Climate and species controls on forest carbon dynamics in the Rocky Mountains

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Climate affects ecosystems

- Climate variables affect ecosystem process rates like plant growth and microbial activity.

- Climate also constrains the distribution of plant community types on the landscape.

- Climate warming in the coming years, decades and centuries will therefore affect both ecosystem processes and ecosystem species composition and structure in any given spot.

- Changes in ecosystem process rates and in species composition will likely combine to alter the ecosystem carbon cycle, resulting in feedbacks to climate.
Plant above and belowground biomass and growth

Net Primary Production → plant carbon
Litterfall
Root Death

atmosphere

soil

saturated zone
Duff, dead wood and litter decomposition

- Litterfall
- Decomposition
- Atmosphere
- (labile)
- Soil
- (recalcitrant)
- Saturated zone

Litter carbon
Soil pools and respiration

Soil carbon

- Soil Respiration
- Root Death

atmosphere

Decomposition

soil

soil saturated zone
**Ecosystem carbon cycle**

- **Net Primary Production**
  - to **plant carbon**
  - to **litter carbon**

- **Litterfall**
  - from **plant carbon**
  - from **litter carbon**

- **Root Death**
  - from **plant carbon**
  - to **soil carbon**

- **Soil Respiration**
  - from **soil carbon**

- **Decomposition**
  - from **litter carbon**

- **Soil Carbon**
  - to **litter carbon**
  - to **soil carbon**

- **Leaching**
  - from **soil carbon**

- **atmosphere**
  - to **litter carbon**
  - to **plant carbon**

- **saturated zone**
  - from **soil carbon**

- **labile**
  - from **litter carbon**

Does climate affect carbon cycling in Rocky Mountain forests and how?

via direct climate effects?
-- or via species effects?
-- or both?
Gradient design

Spruce-fir
(Picea engelmannii-
Abies lasiocarpa)

Mixed pine/
spruce- fir

Pine
(Pinus contorta)

30 x 30 m plot

Δ 4°C
MAT 0.2°C
MAP 425 mm

warmer 3040m
cooler 3550m

P is for pine, S is for spruce
... with elevation
Tree species composition of the forest also changes with elevation.
Ecosystem carbon cycle

- **Net Primary Production**
- **Litterfall**
- **Root Death**
- **Soil Respiration**
- **Decomposition**

- **Soil Carbon**
- **Plant Carbon**
- **Litter Carbon**

- **Atmosphere**
- **Soil**
- **Saturated Zone**
Tree biomass measurement

- Girth and height of all trees taller than 1.4 m
- Allometric equations used to convert height and girth to biomass for each species
- We measured 1378 trees!
Tree biomass does not change systematically with elevation...
... or with climate or species composition variables.
Dead wood and duff biomass measurement

- Volume and decay class (0, I, II, III, IV, V) of wood >10 cm diameter
- 3 density cross sections from 2-4 logs per decay class in 3 plots
- Volume * Density = Biomass
- Standing dead snags measured as for live trees
- Duff (recognizable plant litter) sampled from 15 x 15 cm areas on soil surface
Duff (forest floor) biomass increases slightly with elevation...
... but not with climate or species composition variables.
Litter decay rates do not differ among species, and change only slightly with elevation.
Decay rates are most affected by the **length** and **warmth** of the growing season…

Warmer summers depress spruce and fir decay.
Dead wood biomass increases with elevation, ignoring campfire influence...
Elevation effect seems to be a *temperature* effect, though moisture can’t be ruled out…
Radiocarbon used to measure dead wood decomposition rates

- Outer rings sampled from 2 logs per decay class in 3 plots (N=42)
- Acid-base-bleach treatment used to reduce a ring’s shavings to ~cellulose
- Cellulose converted to graphite and analyzed for $^{14}$C at CAMS
- $^{14}$C values corrected for isotopic fractionation by tree
- Pairs of rings from each log dated using OxCal
- Monte Carlo sampling of possible dates to generate ensembles of decay curves
**CWD decay rates for pine and spruce wood along the elevation gradient**

