EXECUTIVE SUMMARY

Identifying Indicators of State Change in Alaskan Boreal Ecosystems: Testing Previous Hypotheses and Conclusions with Long-term Data

SERDP Project RC-2754

OCTOBER 2019

Distribution Statement A
This document has been cleared for public release

SERDP
DOD ▪ EPA ▪ DOE

Page Intentionally Left Blank

This report was prepared under contract to the Department of Defense Strategic Environmental Research and Development Program (SERDP). The publication of this report does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official policy or position of the Department of Defense. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the Department of Defense.

Page Intentionally Left Blank

EXECUTIVE SUMMARY

Project: RC-2754

TABLE OF CONTENTS

Page

1.0 INTRODUCTION 1
2.0 OBJECTIVES 3
3.0 TECHNICAL APPROACH 5
4.0 RESULTS AND DISCUSSION 7
5.0 IMPLICATIONS FOR FUTURE RESEARCH AND BENEFTIS 13

LIST OF FIGURES

Page

Figure I. SEM Results for Models of Post-fire Seedling Densities (Log-transformed) of a) Black Spruce and b) Deciduous Trees. 8
Figure II. Mean Annual (October to September of the Following Calendar Year) Temperature for the Whole Soil Profile (5 to 150 cm) at Each Site and Burn Treatment. 9
Figure III. Mean Temperature Differences (Burned-unburned) for Shallow (5-35 cm) and Deep (80-150 cm) Soils. 10
Figure IV. Generalized Linear Mixed Model (GLMM) Results of Conifer Seedling Density as a Function of the Interaction Between Treatment Type, Years After Treatment, and Soil Organic Layer (SOL) Depth Excluding Green Moss in Shearbladed (a) and Thinned (b) Sites. 11
Figure V. Linear Mixed Model (LMM) Results of Thaw Depth Difference (TDD; Treated – Unmanaged) as a Function of the Interaction Between Years After Treatment, Treatment Type, and SOL Depth Excluding Green Moss. 12
Figure VI. ROS of All Subsites in 2018 (a) and the Difference in ROS Between Treated and Unmanaged Subsites as a Function of Years After Treatment (b). 12

Page Intentionally Left Blank

1.0 INTRODUCTION

The research team collected, analyzed and synthesized additional long-term data on the resilience and vulnerability of Alaskan boreal forests to ecosystem state change following wildfire or fuel reduction management. This research revisited site networks established during the completed SERDP project RC-2109, which focused on identifying factors controlling ecosystem vulnerability to state change after disturbance in black spruce (*Picea mariana*) forests, the vegetation type that dominates Department of Defense (DoD) lands in Interior Alaska. At the time of initial measurement, sites were relatively recently disturbed (<10 years after disturbance events). The research team revisited sites to determine whether previous conclusions are consistent with findings 15-20 years after disturbance.

Page Intentionally Left Blank

2.0 OBJECTIVES

At the time of initial measurement, sites were relatively recently disturbed (<10 years after disturbance events). The overarching objective was to determine whether the mechanistic links among fire, soils, permafrost, and vegetation succession predictive of state change immediately following disturbance remain robust predictors over longer timescales. The specific objectives were to: (1) determine the long-term effects of wildfire severity on successional trajectories of tree dominance and permafrost degradation; (2) determine the long-term effects of fuel management treatments on successional trajectories of tree dominance and permafrost degradation; and (3) determine the long-term effects of climate and wildfire on permafrost soil temperature regimes.

Page Intentionally Left Blank

3.0 TECHNICAL APPROACH

In 2017, the research team remeasured tree regeneration across a regional wildfire network of 90 sites that burned in the record 2004 wildfire year, which they established in 2005 and re-measured in 2006, 2008, and 2011. They used structural equation modeling (SEM) to test causal hypotheses and determine whether causal pathways differed between 2006 and 2017. Across the fuel management network established in 2012, they remeasured tree regeneration and permafrost degradation and made a new measurement of fuel rate of spread (ROS). The research team used an information-theoretic mixed modeling approach to examine change over time in these treatments. Over the two years of the project, they used soil temperature dataloggers to monitor permafrost soil temperature regimes in paired burned and unburned sites that were established in 2013. The research team used non-linear regression techniques in a mixed modeling framework to predict temperature with depth and analyze profile time series.

