Project Title: Post-Fire Studies Supporting Computer-Assisted Management of Fire and Fuels during a Regime of Changing Climate in the Alaskan Boreal Forest

Principal Investigators: Scott Rupp and Daniel Mann

Affiliation: Department of Forest Sciences, University of Alaska Fairbanks

Address: PO Box 757200, Fairbanks, AK 99775

Telephone/Facsimile Numbers: (907) 474-7535/(907) 474-6184

Email: ffsr@uaf.edu

Point of Contact: Scott Rupp; ffsr@uaf.edu; (907) 474-7535

Federal Cooperator: Karen Murphy, USFWS; Karen_A_Murphy@fws.gov; (907) 786-3501

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Abstract: Land managers face unique challenges in Alaska. Most of the boreal forest is currently managed as wilderness. Though largely free of direct human impacts, the boreal forest grows in a region that is now experiencing significant climate changes. In addition, the fire ecology of Alaska is relatively poorly understood, and these data gaps hinder effective fuel and fire management there. To meet these challenges, we have developed the computer model Boreal ALFRESCO for use as a multi-disciplinary planning tool and as an operational tool for assessing fuels and fire hazards. Boreal ALFRESCO simulates the responses of boreal forest vegetation on real landscapes to changes in fire management, ignition frequency, and climate. Boreal ALFRESCO is up and running – we submitted a beta version to our agency partners in November 2004 as part of our previously funded JFSP project. Here we propose to further develop Boreal ALFRESCO by filling important data gaps and expanding its ability to model climate change. This work will benefit the implementation of the FRCC and LANDFIRE programs in Alaska.

Land managers have identified several data gaps regarding fire regimes in Alaska. One gap concerns the relative importance of stand age, stand type, and fire weather/climate in determining burn severity. The first goal of our proposed work is the post-fire assessment of the factors controlling burn severity using the extraordinary 2004 fire season as a natural laboratory. Another gap in our understanding of the boreal forest is the effect of climate change on the fire regime. High latitude forests like Alaska's are predicted to be affected first and most drastically by anthropogenic climate changes. Our second goal is to enable Boreal ALFRESCO to predict changes in fire regime and fire hazards based on changes in climate. This has not been done before, and the techniques we develop may have important applications elsewhere.

This proposal is submitted under the 2005-2 Local Research Needs AFP. In addition, this work addresses three other tasks described in the 2005 JFSP AFP.

Signature of PI ____ **Date:** _________

Signature of Federal Cooperator ___________________________ **Date:** _________

Signature of Federal Fiscal Representative: ___________________ **Date:** _________

(Sheri Della Silva, Supervisory Contracting Specialist; U.S. Fish and Wildlife Service)

INTRODUCTION

Alaska's boreal forest differs in several fundamental ways from forest types in the lower 48 states. It covers a large contiguous area, most of which is still in a pristine state, and it occurs in a region of marked climatic instability. The burnable acreage in Alaska exceeds the combined areas of the states of Montana and Idaho. Although the Alaskan boreal forest makes up a significant fraction of fire-prone ecosystems in the United States, there is much we do not understand about its fire ecology. While there are several hundred studies of fire history in the intermountain West, there are only five in Alaska. Direct human impacts like logging and land clearing are relatively unimportant in Alaska, but the indirect impacts of anthropogenic climate change are of immediate concern there. Climate models indicate that high latitude regions like Alaska will be the first to experience global warming. Climate-induced changes to Alaska's fire regimes could provide important lessons for managers working in other regions. The unique qualities of the Alaskan boreal forest and our relative ignorance about it pose special challenges for the design and implementation of landscape-level fire and fuels management.

The design of this project evolved through discussions and workshops with Alaskan land managers. Managers and administrators here indicate that they need four things:

1) Empirical data describing the effects of stand age, vegetation type, and weather/climate on burn severity in the Alaskan boreal forest.
2) Predictions about how future changes in climate will affect the natural fire regime.
3) Methods and assistance for adapting FRCC to the unique conditions of Alaska's forests.
4) Modeling tools for exploring different scenarios of fire-management strategy, climate change, and human population growth across multiple scales of space and time.

We plan to address these needs by a combined field and modeling approach. New field data will describe the relative importance of climate, vegetation type, and stand age in determining burn severity during the extreme 2004 fire season in Alaska. This data will be used to further develop the Boreal ALFRESCO model, which is a spatially explicit, frame-based model capable of integrating climate-change scenarios within simulations of fire-vegetation interactions across time scales of years to centuries and spatial scales of hectares to 1000s of square kilometers (Rupp et al., 2000, 2004). The modeling component of this project will provide land managers with the ability to simulate the response of future fire regimes to a changing climate. These model simulations also will provide potential natural vegetation groups (PNVGs) and estimates of fire return intervals required for FRCC mapping. These combined capabilities will enable Boreal ALFRESCO to simulate the impacts of climate change on FRCC – a novel ability that has important ramifications for long-term forest management.

MEETING JFSP TASKS

This project is submitted under the 2005-2 Local Research Needs AFP. It addresses three other tasks as well.

