Spatiotemporal Variation of Algal Nutrient Limitation in Grand Lake, Oklahoma and the Effect of Internal Nutrient Load

Stephen J. Nikolai
Introduction

• Nutrient Limitation
  – Liebig’s “Law” of the Minimum \(^{(1)}\)
    • Yield can only increase only if you add the most limiting resource, and only that resource.
    • Only a single resource is limiting at a given time.
Introduction

• Single Nutrient Limitation
  — Phosphorus Limitation Paradigm \(^{(2)}\)
    • Classical Experimental Lakes Enrichment (Lake 226)\(^{(3)}\)
      — David Schindler
      — Premise: atmospheric inputs of N and N fixation offsets the imbalance of N and P \(^{(4)}\)
  • Textbooks
  • Management Strategies
Introduction

• Review of Nutrient enrichment data.
  – Co-Limitation
    • Greater response to simultaneous enrichment by both nutrients than single addition of N or P \(^{(5)}\)
  – Synergy
    • Two or more nutrients added together creating a greater response than they do individually.

Elser et al. 2007\(^{(6)}\)
Introduction

• N:P ratios
  – Used to predict N or P limitation of algal growth\(^{(7)\(2\)}\)
    • N:P>22 (P limited)
    • N:P<9 (N Limited)
  – Seen in OWRB BUMP reports

Figure 1. Stoichiometric linkages between TN and TP (log-transformed) for 221 lakes in 14 countries, plotted both as TN vs. TP (left) and as their ratio vs. TP. The shaded regions indicate the regions “inside” the TN:TP ratios proposed by Guildford and Hickey (2000) that are associated with N- or P-limitation. The vertical arrows indicate the TP levels above or below which one must extend in order to move outside of the range of variability in the data. Figure modified from Downes and McCauley (1992). Following the original publication, mass units are used.
Introduction

• Importance of determining the limiting nutrient
  – Guide management practices
    • Reducing inputs of the limiting nutrient improves water quality.
Introduction

• Internal nutrient loading
  – Re mineralization of N & P from anoxic sediments
  – Bacterial Mediated
    • Classic: Reduction of iron by bacteria
      FeOOH + 3H^++e^- → Fe^{2+} + H_2O
  – Grand Lake Has an anoxia problem....
Objectives

• Monitor the nutrient limitation status Grand Lake.
  – Can nutrient limitation be accurately predicted from N:P ratios?
• Examine how the internal load affects nutrient limitation.
Methods

• Grand Lake
  – Stretches through Delaware, Ottawa and Mayes County in NE Oklahoma.
  – Surface area of +18,000 Ha
  – $Z_{\text{max}} \sim 36$ m
  – Agricultural Watershed.
  – Highly Developed shoreline.
Methods (Sampling & Analysis)

• Sampling & Analysis
  – June-October 2011 (bimonthly)
  – Physiochemical Profiles
    • Temp, DO, ORP, pH, Cond.
  – 3 Epi & 3 Hypo samples
  – Samples Analyzed within 48 hours
    • TN, TP, NH$_3$-N, NO$_3$
  – Stats: ANOVA, 2 Way ANOVA, Linear Regression (R & Sigmaplot)
Methods (Nutrient Bioassays)

• 20 L collected from 3-4 sites.
  – May, June, August, September, October
• Collected volume filtered to remove macrozooplankton
• Water placed into 12, 1 L glass bioassay jars
  – Initial Relative Florescence (RFU) measured.
Methods (Nutrient Bioassays)

• Control
• Treatments
  – Nitrogen (+N) (1600 µg L\(^{-1}\))
  – Phosphorus (+P) (100 µg L\(^{-1}\))
  – Nitrogen and Phosphorus (+NP)
• Placed into an environmental chamber at mean surface temperature and average day length
• Measured Every 24 hours after setup
• 2 way RM-ANOVA
Figure 2. Mean epilimnetic nutrients (y axis) for each sampling date (x axis) (mean ± s.d.). Top left: TP. Top center: TN. Bottom center: NO₃. Bottom right: NH₄-N.
Sample Dates: (1) Early June, (2) Late June, (3) Early July, (4) Late July, (5) Early August, (6) Late August, (7) Early September, (8) Late September, (9) Early October, (10) Late October.
Results (Hypolimnion)