Page Intentionally Left Blank

4.0 RESULTS AND DISCUSSION

In the research team's previous research, results from the wildfire network showed that severity of soil organic layer disturbance was the most important indicator of state change because of its impacts on tree species composition and permafrost degradation. High severity burning of the soil organic layer exposed mineral seedbeds, which were preferentially colonized by rapidly growing deciduous tree seedlings, shifting initial successional trajectories from spruce self-replacement to deciduous tree dominance, a novel state for black spruce forests. Results from revisiting these sites showed that spruce seedling density in 2006 was the strongest predictor of spruce density in 2017 (Figure IA). Out of the fire, environment, and biotic drivers that the research team examined, only pre-fire spruce density had a small, positive effect on spruce seedling density in 2017 that was independent from its effect on seedling density in 2006, probably indicating that higher density stands sustained seed rain over a longer post-fire period than low density stands. For deciduous tree seedlings, density in 2006 similarly explained most of the variation in density in 2017. However, organic layer depth had a modest, negative direct effect on density in 2017, suggesting that deeper organic layers may have suppressed episodic recruitment of deciduous seedlings (Figure IB). These findings support the research team's previous conclusions and add nuance for understanding biotic and abiotic controls that emerge in the decade after fire.

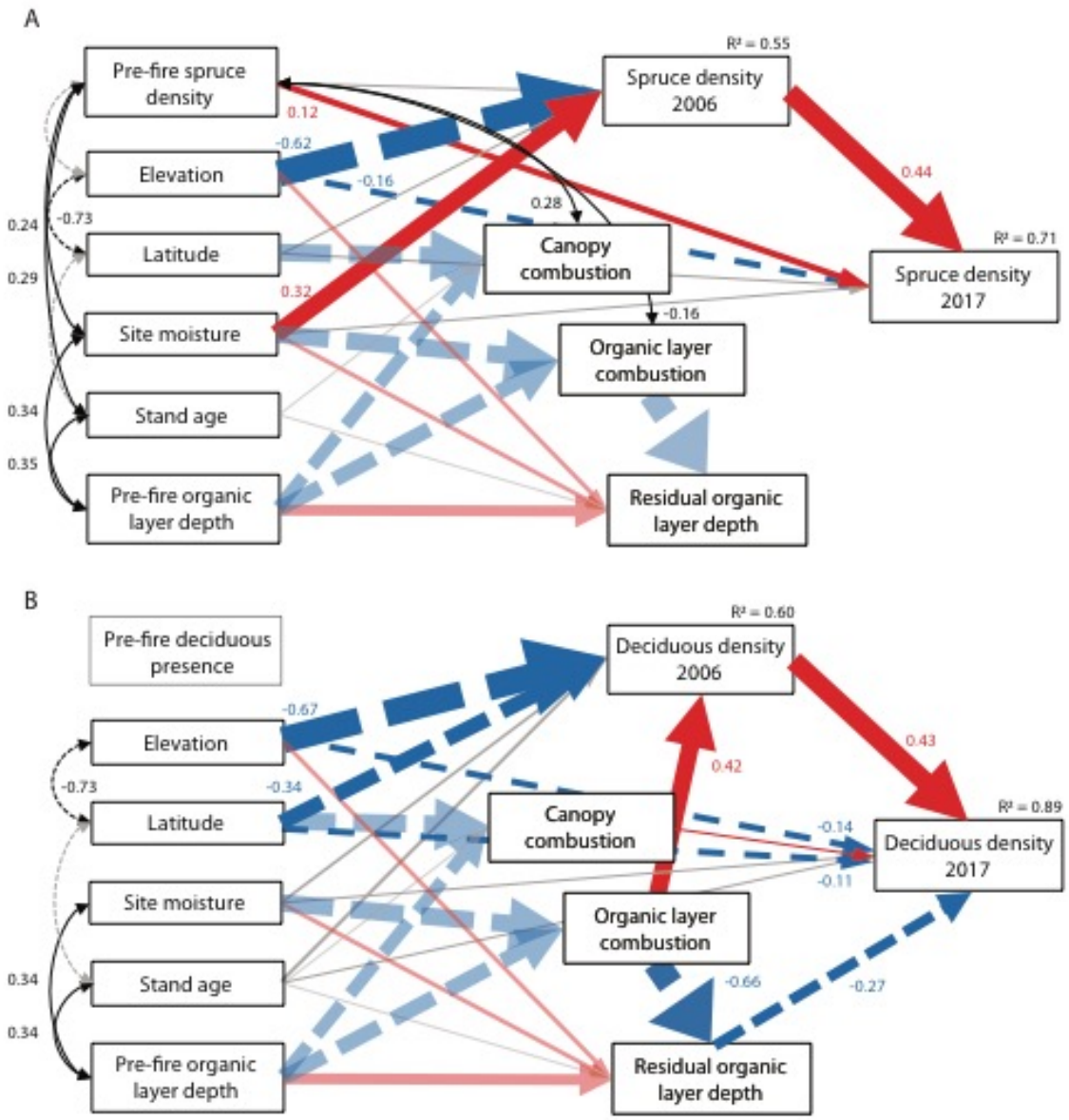

Figure I. SEM Results for Models of Post-fire Seedling Densities (Log-transformed) of a) Black Spruce and b) Deciduous Trees.

The model for black spruce was simplified based on testing of nested models. In the deciduous model, the presence of pre-fire deciduous trees had no significant effects and was removed from the final model. Paths affecting fire are shown with transparency to emphasize drivers of seedling responses. Directed causal paths are shown as straight lines with single-headed arrows; undirected correlations among variables are shown as curved, double-headed arrows. All paths in the model are illustrated. Line color and thickness indicate the magnitude and direction of effects, with standardized path coefficients shown next to significant paths (red = positive effects, blue + dashed = negative effects, grey = not significant [P>0.05]). Tests of SEM fit indicate no significant differences between the illustrated model structure and actual data (p>0.05).

The past research showed that burning reduced ground insulation, leading to deepening of the active layer, permafrost degradation, and in some cases, surface subsidence and changes in site drainage. Across the soil temperature network, the research team found that most of the increase in soil temperature and degradation of permafrost occurred immediately following fire, with site attributes affecting overall warming to a greater degree than time after fire (Figure II). All unburned sites showed a trend toward increasing soil temperature over time, showing that fire-induced changes in soil temperature are proceeding against a background of regional warming (Figure II).

