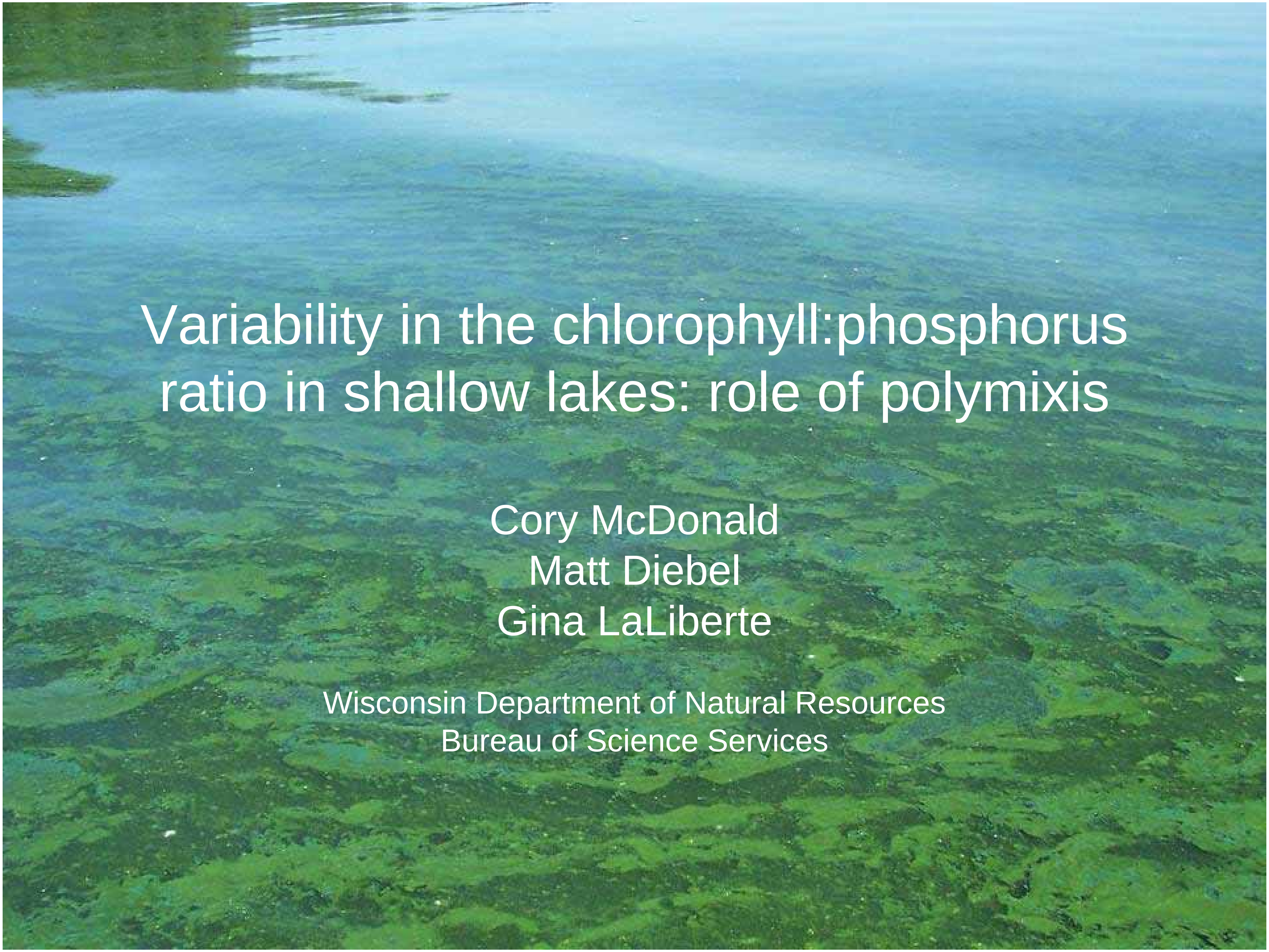
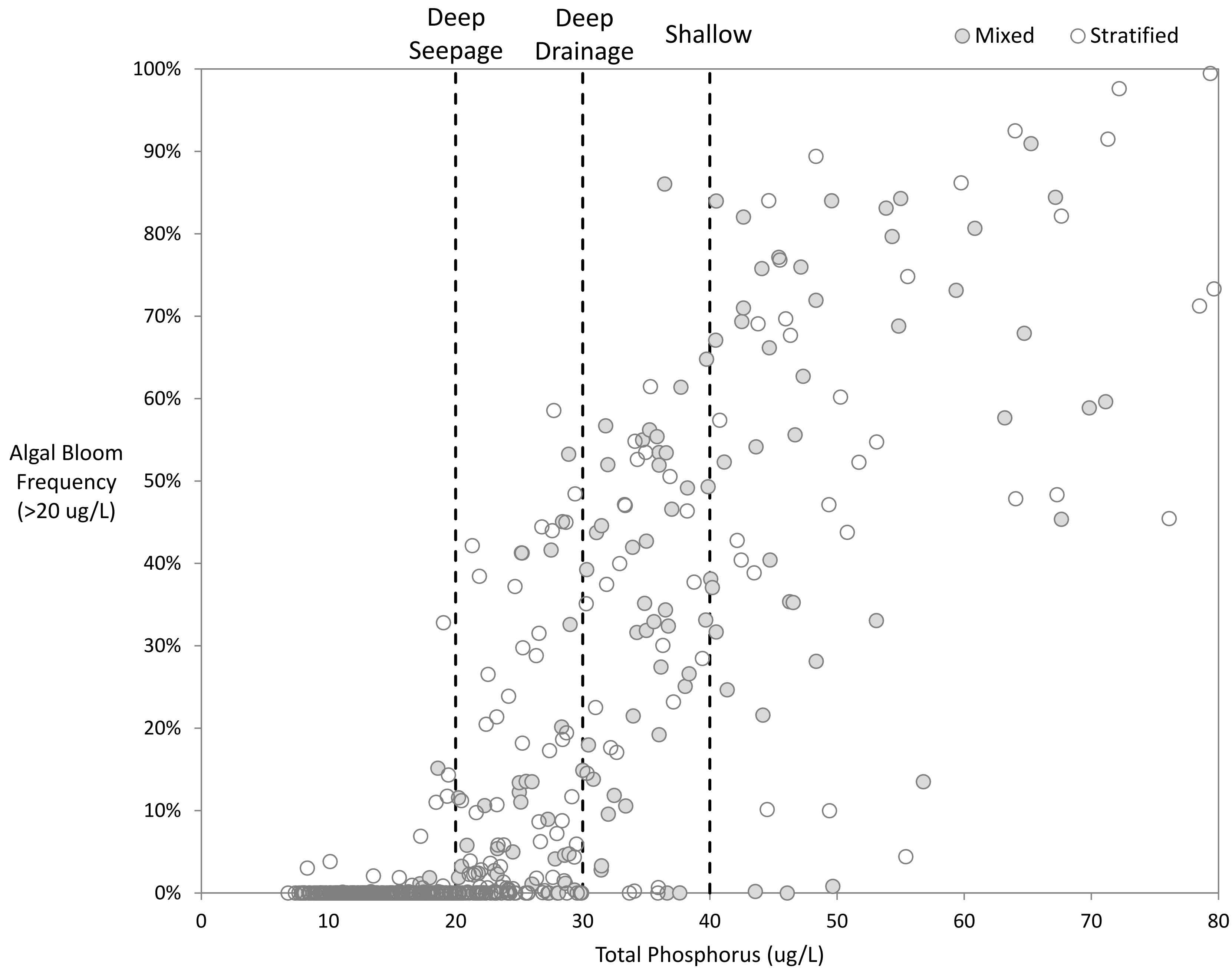


