Fire effects on seedling establishment success across treeline: implications for future tree migration and flammability in a changing climate

Project Active ID: 12-3-01-29

Principal Investigator: F. S. Chapin III[1]
Co-Principal Investigator: Teresa N. Hollingsworth[2]
Student Investigator: Rebecca E. Hewitt[1]

[1] University of Alaska Fairbanks, Institute of Arctic Biology
[2] US Forest Service, PNW-Boreal Ecology Cooperative Research Unit

FIRESCIENCE.GOV
Research Supporting Sound Decisions

Abstract

Understanding the complex mechanisms controlling treeline advance or retreat in the arctic and subarctic has important implications for projecting ecosystem response to changes in climate. Changes in landcover due to a treeline biome shift would alter climate feedbacks (carbon storage and energy exchange), ecosystem services such as wildlife and berry habitat, and landscape flammability. Wildfire frequency and extent has increased in the last half-century in the boreal forest and tundra in response to warmer weather and lower precipitation. Invasion of tundra by trees may be facilitated by wildfire disturbance, which exposes new seedbeds, increases nutrient availability immediately post-fire, and creates opportunities for establishment in an ecosystem where tree recruitment is otherwise rare. Coupled with projects specifically investigating biotic factors influencing tree seedling establishment, we evaluated the regional abiotic factors governing seedling performance and establishment success across treeline after fire. Addressing the Joint Fire Science Program (JFSP) Graduate Research INnovation (GRIN) topic of climate change and fire effects, we investigated regional controls on seedling growth across a latitudinal treeline gradient post-fire in Alaska. We used samples from a tree seedling out-plant experiment and an observational study of naturally established tree seedlings to investigate how establishment success and physiological performance is limited by drought stress and nutrient acquisition across the treeline ecotone. We developed a conceptual model of the abiotic and biotic factors that govern seedling performance at treeline and tundra. This conceptual model has been implemented in ALFRESCO, a landscape-level model of vegetation-fire-climate dynamics. Using ALFRESCO we are investigating the potential for fire-initiated tree migration.

Background and purpose

The location of arctic treeline has important effects on the climate system through changes in carbon storage (McGuire *et al.* 2001), regional albedo (Chapin *et al.* 2000), and the position of the Arctic Front (Pielke & Vidale 1995). Expansion of Alaska treeline is a climatically relevant event due to positive feedbacks to climate warming that arise with conversion of tundra to forest (Chapin *et al.* 2005). Advance of arctic treeline is usually modeled in Dynamic Global Vegetation Models as a function of temperature, where increases in temperature lead to more trees. However there is an increasing body of literature to suggest that, at treeline, warming may negatively affect growth, reproduction, and establishment of trees due to drought stress (Wilmking & Juday 2005). Ecosystem resilience to vegetation change at treeline can be understood through exposure to climate warming and through sensitivity to climate-induced changes in the fire regime. A warming climate promotes disturbances such as fire (Kasischke & Turetsky 2006), which facilitate seedling establishment (Lloyd & Fastie 2003), growth (Hobbie & Chapin 1998), and affects treeline resilience.

The boreal forest is North America's largest biome (Johnson *et al.* 1995), and wildfires are the dominant large-scale disturbance in Alaskan boreal forests. In Alaska, changes in climate have directly affected the fire regime in the boreal forest (Rupp *et al.* 2007). From 1959–99 there has been a doubling of both the annual area burned and frequency of large fire years in North American boreal forests (Kasischke & Turetsky 2006). As climate changes, fires at treeline and tundra are expected to become more frequent due to drier fuel loads and more frequent thunderstorms.

In the boreal forest, fire is a major driver of tree recruitment as well as tree migration (Johnstone *et al.* 2004). Post-fire successional trajectories are closely related to fire severity, which affects density and composition of tree seedlings that establish after fire. High-severity fires expose mineral soils, which are favorable to seedling germination, net seedling establishment, and growth of transplanted seedlings(Johnstone & Chapin 2006). In addition, northern migration of lodgepole pine into Alaska appears to be tightly linked to high-severity fires (Johnstone & Chapin 2003). Because fire disturbance is critical to boreal forest vegetation patterns, it seems likely that a changing fire regime will dramatically affect where on the landscape trees will occur in the future.

In Alaska recent studies have focused on fire effects on post-fire successional trajectories in black spruce forests; however, impacts of fire on successional trajectories and future flammability at treeline forest sites are unknown. In order to make accurate predictions of the rate and magnitude of future changes in boreal-tundra landcover in the next decades, it is important to understand the interacting factors that can influence tree seedling recruitment and performance at treeline. The Joint Fire Science Program (JFSP) Graduate Research INnovation (GRIN) project allowed us to investigate the relative importance of abiotic factors pertaining to fire severity, drought stress, and nutrient availability. The research was in relation to Rebecca Hewitt's dissertation projects focused on fire-severity effects on symbiotic fungal communities and the impacts of plant-fungal interactions of tree seedling growth and establishment at treeline after fire. With the completion of the JFSP GRIN data collect, we were able to develop a hierarchy

of biotic and abiotic filters that determine seedling establishment and performance at treeline after fire. In order to assess treeline ecosystem vulnerability to climate-induced changes in fire activity, we developed a conceptual model of abiotic and biotic controls over seedling establishment based on our field observations and the literature. This conceptual framework has been implemented in the spatially explicit fire-climate-vegetation landscape model, Alaska Frame-Based Ecosystem Code (ALFRESCO)(Rupp *et al.* 2000). This project links mechanistic investigation of regional patterns of seedling establishment to model projects of continental biome shifts after fire using a novel suite of analytical tools in order to address fire effects on treeline successional trajectories and future flammability.

Study description and location

Study sites: The study area includes a burned arctic tundra site north of latitudinal treeline and two burned treeline sites in the upland boreal forest of interior Alaska bounded by the Brooks Range and latitudinal treeline to the north (67˚N) and the Alaska Range to the south (63˚N) (Fig. 1). *Tundra fire* sampling occurred in the burn scar of the 2007 Anaktuvuk River Fire. This fire burned 1000 km^2 on the North Slope of Alaska at mostly moderate to high severities. *Latitudinal treeline* sampling was focused in the uplands of the southern foothills of the Brooks Range at Finger Mountain. *Alpine treeline* sampling was focused in the White Mountains. Forest cover is dominated by black spruce (*Picea mariana*) with patches of trembling aspen (*Populus tremuloides*) and Alaskan paper birch (*Betula neo-alaksana*), and treeline cover is primarily white spruce (*Picea glauca*). The treeline sites burned in the widespread fires of 2004 that burned over 2.7 million ha of forest across the interior of Alaska.

