Big data informing lake ecology: Case study on nutrient and water color effects on lake primary production

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Michigan Inland Lakes Convention

April 2016

Department of Fisheries and Wildlife • Michigan State University •

CSI LIMNOLOGY

Lakes in the landscape

Michigan over 10,000 inland lakes (>4 ha in size)

U.S. estimated over 120,000 inland lakes

MI Lake and Stream Associations, Inc.

Lakes in the landscape

Michigan over 10,000 inland lakes (>4 ha in size)

U.S. estimated over 120,000 inland lakes

How can we effectively study and manage them?

MI Lake and Stream Associations, Inc.

Landscape limnology

The spatially explicit study of lakes, streams, and wetlands as they interact with freshwater, terrestrial, and human landscapes …to affect lake characteristics. *Soranno et al. 2010*

Landscape limnology

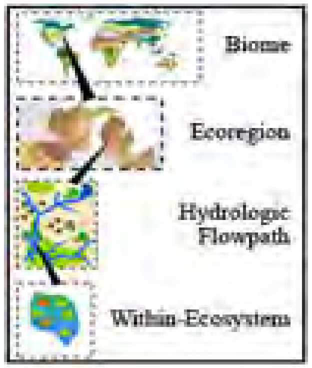
Principles

Patch characteristics

Patch context

Patch connectivity & directionality

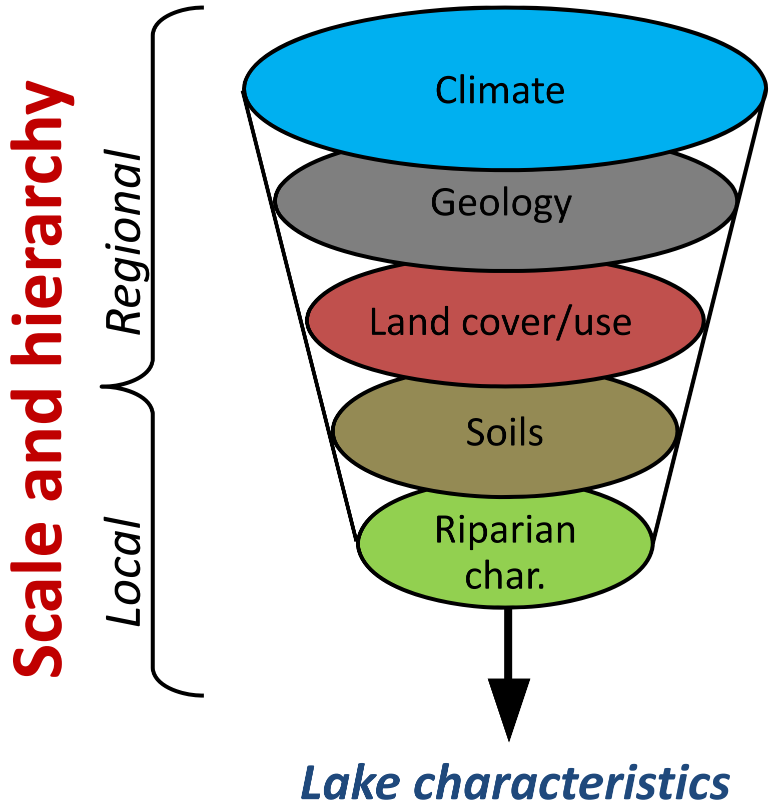
Spatial scale & hierarchy



Soranno et al. 2010. *BioScience*

www.fw.msu.edu/~LLRG

Landscape limnology



http://www.visitusa.com/maine

http://michpics.wordpress.com/2009/12/19/michigan-farming-and-other-success-stories/

Novel questions and perspectives

- Regional variation
- Broad-scale disturbance effects
- Prediction
- Temporal trends

Harnessing 'Big Data' to address lake questions

Harnessing 'Big Data' to address lake questions

Cooperative Lakes Monitoring Program
Michigan Lakes – Ours to Protect

DEQ

Lakes of Missouri Volunteer Program

Indiana Clean Lakes Program

Minnesota Pollution Control Agency

Overall Goals

- More holistic understanding of lake ecology
- Provide information to guide management and conservation action

