Impacts of Fire-free Interval on Soil Carbon Consumption, Fire Distribution, and Carbon Cycling in the Alaska Boreal Forest Region

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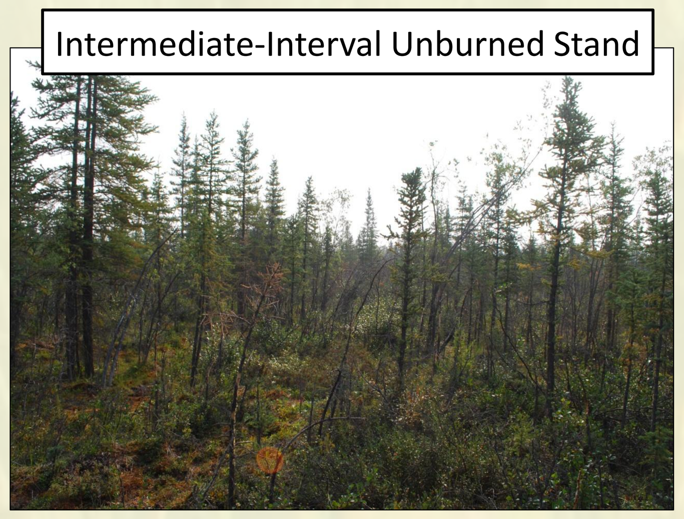
Introduction

One of the projected impacts of climate change is an increase in the frequency of burned area across the boreal forest region of North America, which in turn, will reduce the fire-free interval at regional and landscape scales. Research was conducted to determine how a shorter fire-free interval (e.g., the time since the last fire event) influenced carbon cycling in Alaskan boreal forests. Field-based research was conducted to assess how shorter fire-free intervals affected consumption of soil organic carbon in Alaskan black spruce forests. Satellite remote sensing data were integrated with fire perimeters from a large-fire database to assess how time since the last fire influenced the fraction of the landscape that burned during fire events during the 2002 to 2008 fire seasons.

Field Research Study Sites

In this study, burn patterns in intermediate fire-free interval (~40 years or less, intermediate-interval) black spruce stands were investigated using field data. Sites on various topographic positions were sampled over the course of three field seasons (2009 – 2011) and measurements of the soil organic layer were made.

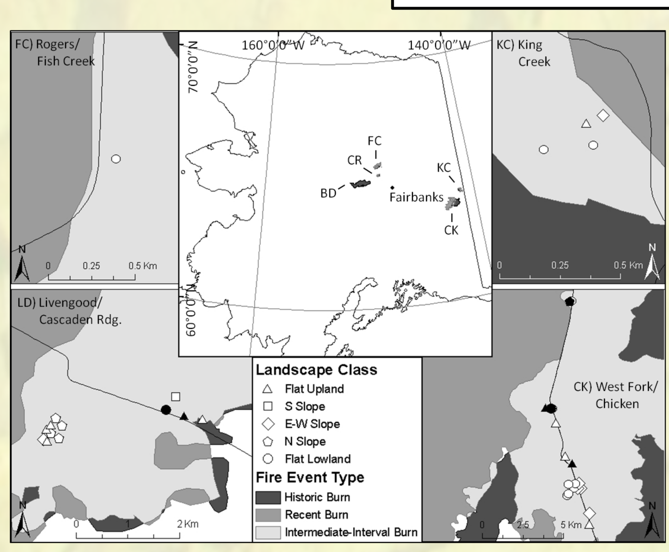
Intermediate-Interval Unburned Stand



Intermediate-Interval Burned Stand

Measurements were taken in intermediate-interval black spruce (*Picea mariana*) stands where the most recent burn occurred during the 2000s, with the prior burn occurring ~40 years ago (in the 1960s); and nearby unburned stands of a similar age which did burn ~40 years ago, but which did not burn in the 2000s. The unburned stands had a mixture of immature and mature live black spruce trees, while the burned stands were in many cases burned to the mineral soil, with no remaining live trees present (figures above).

Study Sites: Interior Alaska



Individual site locations are denoted by landscape class and burn status (opened – intermediate-interval burned plot, closed symbol – historic burn only). All sites were located along the road network (thin black line) due to accessibility issues. One historic burn only site is not pictured, that in the Big Denver (BD) fire event.

