Possible responses of non-tidal stream and river communities to Chesapeake Bay’s “nutrient diet”

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Photo by Adam Griggs
Project:
• requested of ICPRB by Maryland Department of the Environment

Funds:
• American Recovery and Restoration Act (ARRA)

Tasks:
• suggest numeric criteria for nutrients in non-tidal streams and rivers,
• develop a methodology for practical application in Maryland in accordance with the Nutrient Criteria Development Plan for Maryland (MD)
Challenge: Find TN & TP Responses Amongst Confounders

Stressor-Response graphs often produce a “classic wedge” with the biological response to nutrients obscured
Data and Methodology

- Assemble and select stream & river data in Chesapeake Bay region for:
  - **Aquatic Group**
    - Phytoplankton (MD, DE)
    - Periphyton (VA)
    - Macroinvertebrates (MD, PA, VA)
  - **Biometrics**
    - Water column Chl a
    - Attached Chl a, TP and AFDM content
    - 24 family-level metrics, Chessie BIBI

  **All biological samples have associated water quality & habitat data**

- **Applied Recursive Partitioning (RPART)**
  - produces a non-parametric decision tree with thresholds for splitting data
  - same as Category and Regression Tree Analysis (CART)
  - used to identify and remove/account for factors confounding nutrient responses
  - suggests multiple nutrient thresholds

- **Used RPART nutrient thresholds to create a series of nutrient Bins**
  - TN and TP are considered together in relative absence/context of non-nutrient stressors
  - bins are bioregion-specific when bioregion is an important factor

very low TN + very low TP \(\rightarrow\) .... \(\rightarrow\) high TN + high TP
Factors Confounding Nutrient Responses

- **Macroinvertebrate in 1st – 4th order streams**
  remove records with:
  - high conductivity, by bioregion (>200 - 340 μmhos/cm)
  - marginal/poor in-stream habitat quality index by bioregion (<25 - 35 of 60)
    \[ \text{index} = \text{riffle-frequency or riffle-quality} + \text{epifaunal substrate quality} + \text{embeddedness} \]
  - extreme pH levels (<6, >9) and low dissolved oxygen (<5 mg/liter)

- **Periphyton in 1st – 4th order streams**
  remove records with:
  - marginal/poor stream bank metrics (<10 of 20)
    - bank stability, bank vegetation, channel alteration, riparian vegetation, cover
  - exposure to karst geology
  - high conductivity (?) μmhos/cm

- **Phytoplankton in 5th – 7th order Piedmont/Ridges/Valleys rivers and in 1st – 5th order Coastal Plain streams and rivers**
  include with TP and TN when creating bins:
  - water clarity (surrogate = turbidity)
  - dissolved organic carbon

*altered streamflow will impact physical habitats*
Nutrient Responses are Clearer When Confounded Samples are Filtered from Analysis

%Chironomidae (non-biting midges) in Coastal Plain

percentage increases with nutrient enrichment

Unfiltered Data
contains all data, confounded or otherwise

Filtered Data
contains only subset of un-confounded data

Nutrient Bins Nutrient Bins

N and P Increasing

N and P Increasing
Macroinvertebrates (MD with some VA & PA)

Most of the 24 family-level metrics show nutrient responses when confounders are removed

% EPT

% Tolerant

roughly comparable [TN] and [TP]
Chessie BIBI* shows nutrient responses when confounders are removed

* Chessie BIBI* is a multi-metric macroinvertebrate index of biotic integrity for streams in the Chesapeake Bay watershed.
Not all periphyton metrics respond to water column TN and TP – possibly because periphyton consists of heterotrophs (fungi, bacteria) as well as algae.

Reminder: data filtered to exclude sites with marginal/poor habitat scores, high conductivity, and karst geology.
Periphyton

Piedmont Streams in Highly Enriched Conestoga River Watershed (SRBC, PA)

- No clear-cut nutrient responses when all waters are heavily enriched with TN and TP

Conestoga River watershed:
- Average yearly concentrations of TN and TP at monitoring stations are high
  - TN: 0.39 – 17.71 mg/liter
  - TP: 0.013 – 0.663 mg/liter
- Conductivity and total alkalinity levels are high
- Many sites have poor habitat (stream bank) conditions

~ 72% of periphyton samples are above “nuisance” level of >100 Chla mg/m²
Phytoplankton

Piedmont & Ridge-Valley Large Rivers (MD)