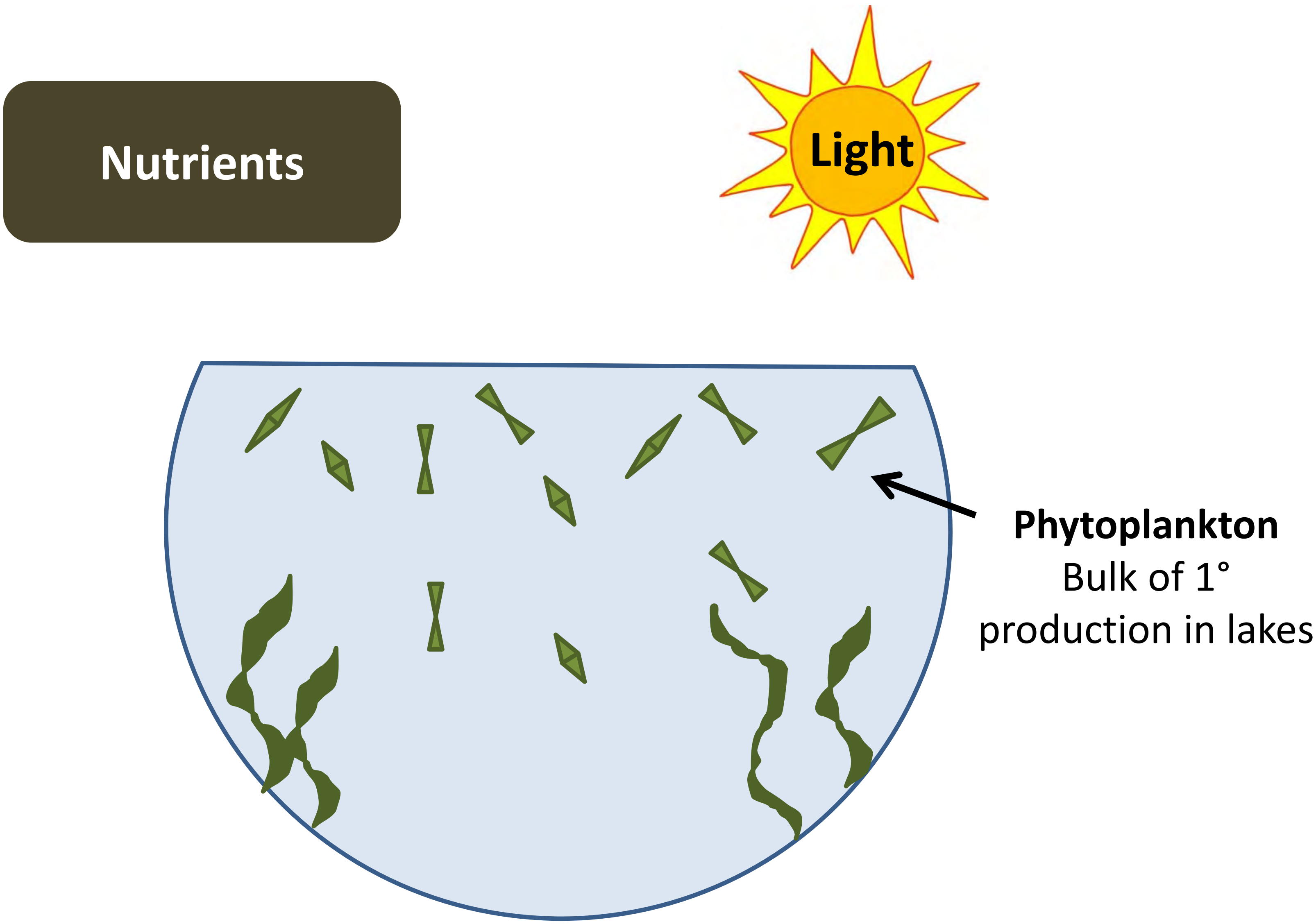
Case study

Lake nutrient and water color effects on lake primary production

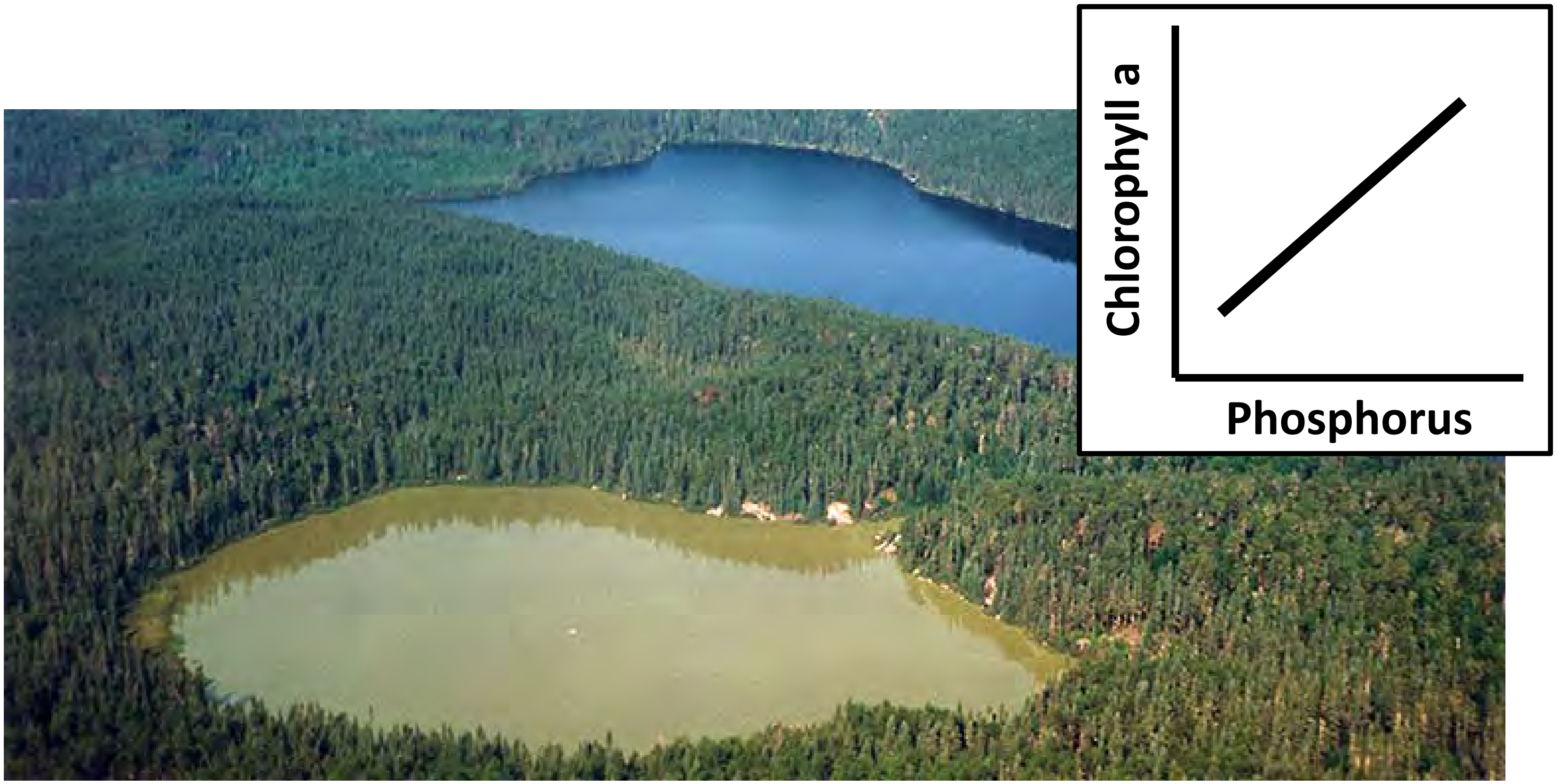
CSILIMNOLOGY

NSF

Drivers of lake primary production



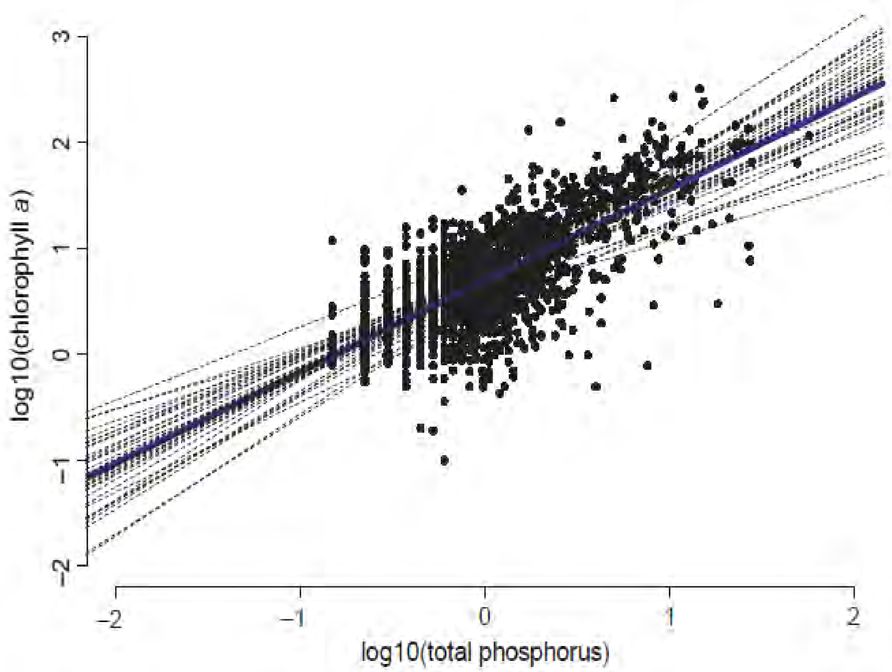
TP ~ Chlorophyll a relationship

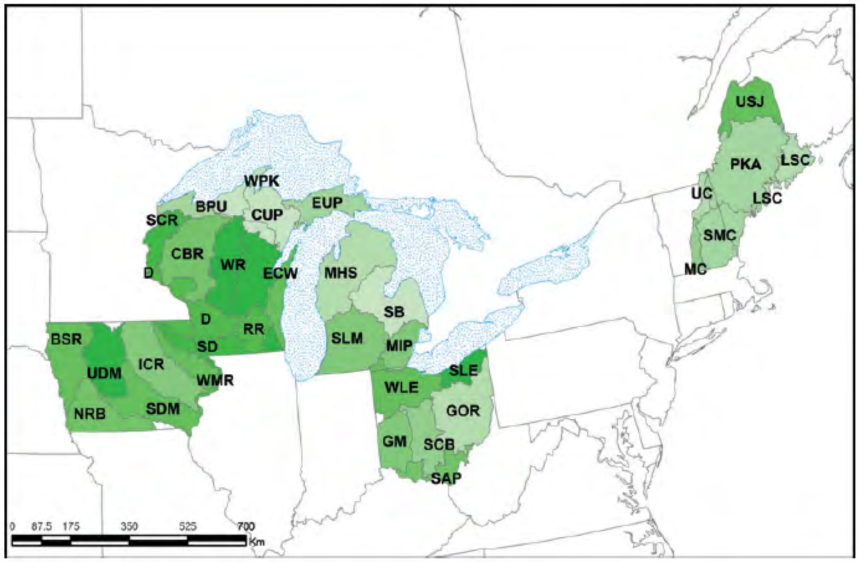


https://www.iisd.org/ela/ecosystem-experimentation

Revisiting the TP ~ Chlorophyll relationship

TP ~ CHL

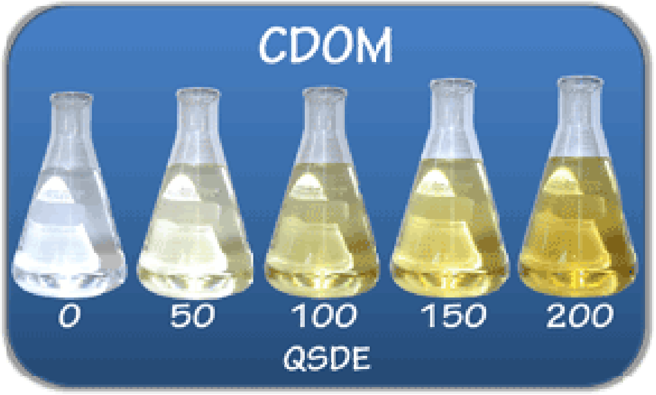




Spatial variation in relationships

Wagner et al. 2011

Colored dissolved organic carbon (water color)

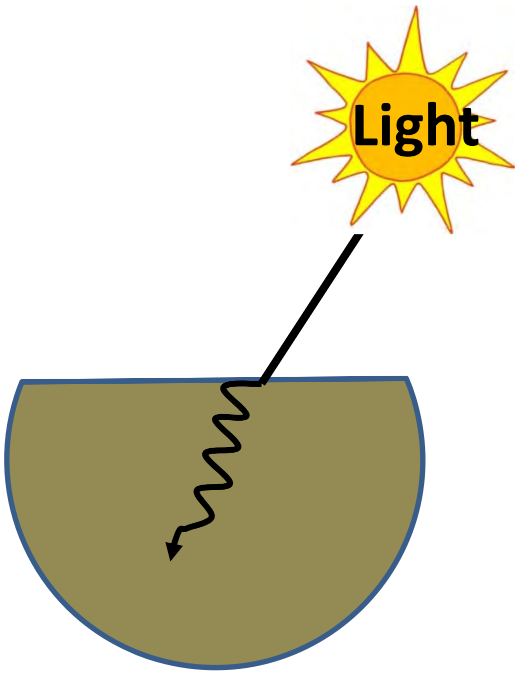


- Humic substances primarily from surrounding landscape
- Alters physical, chemical, and biological environment

http://www.ualberta.ca/ERSC08/water/climate/impacts6.htm
http://recon.sccf.org/definitions/cdom.shtml

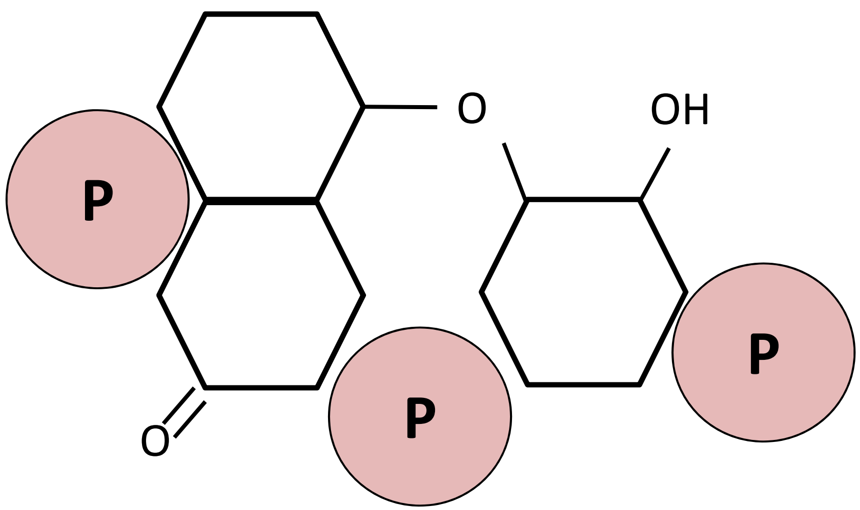
Colored dissolved organic carbon (Water Color)

Negative effects



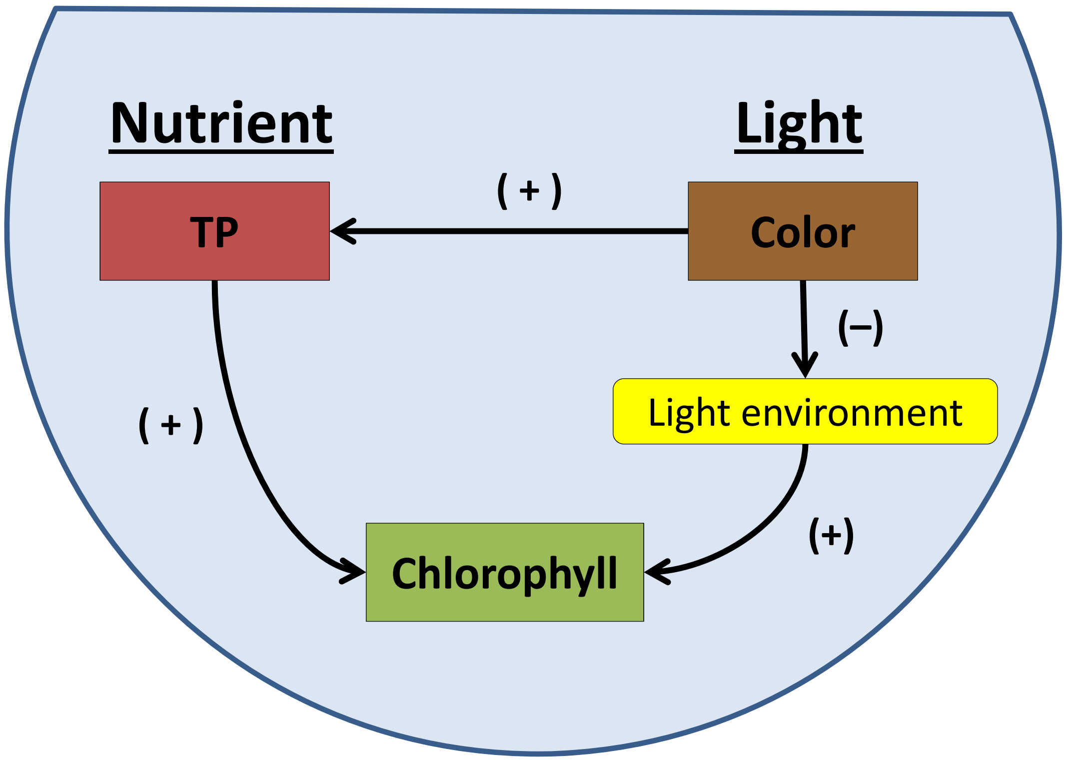
- Weakens light
- Shades algae

Positive effects



- Nutrients bound to humic compounds

Nutrient-water color paradigm



Important to understand in time of global change

Environmental Science & Technology
Article
pubs.acs.org/est

Continental-Scale Increase in Lake and Stream Phosphorus: Are Oligotrophic Systems Disappearing in the United States?

