Relationships between Residence Time and Cyanobacterial Blooms in a Nutrient-Rich River System

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Residence Time and Cyanobacterial Blooms in the St. Johns River

Outline

1. Existing impairment in water quality due to nutrients/algal blooms
2. Relationships between algal blooms, nutrients, and hydrology
3. Thresholds for adverse ecological effects of algal blooms
4. Would water withdrawals exacerbate the adverse effects of algal blooms?
Water Bodies in the St. Johns River Basin Impaired by Excess Nutrients

Water bodies with established total maximum daily loads (TMDLs) or listed as impaired by the Florida Dept of Environmental Protection
**Chlorophyll-a Concentration 1995-2005**

The graph shows the chlorophyll-a concentrations (µg L⁻¹) from 1995 to 2005 at various locations around the region. The locations are indicated on the x-axis: Fulton Pt., Mandarin Pt., Shands Br., Racy Pt., Palatka, L. George, L. Monroe, L. Harney, and L. Poinsett. The y-axis represents the chlorophyll-a concentration levels, with data points indicating the 5%, 10%, 25%, 75%, and 90% confidence intervals. The Algal Bloom threshold is marked with a dashed line at 40 µg L⁻¹.
St. Johns River at Mandarin, August 2005, Microcystis
Chl-a vs TP Relationship
Slope Depends on Water Age

Monthly mean values, Apr – Oct, 1995 – 2005; log Y-scales; regressions $\ln(y) = mx+b$

**Negative** relationship between Chl-a and TP at short retention times
(LG & Pal $p = 0.05$, Racy NS)

**Positive** relationship between Chl-a and TP at long retention times
(All regressions $p < 0.05$)
Hydro-Ecological Models

• Predict algal bloom metrics (dependent variables)
  – Bloom magnitude (Chl-a)
  – Dinoflagellate abundance
  – Bloom duration
  – N$_2$-Fixation

• Use hydrologic prediction (independent) variables: Water age and variables derived from water age

• Multiple linear and logistic regression

• Data sets 11 yr (1995 – 2005)
Example of Ecological Metric - Algal Bloom Duration

Abundance of zooplankton, e.g. cladocera, is reduced during extended algal blooms
Decline in Zooplankton – Seasonal or Algal Bloom Effect?

**Cladocera**
- **p = 0.033 (neg)**

**Copepods**
- **NS**

**Nauplii**
- **NS**

**Rotifers**
- **p = 0.001 (pos)**
### Hydro-Ecological Models

#### Dependent Variables: Algal Bloom Metrics

<table>
<thead>
<tr>
<th>Algal Bloom Metric</th>
<th>Effect(s)</th>
<th>Measured Variable</th>
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</thead>
<tbody>
<tr>
<td>Duration of freshwater algal blooms</td>
<td>Altered zooplankton community; reduction in fish production</td>
<td>Duration of longest annual bloom</td>
</tr>
<tr>
<td>Magnitude of freshwater algal blooms</td>
<td>1) Altered phytoplankton community; cyanobacterial toxins; 2) Depletion of dissolved oxygen; effects on fish reproduction, growth, and mortality</td>
<td>Maximum annual bloom chl-a</td>
</tr>
<tr>
<td>Change (Δ) in N load</td>
<td>Additional N loading</td>
<td>Annual mass N added via N₂-fixation</td>
</tr>
<tr>
<td>Marine algal blooms</td>
<td>Potential toxic species</td>
<td>Maximum annual dinoflagellate biovolume</td>
</tr>
</tbody>
</table>
Prediction (Independent) Variables Based on Water Age (Residence Time)

1) Water age for five quarterly periods starting with the last quarter of the previous year, plus two growth season periods

2) Include mean, maximum, and minimum water age for each period

3) Include the inverse of each water age. Inverse water age is positively related to flow but without negative values at low-flows
Hydro-Ecological Models
multiple linear and logistic regression

- 8 regression models needed to predict 4 algal bloom metrics across multiple river segments
- Used 7 linear regression models and 1 logistic regression model
- Linear regression models
  - 3 to 7 independent variables
  - Adjusted $R^2$ values of 0.80 to 0.97
Example – Prediction of Maximal Bloom Chl-a

Multiple Linear Regression
Adjusted $R^2 = 0.88$

<table>
<thead>
<tr>
<th>Variable</th>
<th>Std Regr Coeff</th>
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<tbody>
<tr>
<td>MinAgeD</td>
<td>-2.318</td>
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<tr>
<td>invMinAgeD</td>
<td>-1.764</td>
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<tr>
<td>MeanAgeD</td>
<td>1.367</td>
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<tr>
<td>MaxAgeE</td>
<td>1.297</td>
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<tr>
<td>invMeanAgeE</td>
<td>0.755</td>
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<tr>
<td>invMean_Age_Apr_Oct</td>
<td>0.636</td>
</tr>
<tr>
<td>invMaxAgeA</td>
<td>0.540</td>
</tr>
</tbody>
</table>

Data set: Segments 3 & 4
LG12 & Racy Pt
Conclusions - 1

- The St. Johns River is impaired by cyanobacterial blooms caused by high nutrient levels
- Blooms are summertime events and are exacerbated by low-discharge
- Blooms cause altered food webs, low DO, algal toxins, and increased N loading through N\textsubscript{2}-fixation
Conclusions-2

• Relationships between algal blooms and nutrients depend strongly on hydrology
• At low river discharge:
  — Lower phosphorus, dissolved color, and turbulence
  — Increased chl-a (relaxed light limitation)
• Algal bloom metrics (e.g. magnitude, duration) are predictable from residence time (water age) with regression models
• Modeled water withdrawals (~$10^6$ m$^3$ d$^{-1}$ *) caused negligible worsening in algal blooms

* 262 x $10^6$ gal d$^{-1}$
Any Questions?

The St. Johns River Water Supply Impact Study
Final Report: *Chapter 8, Plankton*

http://floridaswater.com/watersupplyimpactstudy/