Complex Patterns in Climate and Atmospheric Nitrogen Deposition Influence Rocky Mountain Ecosystems

Loch Vale Watershed
Rocky Mountain National Park

Western Mountain Initiative

Loch Vale is 660 ha
- 80% rock/talus
- 1% permanent ice
- 11% alpine
- 6% old growth forest
- 1% wetlands
- 1% lakes
Excess N in Surface Water

- Nitrogen in LVWS surface waters elevated since ~1950

- $[\text{NO}_3]$ and N flux increase post-2001
- Stream NO$_3$ concentrations increase after 2001
- NO$_3$ elevated nearly year-round
- N flux increasing over time, strong losses 2003-2005
- N flux elevated late May-August
Precipitation: Wet and Dry Cycles

Loch Outlet WY Precipitation (cm)

Precipitation

cm/yr
Temperature is also Changing

<table>
<thead>
<tr>
<th>Mean Temp. °C</th>
<th>1985</th>
<th>2006</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual</td>
<td>1.25</td>
<td>1.60</td>
<td>+0.3</td>
</tr>
<tr>
<td>Summer (JJA)</td>
<td>10.75</td>
<td>11.95</td>
<td>+1.0</td>
</tr>
<tr>
<td>Winter (DJF)</td>
<td>-7.00</td>
<td>-7.45</td>
<td>-0.5</td>
</tr>
</tbody>
</table>
Proxies in Sky Pond sediments record post-1950 ecological and biogeochemical change

Enders et al., in review
Poster B31A-0062
Wednesday AM (now!)
Proxies in Sky Pond sediments record post-1950 ecological and biogeochemical change.

$^{15}$N trend in algal chlorins supports change in N deposition/N cycling beginning ~1950.
Proxies in Sky Pond sediments record post-1950 ecological and biogeochemical change.

<table>
<thead>
<tr>
<th>Algal $\delta^{15}$N (%)</th>
<th>$\delta D_{nC_{16,2}}$ (%)</th>
<th>$\delta^{13}$C$<em>{nC</em>{21}}$ (%)</th>
<th>A. formosa (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$\delta D$ and $\delta^{13}$C$_{nC_{21}}$ trends infer changes in hydrology of glaciers/permafrost and the biology/abundance of lichens or cyanobacteria.

---

USGS

Knowledge to Go Places
Weekly NPP, kg C/ha
DayCent-Chem model output

Loch Vale Alpine

Loch Vale Forest

USGS

Colorado State University Knowledge to Go Places
Weekly Mineralization, kg N/ha
DayCent-Chem model output

Loch Vale Alpine

Loch Vale Forest

[Graph showing weekly mineralization for Loch Vale Alpine and Loch Vale Forest over water years from 1985 to 2005, with color-coded mineralization levels from 0 to 5.]
## What's Changing/What's Not

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream [NO$_3$]</td>
<td>↑</td>
</tr>
<tr>
<td>Stream N Flux</td>
<td>↑</td>
</tr>
<tr>
<td>Temperature (mean, summer)</td>
<td>↑</td>
</tr>
<tr>
<td>Flow:Precipitation</td>
<td>↑</td>
</tr>
<tr>
<td>Lichen, Cyanobacteria Activity</td>
<td>↑</td>
</tr>
<tr>
<td>Alpine/Forest Mineralization</td>
<td>↑</td>
</tr>
<tr>
<td>N Deposition</td>
<td>↔</td>
</tr>
<tr>
<td>Alpine/Forest NPP</td>
<td>↔</td>
</tr>
</tbody>
</table>

[Image of USGS logo]
Loch Vale Hypothesis

Climate and Deposition Drivers

Terrestrial Controls

Aquatic controls and responses

Temperature

Nitrogen Deposition

Cryosphere

Alpine NPP Mineralization

Forest NPP Mineralization

Discharge

Loch Vale NO₃

NO₃ load to Loch Outlet
Conclusions

While elevated atmospheric deposition has affected high elevation ecosystems in Rocky Mountain National Park for many years, we now see additional influence of climate, especially warming, on both stream hydrology and stream nitrogen flux.

Our hypothesis is that warming has enhanced melting in the cryosphere, and stimulated microbial, and possibly lichen, activity in the alpine, talus, and permafrost.
Loch Vale Weekly Temperature, °C, 1985-2006

Average Temperature

Water years

Oct  | Dec  | Feb  | May  | Jul  | Sep

1985 |      |      |      |      |      |
1990 |      |      |      |      |      |
1995 |      |      |      |      |      |
2000 |      |      |      |      |      |
2005 |      |      |      |      |      |

Legend:
-15  -10  -5  0  5  10  15

USGS

Colorado State University
Knowledge to Go Places