John L. Stoddard,[*,†] John Van Sickle,[†,‡] Alan T. Herlihy,[§] Janice Brahney,[∥] Steven Paulsen,[†] David V. Peck,[†] Richard Mitchell,[⊥] and Amina I. Pollard[⊥]

Nutrient

Freshwater Biology
Freshwater Biology (2014) **59**, 325–336 doi:10.1111/fwb.12267

Warming and browning of lakes: consequences for pelagic carbon metabolism and sediment delivery

EMMA S. KRITZBERG, WILHELM GRANÉLI, JESSICA BJÖRK, CHRISTER BRÖNMARK, PER HALLGREN, ALICE NICOLLE, ANDERS PERSSON AND LARS-ANDERS HANSSON
Department of Biology, Aquatic Ecology, Lund University, Lund, Sweden

DOC

http://www.peak-light.com/black-clough

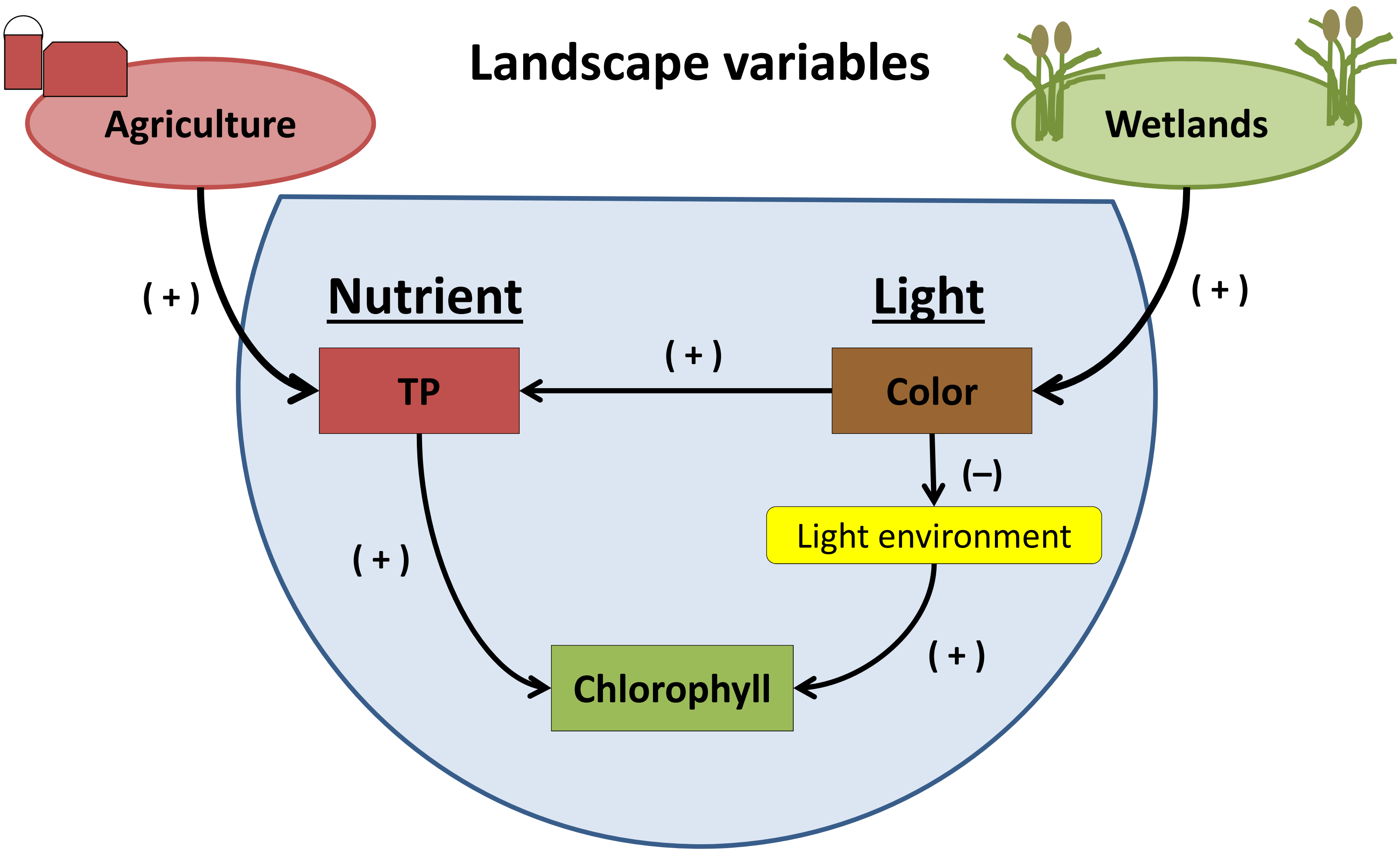
Landscape nutrient and carbon sources

- **Agriculture** – nutrient source
- **Wetlands & Forest** – carbon source

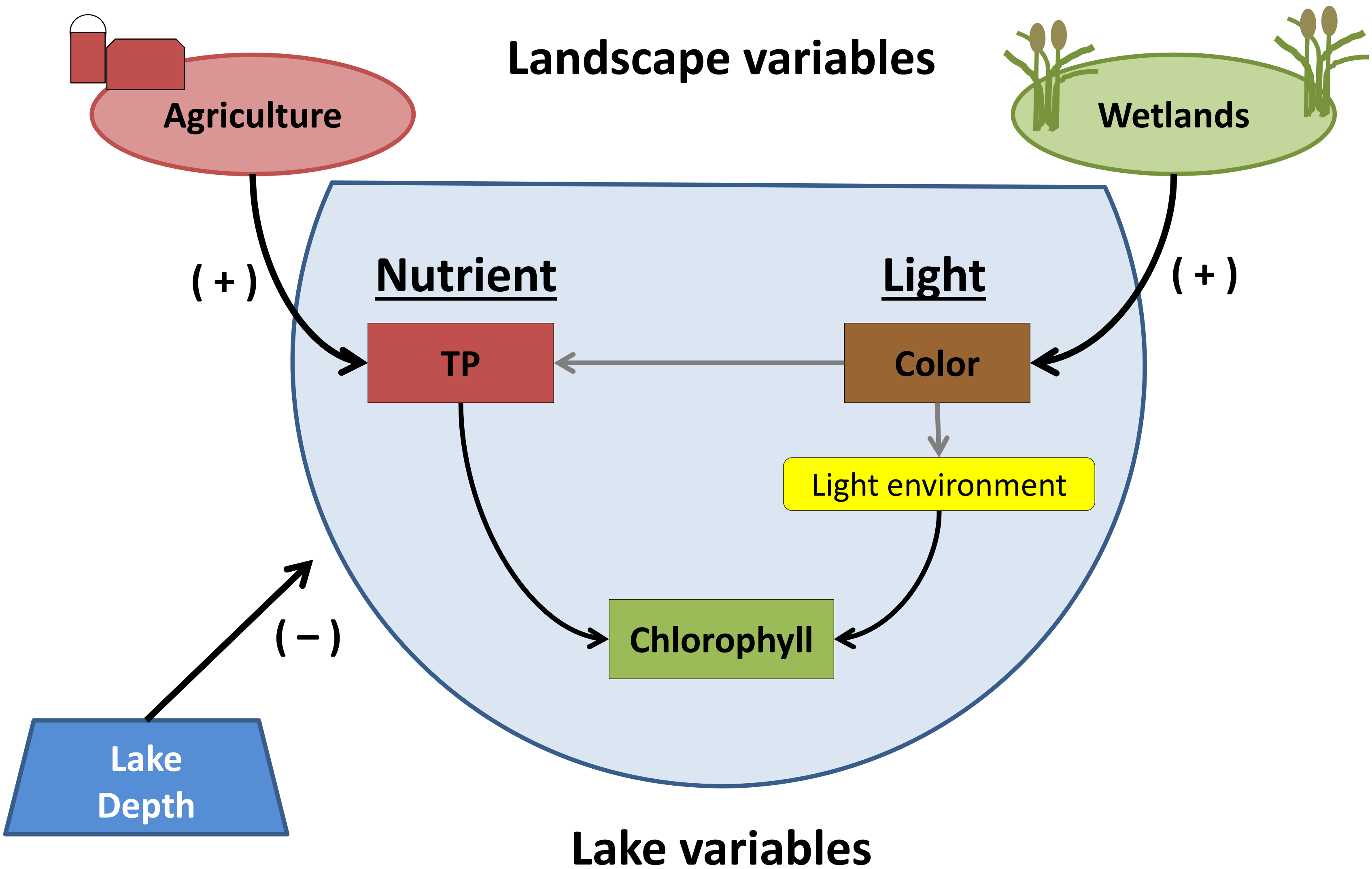
http://www.garthlenz.com/industrial-landscape/agriculture/Ches-Lancaster-8436

http://blogs.ubc.ca/thearodgers/2015/05/03/impacts-of-climate-change-on-carbon-emissions-from-canadian-peatlands/

