Cross-scale controls on boreal wildfire carbon emissions

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Boreal Forest Wildfires

- older than the stand age at the time of fire
Models based on top-down controls of climate and fire weather

↑ carbon emissions
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• Models based on top-down controls of climate and fire weather

• Spatially heterogeneity in bottom-up controls of fuel availability related to topography and stand structure and composition
carbon emissions

- Models based on top-down controls of climate and fire weather
- Spatially variability in bottom-up controls of fuel availability related to topography and stand structure and composition
  - Scale C emissions to the entire area burned

$\Delta$ long-term net ecosystem carbon balance
Could the intensification of wildfire disturbance shift boreal ecosystems across a C cycle threshold?

- Drivers of C emissions
- Scale C emissions
- Legacy C combustion
Drivers of C emissions

- 417 burned plots in 6 ecoregions
Day of Burn

Fine Fuel Moisture Code (FFMC)
Duff Moisture Code (DMC)
Drought Code (DC)
Initial Spread Index (ISI)
Buildup Index (BUI)
Fire Weather Index (FWI)
Daily Severity Rating
5 – 10 trees of the dominant species

Proportion of Black Spruce

Moisture

- **XERIC**: Little surface moisture stabilized sand dunes and dry ridgetops
- **SUBXERIC**: Some noticeable surface moisture; well drained slopes or ridgetops
- **SUBXERIC-MESIC**: Very noticeable surface moisture; flat to gently sloping
- **MESIC**: Moderate surface moisture; flat or shallow depressions including toe-slopes
- **MESIC-SUB-HYGRIC**: Considerable surface moisture; depressions or concave toe-slopes
- **SUB-HYGRIC**: Very considerable surface moisture; saturated with less than 5% standing water

Modified from Johnstone et al. 2008
Each tree assigned score for combustion (0-3)
Allometric equations for biomass
Carbon component = 50% of biomass

Adventitious roots = burn depth
5 soil samples/site for C content and bulk density
Modelled carbon content ~ depth
Pre-fire C pools and C combusted
Drivers of C combustion

Alaska (n=89)

- Day of Burn
- Moisture
- Stand Age
- FFMC
- DC
- Above C
- Black Spruce
- Below C
- Total C loss

M-R² = 0.36
C-R² = 0.44
Drivers of C combustion

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- Day of Burn
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FFMC
DC
Above C
Below C

Total C loss

M-R² = 0.36
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Taiga Plain (n=141)

- Day of Burn
- Moisture
- Stand Age
- Black Spruce

FFMC
DC
Above C
Below C

Total C loss

M-R² = 0.51
C-R² = 0.87

Taiga Shield (n=140)

- Day of Burn
- Moisture
- Stand Age
- Black Spruce

FFMC
DC
Above C
Below C

Total C loss

M-R² = 0.52
C-R² = 0.58
Drivers of C combustion

Alaska (n=89)

- FFMC
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- Black Spruce
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- M-\(R^2 = 0.36\)
- C-\(R^2 = 0.44\)

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- Above C
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- M-\(R^2 = 0.51\)
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- Day of Burn

- M-\(R^2 = 0.52\)
- C-\(R^2 = 0.58\)

Saskatchewan (n=43)

- FFMC
- DC
- Above C
- Black Spruce
- Total C loss
- Moisture
- Stand Age
- Day of Burn

- M-\(R^2 = 0.77\)
- C-\(R^2 = 0.79\)

Bottom-up >>> Top-down
211 burned plots in 7 burn scars and 36 unburned plots in 3 regions

Total carbon combustion = $3.4 \pm 2.0$ Kg C m$^{-2}$
Scale C emissions

Full Model: topographic wetness index, terrain ruggedness, dNBR, relative change in tree cover, % black spruce, and % sand in the top 15 cm of soil

<table>
<thead>
<tr>
<th>Study</th>
<th>Area Burned(Mha)</th>
<th>Total C emissions (Tg C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walker et al. 2018 (this study)</td>
<td>2.85</td>
<td>94.3</td>
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<tr>
<td>Veraverbeke et al. 2017</td>
<td>3.41</td>
<td>164</td>
</tr>
</tbody>
</table>

Differences due to:
1) Spatial resolution (30m vs 500m) and ability to capture small water bodies and unburned areas
2) Regionally specific field training data vs. training data from Alaskan black spruce sites
94.3 Tg C

= 50% annual C uptake in terrestrial ecosystems of Canada
Legacy carbon combustion

Legacy Carbon

Legacy Carbon in young-burned

Combusted

Combusted in young-burned

Topo-edaphic Gradient

Dry

Wet

% Soil Organic Layer
Black spruce dominated sites
• 28 old-burned & 9 young-burned plots
Sectioned the SOL profile
• 0-1cm
• 1-2 cm
• 1cm above mineral soil
Removed roots and filtered soil
\( \Delta^{14}C \) values
Legacy C is present if stand age is younger than soil base.

Legacy C is combusted if stand age is younger than soil surface.
Legacy Carbon Presence

organic soil > 30cm

stand age < 60 years
Legacy Carbon Combustion

- Proportion soil combusted > 50%
- Stand age < 60 years
Legacy C Combustion

45% of young-burned plots = net C source
= 0.34 Mha of forests emitted 8.6 Tg C
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= 0.34 Mha of forests emitted 8.6 Tg C

C emissions were NOT different between sites with legacy C combustion vs. NO legacy C combustion
Summary & Conclusions

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• Predicting future emissions: assess how environmental change will impact these bottom-up controls
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- C emissions controlled by bottom-up drivers
- Scaling emissions: account for spatial heterogeneity in fuel availability and fire severity & use regionally calibrated models
- Predicting future emissions: assess how environmental change will impact these bottom-up controls
- Measuring C emissions alone is insufficient for assessing the long-term impacts of wildfire on boreal net ecosystem carbon balance
Thank you
Summary & Conclusions

↑ frequency of boreal forest fires
↑ proportion of younger forests vulnerable to burning
↑ expanse of forests switching into a new domain of C cycling
Drivers of C emissions

a) Hypothesized Model

Stand Age  →  Below C
Moisture  →  Above C
Day of Burn  →  DC
FFMC  →  Black Spruce

b) All sites (n=417)

Stand Age  →  Below C
Moisture  →  Black Spruce
Day of Burn  →  Above C
DC  →  FFMC

M-R² = 0.45
C-R² = 0.74
Summary & Conclusions

↑ frequency of boreal forest fires
  ↑ proportion of younger forests vulnerable to burning
  ↑ expanse of forests switching into a new domain of C cycling
    ↑ exposure of legacy C to decomposition

Legacy C loss will impact:
  future boreal net ecosystem carbon balance
  global C cycle and climate