Climate Change Impacts on Harmful Algal Blooms in U.S. Freshwater:

A Screening-Level Assessment

Steve Chapra

Tufts UNIVERSITY

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Harmful Algal Blooms (HABs)

Red tides
(Dinoflagellates)

Marine

Bluegreen Algae
(Cyanobacteria)

Freshwater and Estuaries

Lake Taihu
China

A cow killed by consuming Cyanobacteria

Toledo Water Supply Shut Down Due To Lake Erie Microcystis bloom

Environmental Science & Technology

Article

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Climate Change Impacts on Harmful Algal Blooms in U.S. Freshwaters: A Screening-Level Assessment

Steven C. Chapra,[†] Brent Boehlert,[*,‡,§] Charles Fant,[‡] Victor J. Bierman, Jr.,[∥] Jim Henderson,[⊥] David Mills,[#] Diane M. L. Mas,[∇] Lisa Rennels,[‡] Lesley Jantarasami,[○] Jeremy Martinich,[○] Kenneth M. Strzepek,[§] and Hans W. Paerl[∞]

[†]Tufts University, Medford, Massachusetts United States

[‡]Industrial Economics, Inc., Cambridge, Massachusetts United States

[§]Massachusetts Institute of Technology, Cambridge, Massachusetts United States

[∥]LimnoTech, Oak Ridge, North Carolina United States

[⊥]Corona Environmental Consulting, Louisville, Colorado United States

[#]Abt Associates, Boulder, Colorado United States

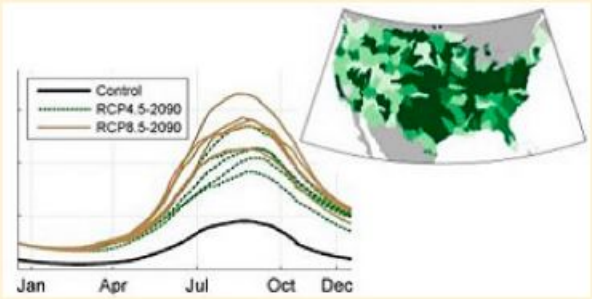
[∇]Fuss & O'Neill, Inc., West Springfield, Massachusetts United States

[○]U.S. Environmental Protection Agency (EPA), Washington, D.C. United States

[∞]Institute of Marine Sciences, University of North Carolina at Chapel Hill, Morehead City, North Carolina United States

Supporting Information

ABSTRACT: Cyanobacterial harmful algal blooms (CyanoHABs) have serious adverse effects on human and environmental health. Herein, we developed a modeling framework that predicts the effect of climate change on cyanobacteria concentrations in large reservoirs in the contiguous U.S. The framework, which uses climate change projections from five global circulation models, two greenhouse gas emission scenarios, and two cyanobacterial growth scenarios, is unique in coupling climate projections with a hydrologic/water quality network model of the contiguous United States. Thus, it generates both regional and nationwide projections useful as a screening-level assessment of climate impacts on CyanoHAB prevalence as well as potential lost recreation days and associated economic value. Our projections indicate that CyanoHAB concentrations are likely to increase primarily due to water temperature increases tempered by increased nutrient levels resulting from changing demographics and climatic impacts on hydrology that drive nutrient transport. The combination of these factors results in the mean number of days of CyanoHAB occurrence ranging from about 7 days per year per waterbody under current conditions, to 16−23 days in 2050 and 18−39 days in 2090. From a regional perspective, we find the largest increases in CyanoHAB occurrence in the Northeast U.S., while the greatest impacts to recreation, in terms of costs, are in the Southeast.



SCREENING ASSESSMENT

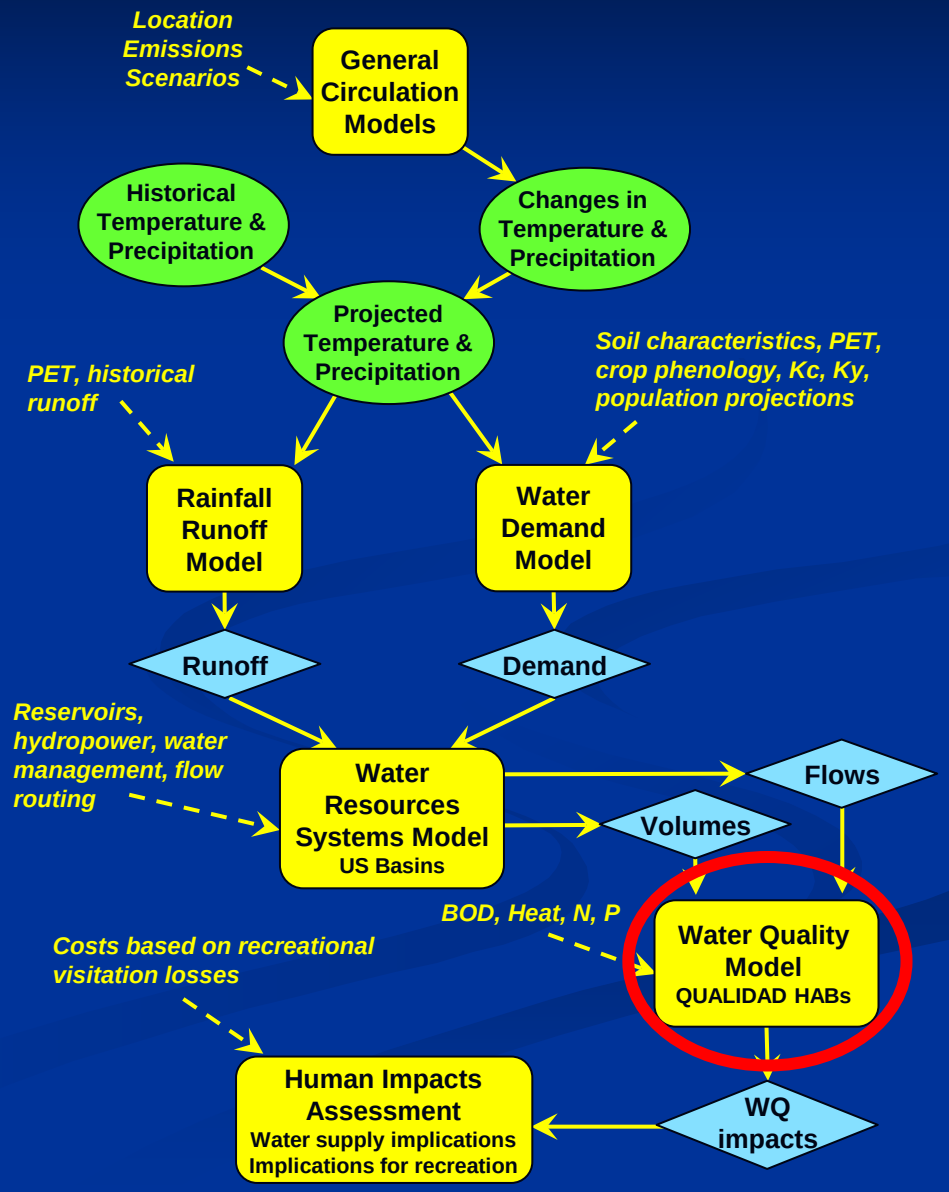
- Intentionally simplified
- Built entirely on well-established and accepted process formulations, and transport and fate mechanisms, rather than in developing new modeling methods or conducting site-specific, data-intensive calibration.
- Not intended to inform management of individual waterbodies
- Applications:
  - Support planning, policy, and identify data or methodological gaps to guide future research on an inherently uncertain issue
  - Intended to quantify and monetize the multisector risks of inaction on climate change and the benefits to the U.S. of global reductions in greenhouse gas emissions.

Climate Change Impacts on Harmful Algal Blooms in U.S. Freshwaters: A Screening-Level Assessment

TEAM

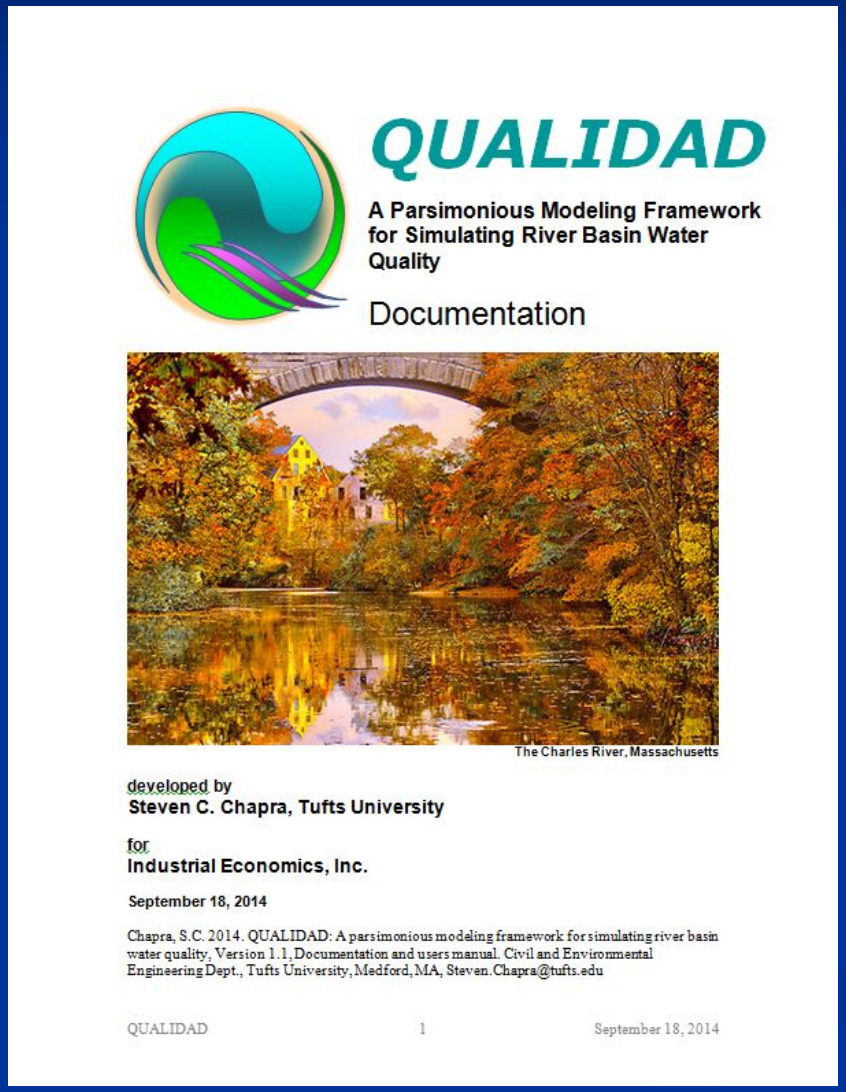
Steve Chapra	Tufts University
Hans Paerl	Univ. North Carolina
Ken Strzepek	MIT
Lesley Jantarasami	U.S. EPA (DC)
Jeremy Martinich	U.S. EPA (DC)
Vic Bierman	LimnoTech
Brent Boehlert	Industr. Econ./MIT
Chas Fant	Industr Econ.
Jim Henderson	Abt Assoc.
David Mills	Abt Assoc.
Diane M.L. Mas	Fuss & O'Neill
Lisa Rennels	Industr. Econ.

- *Freshwater ecologists*
- *Computer Scientists*
- *Economists*
- *Environ. Engineers*
- *Government regulators*
- *Hydrologists*
- *WQ Modelers*
- *Limnologists*



QUALIDAD

"Models should be simple as possible, but no simpler"
Einstein



QUALIDAD

A Parsimonious Modeling Framework for Simulating River Basin Water Quality

Documentation

The Charles River, Massachusetts

developed by
Steven C. Chapra, Tufts University

for
Industrial Economics, Inc.

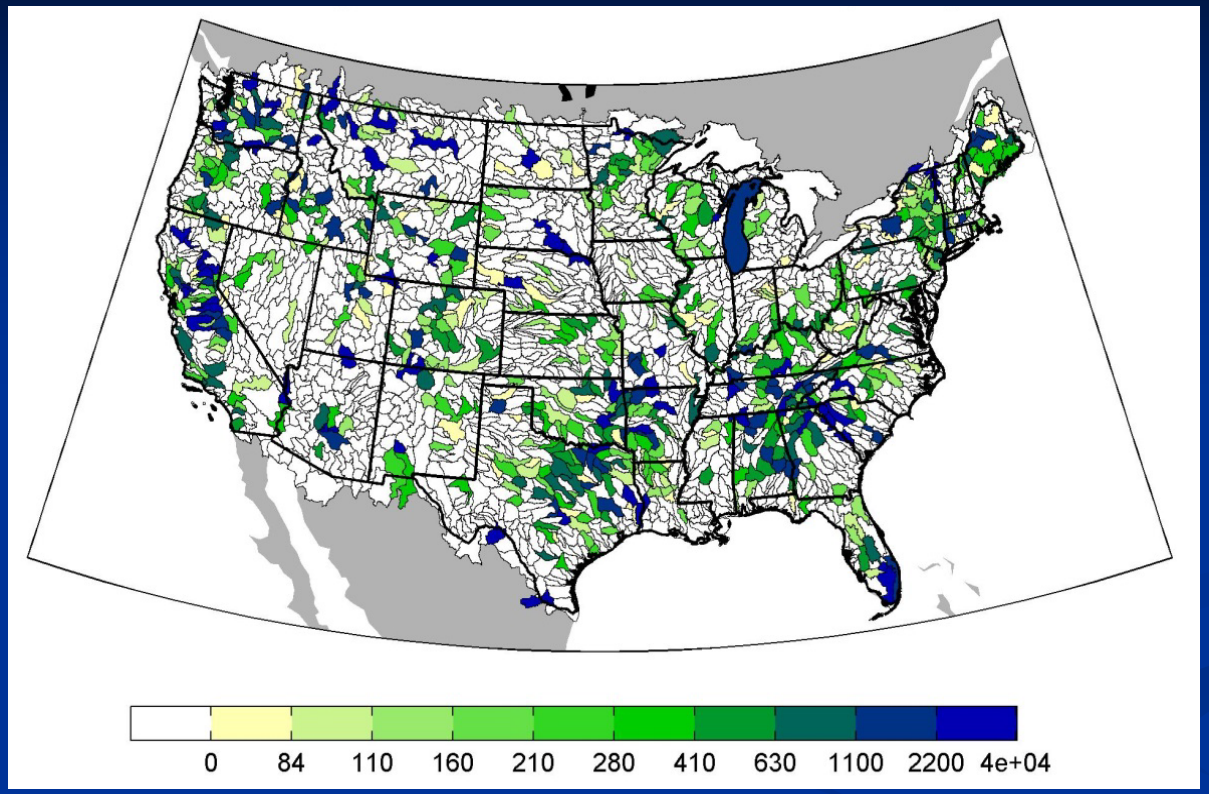
September 18, 2014

Chapra, S.C. 2014. QUALIDAD: A parsimonious modeling framework for simulating river basin water quality, Version 1.1, Documentation and users manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA, Steven.Chapra@tufts.edu