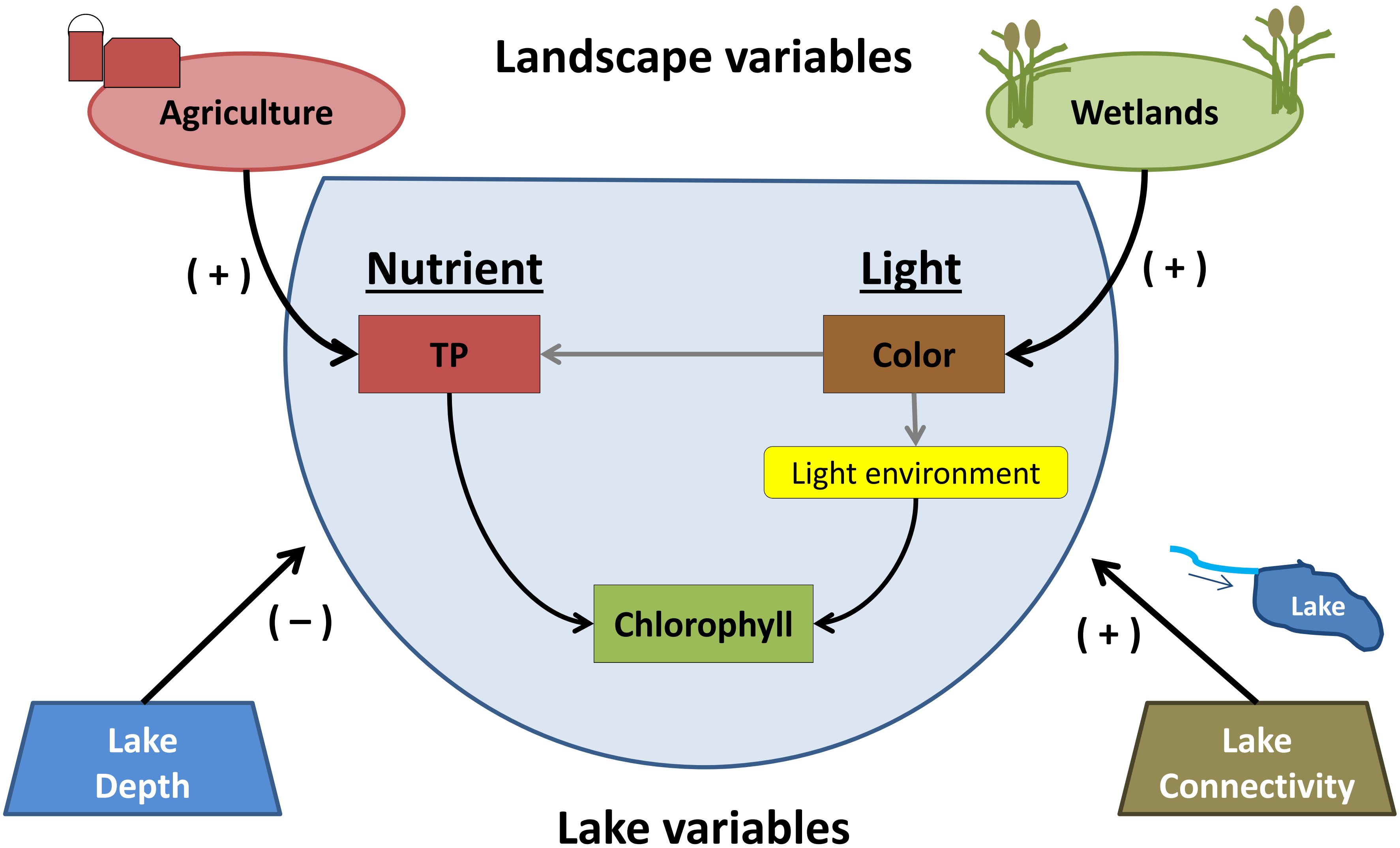
Spatial Nutrient-water color paradigm



Spatial Nutrient-water color paradigm



Spatial Nutrient-water color paradigm

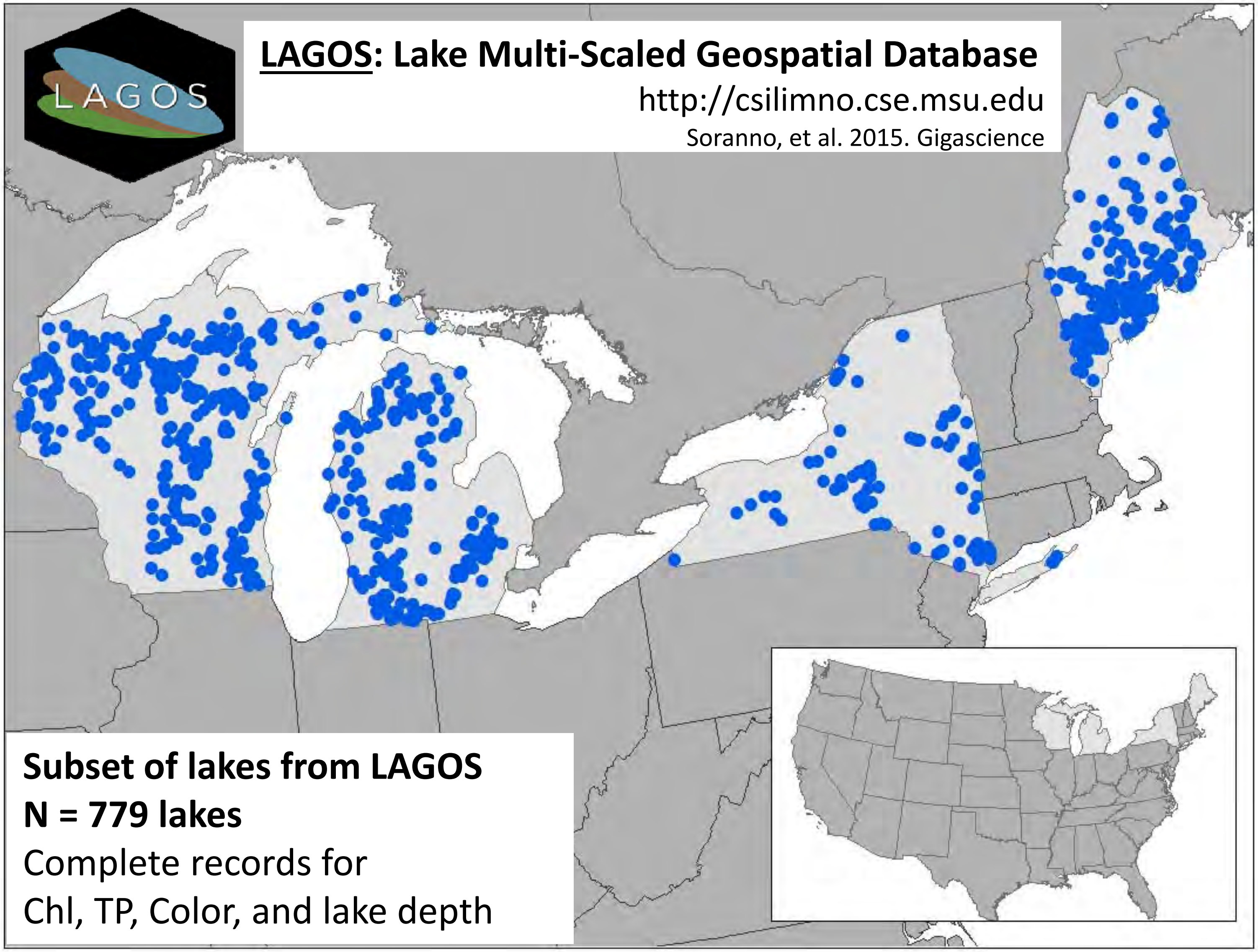


Research questions

1) Do TP and Water Color effects on Chlorophyll vary over space?

2) If so, are there lake and landscape variables that account for variation in these relationships?

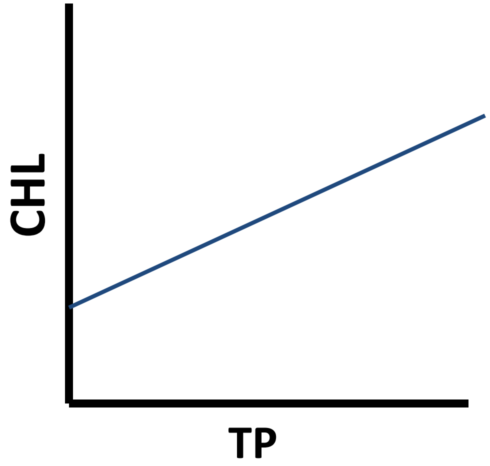
Lake database

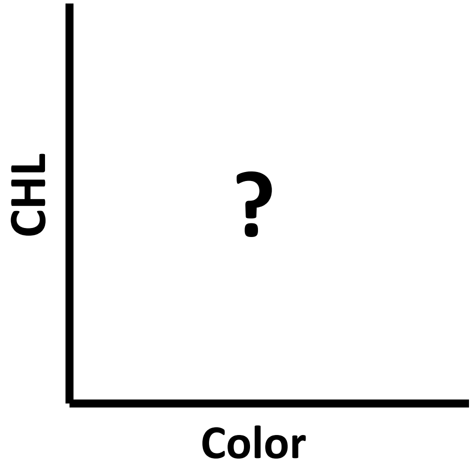


Spatially-varying coefficient model

Co-authors: quantitative ecologists with mad statistical skills

$$Chl_t(s) = \tilde{x}_t(s)\tilde{\beta}(s) + x_t(s)\,\beta + \epsilon_t\,(s)$$

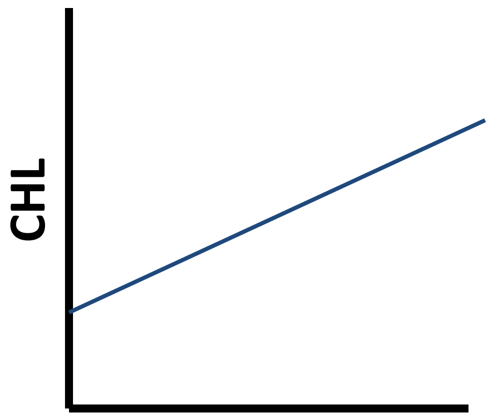


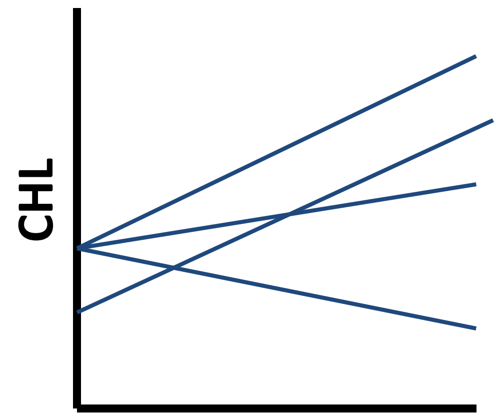


Spatially-varying coefficient model

$$Chl_t(s) = \tilde{x}_t(s)\overbrace{\tilde{\beta}(s)}^{\textbf{Spatially-varying coefficients}} + \ x_t(s)\,\beta + \ \epsilon_t\,(s)$$

$\tilde{\boldsymbol{\beta}}(\boldsymbol{s})$ **= Intercept, TP, and Water Color**





Spatially-varying coefficient model

$$Chl_t(s) = \underbrace{\tilde{x}_t(s)\tilde{\beta}(s)}_{\text{Spatially-varying coefficients}} + \underbrace{x_t(s)\,\beta}_{\text{Stationary coefficients}} + \epsilon_t\,(s)$$

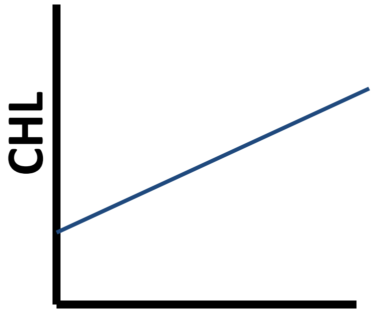
Hypothesized landscape & lake variables

- Lake depth
- Catchment: Lake Area ratio
- Agriculture
- Wetland
- Lake connectivity type (isolated vs. drainage)

Q1) Spatial variation in TP & Color effects?

Non-spatial

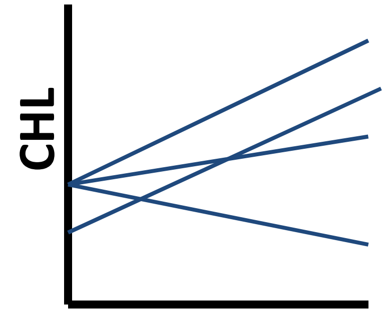
$\mathbf{M_{NULL}}$: CHL ~ Intercept + TP + Color



Vs.

