1. Introduction:

Biological nitrogen fixation drives the productivity of many aquatic ecosystems, but also can be limited by the availability of nutrients. Many of the key enzyme reactions in nitrogen fixation require metals (e.g. Molybdenum, iron) and other nutrients (e.g. phosphorus, sulfur) for their activity. In lakes, a major unknown is how nutrient trace metals that generally exist at very low concentrations control the cycling of nitrogen.

Specifically, we tested for:

- Nutrient controls on nitrogen fixation in lakes with varying trophic status.
- Co-limitation of Mo(V) with other nutrients in lakes as opposed to ocean open waters, to explain why N₂ fixation often does not occur in oligotrophic lakes, despite the presence of potential nitrogen fixers.

2. Study area and methods:

- Location of study stations at each lake.

3. Natural conditions:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Clear Lake</th>
<th>Lake Tahoe</th>
<th>Walker Lake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (m)</td>
<td>125</td>
<td>54</td>
<td>40</td>
</tr>
<tr>
<td>Max. depth (m)</td>
<td>165</td>
<td>100</td>
<td>70</td>
</tr>
<tr>
<td>Trophic status</td>
<td>Mesotrophic</td>
<td>Eutrophic</td>
<td>Oligotrophic</td>
</tr>
<tr>
<td>Nutrients (NO₃, PO₄)</td>
<td>2.5 (1-5)</td>
<td>0.2 (0-0.4)</td>
<td>0.05 (0-0.2)</td>
</tr>
<tr>
<td>Trace metals (Mo(V), Mo(VI), Fe, Co, Cu)</td>
<td>0.05 (0-0.5)</td>
<td>0.05 (0-0.5)</td>
<td>0.05 (0-0.5)</td>
</tr>
</tbody>
</table>

4. Linear response models:

- N₂ fixation explained by the concentration of primarily Mo(V), and also Mo(VI) and P (Model: R² = 0.95; P < 0.001; AIC = 22.0).
- Chl a explained primarily by the concentration of Mo(V) and Mo(VI) and P (Model: R² = 0.99; P < 0.001; AIC = 8.0).
- Bacteria explained primarily by the concentration of Fe (Model: R² = 0.48; P < 0.05 AIC = 29.4).

5. Responses to nutrient additions:

Variable co-limitation of nutrients among lakes.
- In most cases, a distinct response to nutrient additions among bacteria, Chl a and N₂ fixation in each lake was observed.
- Mo(V) plays a role in limiting N₂ fixation primarily in non-eutrophic lakes, contrary to the pattern observed for Chl a.
- No pattern among the lakes was observed for bacteria.

6. Summary:

- In situ and experimental responses indicate nutrients are used differently between groups (e.g. N₂ fixers vs phytoplankton).
- Co-limitation of nutrients (e.g. Mo:P) play a major role on N₂ fixation and Chl a.
- Our results support the hypothesis that co-limitation of Mo(V) with other nutrients explain why N₂ fixation often does not occur in oligotrophic lakes.

7. References:


8. Acknowledgment

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