Diatom Tolerance Metrics to Identify Total Phosphorus as a Candidate Cause of Aquatic Life Impairment in Connecticut Freshwater Streams

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Management Problem

The cause of impairment is listed as unknown in over 95% of those streams impaired for aquatic life uses in CT.

Significant interest in better managing TP and being able to identify as a cause of aquatic life impairment.

No streams are currently listed as impaired for aquatic life uses due to TP.

To identify total phosphorus (TP) as a candidate cause of aquatic life impairment for freshwater rivers and streams in Connecticut that are impaired.

1.) **Identify biological responses to TP** and develop biological tolerance metrics that distinguish between high and low TP concentrations.

2.) Combine these metrics with previous work to form a **weight of evidence approach** to identify TP as a probable cause of impaired streams.
Method

**Taxa Used – Diatoms Species**

**Why use diatoms?**

Many diatom species are directly sensitive to TP. Diatom community samples better capture temporal variability of TP stream conditions than single grab samples of TP.

‘Traditional’ taxa (fish / bugs) used for AQL assessments are indirectly sensitive to TP.
Method

1. **Identified species with significant response** to TP and tested response.

2. Developed metrics using **combined species responses**.

3. **Tested specificity** of metrics response to TP compared to other known ecological gradients of diatom communities, pH & temperature²

4. Propose weight of evidence approach combining metrics with TP (mg/L) thresholds from previous work³ to **identify TP as candidate cause** of AQL impairment in streams.

5. Developed web application for dissemination of information and maintained **open science** practices to ensure a high level of transparency and reproducibility.


Data

Sample Years

Diatoms and TP grab samples
281 samples

Wadeable Streams

Targeted and Probabilistically-Based Sampling Design

Connecticut Department of Energy and Environmental Protection
Species Responses

How we defined species responses:

**tolerant** - frequently occurring in high TP conditions and tending to increase as TP concentrations increase

**sensitive** - frequently occurring in low TP conditions and tending to decline as TP concentration increase

**indifferent** - found across the entire observed TP gradient with no clear response to TP

![Graphs showing species responses](image-url)
Species Responses

Generalized Additive Models\textsuperscript{4} used to model species probability of occurrence across the TP gradient.

Curve classification\textsuperscript{5} to identify tolerant, sensitive and indifferent species.

Receiver operating characteristic (ROC) curves used to test the classification strength of the model.

Species responses were tested for consistency using bootstrap resampling.

53 tolerant, 14 sensitive and 59 indifferent.

Calculated Three Metrics:

~ Relative Abundance of Tolerant Species
~ Relative Abundance of Sensitive Species
~ Tolerant to Sensitive Index

Identified Three TP Groups:

~ Low, Medium & High

Looked for discriminating separation among the groups

~ Discrimination Efficiency $^{6,7}$

---


Diatom Species Metrics

Discrimination Efficiency (Range 0 - 1 )
>0.6 = Good distinction between TP groups

<table>
<thead>
<tr>
<th>Metric</th>
<th>Response</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA Tol</td>
<td>Increase</td>
<td>TP</td>
</tr>
<tr>
<td>RA Sen</td>
<td>Decrease</td>
<td>TP</td>
</tr>
<tr>
<td>Index</td>
<td>Increase</td>
<td>TP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data</th>
<th>H</th>
<th>M</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP (mg/L)</td>
<td>&gt;0.052</td>
<td>0.016 - 0.052</td>
<td>&lt;0.016</td>
</tr>
</tbody>
</table>

Groups (25\textsuperscript{th}, 25\textsuperscript{th}-75\textsuperscript{th} & 75\textsuperscript{th} Percentiles)
Potapova & Charles (2002)\textsuperscript{2} identified three major ecological gradients underlying variation in species composition:

1.) Downstream ‘Nutrient’ gradient
2.) pH gradient
3.) Temperature gradient

We tested the TP metrics against the pH and temperature to identify metric specificity of response to TP.
Specificity of Metric Response to TP