	Historic Burn		Recent Burn		Intermediate-interval Sites		
Code	Fire Event	Discovery Date	Fire Event	Discovery Date	Burned	Unburned	FFI (yrs)
FC	Rogers	6/16/1967	Fish Creek	6/16/2005	10	2	38
KC	King Creek	6/22/1969	King Creek	6/22/2004	4	--	37
LD	Livengood	6/4/1958	Cascaden Rdg.	6/3/2010	1	--	52
CK	West Fork	7/23/1966	Chicken	6/15/2004	14	4	38
BD	Big Denver	6/16/1969	--	--	--	1	--

Depth of Burn Results

A linear mixed effects model was used to compare the intermediate-interval soil organic layer depth data (stratified by landscape position) with the amount of organic material consumed in long-interval stands (>80 years old, from Turetsky et al. 2011). The comparison showed that depth of burn did not vary significantly between intermediate- and long-interval sites, as there was less material available to burn in the intermediate-interval stands. The percent depth reduction was greater in the intermediate-interval stands (78.9 ± 2.6%) than in the long-interval stands (62.9 ± 1.5%). As a result, there was less residual organic soil carbon remaining post-fire in intermediate-interval than in the long-interval stands.

Depth Measurement Results*

Season	Landscape Class (*n*)	Pre-fire	Post-fire	Depth of Burn	Depth Reduction (%)
Early	Flat Upland (4)	14.6 ± 1.4	4.3 ± 1.5	10.3 ± 0.7	73.0 ± 9.12
	S Slopes (1)	11.7	1.0	10.7	91.6
	EW Slopes (2)	14.0 ± 0.2	3.3 ± 1.7	10.7 ± 1.5	76.4 ± 12.0
	N Slopes (0)	--	--	--	--
	Flat Lowland (7)	18.6 ± 1.9	6.2 ± 1.2	12.4 ± 1.4	67.5 ± 5.30
Late	Flat Upland (4)	12.5 ± 1.1	1.5 ± 0.2	11.0 ± 1.0	87.8 ± 1.7
	S Slopes (0)	--	--	--	--
	EW Slope (4)	13.9 ± 0.8	2.4 ± 1.1	11.5 ± 0.5	83.9 ± 6.4
	N Slopes (4)	11.5 ± 0.3	1.1 ± 0.0	10.4 ± 0.3	90.2 ± 0.3
	Flat Lowland (3)	17.2 ± 1.6	3.8 ± 0.7	13.4 ± 2.2	76.8 ± 6.5
Intermediate-interval Site Mean (*29*)		14.9 ± 0.7	3.4 ± 0.5	11.4 ± 0.5	78.9 ± 2.6
Long-interval Site Mean[A] (*178*)		25.2 ± 0.5	9.6 ± 0.5	15.6 ± 0.5	62.9 ± 1.5

[A]Long-interval site data from Turetsky et al. (2011) * In cm unless noted.

Carbon losses estimated are similar between the intermediate- and long-interval sites (below) and again indicate that while less material was stored in intermediate-interval sites, a similar amount of C was consumed in the soil organic layer during burning relative to long-interval sites. However, more frequent burning of black spruce stands will result in further depletion of the large carbon reservoir that currently exists in black spruce forests.