- <u>2005-1, Task 2. Rapid Response to 2004 Wildland Fires:</u> A major gap in our understanding of the fire ecology of the boreal forest is the relative importance of stand age, stand type, and weather/climate in determining burn severity. The record-breaking size of the 2004 burns in Alaska provides an ideal natural laboratory to fill this data gap. We want to use the 2004 fires to partition the effects on burn severity of age-dependent fuel accumulation, the flammability differences inherent to stand type, and climatic factors. It is critical that we start work immediately, before evidence is lost that describes pre-fire fuel loading.
- <u>2005-2, Task 1. Data Gaps Identified by Agency Administrators:</u> Managers from collaborator agencies have identified the age-dependent flammability question just described as an important local need. Understanding the factors that control burn severity will provide crucial information for the design and implementation of fuel thinning projects, and data on these topics will assist managers in developing better VDDT/FRCC models for Alaska. Another gap identified by managers is our understanding of how future climate changes will impact Alaska's fire regimes.

Once calibrated against the last several centuries of climate-fire interactions, Boreal ALFRESCO can simulate the future responses of vegetation and fire regime to different scenarios of climate change.

- 2005-4, Task 1. Extending Technology Transfer: We presented a beta version of Boreal ALFRESCO to land managers in November 2004 for testing. The proposed project will develop Boreal ALFRESCO further as a locally applicable, integrative planning tool.
- 2005-4, Task 2. Produce Syntheses Useful for Fire and Fuel Management: Adding new field data and expanding Boreal ALFRESCO's capacity to incorporate climate change will assist land managers in their participation in the FRCC and LANDFIRE programs. FRCC's VDDT models, for example, assume an equilibrium state, which may not be an accurate assumption for Alaska forests given the background of marked climatic change. FRCC requires estimates of fire return intervals and PNVGs, and Boreal ALFRESCO can provide these.

GENERAL OBJECTIVES

Our goal is to provide a scale-integrative planning and monitoring tool for wildland fuels and fire management that is specifically tailored to Alaska's ecological conditions and that addresses particular threats (notably climate change) to its natural fire regimes. To accomplish this, we will analyze the processes that determine burn severity in the boreal forest and quantify the impacts of climate change on fire regimes and forest age structures. These results will be used to further develop the Boreal ALFRESCO computer model and to extend the technology transfer process initiated by our present JFSP project. Boreal ALFRESCO provides a much-needed tool for synthesizing multi-disciplinary management issues as well as an operational tool in preparing environmental assessments for fuels and fire management. Boreal ALFRESCO outputs will also assist managers in their FRCC efforts by providing the natural reference landscapes and estimates of fire frequency needed by VDDT models. In the longer term, this project will provide valuable information and methodology for the LANDFIRE project in Alaska. Overall, this project will increase our understanding of vegetation and fuel dynamics during a regime of changing climate and improve our ability to manage this vast, dynamic landscape.

BACKGROUND

A FOREST ON THE EDGE

Alaska's boreal forest grows near the physiological limits of trees. Latitudinal treeline lies along the southern flank of the Brooks Range, and altitudinal treeline lies at only about 600 m throughout the region (Lloyd and Fastie, 2003). Moreover, Alaska is located in the climatically unstable, subarctic region. Global climate models agree that the effects of anthropogenic climate warming will occur first and most drastically at high latitudes (IPCC, 2001). In fact, Alaska has warmed significantly over the past several decades with an average increase in mean annual temperature throughout the state of 4^{o}F since 1950. Accompanying this warming has been a 30% increase in precipitation. The US Global Change Research Program (2000) concludes that the greatest environmental stressor to Alaskan ecosystems at the present time is climate change rather than any direct human impact.

Climate modelers predict that rapid warming will continue in Alaska. Both the Hadley and Canadian models predict $1.5\text{-}5^{o}$ F of warming by 2030 (Hadley), and the Canadian model predicts a staggering $7\text{-}18^{o}$ F rise by 2100. Both these models predict increasing precipitation but indicate that the increased evaporation caused by warmer temperatures will offset higher precipitation and actually make soils drier. Climatic warming is predicted to cause an increase in wildland fires at the same time that the range limits of tree species are shifting in response to changes in temperature and effective moisture (Barber et al., 2000; Lloyd and Fastie, 2002). This combination of more frequent fires and altered growing season conditions may cause unprecedented shifts in forest biogeography throughout the subarctic region over the next century.

The influence of climate on the Alaskan fire regime was dramatized last summer when a record area of 6.7 million acres burned. This was the largest fire season since the BLM Alaska Fire Service began official record keeping in 1950. Widespread burning in the eastern Interior in 2004 was a response to record drought conditions that lasted into September. The total area burned was consistent with the climate-fire regression model of Duffy et al. (2004), though long-term forecasts made last spring by the National Weather Service failed to predict the unusually long duration of the blocking high. Such blocking highs are expected to occur more frequently in the region as climate continues to warm.