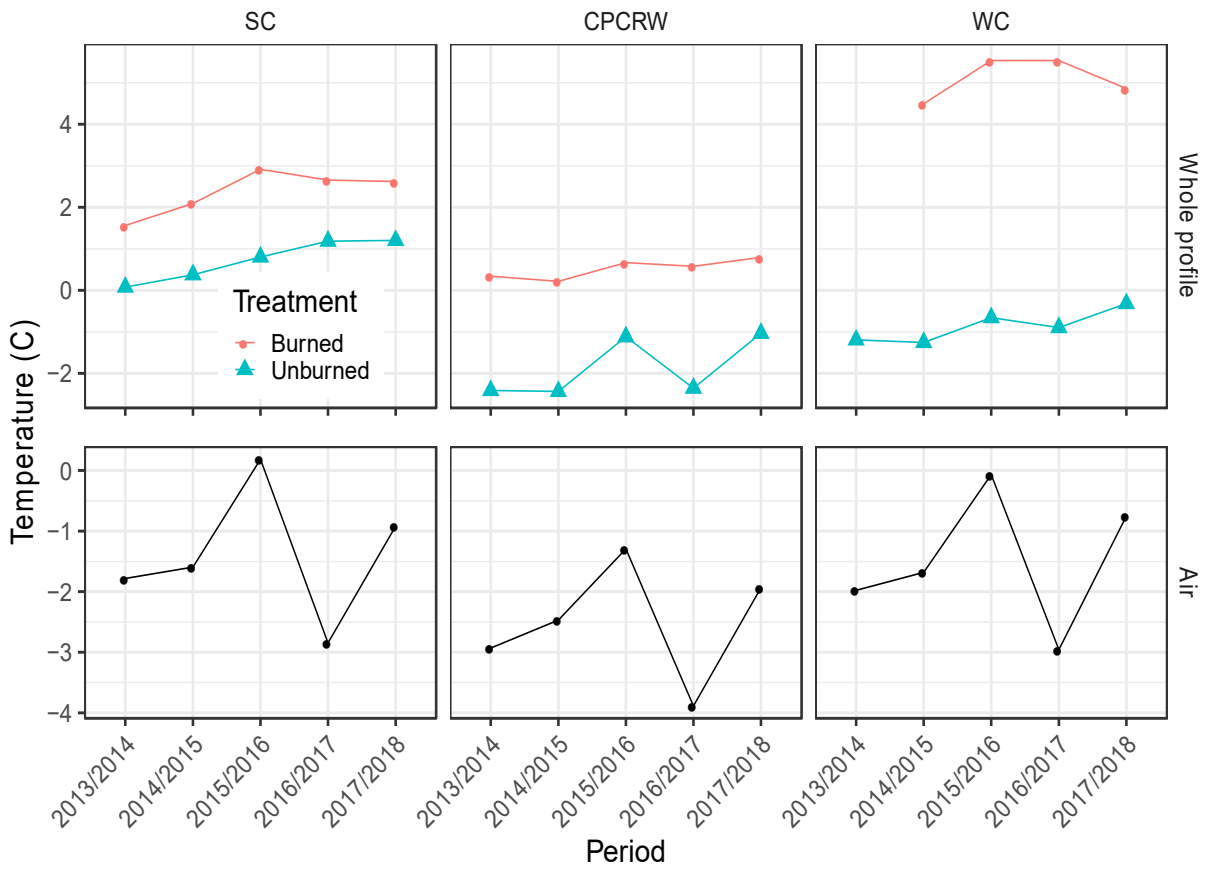

Figure II. Mean Annual (October to September of the Following Calendar Year) Temperature for the Whole Soil Profile (5 to 150 cm) at Each Site and Burn Treatment.

Means were weighted by temperature probe depth to account for disparity in profile depth increments. Air temperatures for Caribou-Poker Creek Research Watershed and Willow Creek are from meteorological stations at the sites; Stuart Creek air temperatures are from Eielson Airforce Base airport, Alaska.

