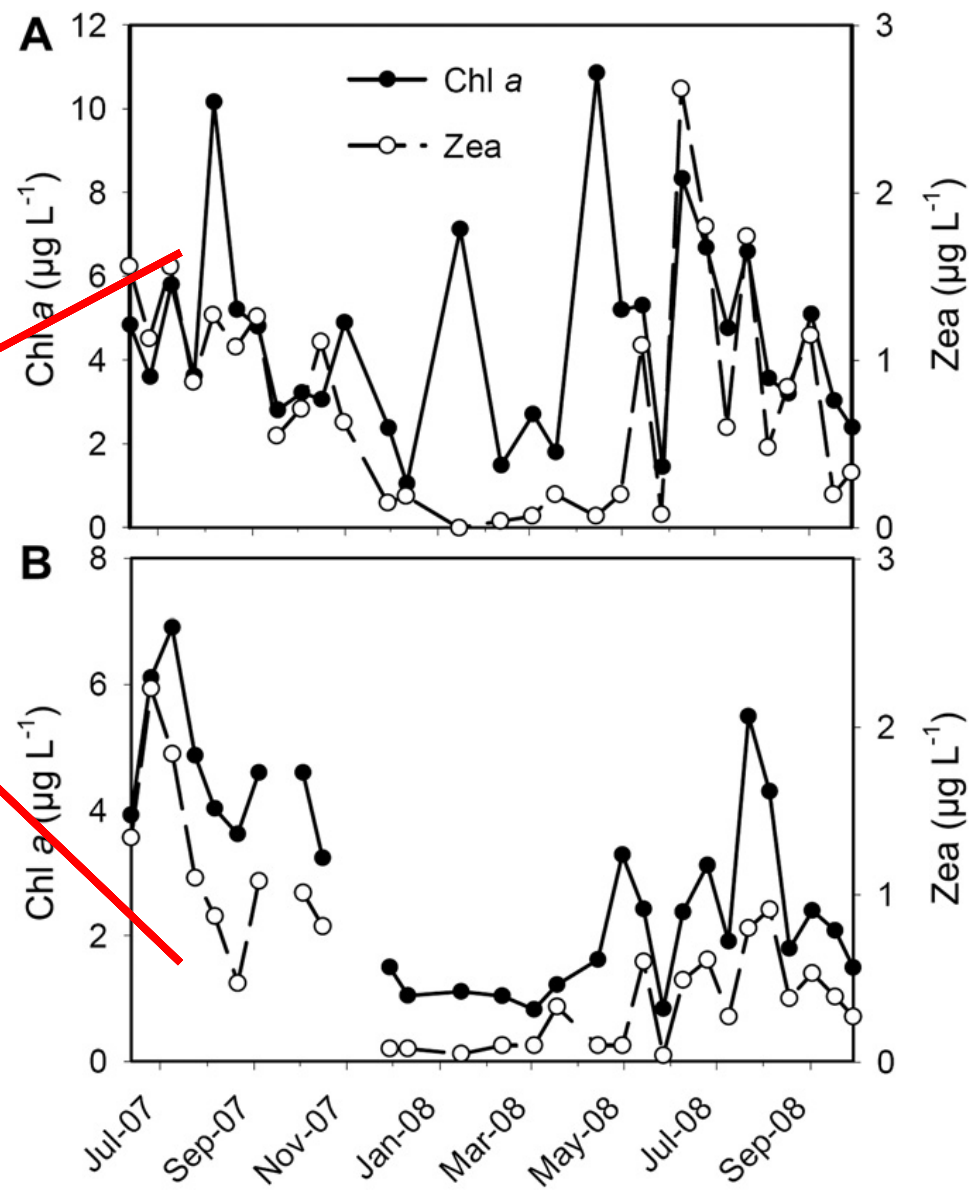
**Moisander et al. 2010 (Science 327: 1512-114).**