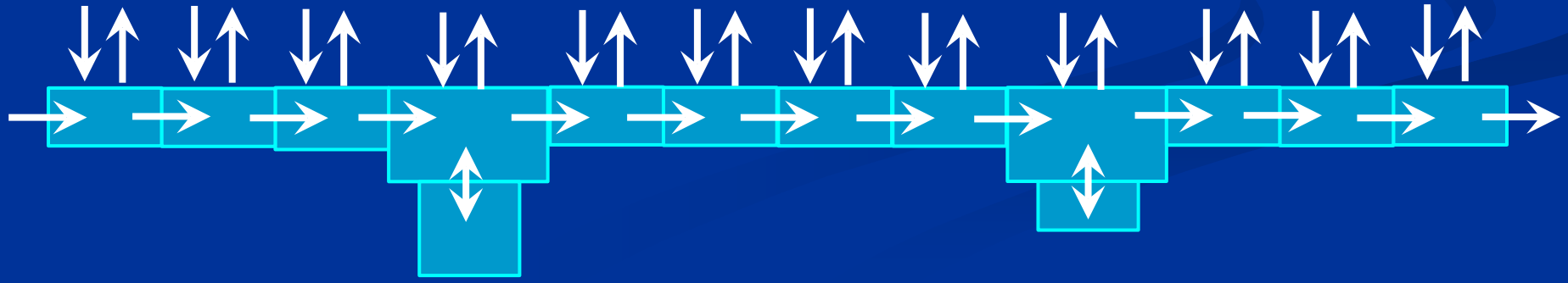
QUALIDAD 1 September 18, 2014

- ***A parsimonious water quality model framework***
- ***River basins (with impoundments)***
- ***Conventional pollution (not toxics)***
- ***Incorrect everywhere but generally correct***
  - ***"Educated guess" model***
  - ***Done all the time for prediction***

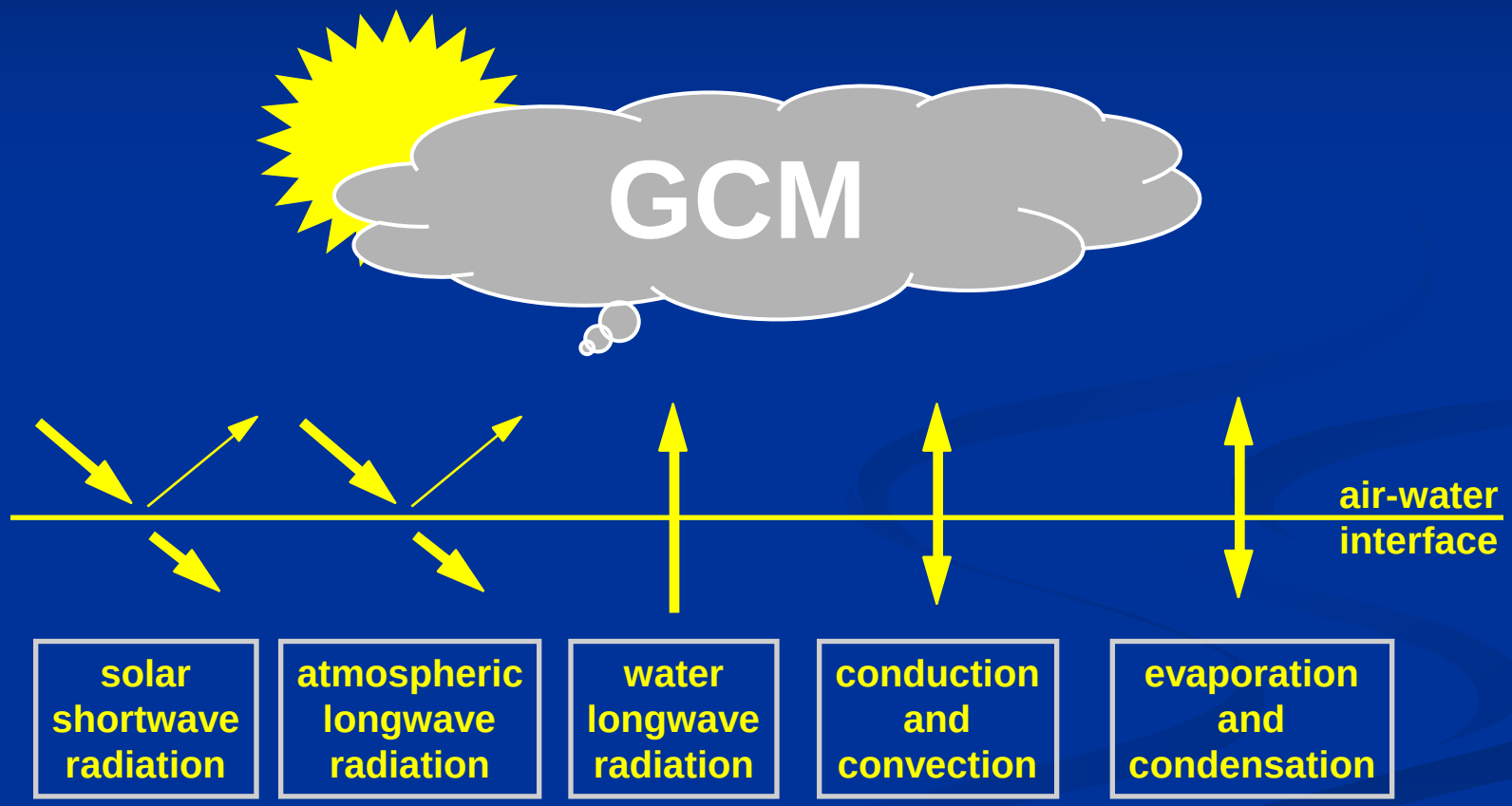
PHYSICS: WATER BALANCE



Drainage, Point sources, Atmosphere, Withdrawals



PHYSICS: HEAT BALANCE



WATER QUALITY: MASS BALANCES

STATE VARIABLES

c_p: particulate organic C
c_d: dissolved organic C
o: dissolved oxygen
n_o: organic N
n_a: ammonia N
n_n: nitrite/nitrate N
p_o: organic P
p_i: inorganic P
a_d: diatoms
a_g: greens
a_f: cyanobacteria (N fixing)
a_n: cyanobacteria (non-N fixing)

Organic carbon (CBOD)

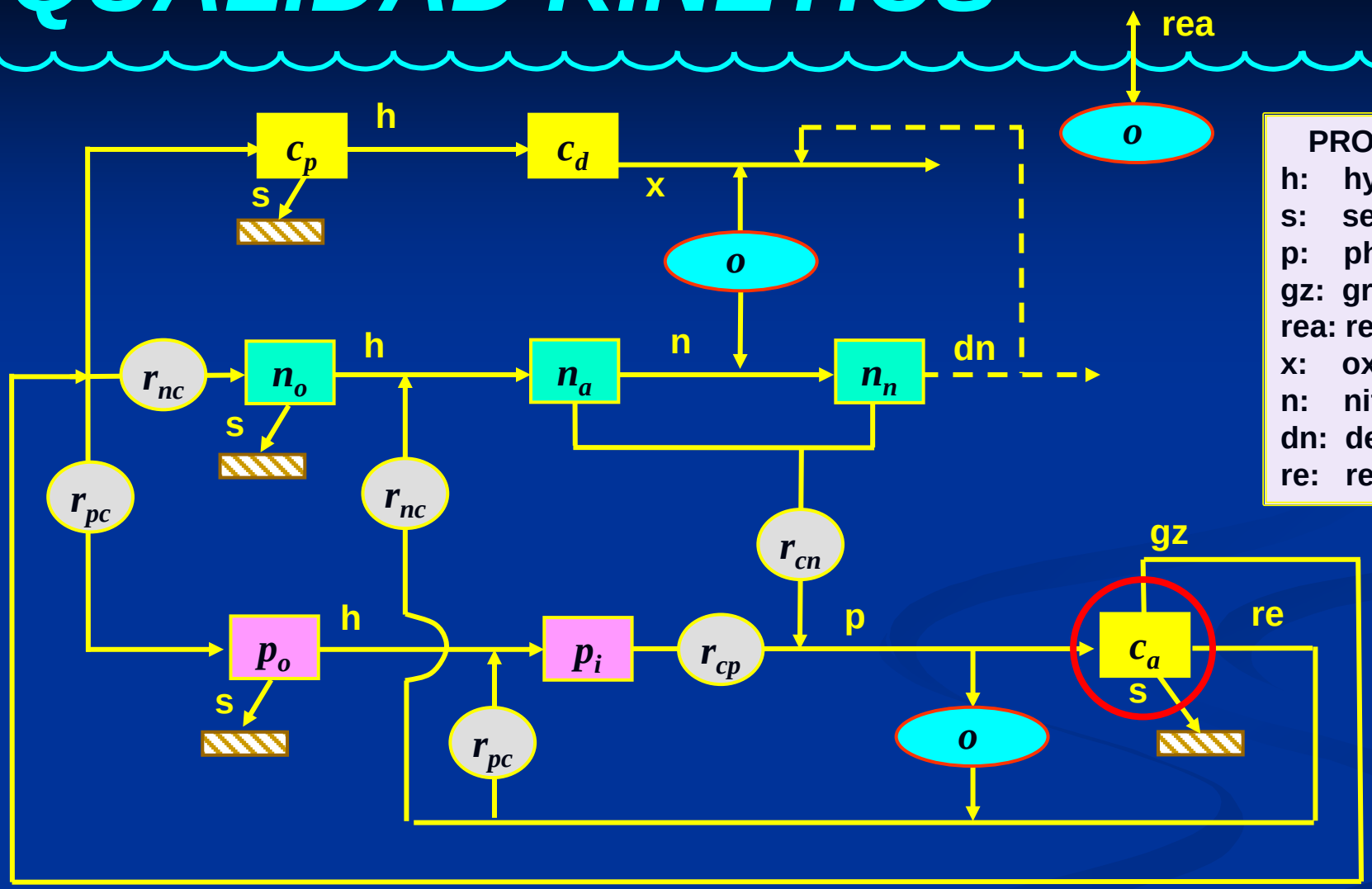
Dissolved oxygen

Nitrogen

Phosphorus

Phytoplankton

QUALIDAD KINETICS



PROCESSES

- h: hydrolysis
- s: settling
- p: photosynth.
- gz: grazing
- rea: reaeration
- x: oxidation
- n: nitrification
- dn: denitrif.
- re: respiration

STATE VARIABLES

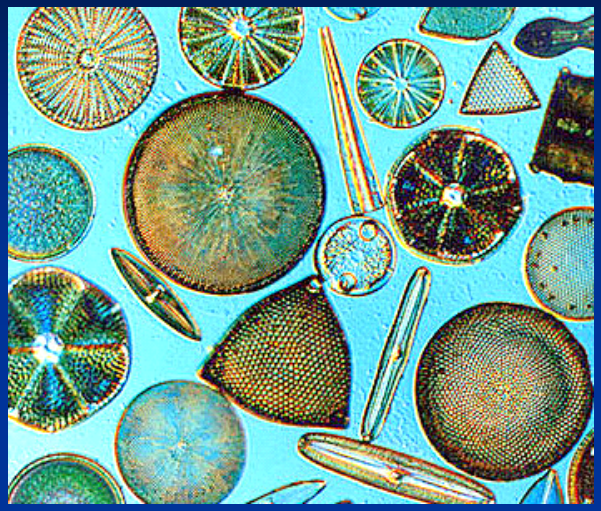
c_p: particulate organic C	c_d: dissolved organic C	o: dissolved oxygen
n_o: organic N	n_a: ammonia N	n_n: nitrite/nitrate N
p_o: organic P	p_i: inorganic P	a: algae

Blue-green algae

"Annie, Phannie, Mike & Oscar"

Name	N-fixation	Toxic
Anabaena	x	x
Aphanizomenon	x	x
Microcystis		x
Oscillatoria	x	x

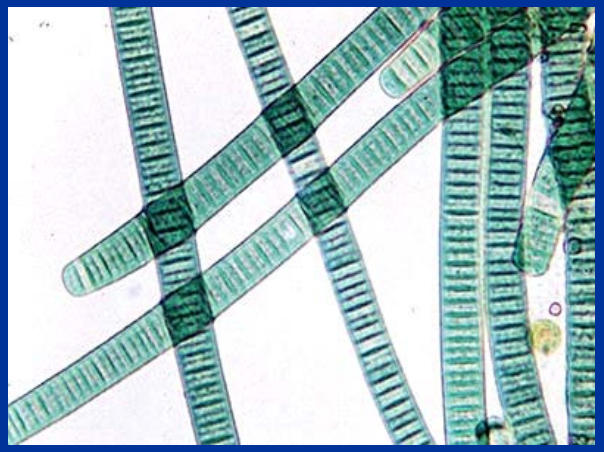
Functional Groups



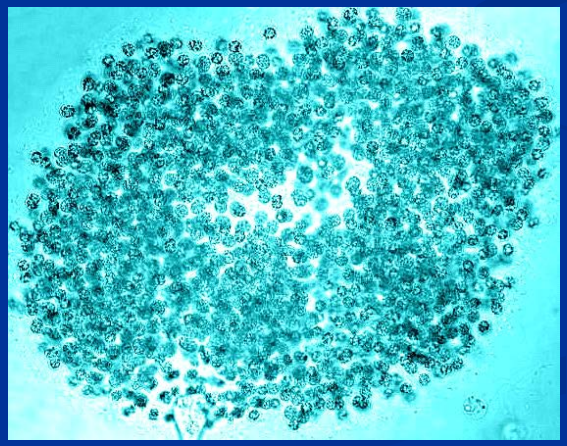
(a) Diatoms

(b) Greens

"Good Algae"
(i.e., nontoxic, edible phytoplankton)