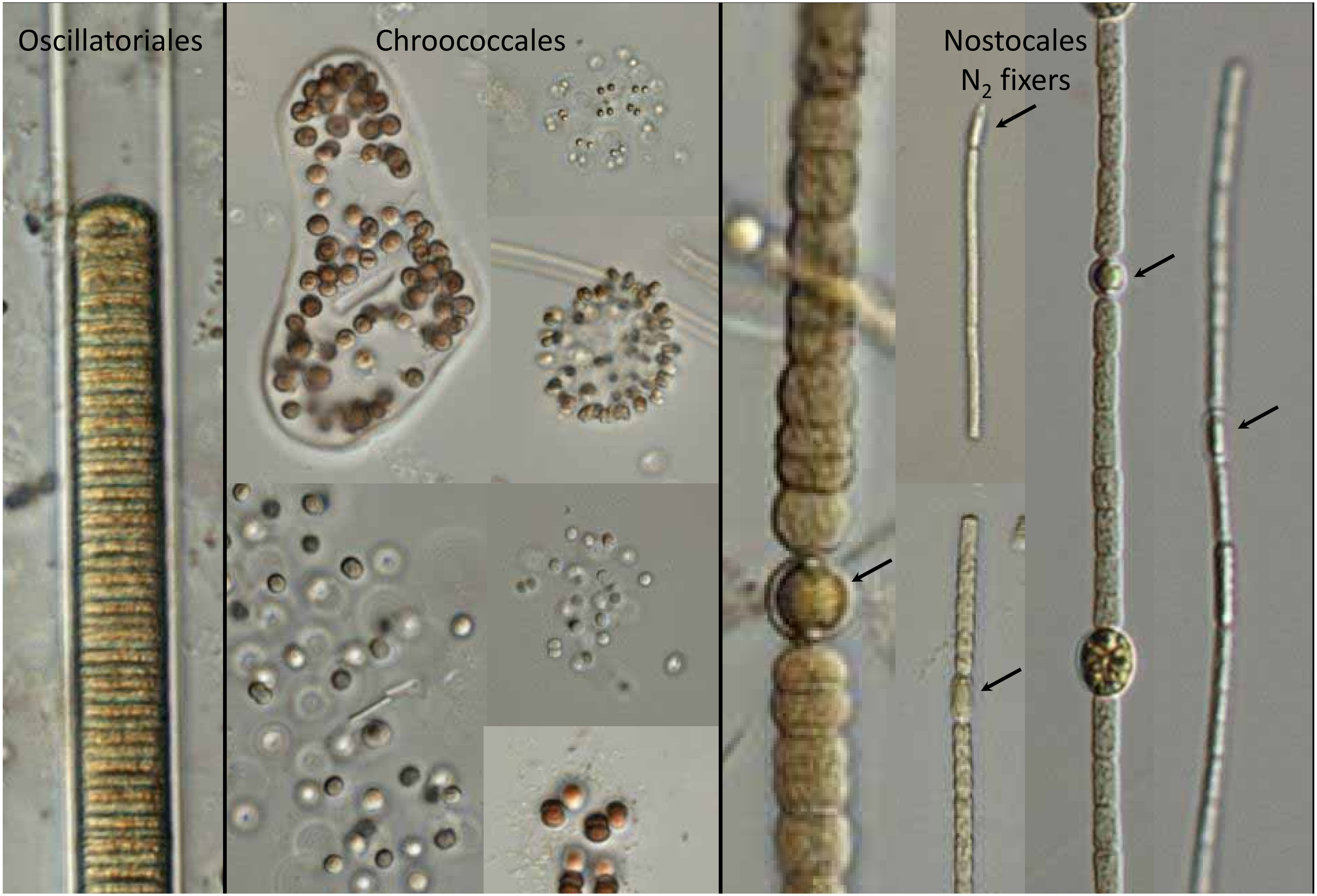
# Variability in the chlorophyll:phosphorus ratio in shallow lakes: role of polymixis

Cory McDonald
Matt Diebel
Gina LaLiberte

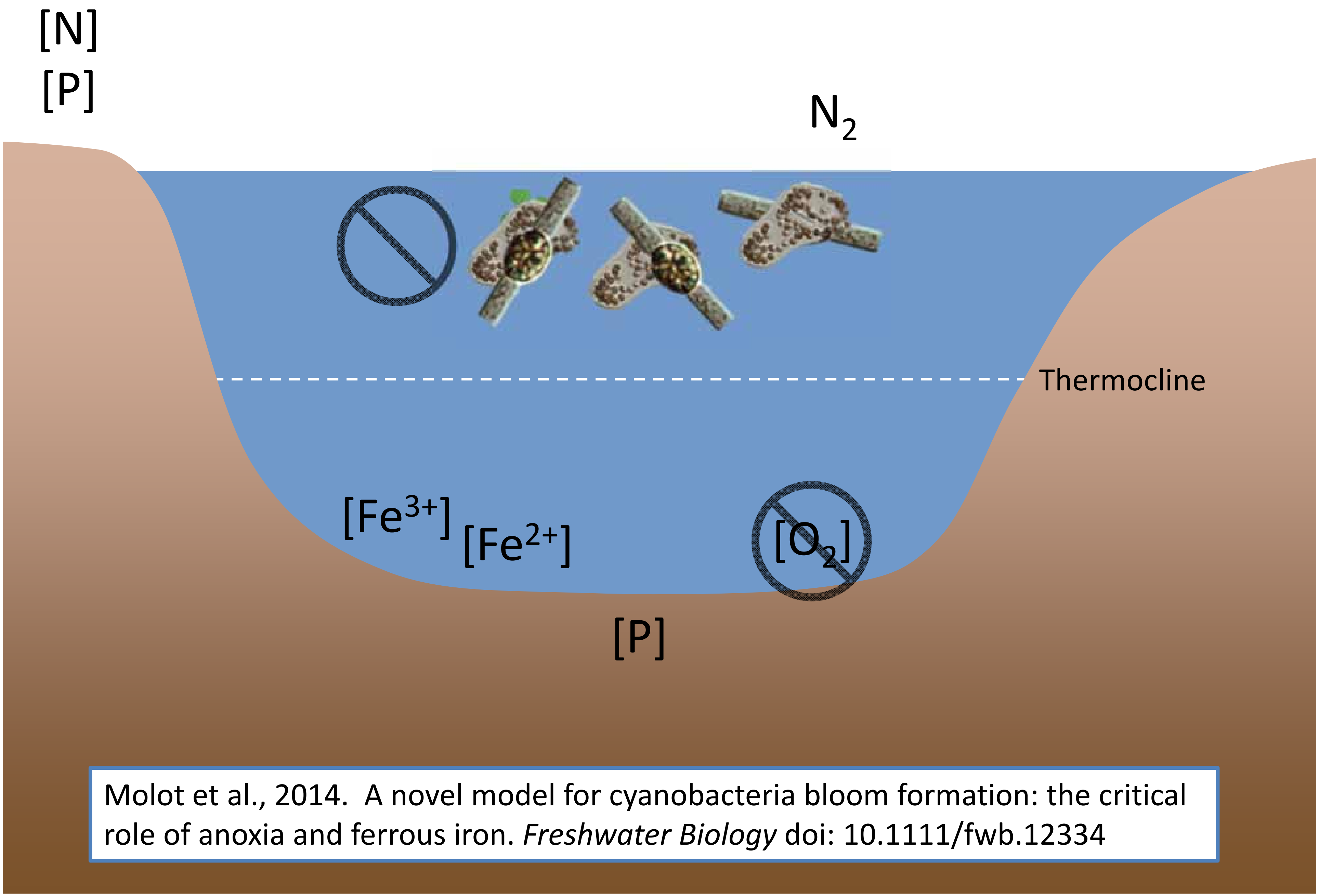
Wisconsin Department of Natural Resources
Bureau of Science Services