<table>
<thead>
<tr>
<th>Species</th>
<th>Elevation</th>
<th>N</th>
<th>Intercept</th>
<th>$-k$ (year$^{-1}$)</th>
<th>$\tau$ (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Both</td>
<td>All</td>
<td>42</td>
<td>0.33</td>
<td>0.0017</td>
<td>580</td>
</tr>
<tr>
<td>Pine</td>
<td>Low</td>
<td>11</td>
<td>0.42</td>
<td>0.0029</td>
<td>340</td>
</tr>
<tr>
<td>Pine</td>
<td>Mid</td>
<td>10</td>
<td>0.34</td>
<td>0.0016</td>
<td>630</td>
</tr>
<tr>
<td>Spruce</td>
<td>Mid</td>
<td>10</td>
<td>0.27</td>
<td>0.0013</td>
<td>800</td>
</tr>
<tr>
<td>Spruce</td>
<td>High</td>
<td>11</td>
<td>0.33</td>
<td>0.0015</td>
<td>650</td>
</tr>
</tbody>
</table>
Dead wood decay is faster at low elevations - but very slow everywhere.
Litter biomass and decomposition conclusions so far...

- Duff biomass is not affected by climate variables, but dead wood biomass decreases as annual average air temperature warms.

- Needle litter takes 6-9 years to decompose, with spruce and fir needles decaying faster in winter and where summer is shorter and cooler.

- Dead wood decomposes VERY slowly in these forests, taking 340-900 years to disappear.

- Pine logs decompose slightly faster at lower elevations where the conditions are warmer.
Soil carbon measured to 60 cm, though data shown are just top 15 cm

- Soil pits dug to 60 cm
- Total carbon and bulk density measured for every horizon and 10 cm increment
- The Rocky Mountains are well named...
Soil carbon (top 15 cm) increases with elevation.
Elevation effect may be partly a temperature or species effect, but is largely a soil moisture effect!
Soil respiration field sampling methods

- Permanent 214 cm² chambers 5/plot (N=55)
- Sampled biweekly during snow-free season (once over winter)
- 24-hour exposure of chamber soil to soda-lime traps (~6-7 month exposure for winter)
- Flux is blank and water corrected difference in soda-lime mass per exposed area per day
Seasonal trend in daily soil CO$_2$ flux rate

**CO$_2$ Flux (g C m$^{-2}$ d$^{-1}$)**

- Middle pine
- Middle mixed
- Upper spruce

**Date**
- 4/00
- 6/00
- 8/00
- 10/00
- 12/00
- 2/01
- 4/01
- 6/01
Annual soil CO\textsubscript{2} flux per unit soil carbon

![Graph showing CO\textsubscript{2} flux vs. elevation, with data points and error bars.](image)
Elevation effect is consistent with a temperature effect,

Moisture effect (if real) is inhibitive…
Total winter and annual soil CO$_2$ efflux

CO$_2$ Flux (g C m$^{-2}$)

Winter Total
Annual Total

Increasing Elevation
Soil carbon and soil CO$_2$ flux conclusions so far

• Stored soil carbon increases with increasing soil moisture. Wetter sites tend to also be colder…

• Warmer temperatures result in higher rates of CO$_2$ production per unit soil carbon.

• Because stored soil carbon is higher in wet cold sites where rates of CO$_2$ production per unit carbon are lower, the total amount of soil respiration per year does not vary with climate.
Feedbacks to climate change

In the Rocky Mountains, if the climate *warms*...

- Spruce and fir needle litter may decompose more slowly (- feedback)
- Dead wood may decompose a bit faster (+ feedback)
- Dead wood carbon stores may decrease (+ feedback)
- Soil respiration rates per unit soil carbon may increase (+ feedback)

If the climate becomes *wetter*...

- Soil carbon stores may increase (- feedback)
Soil respiration releases $10^2$-$10^3 \times$ more C to the atmosphere than CWD decay.
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