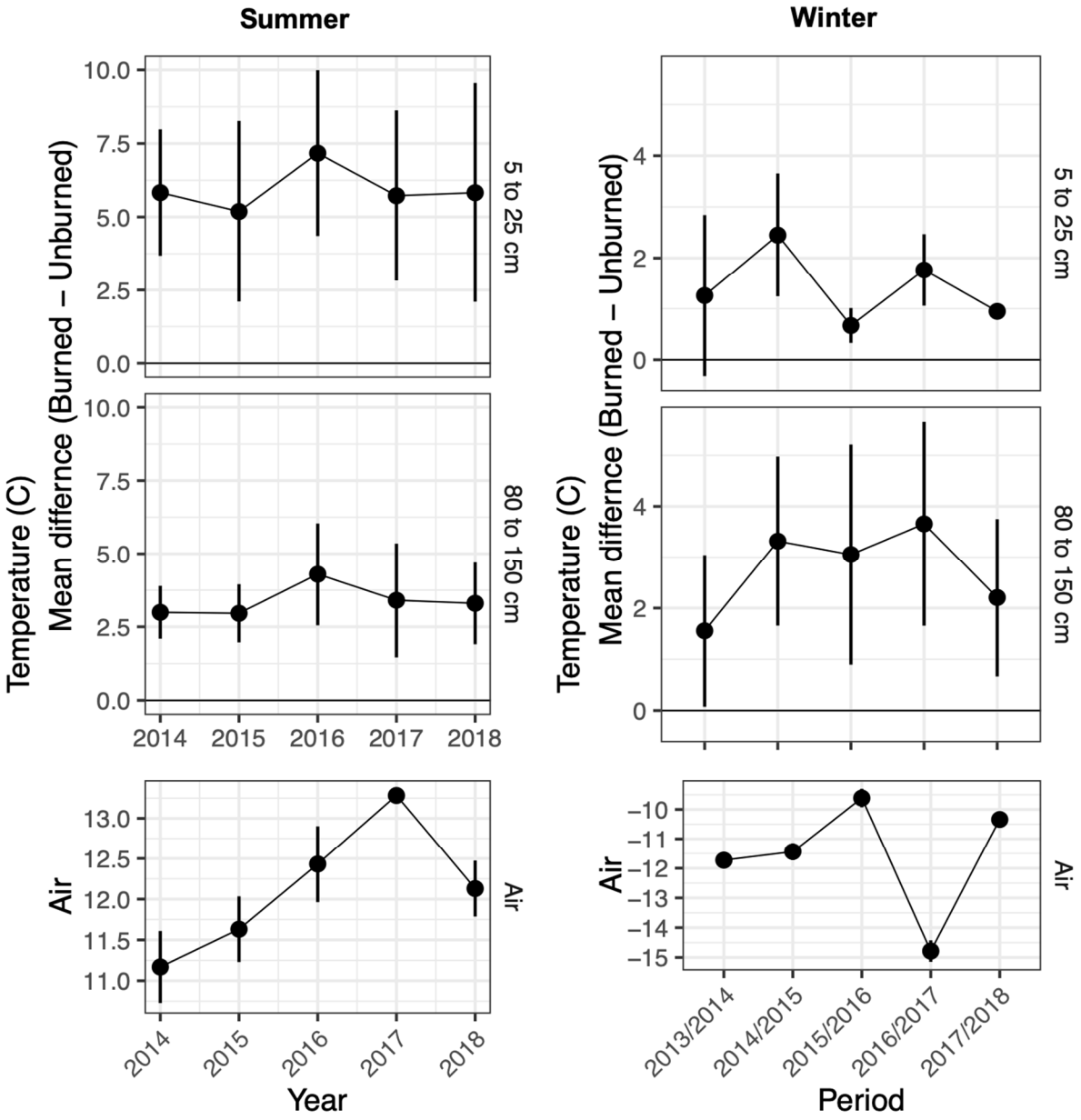

Figure III. Mean Temperature Differences (Burned-unburned) for Shallow (5-35 cm) and Deep (80-150 cm) Soils.

Temperatures for each soil profile are averaged across depths and sites. (left panel) Summer: May-October; (right panel) Winter: October-May of the following calendar year. Air temperatures are from the nearest meteorological station to each site.

From the past research, the research team concluded that fuel reduction management treatments that disturbed the soil organic layer (shearblading) similarly catalyzed large changes in permafrost and tree seedling species composition that may lead to state change over longer timescales, while treatment that had limited impact on the soil organic layer (hand thinning) protected the permafrost from thaw and did not alter tree seedling composition. New insights from revisiting this network included observations of consistent conifer recruitment across the first decade after treatment, which is in contrast to the wildfire network (Figure IV).

