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Portland, Oregon

Law of the Minimum, Chlorophyll-Nutrient Model and Eutrophication Management

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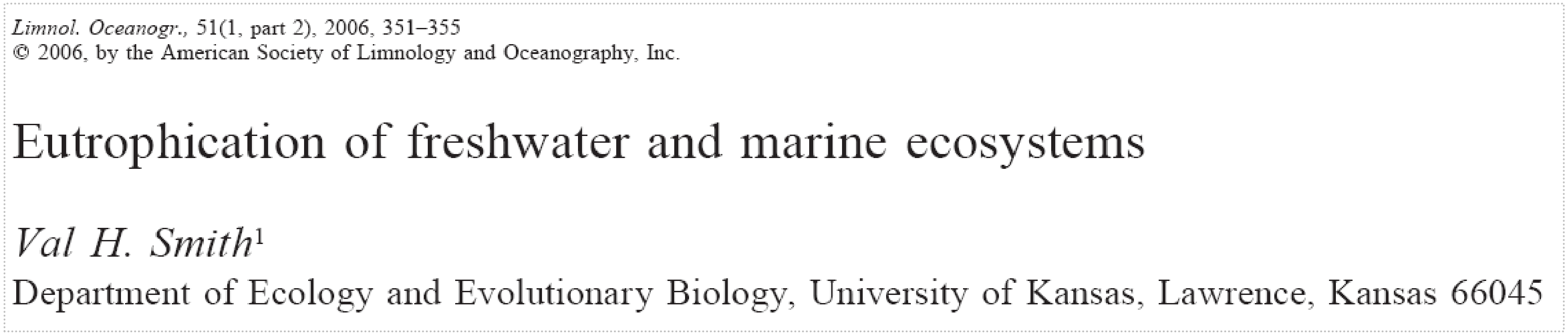
Main Points

1. Harmful Algal Bloom (HAB): Controlling Factors
2. Chlorophyll-Nutrient Model: Origin and Advance
3. Controlling Eutrophication: Nitrogen and Phosphorus
4. Reducing Nutrient: Adaptation to Changing Climate

1. Harmful Algal Bloom

- Factors regulating harmful algal bloom

>Climate (Temperature, solar radiation)
>Lake shape (Depth, volume and surface)
>Basin hydrology (Water discharge)
>Bottom-up effects (Nitrogen, phosphors)
>Top-down effects (Zooplankton, fish)



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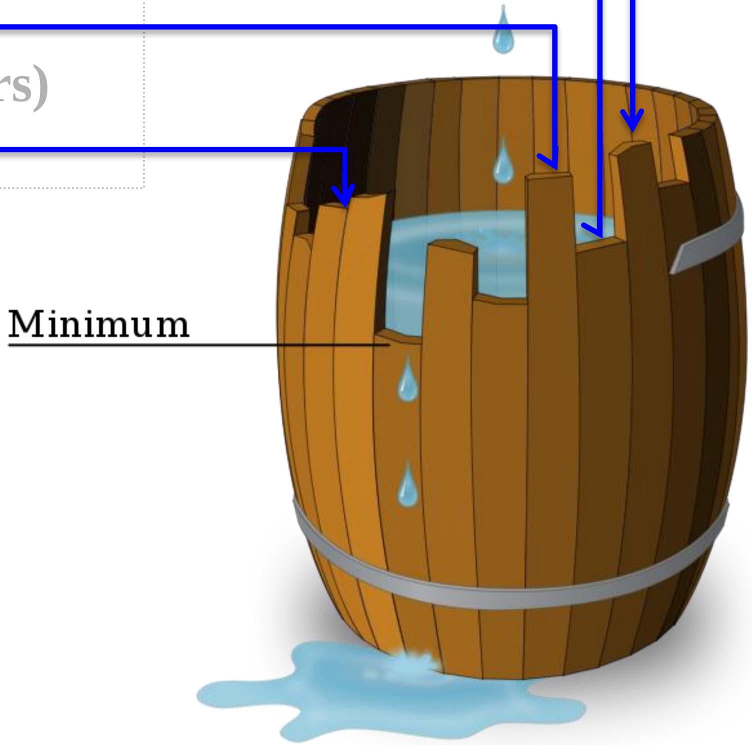
Eutrophication of freshwater and marine ecosystems

Val H. Smith[1]
Department of Ecology and Evolutionary Biology, University of Kansas, Lawrence, Kansas 66045

1. Harmful Algal Bloom

- **Uncontrollable factors**

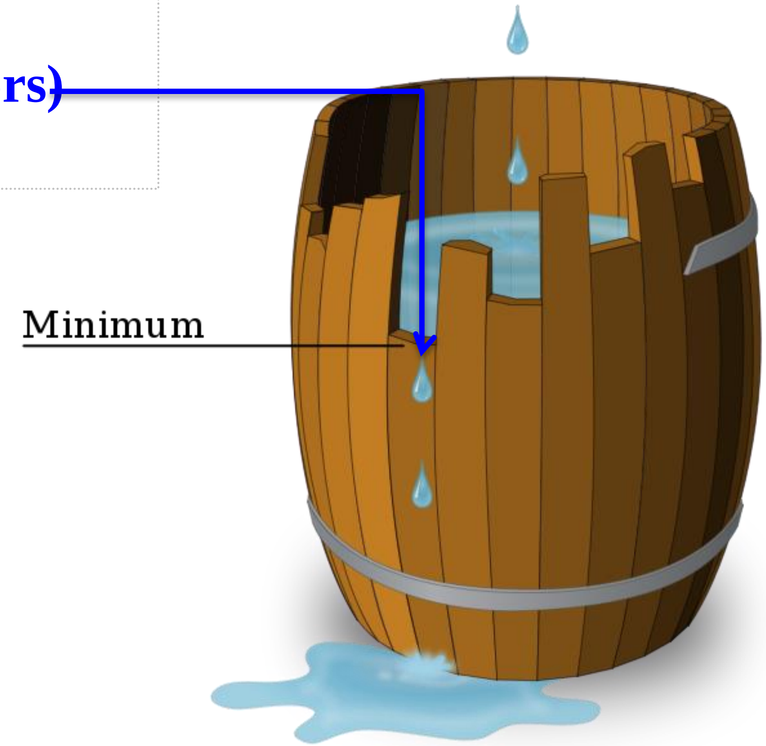
>Climate (Temperature, solar radiation)
>Lake shape (Depth, volume and surface)
>Basin hydrology (Water discharge)
>Bottom-up effects (Nitrogen, phosphors)
>Top-down effects (Zooplankton, fish)



1. Harmful Algal Bloom

Controllable factors

- >Climate (Temperature, solar radiation)
- >Lake shape (Depth, volume and surface)
- >Basin hydrology (Water discharge)
- >**Bottom-up effects (Nitrogen, phosphors)**
- >Top-down effects (Zooplankton, fish)

