Drought-Induced Flux of Metals from Peatlands in Watersheds Vulnerable to Extreme Events

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Canada’s Boreal Shield contains a vast area of peatlands connected to one of the world’s largest freshwater resources.
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Mining Activity in Sudbury, Ontario

100+ years of mining
• Cu, Ni smelters, acid and metal deposition

By the 1970s:
• 17000 ha “industrial barrens”, 72000 ha “semi-barren”
• 7000+ lakes affected

Since the 1970s, major restoration efforts have made this one of the best cases of post-mining recovery in the world
Biological recovery in lakes is lagging, but there are ‘hotspots’

Average log-weight of young-of-year yellow perch
(Szkokan-Emilson, in progress)

Sites where *Hyalella azteca* were found in 2010
(Kielstra, in progress)

Diversity of Benthic Macroinvertebrates
(Szkokan-Emilson et al. 2011)
Drought-induced Re-acidification and release of stored metals

- Peat (organic soil) adsorbs / retains metals
- Under **drought conditions** stored sulphur is oxidized, and re-wetting events form sulphuric acid.

\[
\begin{align*}
\text{Organic S} & \rightarrow \text{O}_2 & \rightarrow \text{H}_2\text{O} & \rightarrow \text{SO}_2 / \text{SO}_3 & \rightarrow \text{H}_2\text{SO}_4 \\
\text{acid} & & & \rightarrow \text{H}^+, \text{SO}_4
\end{align*}
\]

- The protons (H\(^+\)) then exchange with metal ions that are adsorbed to peat, and release metal cations into the water (Tipping et al. 2003)
Tipping et al. 2003:
Stored metals will be released from peatlands in response to drought, and the amount of deposited metals and S, and the size of the soil S pool are the strongest drivers of this release.

Watmough et al. 2008:
Drought-induced sulphur oxidation resulted in metal releases from a peat bog in the Dorset, ON area, and Cd, Co, and Zn exceed provincial water quality objectives by factors of around 3-5x.

What will the magnitude and duration of this effect be in mining-impacted Boreal Peatlands where S and metal deposition is high?
Methods: Streamwater Fluxes

Two sub-catchments draining into two recovering lakes, measured from June 1 2011 to mid-November 2011

Water height is recorded every 15 minutes for conversion to flow rate (L/s). (Standard rating curve methods)

Water samples are collected every 8 hrs, analyzed for trace metals, etc (ISCO automated samplers)
Laurentian

Daisy
Laurentian

Daisy

Two-week spike (post-drought):

21.8 g of Co
66% of the 6 month total!

39.8 g of Co
61% of the 6 month total!
Two-week spike (post-drought):

622.9 g of Ni
64% of the 6 month total!

442.7 g of Ni
59% of the 6 month total!
Laurentian Daisy

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## Metal release pre- and post-drought: Daisy Lake

<table>
<thead>
<tr>
<th>Metal</th>
<th>Pre-Drought</th>
<th>Post-Drought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt (Co)</td>
<td>$SO_4$ adjusted R2=0.090</td>
<td>$SO_4$ adjusted R2=0.912</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>$SO_4$ adjusted R2=0.063</td>
<td>$SO_4$ adjusted R2=0.861</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>$SO_4$ adjusted R2=0.081</td>
<td>$SO_4$ adjusted R2=0.654</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>DOC adjusted R2=0.073</td>
<td>$SO_4$ adjusted R2=0.730</td>
</tr>
<tr>
<td>Aluminum (Al)</td>
<td>$SO_4$ adjusted R2=0.190</td>
<td>$SO_4$ adjusted R2=0.805</td>
</tr>
</tbody>
</table>
# Metal release pre- and post-drought: Lake Laurentian

<table>
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<tr>
<th></th>
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<th>Post-Drought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt (Co)</td>
<td>$SO_4$, DOC adjusted R²=0.142</td>
<td>$SO_4$ adjusted R²=0.834</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>$SO_4$, DOC adjusted R²=0.059</td>
<td>$SO_4$ adjusted R²=0.852</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>$SO_4$, DOC adjusted R²=0.146</td>
<td>$SO_4$ adjusted R²=0.832</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>$SO_4$, DOC adjusted R²=0.141</td>
<td>$SO_4$ adjusted R²=0.896</td>
</tr>
<tr>
<td>Aluminum (Al)</td>
<td>$SO_4$, DOC adjusted R²=0.126</td>
<td>$SO_4$ adjusted R²=0.808</td>
</tr>
</tbody>
</table>
DOM Structure

Coloured DOM (CDOM)

Wetland
Stream
Lake

Daisy
Laurentian
Humification Index of DOM

DOM Structure

Daisy

Laurentian

BR
C1
C2
D4
D5
LU

Wetland
Stream
Lake
Summary and Conclusion

• We will likely see a higher frequency and intensity of droughts, and this will effect the cycles of metals, nutrients, and DOC and have interactive effects with human disturbance in the area.

• Important application to ongoing efforts to restore mining-impacted freshwater systems (high spatial and temporal variability in chemistry ‘missed’ by Ontario Ministry of the Environment methods).
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The Watmough lab
The Gunn Lab