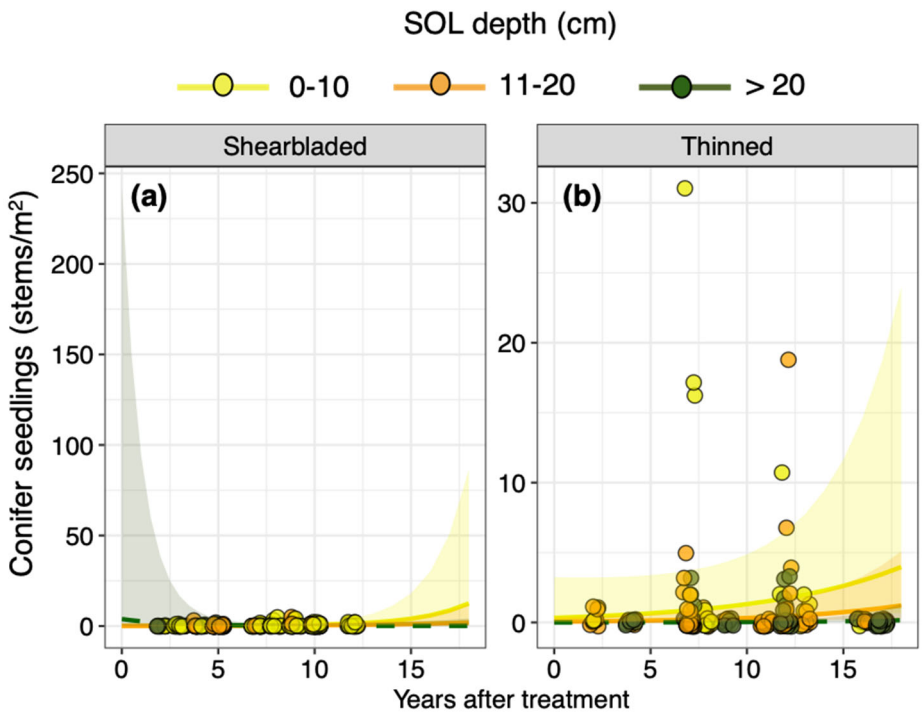

Figure IV. Generalized Linear Mixed Model (GLMM) Results of Conifer Seedling Density as a Function of the Interaction Between Treatment Type, Years After Treatment, and Soil Organic Layer (SOL) Depth Excluding Green Moss in Shearbladed (a) and Thinned (b) Sites.

Lines represent the relationship between years after treatment and predicted conifer seedling density when the SOL depth is 0-10 cm, 11-20 cm, and > 20 cm (a, b), shading the 95% prediction intervals, and points the raw data values colored by SOL depth. Solid lines indicate significant relationship.

Although deciduous tree seedlings dominated in severely disturbed (shearbladed) treatments, recruitment of conifers, likely from surrounding undisturbed stands, established mixed composition stands that will likely undergo complex successional trajectories in the future. Active layer depth and permafrost degradation increased over time, but only in the shearbladed treatments; active layer depth also increased in the thinned treatments, but to a lesser degree (Figure V). New measurements of fire ROS indicated that the initial benefits of reduced ROS diminished to pre-treatment levels by the first decade after treatment (Figure VI). Additionally, shearblading of black spruce-lichen woodlands increased ROS because vegetation composition shifted towards plant species with a higher abundance of fine fuels.

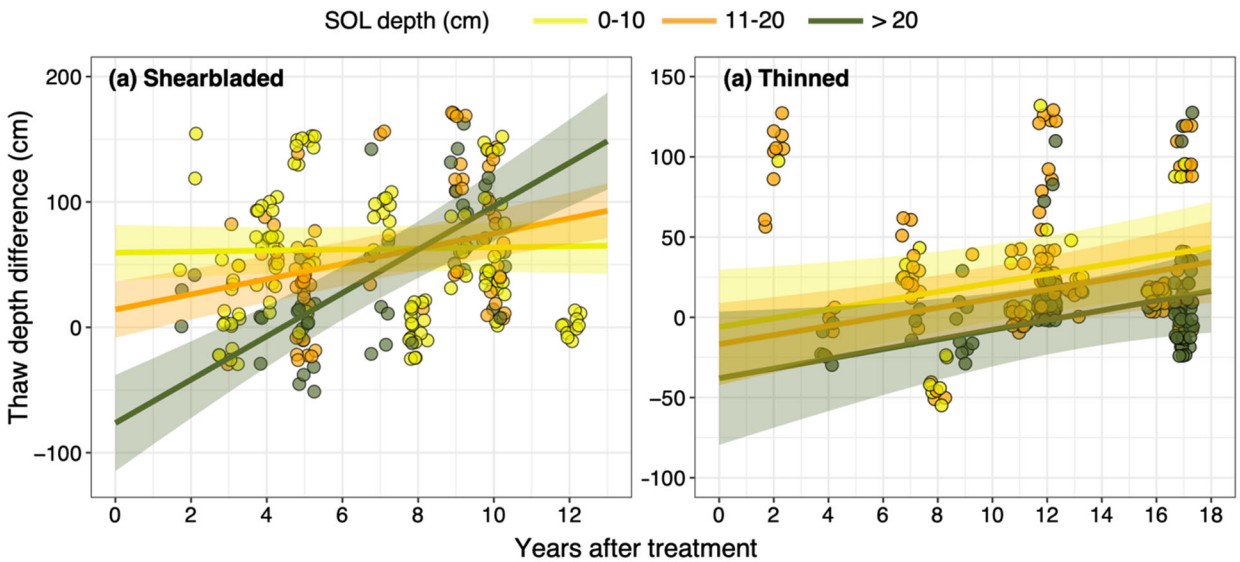

Figure V. Linear Mixed Model (LMM) Results of Thaw Depth Difference (TDD; Treated – Unmanaged) as a Function of the Interaction Between Years After Treatment, Treatment Type, and SOL Depth Excluding Green Moss.

