Global Proliferation of Harmful Cyanobacterial Blooms: The Connections to Human-Induced and Climatic Change

Hans Paerl, UNC-CH Institute of Marine Sciences, Morehead City, NC 28557

Contributors: Pia Moisander[2], Juli Dyble[3], Jennifer & Alan Joyner[1], Michael Piehler[1], and John Burns[4] [1]UNC-CH Institute of Marine Sciences, Morehead City, NC; [2]UC-Santa Cruz, CA; [3]NOAA-GLRL, An Arbor, MI; [4]MACTEC Engineering, Atlanta, GA

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Cyanobacterial Harmful Blooms (CHABs): The link to 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 an interactive role

Blooms are intensifying and spreading

Why are we concerned about CHABs?

- Toxic to zooplankton, fish, shellfish, domestic animals and humans
- Cause hypoxia and anoxia, leading to fish kills
- Odor and taste problems
- Aesthetic problems, loss of recreational and fishing value of affected waters


TUESDAY

FORT PIERCE

TRIBUNE

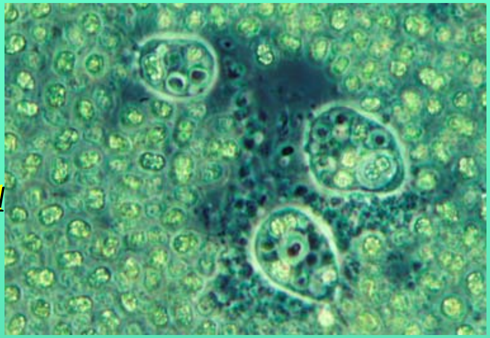
It's back to class for St. Lucie students

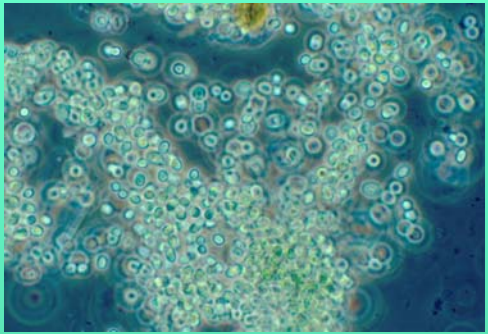
Ewww! River's a 'mess'

Energy bill not a quick fix, says Bush at signing

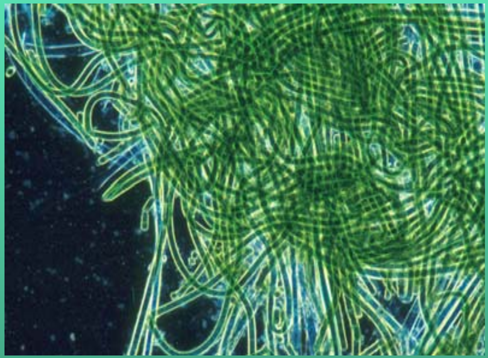
Who are the key Players?

- **Unicellular, (non-N_2 fixing)**
  Microcystis*, Gomphosphaeria





- **Filamentous, non-heterocystous**
  (mostly non-N_2 fixing)
  Lyngbya*, Oscillatoria*,
  Planktothrix*

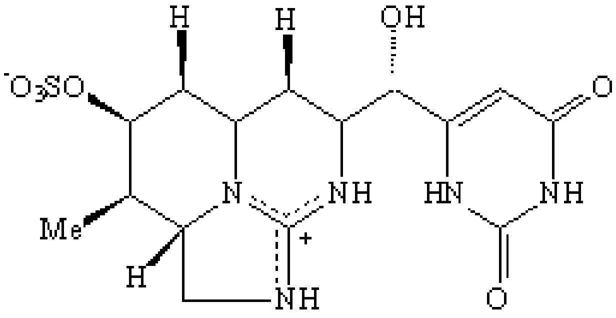


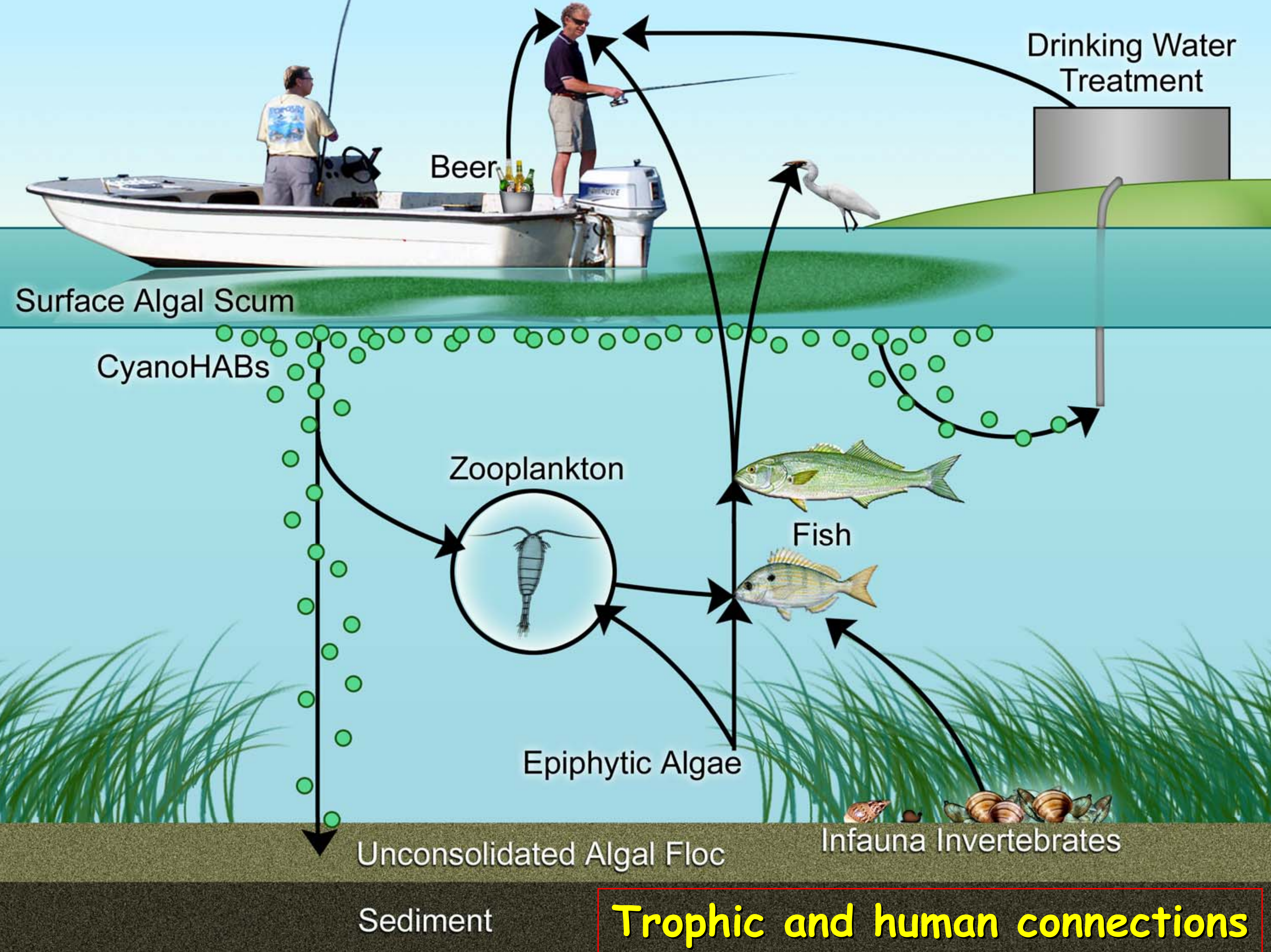
- **Filamentous, heterocystous**
  (N_2 fixing)
  Anabaena*, Aphanizomenon*,
  Cylindrospermopsis*,
  Nodularia*

**** Contains toxic strains***

"Toxins" of Concern

Toxin	Effect
Anatoxin-a	Nerve Synapse
Anatoxin-a(s)	Nerve Synapse
Aplysiatoxins	skin
BMAA ß-N-methylamino-L-alanine	Neurogenerative disease?
Cylindrospermopsins	wide-spread tissue damage
Lyngbyatoxin-a	skin
Microcystins	Liver
Nodularin	Liver
Saxitoxins	Nerve axons




Drinking Water
Treatment
Beer
Surface Algal Scum
CyanoHABs
Zooplankton
Fish
Epiphytic Algae
Infauna Invertebrates
Unconsolidated Algal Floc
Sediment
Trophic and human connections

It's a global problem

- **Freshwater Ecosystems**

(lakes, reservoirs, streams, rivers)



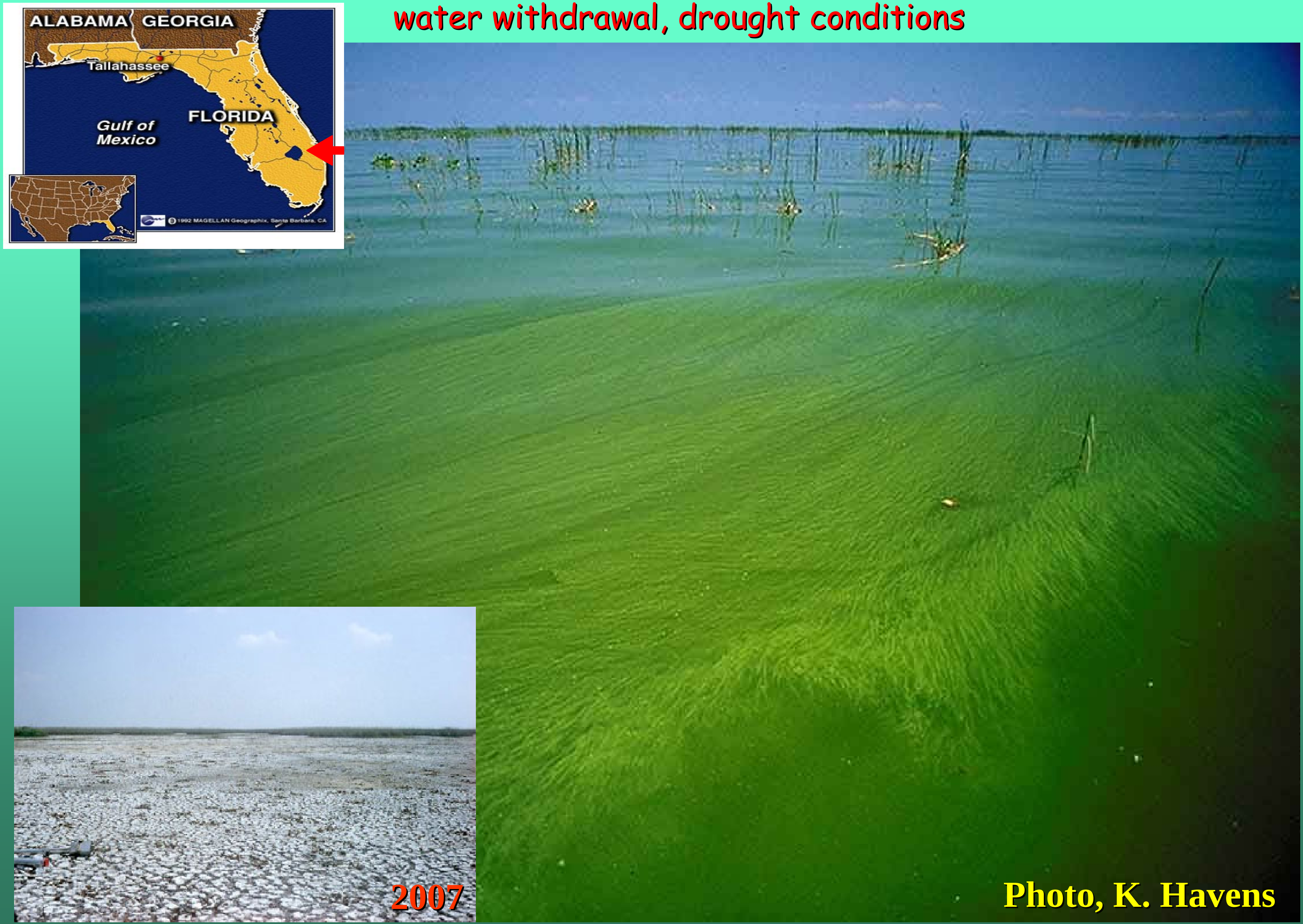
- **Estuaries**



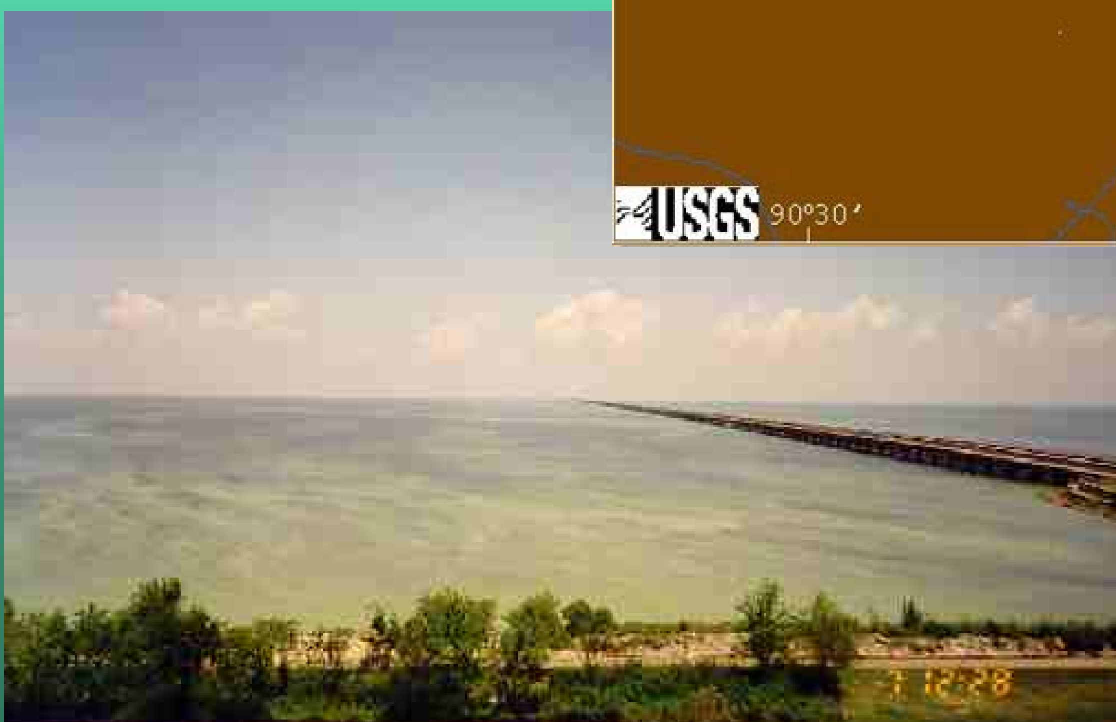
- **Coastal waters & seas**



Lake Okeechobee, Florida: Nutrient enrichment, water withdrawal, drought conditions