Spatially-varying

$\mathbf{M_1}$: CHL ~ *Intercept + TP + Color*



Evaluated using model fit criteria

G = goodness of fit; **P** = penalty; **D** = model criteria

Gelfand and Gohosh 1998

Results: Q1

Model	G	P	D
Null	5456.0	5435.2	10891.3
1	4736.4	4502.9	9239.4

Lower is better

Results: Q1

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Null	5456.0	5435.2	10891.3
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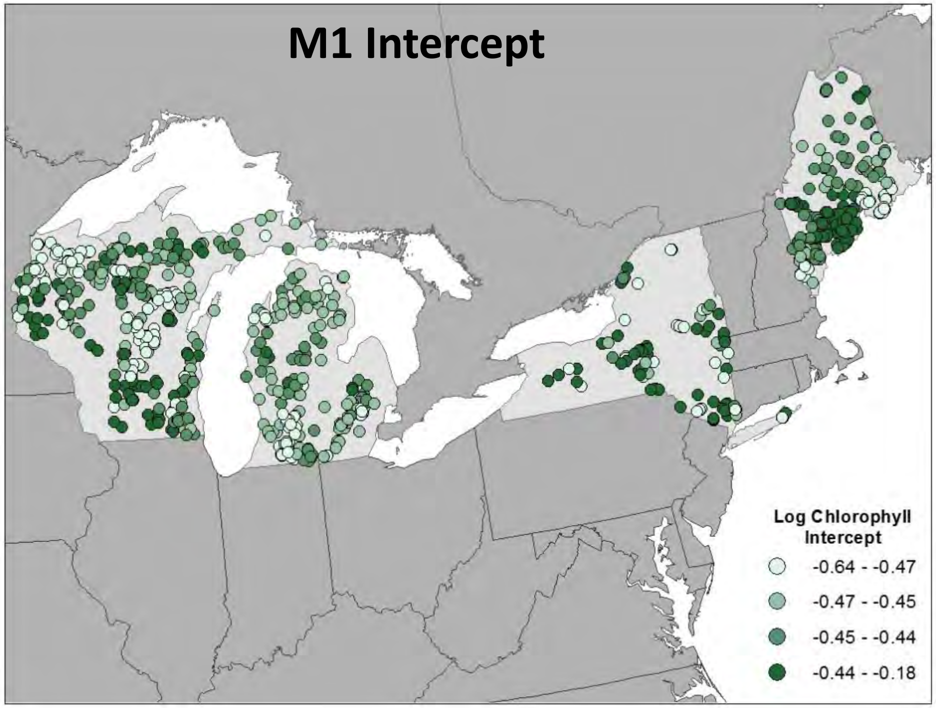

Results: Q1

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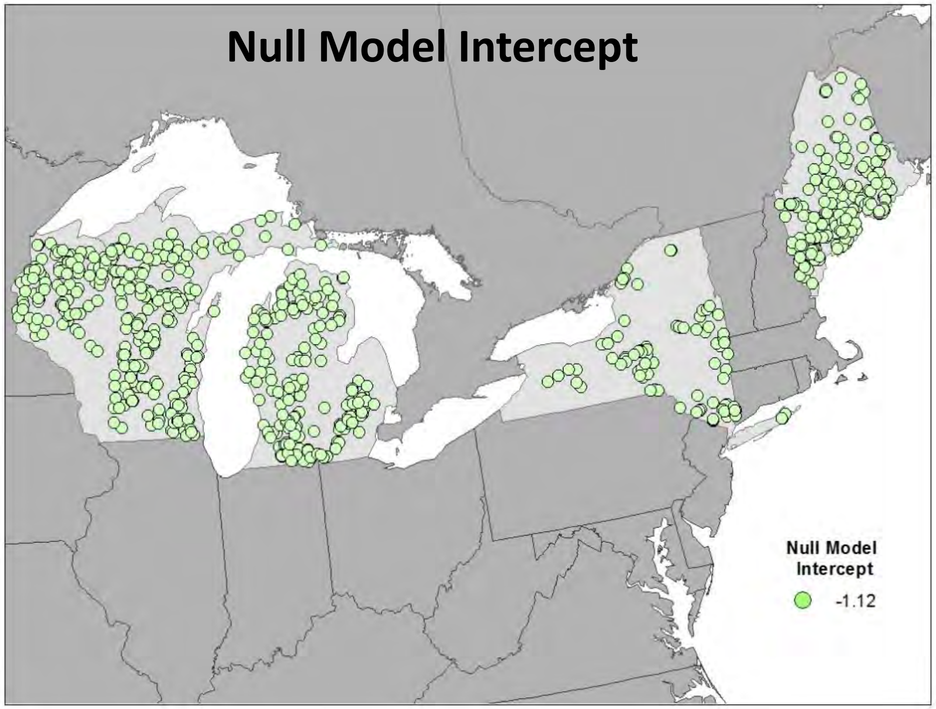
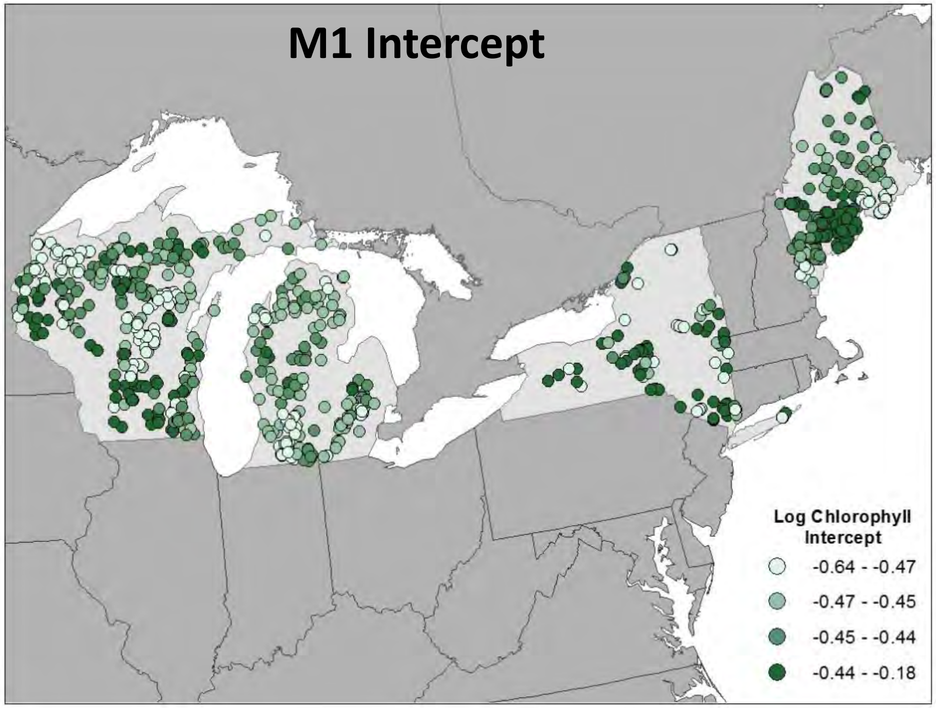
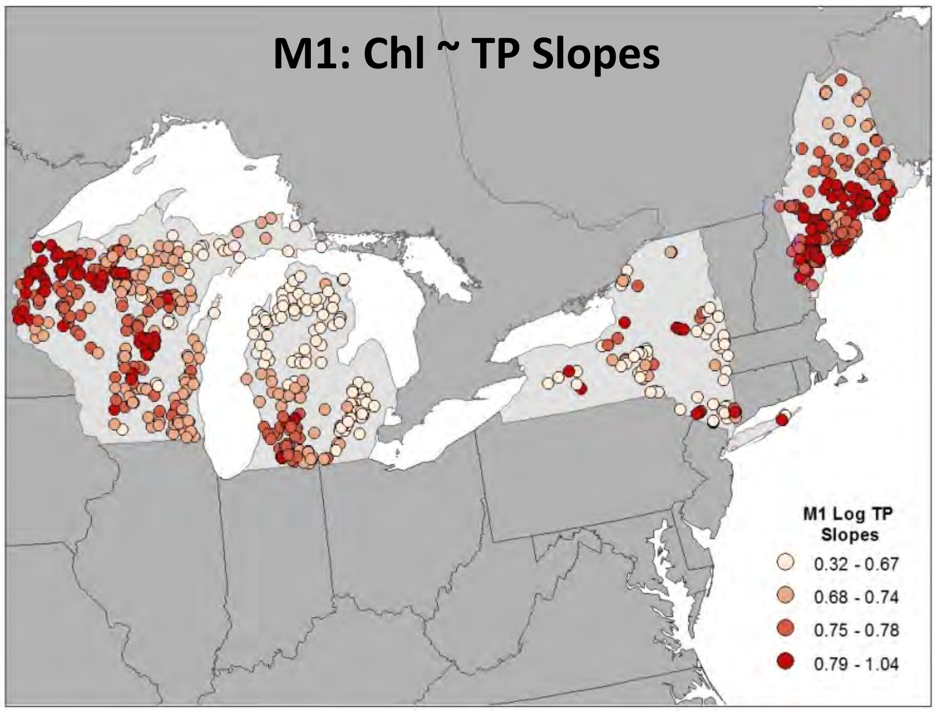
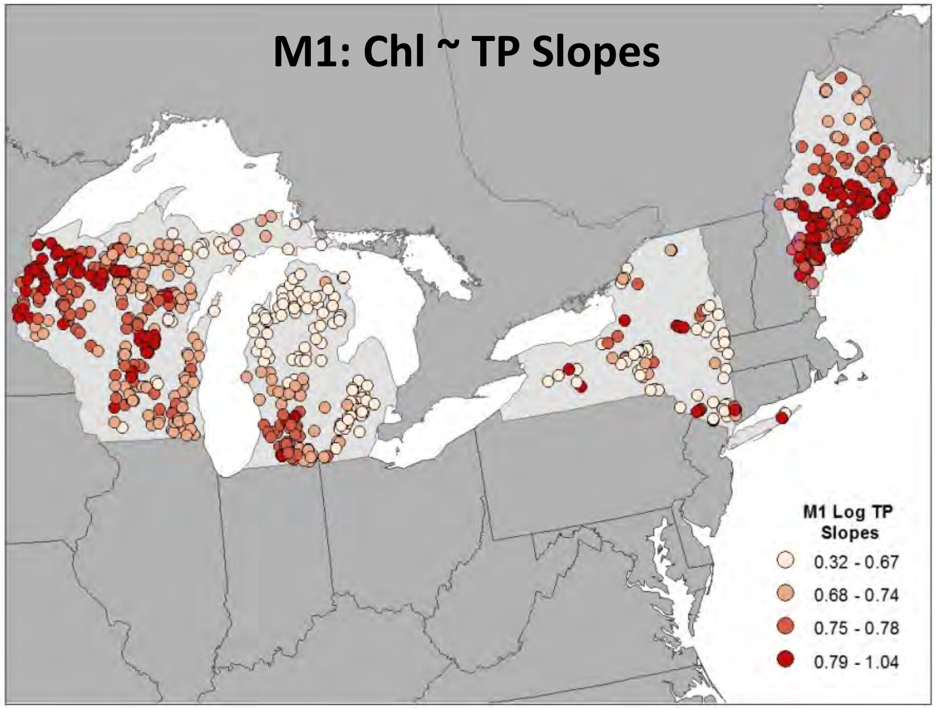




Results: Q1


M1: Chl ~ TP Slopes
M1 Log TP
Slopes
0.32 - 0.67
0.68 - 0.74
0.75 - 0.78
0.79 - 1.04

Results: Q1



M1: Chl ~ TP Slopes
M1 Log TP Slopes
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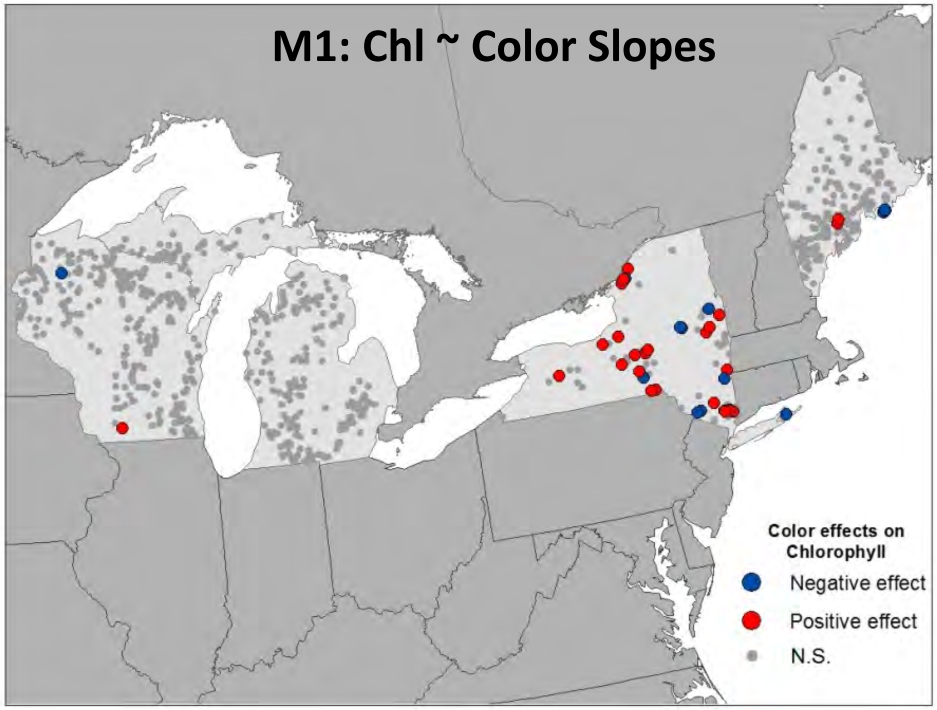


M1: Chl ~ Color Slopes
Color effects on Chlorophyll
Negative effect
Positive effect
N.S.

