Drought Induced Degeneration of *Dicranum* moss and Implications for Carbon Budgets in the Hudson Bay Lowland

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- Earth presently has the lowest concentrations of atmospheric CO$_2$ on a geologic timescale but it is increasing rapidly.
- The global carbon budget doesn’t balance. Present day atmospheric CO$_2$ increases:
  - 0.7% per year when modeled; 0.4% per year when measured.
- Polar regions will undergo the most severe and rapid environmental changes, primarily because of the positive ice-albedo feedback mechanism.
  - Weakened capacity to act as an energy sink for remainder of planet Earth.
  - Weakened oceanic thermohaline circulation system for redistributing global energy.
  - Ice sheet instability and sea level rise.
  - Newly exposed carbon reservoirs due to melting permafrost.
The carbon presently stored in peatlands represents one-third of the global soil reservoir and will increase global atmospheric CO$_2$ by two-thirds if released, independent of fossil fuel emissions.

Peatland carbon is converted to atmospheric carbon when decomposition exceeds photosynthetic uptake.

Both photosynthesis and decomposition are sensitive to temperature, moisture and nutrients so climate change has the potential to upset the carbon budget in the near term.
CO₂ exchange from the terrestrial environment changes inter-annually.

<table>
<thead>
<tr>
<th>CO₂ Flux (gC m⁻² y⁻¹)</th>
<th>Fen</th>
<th>Forest</th>
<th>Tree-line</th>
<th>T (°C)</th>
<th>Soil Moisture Deficit (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>-53.5</td>
<td></td>
<td></td>
<td>10.7</td>
<td>-116</td>
</tr>
<tr>
<td>1996</td>
<td>31.4</td>
<td></td>
<td></td>
<td>10.8</td>
<td>-64</td>
</tr>
<tr>
<td>1997</td>
<td>-19.4</td>
<td>2.7</td>
<td>-8.34</td>
<td>10.8</td>
<td>-36</td>
</tr>
<tr>
<td>1998</td>
<td>30</td>
<td>73.1</td>
<td>51.6</td>
<td>11.0</td>
<td>-31</td>
</tr>
<tr>
<td>1999</td>
<td>-24.5</td>
<td>81.8</td>
<td>28.7</td>
<td>10.4</td>
<td>-42</td>
</tr>
<tr>
<td>Mean</td>
<td>-7.2 (-4.6)</td>
<td>52.5</td>
<td>24.0</td>
<td>10.7</td>
<td>-58</td>
</tr>
</tbody>
</table>

ΔC=57.1

Range=59.9

Plant communities may adjust to climate and soil changes, so the long-term carbon budget will depend on the character of the new plant community.

Major Peatland Types in the Hudson Bay Lowland in Northern Manitoba

- Vary with distance from coast and peatland age due to isostatic uplift of 8-10 mm y\(^{-1}\).
- Polygonized peat plateau (zone B) 12,000 km\(^2\) is inaccessible and poorly understood.
- Peat deposits up to 4 m thick represent the largest potential greenhouse gas sources.
Ice rich peat has already melted in some ice-wedge polygons to form collapse scar (thermokarst) ponds. 4000 yr old peat profile is *Sphagnum* dominated and interlaced with charcoal needle layers indicating past forest environments. Lake banks are collapsing into lakes as permafrost melts.
Dominated by lichens, heaths and mosses which all have adaptations to the dry polar environment.

ArcticNet study site (peat plateau) in coastal Hudson Bay.
Dicranum elongatum covers 26% of the plateau and is 25% dead. Degenerating zones are partially covered with the micro-lichen, Ochrolechia.

What triggered the mortality and when? Why did some individuals completely die while others survived? What were the impacts on carbon exchange?
Field Season 2003- one seventeen day drought but slightly wetter than normal.

- 12- 5x5 m sites selected bracketing the habitat, elevation and slope range for the plateau.
- 100 grid cells measure:
  - Relative elevation
  - Length, width and height of each moss cushion (n=2893)
  - % cover as living, dead, other
  - Depth of dimples
- Continuous meteorological data and moss moisture and temperature.
Spatial patterns of mortality

Mortality increases as cushions decrease in size both on an individual site and plateau wide basis.

Sites with highest variation in topography and steepest slopes have the highest mortality.
Spatial patterns of mortality

- Distinct asymmetry with dead zones predominantly on south facing aspects of cushions.
Spatial patterns of growth

- Tallest cushions grow at lowest elevations in proximity to water table

![Graph showing relationship between elevation and mean cushion height](image)

\[ y = -0.1705x + 0.0856 \]

\[ R^2 = 0.7975 \]
Interpretation

- Mortality is related to severe moisture stress
  - Large scale patterns related to elevation
  - Small scale patterns related to aspect
- Growth is related to moisture stress
  - Taller cushions found in wetter zones
  - Moisture is limiting to moss growth on the plateau
  - Small mounds spend greater time under sub-optimal moisture conditions
Small Cushions are subject to extremes in moisture content because of small volume:surface area ratio and due to their large distance from water table.