(c) N-fixing Bluegreens "Oscillatoria"

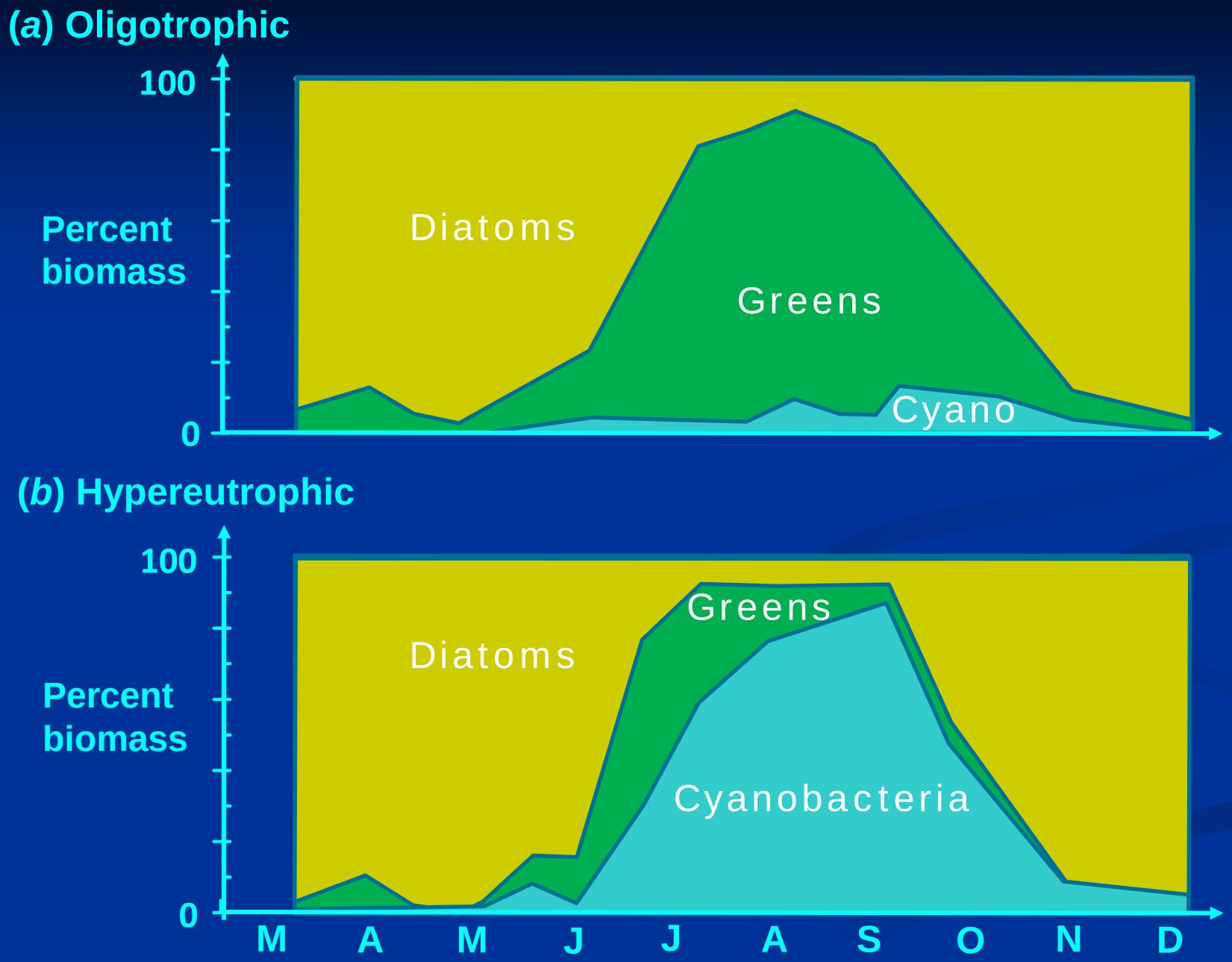


(d) non-N-fixing Bluegreens "Microcystis"

Cyanobacteria (HABs)
(AKA Blue Green Algae)

"The cockroaches of the water"

Seasonal Succession of Phytoplankton in Lakes

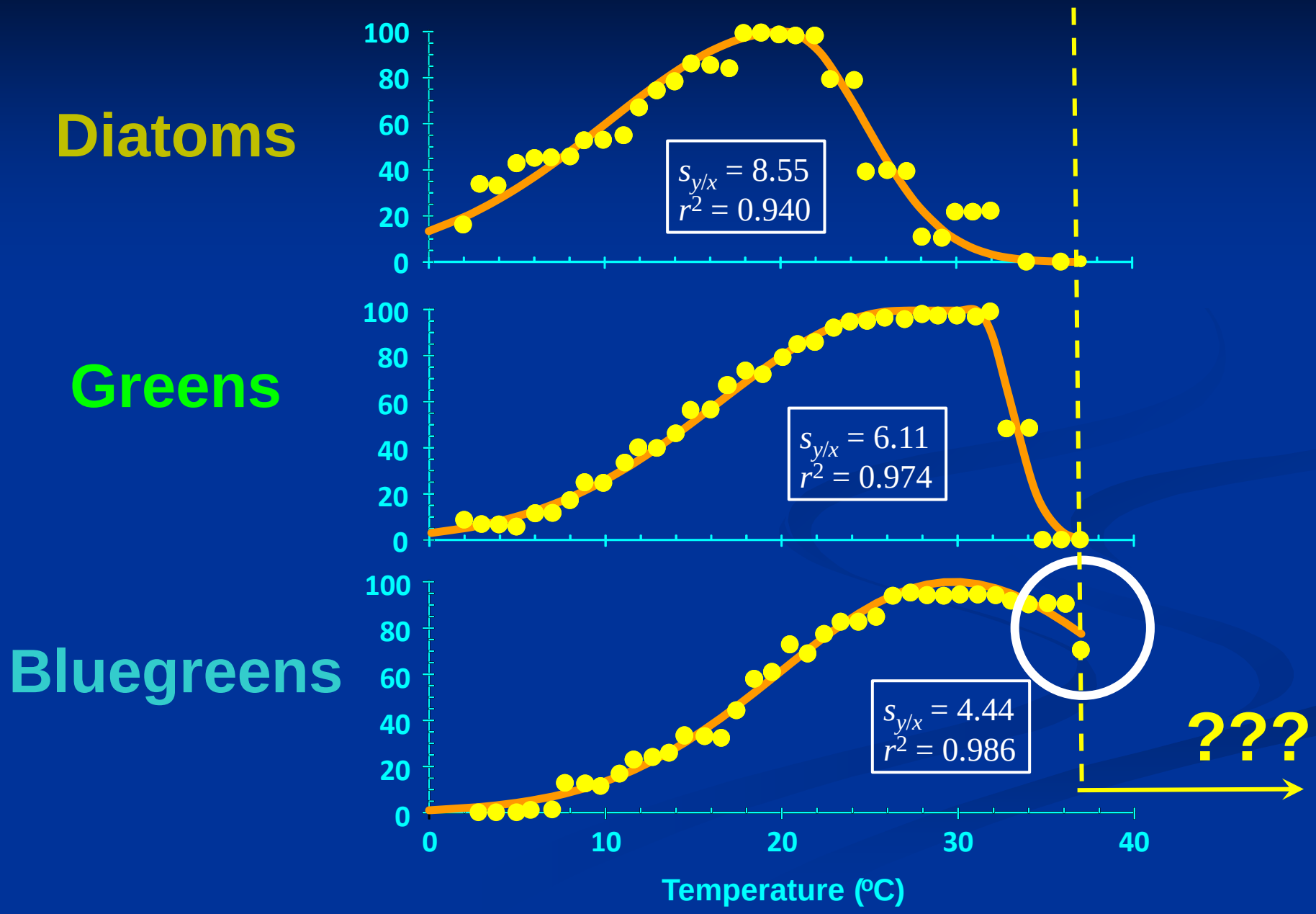


Principal Components Governing Seasonal Succession Patterns

What makes cyanobacteria win?

- ***Temperature***
- ***Nutrient limitation***
- ***Grazing***
- ***Settling/buoyancy***

Paerl & Otten 2012



Algal Nutrient Limitation

- All species need phosphorus
- Only diatoms need silica
- Nitrogen-fixing cyanobacteria (blue-greens) can obtain atmospheric nitrogen (N_2) directly from the water

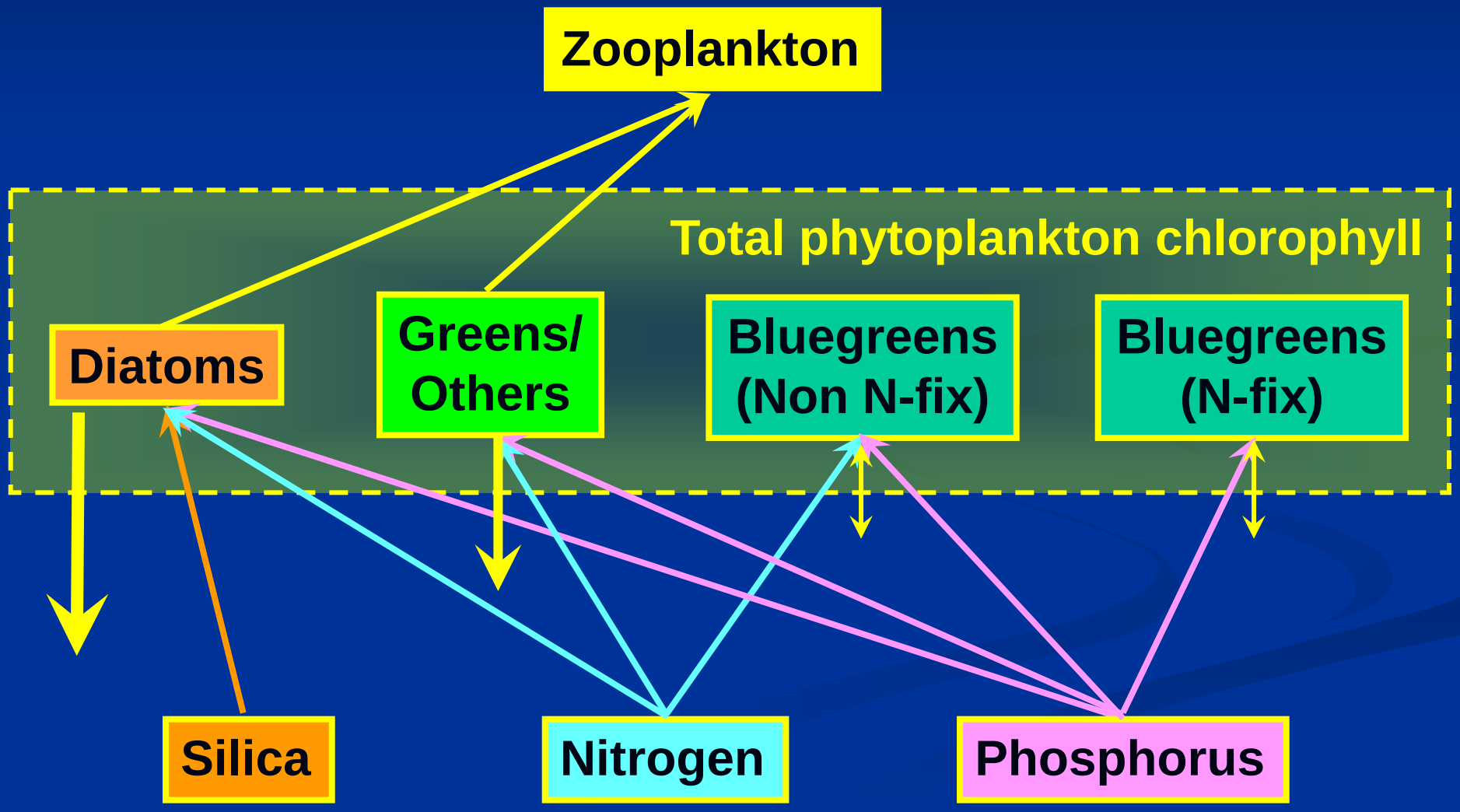
Grazing

- Cyanobacteria are not grazed by zooplankton or other planktivorous organisms (e.g., fish, zebra mussels, etc.)