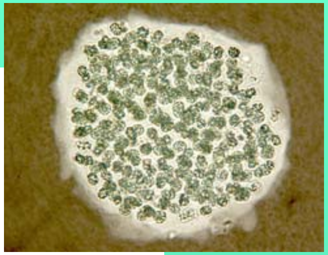


Microcystis Bloom on Lake Ponchartrain, LA, nutrient enrichment & hydrology



Photos, John Burns & USGS

Resurgence of *Microcystis* in Lake Erie (US Great Lakes) , nutrients

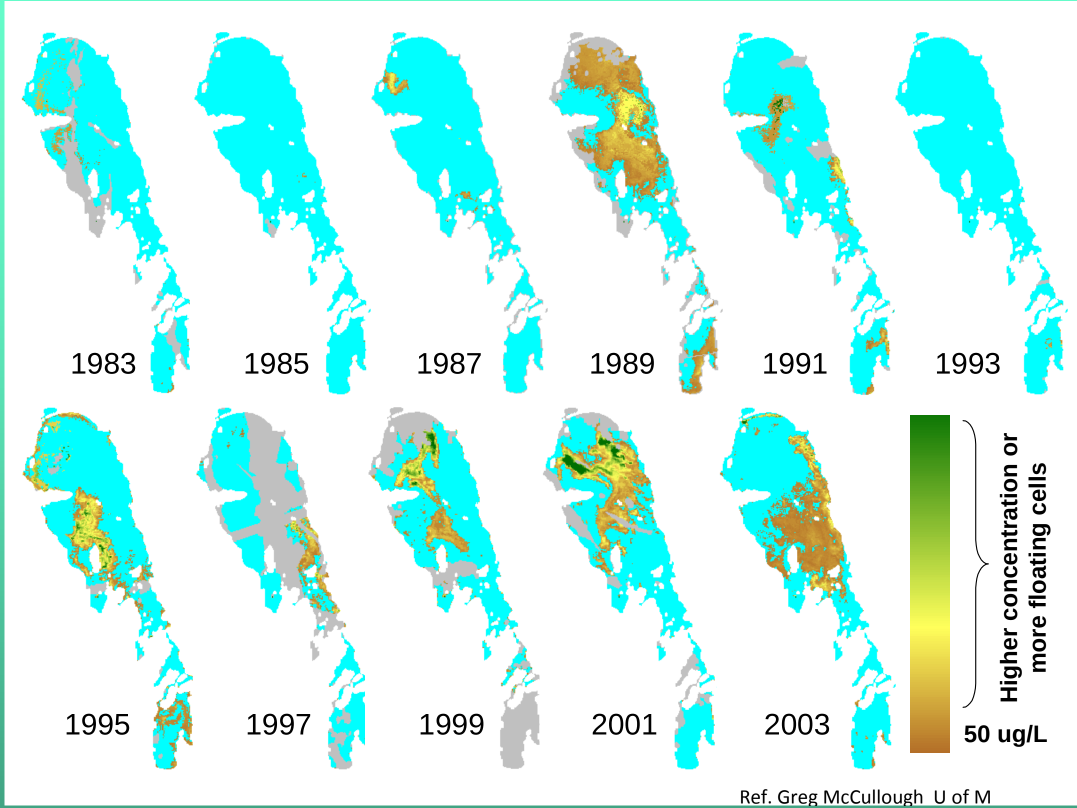


Microcystis plume in Maumee Bay, western Lake Erie

Photos: J. Dyble, S. Wilhelm

Cyanobacteria blooms in Lake Winnipeg, Canada,

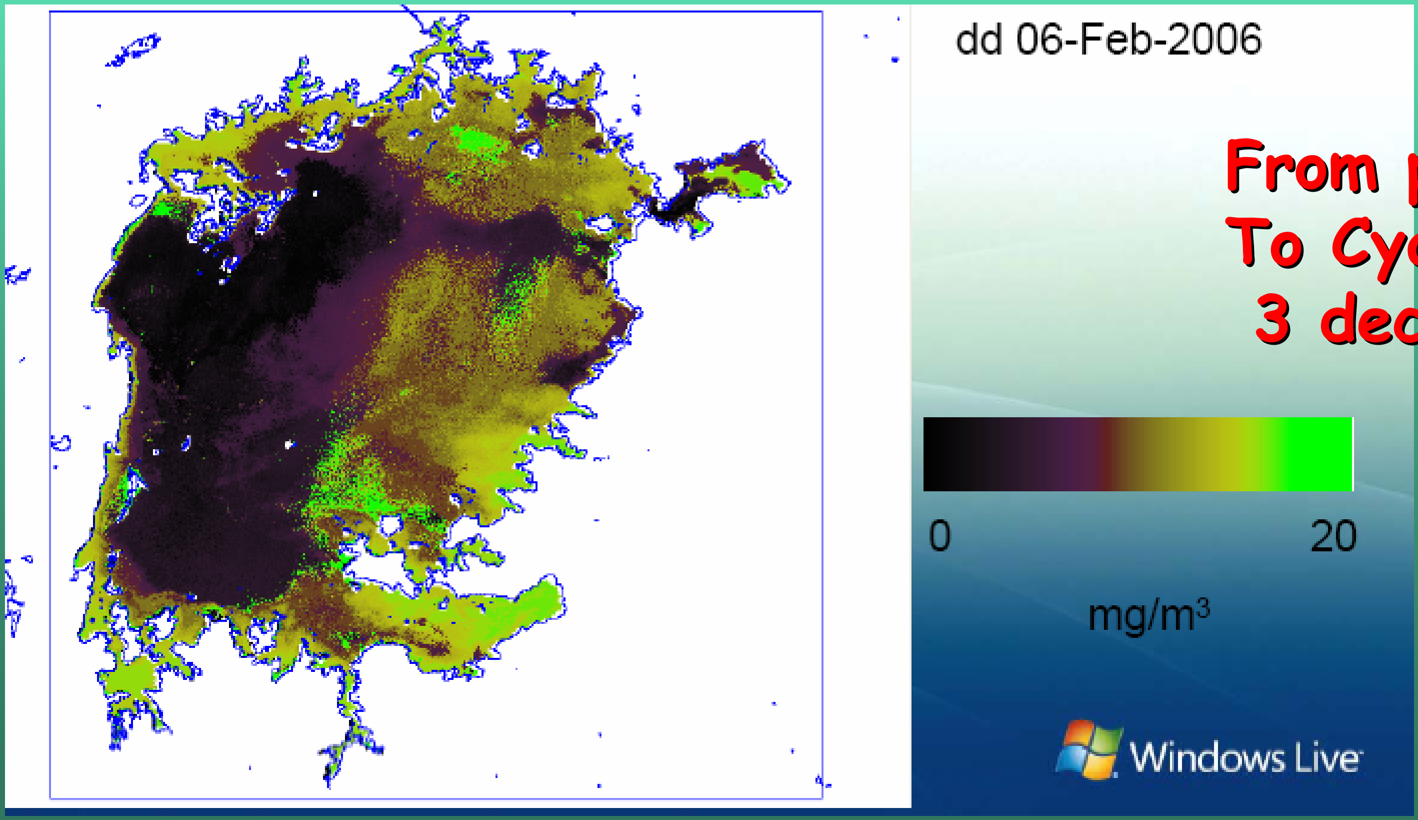
Nutrient Enrichment, climate change?



Courtesy H. Kling

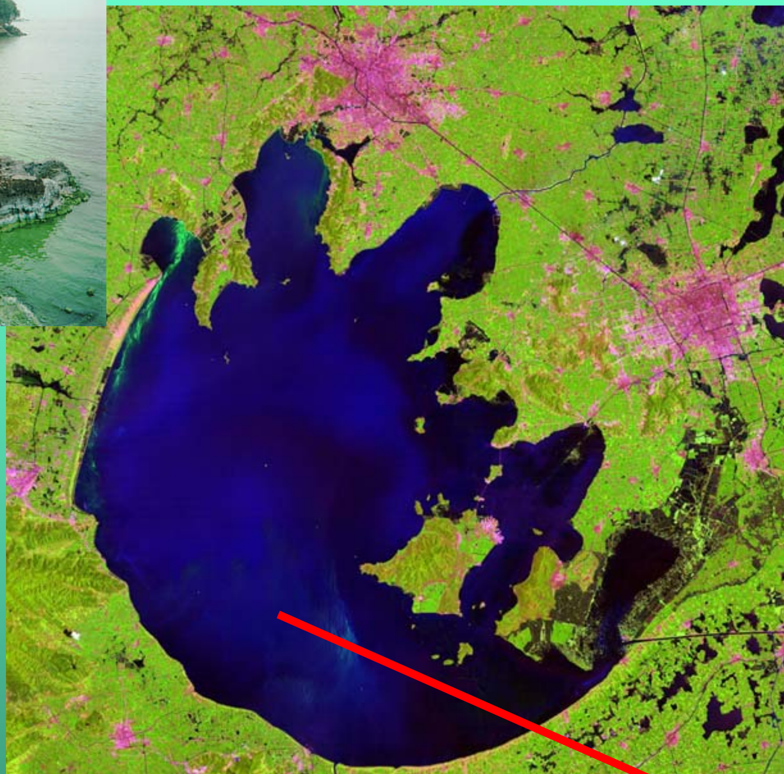
Photo Free Press
From Bartley Kives

Lake Victoria, E. Africa, nutrient enrichment

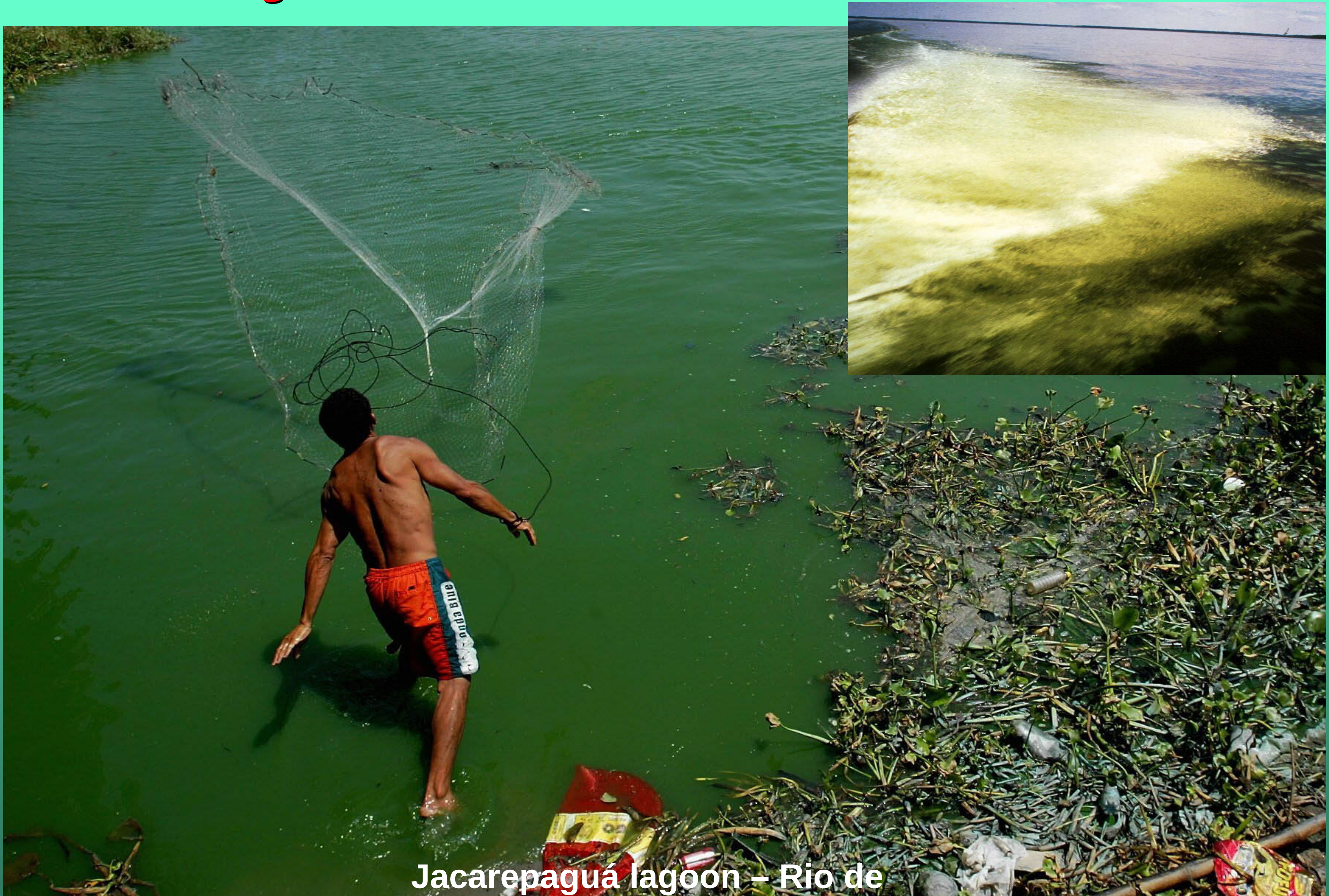


From pristine waters
To CyanoHABs in
3 decades

Lake Taihu 3rd largest lake in China. Nutrients (Lots!). Blooms have grown to "pea soup" conditions within only a few decades



Brazilian lagoons: lots of nutrient enrichment from urban/agricultural growth

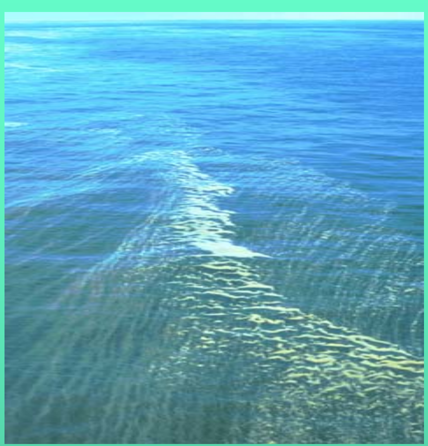


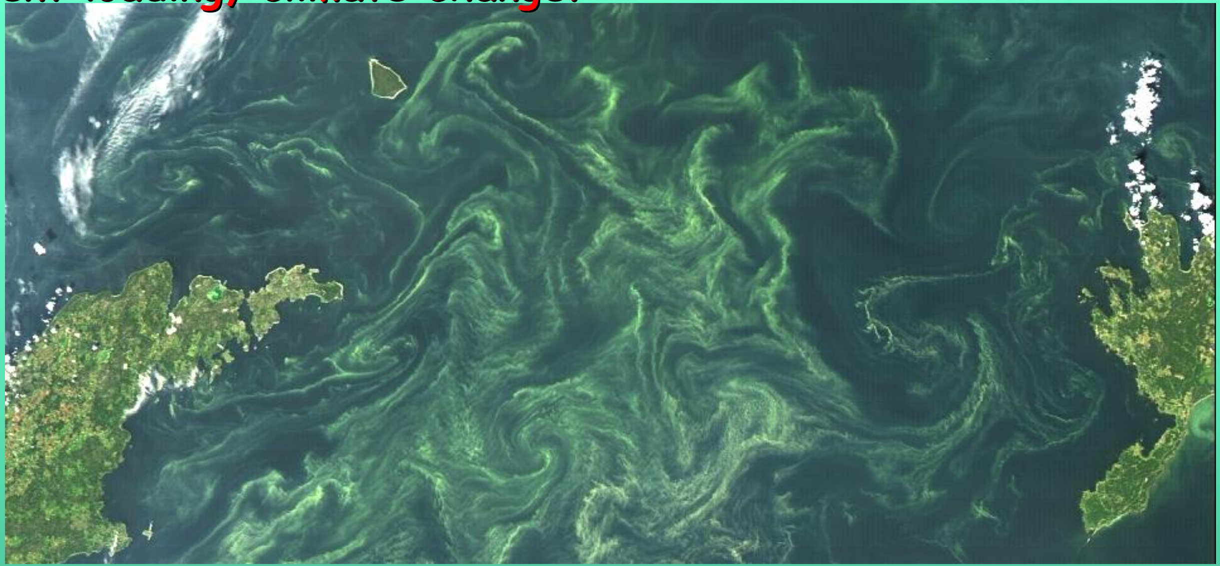
Jacarepaguá lagoon – Rio de Janeiro - 2000

Courtesy Sandra Azevedo

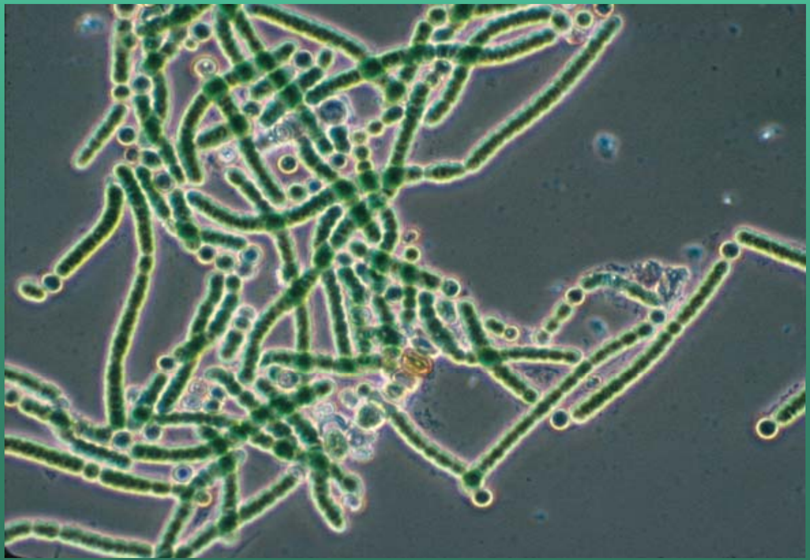
The Baltic Sea: World's largest estuary

History of nutrient loading, climate change?

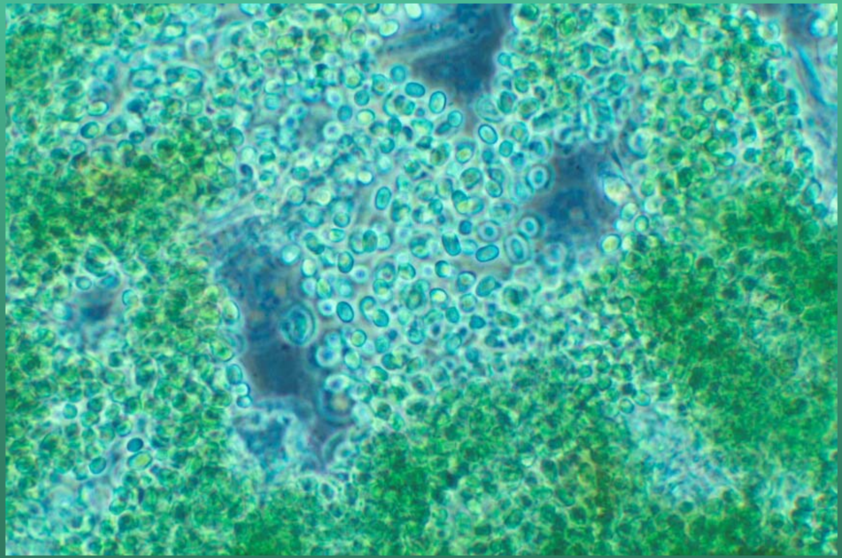




- N_2 Fixers, *Nodularia, Anabaena, Aphanizomenon*

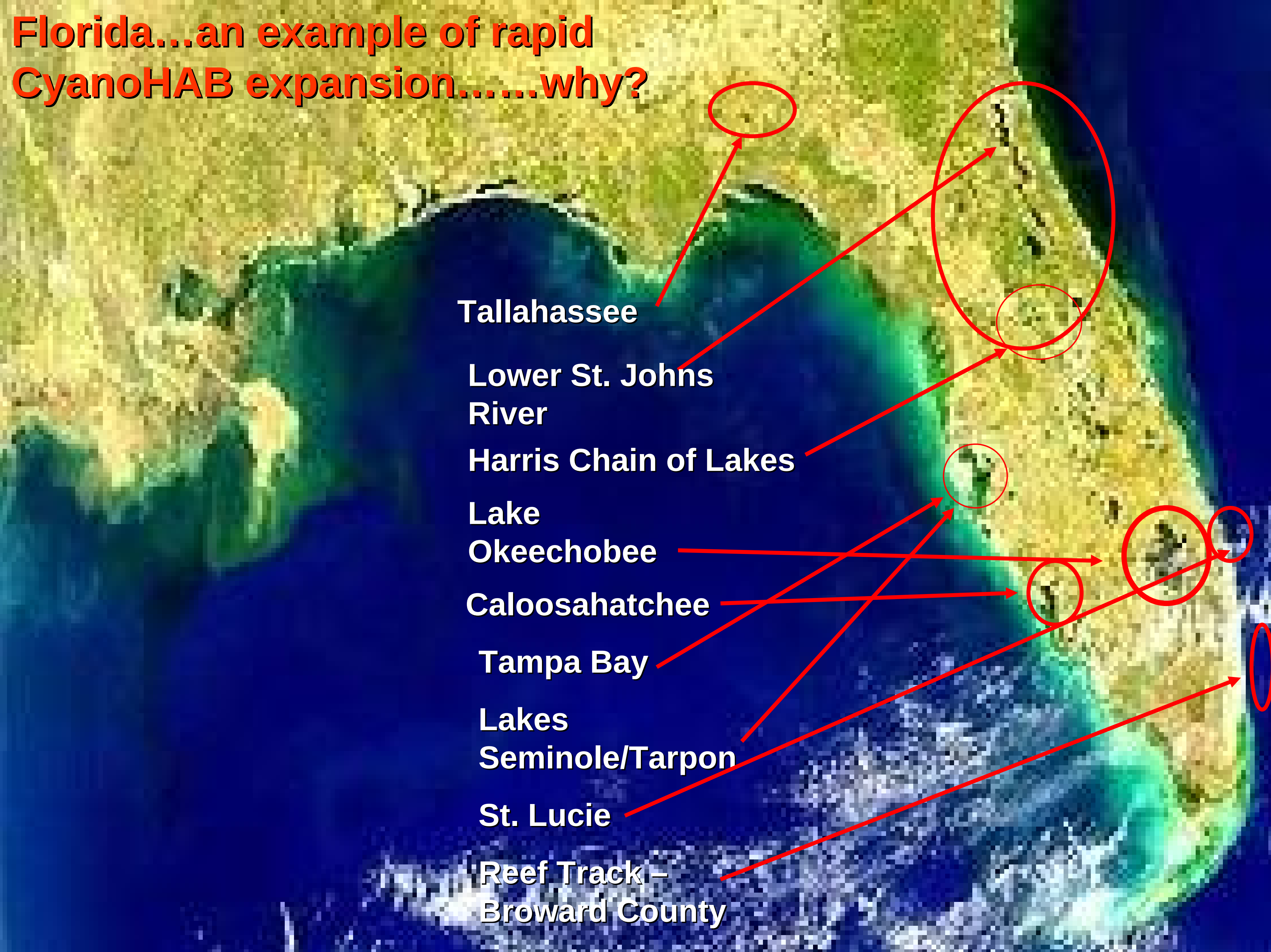


- Non N_2 Fixers, *Microcystis, Oscillatoria*



Photos, Pia Moisander, Kaisa Kononen

Florida…an example of rapid CyanoHAB expansion……why?