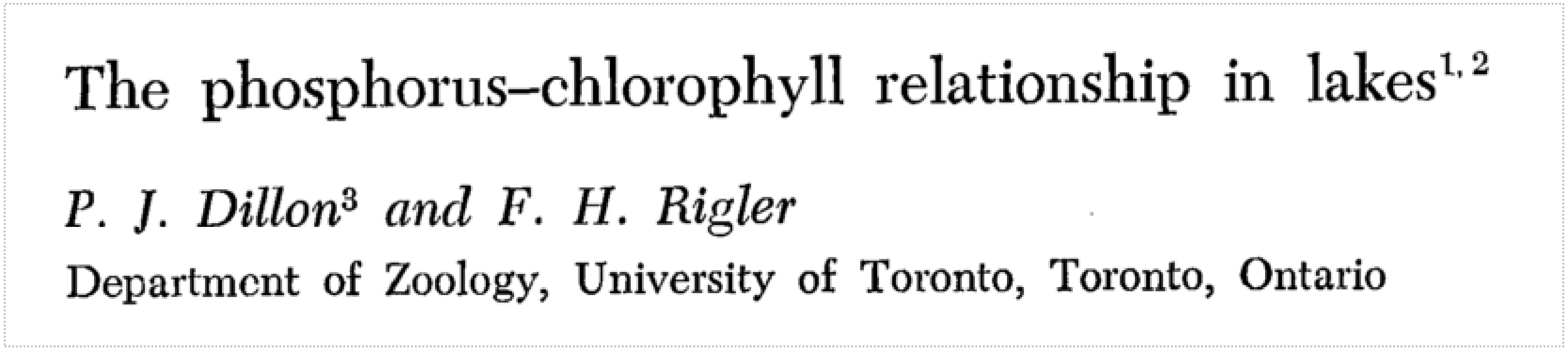


2. Chlorophyll-nutrient model

- **Classic regressions: Relate mean CHL to mean TN or TP**

$$log_{10}Chl = \alpha * log_{10}TN + \beta \tag{1}$$

$$log_{10}Chl = \alpha * log_{10}TP + \beta \tag{2}$$



The phosphorus–chlorophyll relationship in lakes[1, 2]

P. J. Dillon[3] and F. H. Rigler

Department of Zoology, University of Toronto, Toronto, Ontario

2. Chlorophyll-nutrient model

- **Quantile regressions: Relate max CHL to TN or TP**

$$log_{10}Chl = \alpha * log_{10}TN + \beta \qquad (1)$$

$$log_{10}Chl = \alpha * log_{10}TP + \beta \qquad (2)$$

REVIEWS REVIEWS REVIEWS

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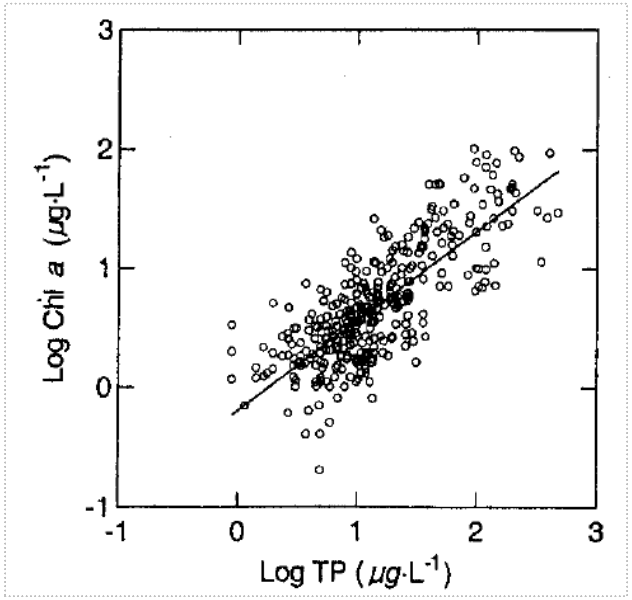
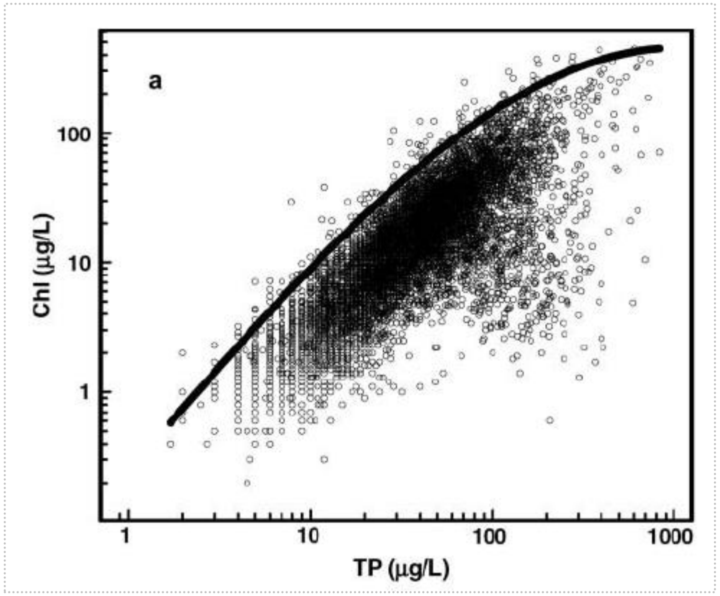
A gentle introduction to quantile regression for ecologists

Brian S Cade[1,2] and Barry R Noon[3]

2. Chlorophyll-nutrient model



Classic regression:
Modeling annual/summer mean
(e.g. Haven et al. 2004)



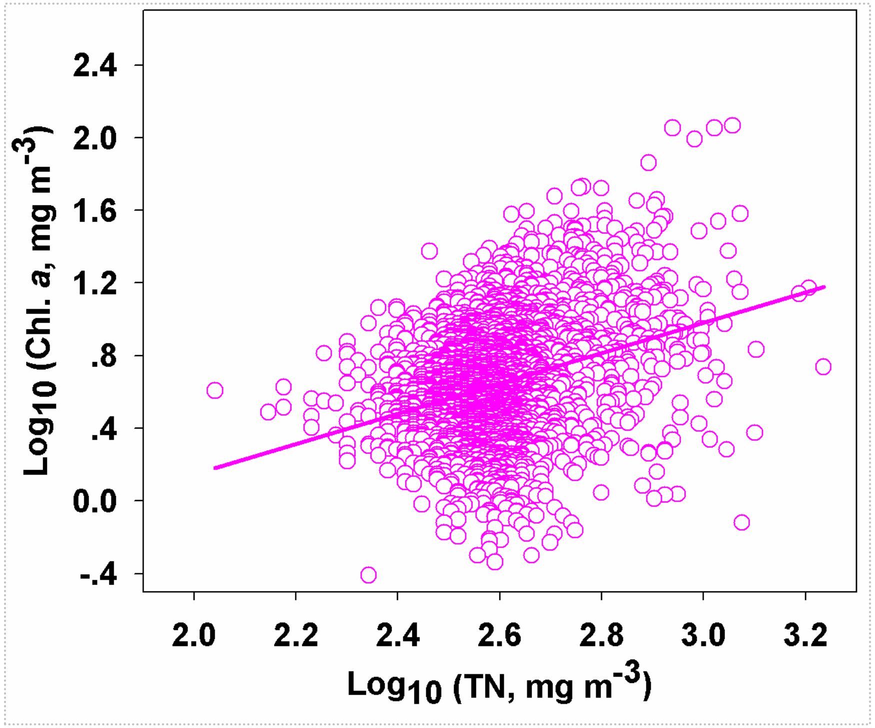
Quantile regression:
Modeling upper bound
(e.g. Jones et al. 2011)