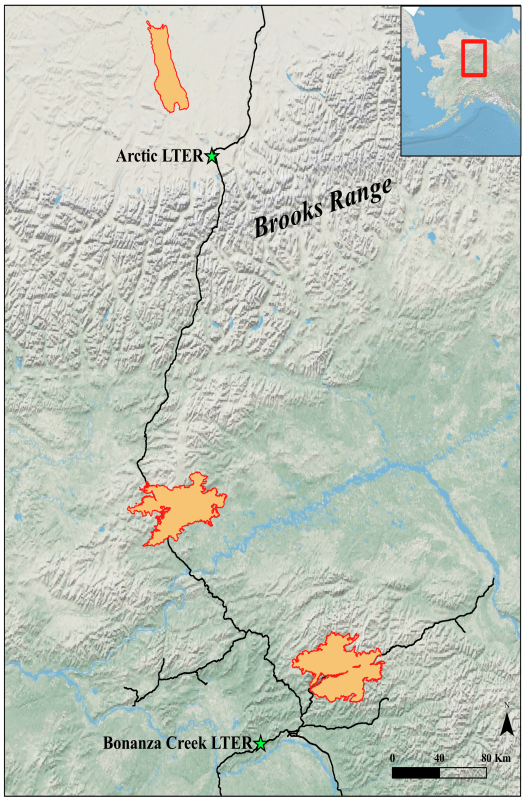

Figure 1: Map of study sites for outplanted and naturally established seedlings. Orange polygons represent burn scars. Seedlings were outplanted at the two northern-most sites in tundra and at latitudinal treeline. Naturally established seedlings were sampled at the latitudinal treeline site and the alpine treeline to the south. The sites are affiliated with the two NSF Long-Term Ecological Research Sites in Alaska.

Sampling design and measurements: In 2009 we sampled naturally established seedlings at alpine and latitudinal treeline sites that had burned in 2004. We excavated root systems to sample for fungal symbionts, ectomycorrhizal fungi (EMF). We noted the substrate, dominant vegetation within one m of the focal seedling, the depth of the organic layer (fire severity metric), and the distance between the seedling and the closest shrub. These samples of naturally established seedlings were used to assess the relative importance of abiotic and biotic factors for seedling biomass.

In 2009 we out-planted seedlings (white spruce, black spruce, birch and alder) inoculated with different fungal communities at a latitudinal treeline site and an arctic tundra site, both of which burned recently. The treatments were (1) sterile autoclaved inoculum, (2) unburned boreal forest inoculum (3) burned boreal forest inoculum. We harvested seedlings in 2010 and 2011, and preliminary results show that there was significantly lower survivorship at the latitudinal treeline site than the arctic tundra site, indicating that abiotic factors may impact seedling establishment success more than fungal symbiont availability at some sites.

For the JFSP GRIN project we collected data on foliar and soil isotopes to determine the relative importance of abiotic factors on seedling attributes. Foliar isotope signatures, which provide an integrative measurement of seedling performance, were related to soil isotopes and previously developed fungal community profiles for each seedling. We measured the natural abundance of $\delta^{15}N$ and $\delta^{13}C$ in leaves and soil, as well as C and N concentrations using Isotope Ratio Mass Spectrometry. During harvest of the out-planted seedlings in 2010 and 2011, we separated current years growth, dried the material, and ground the foliar tissue. With funding from JFSP GRIN, we ran the foliar and soil samples on an Elemental Analyzer (ECS 4010, Costech Analytical, Valencia, California, USA) coupled to a Delta Plus XL Stable Isotope Ratio Mass Spectrometer (Delta Plus XL, Finnigan, Bremen, Germany) via a Conflo III (Finnigan, Bremen, Germany). Foliar $\delta^{13}C$ signatures provide an integrated indicator of photosynthetic activity and water relations with enriched $\delta^{13}C$ signatures indicating greater drought stress. Foliar $\delta^{15}N$ signatures in comparison with soil $\delta^{15}N$ signatures indicate soil N pools accessed by seedlings, ecosystem N availability, and N uptake by fungal symbionts. The use of dual isotope analysis in relation to abiotic and biotic drivers of seedling performance is a novel approach to address regional seedling establishment success.

Random Forest analysis of abiotic and biotic variable importance: We used Random Forest classification and regression tree method to identify important associations between seedling biomass and explanatory variables: fire severity, fungal and vegetation variables. Random Forest is an ensemble decision tree method that uses an algorithmic approach to make predictions based on the input variables (Breiman 2001b). Multiple decision trees are constructed through a process known as bagging (Breiman 1996), which utilizes a bootstrap sample from a subset of the data (~63% of the data) and the random selection of a subset of the predictor variables. The most important variable from the random subset of predictor variables is then used to produce each node split (Breiman 2001a). The fully-grown (statistical) trees are used to predict the observations excluded from the bootstrap sample, i.e. out-of bag-data (~37% of the full dataset). Predictions are calculated by combining the predictions across the forest of regression trees by averaging. The importance of each explanatory variable is determined when

permutations of the observed values for a predictor variable in the out-of-bag data are run down the tree to predict the response variable. If an explanatory variable is important, than the permutation of that variable will have a large effect on the prediction of the response variable (Breiman 2001b). The variable importance is reported as the percent increase in the miscalculation rate, i.e., decrease in accuracy, for each predictor when the predictor is permuted (Breiman 2001b). We used the R package (R Development Core Team, 2013, R Foundation for Statistical Computing, Vienna, Austria), Random Forest to determine which variables are important to predictions of seedling biomass. Using Random Forest we built 500 regression trees using a random sample of the 70 observations of seedling biomass. At each node in the trees, two predictor variables were chosen at random from the nine explanatory variables.

Analysis of natural abundance isotopes: We used linear regression to investigate relationships between $\delta^{13}C$ and $\delta^{15}N$ isotopes and seedling taxon, treatment with EMF, and site. We used ANOVA to initially investigate isotope signatures in relation to a site and soil factors. We also investigated the effect of fungal colonization on drought stress and seedling N acquisition. Enriched $\delta^{13}C$ values indicate drought stress, while relative enrichment of $\delta^{15}N$ values will indicate plant uptake of different sources of soil nitrogen and the role of mycorrhizae in nitrogen uptake. Correlations of $\delta^{15}N$ values with particular biotic drivers of site level soil parameters may indicate fire effects on soil nitrogen availability and plant N acquisition.

This research produced isotopic signature data for foliar material and soils. As with all Long Term Ecological Research (LTER) projects data from this research will be archived with the Bonanza Creek LTER. Data will be available to those that adhere to the LTER data access policy. Model outputs will be archived by the Scenarios Network for Alaska Planning (SNAP). Final model outputs are accessible via web portals. Documentation and presentations of my findings will be available to fire managers through the Alaska Fire Science Consortium.