# Why do similar lakes with similar TP concentrations display very different levels of primary productivity?

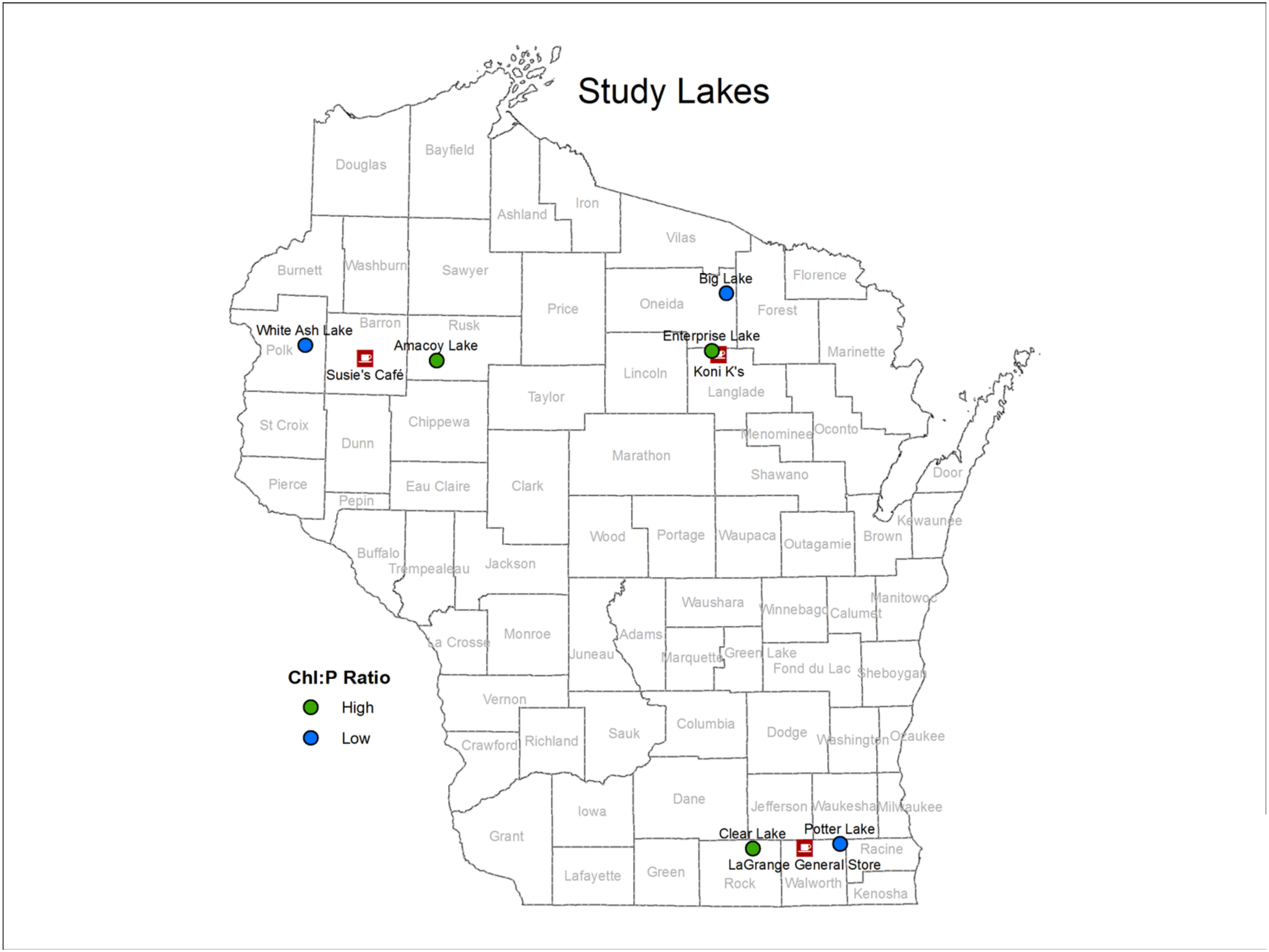


Deep
Seepage
Deep
Drainage
Shallow
Mixed
Stratified
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Algal Bloom
Frequency
(>20 ug/L)
0
10
20
30
40
50
60
70
80
Total Phosphorus (ug/L)

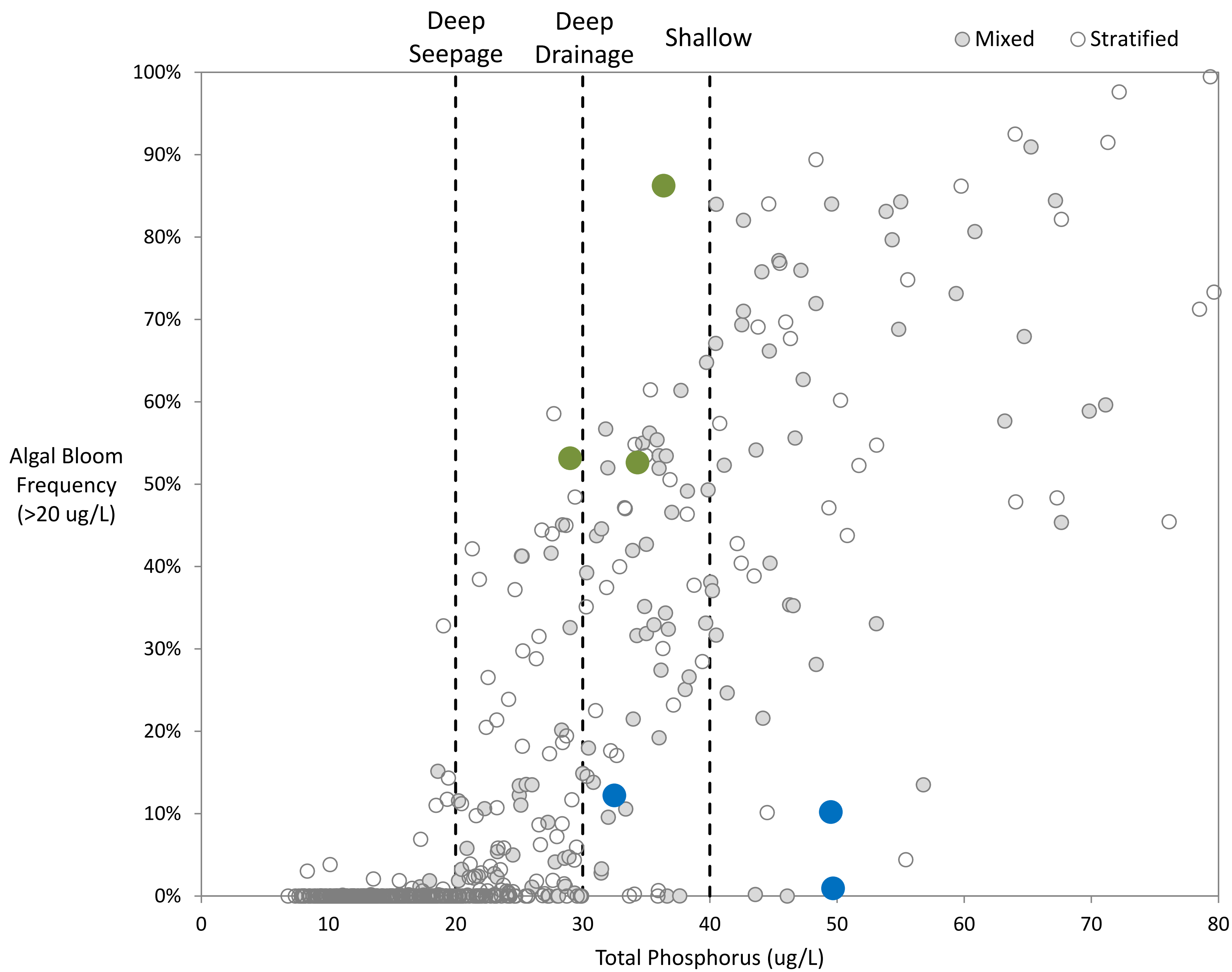



# Cyanobacteria(blue-green algae)



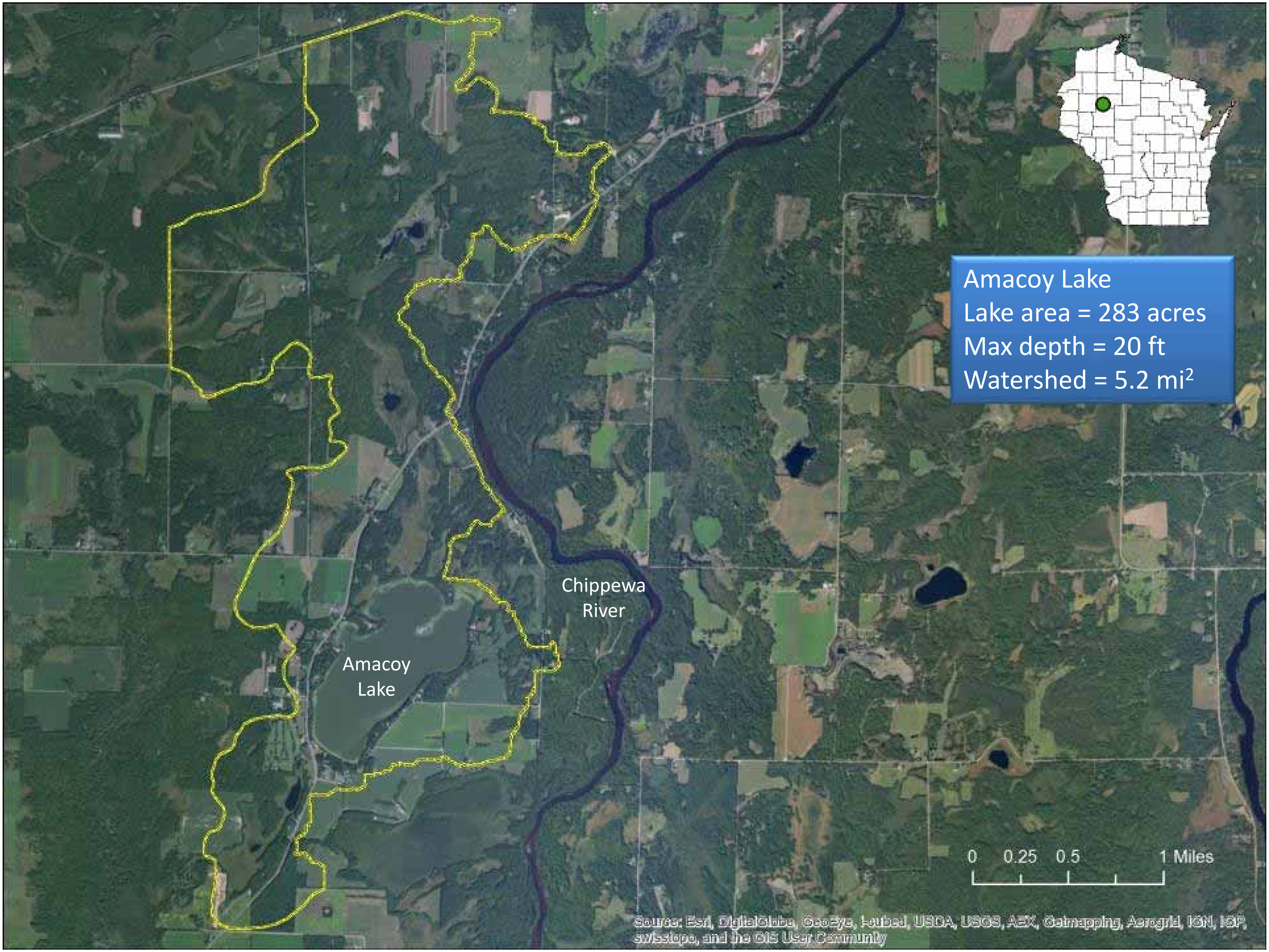

Molot et al., 2014. A novel model for cyanobacteria bloom formation: the critical role of anoxia and ferrous iron. *Freshwater Biology* doi: 10.1111/fwb.12334