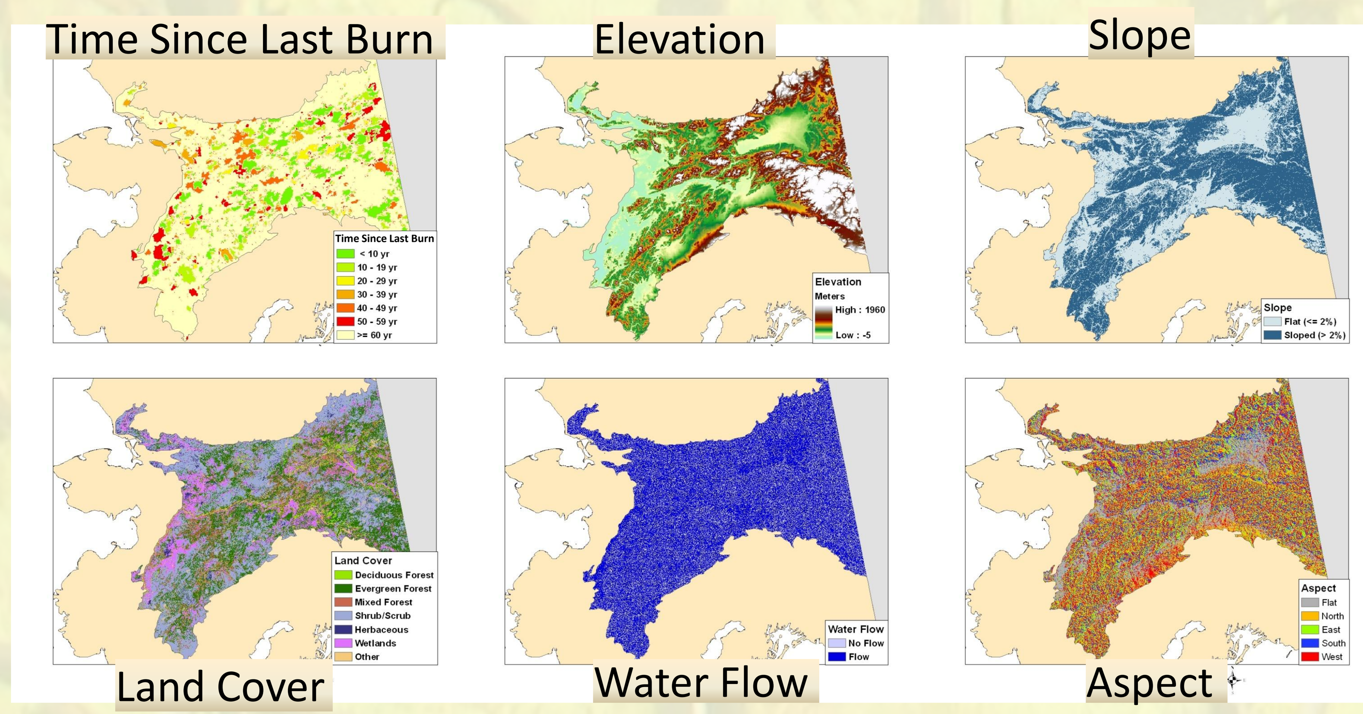
Carbon storage and losses

		Post-fire C Storage (kg C m^{-2})		C Losses (kg C m^{-2})	
Season	Landscape Class	Intermediate-interval	Long-interval[A]	Intermediate-interval	Long-interval[A]
Early	Flat Upland	0.76 ± 0.29	1.79 ± 0.11	1.94 ± 0.14	2.60 ± 0.21
	S Slopes	0.11	1.4 ± 0.35	3.03	3.90 ± 0.29
	EW Slopes	0.31 ± 0.22	1.05 ± 0.33	1.61 ± 0.33	2.15 ± 0.22
	N Slopes	--	2.62 ± 0.24	--	3.33 ± 0.27
	Flat Lowland	1.04 ± 0.25	4.01 ± 0.44	2.68 ± 0.41	3.26 ± 0.34
Late	Flat Upland	0.24 ± 0.04	0.97 ± 0.16	2.08 ± 0.22	3.50 ± 0.30
	S Slopes	--	0.62 ± 0.42	--	7.11 ± 1.12
	EW Slopes	0.20 ± 0.13	0.58 ± 0.40	1.78 ± 0.12	8.29 ± 0.84
	N Slopes	0.16 ± 0.[illegible]	2.30 ± 0.56	2.16 ± 0.07	5.56 ± 0.97
	Flat Lowland	0.50 ± 0.13	5.36 ± 1.19	2.99 ± 0.66	3.58 ± 0.65

[A]Long-interval site data from Turetsky et al. (2011b).

Fire-free Interval Geospatial Analysis

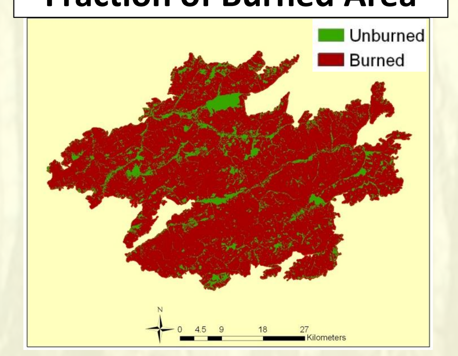
Understanding patterns of burning across the landscape is crucial to investigating variability in carbon consumption in the black spruce forests of interior Alaska. Factors controlling the vulnerability of landscapes to more frequent reburning are being explored by integrating different geospatial data sets with satellite data from fire occurring in Alaska between 2002 and 2008:



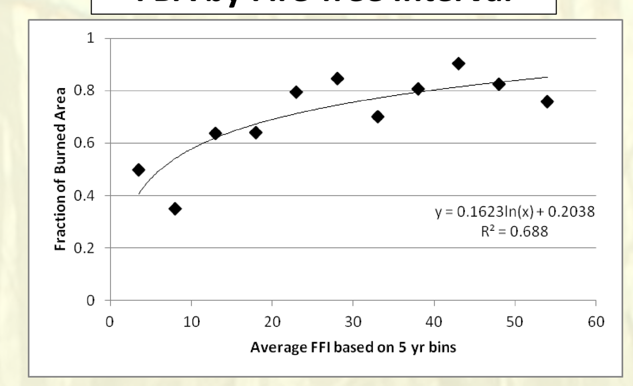
Fire-free Interval Effects on Fraction of Burned Area

The geospatial datasets were combined with a map of burned and unburned areas within 2002-2008 fire events (from the Monitoring Trends in Burn Severity mapping program). Using these burned and unburned areas within a fire perimeter (below left), an analysis was conducted of the fraction of burned area (FBA) within fire events and the fire-free interval (FFI). The analysis indicated a logarithmic relationship (below, right) between FBA and FFI such that as FFI increases (e.g., an increase in the time between fire events), a greater fraction of the area within a fire perimeter burns.