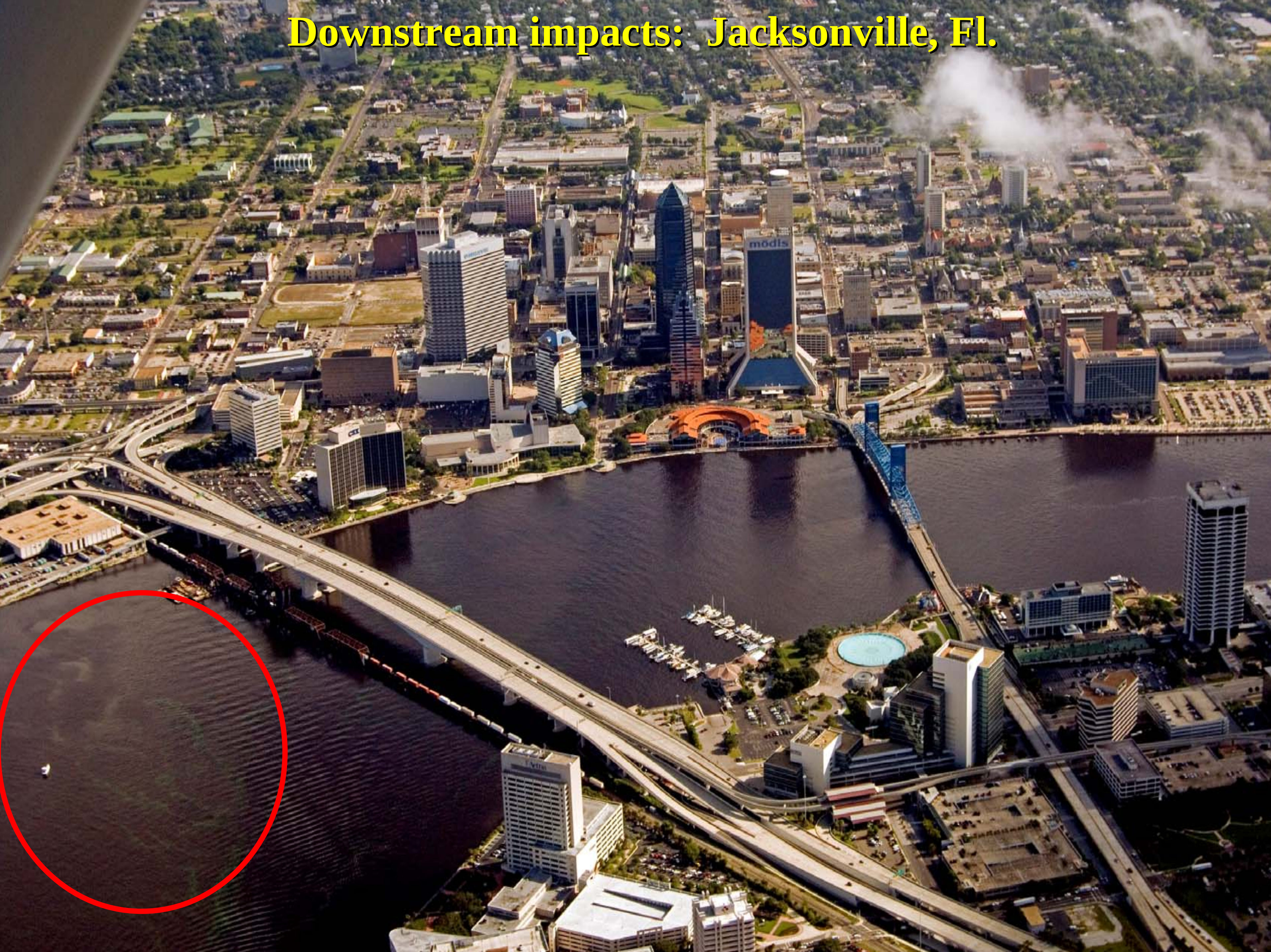


The not-so-magic formula…….impound water + nutrients = Cyanobloom!
Example: St. Lucie, West Palm Beach Canal

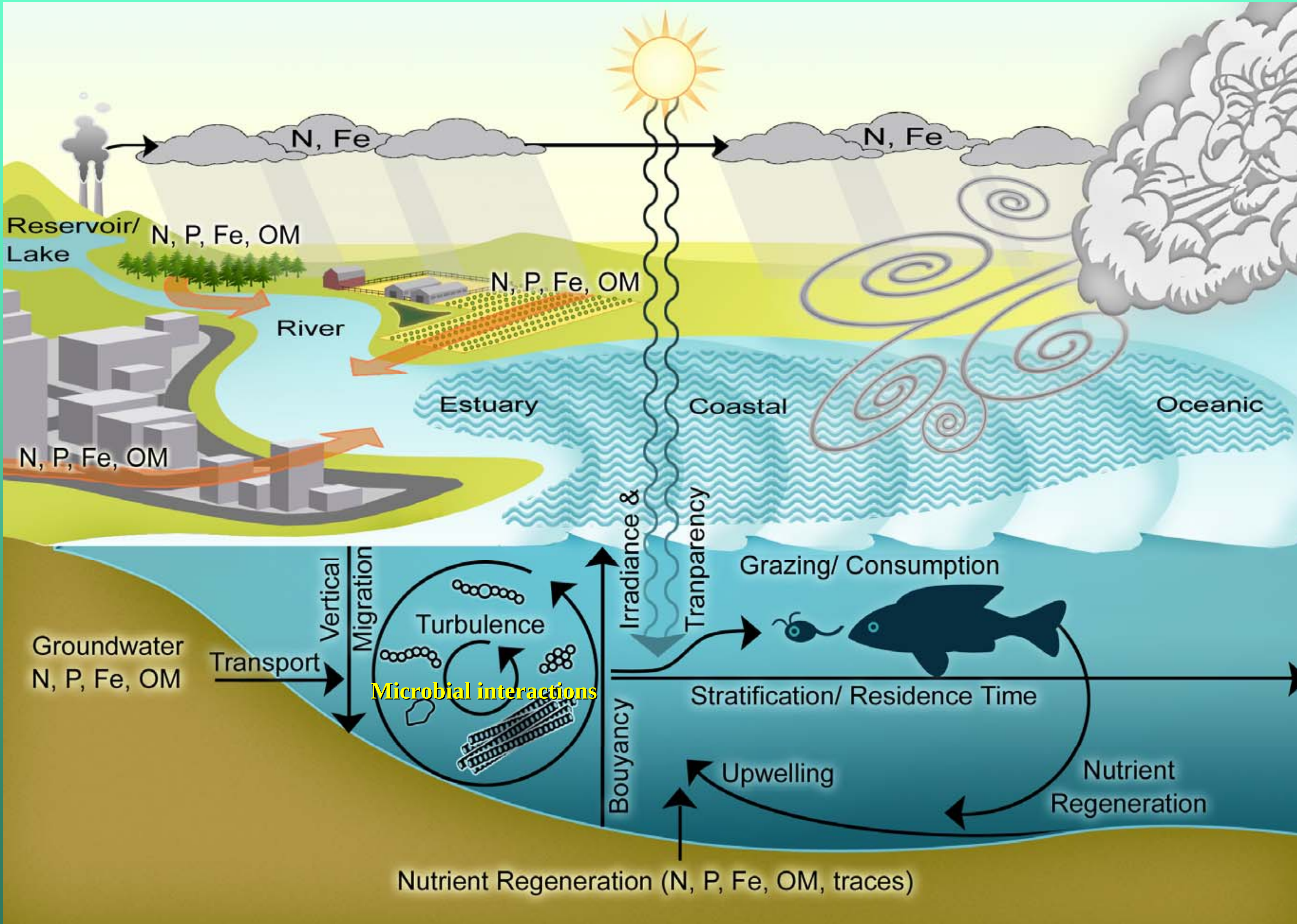
St. Lucie:	108 -373 ug/L Microcystin
WPB Canal:	164 ug/L

St. Johns R.: Nutrients + drought (low flow, stagnant conditions)

Downstream impacts: Jacksonville, Fl.



What Controls CyanoHABS? Interacting Physical, Chemical & Biotic Factors



Nutrient Issues

N & P enrichments are stimulatory

N:P Input ratios are important

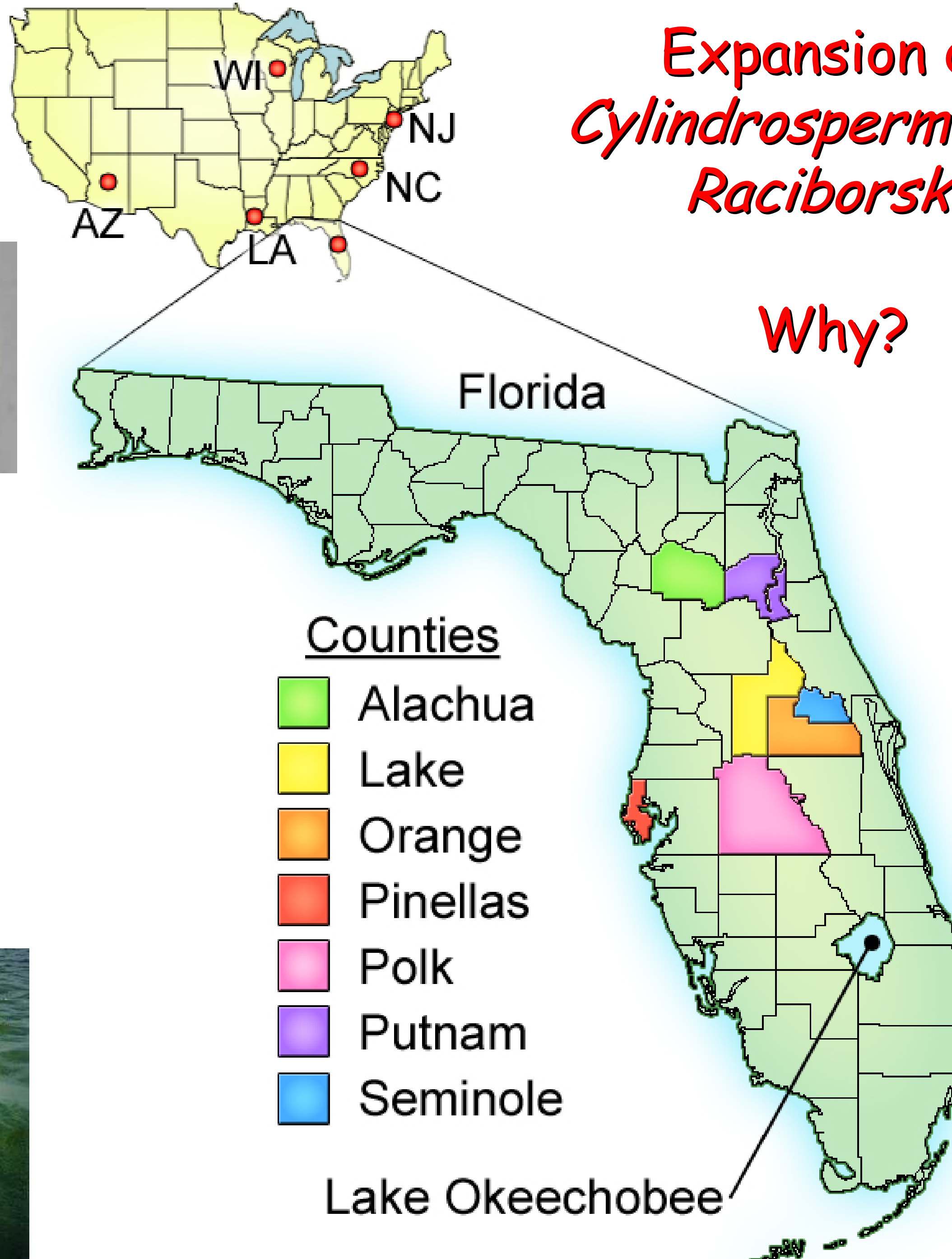
(N:P < 15 favors N_2 Fixers)

Anthropogenic N inputs increasing rapidly:
chemical forms of N
(i.e. nitrate, ammonium, organic N) may
regulate algal community composition & toxicity

Other nutrients (Fe, trace elements)?

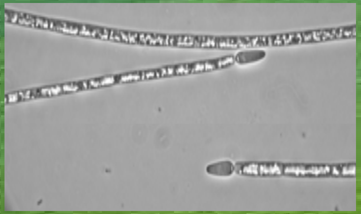
Expansion of *Cylindrospermopsis Raciborskii*

Why?



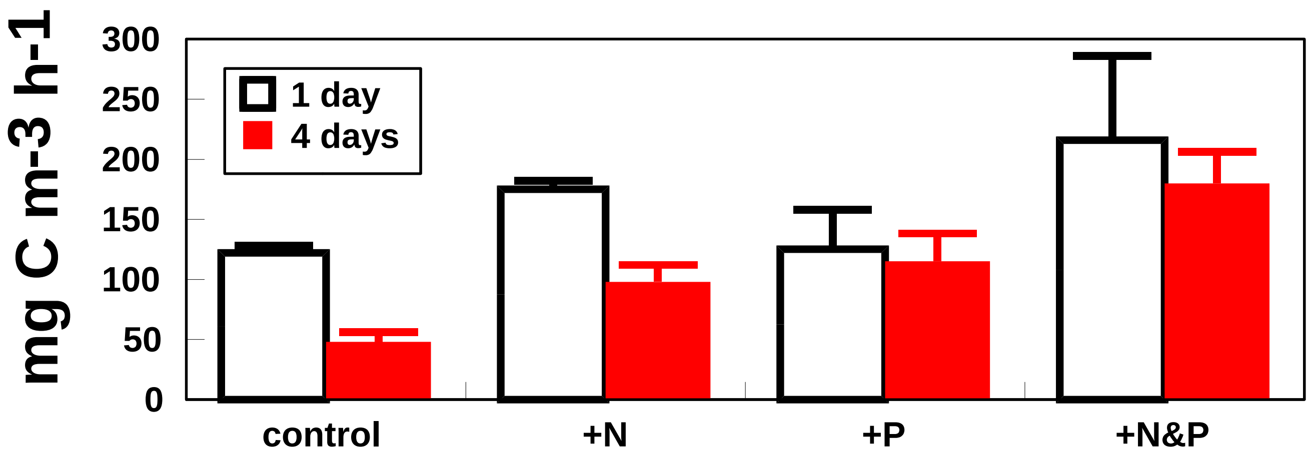
Nutrient/light strategies of *Cylindrospermopsis raciborskii*

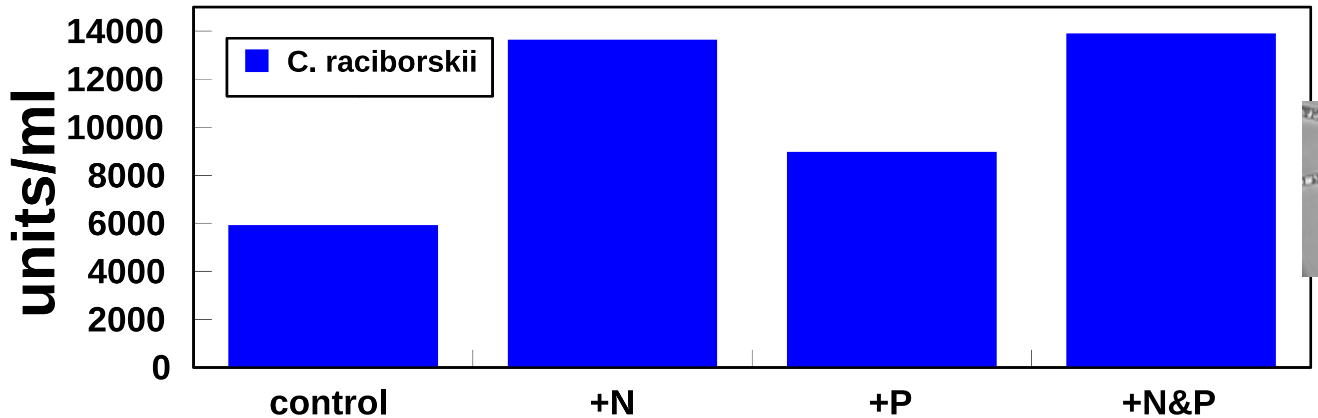
- High P uptake and storage capacity
  (Isvanovics *et al* 2000)
- N_2 Fixer