# North Carolina Coastal Waters:  The Neuse R.-Pamlico Sound System



# Seasonal patterns of Chl *a* and cyanobacterial biomass (zeaxanthin) in the Neuse River Estuary, NC




Gaulke et al. 2010

# Neuse River Estuary: Environmental factors & picocyanobacterial productivity

**Table 2**

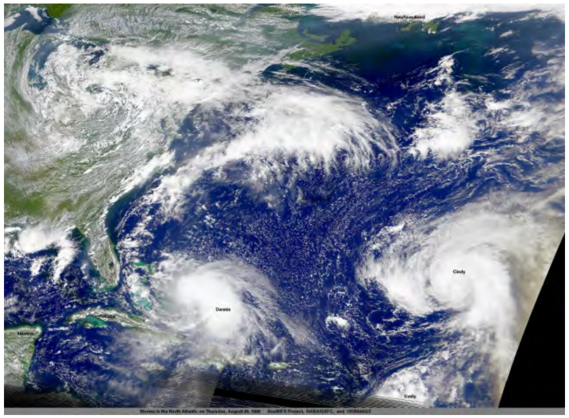
Relationship between <3 μm or >3 μm chlorophyll *a* (Chl *a*) or primary productivity and select environmental parameters from June, 2007, to September, 2008. Shown are the Spearman rank correlation coefficient, significance level, and number of samples. Values in bold are those determined to be significant at $p < 0.05$.

| | | Temp. | Salinity | NOx | $NH_4^+$ | $PO_4^{3-}$ |
|---|---|---|---|---|---|---|
| <3 μm Chl *a* | Corr. Coeff. | **0.51** | −0.09 | **−0.19** | **−0.32** | **0.44** |
| | Sign. | 0.00 | 0.28 | 0.02 | 0.00 | 0.00 |
| | *n* | 148 | 148 | 148 | 148 | 148 |
| <3 μm Productivity | Corr. Coeff. | **0.45** | −0.03 | **−0.21** | **−0.38** | **0.52** |
| | Sign. | 0.00 | 0.72 | 0.01 | 0.00 | 0.00 |
| | *n* | 147 | 147 | 147 | 147 | 147 |
| >3 μm Chl *a* | Corr. Coeff. | **0.24** | **−0.24** | −0.05 | **−0.22** | **0.28** |
| | Sign. | 0.00 | 0.00 | 0.57 | 0.01 | 0.00 |
| | *n* | 148 | 148 | 148 | 148 | 148 |
| >3 μm Productivity | Corr. Coeff. | 0.10 | **−0.27** | 0.09 | −0.10 | **0.24** |
| | Sign. | 0.22 | 0.00 | 0.28 | 0.22 | 0.00 |
| | *n* | 147 | 147 | 147 | 147 | 147 |

Gaulke et al. 2010

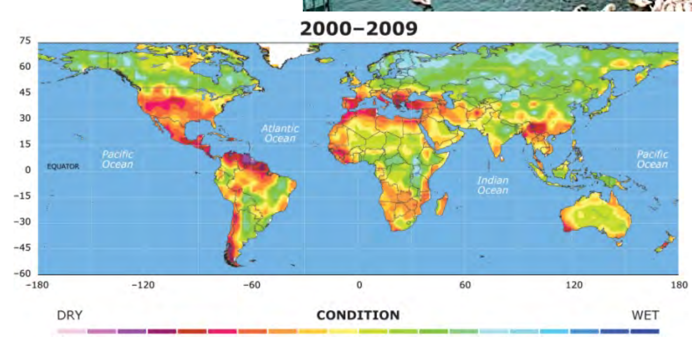
# Hydrologically: Things are getting more extreme