Study Lakes
Chl:P Ratio
High
Low
White Ash Lake
Susie's Café
Amacoy Lake
Big Lake
Enterprise Lake
Koni K's
Clear Lake
Potter Lake
LaGrange General Store
Douglas
Bayfield
Ashland
Iron
Vilas
Burnett
Washburn
Sawyer
Price
Oneida
Florence
Forest
Polk
Barron
Rusk
Marinette
Lincoln
Langlade
Taylor
St Croix
Dunn
Chippewa
Menominee
Oconto
Marathon
Shawano
Door
Pierce
Pepin
Eau Claire
Clark
Wood
Portage
Waupaca
Outagamie
Brown
Kewaunee
Buffalo
Trempealeau
Jackson
Waushara
Winnebago
Calumet
Manitowoc
Monroe
La Crosse
Juneau
Adams
Marquette
Green Lake
Fond du Lac
Sheboygan
Vernon
Richland
Sauk
Columbia
Dodge
Washington
Ozaukee
Crawford
Grant
Iowa
Dane
Jefferson
Waukesha
Milwaukee
Racine
Lafayette
Green
Rock
Walworth
Kenosha

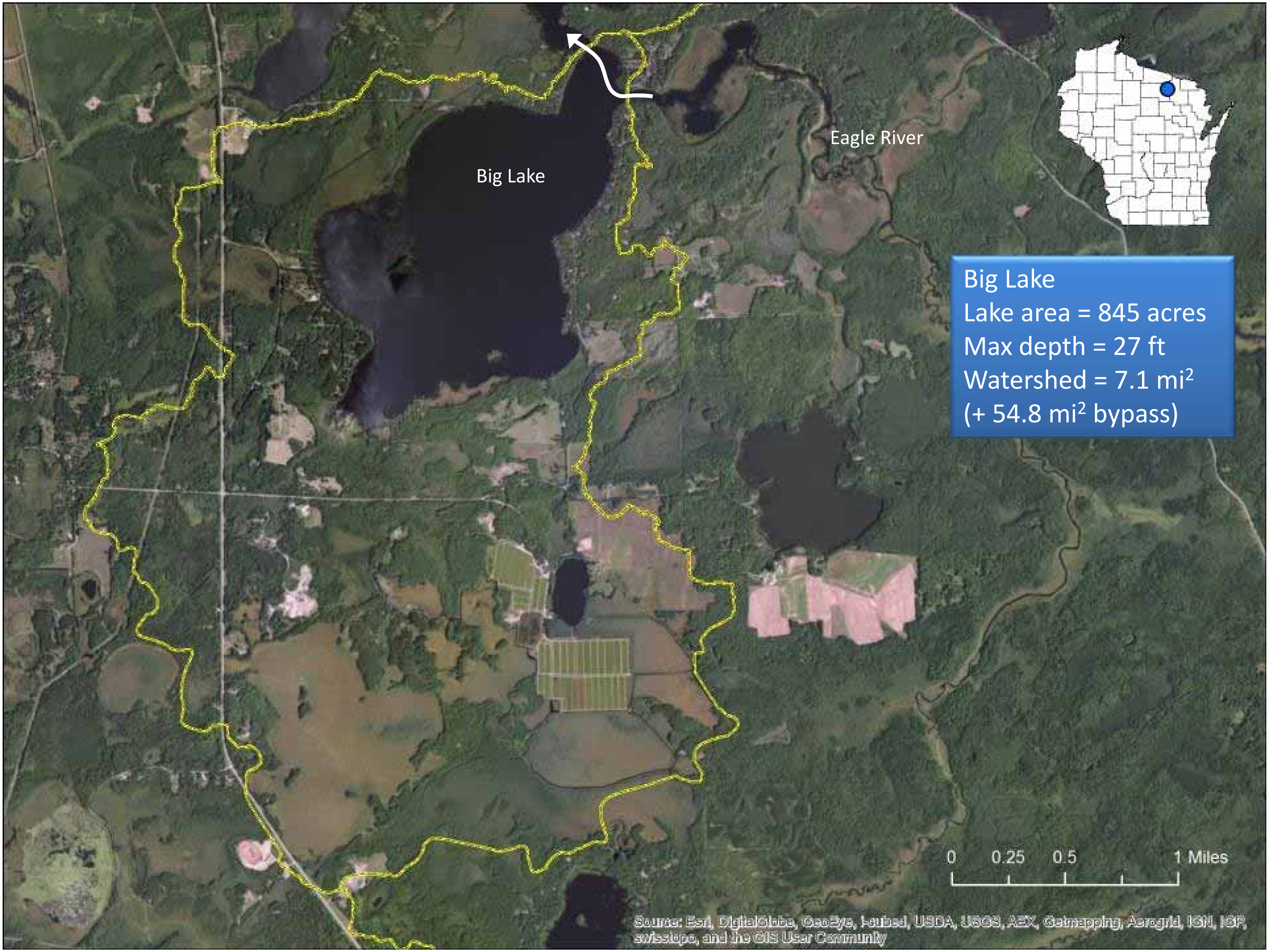


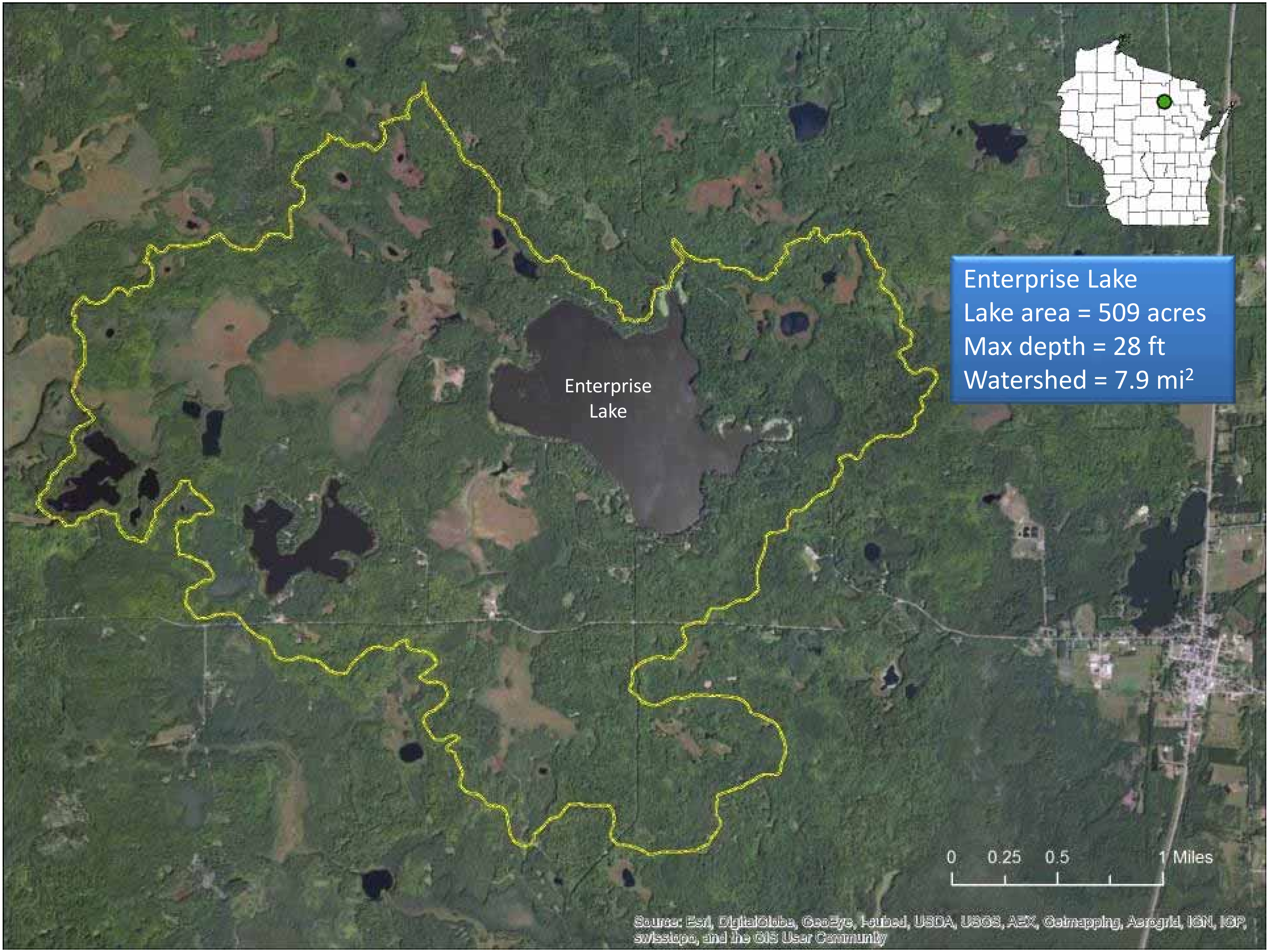
Deep Seepage
Deep Drainage
Shallow
Mixed
Stratified
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Algal Bloom Frequency (>20 ug/L)
0
10
20
30
40
50
60
70
80
Total Phosphorus (ug/L)