- High NH_4^+ uptake affinity
  - N additions (NO_3^- + NH_4^+) often significantly increase growth (chl *a* and cell counts) and productivity (Presing *et al* 1996)
- Tolerates low light intensities
  - "Tracks" eutrophication (expand in waters w/ increasing turbidity)
  - Can coexist in water column with other cyanoHABs
    (Fabbro and Duivenvoorden 1996)

St. Johns R. System, FL: Nitrogen and Phosphorus Effects CyanoHAB Growth and Bloom Potential





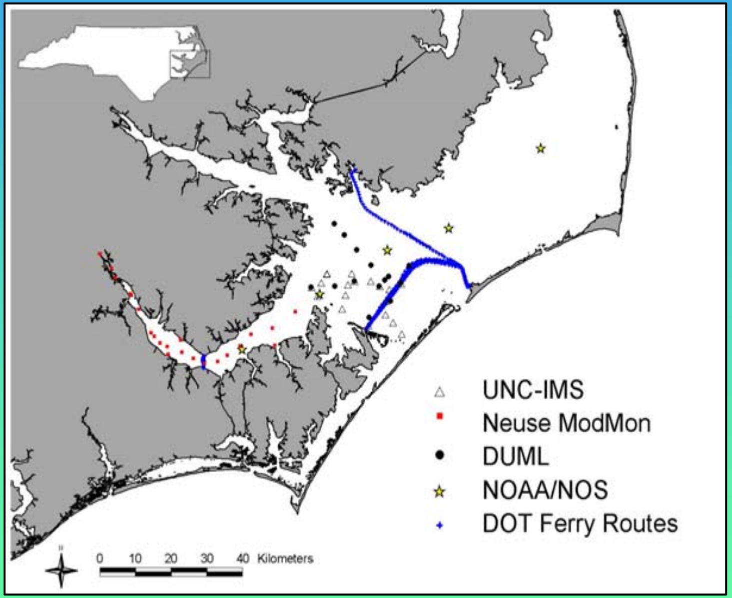
Take home message: Cylindrospermopsis raciborskii is opportunistic
Dual N & P input constraints likely be needed to control it

Piehler et al, in press

Neuse River Estuary-Pamlico Sound

Excessive N loading → eutrophication →

hypoxia → WQ/habitat decline



Neuse R Modeling & Monitoring Program (ModMon)

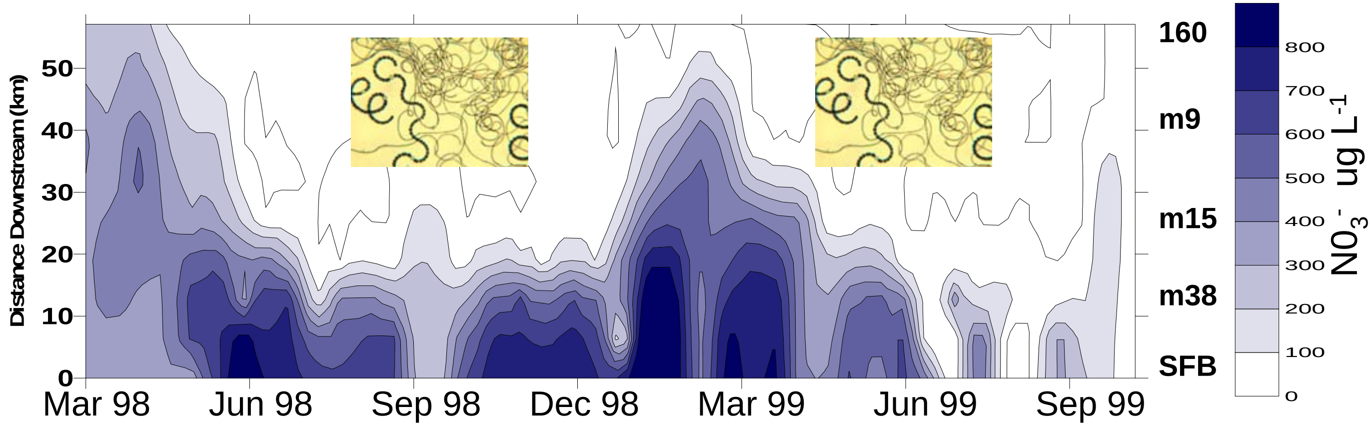
www.marine.unc.edu/neuse/modmon

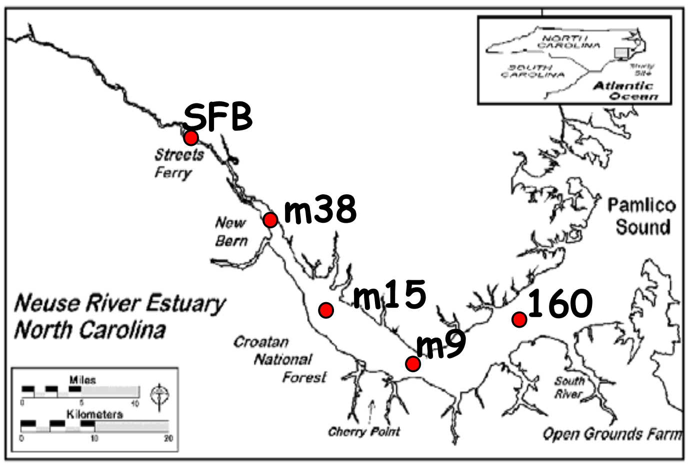
Partners: UNC, ECU, Duke, NCSU, USGS, NCDENR, EPA,

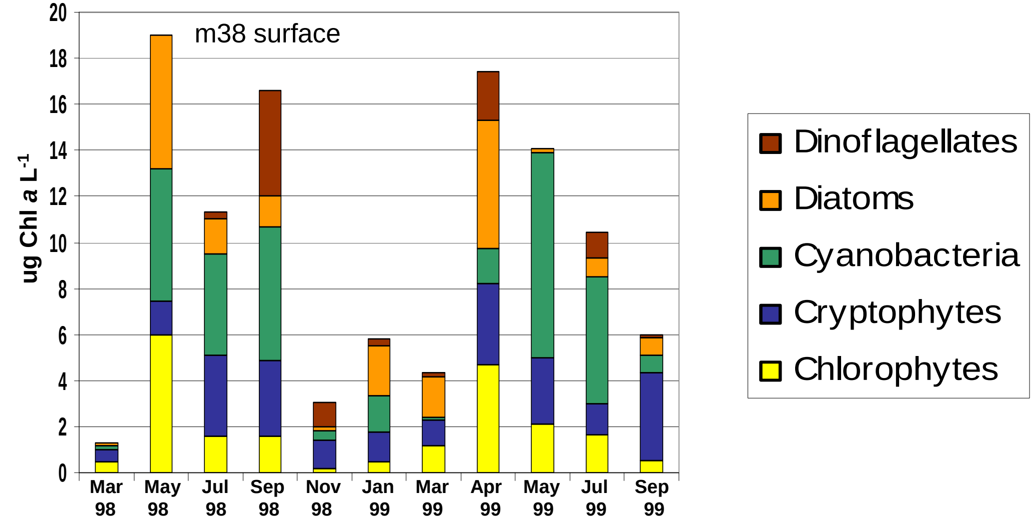
Collaborators: NOAA-NOS, NASA, NADP, Weyerhaeuser

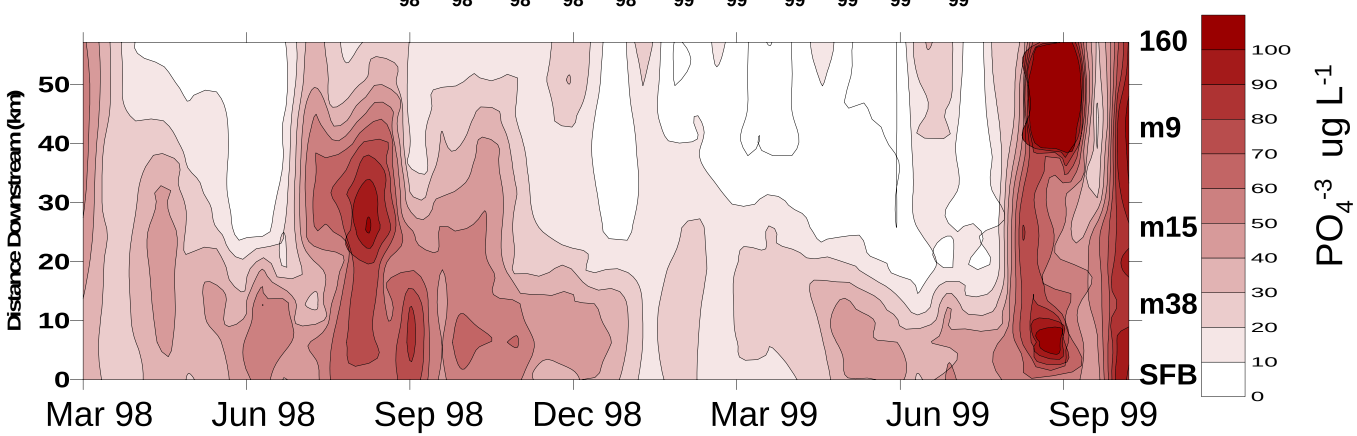
Neuse R. Estuary:
Lowering N:P favors N_2 fixing cyanos.

The strategy:
Reduce N but keep P inputs down too!



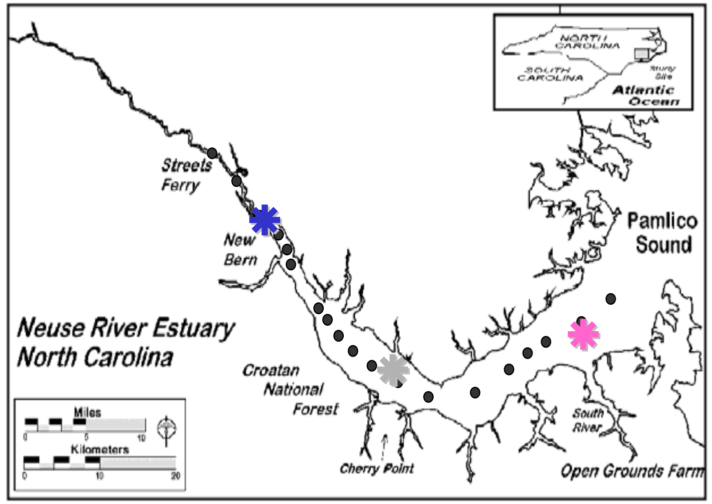




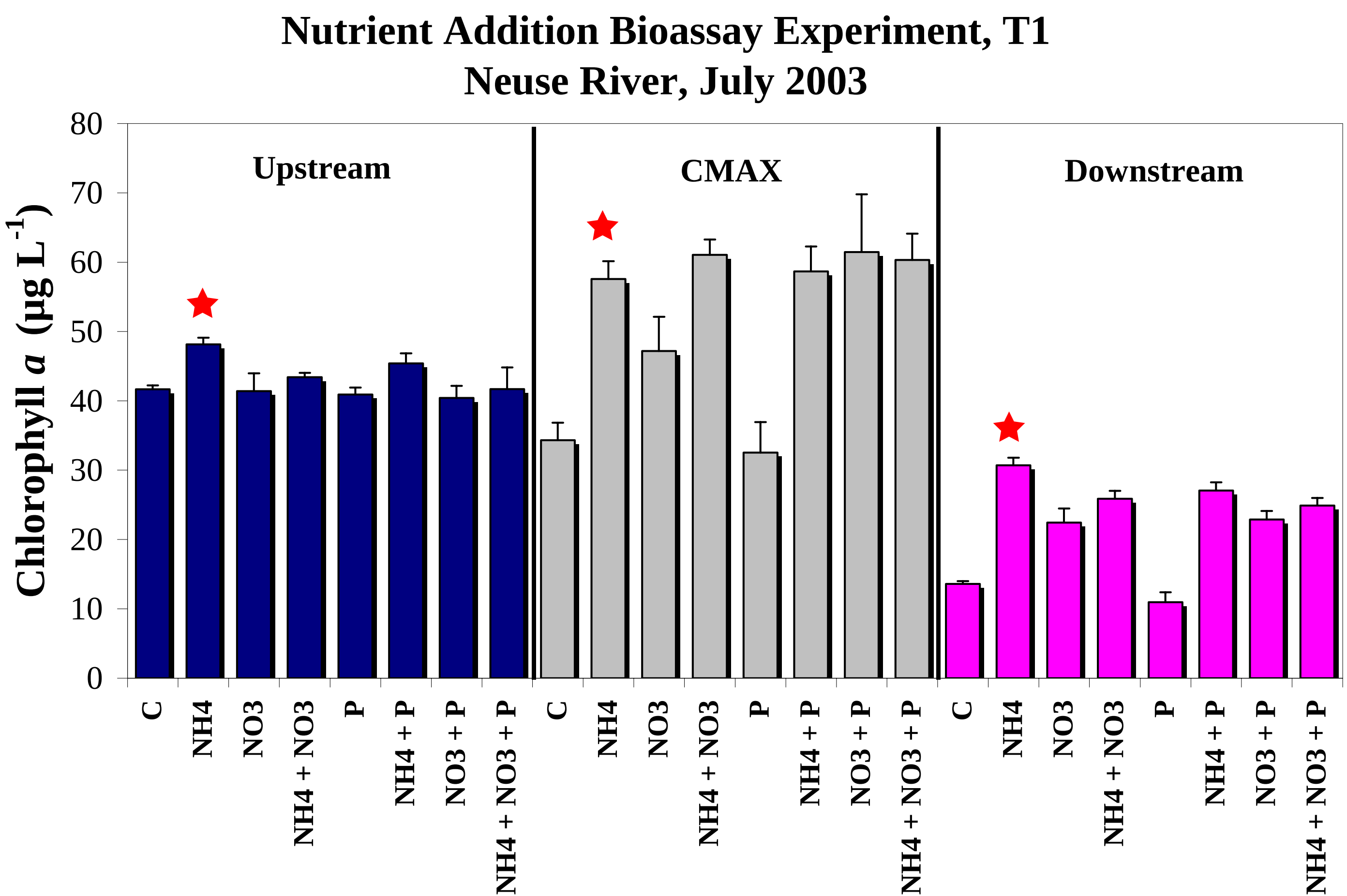


Piehler et al. 2002 & in prep

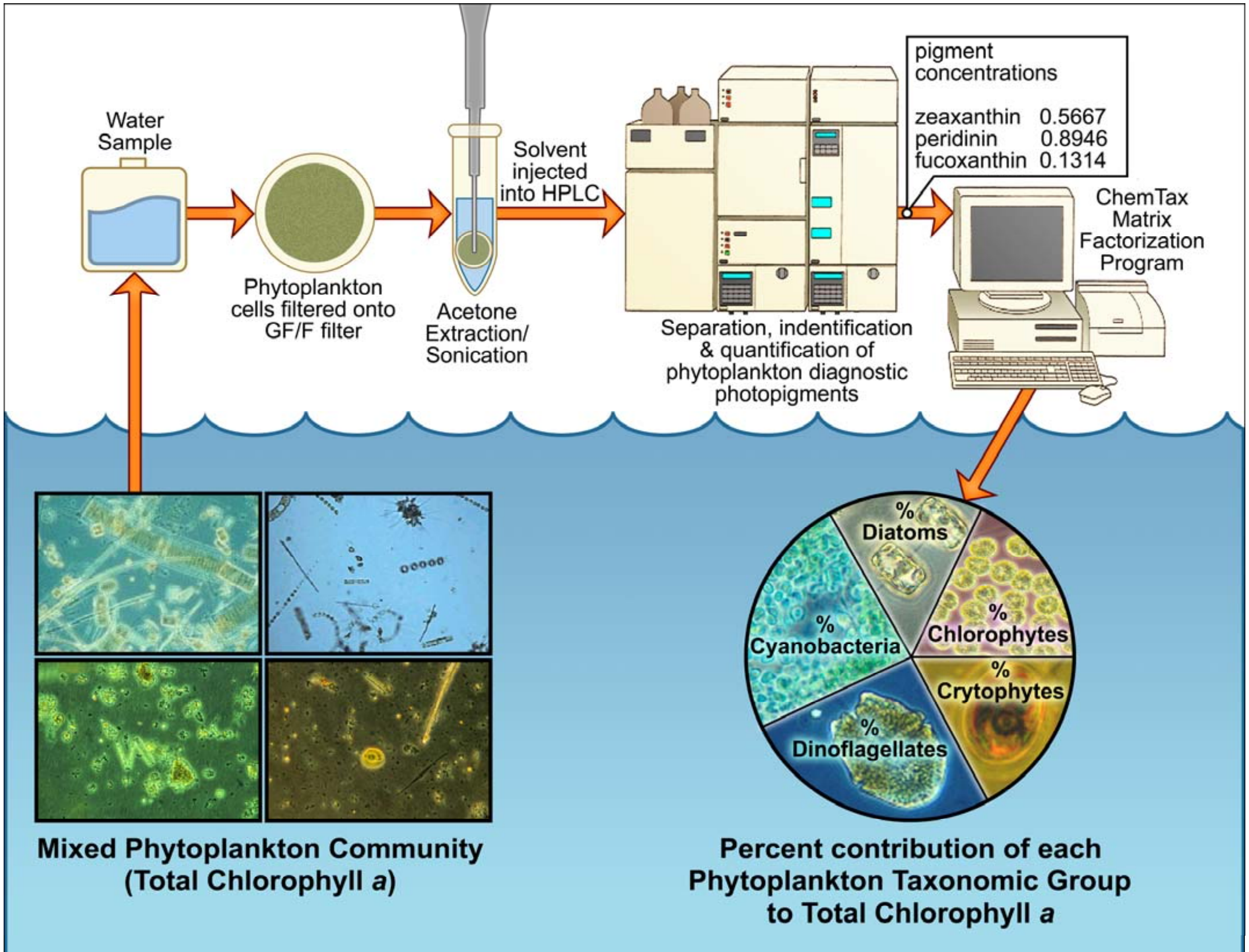
Also: N sources can affect Algal Community Structure. In particular ammonium plays a role