In summary, the most pervasive human impacts on the Alaskan forest will occur not directly through human-caused fuel buildup or logging but *indirectly* through anthropogenically induced climate changes. These changes are predicted to affect high latitude regions first and to cause radical shifts in temperature and moisture, with subsequent impacts on soil conditions and plant species distributions. Fire regime will change in response to these shifts in climate. Changes in fire regimes will have widespread impacts on boreal forest ecosystems because fire is this forest's single most important disturbance factor.

DATA GAPS

Boreal ALFRESCO simulations and FRCC workshops reveal significant gaps in our understanding of the fire ecology of the Alaskan boreal forest. These gaps need to be filled before we can effectively manage this forest. The first gap concerns what factors control the hazard of burning. How do stand age, stand type, and climate interact to determine hazard of burning in the boreal forest? Fuel buildup that occurs as stands grow older lies at the heart of the JFSP program. As detailed below, there is disagreement among researchers whether age-dependent flammability is an important determinant of fire hazard in the boreal forest. Extreme fire weather and/or age-*independent* variation in flammability according to stand type may be more important.

A second major gap concerns the influence of climate change on fire regime in the boreal forest. As described earlier, Alaska will see earlier and probably more drastic climate changes than other parts of the United States over the next century. Although the boreal forest may be remote and unroaded, it is vulnerable to the impacts of climate change, and these impacts are likely to be mediated through changes in the fire regime.

Gap 1: Hazard of Burning

Age-Dependent Flammability?

Age-dependent flammability in the boreal forest is currently a topic of controversy. Foresters and land managers in Alaska often assume that fire hazards increase with stand age because of fuel buildup. However, E.A. Johnson (1992) argues convincingly that bouts of extreme fire weather, coupled with the continually high flammability of boreal forest vegetation, determines the fire regime of the boreal forest and overwhelms any consequences of age-dependent fuel buildup (Bessie and Johnson, 1995). As Johnson et al. (2001) put it: "*This is because fuel moisture, which is determined by weather, varies over four orders of magnitude, whereas fuel load varies only sevenfold*." Johnson (1992) argues that flammability increases to a high, constant level within 10-20 years of a previous burn in the boreal forest because fuels accumulate rapidly, and that in many cases there is no flammability lag at all because abundant fuels survive from the previous fire.

Climate-Dependent Flammability Is a Fact

Our ongoing JFSP-funded research reveals that indeed climate exerts a strong effect on the annual area burned in Alaska (Duffy et al., 2004). As a first step in quantifying climate-fire connections in Alaska, we used multiple linear regressions (MLR) to systematically explore the relationships between climate variables and the annual area burned in Alaska. Seven explanatory variables and an interaction term collectively explain 79% of the variability in the hectares burned annually by lightning-caused fires between 1950 and 2003. June average temperature is the most significant explanatory variable, by itself explaining 34% of the variability in the response (Duffy et al., 2004).

At multi-month scales, two teleconnection patterns influence area burned in Alaska. Strong positive phases of the Eastern Pacific (EP) pattern in summer months favor the development of blocking highs that create stable periods of hot, dry weather that are conducive to burning. Negative phases of the

EP pattern are associated with strengthened westerlies in the northeast Pacific as a consequence of a more zonal pattern of upper-level airflow. A shift in sign of the EP teleconnection over a period of several months in winter can presage summer weather in Alaska. The shift from a negative phase of the EP in winter to a positive phase in spring is correlated with a dry, hot summer in Alaska.

Another teleconnection, the Pacific Decadal Oscillation (PDO), also influences the area burned in Alaska. During cool phases of the PDO, drier spring conditions are more likely. Sixty-nine percent of the area burned for the period of this study occurred during cool phases of the PDO. The Pacific Decadal Oscillation and the East Pacific teleconnection indices are useful in predicting the number of hectares that will burn in an upcoming fire season (Duffy et al., 2004).

The Fire-Fighters' Perspective

But there are problems with the weather-centric view. If you inspect recent burns in Alaska and talk to wildland fire fighters, there are several things that do not make sense about Johnson's hypothesis. One of his arguments against the importance of fuel buildup is that 99% of the area burned does so during only 1% of the fires. This statistic suggests that large fires burn everything in their paths. Yet burn-area estimates are perimeter-based and they ignore the fact that significant areas of unburned vegetation are left within a fires' perimeter. Last summer's fires in Alaska seem to show the same pattern of fuel-controlled, burn severity within burns as displayed along their perimeters. For instance, unburned islands within burns were typically deciduous stands. It seems that there are fuel-controlled effects that even the fires burning during extreme fire weather cannot erase.

The Conundrum

If fuel loading does matter to fire hazard, how do we reconcile this with Johnson's observations and with our previous results describing the important role played by extreme fire weather in determining the annual area burned? And how do we reconcile the lack of correlation between stand age and flammability that Johnson cites with field observations that repeatedly demonstrate the differing flammability of different stand types?

An Integrated Conceptual Model

A possible way out of this conundrum is that stands differ in their flammability for reasons other than their age. Perhaps certain stand types, regardless of age, are always more flammable than others. Black spruce stands, whether they are 20 years old or 200, are more flammable than birch stands. Stand *type* rather than stand *age* may be the most important, *vegetation-derived* determinant of fuel availability and flammability.