Figure 3. Mean hypolimnetic nutrients (y-axis) for each sampling date (x-axis) (mean ± s.d.). Top left: TP. Top center: TN. Bottom center: NO₃. Bottom right: NH₄-N. Sample Dates: (1) Early June, (2) Late June, (3) Early July, (4) Late July, (5) Early August, (6) Late August, (7) Early September, (8) Late September, (9) Early October, (10) Late October.
Results

Figure 4. Mean epilimnetic and hypolimnetic nutrients (±s.d.) for each sampling date. Left: TP. Center: TN. Right: TN:TP. Sample Dates: (1) Early June, (2) Late June, (3) Early July, (4) Late July, (5) Early August, (6) Late August, (7) Early September, (8) Late September, (9) Early October, (10) Late October.
Results

Regression, Conf. & Pred.

$R^2=0.66, \ p<0.001$

Regression, Conf. & Pred.

$R^2=0.32, \ p<0.001$

TN: no significant relationship
Results

![Graph showing the relationship between TN (Total Nitrogen) and TP (Total Phosphorus) with different seasons labeled (Early June, Late June, Early July, Late July, Early August, Late August, Early September, Late September, Early October, Late October). The graph includes two lines: N:P=9 and N:P=22, indicating the concentration limits for P limited and N limited conditions.](image-url)
# Results (Bioassays)

<table>
<thead>
<tr>
<th>Month</th>
<th>Riverine</th>
<th>Transition</th>
<th>Lacustrine</th>
<th>Dam</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>P Limitation</td>
<td>P Limitation</td>
<td>No Response</td>
<td>No Response</td>
</tr>
<tr>
<td>June</td>
<td>P Serial Limitation</td>
<td>P Serial Limitation</td>
<td>P Serial Limitation</td>
<td>P Serial Limitation</td>
</tr>
<tr>
<td>August</td>
<td>N Serial Limitation</td>
<td>Independent Co-Limitation</td>
<td>Independent Co-Limitation</td>
<td>P Serial Limitation</td>
</tr>
<tr>
<td>Sept</td>
<td>N Serial Limitation</td>
<td>No Response</td>
<td>No Response</td>
<td>No Response</td>
</tr>
<tr>
<td>October</td>
<td>No Response</td>
<td>No Response</td>
<td>No Response</td>
<td>No Response</td>
</tr>
</tbody>
</table>
Results (Bioassays)

P Limitation

May GRDA1 Bioassay

P Serial Limitation

June GRDA 4 Bioassay
Results (Bioassays)

Independent Co-Limitation

August GRDA 2 Bioassay

Log$_{10}$(RFU)

Day

Control
Nitrogen
Phosphorus
+NP

N Serial Limitation

September GRDA 4 Bioassay

Log$_{10}$(RFU)

Day

Control
Nitrogen
Phosphorus
+NP

See Harpole et al. (2011)
Results (Bioassays)

![Graph showing the relationship between TN and TP with different N:P ratios and months.

- **Axes:**
  - X-axis: TP (ug L⁻¹)
  - Y-axis: TN (ug L⁻¹)

- **Data Points:**
  - August
  - June
  - September

- **Lines:**
  - N:P=22
  - N:P=16
  - N:P=9

- **Annotations:**
  - The red oval highlights the data points for June.
Conclusions

• Nutrient Limitation Varied Spatially and temporally in Grand Lake
• N:P ratios and Actual Nutrient Limitation need more development.
  – Serial Limitation vs. Co limitation
• The internal phosphorus load may have driven N:P ratios lower later in the year.
Comments/Questions?