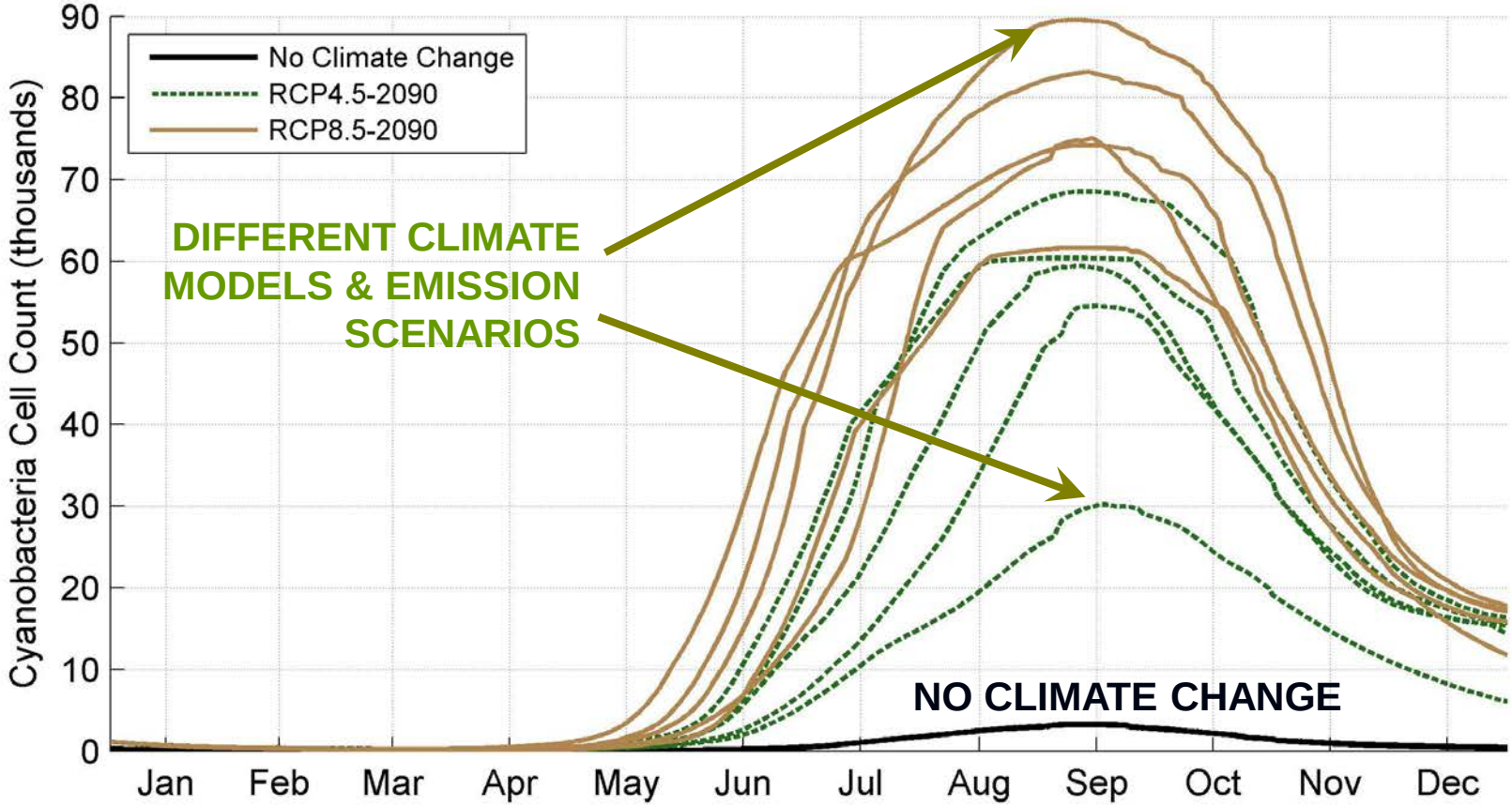
Settling and Buoyancy

- Blue-greens settle slowly and can actually rise
  - Negative settling velocity
- Gas vacuoles
- Primarily during stagnant periods
- Implications:
  - Multi-layer vertical segmentation
  - Might require diel time scale