Fraction of Burned Area



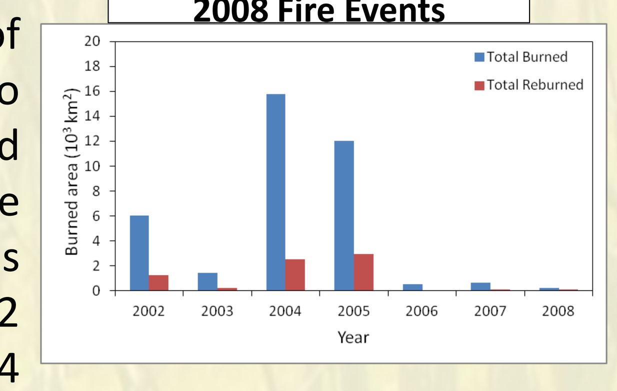
FBA by Fire-free Interval



Patterns of Fire Occurrence

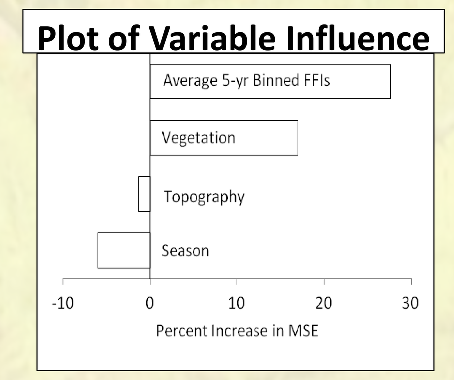
Over 45 x 10^3 km^2 of vegetated areas within interior Alaska were impacted by fire between 2002 and 2008, with an overall fraction of burned area (FBA) of 82.7%. Areas of short- to intermediate-FFI (~2-60 year FFI) represented almost 20% of the burned areas within the 2002-2008 fire events. These reburned areas were primarily from the large fire year of 2002 (18%) and the ultra-large fire years of 2004 (35%) and 2005 (41%) (at right).

Burned Area within 2002-2008 Fire Events

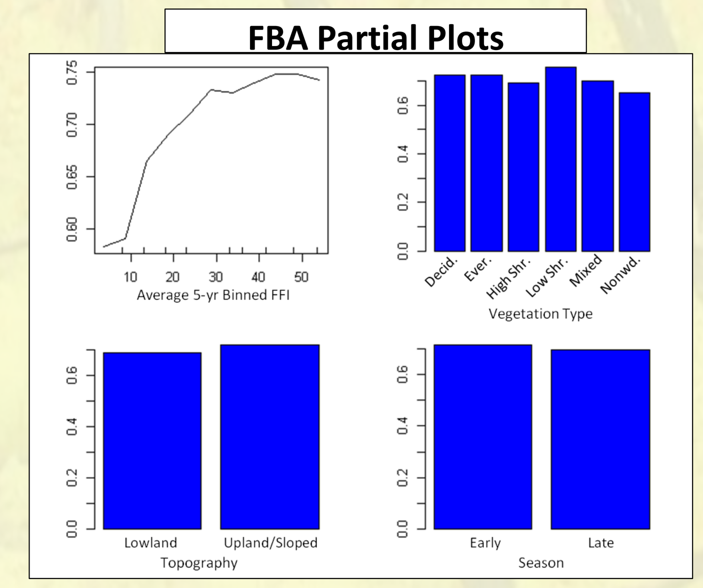


A random forest regression tree technique was used to assess the impact of FFI, vegetation type, topography and seasonal variation in burning within the 2002-2008 fire events. A variable importance plot showed FFI to be the most important variable in the analysis (below left). Partial plots (below right) indicated that vegetation type, topographic position and the season of burn did not strongly influence the FBA within the 2002-2008 fire events. The random forest model explained only 30.99% of the variance between the different factors and FBA (mean of squared residuals = 0.022).

Plot of Variable Influence



FBA Partial Plots



Additional research is now needed to better understand the patterns of fire occurrence across the landscape and better map carbon consumption and emissions related to FFI in this region.

Sources

Turetsky MR, Kane ES, Harden JW, Ottmar RD, Manies KL, Hoy E, Kasischke ES (2011) Recent acceleration of biomass burning and carbon losses in Alaskan forests and peatlands. *Nature Geoscience* **4**, 27-31.

Acknowledgements

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