Twomey et al. 2005
Paerl et al. 2007



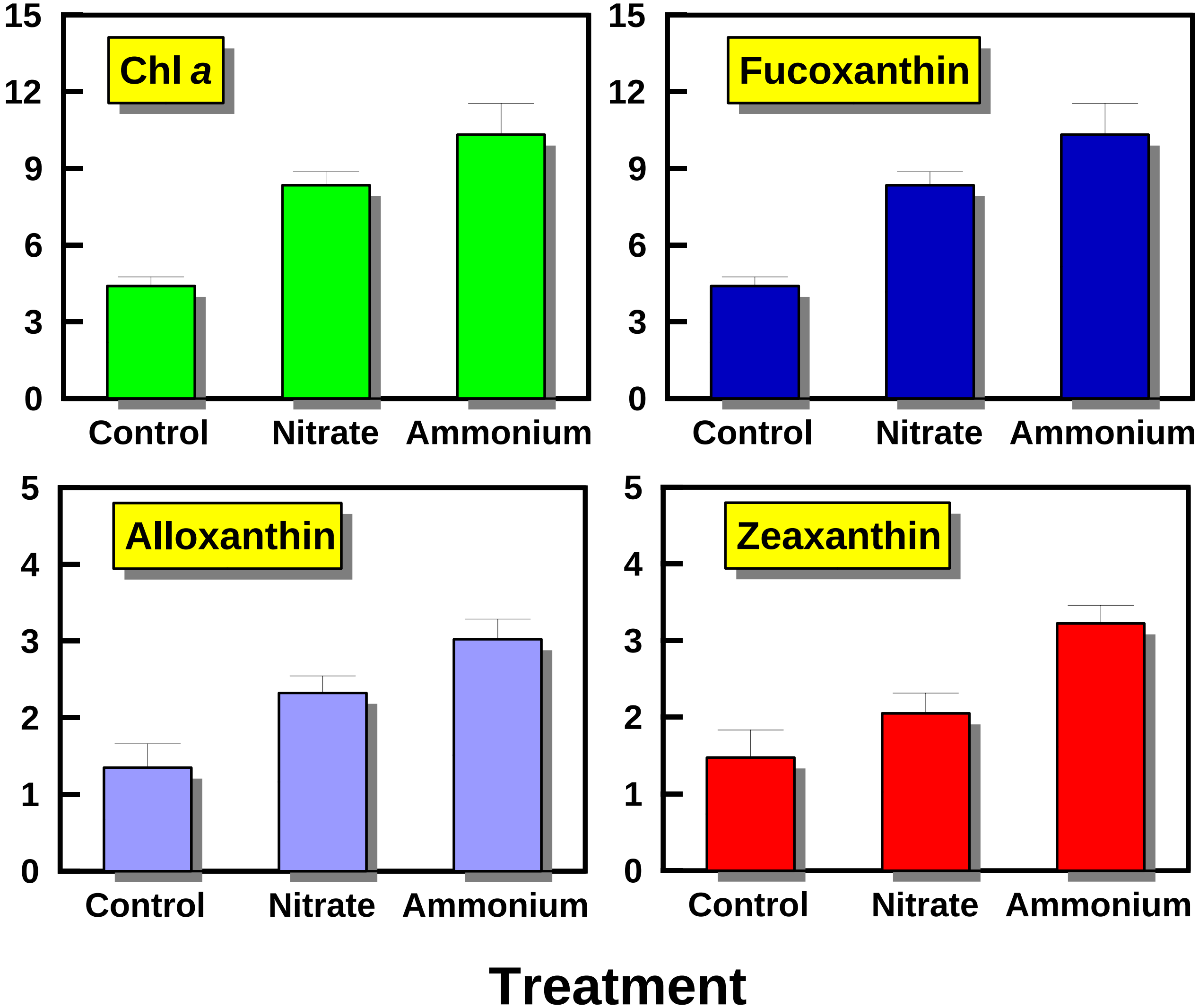
Looking into the "green box": Algal taxonomic group responses to nitrate vs. ammonium as N sources using HPLC-ChemTax Analysis

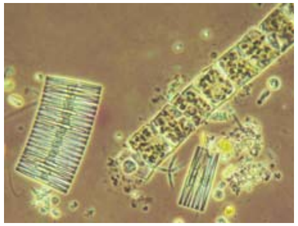


Nitrate vs Ammonium effects on algal production

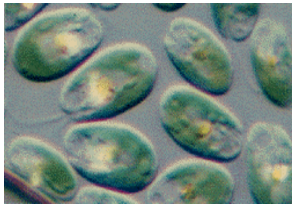
All phytos

Bogue Sound Bioassay August, 1996

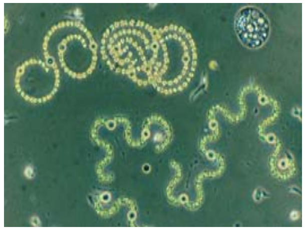




diatoms



cryptophytes



cyanobacteria

Pinckney et al. 1999

Hydrodynamics

- **Turbulence/Vertical Mixing**

(Low turbulence conditions favor cyanobacteria, especially N_2 fixers)

- **Water residence time/flushing**

(long residence time favors cyanobacterial dominance)

Climatic Factors

- **Temperature**

(high temperature favors cyanobacteria)

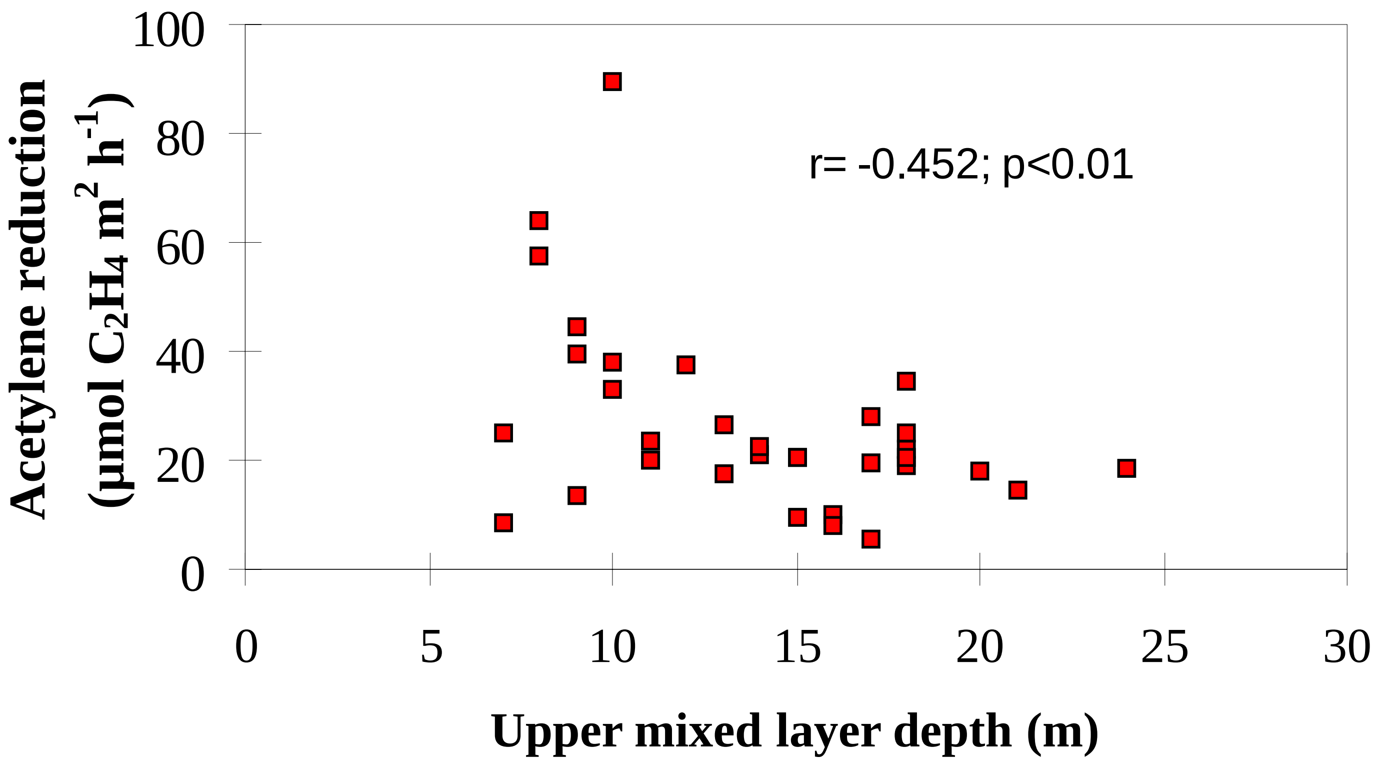
- **Irradiance**

(high irradiance favors *most* cyanobacteria)

Salinity

- **Selects for specific taxa**

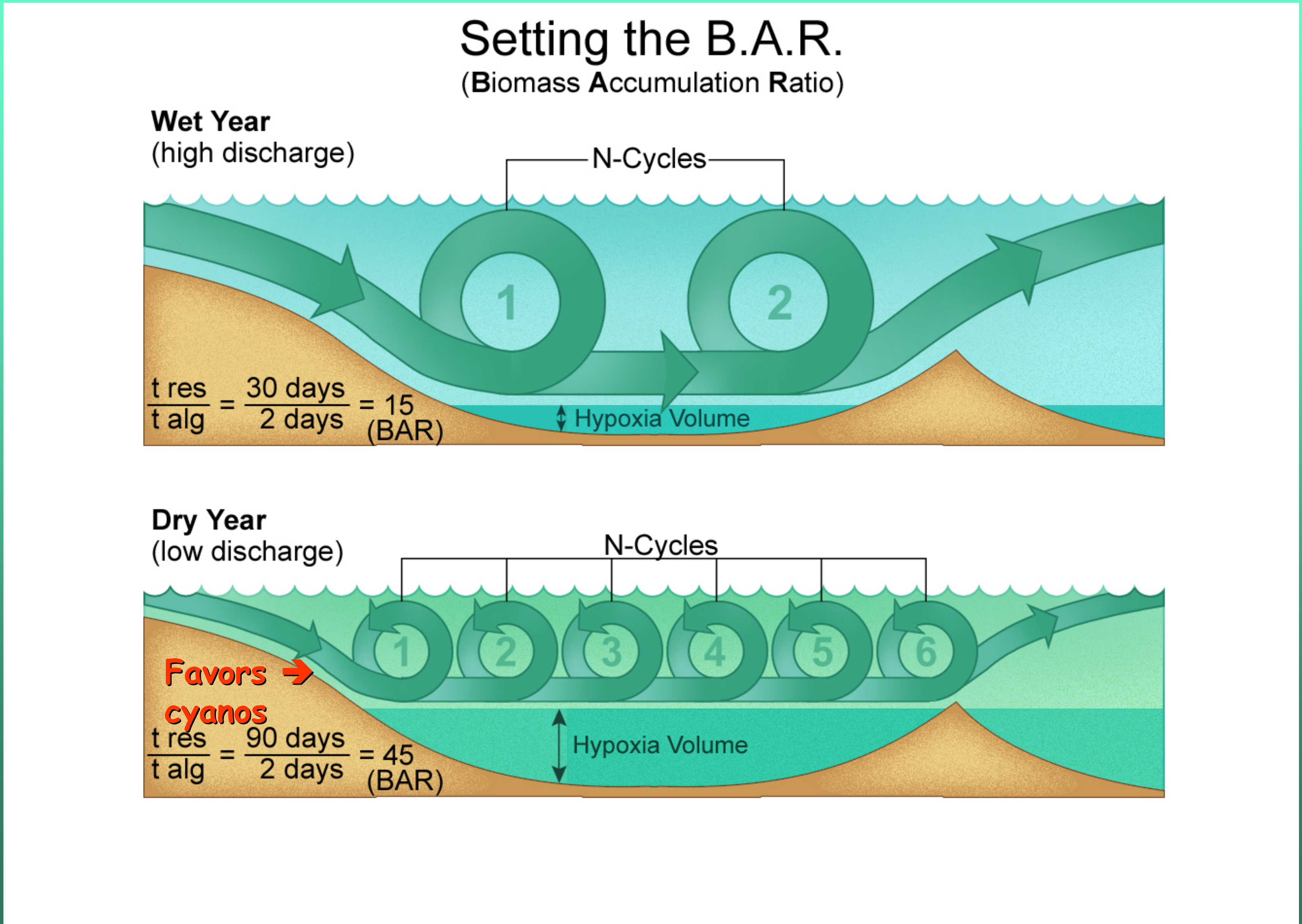
Turbulence in the Baltic Sea: Impacts on N_2 fixation



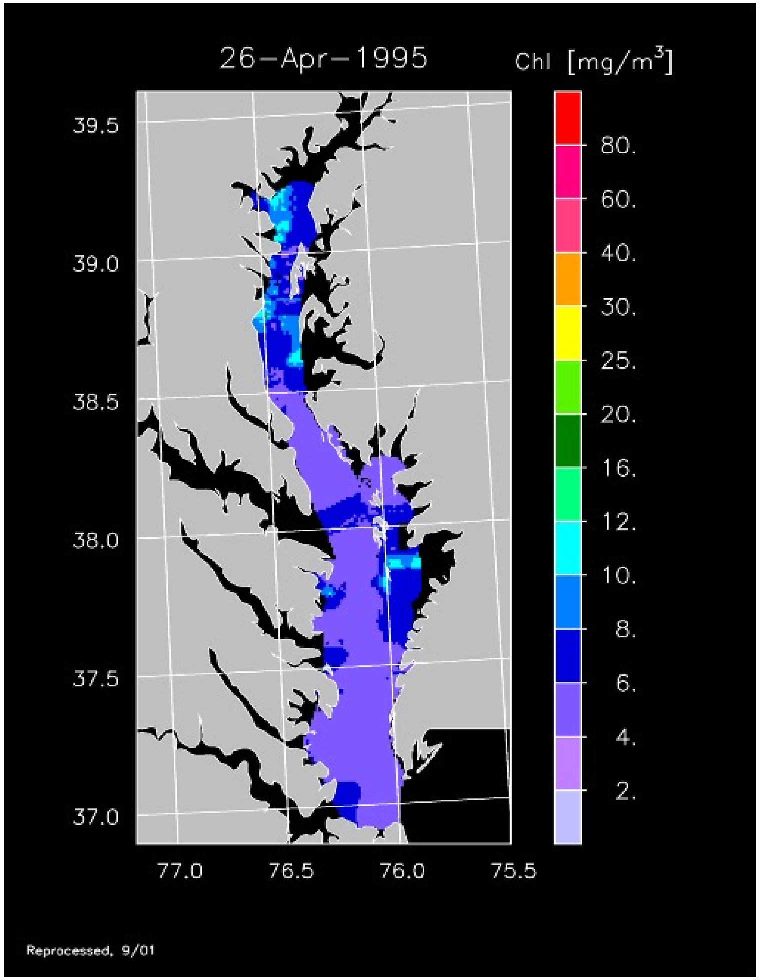
Take home message: 1) Mixing depth matters, 2) Mixing affected by climate!