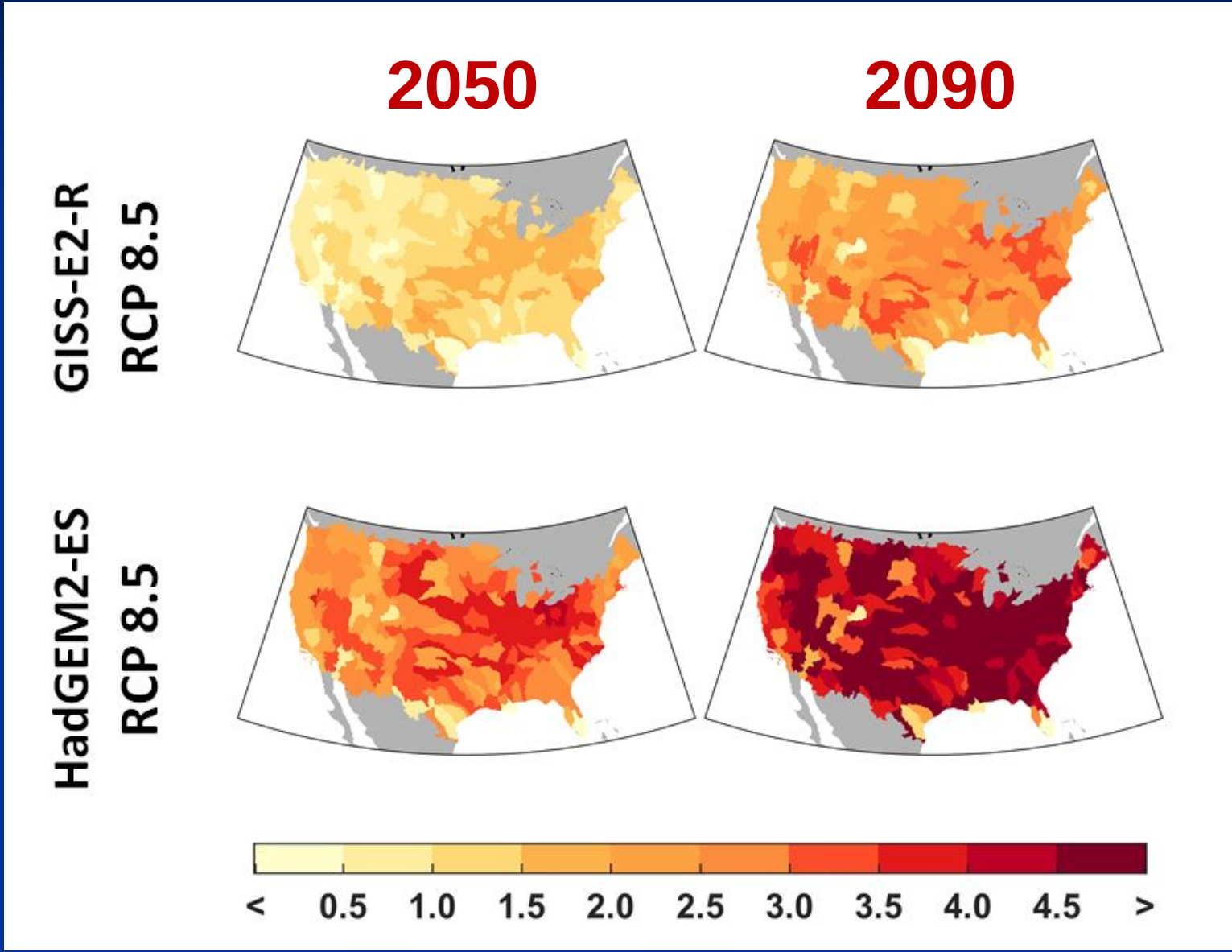
NUTRIENT LIMITATION, SETTLING & GRAZING



Seasonal Predictions

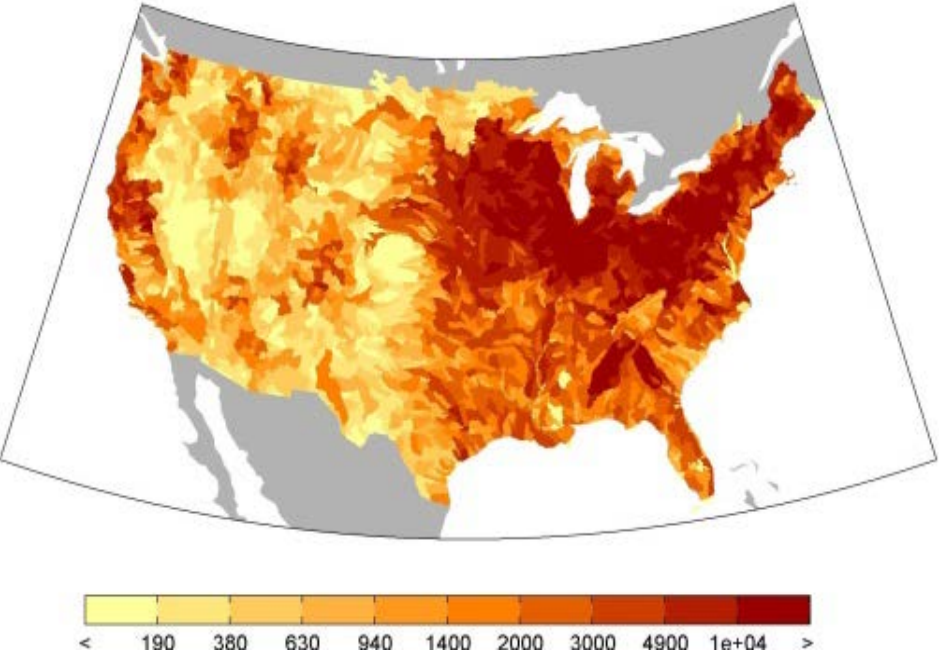


Future Temperature Rise

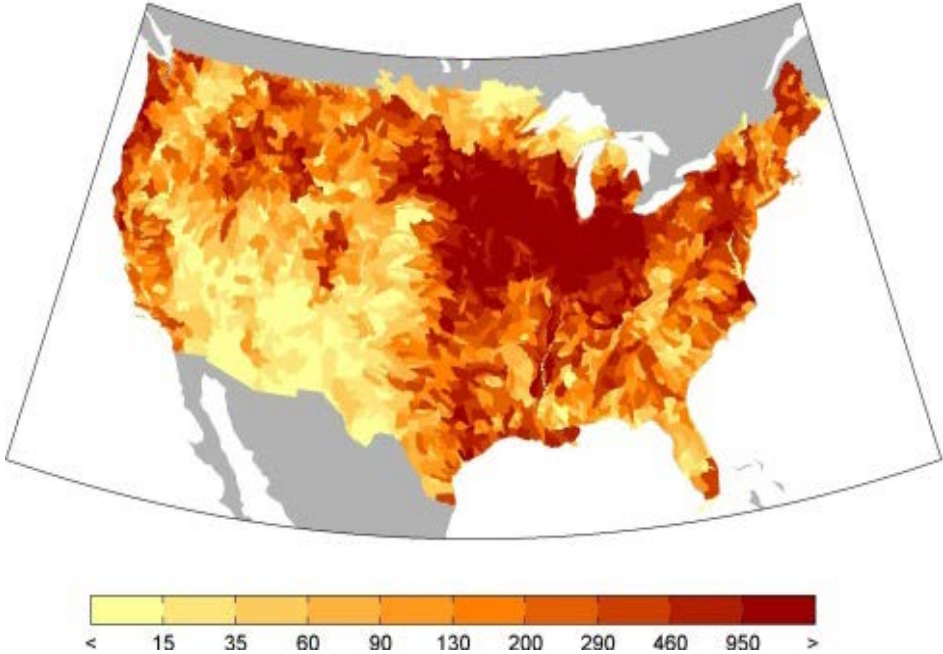


Nonpoint loadings for the baseline scenario

Total Nitrogen

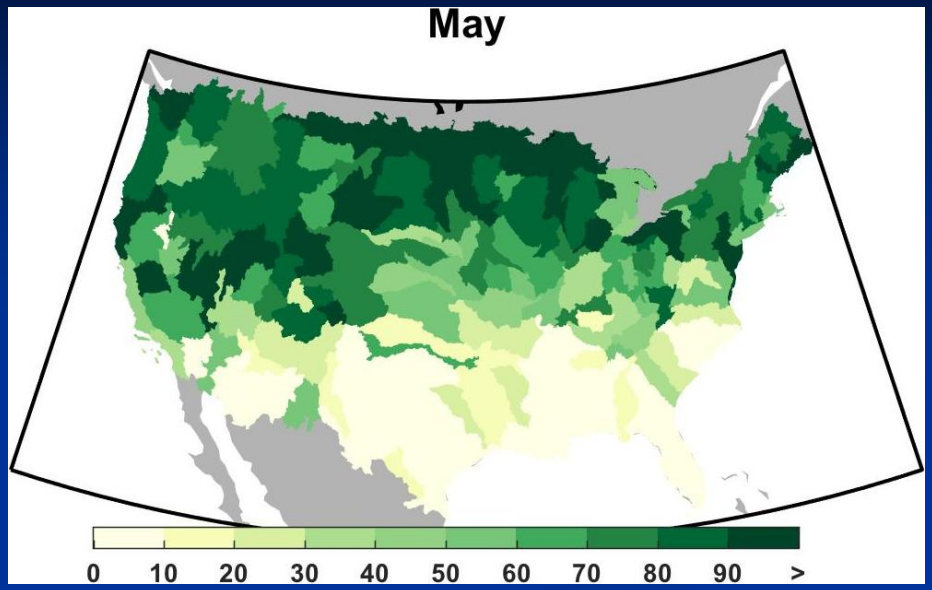


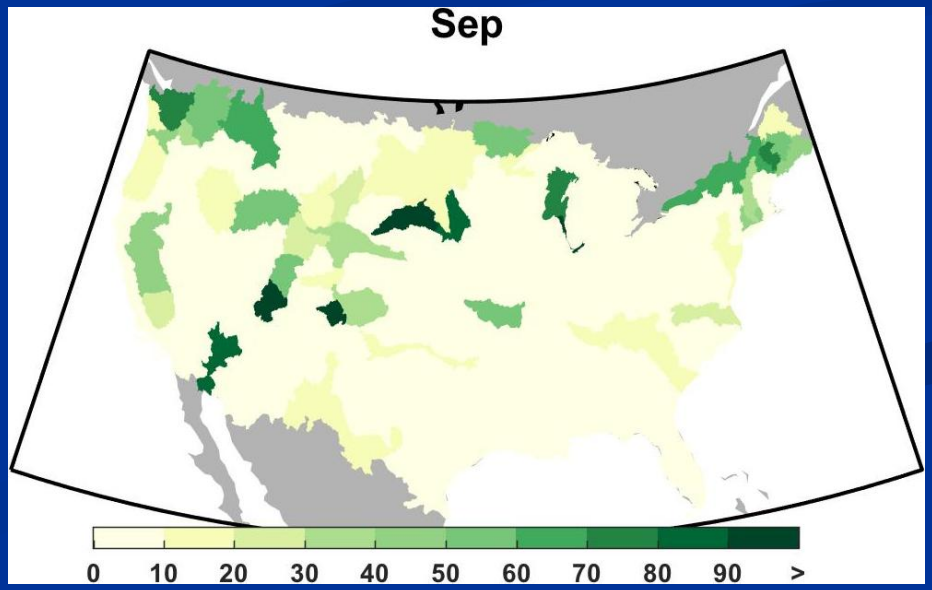
Total Phosphorus



Diatoms

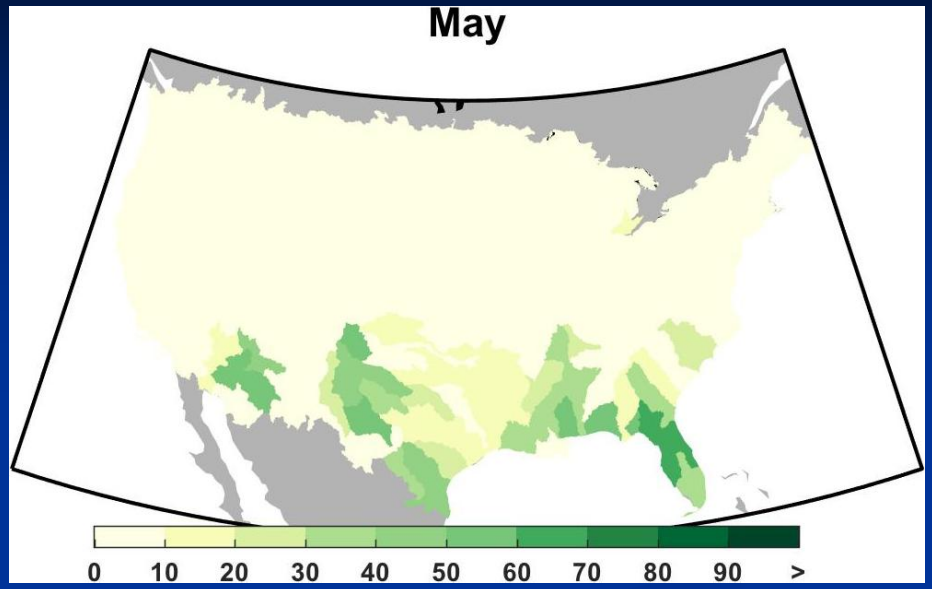
Fraction of total (%)

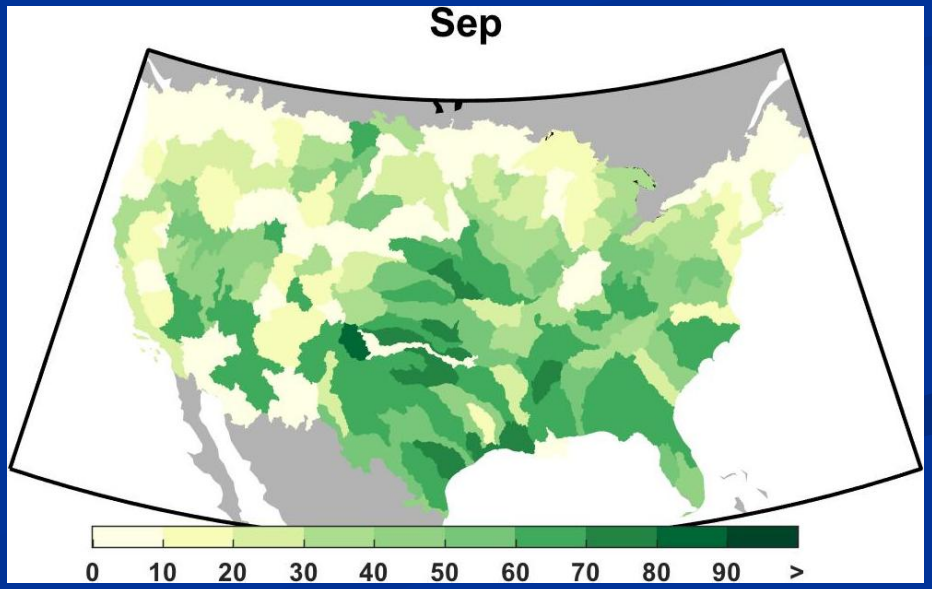




CyanoHAB non-fixers

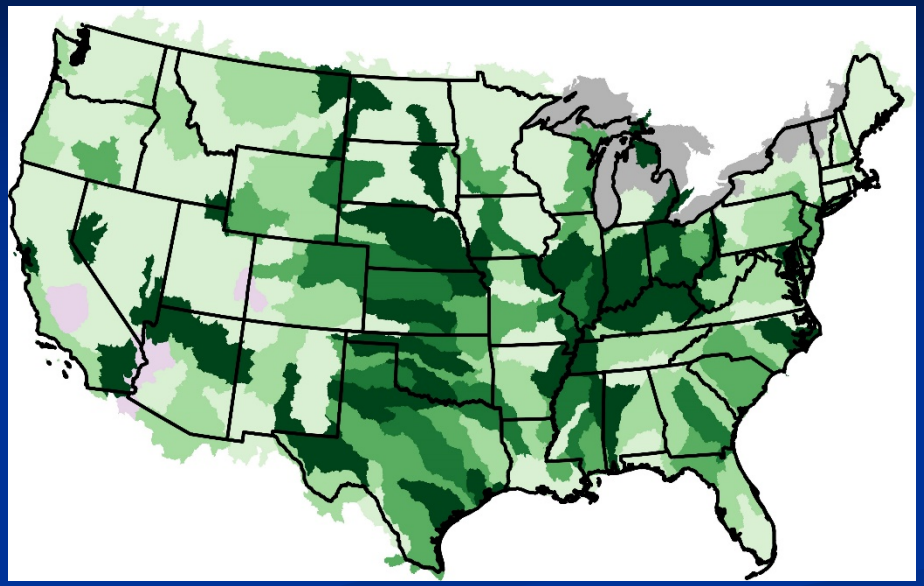
Fraction of total (%)