Synthesizing Results: Modeling the potential for fire-initiated tree migration into previously unforested alpine and arctic tundra. We collaborated with Dr. T. Scott Rupp, director of the SNAP, to develop the conceptual model from our empirical data on seedling establishment success and seedling physiology. We parameterized the model based on our findings from the tree out-planting experiment (drought tolerance and nutrient limitation impacts on performance and survival) and previous investigations of biotic parameters. ALFRESCO simulations now include more biologically accurate mechanisms governing seedling establishment and vegetation transitions from tundra to spruce.

Key findings

Outcomes from field investigations

The importance of fungal communities in seedling biomass: At post-fire treeline and tundra sites across a latitudinal gradient in Alaska we investigated the relative importance of abiotic and biotic factors influencing seedling biomass for naturally established seedlings. Analysis with Random Forest showed that seedling age was the most important variable predicting seedling biomass, followed by site, fire severity (organic

depth), fungal composition, and vegetation composition (Fig. 2). The distance between a seedling and resprouting shrub, seedling taxon, % fungi shared with a resprouting shrub and the shrub taxon all had a less important influence on seedling biomass. Site and fire severity are correlated variables, which contributes to the similarity in their ranked variable importance scores. Previous research in the boreal forest has shown that residual organic depths strongly influence successional trajectories and successful seedling establishment (Johnstone & Chapin 2006; Johnstone *et al.* 2010). These results support those findings and also highlight for the first time the importance of fungal symbionts to seedling biomass.

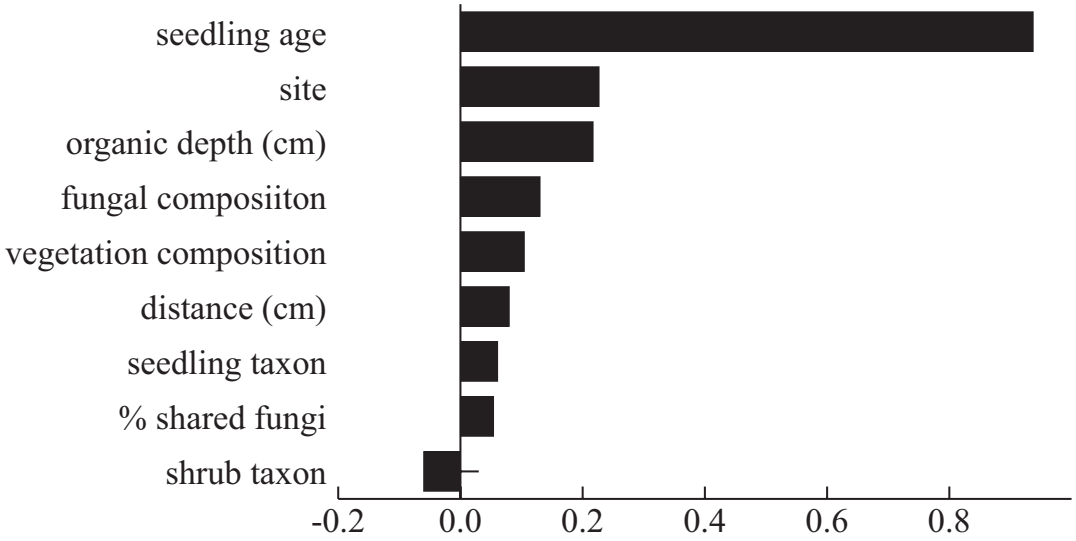

Figure 2: Variable importance scores resulting from Random Forest regression trees. Variable importance scores are derived from the percent increase in the miscalculation rate when the variable is permuted. % shared fungi is the percentage of fungal taxa shared between a seedling and the adjacent shrub sampled.

The importance of fungal communities in mediating nutrient effects: Because of our observation that EMF composition was important to the natural establishment of seedlings after fire, we specifically wanted to investigate whether fungal inoculum influenced drought stress and nutrient availability to seedlings. We tested the importance of seedling taxon, treatment (provision of fungal inoculum), and site effects on foliar C and N isotopic signatures from out-planted boreal tree seedlings. We found that seedling taxon, treatment with inoculum, and site all significantly influenced the $\delta^{15}N$ of foliar tissue ($F=13.8228$, $p<0.0001$, $R^2=0.49$). We were surprised to see such a strong influence of fungal inoculum on $\delta^{15}N$ given the difficulty in performing an inoculation experiment in the field. Upon further investigation we saw that the uninoculated seedlings were more enriched in $\delta^{15}N$ than those that received inoculum from burned forest or unburned forest. This indicates that the uninoculated seedlings were not relying on mycorrhizal symbionts to acquire nitrogen. Furthermore, increased colonization by root systems was related to

depletion in $\delta^{15}N$ (F=6.789, p=0.012, R^2=0.12), indicating that mycorrhizal seedlings accessed more nitrogen than uninoculated seedlings.

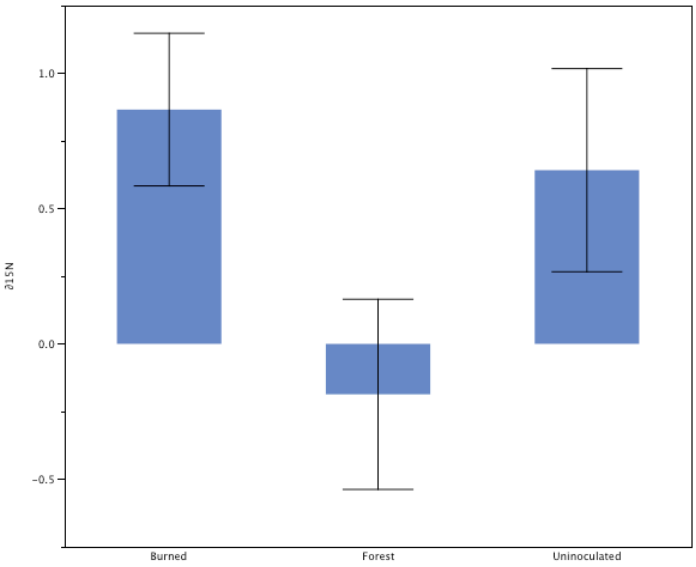

Figure 3: Effects of mycorrhizal inoculation on nitrogen acquisition for seedlings outplanted at treeline and in tundra after fire. The more enriched signature of uninoculated seedlings and seedlings that received burned inoculum indicates less reliance on ectomycorrhizal symbionts.