North White Ash Lake
Lake area = 116 acres
Max depth = 9 ft
Watershed = 2.5 mi²
North White
Ash Lake
Apple River
White Ash
Lake
0
0.25
0.5
1 Miles
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



Amacoy Lake
Lake area = 283 acres
Max depth = 20 ft
Watershed = 5.2 mi$^2$
Chippewa River
Amacoy Lake
0 0.25 0.5 1 Miles
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


Big Lake
Eagle River
Big Lake
Lake area = 845 acres
Max depth = 27 ft
Watershed = 7.1 mi2
(+ 54.8 mi2 bypass)
0 0.25 0.5 1 Miles
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


Enterprise Lake
Enterprise Lake
Lake area = 509 acres
Max depth = 28 ft
Watershed = 7.9 mi$^2$
0 0.25 0.5 1 Miles
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

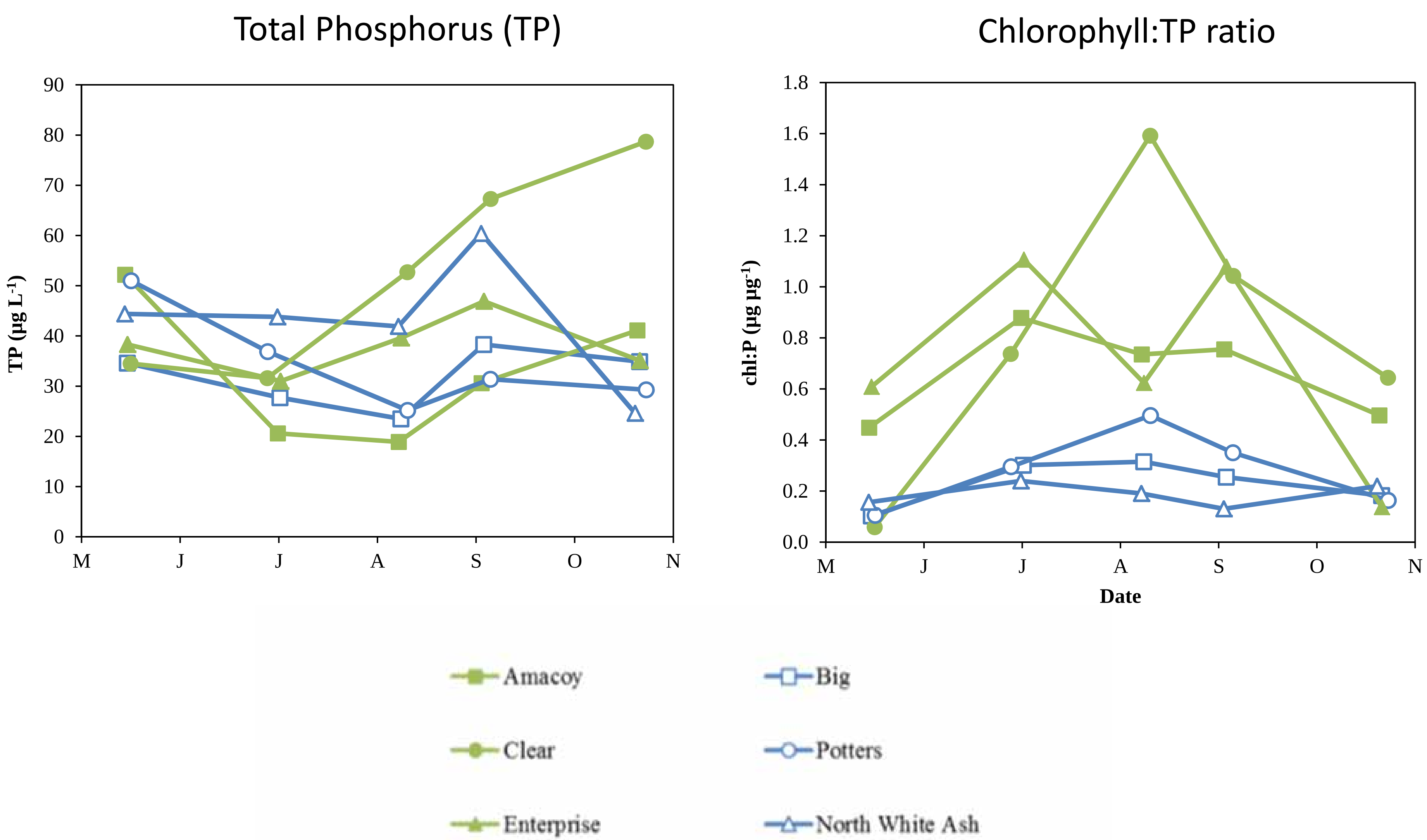

Potters Lake
Lake area = 155 acres
Max depth = 26 ft
Watershed = 1.4 mi$^2$
Potters Lake
0
0.25
0.5
1 Miles
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


Clear Lake
Clear Lake
Lake area = 77 acres
Max depth = 20 ft
Watershed = 1.4 mi$^2$
0
0.25
0.5
1 Miles
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

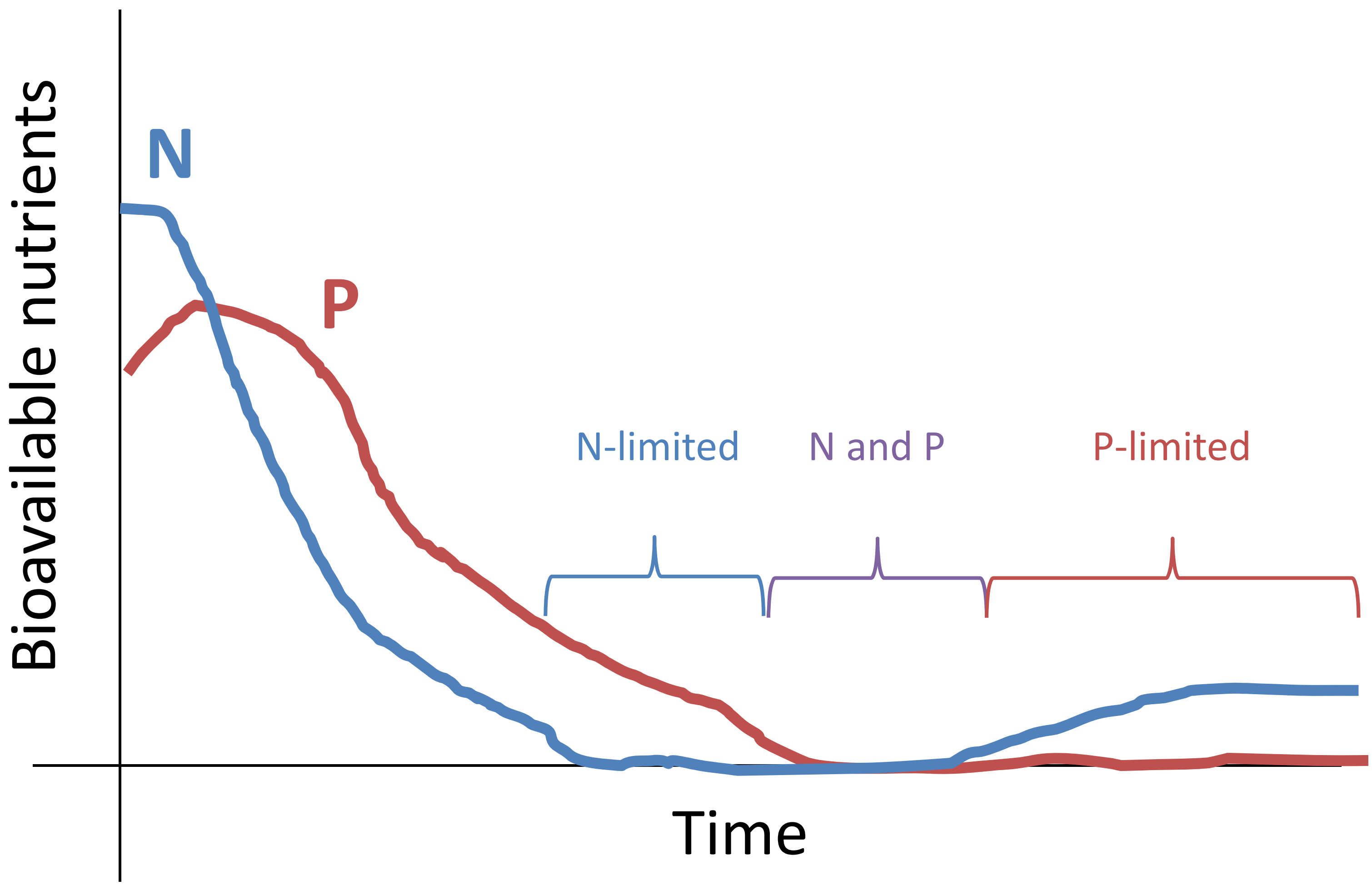
# Summer 2013 Sampling

- 5 visits
  - May 14-16, June 28-July 2, August 8-11, September 3-6, October 22-25
- Profiles (T, DO, pH, etc.)
- Chlorophyll, Phosphorus (TP, ortho-P), Nitrogen ($NH_3$-N, $NO_2$+$NO_3$, TKN), DOC
- Phytoplankton
- Zooplankton