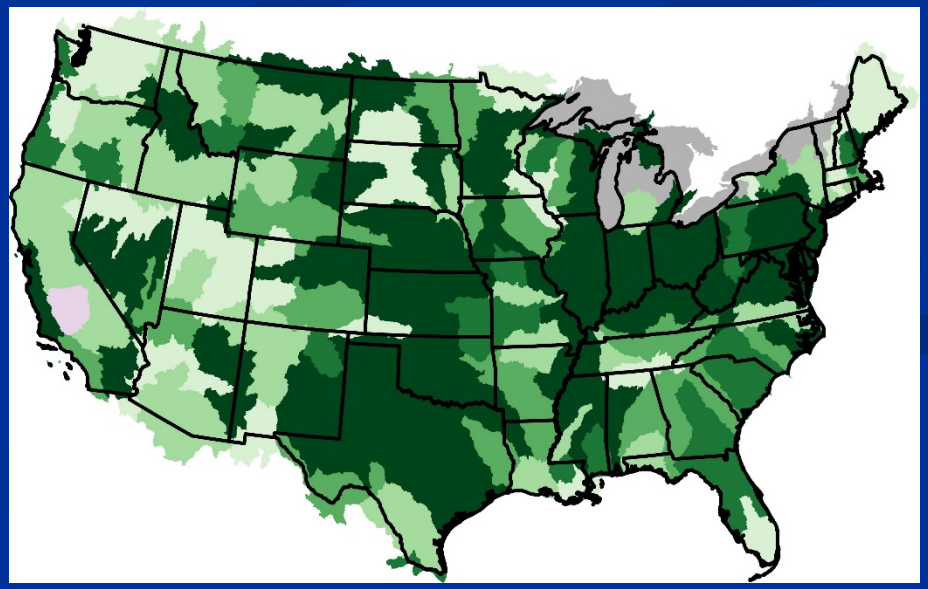


Critical HABs blooms

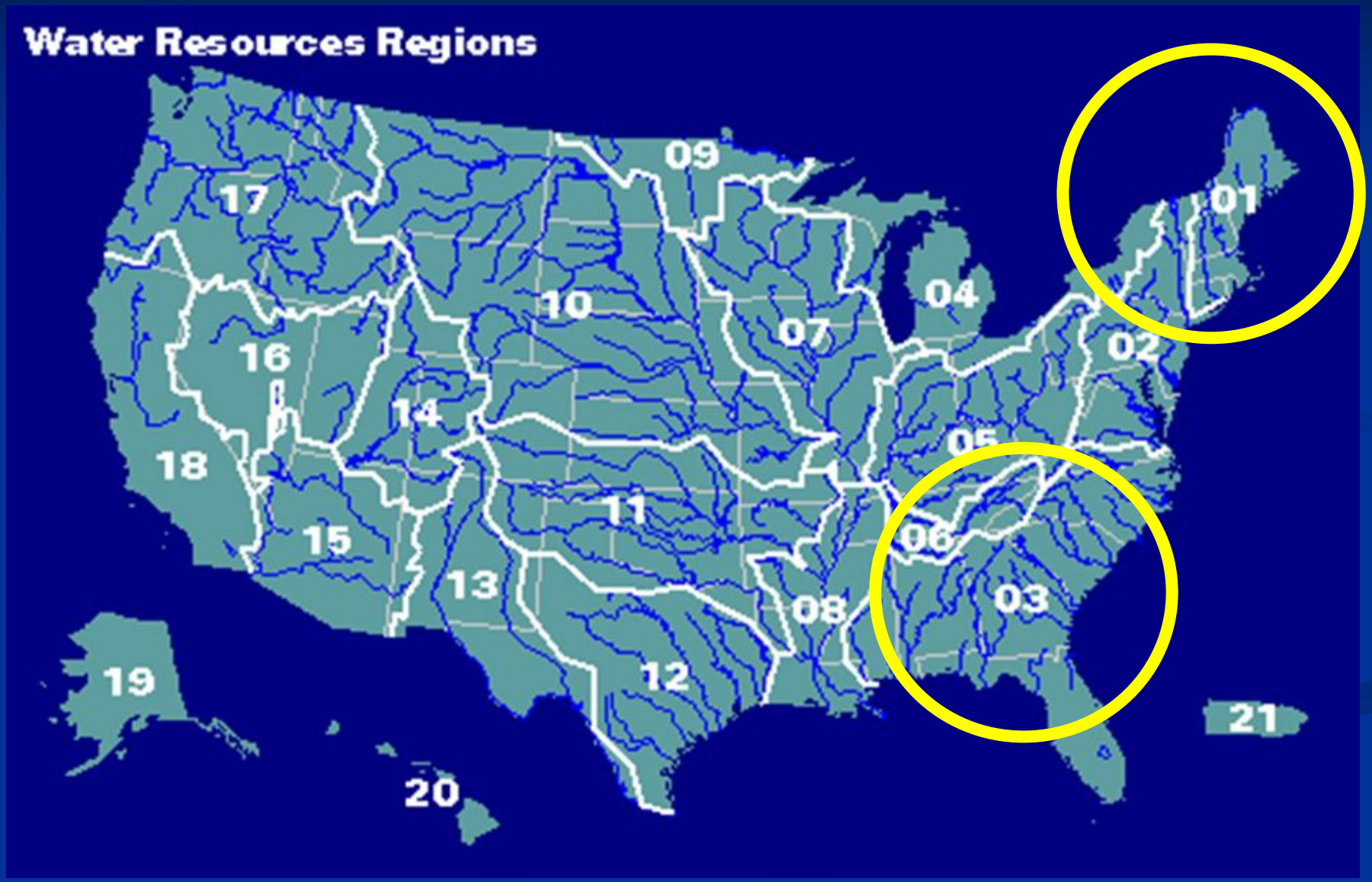
2050



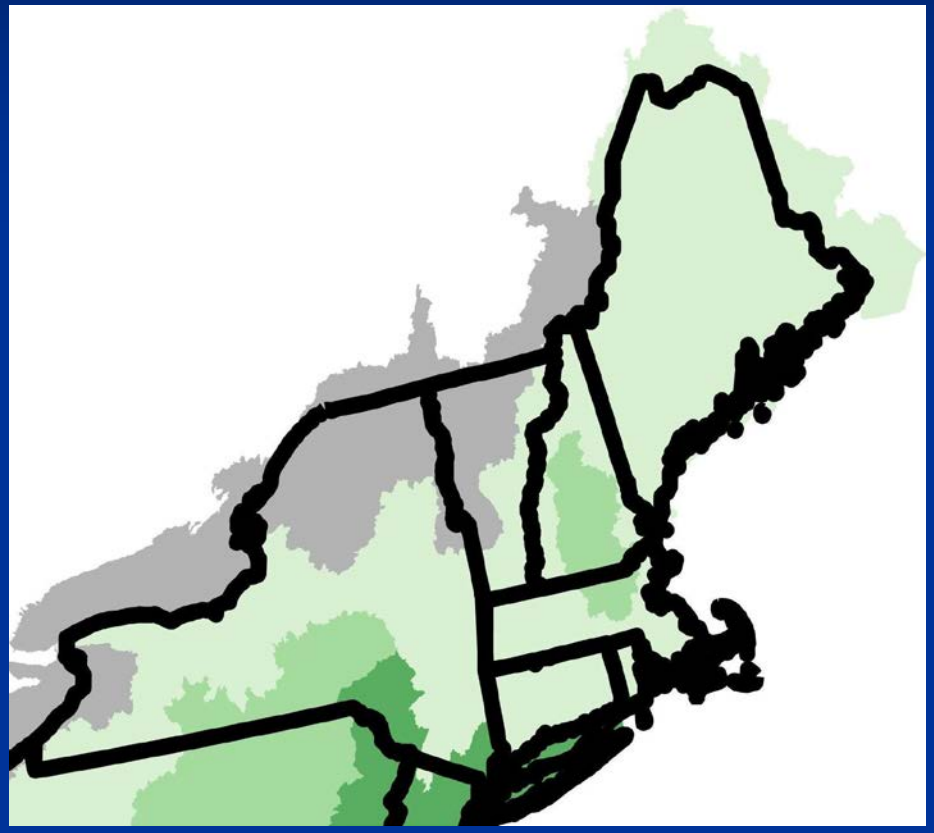
2090



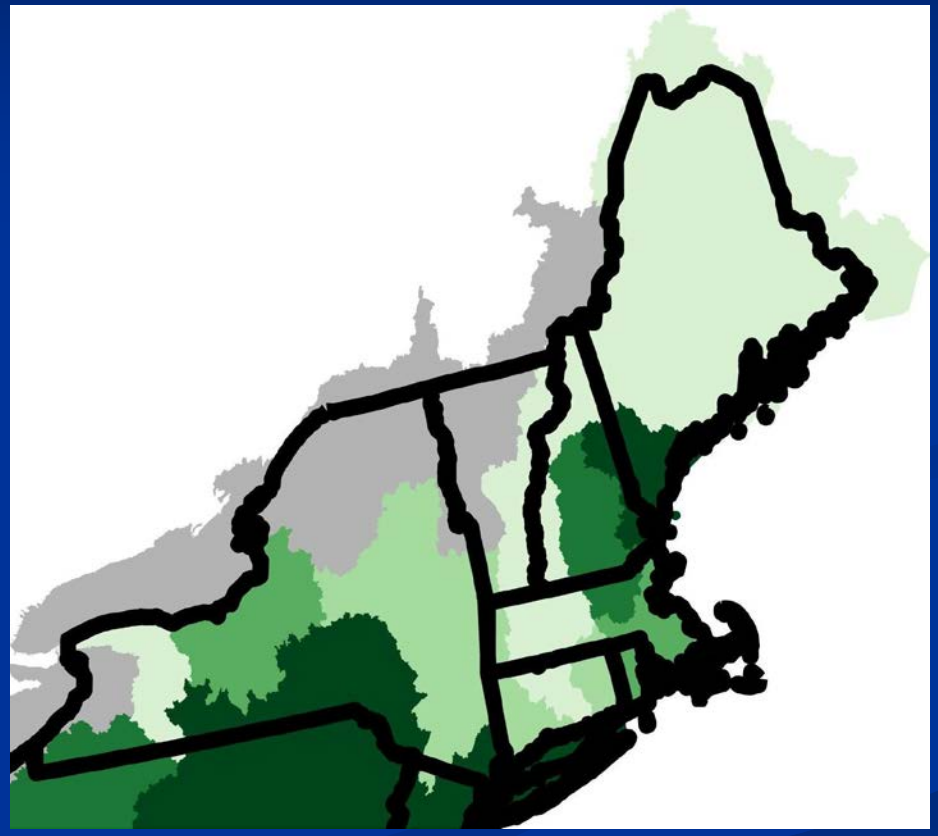
Regional Climate Change Projections



Northeast USA



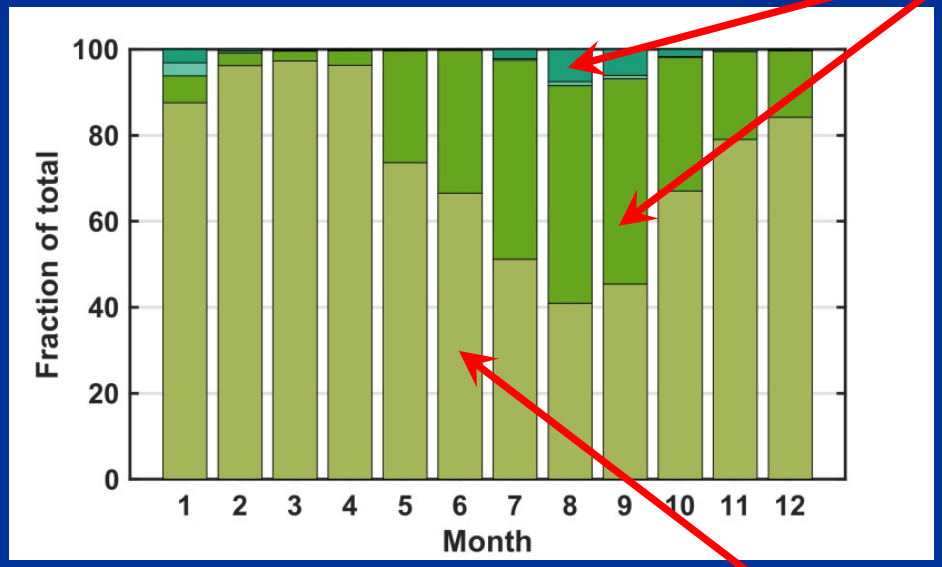
2050

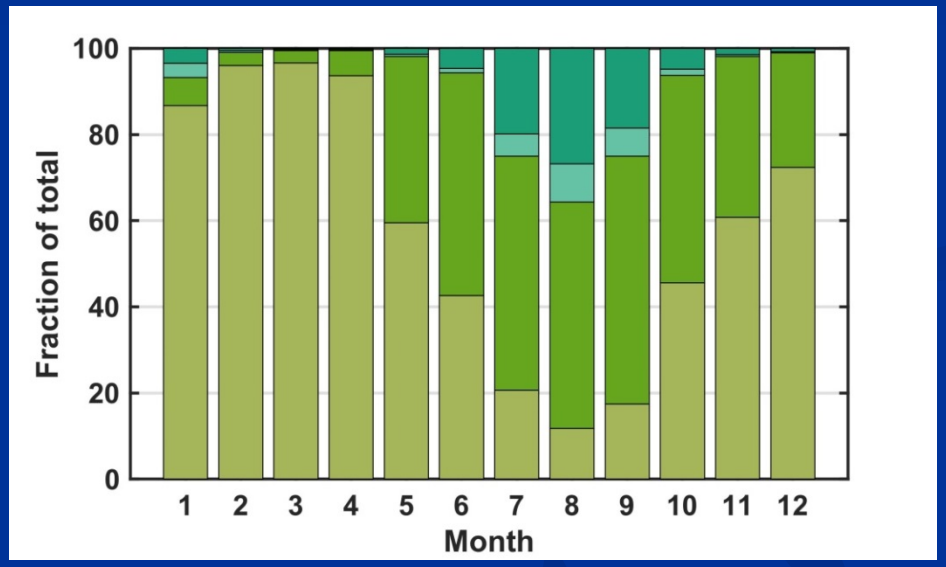


2090

Climate Change Projections New England (01)

CYANOBACTERIA





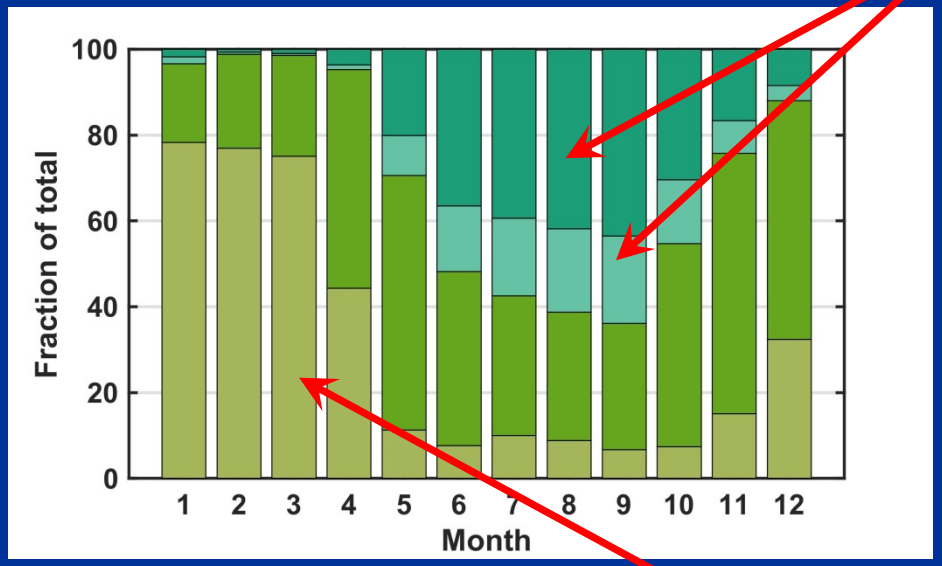
Baseline

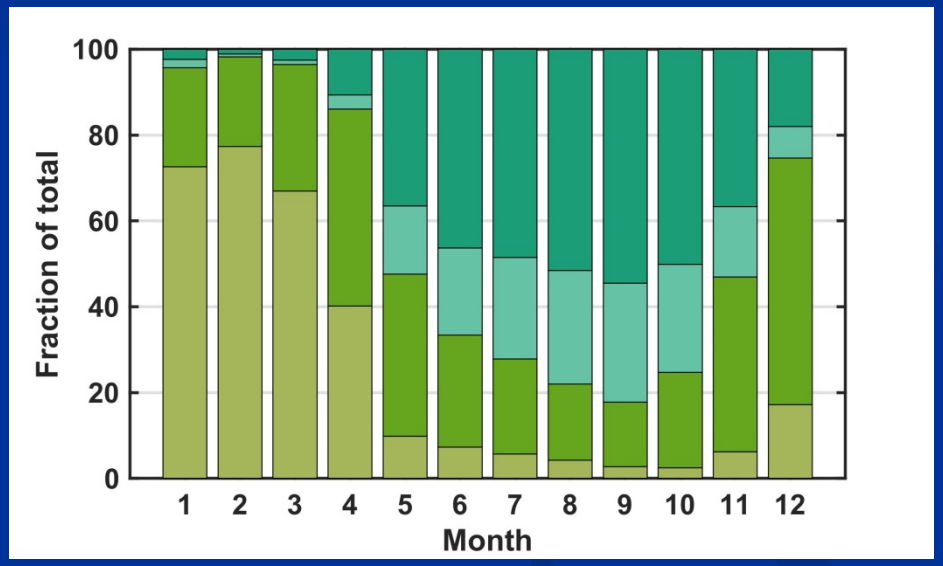
2050

DIATOMS

Climate Change Projections Southeast (03)

CYANOBACTERIA





Baseline

2050

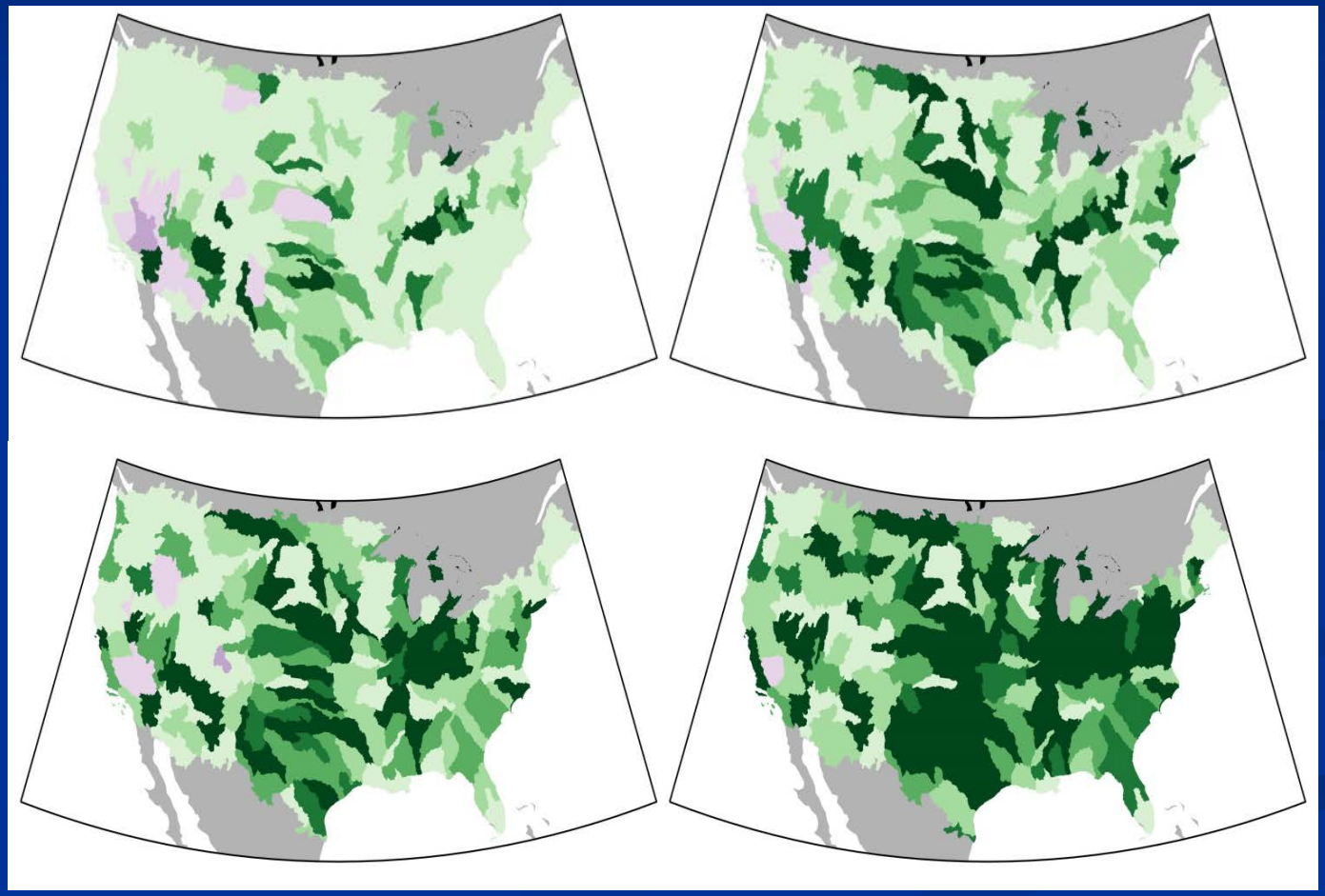
DIATOMS

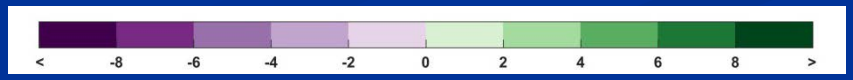
Change in Cyanobacteria Concentrations (1000 cells / ml)