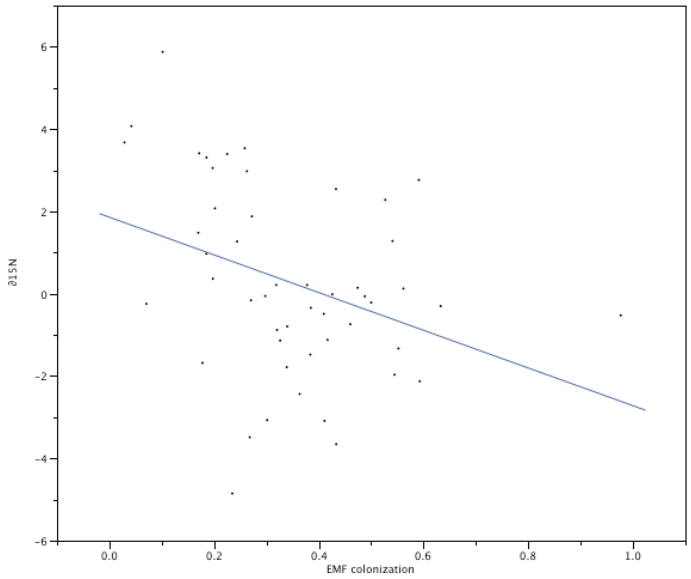

Figure 4: Effects of mycorrhizal colonization on nitrogen acquisition for seedlings outplanted at treeline and in tundra after fire.

When investigating drought effects, we found that seedling taxon was significantly related to $\delta^{13}C$ (F=4.660, p=0.0004, R^2=0.247). Alder seedlings had the greatest enrichment in ^{13}C and thus the most drought stress. We also observed a trend, although not significant, towards greater depletion in ^{13}C with higher percentages of fungal root colonization (colonization parameter estimate = -1.789 ±1.064, p=0.09). Together these results indicate that EMF play an important role in N acquisition and may also be important to reducing drought stress. In sister studies we have observed relationships between EMF taxon abundance and decreasing C:N ratios for naturally established

seedlings supporting these isotopic results. These isotope data show that EMF are important to both the nutrition and water relations of seedlings.

We observed expected patterns of $\delta^{15}N$ in soils with organic soils being more depleted in ^{15}N than mineral soils. This pattern was significant at the burned alpine and latitudinal treeline sites (alpine F=22.038, p=0.001 and latitudinal F=7.386, p=0.035).

Progress with modeling effort

Modeling the potential for fire-initiated tree migration into previously unforested alpine and arctic tundra. In collaboration with SNAP, we developed a conceptual model that incorporated our mechanistic understanding of abiotic and biotic controls over seedling establishment based on the JFSP GRIN-supported isotope study. ALFRESCO is a frame-based spatially explicit state–and-transition model that simulates vegetation succession and fire occurrence (fig. 5). The model domain includes all of Alaska and the western Yukon Territory. Simulations of landscape flammability and vegetation response were driven by downscaled outputs from five global climate models and three emissions scenarios at a 1 x 1 km resolution for Arctic Alaska. Transitions for each 1 km^2 tundra cell were determined by proximity to seed source, seedling establishment conditions, and growth conditions (described below). These landscape-modeling scenarios directly address how future fire regime may influence treeline dynamics, which has important implications for land managers in Alaska.

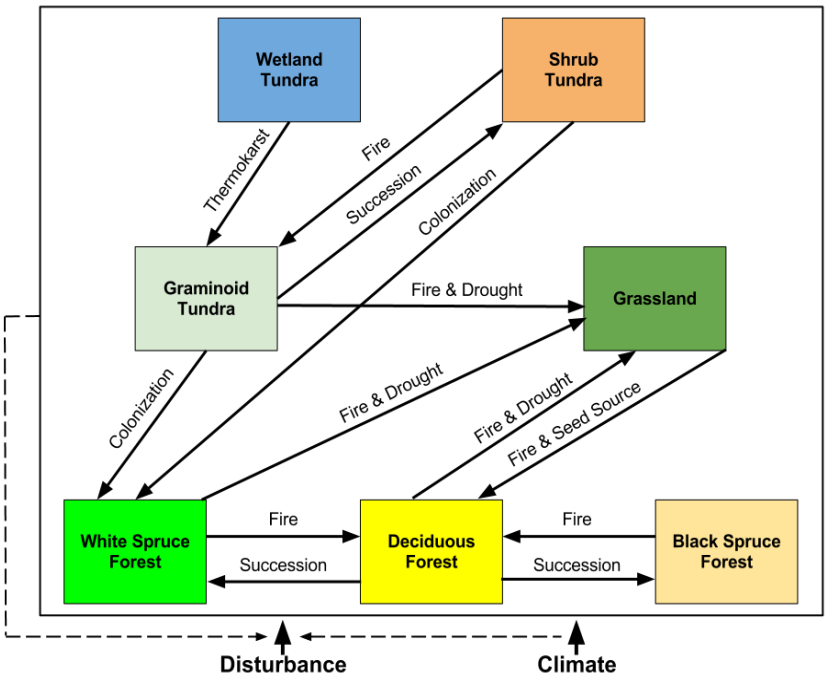

Figure 5: Conceptual diagram of the processes affecting state transitions in ALFRESCO. Arrows indicate causal relationships.

Components of ALFRESCO Development and Testing

1. *Landcover map:* The model input landcover dataset represents a highly modified output originating from the North American Land Change Monitoring System.
2. *Downscaling of climate forcing variables:* Model development activities focused on ingestion of driving climate datasets and partitioning regional fire sensitivity parameters. CMIP3 monthly air temperature and total precipitation data was downscaled to 1km spatial resolution for historical and the five best performing GCM projections in Alaska. Climate scenarios for the three primary emission scenarios (B1, A1B, and A2) for each model were downscaled.
3. *Flammability and ignition:* Regional fire sensitivity parameters were developed to modify fire ignition potential at the ecoregion level. This utility provides capacity to represent and calibrate broad-scale differences in climate-ecosystem interactions across the entire state of Alaska. Preliminary model testing and calibration has been completed using a statewide simulation domain for the historical period (1900-2010) and projections (2011-2099). Each climate scenario (five GCMs each with three emission scenarios) was simulated 200 times (n = 3000). Additional calibration and testing is currently focused on interior boreal forest and tundra regions of the model domain.
4. *Modifying state transitions from tundra to spruce:* We refined the steps that affect the transition of a 1 km^2 cell from tundra to spruce due to colonization by seedlings. This transition is influenced by fire occurrence and severity, proximity to a seed source, and favorable conditions for germination, establishment and growth. Our studies supported by JFSP GRIN informed the development of the climate and mycorrhizal modifiers that influence establishment and growth (Fig. 6). Within a given time step, if a fire occurs in a tundra cell the cell does not transition. If a fire has not occurred in that time step, then the model checks to see if there is a spruce seed source close by. Dispersal of seeds is characterized by high dispersal ability within a 1 km^2 cell with the possibility of rare long distance dispersal events. If seed is present, the model checks to see if the conditions are favorable for germination and establishment. Our recent modifications to this stage include the effects of mycorrhizal fungi (see in depth description below) and climate. Climate is suitable for germination and growth (the next step) when the Summer Warmth index is > 27 and the average July temperature is >10°C. If conditions continue to be favorable for growth, then basal area increases in the cell with time. When spruce trees become abundant in the cell, then the cell transitions to spruce.