2. Chlorophyll-nutrient model

- **Lake Champlain dataset: 15 sampling stations (1992~2012)**

2. Chlorophyll-nutrient model

- **Mean Chl-TN model with effects of uncontrollable factors**

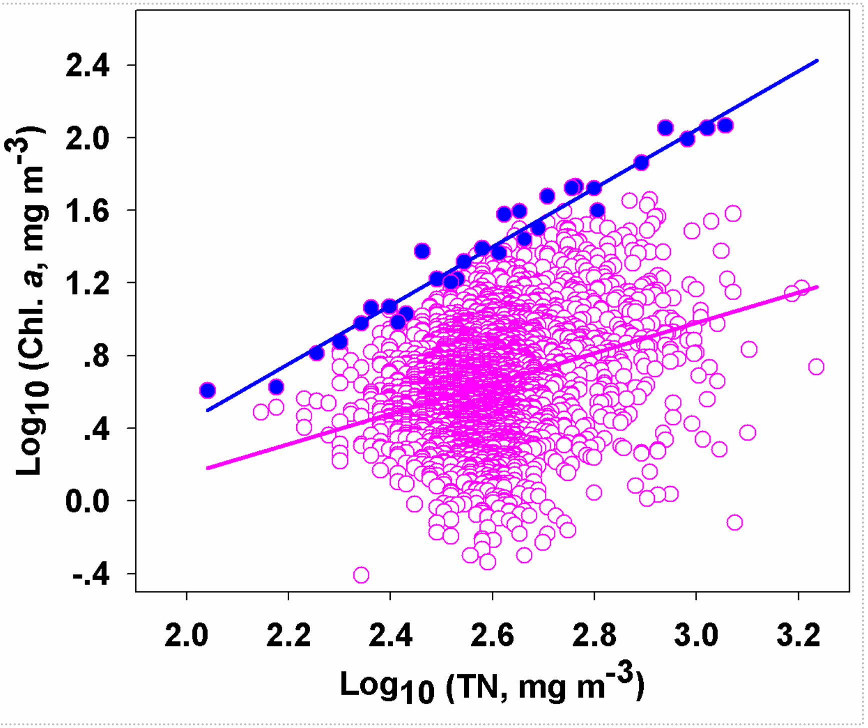


$$log_{10}Chl = 0.82 * log_{10}TN - 1.52$$

$$r^2 = 0.101, p < 0.01$$

2. Chlorophyll-nutrient model

- **Max Chl-TN model without effects of other uncontrollable factors**



$$log_{10}Chl_{\max} = 1.61 * log_{10}TN - 2.79$$

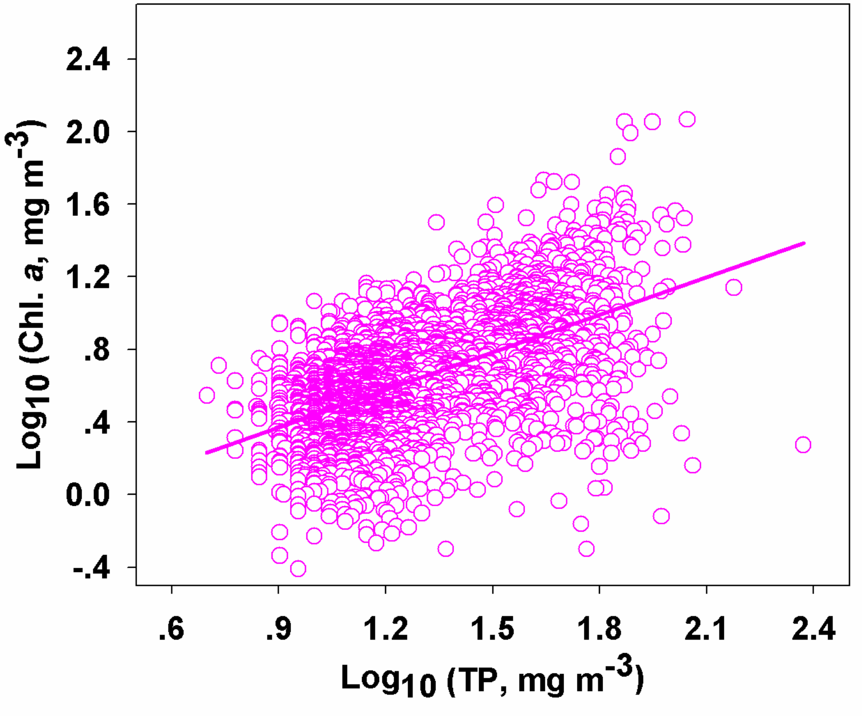
$$r^2 = 0.962,\ p < 0.01$$

$$log_{10}Chl = 0.82 * log_{10}TN - 1.52$$

$$r^2 = 0.101,\ p < 0.01$$

2. Chlorophyll-nutrient model

- **Mean Chl-TP model with effects of uncontrollable factors**

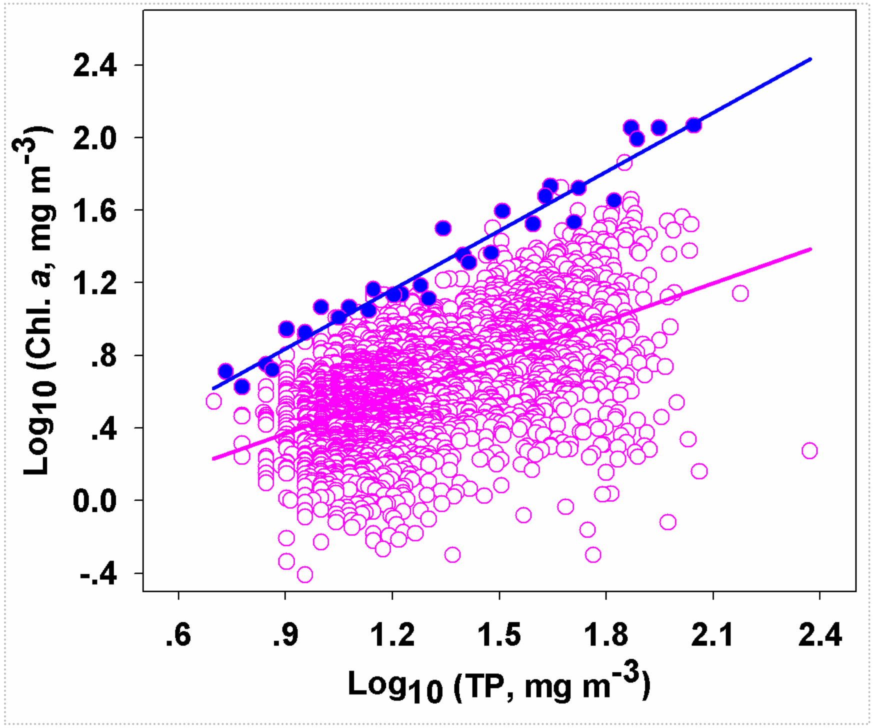


$$log_{10}Chl = 0.69 * log_{10}TP - 0.25$$

$$r^2 = 0.316, p < 0.01$$

2. Chlorophyll-nutrient model

- **Max Chl-TP model without effects of other uncontrollable factors**

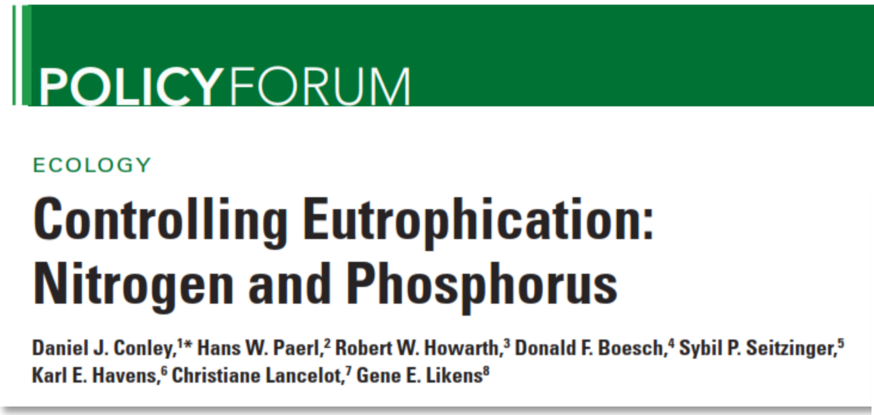


$$log_{10}Chl_{\max} = 1.08 * log_{10}TP - 0.14$$

$$r^2 = 0.948, p < 0.01$$

$$log_{10}Chl = 0.69 * log_{10}TP - 0.25$$

$$r^2 = 0.316, p < 0.01$$

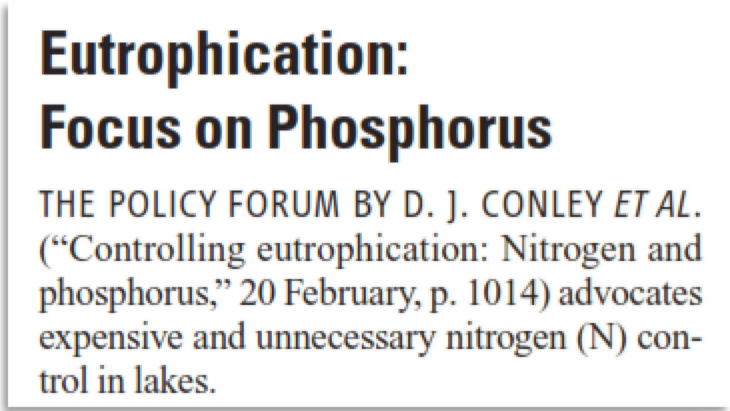


POLICYFORUM

ECOLOGY

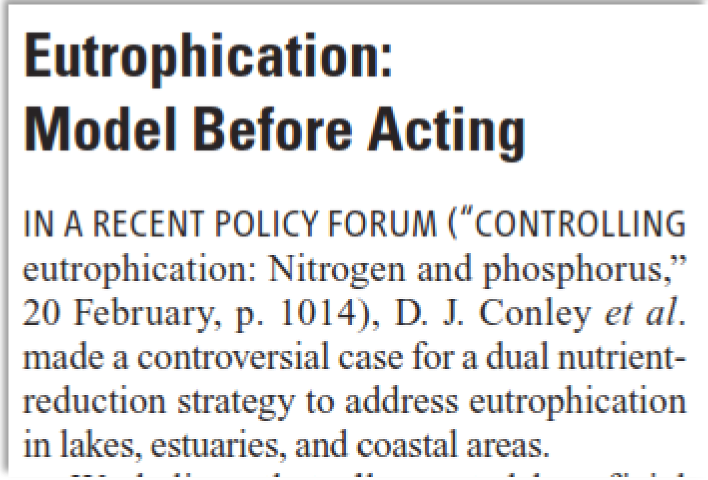