If this stand-dependent flammability hypothesis is true, then it can put our conceptual model of the boreal forests fire regime into a more consistent framework. Johnson can be correct about the importance of extreme fire weather events in determining the perimeter-area burned annually in the boreal forest, a result supported by the findings of Duffy et al. (2004) for Alaska. Johnson can also be correct that stand age is not a particularly important factor in determining flammability. Yet wildland fire fighters also are correct that stand types differ in their flammability. If flammability differences are primarily a function of stand type, not stand age, then stand-dependent flammability could be the most important factor in determining the pattern of burn severity *within* the overall perimeter of a burn. Climate and weather determine the perimeter area of burns, but stand-dependent flammability (and perhaps age-dependent flammability to a limited extent) determines which stands burn within the outer fire perimeter. Quantifying these phenomena will improve Boreal ALFRESCO's ability to model the forest's responses to changes in fire regime and shifts in fire-management policies. This translates into fire managers being better informed about the ecosystems they manage.

<u>GAP 2: Changing Climate and Fire Regime</u>

Climate change directly affects fire regimes, and fire is the keystone disturbance agent of the boreal forest. The importance of climate as a driver of fire frequency and intensity has been amply demonstrated in the western United States. Climate can affect fire indirectly by controlling fuel buildup (e.g., Swetnam and Betancourt, 1998) or directly by controlling fuel moisture (Schoennagel et al., 2004). High latitude climates are changing rapidly (Serreze et al., 2000), and are predicted to continue changing. Our ongoing JFSP-funded research reveals that climate exerts a strong effect on fire frequency and hence forest regeneration in Alaska. Changes in climate will change fire regimes here.

Our work relating area burned in Alaska to monthly weather conditions and teleconnection indices (Duffy et al., 2004) is the first step in quantifying the link between climate and fire in Alaska. There are several important things to do next. One is to look for correlates between the characteristic fire frequency occurring in different parts of Alaska and particular climatic conditions there. For instance, how have climatic shifts over the last 200 years influenced fire frequency during this same period? How sensitive is fire frequency to climatic change? If we understand the results of these past "natural experiments" in climate-fire relationships, we can better predict future changes.

MATERIALS AND METHODS (ABBREVIATED)

1) New Field Data

Study Areas

We will focus our efforts on remote fires (both 2004 and older) on the Kanuti and Yukon Flats National Wildlife Refuges and on Yukon-Charley National Park. In addition, we will evaluate burned areas in Tetlin National Wildlife Refuge, Denali National Park, White Mountains National Recreation Area, and the Steese National Conservation Area. We will also take advantage of road-accessible fire complexes that burned in Interior Alaska during 2004 (e.g., Taylor, Eagle, Central, Boundary, and Camp Creek). Burn severity mapping has been completed or is currently in progress for most of the 2004 burns (2004 Burned Area Emergency Response (BAER) Team). Time is of the essence, with respect to the 2004 fires, because part of our study involves reconstructing pre-fire vegetation, specifically the determining of tree ages and estimating the thickness of the pre-fire organic mat.

Data Gap 1: Factors Controlling Flammability

a) Age-Dependent Flammability

There are two ways to test for age-dependent flammability, one more direct than the other. The indirect method is to quantify fuel loading in unburned stands of known age, and then using the amounts and types of fuels to try and model the severity of future burns (see JFSP 2004 Camp and Omi award). The more direct method is to go into recent burns, collect tree ages, and ground truth the burn severity mapping based on remote sensing. We think that the direct method is the most practical, especially given the natural laboratory presented by the large 2004 fires in Alaska. Part of our choice of methods is conditioned by the Boreal ALFRESCO model. The model tracks stand ages, not fuel conditions *per se*. The direct approach also makes sense from a manager's perspective. It is easier to determine stand age than to quantify fuel loading. That said, we will record all evidence for what the pre-fire fuel conditions were in our study plots. Many fires in Alaska depend on ground-layer fuels for fire spread. By recording the pre-fire thickness of soil organic horizons, we may be able to correlate any age-dependent flammability effects that we detect to specific processes of fire spread. Typically in burned stands, some evidence for the pre-fire thickness of the organic mat is recorded by patches of unburned moss and by the level of adventitious roots exposed on the snags of black spruce trees.

Our null hypothesis is that no difference exists in the Normalized Burn Ratio (NBR) between stands of different ages. NBR is a remotely sensed metric of burn severity. A total of approximately 500, 10 x 10 m plots will be placed in stands that burned in 2004. These plots will be located over an area the size of Idaho. We will locate stands of varying ages using the Alaska Fire Service's Large Fire Database to find stands <50 years old. We will use all available pre-fire remote sensing imagery (e.g., LANDSAT, SPOT and Quickbird) to locate older stands as judged by tree height/density and the development of their lichen understory. It is of special importance to find stands with an age <40 years, the time when the highly flammable feather mosses are thought to first become abundant in many black spruce stands (Foote, 1985). To obtain stands of a wide range of ages, sampling will be iterative. The comparison of interest is stand age versus NBR, and most stands on the landscape will likely be in the 70-120 year range. We will use ANOVA to test for differences in the burn severity of stands grouped into 20-year age classes. Black spruce is the dominant tree species in Interior Alaska, so most of these plots will be in small-stature black spruce-dominated vegetation.

