Remote sensing approaches for detecting and monitoring cyanobacteria blooms in lakes

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Optical components and pathways of radiance and reflectance in lake waters

Multiple light paths

- **Scattering due to:**
  - atmosphere
  - aerosols
  - water surface
  - suspended particles
  - bottom

- **Absorption due to:**
  - atmosphere
  - aerosols
  - suspended particles
  - dissolved matter
What is lake optical color?

Figure 1. Electromagnetic spectrum and region of reflected light remote sensing.
Definition of Remote Sensing Reflectance

\[ R_{rs}(0^+, \lambda) = \frac{L_w(0^+, \lambda)}{E_s(0^+, \lambda)} \]

- \( R_{rs} = \text{remote sensing reflectance (1/sr)} \)
- \( L_w(0^+, \lambda) = \text{water leaving radiance measured above the air/water interface (W m}^{-2} \text{ sr}^{-1}) \)
- \( E_s((0^+, \lambda) = \text{downwelling irradiance measured above the air/water interface (W m}^{-2} \text{ sr}^{-1}) \)
Type 1 spectra
Bright blue, clear lakes low chl a, and dominated by CDOM

Type 2 spectra
Green lakes with high chl a and cyanobacteria present.

Type 3 spectra: similar to Type 2 with lower chl a and cyanobacteria
Aircraft monitoring with hyperspectral sensor packages

Advantages:
* Better temporal and spatial coverage compared to field sampling.

Optimal coverage of small lakes (<10 to >1000 hectares).
Retrieval of phytoplankton biomass [chl $a$] from Red and NIR spectral data (Le et al., 2002; Hunter, 2010)

Pigment concentration $\propto \left[ R_{rs}^{-1}(\lambda_1) - R_{rs}^{-1}(\lambda_2) \right] \times R_{rs}(\lambda_3)$

$R^2 = 0.97$

<table>
<thead>
<tr>
<th>Location</th>
<th>$[R_{rs}^{-1}(672) - R_{rs}^{-1}(712)] \times R_{rs}(749)$</th>
<th>Chl $a$ measured (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canaan Street Lake, NH</td>
<td>0.86</td>
<td>3</td>
</tr>
<tr>
<td>Crooked Pond, NH</td>
<td>2.70</td>
<td>10</td>
</tr>
<tr>
<td>French Pond, NH</td>
<td>3.59</td>
<td>15</td>
</tr>
<tr>
<td>Harvey Lake, NH</td>
<td>2.04</td>
<td>8</td>
</tr>
<tr>
<td>Howe Reservoir, NH</td>
<td>1.35</td>
<td>7</td>
</tr>
<tr>
<td>Powder Mill Pond, NH</td>
<td>0.74</td>
<td>2</td>
</tr>
<tr>
<td>Thorndike Pond, NH</td>
<td>0.84</td>
<td>5</td>
</tr>
<tr>
<td>Turtle Pond, NH</td>
<td>6.52</td>
<td>36</td>
</tr>
<tr>
<td>Webster Lake, NH</td>
<td>2.10</td>
<td>8</td>
</tr>
<tr>
<td>Lake Attitash, Ma</td>
<td>6.63</td>
<td>40</td>
</tr>
<tr>
<td>Flat River Reservoir, RI</td>
<td>0.14</td>
<td>2</td>
</tr>
<tr>
<td>Beach Pond, RI</td>
<td>0.15</td>
<td>2</td>
</tr>
<tr>
<td>Watchaug Pond, RI</td>
<td>1.47</td>
<td>5</td>
</tr>
<tr>
<td>Yawgoo Pond, RI</td>
<td>6.05</td>
<td>27</td>
</tr>
</tbody>
</table>
Model Validation

\[ y = 0.98 + 0.019 \]
\[ R^2 = 0.97 \]
\[ \text{RMSE} = 2.64 \, \mu g/L \]
\[ N = 31 \]
Summary of trophic status for New England lakes based on phytoplankton concentrations

<table>
<thead>
<tr>
<th>Trophic status</th>
<th>NE Coastal Zone Ecoregion (No. of lakes and ponds surveyed)</th>
<th>NE Highlands Ecoregion</th>
<th>% of total lakes and ponds surveyed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oligotrophic (Chl a &lt; 2 μg/L)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mesotrophic (Chl a &gt; 2 to 7 μg/L)</td>
<td>18</td>
<td>16</td>
<td>69</td>
</tr>
<tr>
<td>Eutrophic (Chl a &gt; 7 to 30 μg/L)</td>
<td>5</td>
<td>4</td>
<td>18</td>
</tr>
<tr>
<td>Hypereutrophic (Chl a &gt; 30 μg/L)</td>
<td>5</td>
<td>1</td>
<td>12</td>
</tr>
</tbody>
</table>

Trophic status definitions from EPA National Lakes Assessment Program
### Summary of biological condition for New England lakes based in chl a concentrations