Controlling Eutrophication: Nitrogen and Phosphorus

Daniel J. Conley,[1]* Hans W. Paerl,[2] Robert W. Howarth,[3] Donald F. Boesch,[4] Sybil P. Seitzinger,[5] Karl E. Havens,[6] Christiane Lancelot,[7] Gene E. Likens[8]



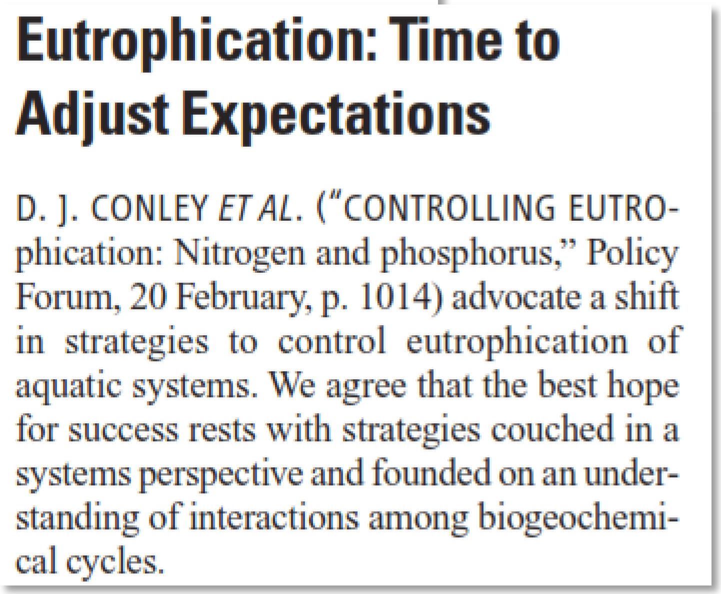
Eutrophication: Focus on Phosphorus

THE POLICY FORUM BY D. J. CONLEY *ET AL.* ("Controlling eutrophication: Nitrogen and phosphorus," 20 February, p. 1014) advocates expensive and unnecessary nitrogen (N) control in lakes.



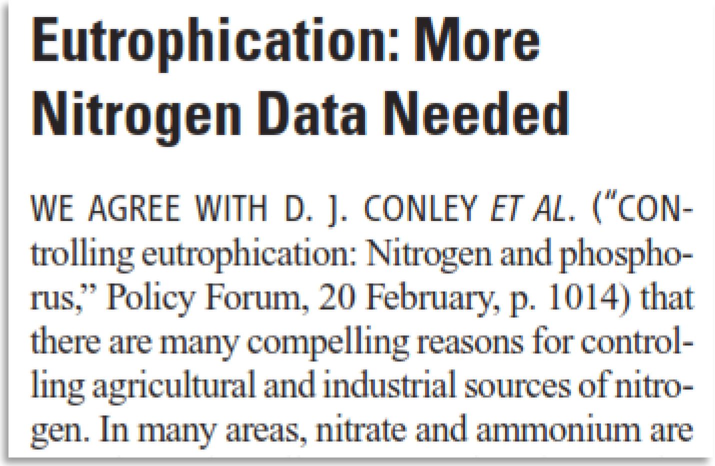
Eutrophication: Model Before Acting

IN A RECENT POLICY FORUM ("CONTROLLING eutrophication: Nitrogen and phosphorus," 20 February, p. 1014), D. J. Conley *et al.* made a controversial case for a dual nutrient-reduction strategy to address eutrophication in lakes, estuaries, and coastal areas.



Eutrophication: Time to Adjust Expectations

D. J. CONLEY *ET AL.* ("CONTROLLING EUTROphication: Nitrogen and phosphorus," Policy Forum, 20 February, p. 1014) advocate a shift in strategies to control eutrophication of aquatic systems. We agree that the best hope for success rests with strategies couched in a systems perspective and founded on an understanding of interactions among biogeochemical cycles.