2050 **2090**

GISS-E2-R RCP 8.5

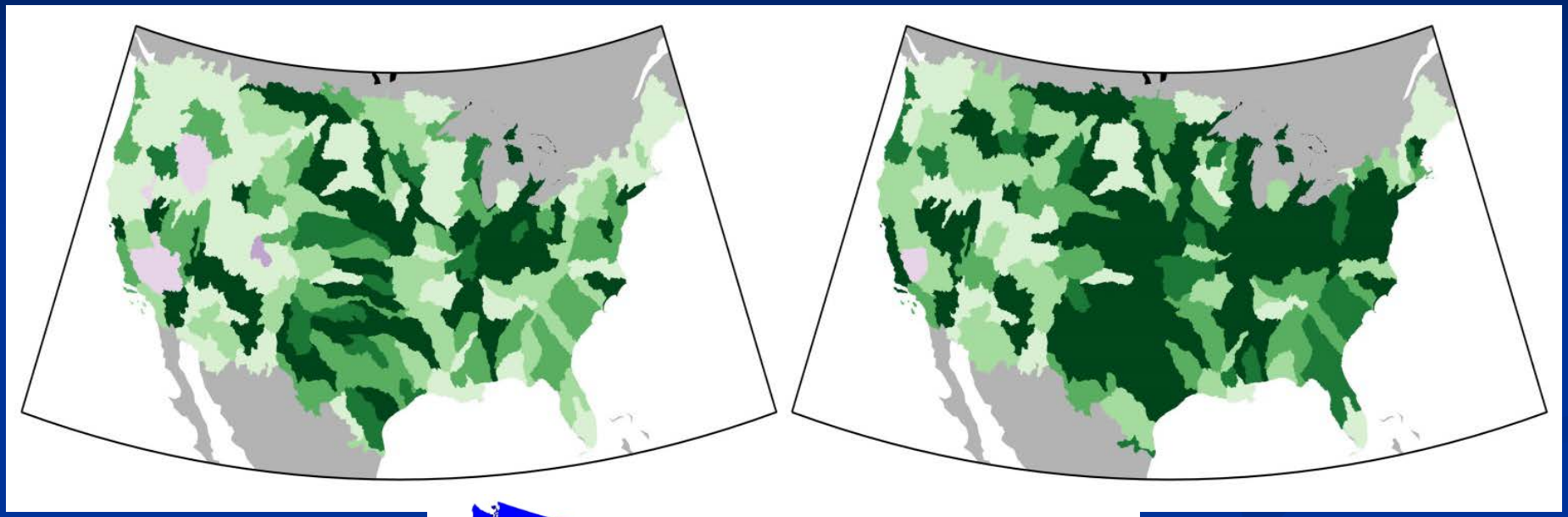
HadGEM2-ES RCP 8.5

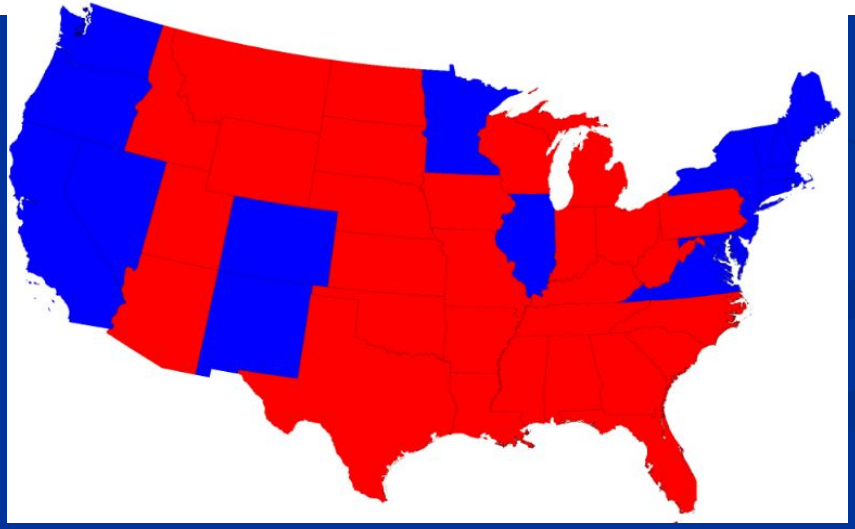




Change in Cyanobacteria Concentrations (1000 cells / ml)

2050 **2090**





Conclusions

- *Climate change will increase duration, magnitude, and spatial extent of CyanoHABs*
- *Climate impacts go well beyond temperature rise (and we are only scratching the surface)*
- *National or regional screening level models are useful for guiding planning strategies*
- *Impact of very high temperatures on cyanobacteria needs further study*
- *Interdisciplinary teams & systems approaches are critical for informing policy regarding HABs*

CONCLUSIONS

- *All models are wrong (and possibly evil)*
- *All models are right (especially if they are animated and in vivid colors)*
- *"All models are wrong, but some are useful"*

G.E.P. Box

THE END

Major Differences Between "Good" Algae & HABs

	"Good" Algae		Cyanobacteria	
Factor	**Diatoms**	**Greens**	**N_2 Fixers**	**non N_2 Fixers**
Settling	High	Medium	Low	Low
Edible	Yes	Yes	No	No
Phosphorus	Need	Need	Need	Need
Nitrogen	Need	Need	Need	
Silica	Need			
Max growth rate	High	Medium	Low	Low
Min light	High	Medium	Low	Low
Optimal temperature	Low	Medium	High	High
C:Chl ratio	High	High	Low	Low

Major Differences Between "Good" Algae & HABs

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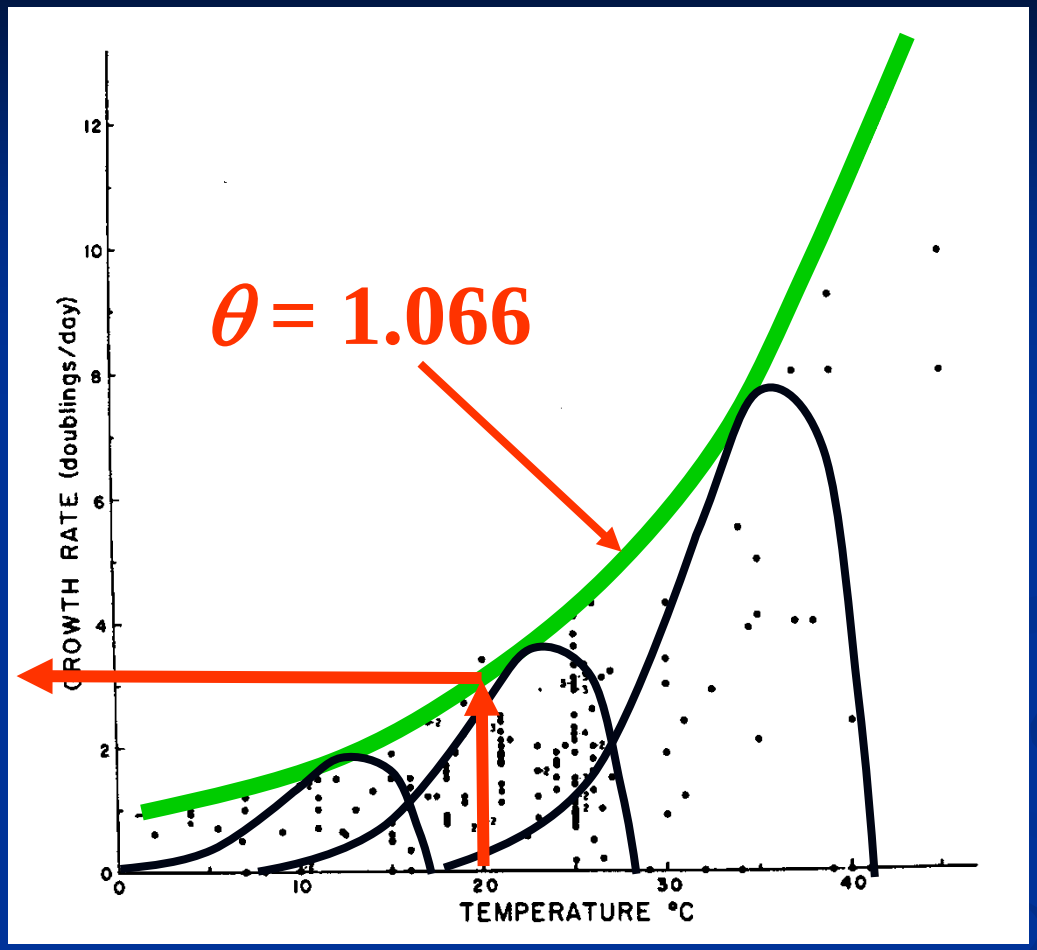
Phosphorus	Need	Need	Need	Need
Nitrogen	Need	Need	Need	
Silica	Need			
Max growth rate	High	Medium	Low	Low
Min light	High	Medium	Low	Low
Optimal temperature	**Low**	**Medium**	**High**	**High**
C:Chl ratio	High	High	Low	Low

Research Issues

- High temperature kinetics
- Scum formation
- Model modifications
- Toxin modeling

TEMPERATURE DEPENDENCY

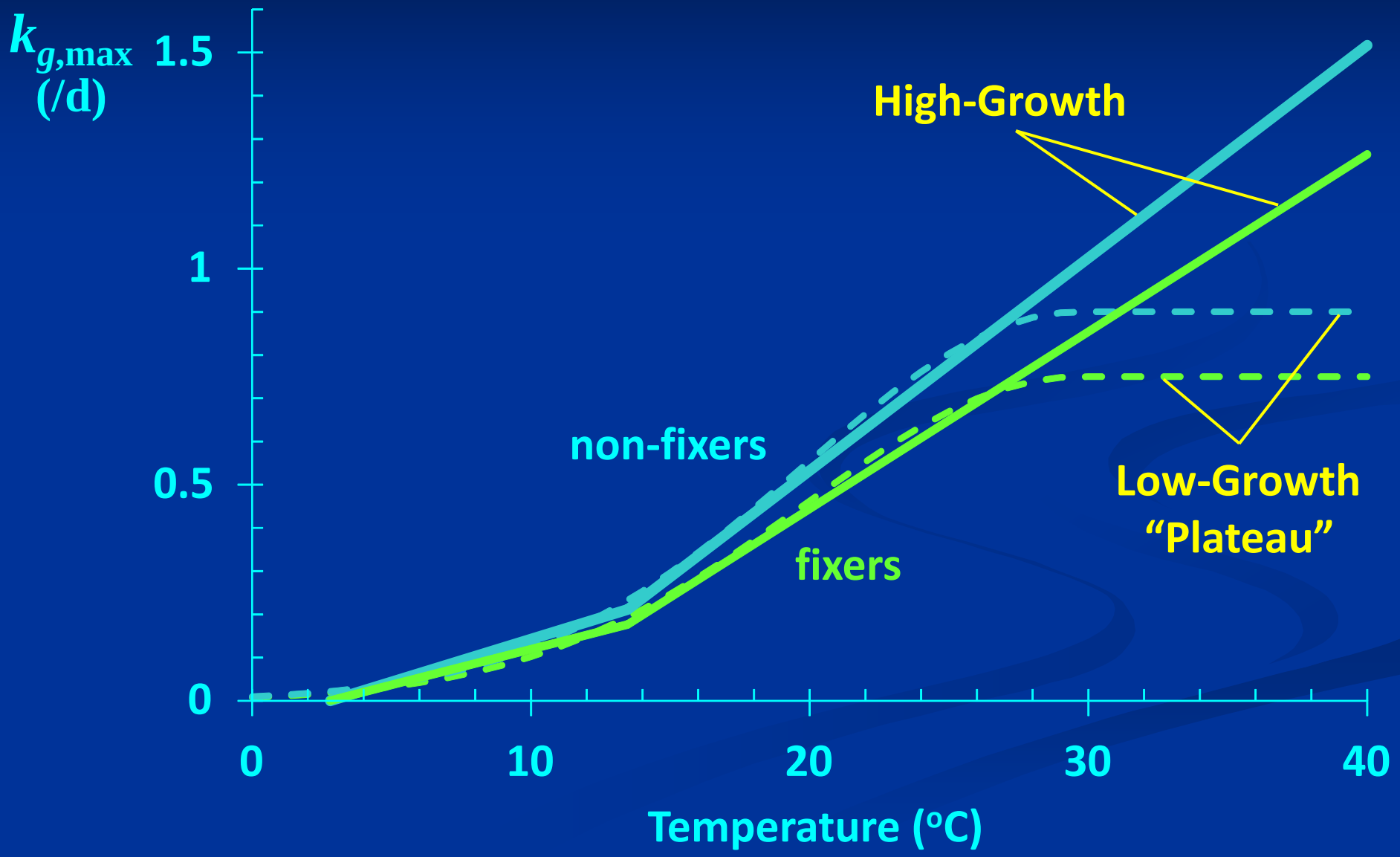
3 doublings/d



$$k_g(T) = 2.1 \times 1.066^{\,T-20}$$

Rate doubles for 10ºC rise

Very High Temperature???