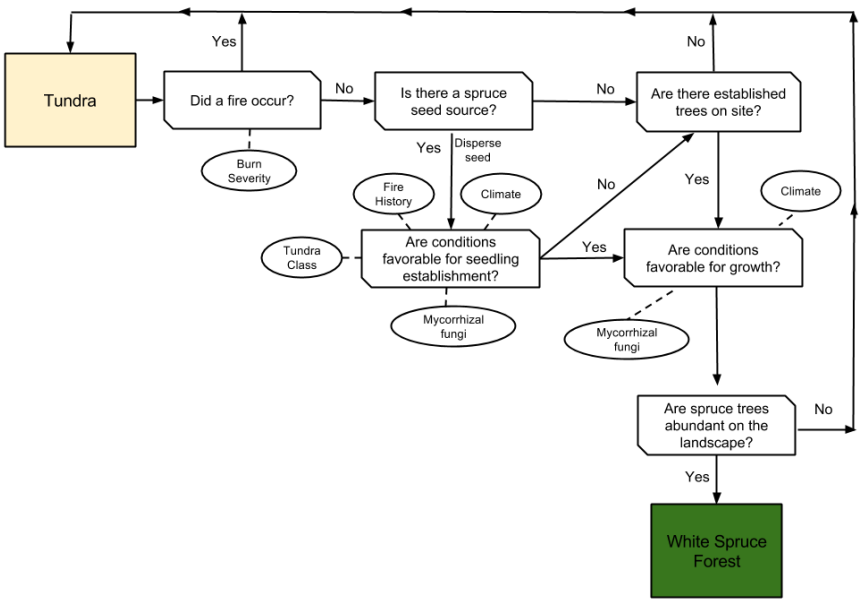

Figure 6: Conceptual diagram of the processes affecting state transitions from tundra to spruce in ALFRESCO. Arrows indicate the progression from one step in the transition process to the next step in the process.

5. *Incorporating mycorrhizal effects on seedling performance:* The research supported by the Joint Fire Science GRIN award directly informed the modeling of landcover change and forest advancement from boreal forest into tundra by supporting research that revealed the physiological importance of mycorrhizal fungi to tree seedling establishment. Below we describe the mechanics of how we incorporate mycorrhizal effects into components of the model determining successful tree seedling establishment and growth. This modeling exercise was also informed by other components of Rebecca Hewitt's dissertation research described below (relationship to other recent findings).

   We synthesized our understanding of fungal effects on tree seedling establishment from the growth chamber experiment and field observations in post-fire tundra and treeline sites (project abstracts provided below). Overall our empirical studies showed 1) that soils beyond current treeline are not strong sources of mycorrhizal inoculum, and instead fire severity influences tree and shrub performance through pathogenic effects or potentially beneficial effects of root endophytes; 2) shrubs that resprout after wildfire in tundra and at treeline are sources of fungal resilience; and 3) boreal tree species can associate with at least some of the fungi maintained on resprouting shrubs after fire and may facilitate seedling establishment due to a positive influence on seedling nutrition. In our modeling effort we emphasized the role of shrubs as an important source of inoculum on the tundra landscape. We used shrub densities from the Viereck (1992) vegetation classification to estimate inoculum potentials for three tundra classes represented in the model domain: shrub tundra, graminoid tundra, and wet sedge tundra. We view these tundra classes as having a gradient of host plant densities that could support mycorrhizal fungi and therefore mycorrhizal effects

on seedling establishment. We have also parameterized the effects of fire severity on fungal inoculum potential as part of the fire history modifier. There are five classes of fire severity: 0=unburned, 1=low burn severity, 2=moderate burn severity= 3= high crown severity with low surface severity, and 4= high crown severity with high surface severity. Of these burn classes, we expect only classes three and four to have a strong effect on inoculum potential. Fire-severity effects on fungal symbionts are related to the degree to which host plants are killed and the amount of soil combusted (Dahlberg 2002).