Groups (25th, 25th-75th & 75th Percentiles)

<table>
<thead>
<tr>
<th>Grp</th>
<th>TP mg/L</th>
<th>pH units</th>
<th>July Temp °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>&gt;0.052</td>
<td>&gt;7.47</td>
<td>&gt;23.47</td>
</tr>
<tr>
<td>M</td>
<td>0.016 - 0.052</td>
<td>6.92 - 7.47</td>
<td>20.23 - 23.47</td>
</tr>
<tr>
<td>L</td>
<td>&lt;0.016</td>
<td>&lt;6.92</td>
<td>&lt;20.23</td>
</tr>
</tbody>
</table>

Discrimination Efficiency (- = Lower DE value than TP groups)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Response</th>
<th>Group</th>
<th>TP</th>
<th>pH</th>
<th>Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA Tol</td>
<td>Increase</td>
<td>LH</td>
<td>0.94</td>
<td>0.66</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LM</td>
<td>0.60</td>
<td>0.51</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MH</td>
<td>0.77</td>
<td>0.31</td>
<td>0.21</td>
</tr>
<tr>
<td>RA Sen</td>
<td>Decrease</td>
<td>LH</td>
<td>0.90</td>
<td>0.53</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LM</td>
<td>0.54</td>
<td>0.47</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MH</td>
<td>0.69</td>
<td>0.22</td>
<td>0.30</td>
</tr>
<tr>
<td>Index</td>
<td>Increase</td>
<td>LH</td>
<td>0.92</td>
<td>0.57</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LM</td>
<td>0.62</td>
<td>0.47</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MH</td>
<td>0.75</td>
<td>0.22</td>
<td>0.21</td>
</tr>
</tbody>
</table>
Define Metric Threshold for Assessments

Metric identified as ‘High’ above the 50th percentile for ‘increasing’ metrics (RA tolerant & index) and below the 50th percentile for ‘decreasing metric (RA sensitive).
**CTstream TP concentration thresholds based on Smucker et al (2013)**

<table>
<thead>
<tr>
<th>Category</th>
<th>TP (mg/L)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>&gt;= 0.065</td>
<td>Most sensitive taxa lost. Tolerant taxa steeply increase.</td>
</tr>
<tr>
<td>Medium</td>
<td>&gt;0.02 - 0.065</td>
<td>Sensitive taxa steeply declined. Tolerant taxa increase.</td>
</tr>
<tr>
<td>Low</td>
<td>&lt;= 0.02</td>
<td>Sensitive taxa in good abundance.</td>
</tr>
</tbody>
</table>

Concentrations are based on single grab chemistry samples
Identify TP As Cause of AQL impairment

TP identified as cause of AQL impairment using weight of evidence approach

<table>
<thead>
<tr>
<th>Measure</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>AQL assessment using bugs &amp;/or fish</td>
<td>IMPAIRED</td>
</tr>
<tr>
<td>TP Concentration Threshold</td>
<td>HIGH or MED</td>
</tr>
<tr>
<td>RA Tolerant Diatoms</td>
<td>HIGH</td>
</tr>
<tr>
<td>RA Sensitive Diatoms</td>
<td>HIGH</td>
</tr>
<tr>
<td>Diatom Index</td>
<td>HIGH</td>
</tr>
</tbody>
</table>
Identify TP As Cause of AQL impairment

Sites that meet all criteria to add TP as cause of AQL impairment

Connecticut Department of Energy and Environmental Protection

Total Phosphorus Yield (KG/YR/KM2)
- Low
- Medium
- High
- Very High
Open science: Open source, Open access, Open data

Complete reproducibility and transparency.

Used all open source software to develop research.

Close to submitting research for peer-review. Will post pre-publication on pre-pub website (PeerJ).