Light is an essential resource for phytoplankton

- Binning approach is not successful when light condition is *not* considered
- Analysis approach is successful when light condition is *is* considered

Used Turbidity as a surrogate for light attenuation

TN, TP, and Turbidity concentrations in the analysis adjusted to remove phytoplankton component

<table>
<thead>
<tr>
<th>BIN</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>AdjTurb</td>
<td>&lt;1.9</td>
<td>&lt;7.2</td>
<td>&lt;7.2</td>
<td>7.2 - &lt;9.6</td>
<td>≥9.6</td>
<td>≥9.6</td>
<td>≥16.4</td>
</tr>
<tr>
<td>AdjTP</td>
<td>&lt;0.160</td>
<td>&lt;0.180</td>
<td>&lt;0.180</td>
<td>≥0.180</td>
<td>&lt;3.49</td>
<td>≥3.49</td>
<td>≥0.377</td>
</tr>
<tr>
<td>AdjTN</td>
<td>&lt;3.20</td>
<td>&lt;3.49</td>
<td>≥3.49</td>
<td>mixed</td>
<td>mixed</td>
<td>mixed</td>
<td>mixed</td>
</tr>
</tbody>
</table>

Increasing nutrients
Phytoplankton

Piedmont & Ridge-Valley
Large Rivers (MD)

When the frequency of water quality bins 5-7 at a station exceeds ~22%, the probability of Chl a > 30 µg/liter (algal blooms) increases above zero and when the frequency of bins 5-7 is ~40% at a station, there is presently a 1 in 20-25 probability that monthly samples will have Chl a > 30 µg/liter.

- The mean Chl $a$ concentration can indicate the likelihood of algal blooms (Walker 1984)
- The frequency of turbid, nutrient-enriched waters can indicate the likelihood of algal blooms
Phytoplankton

Mid-Atlantic Coastal Plain Streams & Rivers (MD, DE)

Slow moving waters in Coastal Plain make water column Chl a a useful indicator in streams as well as rivers

- Nutrient responses in “blackwaters” (high DOC) are somewhat exaggerated
  1. proportions of TN and TP “species” differ
  2. DOC also attenuates light

MD drinking water reservoir criteria

Local water chemistry is important
Major Findings

- Nutrient thresholds protective of high quality streams are clearly seen and excess nutrients significantly degrade aquatic communities.

- Protective nutrient response thresholds are most evident when the impacts of confounding stressors are removed or accounted for:
  - In-stream habitat and riparian/bank conditions
  - Conductivity
  - pH
  - Dissolved Oxygen
  - Water clarity (phytoplankton)

- Protective nutrient thresholds vary by biological group and/or by physiographic region:
  - TP: 0.012 – 0.087 mg/liter
  - TN: 0.58 – 2.67 mg/liter
  - Turbidity: 4.7 – 10.0 NTU (phytoplankton only)
Major Findings

- Degraded communities are not necessarily “impaired”

- Macroinvertebrates appear to have lower TN and TP thresholds than the two algal types

- In “blackwaters” (high DOC), TP thresholds are higher and TN thresholds are lower, suggesting thresholds are affected by differences in regional water chemistry

- Degradation caused by excess nutrients is likely occurring even when masked by confounding stressors, but impacts are difficult to quantify

- In rivers and streams, nutrient impacts on aquatic communities might be secondary to other stressors
Will streams and rivers in Chesapeake Bay watershed benefit directly from Bay TMDL nutrient reductions?
CAVEAT:
Answer reflects the locations of the “filtered” data used in study

Legend
Sampling Stations
PM: Connecticut
VA
State Boundaries
Chesapeake Bay
Bioregions
North Central Appalachians
Northern Appalachian Plateaus and Uplands
Valleys
Ridges
Floodplain
Southeastern Coastal Plains
Mid-Atlantic Coastal Plains

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Sampling Stations
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Legend
Phytoplankton
Periphyton
Macroinvertebrates
Phytoplankton (Chlorophyll $a$) Sampling Events

Data are from MD and DE portions of Chesapeake Bay watershed

<table>
<thead>
<tr>
<th></th>
<th>Piedmont/ Ridges/ Valleys Rivers ($\geq$5th order)</th>
<th>Coastal Plain Rivers and Streams</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Chl $a$ samples with TN, TP, DOC and turbidity data:</td>
<td>741</td>
<td>3255</td>
</tr>
</tbody>
</table>