# Seasonal Trends – Phosphorus and chlorophyll



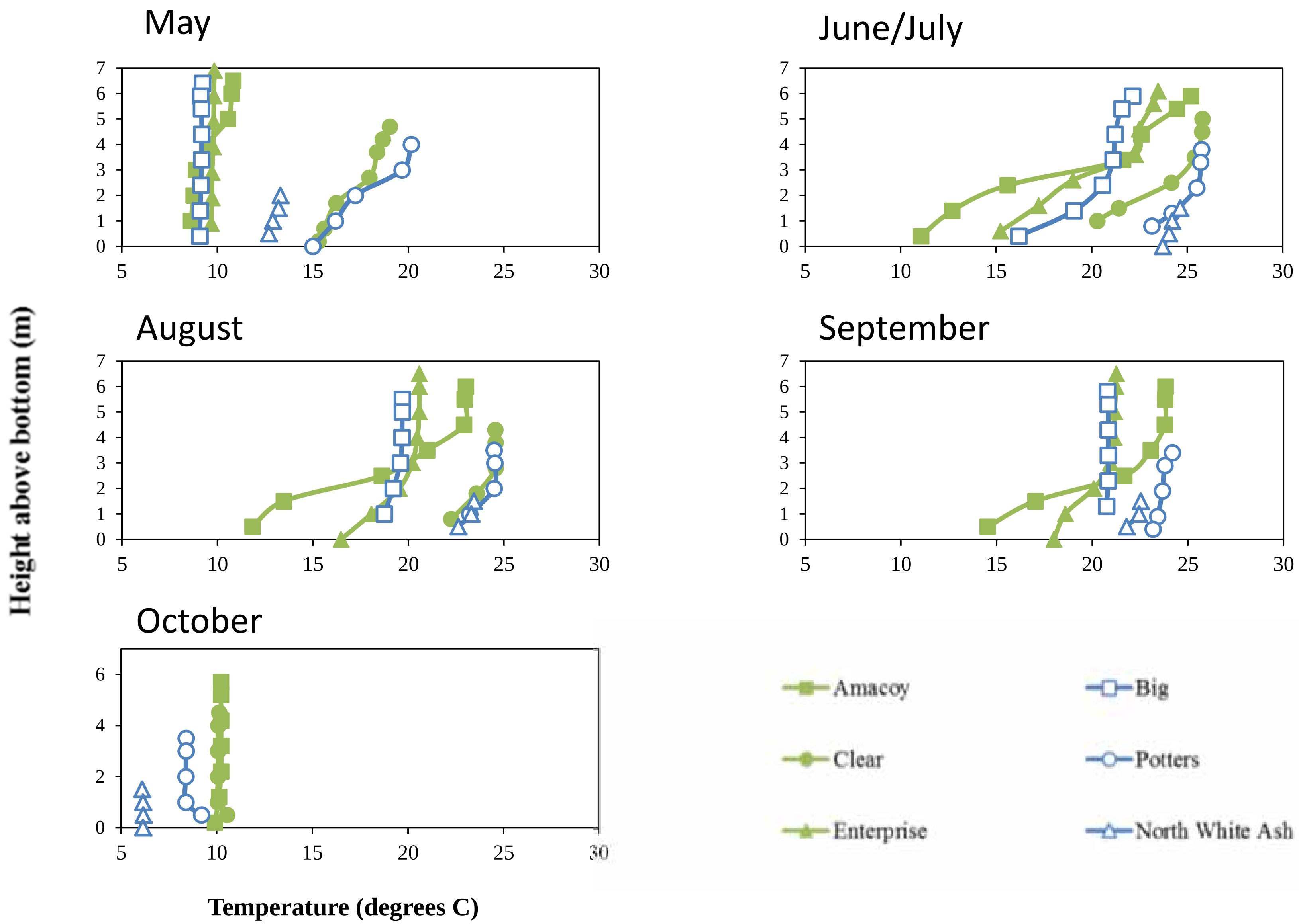
# Nutrient Limitation – P vs. N



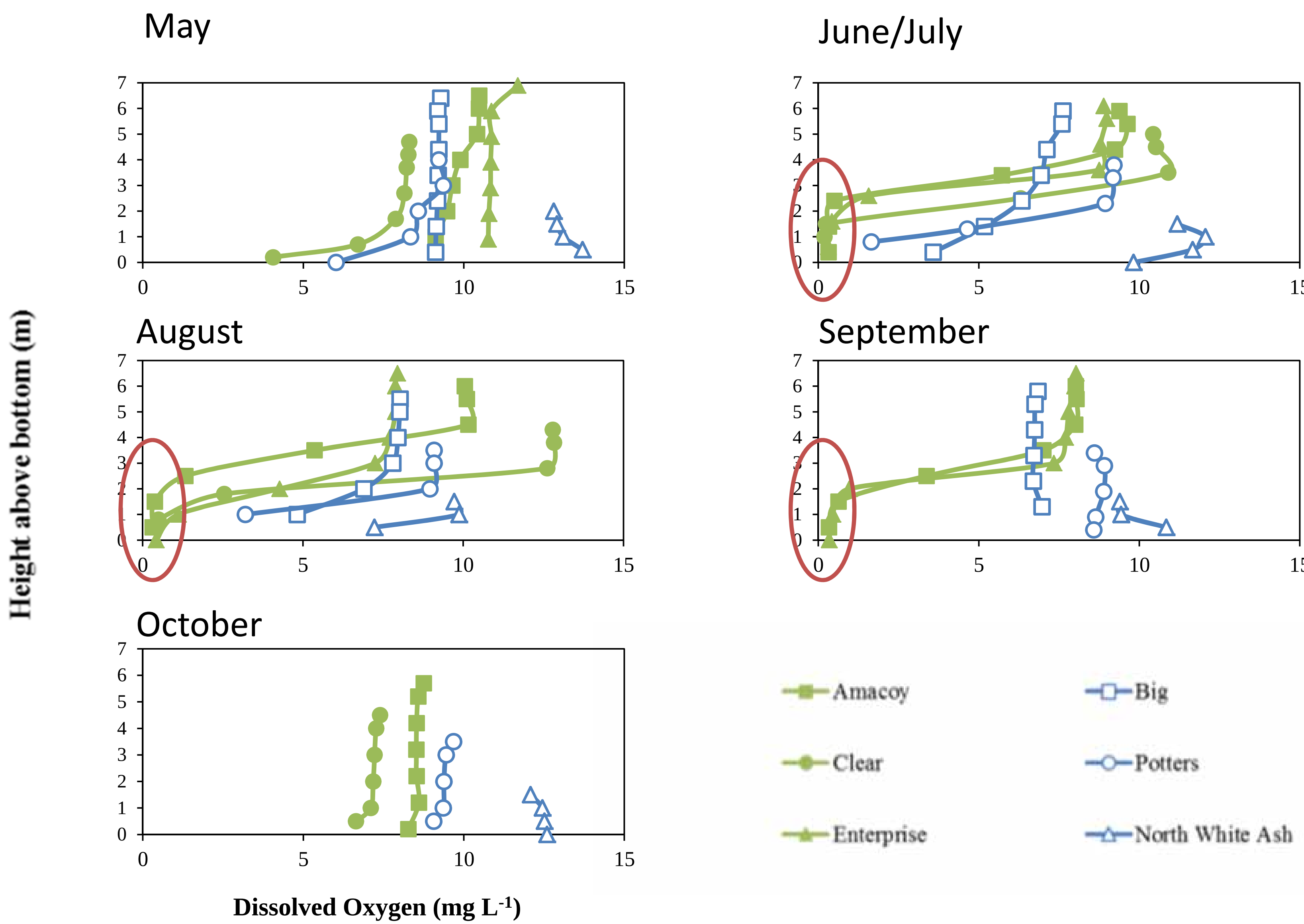
# Nutrient Limitation – Seasonal

| | May | Jun/Jul | Aug | Sep | Oct |
|---|---|---|---|---|---|
| Amacoy Lake | neither | both | both | P | P |
| Clear Lake | neither | neither | both | neither | P |
| Enterprise Lake | N | both | N | both | P |
| | | | | | |
| Big Lake | neither | neither | both | N | neither |
| Potter Lake | neither | neither | N | N | neither |
| North White Ash Lake | neither | N | P | neither | P |