Conclusions: Q1

Lake Chlorophyll exhibits spatial variation even after accounting for TP & Color

- Landscape, lake, & other spatial variables may explain remaining spatial variation

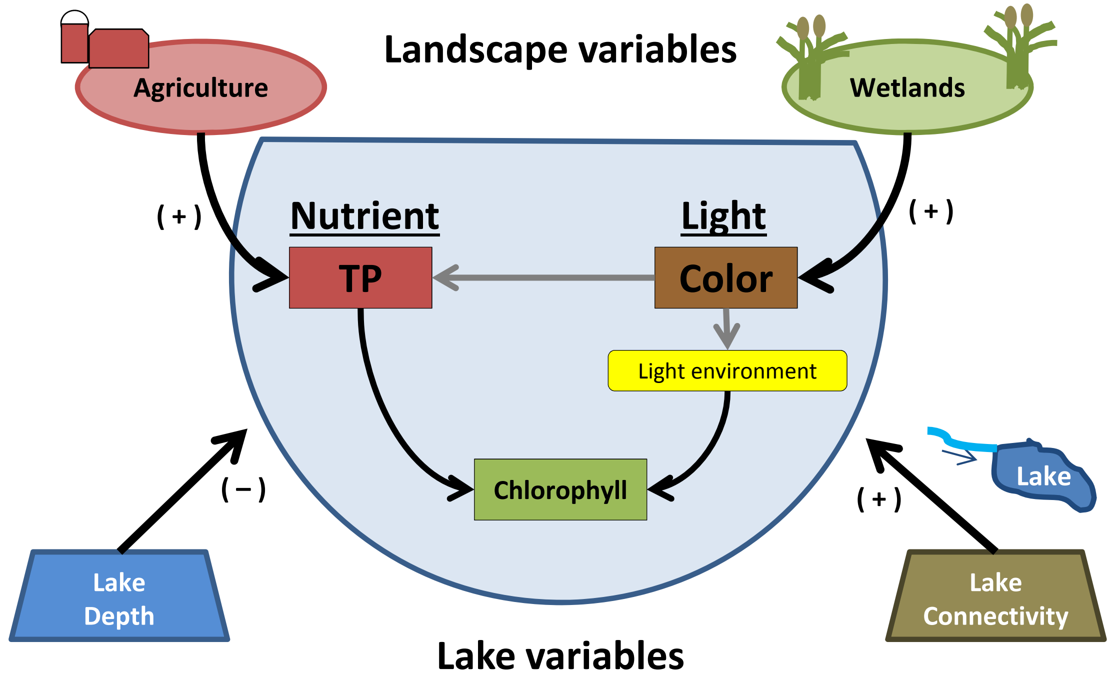
TP effects on Chlorophyll vary over space but Color effects were not significant for most lakes

- TP is primary driver of lake productivity in Upper Midwest and NE U.S.

Q2) Lake & landscape drivers of variation

Spatially-varying

$\mathbf{M_1}$: CHL ~ *Intercept + TP + Color*

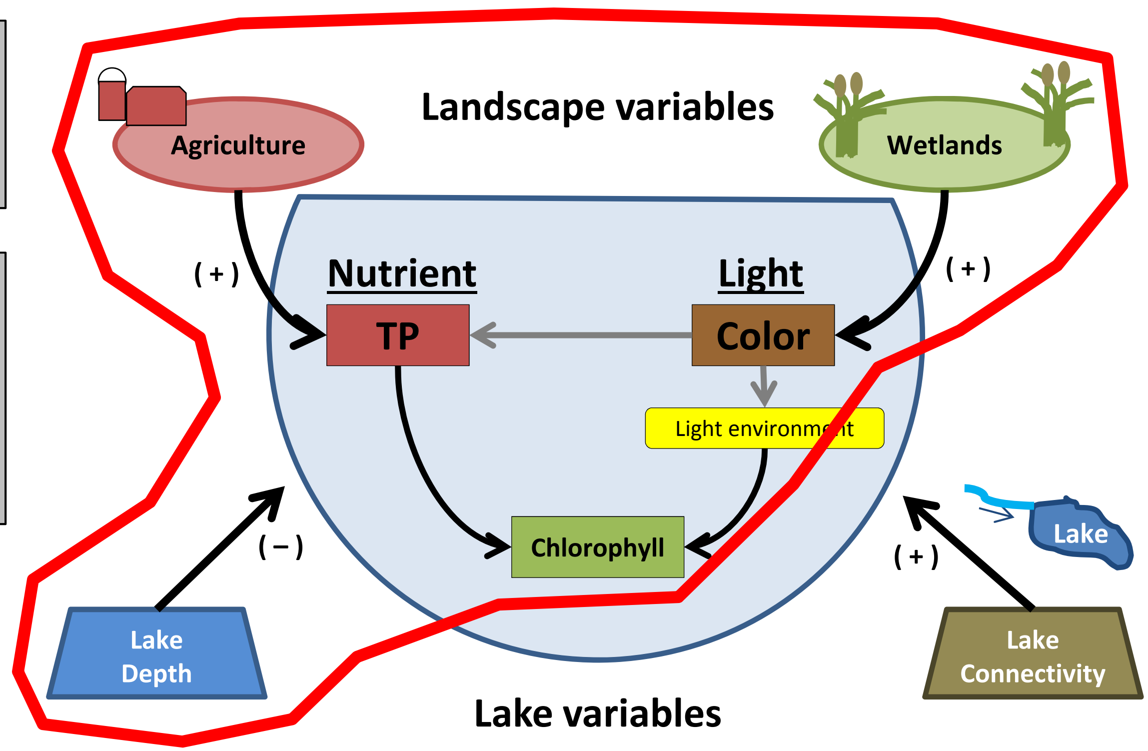


Q2) Lake & landscape drivers of variation

Spatially-varying

M_1: CHL ~ *Intercept* + *TP* + *Color*

M_2: CHL ~ *Intercept* + *TP* + *Color* + Depth + CA:LK + AGR + WET



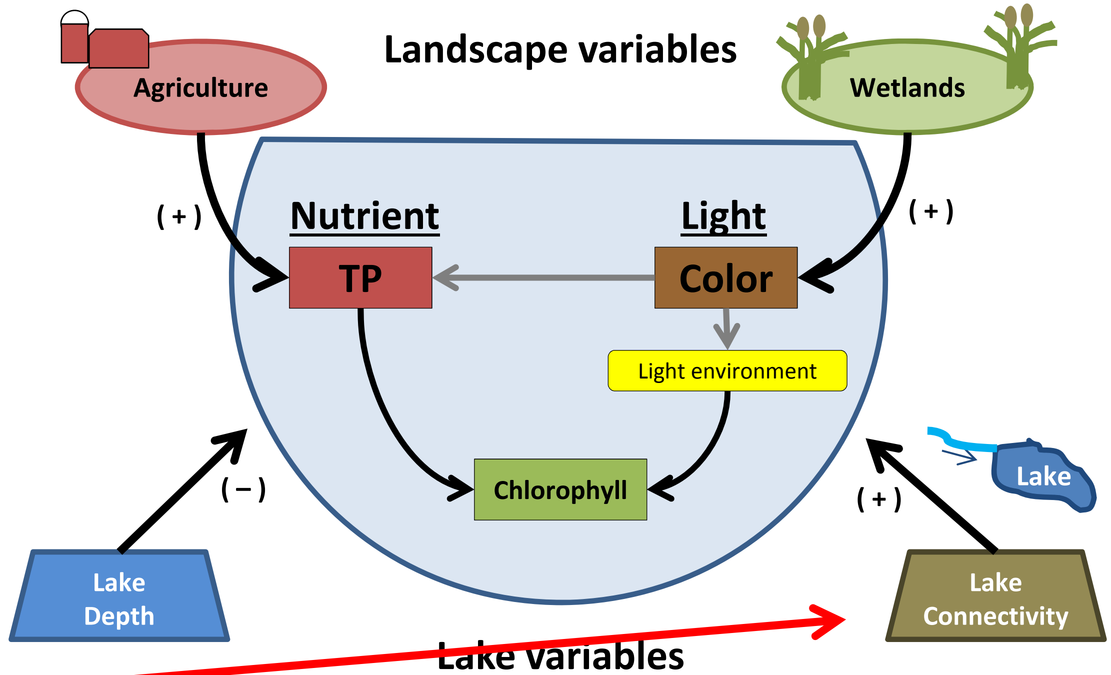
Q2) Lake & landscape drivers of variation

Spatially-varying

$\mathbf{M_1}$: CHL ~ *Intercept + TP + Color*

$\mathbf{M_2}$: CHL ~ *Intercept + TP + Color* + Depth + CA:LK + AGR + WET

$\mathbf{M_3}$: CHL ~ *Intercept + TP + Color* + Depth + CA:LK + AGR + WET + Connectivity



Results: Q2

Spatially-varying

M_1: CHL ~ *Intercept* + *TP* + *Color*

M_2: CHL ~ *Intercept* + *TP* + *Color* + Depth + CA:LK + AGR + WET

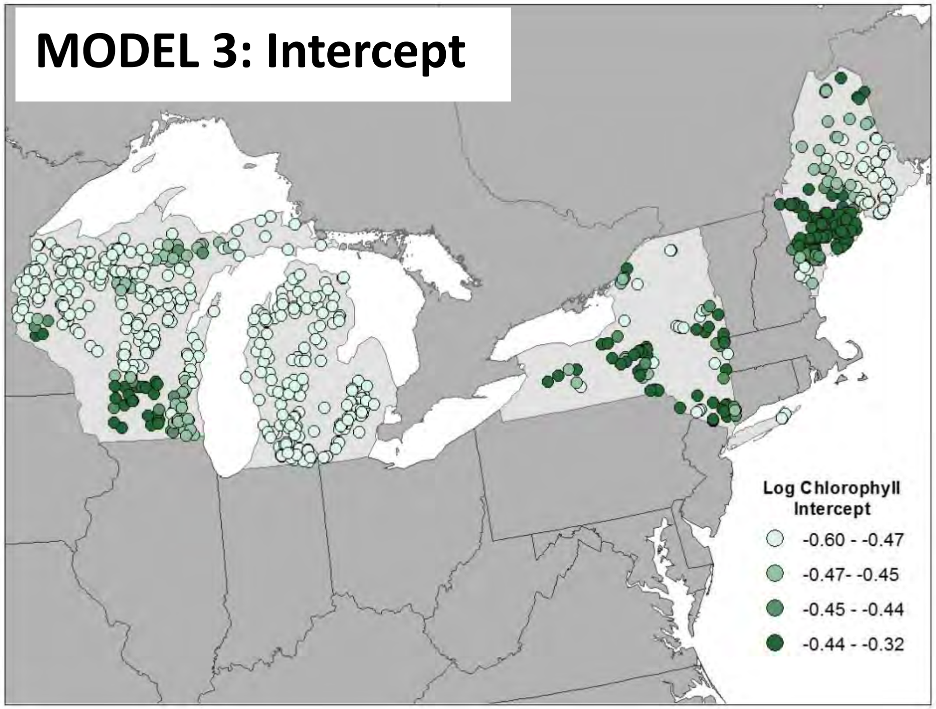
M_3: CHL ~ *Intercept* + *TP* + *Color* + Depth + CA:LK + AGR + WET + Connectivity