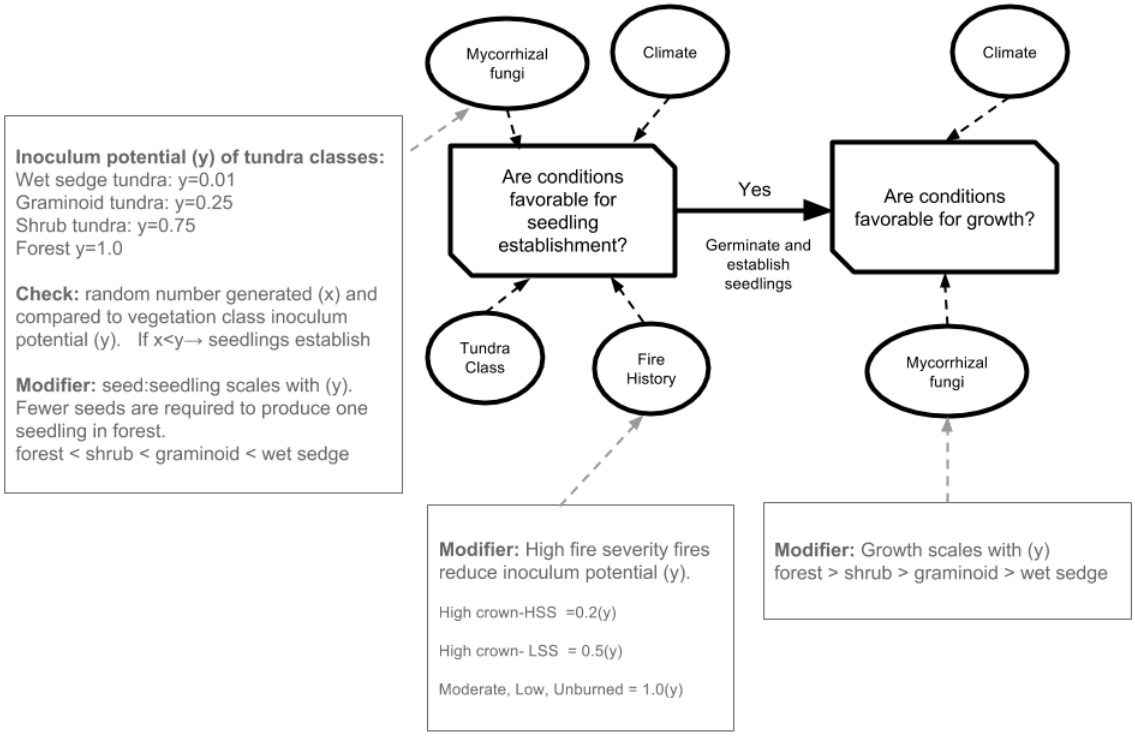

Figure 7: Conceptual diagram of the influence of mycorrhizal fungi on tree seedling establishment and growth. The arrows show the progression from addressing ecological factors for one life history stage to the next. Fire-severity classes are as follows: 0=unburned, 1=low burn severity, 2=moderate burn severity= 3= high crown severity with low surface severity (LSS), and 4= high crown severity with high surface severity (HSS). Tundra classes are based on a highly modified output originating from the North American Land Change Monitoring System. We assigned inoculum potential scores to the tundra classes based on shrub densities reported by Viereck (1992).

6. *Calibration:* Preliminary results of the ALFRESCO calibration and testing of historical fire regime trends have been completed. Comparison of model simulation results with observed (1950-2010) wildfire activity indicated good agreement for both cumulative area burned and the cumulative distribution of individual fire size. Simulated cumulative area burned for the historical period 1950-2010 showed good agreement with observed trends (Fig. 8). Individual simulation replicates (n = 200) vary closely around observed fire activity and the best performing model replicates match closely to observed cumulative area burned in 2010. All model replicates underestimate the record wildfire activity of 2004 and 2005. The distribution of individual simulated fire sizes for the period 1950-2010 also matches well with the observed record (Fig. 9). Both simulations and historical observations indicate a large proportion of cumulative area burned is the result of a relatively small number of very large individual fires. The interannual variability of annual total area burned was simulated adequately by the model (Fig. 10). The model currently and consistently underestimates annual area burned in the years with the largest observed fire activity and specifically the years 2004 and 2005. The spatial extent of wildfire occurrence matches well with general observations of fire activity. The great majority of wildfire activity occurs in the interior boreal forest region of Alaska. This region is bounded by the Brooks Range to the North (and tundra ecosystem types) and the Alaska Range to the south (and substantial increases in monthly and annual precipitation).

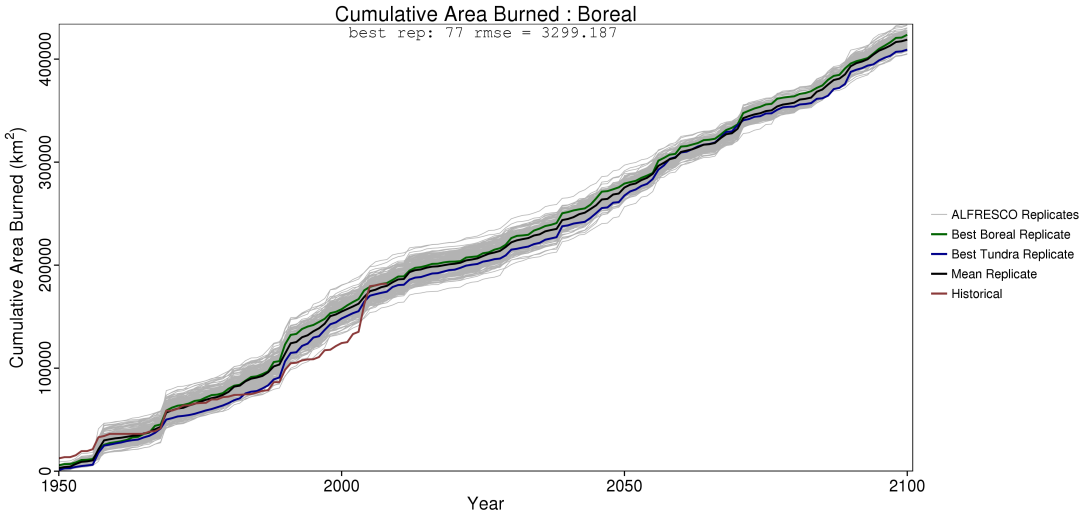

Figure 8: Cumulative area burned (km^2) through time. Record of observation 1950-2010 indicated by the red line. Individual model simulations (n = 200) indicated by gray lines. Projections through 2099 are for the CCMA A1B climate scenario.

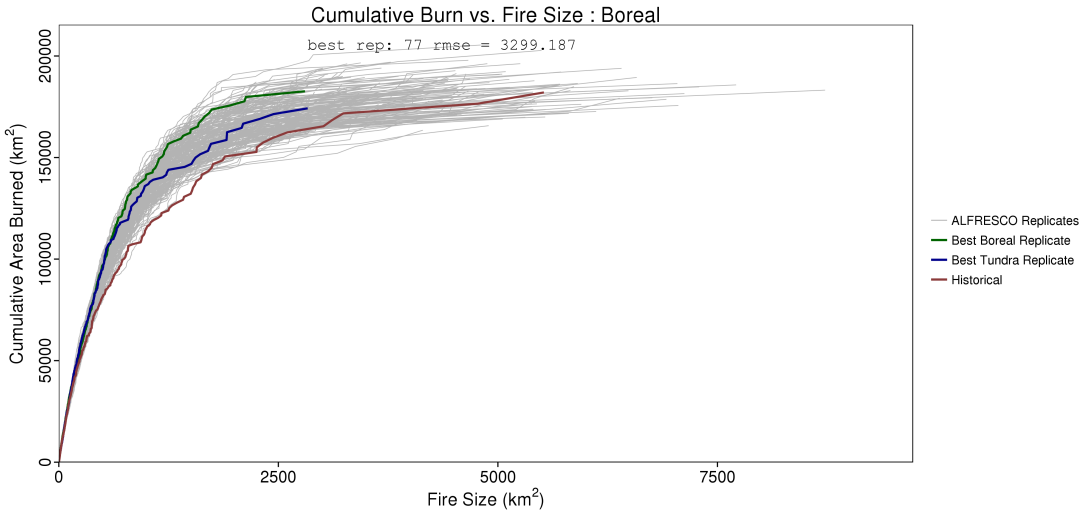

Figure 9: Cumulative area burned versus individual fire size (km^2) for the historical observation period 1950-2010. Red line indicates observed distribution. Green and blue lines indicate best performing simulation replicates. Gray lines indicate individual replicates (n = 200).