Moisander 1992

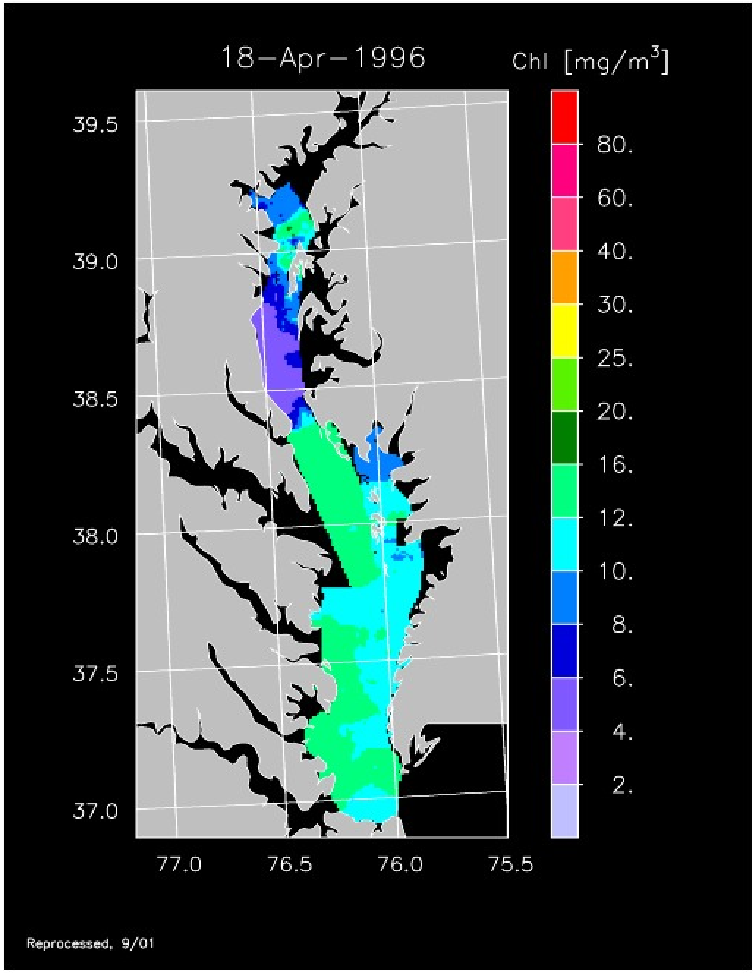
Water Residence Time Impacts CyanoHAB Growth and Bloom Potential in Nutrient-enriched Waters



Chesapeake Bay: Remotely sensed chl-a from SeaWiFS Aircraft Simulator (SAS II) during low flow ('95) and high flow ('96) years



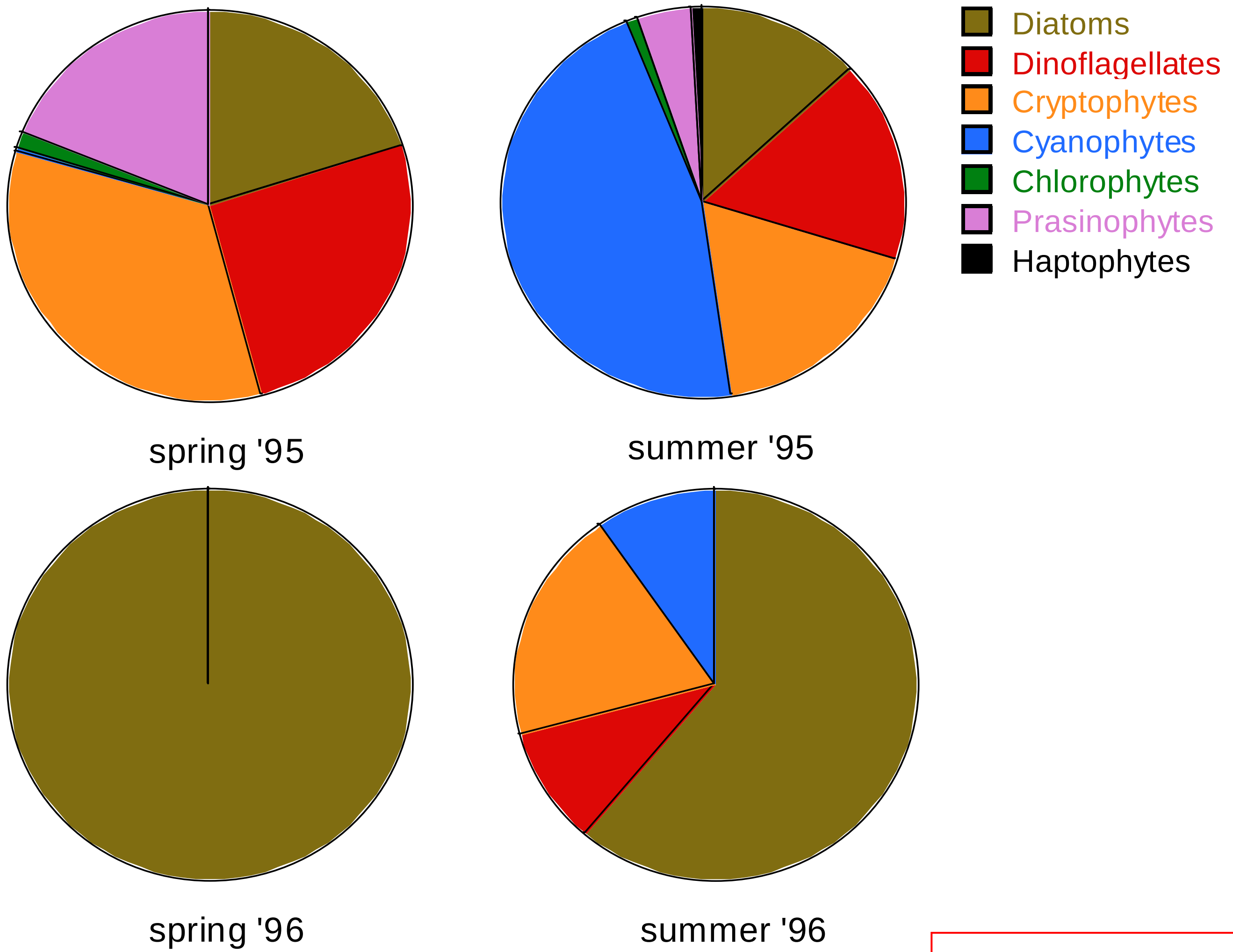
spring '95



spring '96

Harding et al. 2006

Chesapeake Bay CHEMTAX – contrasting flow years



Adolf et al. 2007

Hydrodynamics

- **Water residence time/flushing**

(long residence time favors cyanobacterial dominance)

- **Turbulence**

(Low turbulence conditions favor cyanobacteria, especially N_2 fixers)

Climatic Factors

- **Temperature**

(high temperature favors cyanobacteria)

- **Irradiance**

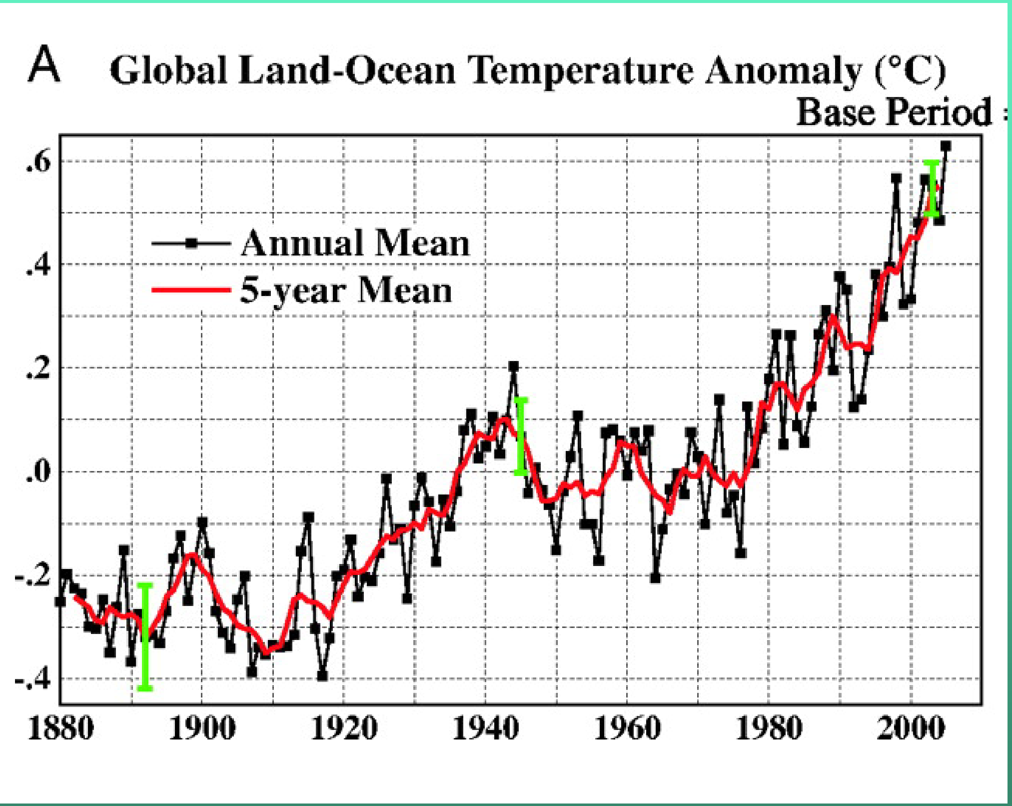
(high irradiance favors *most* cyanobacteria)

Salinity

- **Selects for specific taxa**

Climate change – the data

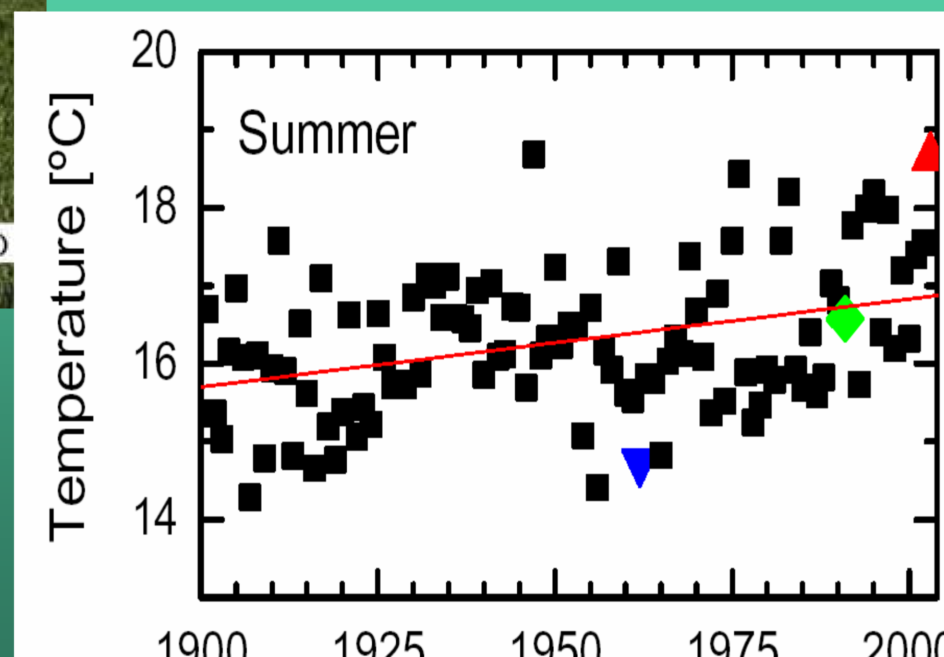
Temperature



Additional Evidence

2003 was the hottest summer in 500 years in Europe!

2005 was the hottest year ever in N. America

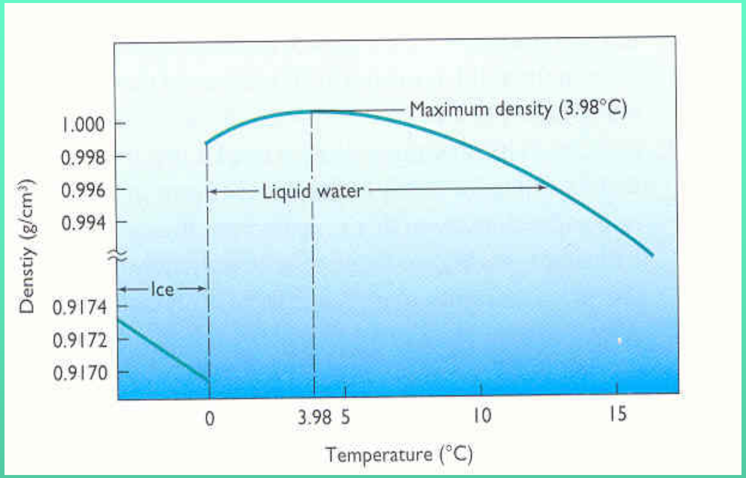


!!

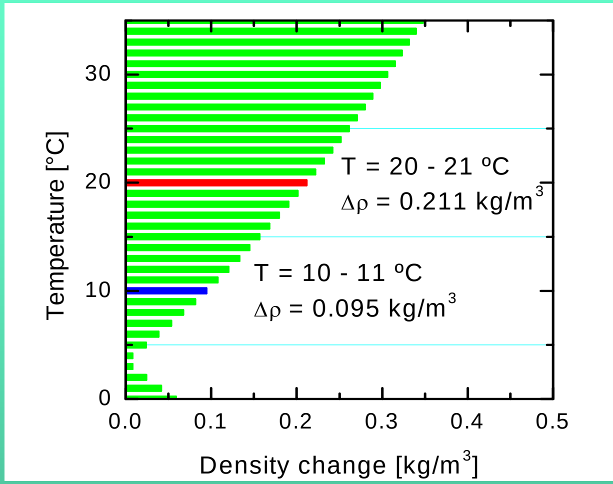
Huisman et al. 2006, KNMI, De Bilt

Temperature affects stratification

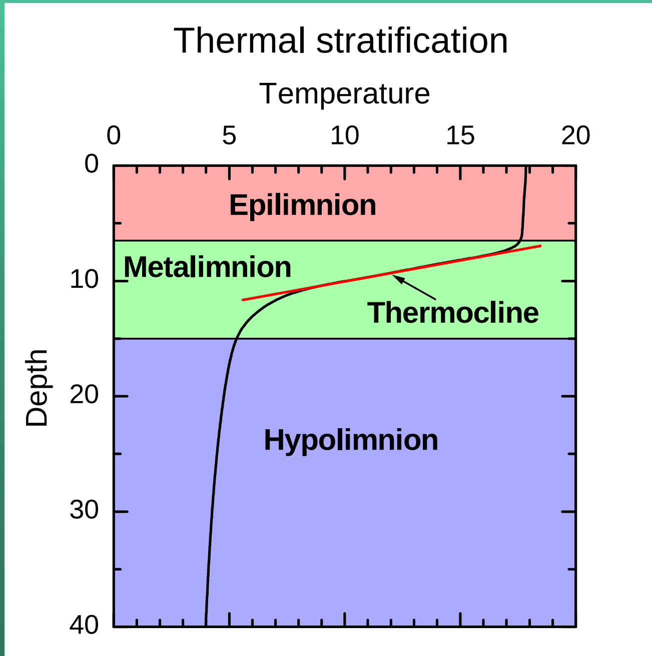
density profile of water

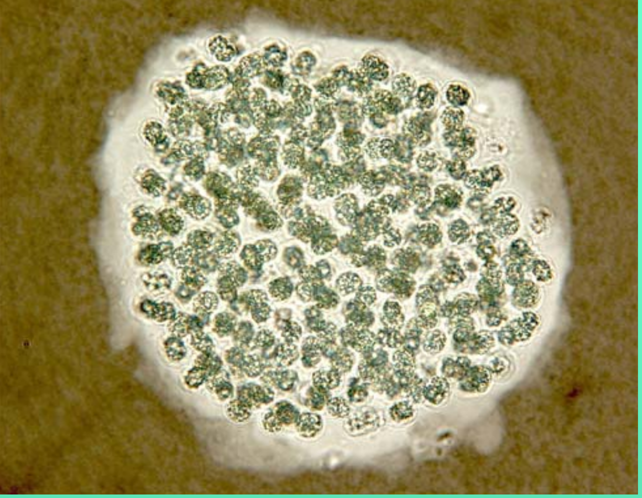


➔ density change per 1 ºC



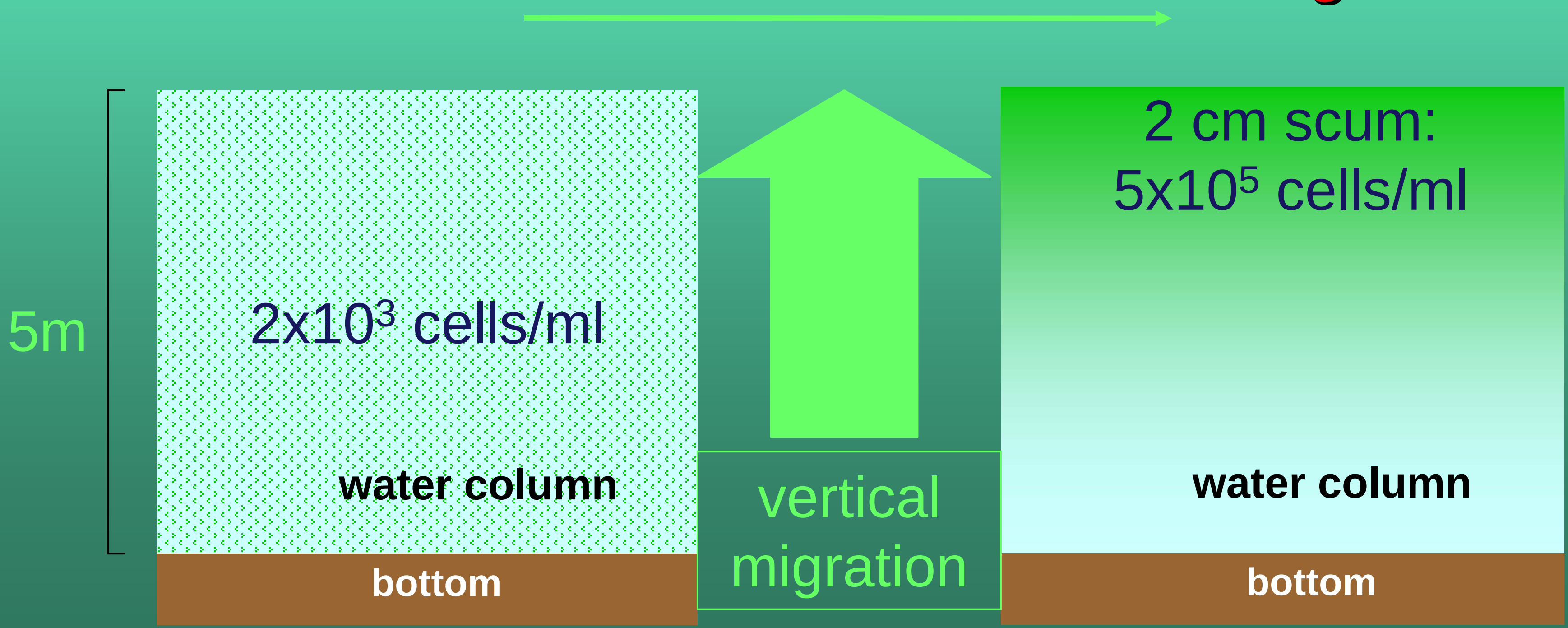
➔ At higher temperature, stratification is stronger !