In progress data and analysis code is available for download: https://github.com/marybecker/DiatomTPMetrics

Developing a web application to view and download metrics for sites: https://ctriverresearch.shinyapps.io/TPAQLapp

In progress code to develop the web application: https://github.com/marybecker/TPAQLapp
Open science:
Open source, Open access, Open data

Open Source Tools used in this project:

Data Management
SQLite
SQLiteStudio

Data Analysis
R (Packages GAM, ggplot2, grid, ptyr, reshape2, Functions by Lester Yuan for curve classification)

GIS
R packages Rgdal, Tmap, Leaflet
QGIS

Web Application
R packages Shiny & Leaflet
D3 (in progress for future ver. of app)
Next Steps

Finalizing research for publication submittal

Finalizing data visualization tool to post on TP monitoring research DEEP website

Incorporate into the 2018 CALM

Expand work to other stressors

Update data visualization tool and add additional features

Exploring available data to examine potential to expand from single variable model to multivariable model
We Thank...

Current and past CT diatom monitoring staff, in particular, Walter Tokarz and Lisa Wahle; Lee Dunbar for providing critical reviews on earlier drafts of the manuscript; Mike Beauchene for his dedication to properly managing the data from the start of this project; Don Charles and the taxonomists at the ANSP Phycology Lab, Julia Eichman formerly at Eco-Analysts Inc., and taxonomists in R. Jan Stevenson’s lab for analyzing all of our diatom data; U.S. EPA for providing partial funding through grants that aided the collection of data in this study.
Questions?

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https://github.com/marybecker/DiatomTPMetrics
WHEN LIVE DEMO FAILS
Web Application Screenshots

Aquatic Life Impacts of Total Phosphorus (TP) Project

Explore Metrics
Select stream below or click a site on the map:

Metric:
Tolerant TP Diatoms

See 'About Project' tab for more information on metrics

Average TP (mg/L) category
- Low
- Medium
- High

Connecticut Department of Energy and Environmental Protection
Web Application Screenshots

Aquatic Life Impacts of Total Phosphorus (TP) Project

Explore Metrics
Select stream below or click a site on the map:
Quinnipiac River_14413

Metric:
Tolerant TP Diatoms

Quinnipiac River
Relative Abundance of Tolerant TP Indicator Diatoms
High | Medium | Low

See 'About Project' tab for more information on metrics.

Download All Metric Data for this Site
Web Application Screenshots

Aquatic Life Impacts of Total Phosphorus (TP) Project

Explore Metrics
Select stream below or click a site on the map:
Quinnipiac River_14413

Metric:
- Tolerant TP Diatoms
- Tolerant TP Diatoms
- Sensitive TP Diatoms
- Total Phosphorus

See 'About Project' tab for more information on metrics

Download All Metric Data for this Site

Average TP (mg/L) category
- Low
- Medium
- High
Web Application Screenshots

Aquatic Life Impacts of Total Phosphorus (TP) Project

Explore Metrics
Select stream below or click a site on the map:
Quinnipiac River_14413

Metric:
Sensitive TP Diatoms

Quinnipiac River
Relative Abundance of Sensitive TP Indicator Diatoms

See 'About Project' tab for more information on metrics

Average TP (mg/L) category
Low Medium High

Download All Metric Data for this Site
Web Application Screenshots

Aquatic Life Impacts of Total Phosphorus (TP) Project

Explore Metrics
Select stream below or click a site on the map:
Quinnipiac River_14413

Metric:
Tolerant TP Diatoms

See 'About Project' tab for more information on metrics.

Connecticut Department of Energy and Environmental Protection
Web Application Screenshots

Total Phosphorus (TP) Management in CT Freshwater Streams

Explore Management Efforts
Hover over regional basin on map to view estimated TP yield reductions over time.