Lines represent predicted fits of TDD with years after treatment when SOL depth is between 0 – 10 cm, 11 - 20 cm, and > 20 cm in shearbladed (a) and thinned (b) sites, shading the 95% prediction intervals, and points the raw data values. In shearbladed areas, this trend was the strongest when SOL depth was > 20 cm (20.12 cm ± 0.24, p<0.001; Estimate ± SE), followed by 11- 20 cm (6.06 cm ± 0.12, p<0.001) and 0 – 10 cm (0.42 cm ± 0.12, p<0.001). In thinned areas this trend was slightly stronger when SOL depth was > 20 cm (3.06 ± 0.06, p<0.001) than 11 – 20 cm (2.75 cm ± 0.03, p<0.001) or 0 – 10 cm (2.75 cm ± 0.03, p<0.001).

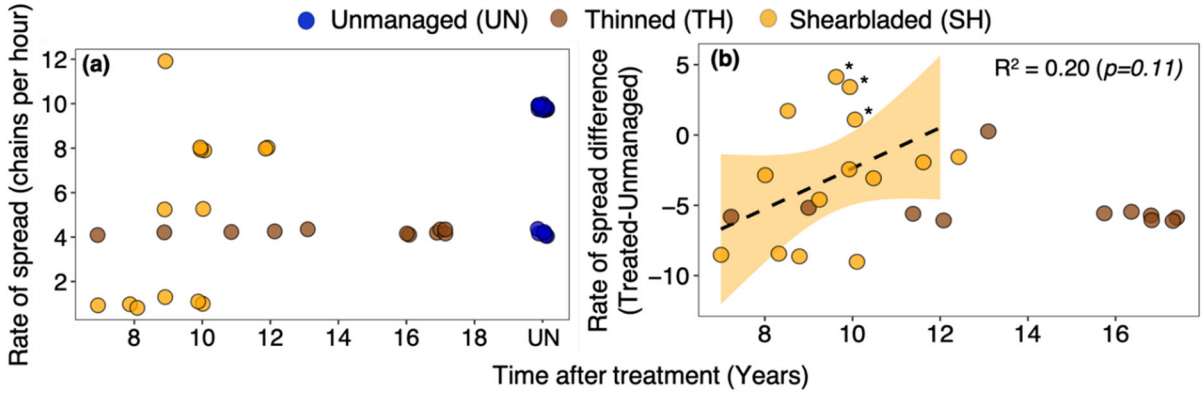

Figure VI. ROS of All Subsites in 2018 (a) and the Difference in ROS Between Treated and Unmanaged Subsites as a Function of Years After Treatment (b).

Dashed line represents relationship between ROS difference and years after treatment in shearbladed areas (1.44 ± 0.84, p=0.11), and asterisks on points indicate shearbladed areas that were paired with an open black spruce or open black spruce with paper birch stand where the ROS was greater in the treated than unmanaged stand (b).

5.0 IMPLICATIONS FOR FUTURE RESEARCH AND BENEFTIS

The data confirm that managers can use early post-fire data to predict vulnerability to ecosystem state change after wildfire because tree seedling regeneration and soil temperature regime are entrained soon after fire. In fuel management treatments, however, the prolonged window of conifer recruitment will require longer-term (e.g., decadal) observations of composition to predict successional trajectory. Managers are interested in the idea of a "living fuel break," that treatment-driven changes in species composition could result in establishment of low flammability deciduous stands that could persist for a century. Given the continued recruitment of conifers, the research team needs to follow treatments over more than one decade to determine whether this is a probable outcome. New measurements showed that fuel management effects on fire ROS returned to prefire levels about a decade after treatment. Because shearblading treatments increase ROS in open canopy black spruce woodlands, these ecosystems are not effective candidates for fuel brakes created by this method.