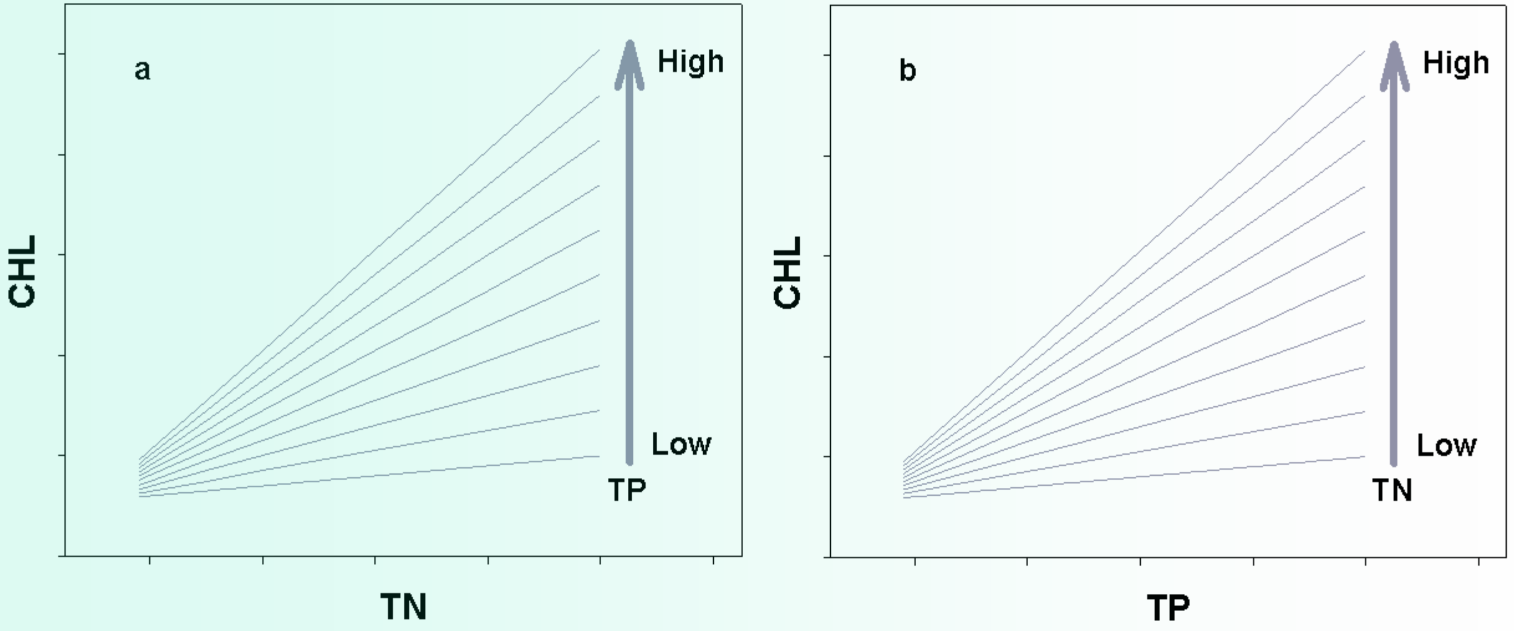


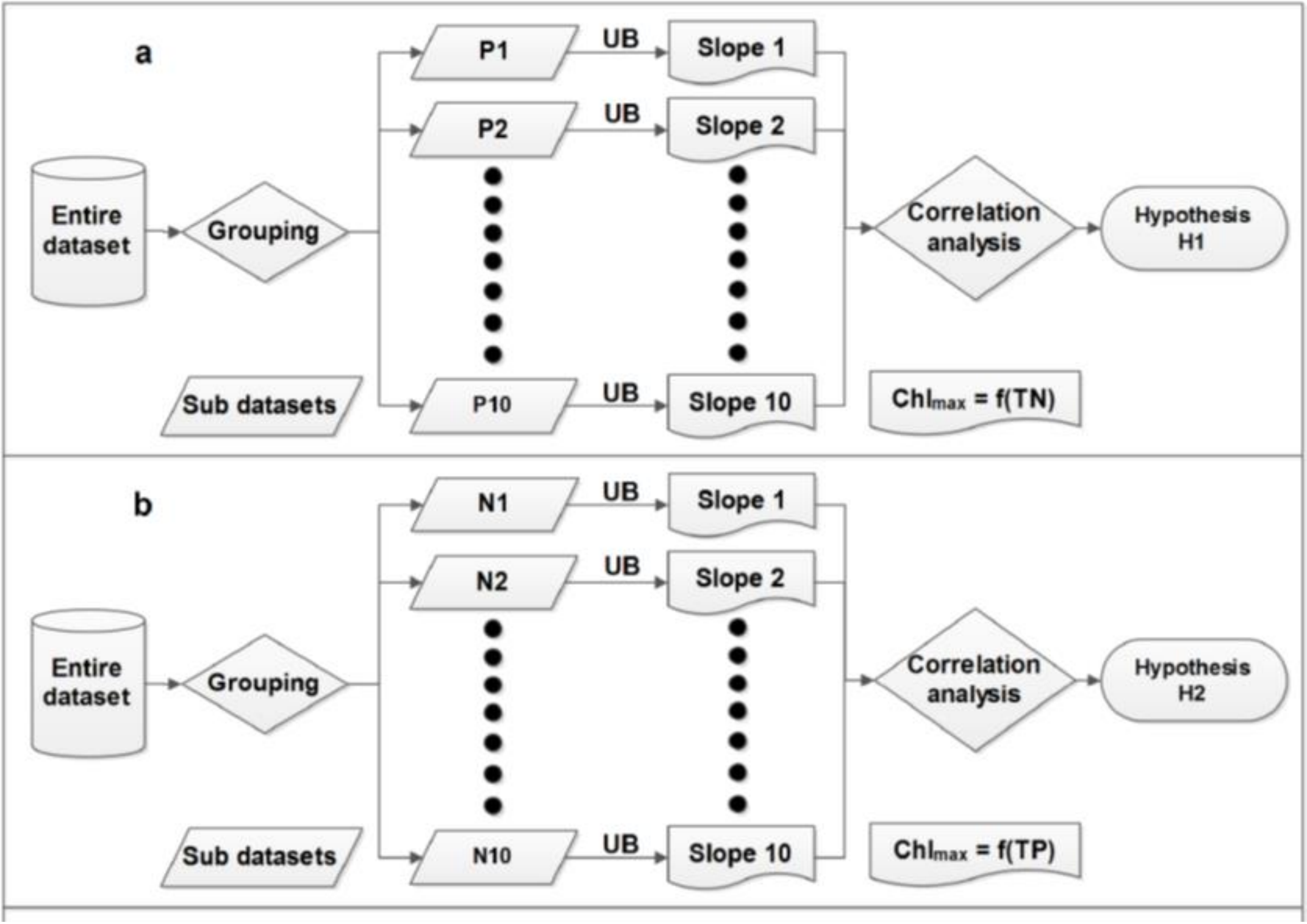
Eutrophication: More Nitrogen Data Needed