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

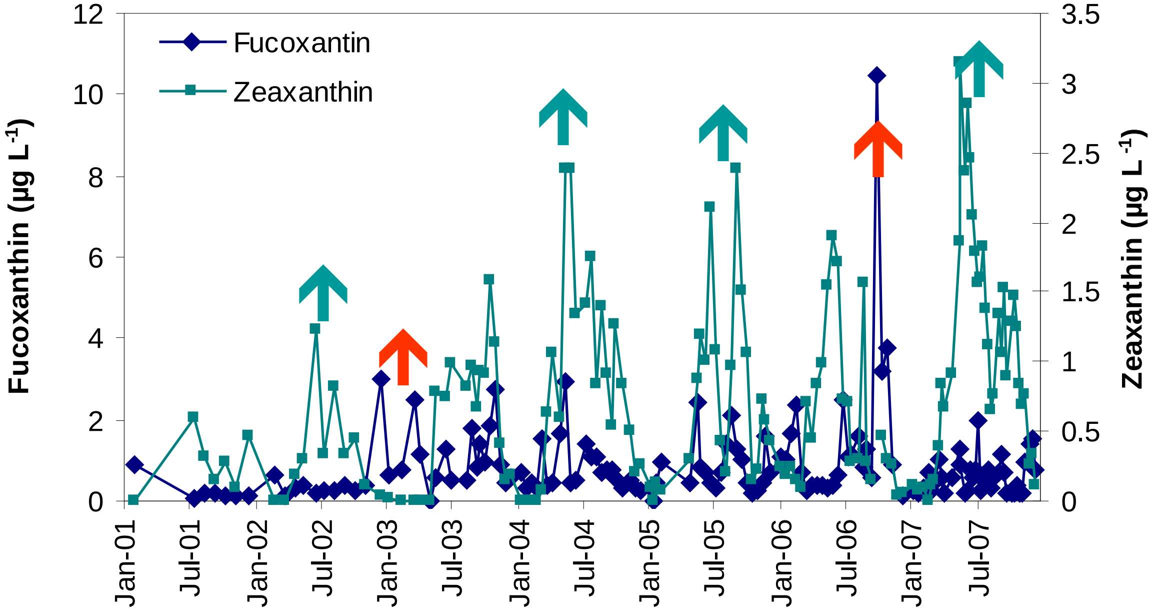


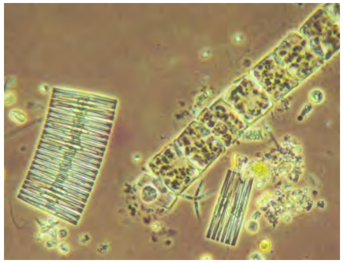




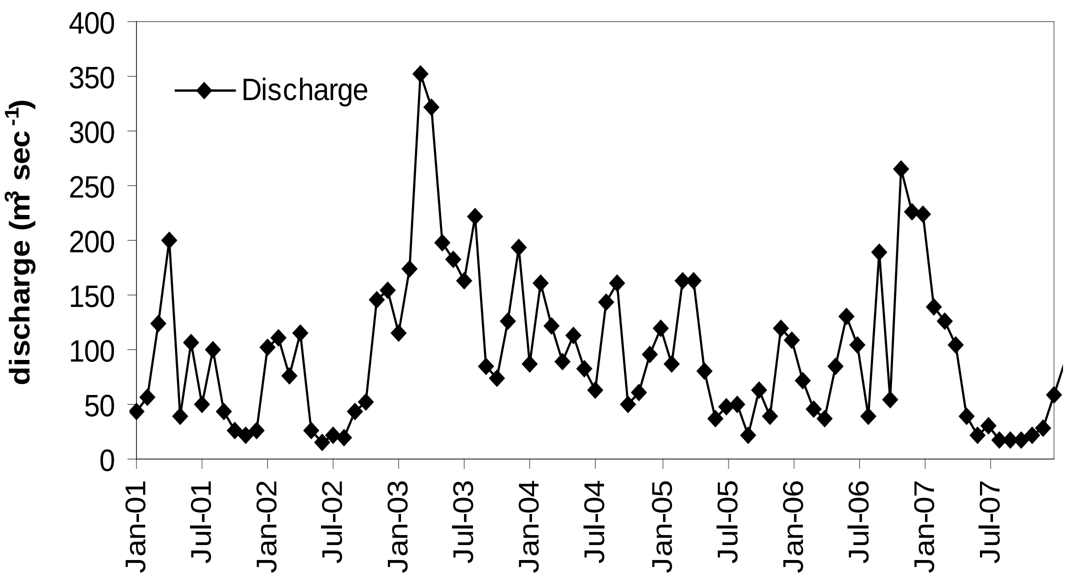



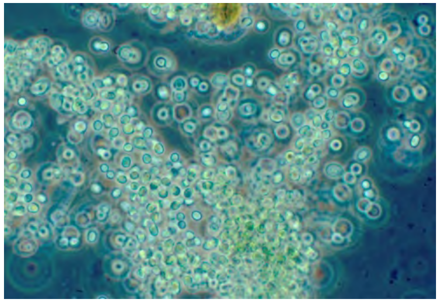
# Effects of Freshwater discharge (flushing) on diatoms (fucoxanthin) and cyanobacteria (zeaxanthin) in the Neuse R. Estuary, NC