M	G	P	D
1	4736.4	4502.9	9239.4
2	4667.8	4508.4	9176.2
3	4593.7	4495.0	9088.8

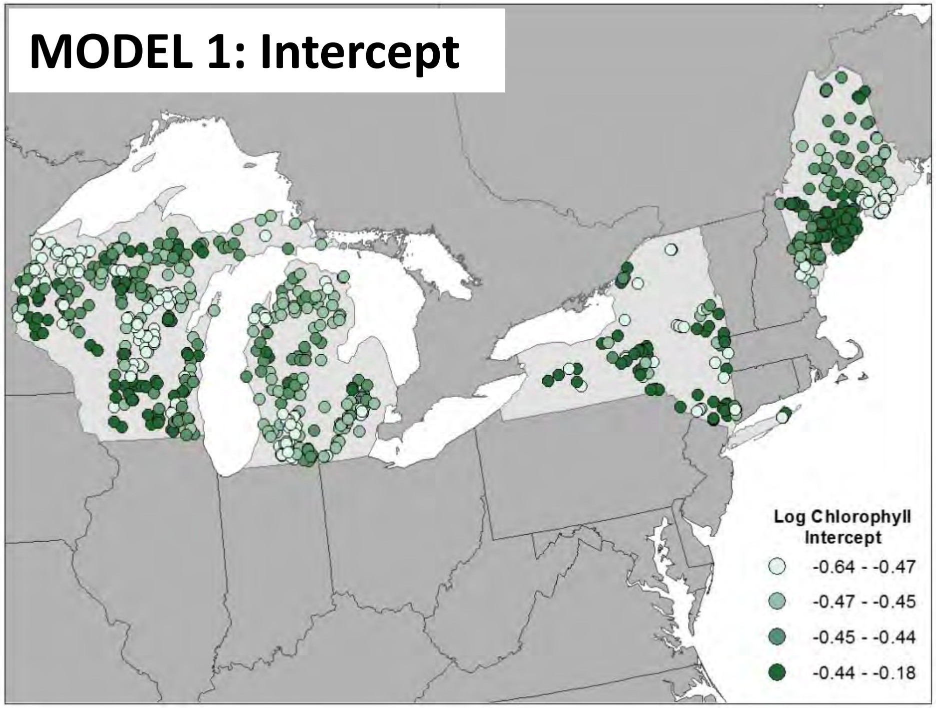
Model 3: Global parameter estimates

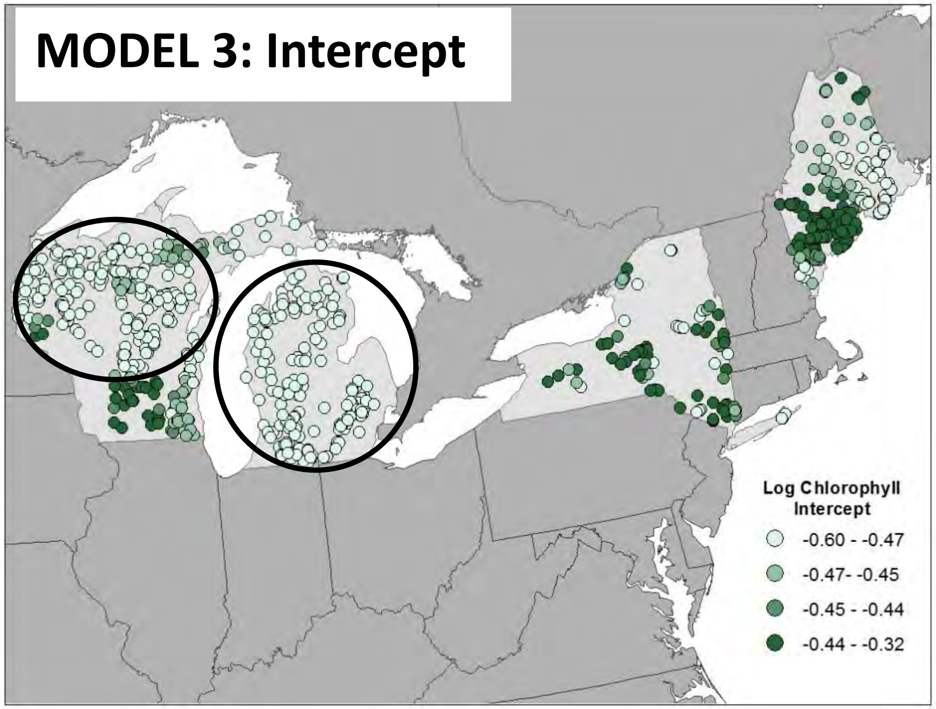
Spatially-varying			Fixed over space				
β_0	TP β_1	Color β_2	Depth β_3	CA:LK β_4	AGR β_5	WET β_6	Lake Type β_7
-0.48 **(-0.6 – -0.3)**	**0.68** **(0.5 – 0.7)**	0.01 (-0.09 – 0.13)	**-0.01** **(-0.01 – -0.01)**	**-0.0003** **(-0.0005 – -0.0001)**	**0.51** **(0.2 – 0.8)**	0.13 (-0.34 – 0.65)	**0.22** **(0.1 – 0.3)**

Comparing model with lake & landscape covariates



Comparing model with lake & landscape covariates





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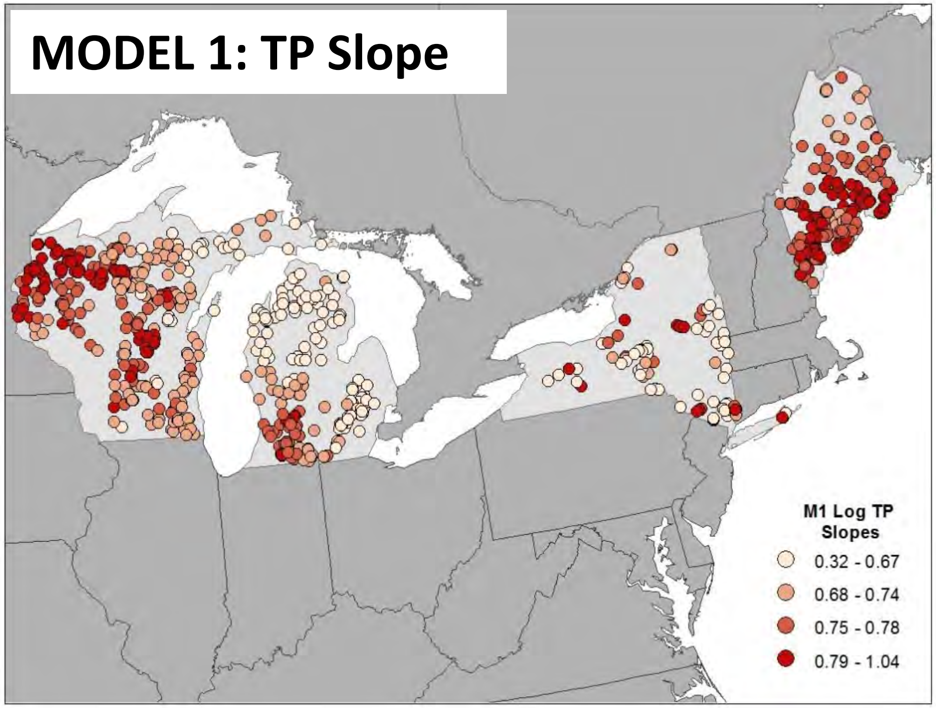

