Climate-fire-permafrost interactions

Section I

Climate Warming

H2a: Climate-Fire Interactions

Seedling Establishment & Species Interactions

Changing Fire Regimes

Vegetation Composition & Successional Trajectory

NPP, Ecosystem Structure, Biogeochemical Cycling

Section III

Climate Feedbacks

Section IV

Landscape Structure

Ecosystem Services

H2b

Permafrost-Climate Interactions

H2c

Pest-Herbivore-Climate Interactions
How will a more deciduous landscape function?
What is next?

Cross-scale interactions and landscape resilience

*Legacy locks and legacy links*

1. Do deeper burns release legacy carbon?

2. How do unburned “kipukas” affect dynamics of regeneration and future fires?

3. Where and when does seed limitation drive patterns of tree establishment and succession?

4. Where and when does mycobiont limitation drive patterns of community assembly?

5. Can herbivores shift successional trajectories?
What is next?

*Cross-scale interactions and landscape resilience*

*Legacy locks and legacy links*

1. How does permafrost play into successional trajectories?

2. When successional trajectories shift, how does permafrost C loss compare to deciduous C gain?

3. What is the fate of permafrost N and how does it contribute to extant productivity?

4. How will terrestrial-aquatic linkages change in a more deciduous landscape?

1. Will changes in composition and age structure increase fire return interval in a warming climate?
Carbon pools over the disturbance cycle

Net C accumulation \((t_{100}-t_{1})\):
- Spruce: 2877 g C m\(^{-2}\)
- Deciduous: 7110

\% legacy carbon at \(t_{100}\):
- Spruce: 64 %
- Deciduous: 28

NECB \((t_{100}-t_{0})\):
- Spruce: 375 g C m\(^{-2}\)
- Deciduous: 3,233
Results:
Spruce $\rightarrow$ Deciduous

$\uparrow$ [CO$_2$] $\rightarrow$ $\uparrow$ T $\rightarrow$ $\uparrow$ Fire $\rightarrow$ $\uparrow$ NECB$_{100}$ $\rightarrow$ $\uparrow$ Deciduous trees

$\downarrow$ Soil C $< \uparrow$ Plant C

$\downarrow$ Soil C, N $\rightarrow$ $\uparrow$ Deciduous trees
Permafrost response to depth of burning

Stable climate

Changing climate

Romanvosky et al. in progress
Deepening of the active layer could drive sustained release of nitrate.

Betts and Jones 2009, Harms and Jones 2012
What’s next?

What have we learned?
• Fire regimes are intensifying in black spruce forest and tundra
• Area burned is increasing
• Bigger burns are deeper burns
• Intensity may be unique in paleo-record

What new questions are emerging?
• Spatial heterogeneity within fires
• Linking current depth of burning to historic burning
• Landscape flammability feedbacks (demography, composition)
Nitrogen pools over the disturbance cycle

Net N accumulation (t_{100}-t_{1}):  
- Spruce: 70 g N m^{-2}  
- Deciduous: 110

% legacy N at t_{100}:  
- Spruce: 70%  
- Deciduous: 35

NENB (t_{100}-t_{0}):  
- Spruce: -0.8 g N m^{-2}  
- Deciduous: -6.8
C:N ratio over the disturbance cycle

Spruce → Spruce
Spruce → Deciduous
Summary

• NECB was an order of magnitude greater in spruce→deciduous than in spruce→spruce

• Spruce→spruce harbored twice as much legacy C and N as spruce→deciduous

• Over both trajectories, N pools were resilient, recovering to pre-fire pool sizes by 100 years

• Change in species composition catalyzed transfer of N from low C:N soil organic matter to high C:N trees, resulting in greater ecosystem N use efficiency
Stabilizing feedbacks that maintain trajectories

High severity fire

Long fire-free interval (succession)

Low severity fire

Low moss NPP

High moss NPP

Low vascular NPP

Thick organic layer

Cool, moist soils

Slow decomposition

Slow nutrient turnover

Low vascular NPP

High moss NPP

Low moss NPP

Thick organic layer

Warm, dry soils

Fast decomposition

Fast nutrient turnover

Bryospheric feedbacks!
Hypothesis: Spruce → Deciduous

\[ \uparrow \text{[CO}_2\text{]} \]

\[ \uparrow T \]

\[ \uparrow \text{Fire} \]

\[ \downarrow \text{Soil C,N} \]

\[ \downarrow \text{Soil C} \]

\[ \uparrow \text{Plant C} \]

\[ \downarrow \text{NECB}_{100} \]

\[ \uparrow \text{Deciduous trees} \]
Results:

Spruce → Deciduous

\[ \uparrow [\text{CO}_2] \]
\[ \uparrow \text{T} \]
\[ \uparrow \text{Fire} \]

↓ Soil C < \uparrow \text{Plant C}

↓ Soil C, N → \uparrow \text{Deciduous trees}

↑ NECB\textsubscript{100}
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A deciduous tipping point in boreal forest?
Carbon stocks and age in burned and unburned profiles at Willow Creek

Unburned profile

Burned profile

Stand age

C Pool (g C m⁻²)

Age (years)

Depth (cm)

Unburned

Burned
Residual SOL-C pools and successional trajectory

Trajectories in year 10:
Spruce = 30
Mixed = 17
Deciduous = 35
[0 trees = 8]

Mean depth ~ 9 cm