The 500 plots will be evenly distributed within burns scattered across our study regions. We are interested in sampling large burned areas (i.e., >40,000 ac [>16,500 ha]) and anticipate sampling at least 10 different burns. Plots will be established randomly along transects with a minimum of 300 m between plots. In each plot, we will fell the two largest trees (a majority will be dead, but some may still be alive) and retrieve cross sections at root collar. In severely burned stands, it may be impossible to find burned trees preserving the outermost annual rings. In this case, cross dating using skeleton plots will be used to determine the pith age of trees. Basal area will be estimated where possible, and evidence collected for the thickness of the pre-fire organic horizons. In the laboratory, cross sections will be sanded to 400-600 grit and their rings counted under a dissecting microscope.

b) Stand-Dependent Flammability

Here we are quantifying fire fighters' observations about the dependence of burn severity on vegetation type. The null hypothesis is that there is no difference in burn severity during fires in 2004 between stands of different species that were 80 and 100 years old. Alternatively, spruce stands may typically burn more severely than aspen or birch stands. Preliminary analyses relating NBR to topographic position suggests that topography is an important modifier of burn severity (Duffy et al., *in preparation*). Therefore, we have stratified the forested landscape into four main types: birch, aspen, black spruce (flats), and black spruce (slopes). White spruce is insignificant over much of the region burned in 2004, and birch and aspen stands are typically restricted to slopes. However, if the opportunity arises to sample white spruce vegetation or deciduous vegetation (flats) we will take advantage of the opportunity and increase our sample size.

Again using available pre-fire remote sensing imagery, we will randomly locate 50 stands of each of the four stand types across the 2004 fires sampled. All 200 stands chosen will be within the perimeters of 2004 fires, though individual stands may not have burned in these fires (i.e., they are unburned inclusions). Plot locations will be a minimum of 300 m apart, and unburned inclusions < 100 m^2 will not be selected to ensure our sampling does not alter the ability of the stand to regenerate burned areas. We will visit each plot, fell the two largest trees (burned or alive) of the dominant species, collect a cross section at root collar, and estimate pre-fire basal area and species composition. Cross sections will be processed and rings counted as described earlier. In order to control for age-dependent flammability, stands will be eliminated from analysis if they are <80 years old or >100 years old. Some of the same study plots used in testing age-dependent flammability will likely be used again here.

If stand-dependent flammability is important, a higher proportion of certain stand types (e.g., black spruce) should have burned and burned more severely than other types (e.g., birch stands). The method of analyzing the burn severity data (NBR) is essentially an ANOVA with a spatial component. This class of models is often referred to as Conditional Auto-Regression (CAR) models (Cressie 1993). Since fire is a contagion process, there will be spatial autocorrelation (e.g. stands closer together will be more likely to have similar burn severities). If a standard ANOVA model is used in the presence of spatial autocorrelation, it is more likely that parameters representing explanatory variables (e.g. stand-type) will be found to be significant when in fact they are not. In other words, the presence of auto-correlation introduces a negative bias for the p-values of the ANOVA test. A consequence of failing to account for the spatial auto-correlation in burn severity would be an increased probability of concluding that the mean NBR is different between stand types when in fact it is not. CAR models incorporate the spatial correlation structure into the error matrix of the linear model used to analyze the data. A single parameter (typically referred to as "alpha") in the model estimates the strength of auto-correlation. If alpha is statistically significant, then the auto-correlation is taken into account, and the significance of parameters representing factors (e.g. stand type) can be assessed in a manner unaffected by the spatial auto-correlation. The results of this modeling approach will be a test of the difference of the mean burn severities for each of the stand types. Additional graphical analyses will allow us to introduce an ordering for flammability of stands in the case that differences between the mean burn severities for different stand types are found to be significant.

c) Climate's Role in Fire Hazard

Our conceptual model of the interactions between stand age, stand type, and climate assigns to climate the primary role for determining total area burned, leaving stand type (and possibly stand age) to determine the burn-severity mosaic within a fire's perimeter. Results to date (Duffy et al., 2004) show that climate explains more than 75% of the observed variability in the annual area burned in Alaska since 1950.

Our null hypothesis is that regardless of fire weather (and the preceding months of fire-conducive climate) unburned inclusions of particular stand types and/or stands of particular ages occur within the overall fire perimeter at the same relative frequency. In other words, no matter how extreme or prolonged the fire weather is, unburned inclusions of similar stand types always occur in similar numbers and sizes. If this is true, it suggests that climate/weather determines only the perimeter-area of a fire season, not the mosaic of fire severity occurring within burned areas. The alternative hypothesis is that extreme weather conditions modify patterns of heterogeneity of burn severity within burned areas.

Our test of this hypothesis involves mapping unburned inclusions inside several of the large, 2004 fire complexes that burned during extreme fire weather and climate. After normalizing for the perimeter area of each fire, we will compare the number and areas of these unburned inclusions to those found in a suite of older fires that burned during summers of "normal" fire weather and climate. Testing the null hypothesis will answer the following question: Are there statistically significant differences in the number and sizes of unburned inclusions formed during summers of extreme versus normal fire weather/climate?