WE AGREE WITH D. J. CONLEY *ET AL.* ("Controlling eutrophication: Nitrogen and phosphorus," Policy Forum, 20 February, p. 1014) that there are many compelling reasons for controlling agricultural and industrial sources of nitrogen. In many areas, nitrate and ammonium are

3. Eutrophication: Nitrogen and Phosphorus

- **Hypothesis (H1): The response of CHL to TN is raised by TP?**
- **Hypothesis (H2): The response of CHL to TP is raised by TN?**



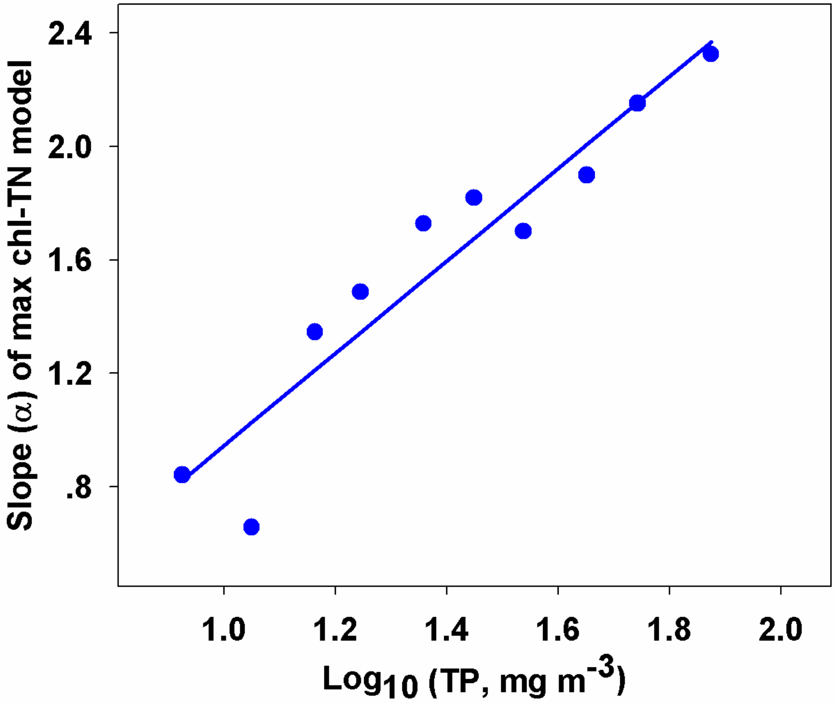

a
Entire dataset
Grouping
Sub datasets
P1
P2
P10
UB
UB
UB
Slope 1
Slope 2
Slope 10
Correlation analysis
Hypothesis H1
Chl_{max} = f(TN)
b
Entire dataset
Grouping
Sub datasets
N1
N2
N10
UB
UB
UB
Slope 1
Slope 2
Slope 10
Correlation analysis
Hypothesis H2
Chl_{max} = f(TP)

Sub-dataset	TP	Samples	Sub-dataset	TN	Samples
P1	$0.7 \leq \text{Log}_{10}(\text{TP}) < 1.0$	187	N1	$2.04 \leq \text{Log}_{10}(\text{TN}) < 2.45$	214
P2	$1.0 \leq \text{Log}_{10}(\text{TP}) < 1.1$	516	N2	$2.45 \leq \text{Log}_{10}(\text{TN}) < 2.50$	233
P3	$1.1 \leq \text{Log}_{10}(\text{TP}) < 1.2$	527	N3	$2.50 \leq \text{Log}_{10}(\text{TN}) < 2.55$	479
P4	$1.2 \leq \text{Log}_{10}(\text{TP}) < 1.3$	335	N4	$2.55 \leq \text{Log}_{10}(\text{TN}) < 2.60$	556
P5	$1.3 \leq \text{Log}_{10}(\text{TP}) < 1.4$	233	N5	$2.60 \leq \text{Log}_{10}(\text{TN}) < 2.65$	521
P6	$1.4 \leq \text{Log}_{10}(\text{TP}) < 1.5$	178	N6	$2.65 \leq \text{Log}_{10}(\text{TN}) < 2.70$	269
P7	$1.5 \leq \text{Log}_{10}(\text{TP}) < 1.6$	223	N7	$2.70 \leq \text{Log}_{10}(\text{TN}) < 2.75$	123
P8	$1.6 \leq \text{Log}_{10}(\text{TP}) < 1.7$	226	N8	$2.75 \leq \text{Log}_{10}(\text{TN}) < 2.80$	95
P9	$1.7 \leq \text{Log}_{10}(\text{TP}) < 1.8$	152	N9	$2.80 \leq \text{Log}_{10}(\text{TN}) < 2.85$	64
P10	$1.8 \leq \text{Log}_{10}(\text{TP}) < 2.4$	121	N10	$2.85 \leq \text{Log}_{10}(\text{TN}) < 3.24$	144

3. Eutrophication: Nitrogen and Phosphorus

- **Hypothesis (H1): True**

Increase in TP enhance phytoplankton response to TN (Slope, α_{TN})



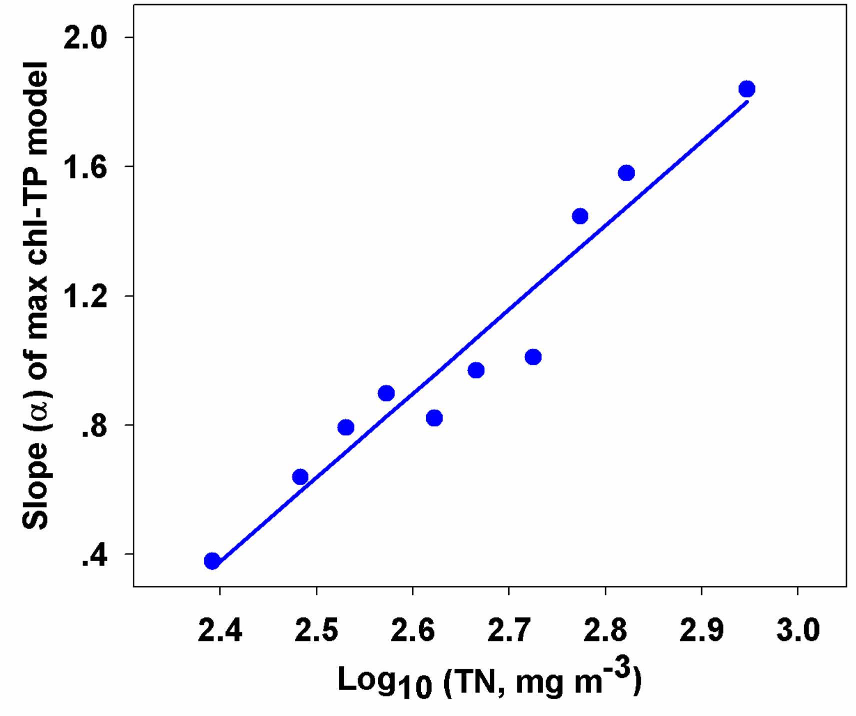
$$\alpha_{TN} = 1.63 * log_{10}TP - 0.68$$

$$r^2 = 0.897, p < 0.01$$

3. Eutrophication: Nitrogen and Phosphorus

- **Hypothesis (H2): True**

Increase in TN enhance phytoplankton response to TP (Slope, α_{TP})



$$\alpha_{TP} = 2.60 * \log_{10} TN - 5.87$$

$$r^2 = 0.941, p < 0.01$$

3. Eutrophication: Nitrogen and Phosphorus

- **Hypothesis (H1): True**
Increase in TP enhance phytoplankton response to TN (Slope, α_{TN})

- **Hypothesis (H2): True**
Increase in TN enhance phytoplankton response to TP (Slope, α_{TP})

Dual-nutrient control would be more effective than phosphorus-only reduction to mitigate eutrophication in Lake Champlain

CLIMATE

Blooms Like It Hot

Hans W. Paerl[1] and Jef Huisman[2]

A link exists between global warming and the worldwide proliferation of harmful cyanobacterial blooms.