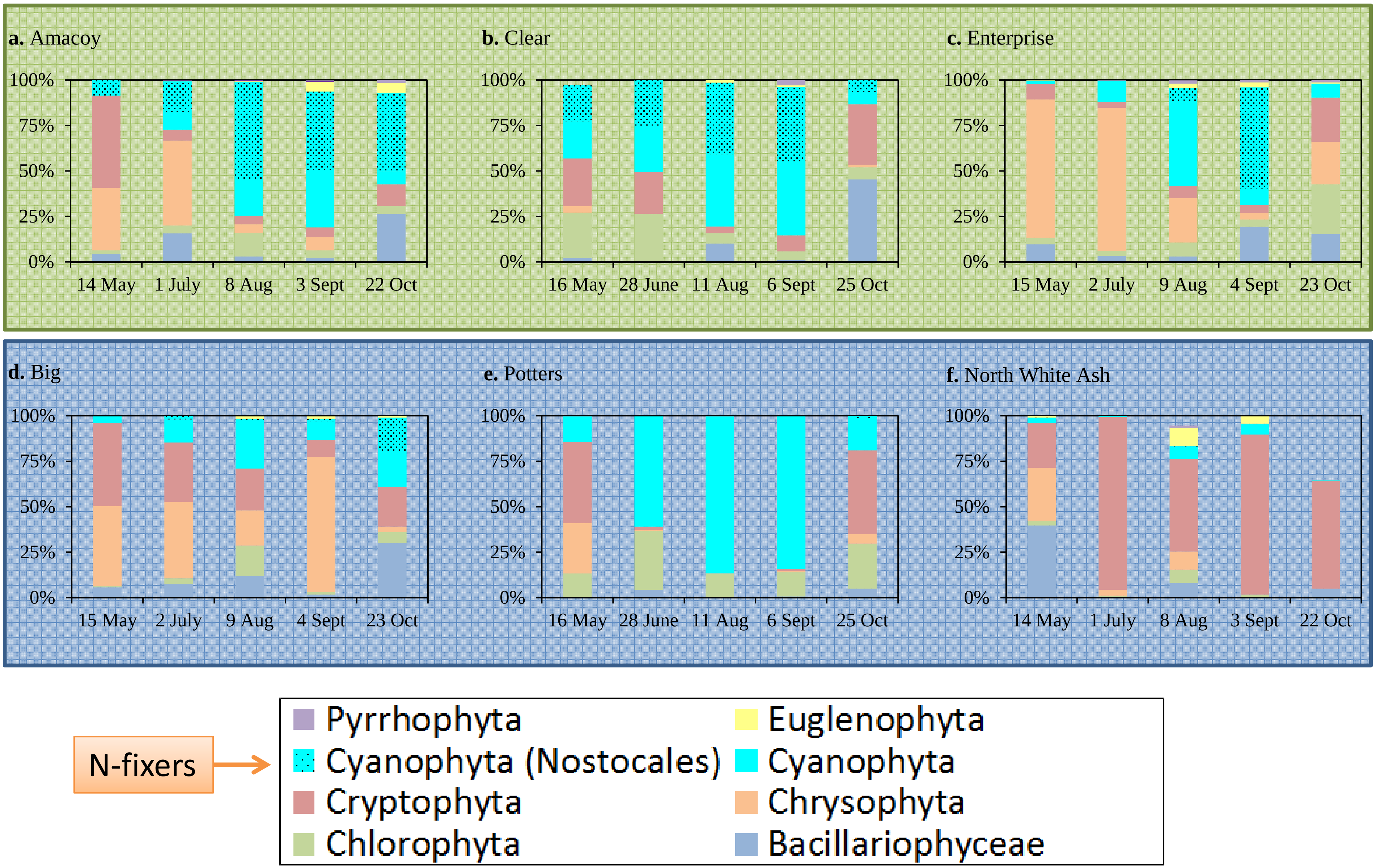
# Seasonal Trends - Temperature



# Seasonal Trends – Dissolved Oxygen



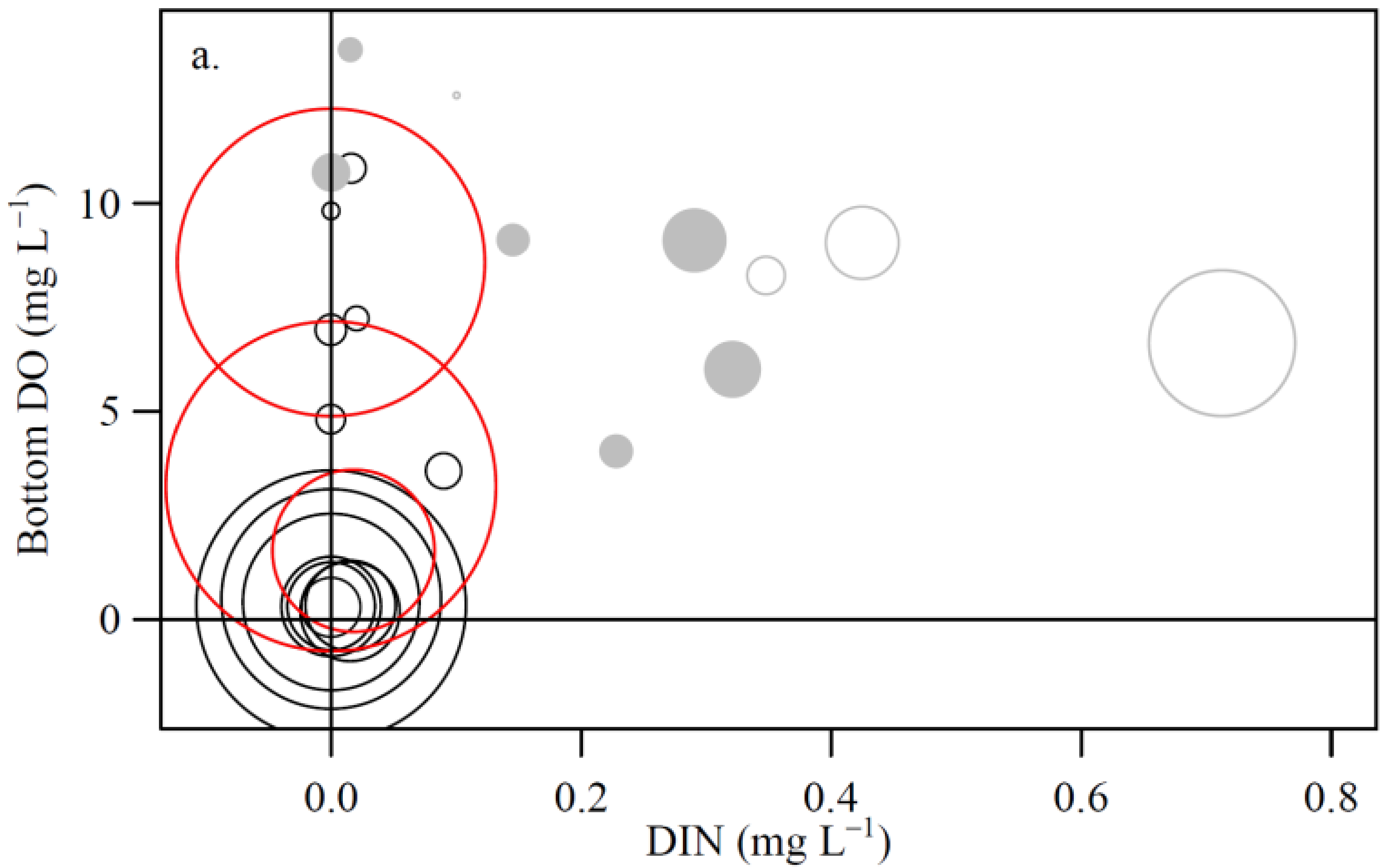
# Phytoplankton



# Summary of Findings

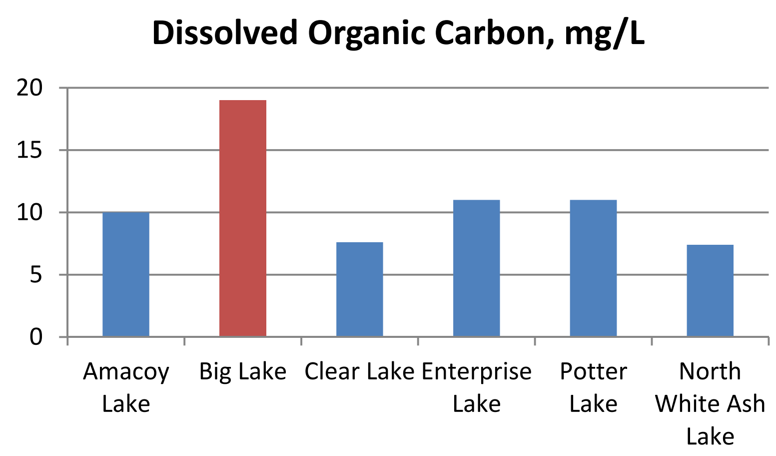
- All six lakes experienced seasonal N limitation
- High chl:P lakes tended to be N+P limited
  - N fixation leads to higher chl per unit P
- Cyanobacteria more abundant in high chl:P lakes + Potter Lake
  - **N-fixers** only in high chl:P lakes
- High chl:P lakes were **anoxic** near bottom
  - Potter may have been anoxic in deep hole