% stressed by high turbidity and excess nutrients
- Direct nutrient TMDL benefit is not quantifiable or immediately obvious?
- 35%                                               11%

% stressed by high turbidity but not by nutrients
- **NO direct nutrient TMDL benefit**             10%                                               25%

% stressed by excess nutrients but not by turbidity
- Direct nutrient TMDL benefit                    8%                                               34%

% not stressed by nutrients or turbidity
- **NO direct nutrient TMDL benefit**             47%                                               30%
Macroinvertebrates Sampling Events

Data are from portions of MD, PA, and VA in Chesapeake Bay watershed

<table>
<thead>
<tr>
<th></th>
<th>Coastal Plain</th>
<th>Piedmont</th>
<th>Valleys</th>
<th>Ridges</th>
</tr>
</thead>
<tbody>
<tr>
<td># of samples with full suite of water quality data:</td>
<td>778</td>
<td>557</td>
<td>116</td>
<td>261</td>
</tr>
<tr>
<td>% stressed by pH, DO, conductivity, and/or habitat quality as well as excess TN and/or TP</td>
<td>77%</td>
<td>56%</td>
<td>64%</td>
<td>41%</td>
</tr>
<tr>
<td>• Direct nutrient TMDL benefit is not quantifiable or immediately obvious?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% stressed by excess TN and/or TP (conductivity, DO, pH, and habitat quality are all in acceptable ranges)</td>
<td>9%</td>
<td>33%</td>
<td>14%</td>
<td>3%</td>
</tr>
<tr>
<td>• Direct nutrient TMDL benefit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% not stressed by TN, TP, or other water quality parameters</td>
<td>14%</td>
<td>11%</td>
<td>22%</td>
<td>56%</td>
</tr>
<tr>
<td>• <strong>NO direct nutrient TMDL benefit</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

- Significant numbers of stream and river sites do not need nutrient reductions to protect local water quality because they have TN and TP concentrations below the protective thresholds.

- For streams impacted by excess nutrients and confounding factors, nutrient reductions may not be effective in improving local stream condition unless confounding stressors are also addressed.

- Additional data and analysis will clarify best course of action for each stream.
### Compilation of Protective Nutrient Thresholds*

<table>
<thead>
<tr>
<th>Desirable levels (biology)</th>
<th>Phytoplankton Chl a &lt;30 ug/liter</th>
<th>Periphyton Chl a &lt;100 mg/m²</th>
<th>Macroinvertebrate avg. score of the nutrient-sensitive metrics is ≥3 in &gt;80% samples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strahler Stream Order</strong></td>
<td><strong>DOC level</strong></td>
<td><strong>Lo</strong></td>
<td><strong>Hi</strong></td>
</tr>
<tr>
<td>---------------------------</td>
<td>-------------------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td><strong>Median TP (mg/liter)</strong></td>
<td>0.036</td>
<td>0.087</td>
<td>0.012</td>
</tr>
<tr>
<td><strong>Median TN (mg/liter)</strong></td>
<td>2.44</td>
<td>2.37</td>
<td>2.36</td>
</tr>
</tbody>
</table>

**Light Co-Variant**

| Median Turbidity (NTU) | 10.0 | 10.0 | 5.0 | 4.7 | 6.3 | 8.9 |
| Median DOC (mg/liter) | 2.16 | 3.81 | 2.37 | 4.73 | 2.37 | 4.85 |

*Conditional requirements are met (confounding habitat and water quality factors are removed/accounted for)
Diverse Macroinvertebrate Metrics Respond to Nutrients

<table>
<thead>
<tr>
<th>Selected Nutrient-Sensitive Metrics</th>
<th>Coastal Plain</th>
<th>Piedmont/Valleys</th>
<th>Ridges</th>
</tr>
</thead>
<tbody>
<tr>
<td>% EPT</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td># EPT Taxa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Plecoptera</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td># Sensitive Taxa</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>% Tolerant</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Hilsenhoff FBI</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>% Chironomidae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASPT Modified</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>% Collector</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Swimmer</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>% Clinger</td>
<td></td>
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</tbody>
</table>

**Baseline**: select five nutrient-sensitive metrics, identify bins for which ≥ 80% of samples have an average metric score of ≥3 (1-3-5 scale)

**Nutrient Thresholds**: median TN and TP of last bin meeting baseline conditions