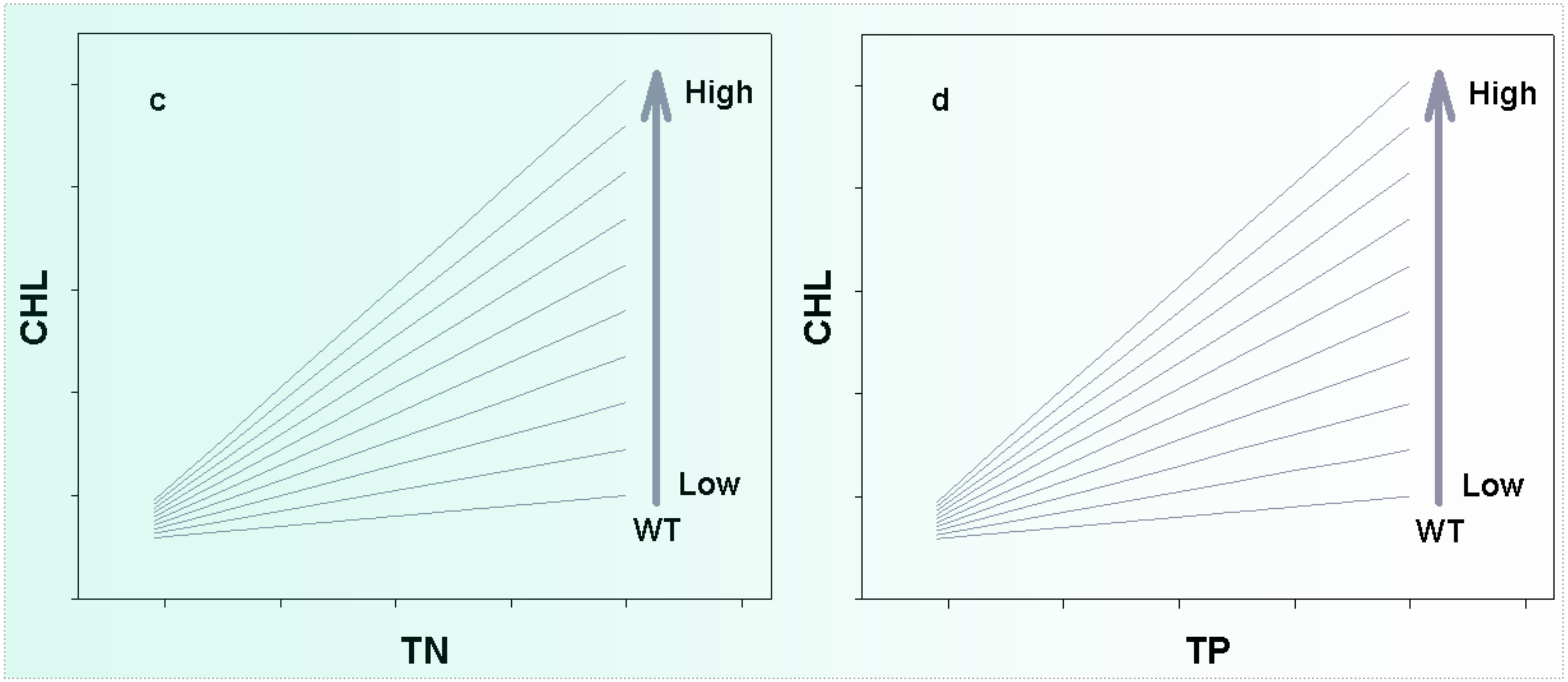
Resilience to Blooms

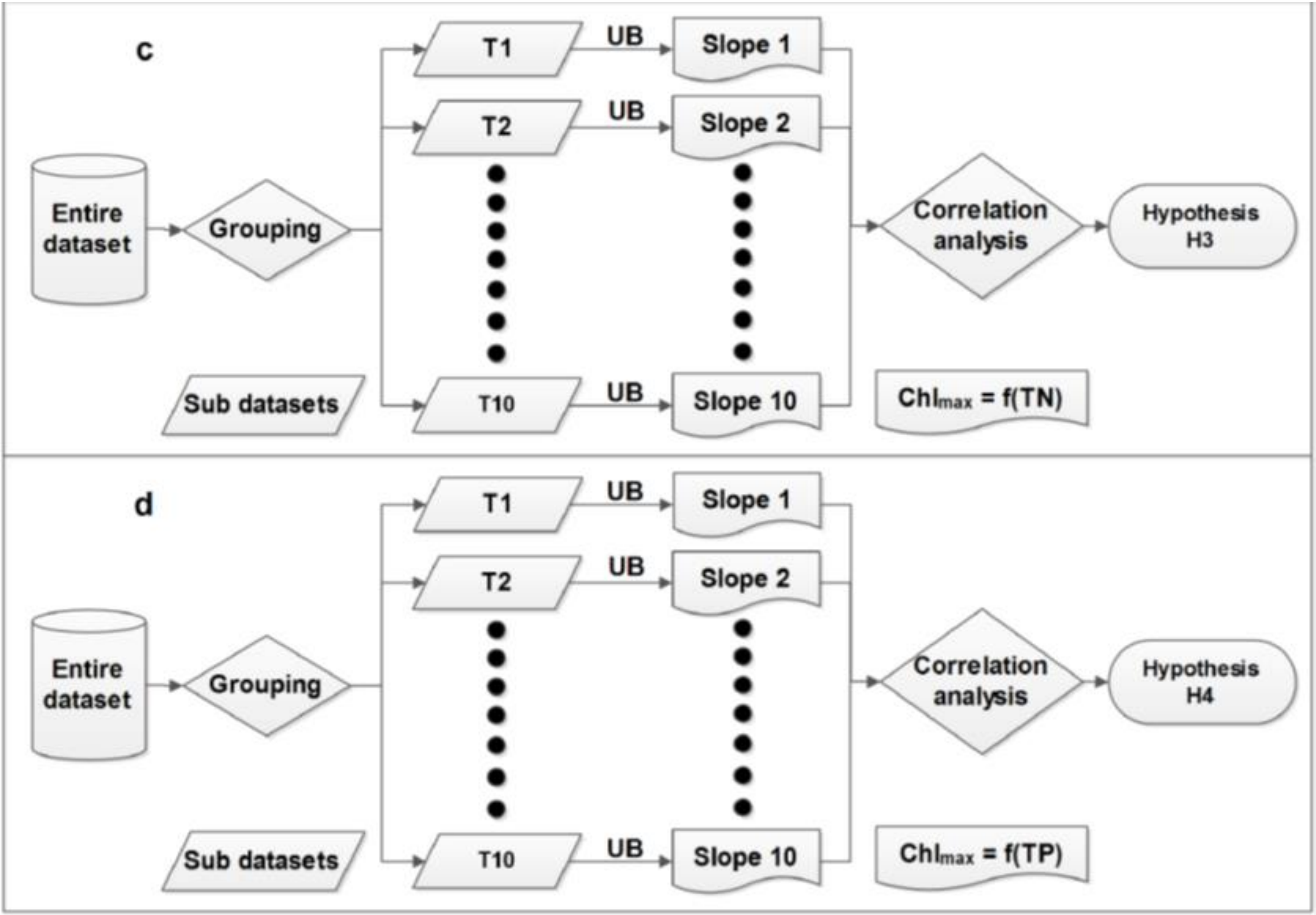
Justin D. Brookes[1] and Cayelan C. Carey[2]

Managing nitrogen and phosphorus pollution of fresh water may decrease the risk of cyanobacterial blooms, even in the face of warming temperatures.