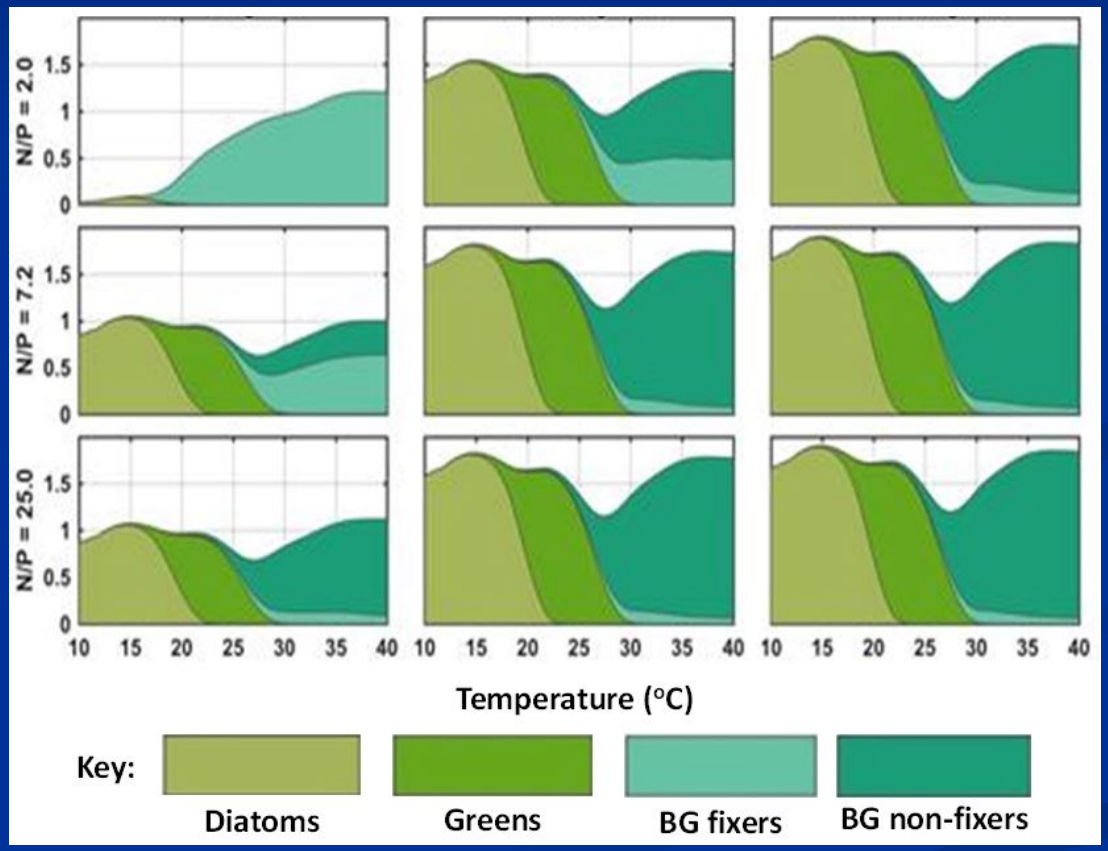
Sensitivity Analysis: Effects of Nutrient Levels and IN/IP Ratios

		oligotrophic IP = 5 μgP/L	eutrophic IP = 25 μgP/L	hypereutrophic IP = 50 μgP/L
N limited	IN/IP = 2	IN = 10 μgN/L	IN = 50 μgN/L	IN = 150 μgN/L
	IN/IP = 7.2	IN = 36 μgN/L	IN = 180 μgN/L	IN = 540 μgN/L
P limited	IN/IP = 25	IN = 125 μgN/L	IN = 625 μgN/L	IN = 1875 μgN/L

END OF SUMMER LEVELS

INCREASING PHOSPHORUS

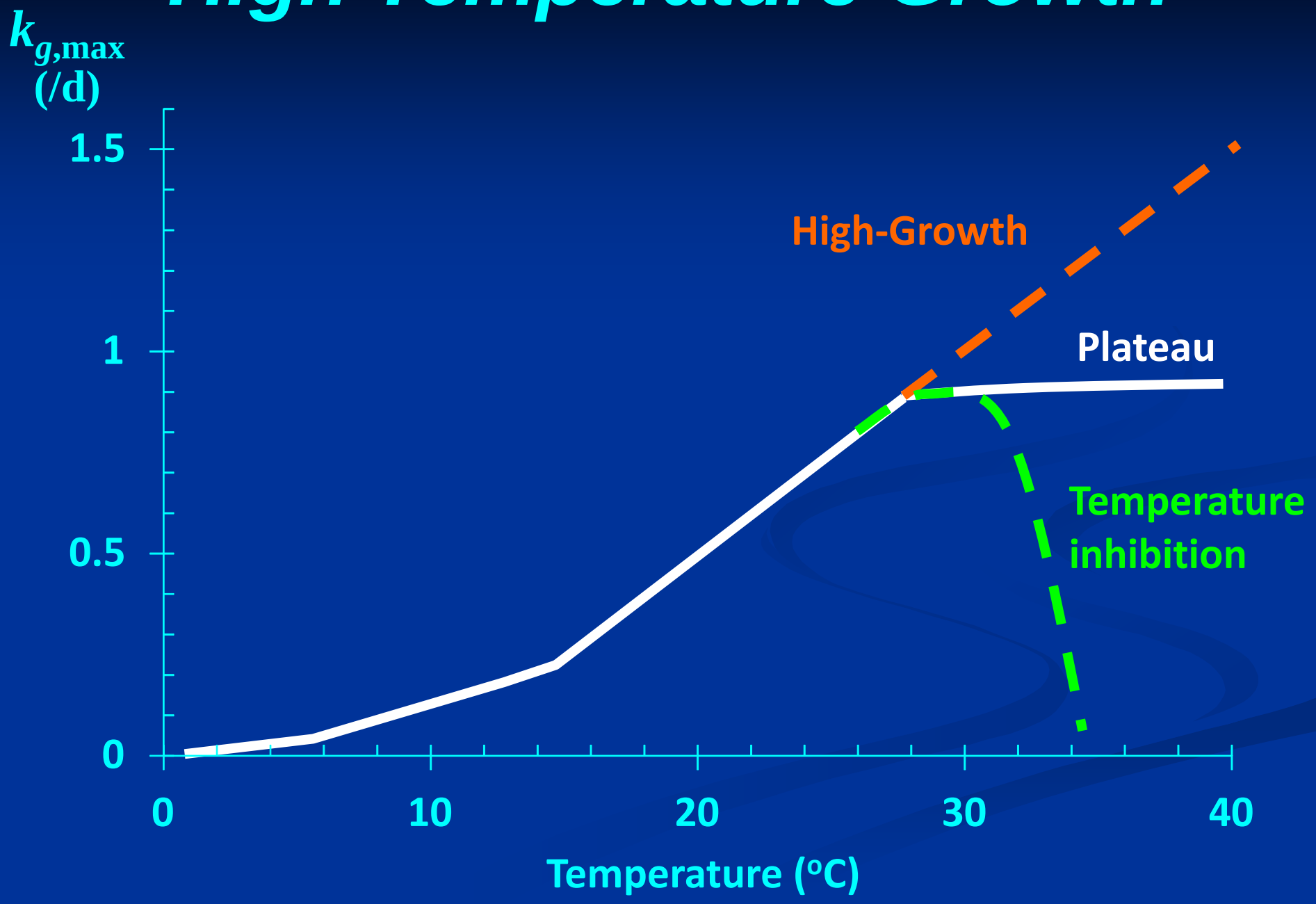
INCREASING NITROGEN



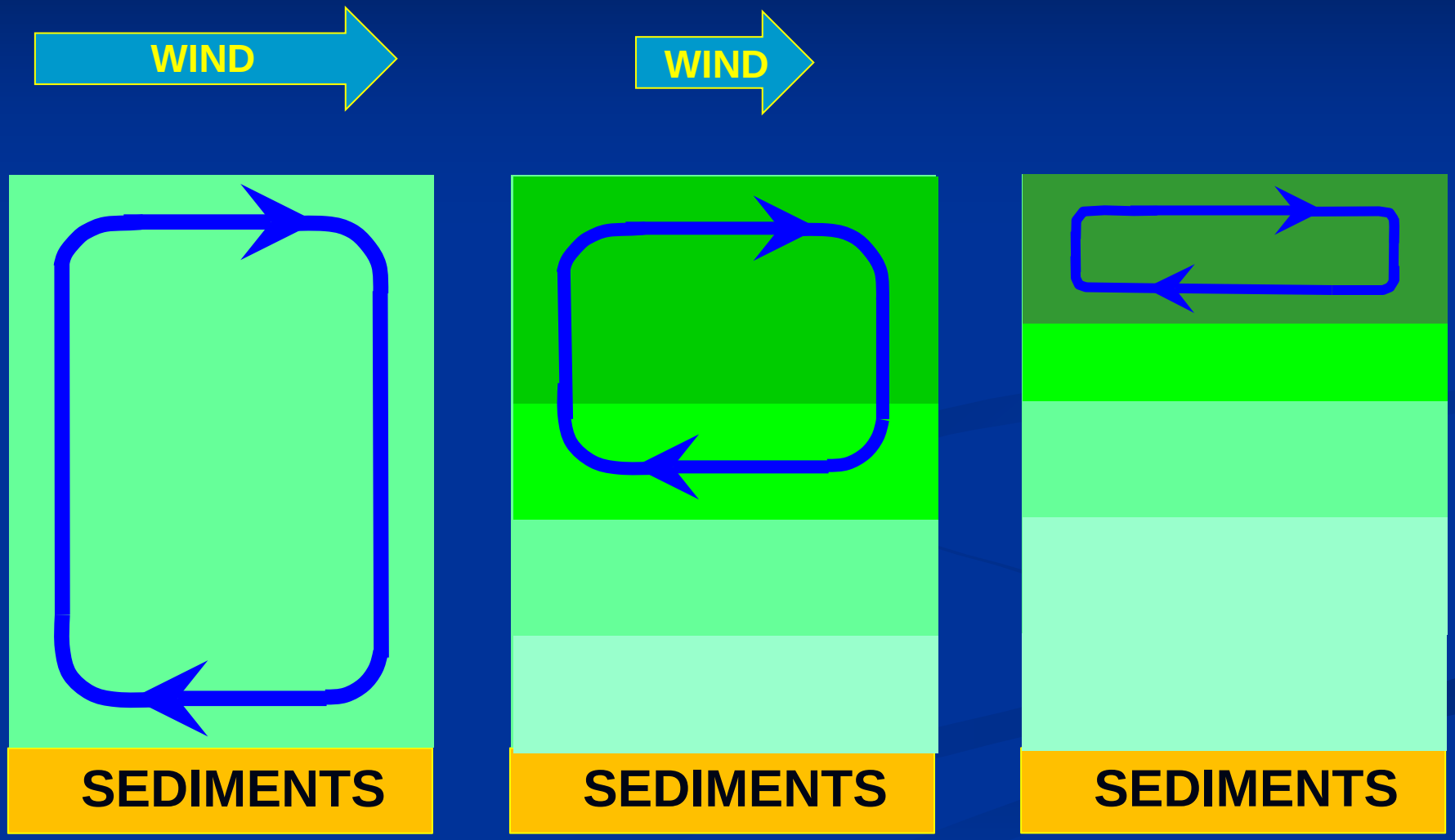
"GOOD"

BAD

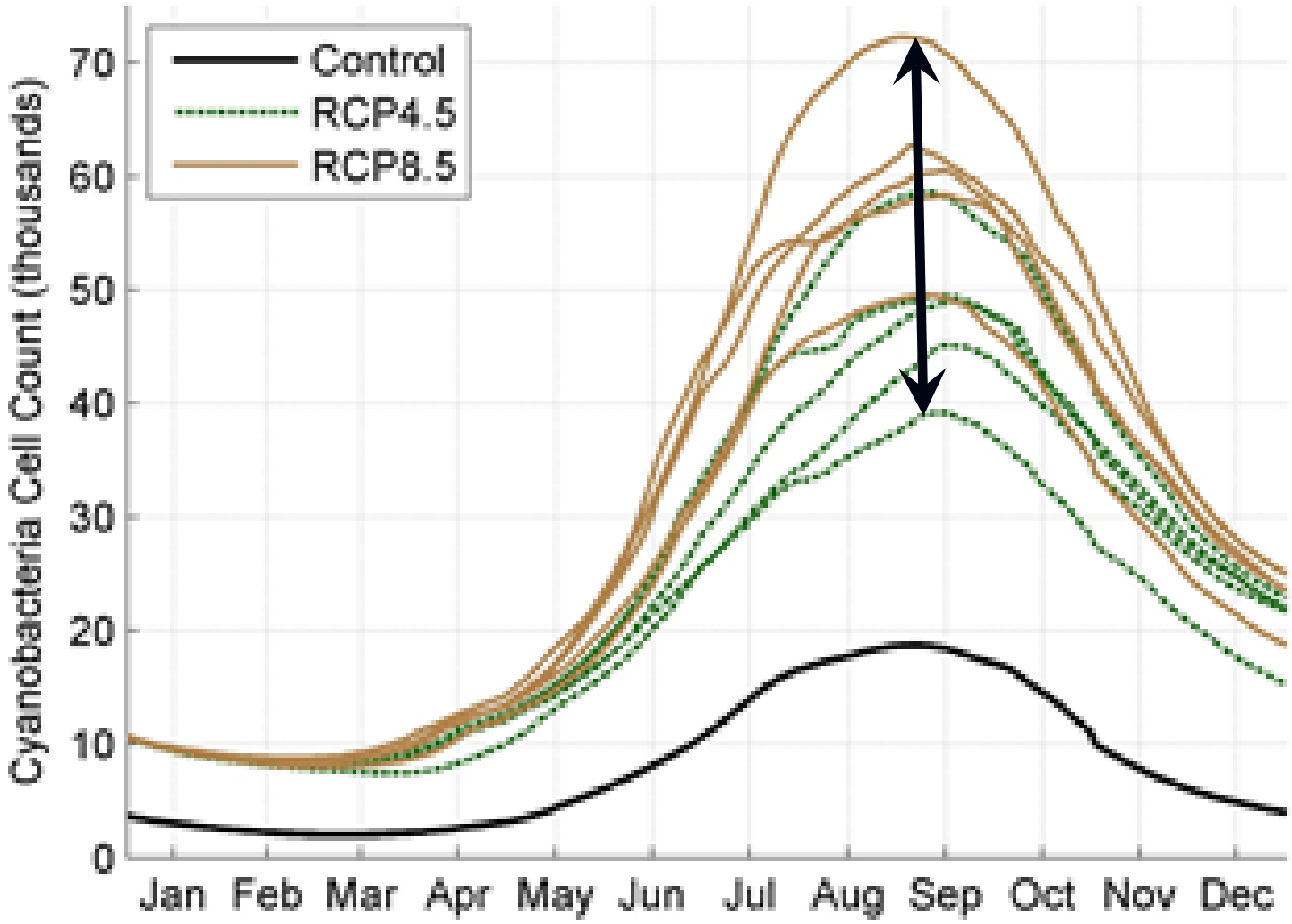
High Temperature Growth



SCUM FORMATION



Model Modifications

- Build on existing
- Open source
- Functional groups (easy)
- Kinetics (easy)
- Scum formation (???)
  - Thin surface layer

Seasonal Profile of aggregate cyanobacteria concentration (1000 cells / ml) in 2090