<table>
<thead>
<tr>
<th>Biological Condition</th>
<th>Ecoregion</th>
<th>Chlorophyll Thresholds</th>
<th>Number of lakes and ponds</th>
<th>% of lakes and ponds surveyed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good-Fair</td>
<td>NE Coastal Zone</td>
<td>&lt;29 µg/L</td>
<td>23</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>NE Highlands</td>
<td>&lt;7.6 µg/L</td>
<td>16</td>
<td>33</td>
</tr>
<tr>
<td>Fair</td>
<td>NE Coastal Zone</td>
<td>29 to 76 µg/L</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>NE Highlands</td>
<td>7.6 to 13 µg/L</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fair-Poor</td>
<td>NE Coastal Zone</td>
<td>&gt; 76 µg/L</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>NE Highlands</td>
<td>&gt; 13 µg/L</td>
<td>4</td>
<td>8</td>
</tr>
</tbody>
</table>

Biological condition definitions and chlorophyll thresholds from EPA National Lakes Assessment Program
**Space-based Lake Color Sensors**

**SENSOR (spatial resolution)**
- **HICO**
  - 100 m

**PLATFORM**
- **International Space Station**
  - (Sept 2009 –present)

**AGENCY**
- **NASA ISS Program**

**Data Distribution Policy**
- Products distributed online from HICO/OSU web site

**Data Access**
- Investigator Proposal Required

**Cost to User**
- No cost

**SENSOR (spatial resolution)**
- **MERIS**
  - 300/1000 m

**PLATFORM**
- **ENVISAT**
  - (Jan 2002-Apr 2012)

**AGENCY**
- **European Space Agency**

**Data Distribution Policy**
- Free online access of reduced resolution datasets through 'My Earthnet’ website

**Data Access**
- Registration required

**Cost to User**
- No cost

**Advantage:** spatial and temporal coverage for “large” lakes
Phytoplankton distribution and abundance in Lake Champlain: June 4, 2009

Also see: S.M. Wheeler et al. / Journal of Great Lakes Research 38 (2012) 68–75

[Chl a] µg/L
- 0.5 – 1.8
- 1.8 – 5.4
- 5.4 – 14.4
- 14.4 – 27.5
- 27.5 - >46

MERIS image courtesy of the European Space Agency
Retrieval of cyanobacterial biomass [C-PC] from spectral data (Simis et al., 2005; Gons et al., 2005; Hunter et al., 2010)

\[
[C-PC] \text{ (µg/L)} = \frac{a_{C-PC}(620)}{(a_{C-PC}^*(620))} \approx 0.007
\]

\[
a_{C-PC}(620) = \left(\left[a_w(709) + b_b(779)\right] \times \left[R(709)/R(620)\right]\right) - b_b(779) - a_w(620) - a_{chl}(665)
\]

\[
a_w(709) = \text{water absorption at 709 nm},
\]
\[
a_w(620) = \text{water absorption at 620 nm},
\]
\[
b_b(779) = \text{backscatter at 779 nm},
\]
\[
R(709) = \text{reflectance at 709 nm},
\]
\[
R(620) = \text{reflectance at 620 nm},
\]
\[
a_{chl}(665) = \text{chl a absorption at 665 nm}.
\]
Phycocyanin distribution from MERIS image: June 4, 2009

- Missisquoi Bay
- Malletts Bay
- Central Lake Champlain
- South Lake Champlain

Color legend:
- Green (<2 ug/L)
- Yellow (2-8 ug/L)
- Red (>8 ug/L)
Relative risk of cyanobacteria dominance for New England lakes and ponds based on measured total phosphorus (Total P) concentrations and lake susceptibility to dominance (C-PC:Chl a).

Relative risk of cyanobacteria dominance for New England lakes and ponds based measured total nitrogen (Total N) concentrations and lake susceptibility to dominance (C-PC:Chl a)

Recreational Suitability of New England Lakes based on Potential Human Health Hazards

<table>
<thead>
<tr>
<th>Relative Probability of Acute Health effects</th>
<th>NE Coastal Zone Ecoregion (no. of lakes and ponds)</th>
<th>NE Highlands Ecoregion</th>
<th>Health Effects *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (Chl a &lt; 10 μg/L)</td>
<td>19</td>
<td>16</td>
<td>Skin irritations, Gastrointestinal illness</td>
</tr>
<tr>
<td>Moderate (Chl a 10-50 μg/L)</td>
<td>8</td>
<td>5</td>
<td>Long term illness, Skin irritations, Gastrointestinal illness</td>
</tr>
<tr>
<td>High (Chl a 50-5000 μg/L)</td>
<td>1</td>
<td>0</td>
<td>Potential for acute poisoning, Long term illness, Skin irritations, Gastrointestinal illness</td>
</tr>
</tbody>
</table>

* from World Health Organization
Questions?

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Trophic status, ecological condition, and cyanobacteria risk of New England lakes and ponds based on aircraft remote sensing

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