![Seasonal Variation in Moisture Storage of Three D. elongatum Specimens](image_url)

**Gravimetric Moisture Content (gH₂O/g)**

- **26.5 g**
- **172 g**
- **380.5 g**
- **Threshold**

**Date**

- 21
- 24
- 28
- 1-Jul
- 5
- 8
- 12
- 15
- 19
- 22
- 26
- 29
- 2-Aug
- 5
- 9
How old are the *D. elongatum* cushions on the plateau? How long ago did mortality set in?

- *D. elongatum* grows slowly from 0-5 mm/y.
- No distinguishing morphological features for dating.
- Deepest dimples occur on fastest growing mounds
- Assume growth rates pre- and post-drought are comparable.
- Mounds established in 1949 (53 y B.P.) and degeneration triggered in 1994 (9 y B.P.).
D. elongatum green photosynthesizing tissue turns brown after three years. Varying canopy depths were used to estimate growth rates and age in three different micro-habitats. (shade=tall, open-moist=medium, open-dry=small)

- Moss growing in three very different habitats all established 52-53 years ago in agreement with dimple analysis.
- Shade (rare) is not limiting for growth.
- Ample moisture closer to water table produces consistent low-density annual growth.
- Exposed sites (majority) experience highly variable high-density annual growth.
Drought severity is dependent on duration. Laboratory experiments indicate drought duration is critical to moss mortality and metabolism recovery.
How do the long term apparent rates of carbon accumulation compare to present day fluxes?

2004 growing season: normal precipitation

- Insert 10 cm diameter collars approx. 25 cm deep into three healthy living D. elongatum cushions.
- Insert three collars into dead D. elongatum with Ochrolechia growing on surface.
- Sample CO₂ exchange from mid-June to October.
- Ancillary measurements of temperature and moisture in the air and soil as well as photosynthetically active radiation (PAR) are collected.
Dark chamber CO₂ concentrations increase over time in response to autotrophic and heterotrophic respiration.

Clear chamber CO₂ concentrations decrease over time during the day as photosynthesis exceeds respiration.
Photosynthetic response of *D. elongatum* to sunlight and temperature behaves in predictable manner.

Negative values indicate decrease in atmospheric CO₂ and uptake by moss.
Respiration is three times more sensitive to a temperature increase when the moss is wet compared to dry.

Increasing temperatures lead to increasing respiratory losses. Large time lags suggest deep decomposition driving CO₂ release. When considering respiration alone, warm and moist future climates are most conductive to peat degeneration.
Living Moss NEE: Over the growing season, net ecosystem exchange of living moss removes CO$_2$ from the atmosphere during the day. This is offset by CO$_2$ release to the atmosphere at night. The net effect is an overall uptake of CO$_2$ from the atmosphere of 164 mg C m$^{-2}$ d$^{-1}$.

Positive daytime fluxes represent plant uptake.
**Ochrolechia spp. growing on dead moss NEE**: Over the growing season, net ecosystem exchange of dead moss continually releases CO$_2$ to the atmosphere. The flux is stronger at night than during the day indicating *Ochrolechia* photosynthesis is present, but weak. The net effect is an overall release of CO$_2$ to the atmosphere of 642 mg C m$^{-2}$ d$^{-1}$...a difference of 806 mg C m$^{-2}$ d$^{-1}$ compared to living moss.
Net growing season impacts of moss mortality on peat plateau carbon balance.

<table>
<thead>
<tr>
<th></th>
<th>Dead Moss</th>
<th>Living Moss</th>
<th>Plateau pre-1994</th>
<th>Plateau post-1994</th>
</tr>
</thead>
<tbody>
<tr>
<td>flux</td>
<td>-77.1 g C m⁻² y⁻¹</td>
<td>19.7 g C m⁻² y⁻¹</td>
<td>4.92 g C m⁻² y⁻¹</td>
<td>-1.13 g C m⁻² y⁻¹</td>
</tr>
<tr>
<td>survey</td>
<td></td>
<td>76.78 g C m⁻² y⁻¹</td>
<td>19.23 g C m⁻² y⁻¹</td>
<td></td>
</tr>
</tbody>
</table>

120 day growing season. Peat plateau losses are negative!
Discussion

- The drought of 1994 reduced the coverage of peat accumulating *D. elongatum*. This shifted the moss contribution to the carbon budget of the plateau to net losses to the atmosphere compared to gains by the plateau that existed prior to 1994. This year also represented the largest losses of carbon from the fen.

- Mortality of the remaining living moss requires a drought of a magnitude not yet recorded. Severe droughts should be treated as disturbances, rather than stresses.

- Decomposition of the underlying peat exceeds the capacity of the moss community to uptake CO$_2$.

What proportion of the decomposition is finding its way to Hudson Bay?

- Healthy moss takes up carbon at a rate comparable to the maximum rate for fens and 40% of the average for forests.

- Decomposition is sensitive to peat temperature and moisture content indicating warmer and wetter future climates could enhance carbon losses.
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Questions?