Characterization of unburned inclusions within the 2004 burn scars will utilize NBR maps already compiled by the BAER Team. GIS-mapped inclusions will be characterized according to their area, topographic position, dominant tree-species, and aspect. Available remote sensing data will be used to differentiate vegetation in the unburned inclusions. We will utilize as many burn scars as possible, and will ground truth as many inclusions as logistically feasible. We will also take advantage of ground – truthing fieldwork already scheduled by both USFWS and NPS to increase our sample size.

Pre-2004 fires that occurred during summers of "normal" fire weather/climate will be selected from the BLM Alaska Large Fire Database according to the following criteria. First, they must have occurred during summers when total acreage burned was relatively low (e.g., <1 million acres). Second, they must be located in northeastern regions of Interior Alaska, the location of the large 2004 fires. Third, they must possess similar topography to the 2004 fires. We anticipate compiling records of 300-600 unburned inclusions each from 2004 and pre-2004 fire scars.

<u>Data Gap 2: Predicting the Impact of Future Climate Changes</u>

How much control does climate exert over the age structure of the boreal forest through its effects on the incidence of fire? We will answer this question in two ways. First, if E.A. Johnson is correct, most wildland fires in Alaska, and hence most tree recruitment there, occurred during episodes of extreme fire weather in the past. During our previous JFSP project, we gathered 5000 tree ages at random from sites across Alaska. We propose to compare these ages to the record of fire-season weather over the last several centuries. The key question is: Do past recruitment spikes correlate with summers of extreme fire weather?

To compare past climate with tree recruitment, we will use recently developed climate reconstructions that cover the last 200 years of climate history. These data come from several sources. Monthly temperature and precipitation reconstructions developed at the Climate Research Unit (CRU) at the University of East Anglia cover Alaska at 0.5^{o} x 0.5^{o} geographical resolution from A.D. 1900 to 1995 (www.cru.uea.ac.uk/cru/data/). The Cramer-Leemans dataset of monthly temperature and precipitation, also produced by a combination of weather records and regional-scale climate models, extends from A.D. 1859 to 1995 (www.pik- potsdam.de/~cramer/climate.html). Reaching further back in time, dendrochonological reconstructions of growing season temperature extend the record back to around A.D. 1700 in Interior Alaska (Jacoby et al., 1985; Barber et al., 2004). We will use these records to create a composite record of fire-season weather, and age data will then be compared to the reconstructed climate data to identify relationships between fire weather and tree recruitment. Age structures will be normalized following methods of Szeicz and MacDonald (1995). We will ultimately use regression analysis to quantify the proportion of variation in recruitment that is explained by climate.

The second way we will quantify climate's control over fire regime in Interior Alaska employs Boreal ALFRESCO as a virtual reality laboratory. These methods are described in the modeling section below.

2) New Developments in the Boreal ALFRESCO Model

Model Background

ALFRESCO was originally developed to simulate the response of subarctic vegetation to a changing climate and disturbance regime (Rupp et al. 2000a, 2000b). Currently, the Boreal ALFRESCO version (developed under our current JFSP project) operates at multiple time steps (annual or decadal), and calculates vegetation change in response to disturbance at a landscape-level (either 1 x 1 km or 2 x 2 km pixels), a scale appropriate for interfacing with mesoscale climate and carbon models (Starfield and Chapin, 1996). The model currently simulates five major subarctic/boreal ecosystem types: upland tundra, black spruce forest, white spruce forest, deciduous forest, and grassland-steppe. These ecosystem types represent a generalized classification of the complex vegetation mosaic characteristic of the circumpolar arctic and boreal zones of Alaska (Starfield and Chapin, 1996; Rupp et al., 2000a).

Previous research has highlighted both direct and indirect (through changes in fire frequency and extent) effects of climate on the expansion rate, species composition, and extent of treeline in Alaska (Rupp et al. 2000b, 2001). Additional research focused on boreal forest vegetation dynamics has emphasized that fire frequency changes – both direct (climatically or anthropogenically driven) and indirect (as a result of vegetation succession and species composition) – strongly influence landscape-level vegetation pattern and associated feedbacks to future fire regime (Rupp et al. 2002; Chapin et al. 2003; Turner et al. 2003).

Accomplishments in Current JFSP project

Intensive work has proceeded in development of the Boreal ALFRESCO model. Specifically we have:

1) Incorporated new rules for secondary succession into Boreal ALFRESCO.
2) Informed the model with hazard-of-burning rules derived from the tree-age distributions obtained from field sampling of tree populations across the Interior.
3) Incorporated into Boreal ALFRESCO climate-fire histories derived from the Duffy et al. (2004) study of fire-climate interactions in Alaska over the past fifty years.
4) Developed explicit representations of the impacts of fire suppression and human activities (e.g., ignitions) on fire regime and vegetation.