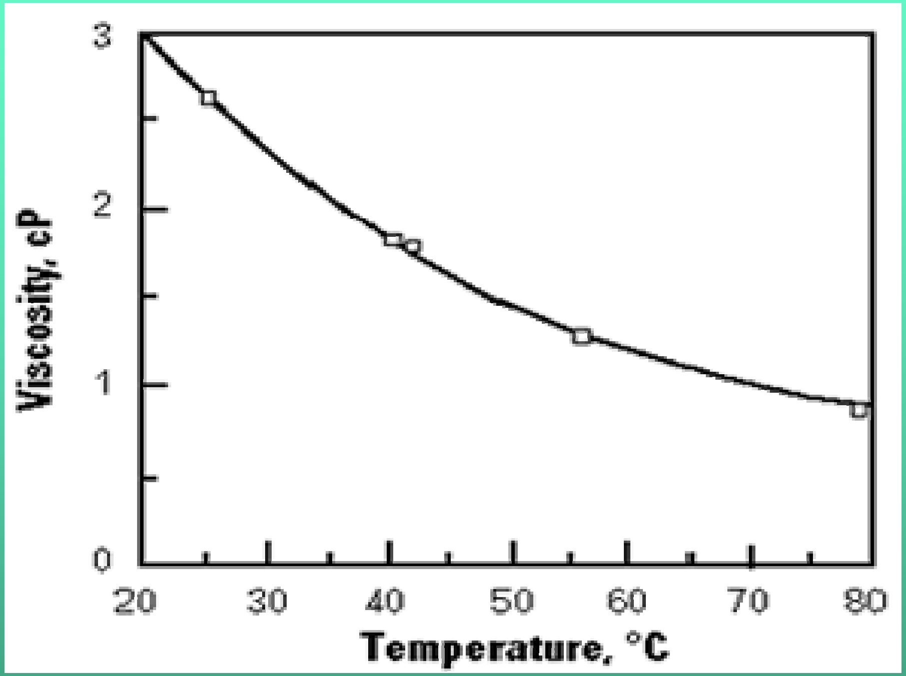


Microcystis
Buoyant CyanoHAB favored by Stronger Stratification

Calm weather, Little mixing



Temperature also affects viscosity

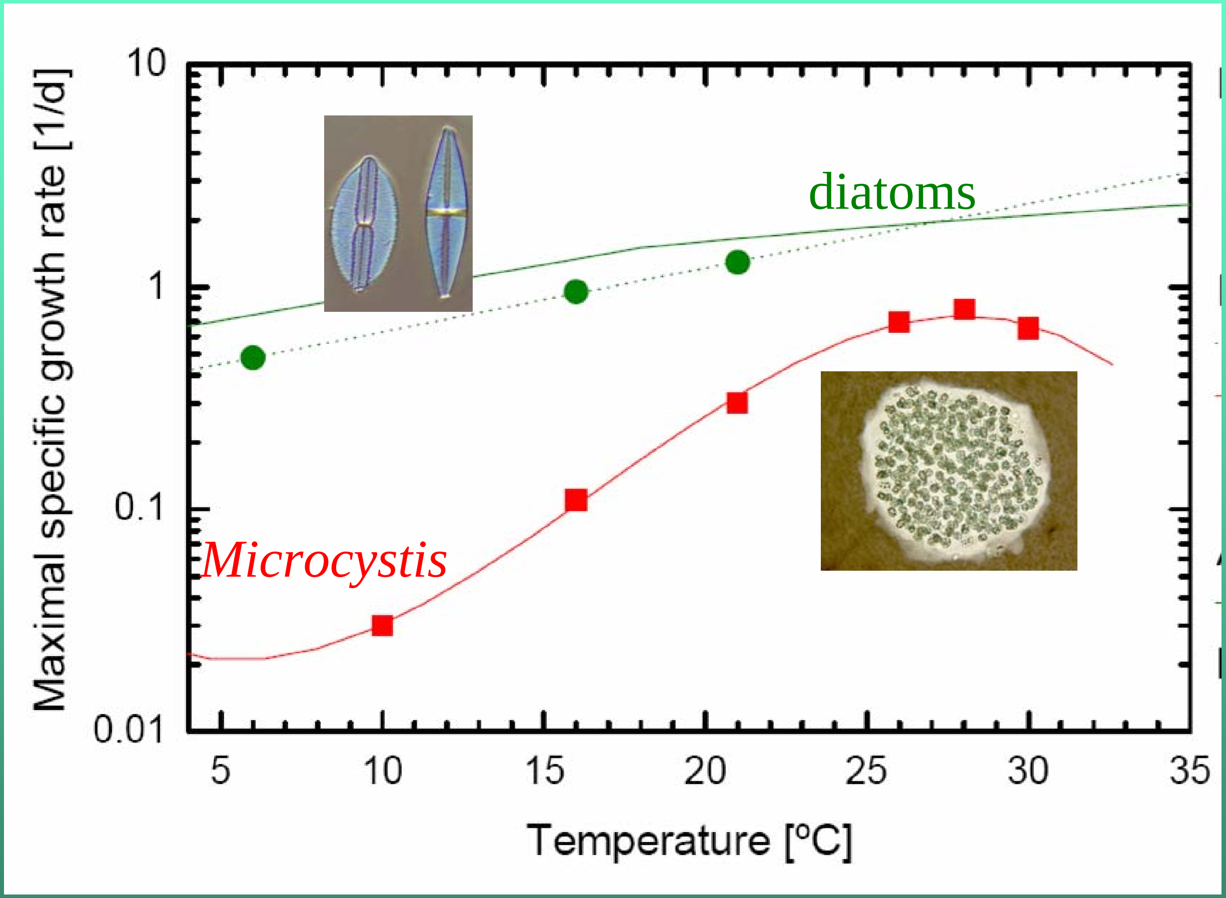


Stokes' Law:

$$v_z = \phi \frac{g(\rho_w - \rho_o)d^2}{18\mu}$$

➔ At higher temperature,
sinking species sink faster
buoyant species float upwards faster !

and temperature affects growth rates



➔ Growth of *Microcystis* is strongly temperature dependent !

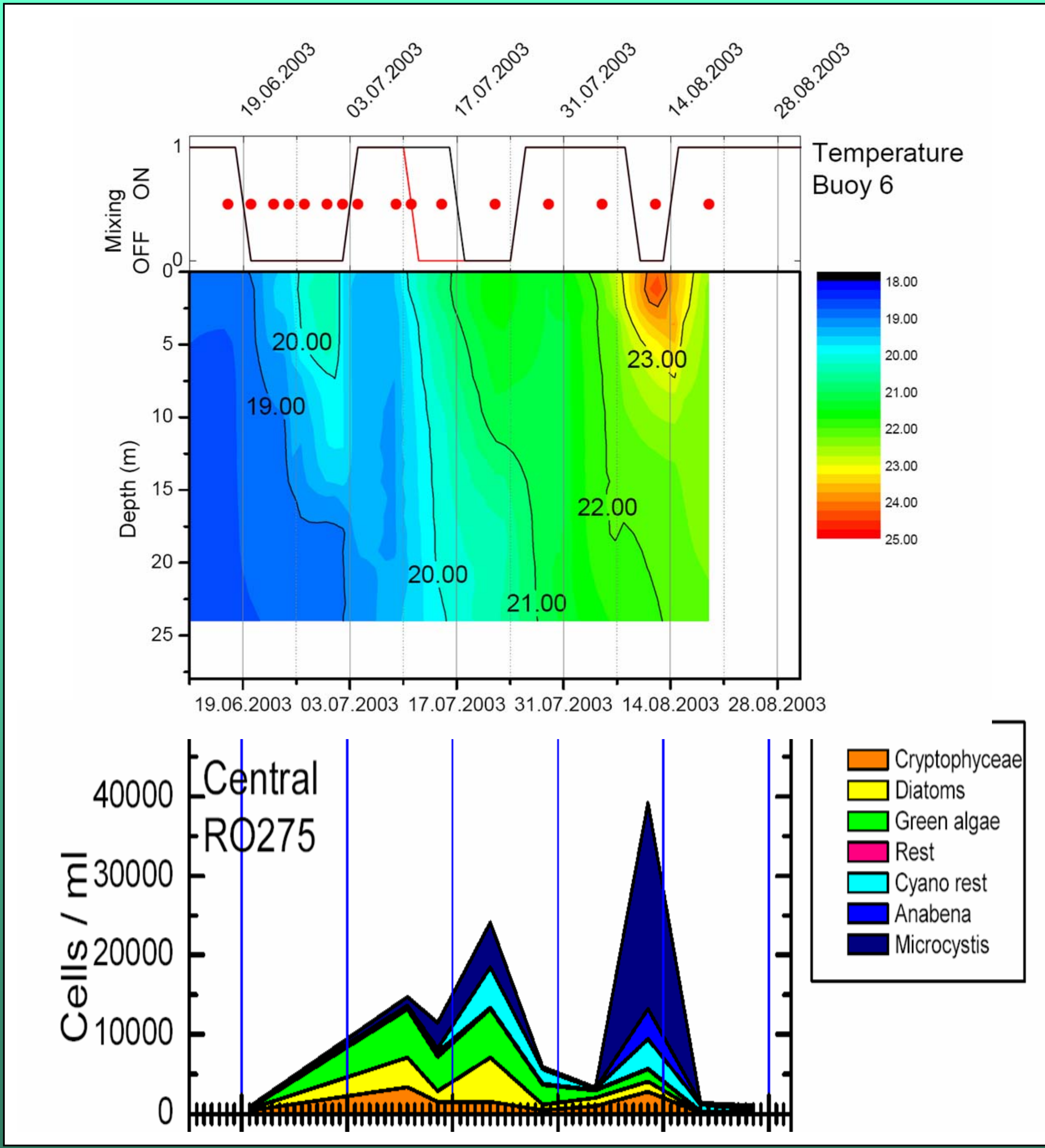
Reynolds (1997)

Mid August 2003:

Lake Nieuwe Meer, Holland

Heatwave & little mixing

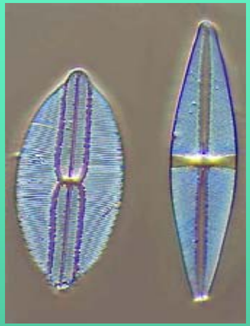
Microcystis benefits!



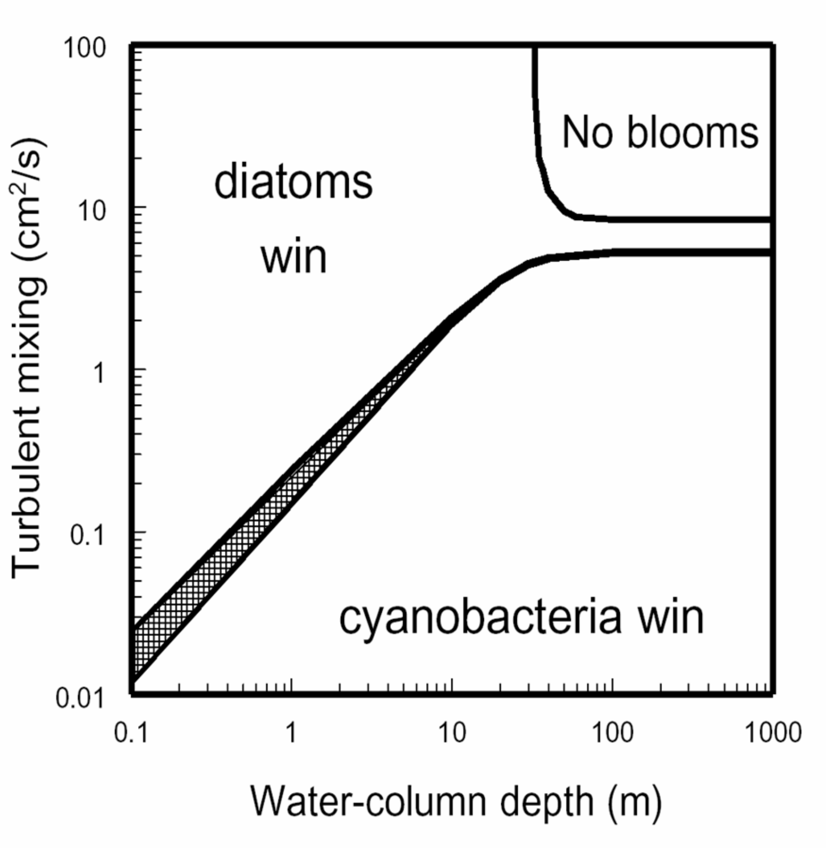
Jöhnk & Huisman, submitted

Model prediction

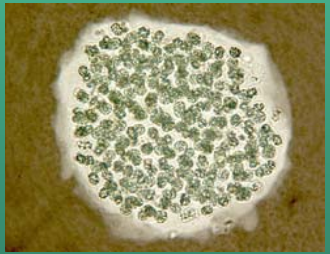
High turbulence: ***sinking*** species win