**Diatoms like it cool & fast**

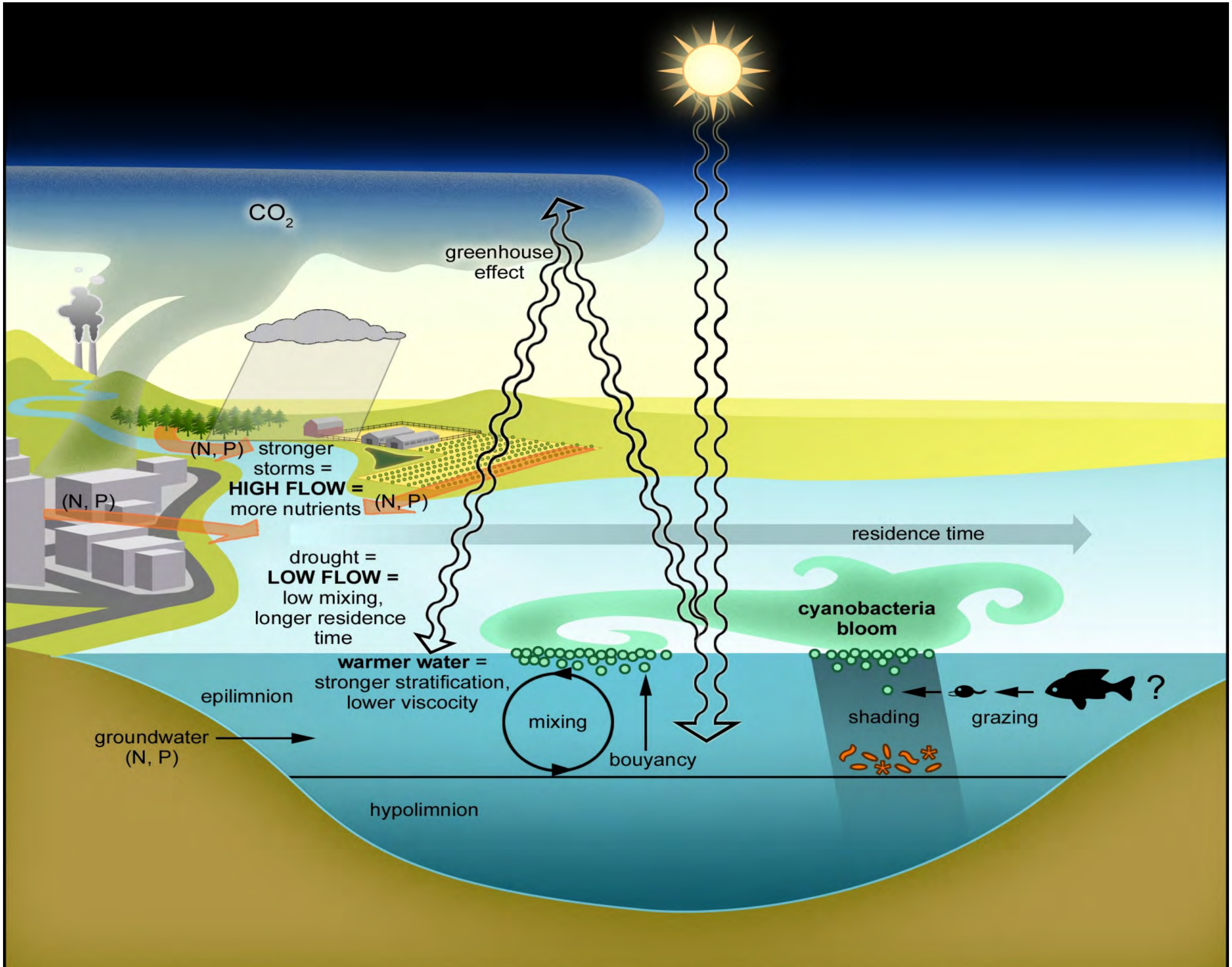


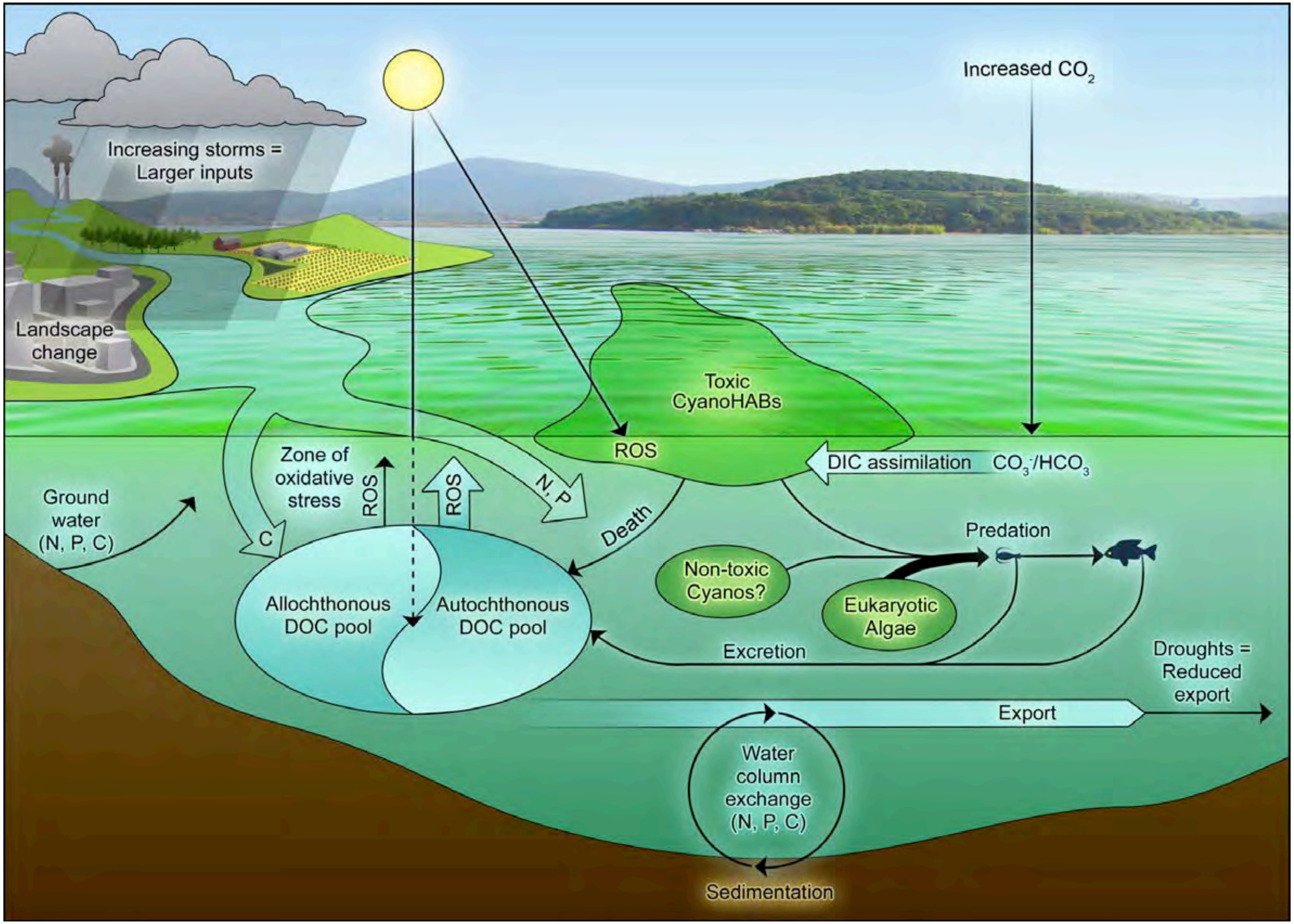
***Cyanos like it hot & slow***

Paerl et al. 2009

# Global warming, associated climate change and CyanoHAB potential



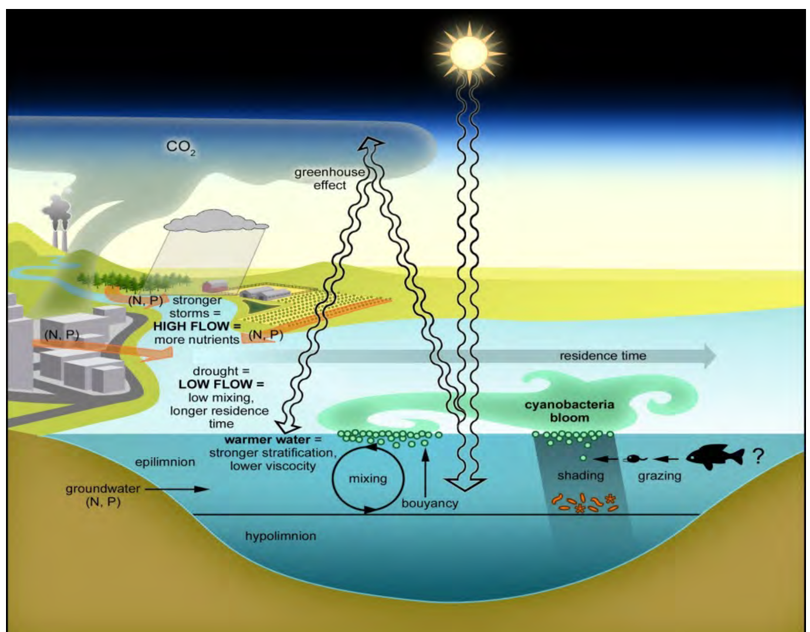
# Potential linkage to "cyanotoxin" (microcystin) production in aquatic ecosystems

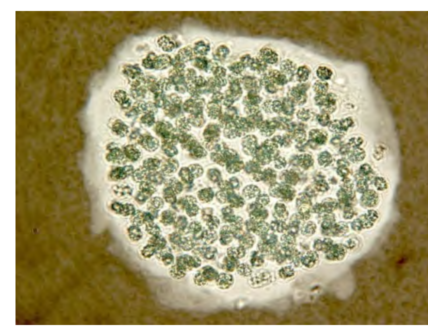



Paerl and Otten, Science 342: 433 (2013)

# With regard to management, what's most practical across systems?

- Reduce both N & P inputs
  - Nutrient-bloom threshold are system-specific
  - May need to reduce N and P inputs even more in a warmer world
- Impose nutrient input restrictions year-round
  - Residence time is long in large ecosystems (> several years)
  - Warmer, longer growing seasons



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

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