# Nitrogen, Anoxia, and Cyanobacteria

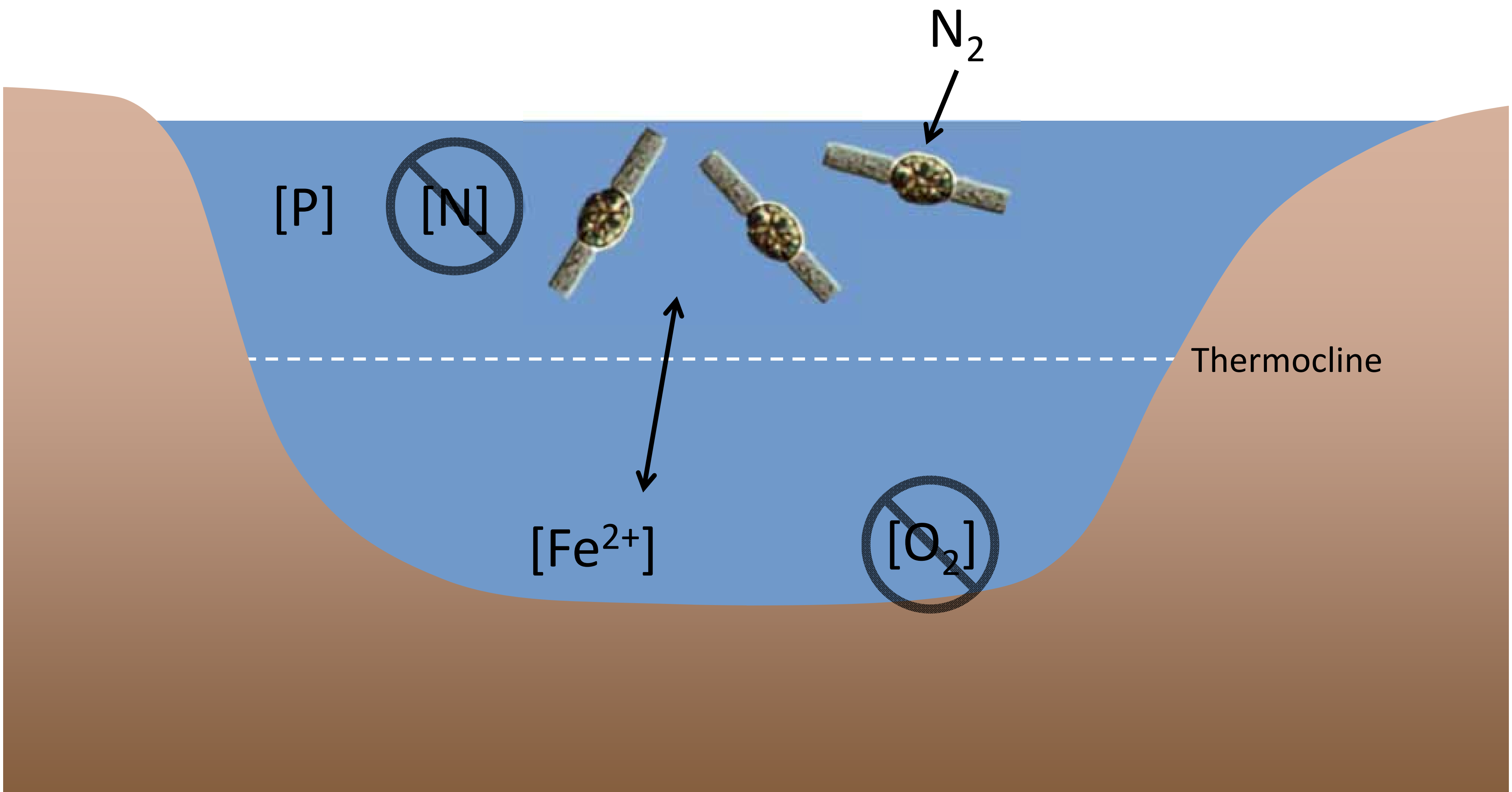


# What about low chl:P lakes?

- No clear commonality among Big, Potter, or North White Ash; Likely site-specific factors
  - Dense macrophytes (N. White Ash)
  - Stained Water (Big)
  - Herbicide treatment? (Potter)



# High chl:P lakes

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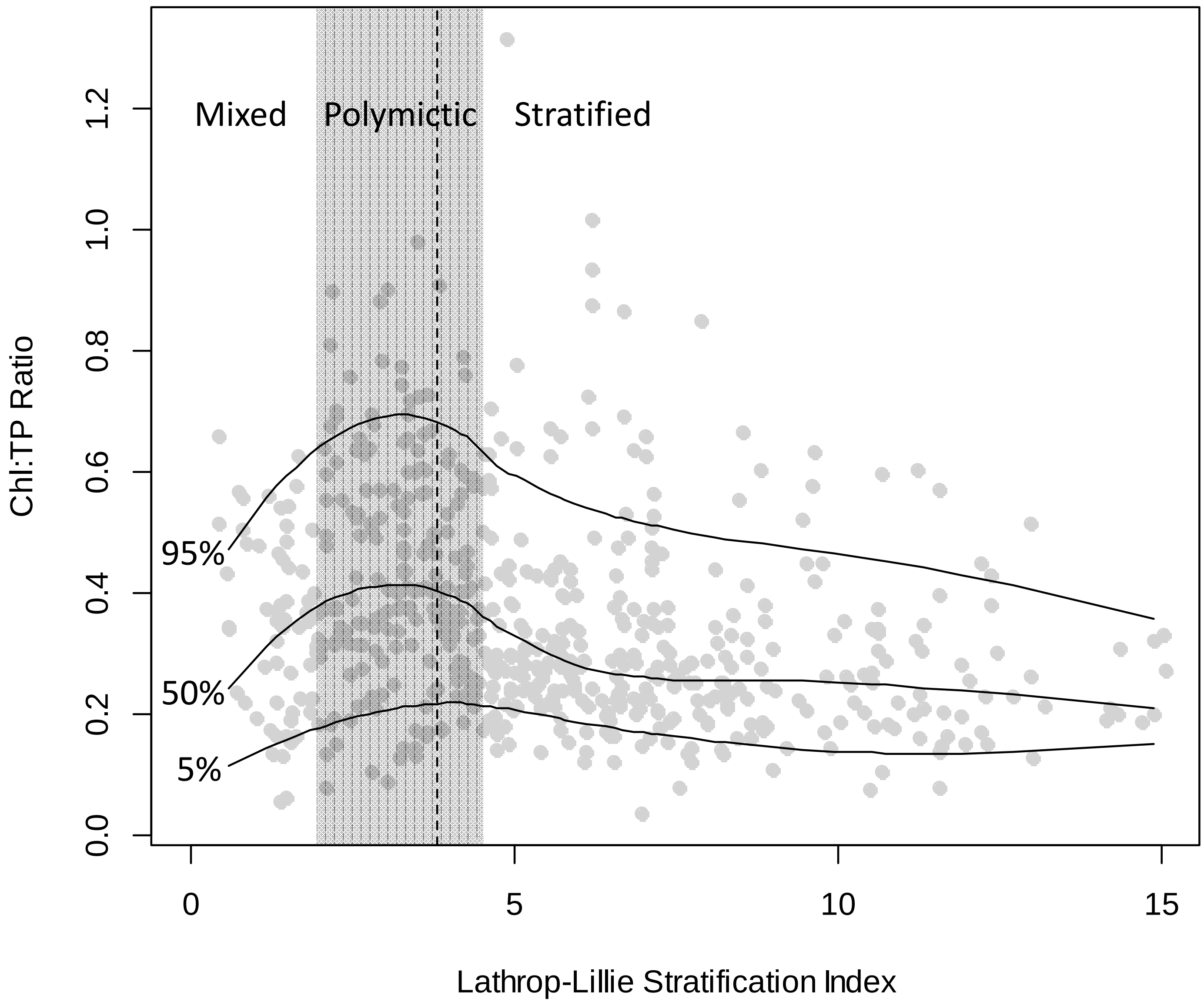
# Polymictic lakes and chl:P

- All study lakes were polymictic
- Internal P loading often high in polymictic systems -> N limitation more likely
- High productivity -> anoxia ($Fe^{2+}$ available)
- Relatively shallow -> short migration path
- Ideal environment for cyanobacterial dominance



Mixed
Polymictic
Stratified
95%
50%
5%
Chl:TP Ratio
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
5
10
15
Lathrop-Lillie Stratification Index

# Management options for polymictic lakes

- Reduce P loading
- Immobilize sediment P
  - Alum
  - Aeration
- Increase algal grazing through fisheries management
- Site-specific P criteria

# Next Steps

- Investigate Molot model
  - Sample hypolimnetic Fe and P
  - Cyanobacteria migration
- Develop site-specific criteria for some lakes
  - Polymictic lakes unique
  - Looking at algal community
  - More frequent monitoring in polymictic lakes?