4. Adaptation to Changing Climate

- **Hypothesis (H3): The response of CHL to TN is raised by WT?**
- **Hypothesis (H4): The response of CHL to TP is raised by WT?**



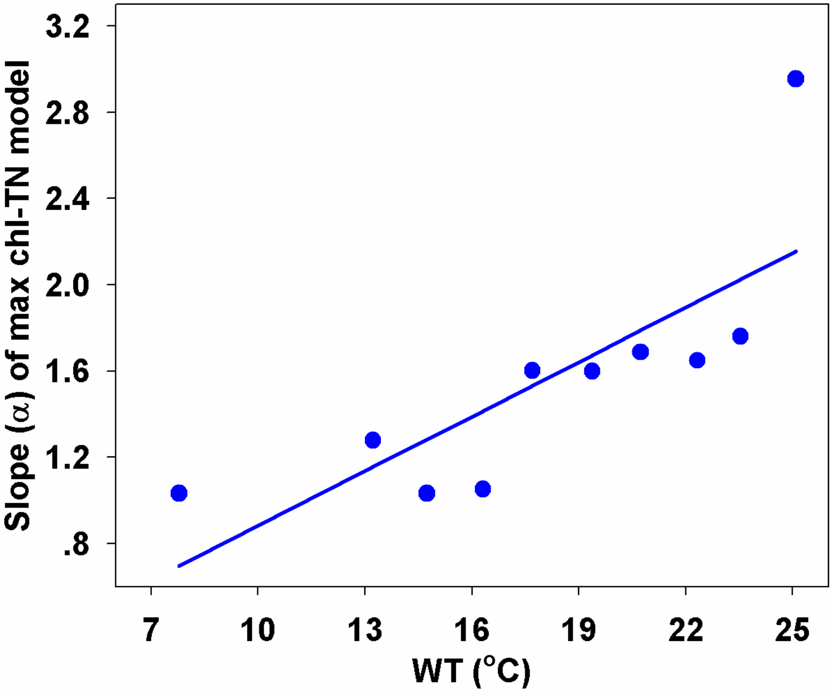

c
Entire dataset
Grouping
Sub datasets
T1
T2
T10
UB
UB
UB
Slope 1
Slope 2
Slope 10
Correlation analysis
Hypothesis H3
$Chl_{max} = f(TN)$
d
Entire dataset
Grouping
Sub datasets
T1
T2
T10
UB
UB
UB
Slope 1
Slope 2
Slope 10
Correlation analysis
Hypothesis H4
$Chl_{max} = f(TP)$

Sub-dataset	WT	Samples
T1	$2.7 \le WT < 12.5$	364
T2	$12.5 \le WT < 14.0$	165
T3	$14.0 \le WT < 15.5$	183
T4	$15.5 \le WT < 17.0$	192
T5	$17.0 \le WT < 18.5$	266
T6	$18.5 \le WT < 20.0$	264
T7	$20.0 \le WT < 21.5$	399
T8	$21.5 \le WT < 23.0$	390
T9	$23.0 \le WT < 24.5$	320
T10	$24.5 \le WT < 29.0$	155

4. Adaptation to Changing Climate

- **Hypothesis (H3): True**

Increased temperature enhance phytoplankton response to nitrogen (Slope, α_{TN})



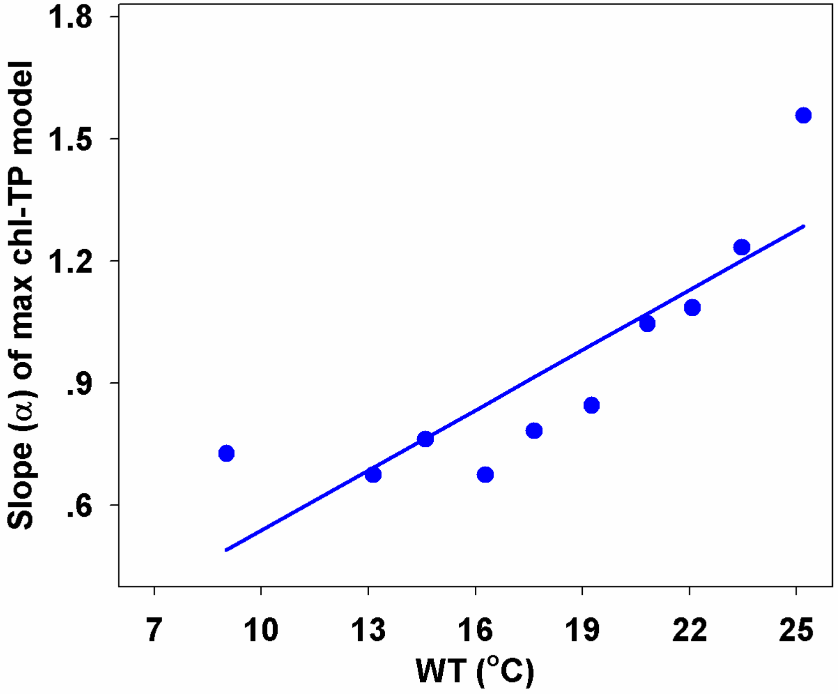
$$\alpha_{TN} = 0.084 * WT + 0.039$$

$$r^2 = 0.612, p < 0.01$$

4. Adaptation to Changing Climate

- **Hypothesis (H4): True**

Increased temperature enhance phytoplankton response to phosphorus (Slope, α_{TP})



$$\alpha_{TP} = 0.049 * WT + 0.046$$

$$r^2 = 0.729, p < 0.01$$

4. Adaptation to Changing Climate

- **Hypothesis (H3): True**

Increased temperature enhance phytoplankton response to nitrogen (Slope, α_{TN})

- **Hypothesis (H4): True**

Increased temperature enhance phytoplankton response to phosphorus (Slope, α_{TP})

Tightening nutrient reduction helps mitigate the climate-driven eutrophication, and improve lake adaptation to changing climate

Main Points

1. Harmful Algal Bloom (HAB): Controlling Factors
2. Chlorophyll-Nutrient Model: Origin and Advance
3. Controlling Eutrophication: Nitrogen and Phosphorus
4. Reducing Nutrient: Adaptation to Changing Climate

Acknowledgements

RACC
Research on Adaptation to Climate Change

NSF

JOINT AQUATIC SCIENCES MEETING
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Portland, Oregon

Vermont
EPSCoR

Lake Champlain
Basin Program

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