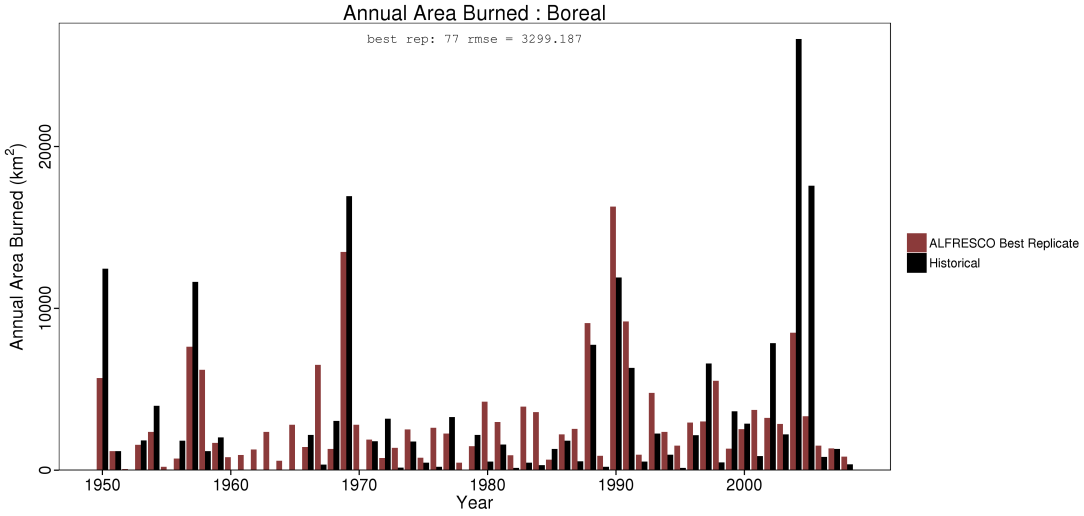

Figure 10: Annual area burned (km^2) for the historical observation period 1950-2010. Black bars indicate historical observations and red bars indicated simulated results from best performing individual model replicate (n = 1).

Management implications

Both the mechanistic underpinning of our modeling effort and model outputs can be used to inform land and fire managers about treeline sensitivity to fire and to assess the vulnerability of forest ecotones to future change. This will support land management decisions in the face of high uncertainty about vegetation change with fire at treeline. Our field investigations and modeling results have improved our understanding of the mechanisms impacting tree seedling survivorship and growth post-fire at and beyond treeline. This mechanistic understanding of controls over seedling establishment enhances the accuracy of predictions of fire effects and flammability across the treeline ecotone and into tundra.

Outputs from ALFRESCO simulations are decision-support tools for land managers in the state of Alaska because they show the spatially explicit likelihood of conversion from tundra to forest. Model outputs will contribute to fire management decisions affecting the protection of ecosystem services, vegetation change, and future flammability. We have presented a "concept talk" at the Fire Task Force meeting through the Alaska Fire Science Consortium, which promotes communication between land managers, fire managers, and scientists. We will present our model outputs in a webinar hosted by the Alaska Fire Science Consortium.

Relationship to other recent findings and ongoing work on this topic

Fire severity effects on plant-fungal interactions with implications for tree migration

Project abstract: Vegetation change in high-latitude tundra ecosystems is expected to accelerate due to increased wildfire activity. High-severity fires increase the availability of mineral soil seedbeds facilitating recruitment, yet these soils also undergo shifts in soil microbes. We experimentally investigated the effects of fire severity on soil biota and associated feedbacks to plant performance for two plant species predicted to expand into Arctic tundra. We inoculated seedlings in a growth chamber experiment with soils collected from the largest tundra fire recorded in the Arctic and used molecular tools to characterize fungal communities. Seedling biomass was significantly related to the composition of fungal inoculum and declined across the fire-severity gradient as the proportion of pathogenic fungi increased. Our results suggest that effects of fire severity on soil biota may dampen or even reverse the expected increases in tree and shrub establishment after fire, thus influencing predicted changes in Arctic vegetation. *This project informed the modeling process by testing whether there was a relationship between fire severity and the outcomes of plant-fungal interactions for tree and shrub establishment and informing our conceptualization of the presence of inoculum after fire.*

The importance of post-fire resprouting vegetation in supporting fungal communities

Project abstract: Climate-induced changes in the tundra fire regime are expected to alter shrub abundance and distribution across the Arctic. However, little is known about how fire may indirectly impact shrub performance by altering mycorrhizal symbionts. We used molecular tools, including ARISA and fungal ITS sequencing, to characterize the mycorrhizal communities on resprouting *Betula nana* shrubs across a

fire-severity gradient after the largest tundra fire recorded in the Alaskan Arctic (July-October 2007). Fire effects on the components of fungal composition depended on the scale of taxonomic resolution. Fungal richness and relative abundance of dominant taxa declined with increased fire severity. Yet, in contrast to temperate and boreal regions with frequent wildfires, mycorrhizal fungi on resprouting shrubs in tundra were not strongly differentiated into fire-specialists and fire-sensitive fungi. Instead, dominant fungi, including taxa characteristic of late successional stages, were present regardless of fire severity. It is likely that the resprouting life history strategy of tundra shrubs confers resilience of dominant mycorrhizal fungi to fire disturbance by maintaining an inoculum source on the landscape after fire. Based on these results, we suggest that resprouting shrubs may facilitate post-fire vegetation regeneration and potentially the expansion of trees and shrubs under predicted scenarios of increased warming and fire disturbance in Arctic tundra. *This project informed our modeling effort by help us understand how fire affects inoculum availability from resprouting shrubs and how this may vary across the different tundra classes in the model.*

Project abstract: Ectomycorrhrizal fungi (EMF) are critical symbionts of all boreal tree species. These mycobionts are potentially limiting to seedling establishment beyond current treeline in tundra. In addition, fire frequency and extent has increased in the last half century in the boreal forest and tundra in response to warmer weather and lower precipitation. These indirect effects of climate change have been hypothesized to increase vegetation transitions from tundra to forest; yet, fire can reduce fungal inoculum along with host plant abundance. The provision of fungal inoculum by resprouting shrubs and the development of a common mycorrhizal network (CMN) between establishing seedlings and resprouting tundra shrubs could play an important roll in seedling establishment success at treeline and migration into tundra. This study had two main research goals: 1) to investigate whether there is indirect evidence of CMN between seedlings that have established after fire and resprouting shrubs 2) to examine what fire and host plant effects influence the extent that taxa overlap between seedlings and shrubs. We found that EMF composition was most strongly correlated with vegetation composition and fire severity (the depth of the organic horizon). EMF composition on tree seedlings was also significantly related to the EMF composition of the closest resprouting shrub, and distance to these shrubs was the main factor determining similarity in fungal communities. There were also significant relationships between EMF composition and seedling C:N ratio and biomass. These results suggest that EMF mycobionts provided by resprouting post-fire vegetation are important to nutrient acquisition and biomass accrual of naturally establishing tree seedlings at treeline and in tundra. *Similar to the project described above, this project informed the model by testing the importance of fire severity on inoculum from resprouting shrubs. This project also connects the importance of resprouting shrubs in maintaining inoculum to seedling attributes.*