We have used these new model developments to simulate the impacts of changing fire regimes on caribou winter-foraging habitat (Rupp et al. *submitted*, *Ecological Applications*). In November 2004, we held a workshop to train agency managers in using the beta version of the Boreal ALFRESCO model. A software CD and accompanying users' manual was distributed to agency personnel for further testing and developmental feedback.

Proposed Modeling Work

We will perform a series of experiments that isolate the effect of past climatic change on the present-day age structure of the forest as described by our empirical tree-age data. This experiment will be conducted in the following way.

First we will post-dict the area burned in Interior Alaska using a climate-fire regression equation developed in Duffy et al. (2004) to predict area burned from monthly weather data. The Cramer-Leemans and CRU datasets will be used to provide estimates of monthly temperature and precipitation back to the mid-1800s. Prior to that, back to around A.D. 1700, we will use estimates of growing season temperature and precipitation from dendrochronological records (Jacoby et al., 1985; Szeicz and MacDonald, 1995). Once we have post-dicted the annual area burned, we will calibrate Boreal ALFRESCO to produce statistically similar output.

Calibrating Boreal ALFRESCO to produce a climate-derived history of area burned will enable the model to do two new things. First, we can use the model to predict the ages of trees growing on the present forested landscape, given the last several centuries of post-dicted fire extent. From repeated model runs that output an age distribution of stands, we can construct statistical models of tree-age distributions. These modeled distributions will be compared to the tree-age data gathered in our fieldwork. If climate is a major controller of the tree-age distribution, then Boreal ALFRESCO can isolate this effect from the other possible hypotheses (e.g., changes in ignition frequency caused by gold miners around A.D. 1905, age-dependent flammability). Second, based on the calibrated and historically validated simulations we can forecast the next century of possible climate-fire-vegetation interactions in Alaska, including potential feedbacks from specific management scenarios. We will utilize a suite of spatially explicit climate scenarios generated by the National Center for Atmospheric Research (NCAR) as part of the Arctic Climate Impacts Assessment (ACIA 2004). Using these driving climate datasets under various management scenarios, we will simulate future fire regimes and associated vegetation responses. These simulations will help inform managers about the potential future impacts of climate change on fire regimes at landscape scales.

We also propose to develop a prototype Boreal ALFRESCO model version that operates at a spatially fine-scale (30 x 30 m pixel) for project assessments at the spatial scale of individual refuges and parks. This prototype model version would maintain all the functionality of the current Boreal ALFRESCO model version but also allow for the incorporation of fine-scaled, remotely sensed, biophysical data products. These new model developments will provide federal and state fire managers in Alaska with a truly integrative planning tool that can assist in the assessment of past, current, and future management strategies under differing scenarios of environmental and management-policy changes. Based on climate change projections and model simulations, managers will be able to develop project-scale future FRCC predictions under a defined management scenario.

BENEFITS TO THE ALASKAN FRCC AND LANDFIRE EFFORTS

1) Further development of the field-informed Boreal ALFRESCO model will assist FRCC procedures by providing VDDT models with realistic, simulation-based estimates of successional rates and trajectories within the major ecosystems of Alaska. Boreal ALFRESCO is uniquely suited to do this because it simulates vegetation succession (i.e., transition rates) and accommodates changes in fire regime and climate on model landscapes that possess real topographies and climate histories.

2) Boreal ALFRESCO will provide temporal sequences of spatially explicit maps under transient conditions statewide. We will simulate the past 200-300 years of climate-fire-forest interactions in order to develop realistic, spatially explicit reference landscapes against which VDDT simulation results can be compared and tested. Because of Alaska's remoteness, the observations required to develop ground-truthed, reference landscapes are extremely limited. Boreal ALFRESCO offers an efficient and accurate way to derive multiple reference landscapes to serve as test landscapes for VDDT. Currently, we are working with managers at the Kanuti National Wildlife Refuge developing some of this new methodology. These reference landscapes and future PNVGs will be valuable to the Alaskan LANDFIRE effort and its integration with FRCC (see letters of support from W. Hann and M. Rollins). Development of a fine-scaled Boreal ALFRESCO version will be particularly useful in this regard.

3) Linking Boreal ALFRESCO and VDDT offers the novel opportunity to simulate future FRCCs based on climate change scenarios. Alaska's vulnerability to ongoing climate change makes it the ideal site for such investigations. This information will be particularly important to Alaska's fire managers as they face the challenges of managing fuels and fires in the face of global change. The techniques we develop here may prove valuable in other parts of the United States.

PROJECT MANAGEMENT PLAN

The University of Alaska Fairbanks is the lead institution, with Rupp and Mann sharing overall responsibility for the project. Responsibilities are distributed primarily according to our two primary tasks, with Mann leading the field component and Rupp leading the modeling component of the study. Our main Federal cooperator is the USFWS, with Murphy having overall responsibility for coordinating Federal cooperation. Rupp and Mann will supervise and direct the research technicians, two will work on the field component of the study, and the other will be involved in the modeling. The entire research team (including all Federal and State cooperators) will have annual meetings to discuss strategies for developing, modifying, and implementing the model. Subsets of the larger group (see Appendix 5) will meet more frequently to guide development of particular components within the modeling and field research programs (e.g., fuel-types classification and climate change). We will make these meetings accessible to other land managers who are not directly involved in the project, but who might benefit from the deliverables (see Appendix 1) and provide input during development phases.