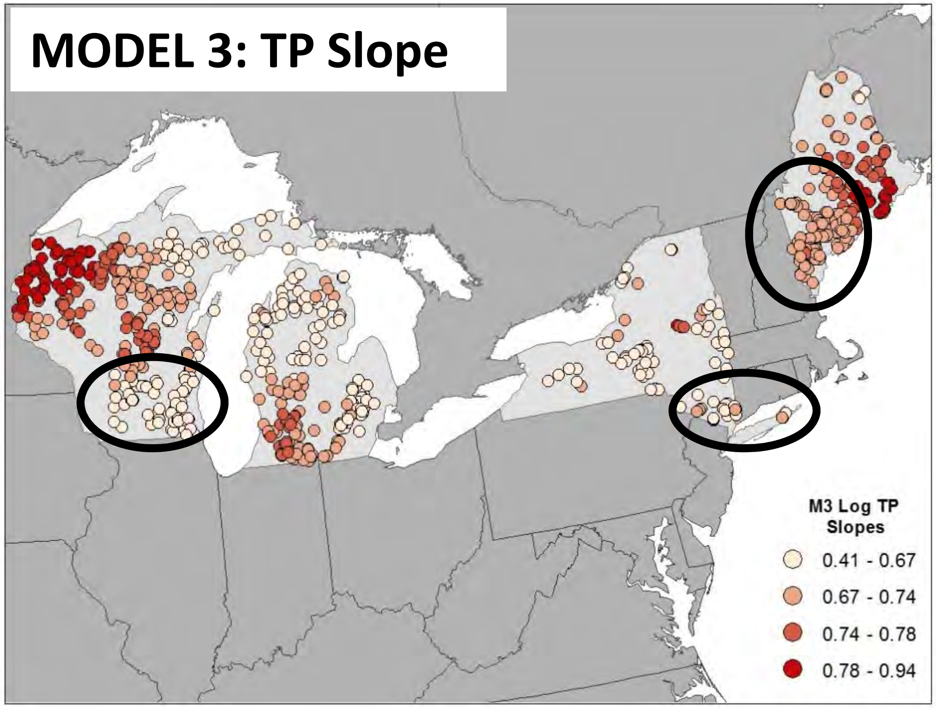

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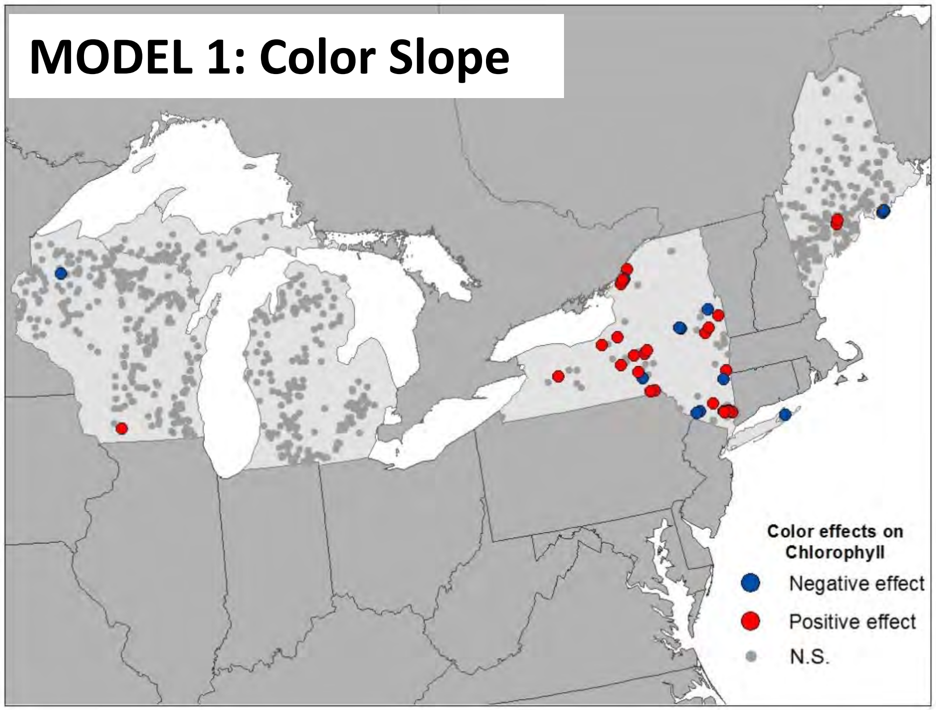
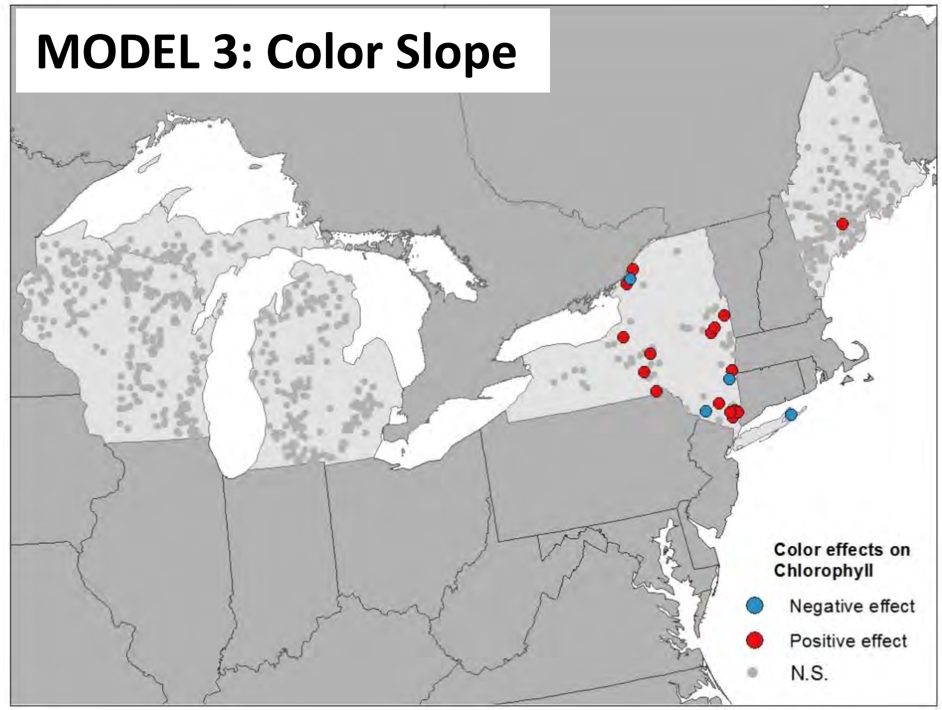
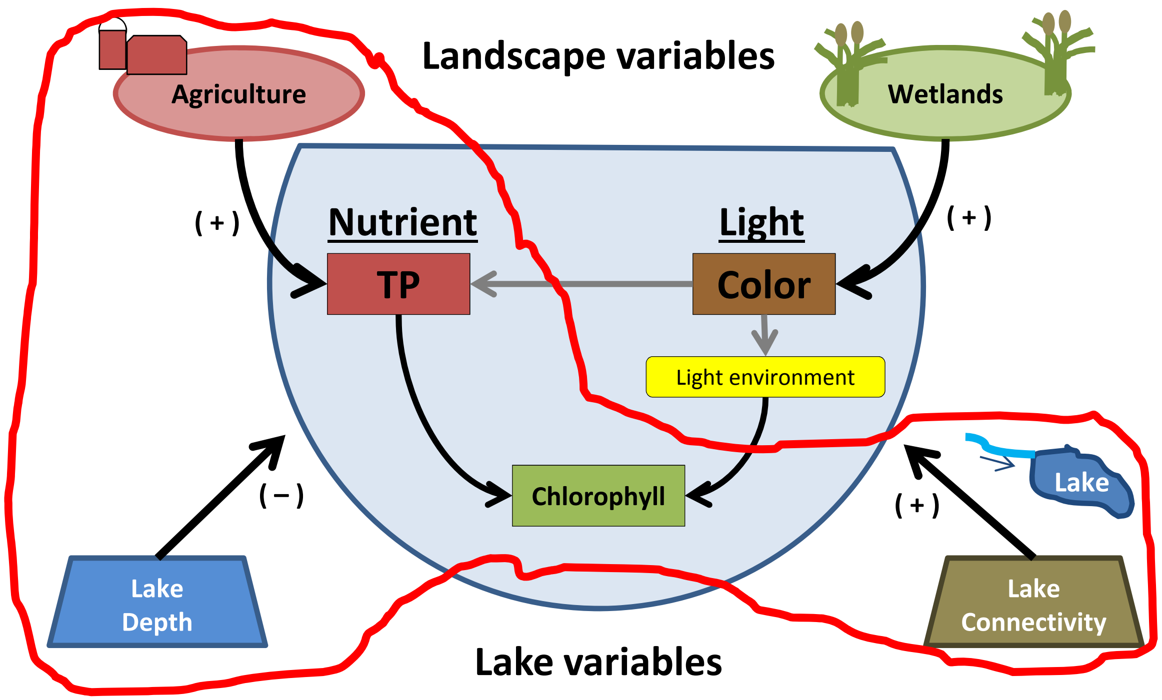




Conclusions: Q2

Hypothesized lake and landscape variables account for spatial variation

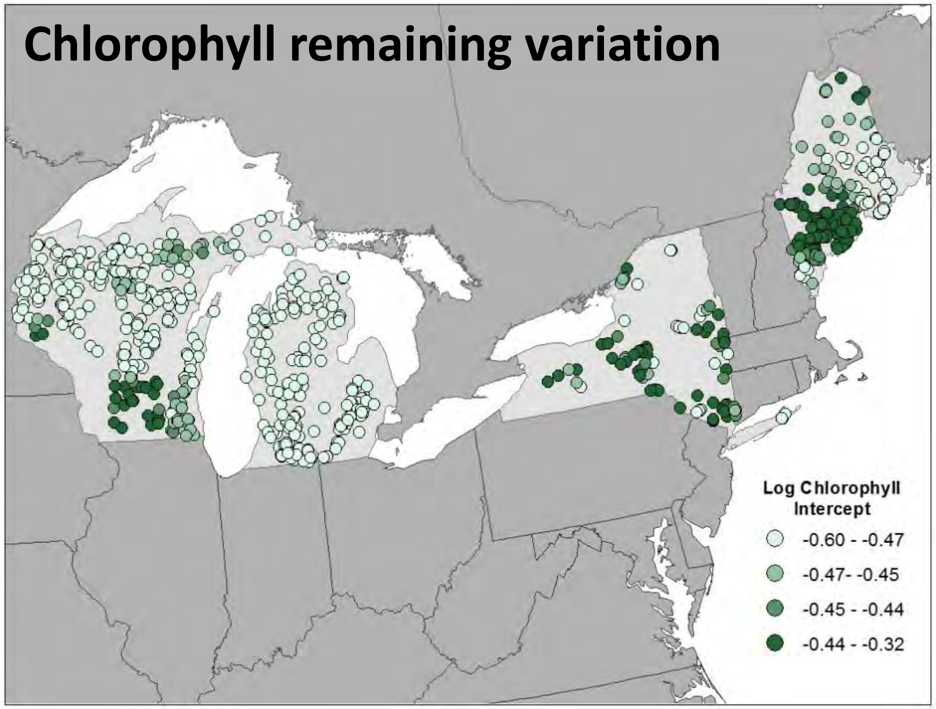
- To a great deal for Chlorophyll
- Moderately for CHL~TP
- And less for CHL~Color

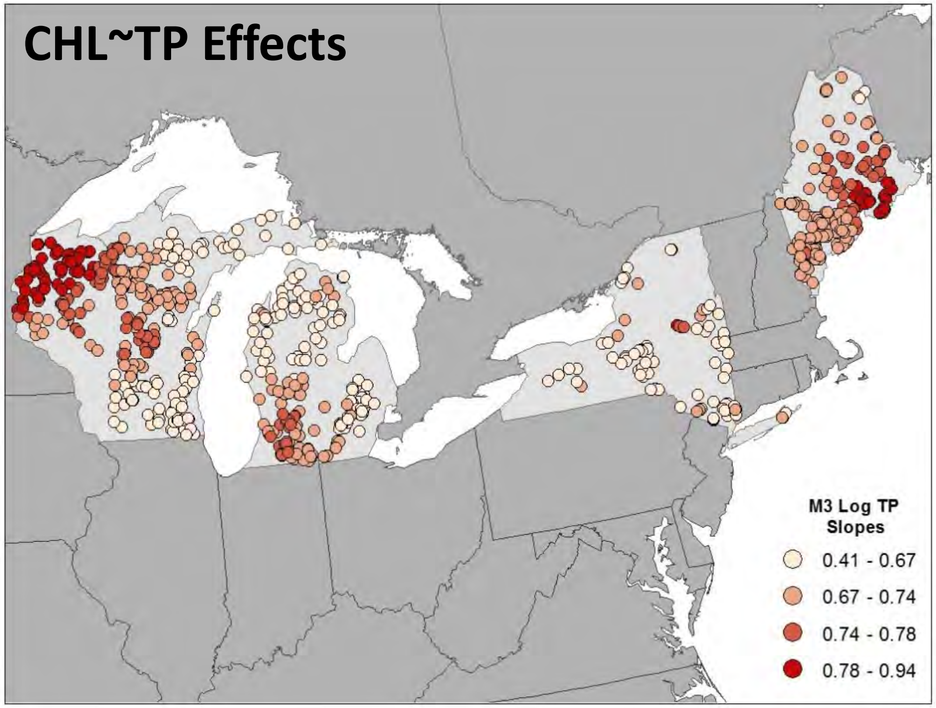


Conclusions: Q2

BUT spatial variation remains

- Scale of variation remaining – help identify potential predictors to consider for future models





Big data informing lake ecology

- Evaluate existing theory
- Help meet management and conservation goals
  - Assess lake water quality and ecological health
  - Set regional restoration targets

Acknowledgements

Funding: NSF Macrosystems Ecology

Database support: Ed Bissell

Special thanks: CSI Limnology Team, MSU Limnology Lab