Future work needed

Future directions for this project involve the post-processing of model outputs. Currently, the post-processed data from the ALFRESCO outputs are focused on flammability variables: cumulative area burned and fire size. In the upcoming months we will be working towards computing the vegetation outputs. Vegetation outputs will allow us to directly test improvements in model accuracy by evaluating historic data and computing predictions for landcover change. Specifically, we will make comparisons between model outputs that based seedling establishment and transition from tundra to spruce solely on climate to model outputs from the improved version of ALFRESCO that incorporates several abiotic and biotic factors into successful seedling establishment and state transition. We will compare the ratio of the areal extent of tundra vs. spruce across simulations with historical forest cover data to see if the rules used to modify establishment and growth actually improve the accuracy of vegetation ratios or state transition. With these capabilities, we will produce model outputs that predict how wildfire-induced changes in tree establishment at treeline will drive landscape patterns of treeline movement.

Deliverables crosswalk

Deliverable Type	Description	Status	Delivery Dates
Outreach	Presented concept talk at the Alaska Fire Science Consortium	Complete	Spring 2013
Dataset	I produced a dataset that assesses the sensitivity of tree seedling establishment at treeline and in tundra to fire factors and fire-induced abiotic stressors.	Complete	Summer 2013
Computer model	I modified ALFRESCO, a fire-vegetation-climate model, to improve accuracy of predictions of the vulnerability of treeline and tundra sites to future changes in vegetation.	Framework implemented; validation in progress	Spring 2014
Ph.D. dissertation	I will complete my PhD program in treeline-fire dynamics and the potential for changes in treeline position with climate-induced changes to the fire regime in Alaska.	Defense to occur Spring 2014	Spring 2014
Refereed publication	I will publish a manuscript addressing fire effects on the potential for tree migration and future flammability at treeline and in tundra.	In preparation	Summer 2014

References

Breiman L. (1996). Bagging predictors. *Machine learning*, 24, 123-140.

Breiman L. (2001a). Random forests. *Machine learning*, 45, 5-32.

Breiman L. (2001b). Statistical modeling: The two cultures. *Statistical Science*, 16, 199-231.

Chapin F.S., McGuire A.D., Randerson J., Pielke R., Baldocchi D., Hobbie S.E., Roulet N., Eugster W., Kasischke E., Rastetter E.B., Zimov S.A. & Running S.W. (2000). Arctic and boreal ecosystems of western North America as components of the climate system. *Global Change Biology* 6, 211-223.

Chapin F.S., Sturm M., Serreze M.C., McFadden J.P., Key J.R., Lloyd A.H., McGuire A.D., Rupp T.S., Lynch A.H., Schimel J.P., Beringer J., Chapman W.L., Epstein H.E., Euskirchen E.S., Hinzman L.D., Jia G., Ping C.L., Tape K.D., Thompson C.D.C., Walker D.A. & Welker J.M. (2005). Role of land-surface changes in Arctic summer warming. *Science*, 310, 657-660.

Dahlberg A. (2002). Effects of fire on ectomycorrhizal fungi in fennoscandian boreal forests. *Silva Fennica*, 36, 69-80.

Hobbie S.E. & Chapin F.S. (1998). An experimental test of limits to tree establishment in Arctic tundra. *J. Ecol.*, 86, 449-461.

Johnson D., Kershaw L., MacKinnon A. & Pojar J. (1995). *Plants of the Western Boreal Forest and Aspen Parkland*. Lone Pine Publishing, Edmonton.

Johnstone J., Chapin III F., Foote J., Kemmett S., Price K. & Viereck L. (2004). Decadal observations of tree regeneration following fire in boreal forests. *Canadian Journal of Forest Research*, 34, 267-273.

Johnstone J.F. & Chapin F.S. (2003). Non-equilibrium succession dynamics indicate continued northern migration of lodgepole pine. *Global Change Biology*, 9, 1401.

Johnstone J.F. & Chapin F.S. (2006). Effects of soil burn severity on post-fire tree recruitment in boreal forest. *Ecosystems*, 9, 14-31.

Johnstone J.F., Chapin F.S., Hollingsworth T.N., Mack M.C., Romanovsky V. & Turetsky M. (2010). Fire, climate change, and forest resilience in interior Alaska. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere*, 40, 1302-1312.

Kasischke E.S. & Turetsky M.R. (2006). Recent changes in the fire regime across the North American boreal region - Spatial and temporal patterns of burning across Canada and Alaska. *Geophys. Res. Lett.*, 33, 5.

Lloyd A.H. & Fastie C.L. (2003). Recent changes in treeline forest distribution and structure in interior Alaska. *Ecoscience*, 10, 176-185.

McGuire A.D., Sitch S., Clein J.S., Dargaville R., Esser G., Foley J., Heimann M., Joos F., Kaplan J., Kicklighter D.W., Meier R.A., Melillo J.M., Moore B., Prentice I.C., Ramankutty N., Reichenau T., Schloss A., Tian H., Williams L.J. & Wittenberg U. (2001). Carbon balance of the terrestrial biosphere in the twentieth century: analyses of CO2, climate and land use effects with four process-based ecosystem models. *Global Biogeochemical Cycles*, 15, 183-206.

Pielke R.A. & Vidale P.L. (1995). The boreal forest and the polar front. *J. Geophys. Res.-Atmos.*, 100, 25755-25758.

Rupp T.S., Chen X., Olson M. & McGuire A.D. (2007). Sensitivity of simulated boreal fire dynamics to uncertainties in climate drivers. *Earth Interactions*, 11, 1-19.

Rupp T.S., Starfield A.M. & Chapin F.S. (2000). A frame-based spatially explicit model of subarctic vegetation response to climatic change: comparison with a point model. *Landsc. Ecol.*, 15, 383-400.

Viereck L.A., Dyrness C.T., Batten A.R. & Wenzlick K.J. (1992). The Alaska vegetation classification. In: *General Technical Report PNW-GTR-286* U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, Oregon, USA, p. 278.

Wilmking M. & Juday G.P. (2005). Longitudinal variation of radial growth at Alaska's northern treeline - recent changes and possible scenarios for the 21st century. *Global and Planetary Change*, 47, 282-300.