Sinking diatoms



Buoyant cyanobacteria

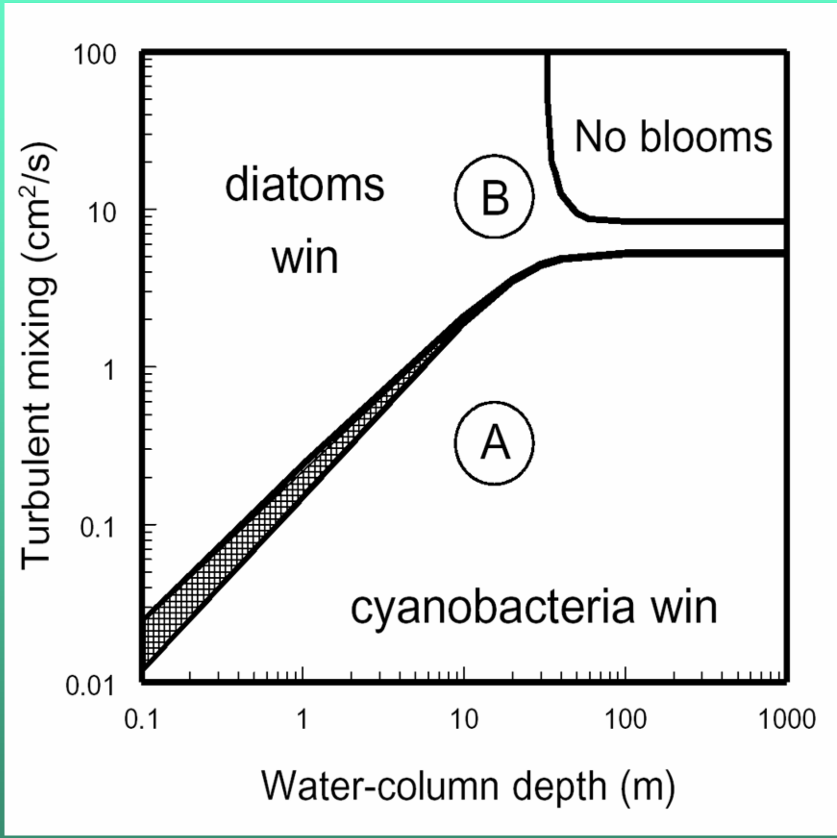


Low turbulence: ***buoyant*** species win

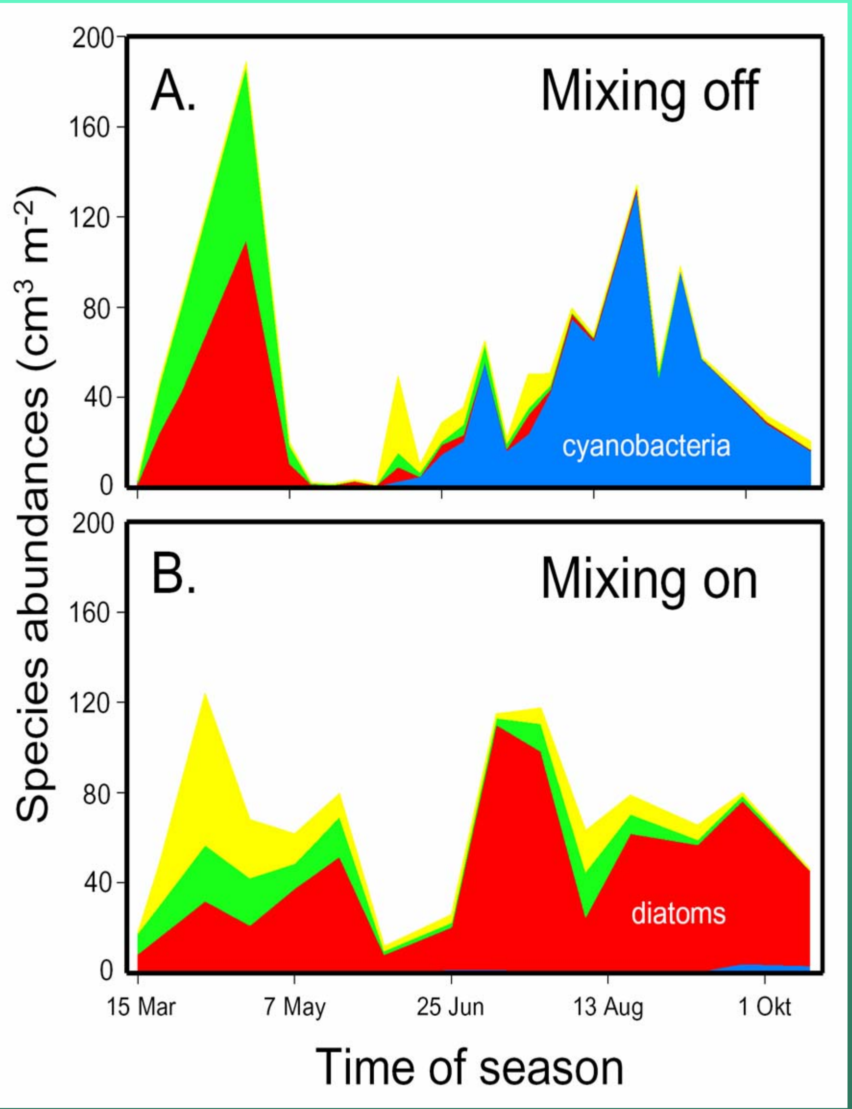
Huisman et al. 2006

Testing the Model

Theory



Lake data

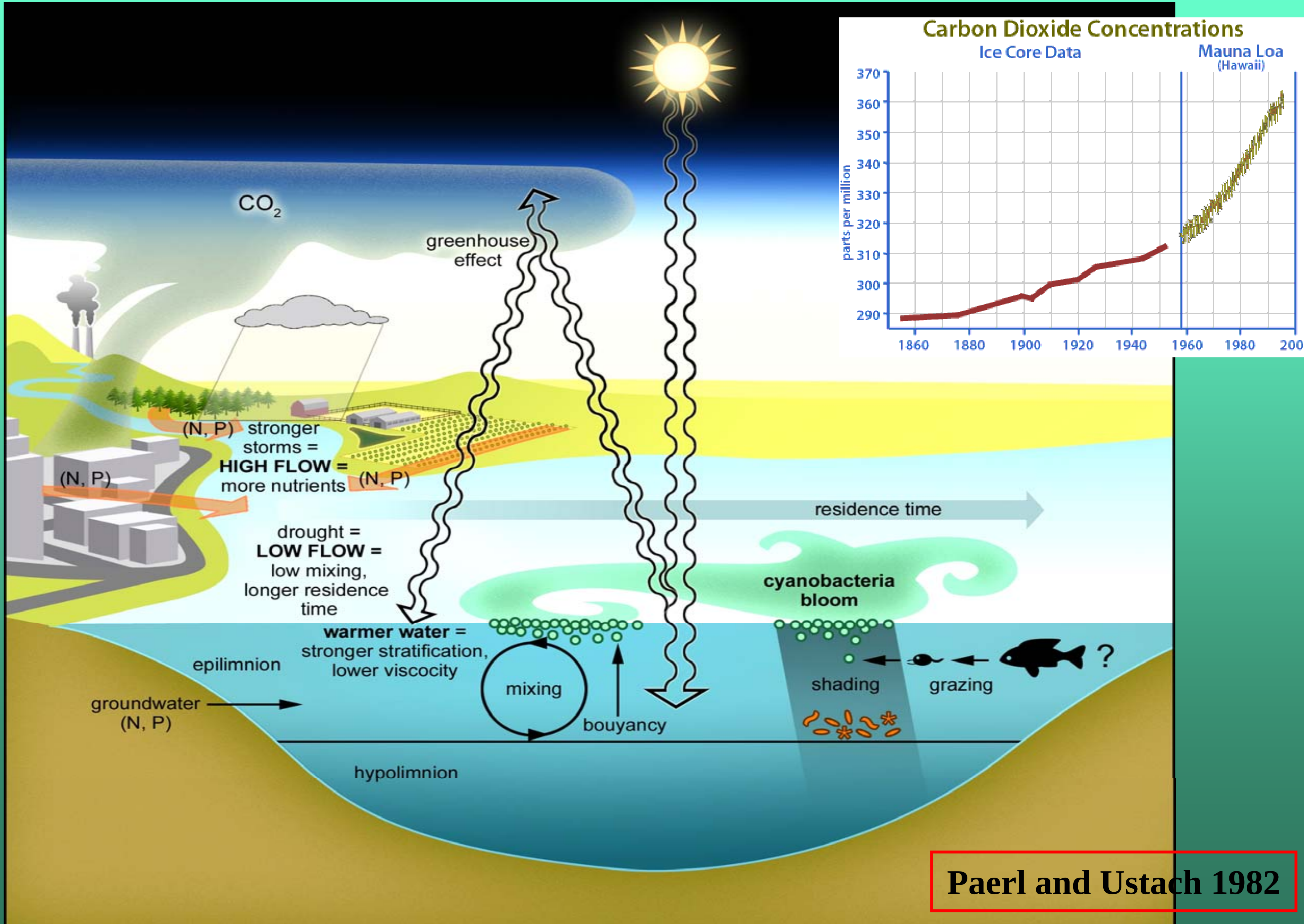


A = mixing off

B = mixing on

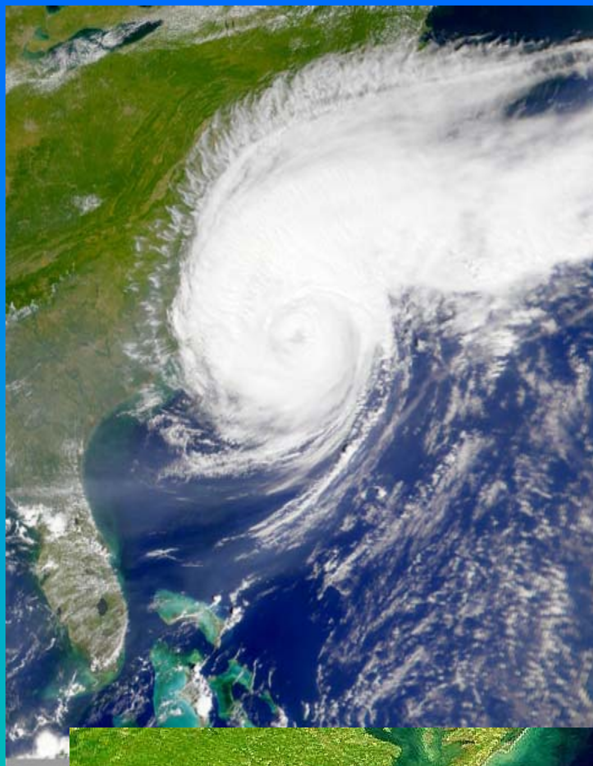
Huisman et al., 2004

Global climate change and CyanoHAB potential

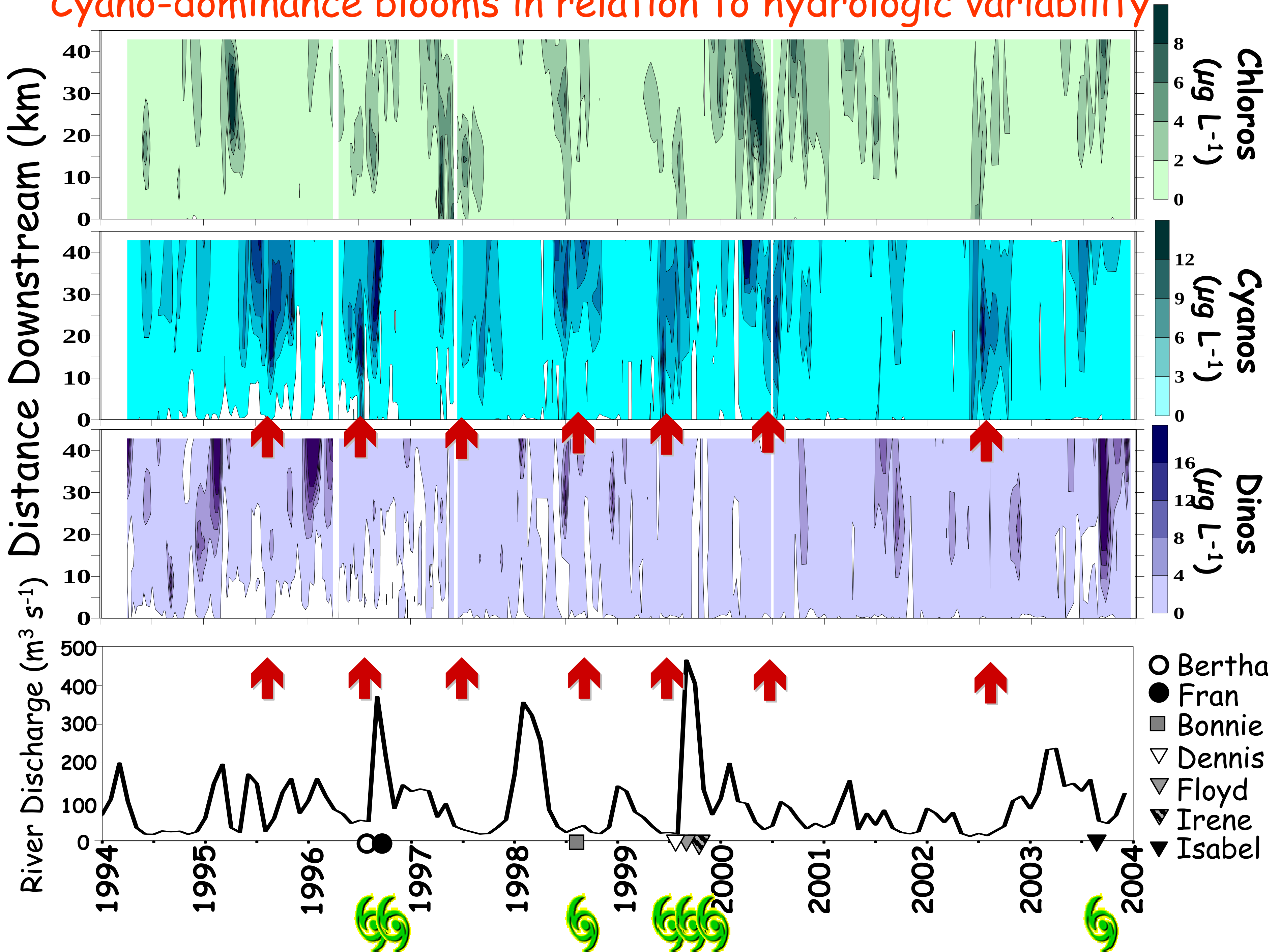


Paerl and Ustach 1982

Cyanos and extreme climatic (hydrologic) events



Cyano-dominance blooms in relation to hydrologic variability



Hydrodynamics

- **Water residence time/flushing**

(long residence time favors cyanobacterial dominance)

- **Turbulence**

(Low turbulence conditions favor cyanobacteria, especially N_2 fixers)

Climatic Factors

- **Temperature**

(high temperature favors cyanobacteria)

- **Irradiance**

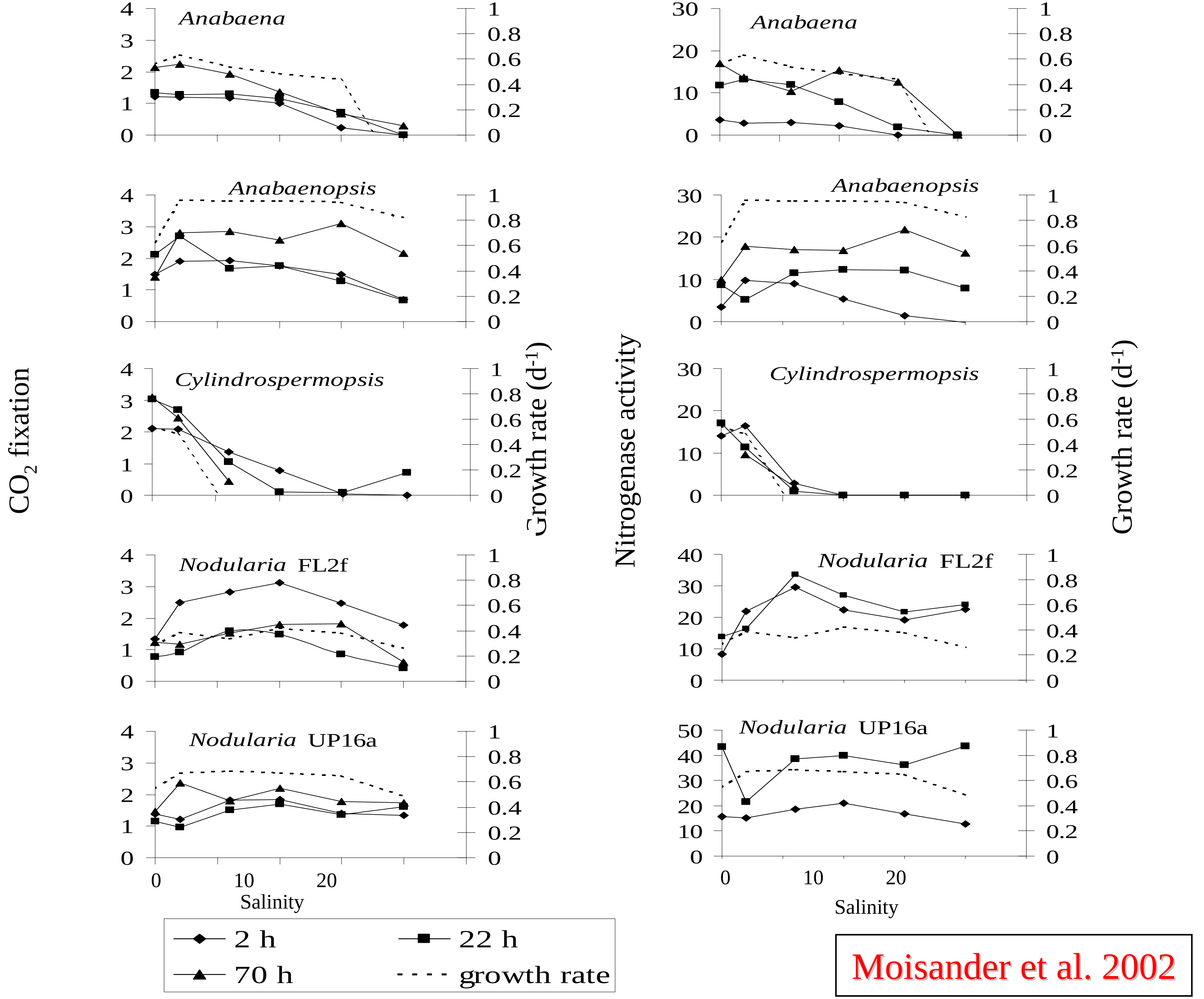
(high irradiance favors *most* cyanobacteria)

Salinity

- **Selects for specific taxa**

Salinity tolerance of a various diazotrophic cyanos

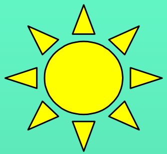
Take home message: Salinity is not necessarily a barrier for all CyanoHABs



Moisander et al. 2002

Climate change (warming) Favors CyanoHABs

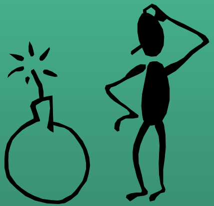
- ↑ temperatures; optimal temperatures for CyanoHABs (>20º C)
- ↑ vertical temperature stratification/stabilization



- Rainfall and hydrologic conditions will change

  In some regions more rain & runoff, which brings in more nutrients and can stratify the water column.
  In others regions more protracted droughts
  Both conditions favor CyanoHABs

- More extreme events tend to favor cyanoHABs



- Why? Cyanos have been on Earth for over 3 billion years.
  They've seen it all! ☺3~O~O~O~O~O~O~O~O~O!!

So What's Feasible? CHAB Control & Management

- **Nutrient input reductions**

N, P, N&P, Fe?

Must establish bloom thresholds & resolve timing issues

Dual N&P reductions are often most effective (e.g. *Cylindro*)

- **Nutrient ratio manipulations**

Molar N:P >15 favors non-cyanobacterial taxa

***Caveats*: must accompany overall nutrient reduction;**

at high N concentrations non-N_2 fixing cyanos (e.g. *Microcystis, Lyngbya, Oscillatoria)* may still dominate

- **Reduce water residence time**

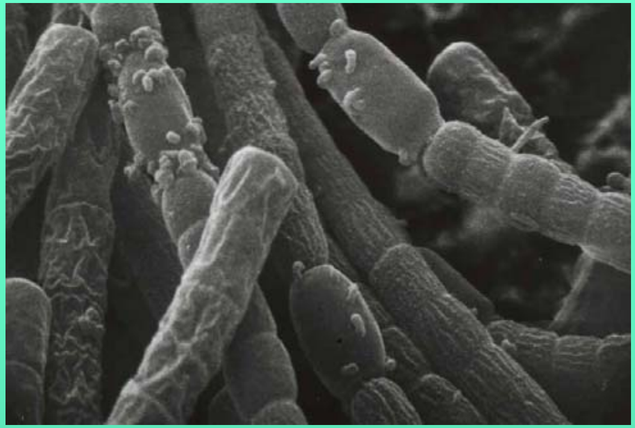
Increase flushing rate, if water supply is available

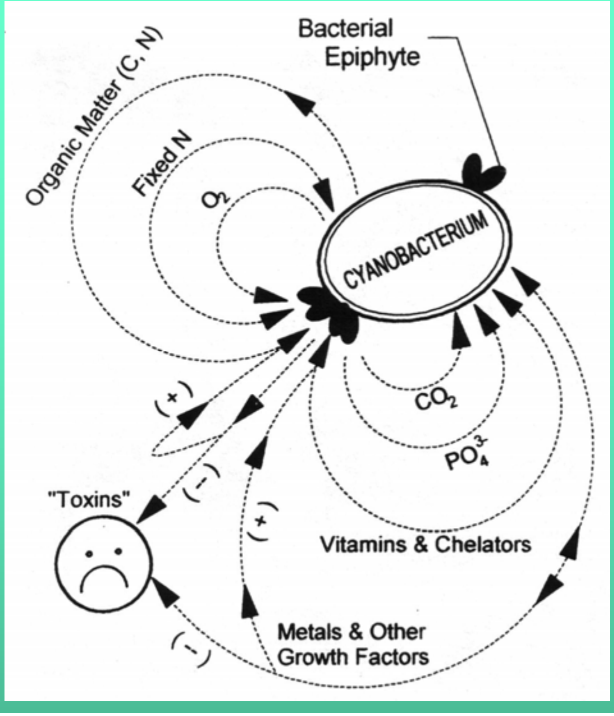
Increase water exchange with coastal ocean

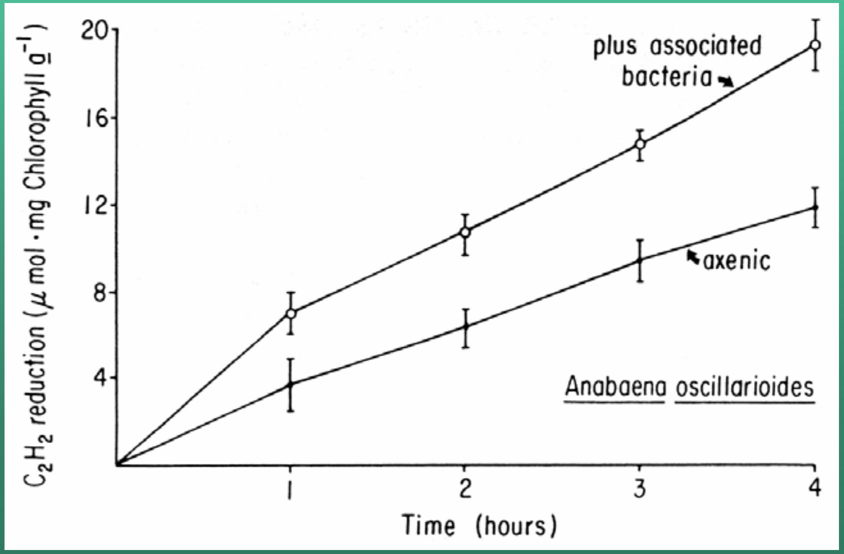
- **Biomanipulation??**

Experimental, ecosystem consequences must be assessed

Role of "toxins" in biotic interactions??







Paerl 1982, Paerl & Millie 1996

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