Year 1	- Research team organization and project initiation - Field preparation: site location, sampling design, logistical planning; Initiate fieldwork - Model development: modifications to spatial resolution - All-Cooperators Meeting (presentation of field and modeling results, cooperators' feedback) - Annual report to JFSP and agency partners
Year 2	- First technology-transfer session with agency cooperators - Laboratory work – sample analysis - Initiate second field season - Model development: climate work - Develop prototype fire management tool - All-Cooperators Meeting (presentation of field and modeling results, cooperators' feedback) - Annual report to JFSP and agency partners - Perform model testing and initial calibration efforts
Year 3	- Finish any uncompleted fieldwork - Complete laboratory and modeling work - Peer-reviewed journal publications based on field data and modeling work - All-Cooperators Meeting; Final report to JFSP and agency partners - Two training workshops with key agency personnel to transfer modeling program - Deliver user-guide for management model

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APPENDIX 1—DELIVERABLES

The primary goal of this project is to further develop the computer-based management tool, Boreal ALFRESCO, to assist land managers faced with the task of managing wildfires for the mutual benefit of the natural ecosystems and the human residents of Interior Alaska. The primary deliverable will be a user-friendly, fire-management computer model, Boreal AFRESCO. Details of how this model works and its program will be delivered as described in the technology transfer section (see Appendix 2). In the process of developing this modeling program, we will develop spatial data sets and maps showing the results of our calibration studies for Interior Alaska. These results will be posted for access by the cooperating agencies and the public on the Alaska Geospatial Data Clearinghouse (AGDC) website. All data sets will be documented using FGDC metadata standards. Specific details of deliverables are detailed below:

Deliverable	Description	Delivery Date
Study Sites Map	GIS data layer identifying plot locations, burn perimeters, etc.	Fall 2005
Annual Report	Project status report to JFSP and agency partners.	Spring 2006
Cooperators Meeting	Presentation of fieldwork, model development, etc; request feedback from collaborators.	Spring 2006
Tech Transfer Workshop	First workshop to initiate model testing and manager input.	Spring 2006
Study Site Data Delivery	Provide preliminary results of fieldwork to specific NWRs and NPs	Fall 2006
FRCC Information Transfer	Initialize discussions on manager requested FRCC support and methodology.	Fall 2006
Annual Report	Project status report to JFSP and agency partners.	Spring 2007
Cooperators Meeting	Presentation of fieldwork, model development, etc; request feedback from collaborators.	Spring 2007
Tech Transfer Workshop	Second workshop to test and calibrate model.	Spring 2007
FRCC Information Transfer	Provide VDDT parameterization data sets to Alaskan managers task with FRCC compliance.	Spring 2007
Study Site Data Delivery	Provide final results of fieldwork to specific NWRs and NPs	Fall 2007
FRCC Information Transfer	Provide improved VDDT parameterization data sets to Alaskan managers task with FRCC compliance.	Fall 2007
Cooperators Meeting	Presentation of fieldwork, model development, etc; request feedback from collaborators.	Spring 2008
Journal Articles	Write and submit series of peer-reviewed journal articles.	Spring 2008
Tech Transfer Workshops	Two workshops to train and implement Boreal ALFRESCO model.	Spring 2008
Final Report	Final project report to JFSP and agency partners	Summer 2008

APPENDIX 2—TECHNOLOGY TRANSFER

The transfer of knowledge, data, and computer resources from this research will occur in six ways:

1) We will work with BLM's GIS specialist, Mr. Parker Martyn, to ensure that relevant model output (in the form of GIS coverages) will be accessible to cooperating agencies and to the public. We will use the Alaska Geospatial Data Clearinghouse website as an electronic forum to widely distribute field data, model results, and associated metadata.
2) Rupp and Duffy will work with BLM's GIS coordinator, Parker Martyn, to further develop the new version of Boreal ALFRESCO for use by various Federal and State user groups. Both Duffy and Martyn have experience in technology transfer. We will begin technology transfer in year two of this project and continue it during year three.
3) Our All Cooperators Meetings/Workshops hosted by the University of Alaska Fairbanks will provide a forum for presentations and progress reports where managers and resource specialists can receive updates on the research and provide valuable input. We expect the new version of Boreal ALFRESCO to be a useful management tool for many other Federal, State and Native land managers in Interior Alaska including Native-village and regional corporations, State Department of Forestry, and the United States Army. All these agencies administer large areas of wildlands where fire is both a key ecosystem process and a constant threat to human affairs.
4) Reports will be delivered annually at JFSP workshops and several scientific papers will be developed for publication in peer-reviewed scientific journals.
5) A hard-copy and web-based user's guide will be developed that describes all relevant advances and new functionality of Boreal ALFRESCO, and provides guidance for its application by resource managers.
6) Rupp, Duffy, and Martyn will conduct multiple training sessions and workshops with key agency personnel to transfer the modeling program and its application to the managers.