Estimated TP Yield (kg/km2)
Framington Regional Basin

TP Yield Category: High, Medium High, Medium Low, Low

Pre-Management, 2015, Future

See ‘About Project’ tab for more information on data used

Delta Download All TP Yield Data

Full Implementation
TP Percent Reduction:
- > 75%
- 50 - 75%
- 25 - 50%
- 1 - 25%
- Cap
- NA
Web Application Screenshots

Total Phosphorus (TP) Management in CT Freshwater Streams

Explore Management Efforts
Hover over regional basin on map to view estimated TP yield reductions over time.

Estimated TP Yield (kg/km2) Tenmile Regional Basin

TP Yield Category: High, Medium High, Medium Low, Low

Pre-Management, 2015, Future

See 'About Project' tab for more information on data used.

Download All TP Yield Data

Do you want to open or save TPYieldData.csv (5.45 KB) from ctriverresearch.shinyapps.io?
Web Application Screenshots

Project Overview

The purpose of this research project is to support the Connecticut Department of Environmental Protection's (CT DEEP) ongoing phosphorus management efforts to protect aquatic life in freshwater rivers and streams. The CT DEEP water monitoring program collects and analyzes river and stream data as part of this effort. This R web app is designed to disseminate data and information related to this research to the public.

Phosphorus is a nutrient that is naturally occurring in inland, non-tidal CT rivers and streams; however, when added in excess can contribute to cultural eutrophication. Eutrophication is the process which leads to an increase in the level of primary production or biomass occurring within a water body. Eutrophication is a slow natural process that occurs within a water body, but human activity can greatly speed up the process primarily through the addition of excess nutrients. Cultural eutrophication is described as human-caused acceleration of eutrophication through excess nutrients in water bodies. Cultural eutrophication causes harmful effects on water bodies such as fish kills, reduction of dissolved oxygen and pH values, and loss of diversity or changes in community structure in aquatic plant, invertebrate and fish communities.

Cultural eutrophication is a serious threat to water quality in Connecticut (CASE 2014, Becker 2014) and is also one of the most pressing water quality issues facing the nation. The EPA has identified cultural eutrophication as one of the primary factors resulting in impairment of U.S. surface waters and is encouraging all states to develop strategies to reduce nutrient pollution that address impairments caused by cultural eutrophication. CT DEEP has taken several steps to implement reductions in the most impacted rivers and streams and is continuing to develop the science to better understand where further reductions are needed.

Research Tab Overview

The CT DEEP monitoring program collects total phosphorus and algae community samples in rivers and streams. The type of algae collected are called diatoms. Diatoms are good indicators of eutrophication in rivers and streams. The graph displays three metrics:

- Relative Abundance Tolerant Diatoms: Tolerant diatoms are defined as species frequently occurring in high TP conditions and tending to increase in abundance as TP increases
- Relative Abundance Sensitive Diatoms: Sensitive diatoms are defined as frequently occurring in low TP conditions and tending to decline in abundance as TP increases
- Total Phosphorus: Total phosphorus represents the average concentration of collected stream samples under ambient conditions for a given year

The metrics are a result of ongoing work and are subject to change. For additional information, see references Smucker et al. (2013) and link to pre-publication version of ongoing work.

Management Tab Overview

In 2011, CT DEEP developed a strategy based on best available information to reduce phosphorus in watersheds with the highest yields (kg/km2) of phosphorus (Becker 2014). The high yield of phosphorus in these watershed was largely due to municipal water pollution control facilities (WPCFs), therefore DEEP targeted reductions at these facilities. These methods were approved by the EPA in a letter dated October 26, 2010 as an interim strategy to establish water quality based phosphorus limits in non-tidal freshwater for National Pollutant Discharge Elimination permits for WPCFs while DEEP further developed research on the effects of phosphorus in freshwaters. These reductions are being implemented in phases as permits get renewed with additional time allocated for facilities that need to upgrade technology to achieve large reductions. Interim requirements are occurring at facilities that cannot achieve final limits in the first permitting cycle.

Estimates of seasonal (April-October) TP land cover and WPCF TP loads were summed and divided by the regional basin area to estimate a seasonal yield for that basin. Land cover loads were