Project Title:	**Reconstructing fire regimes in tundra ecosystems to inform a management-oriented ecosystem model**
AFP and relevant task statement:	Joint Fire Sciences AFP 2006-3 Task 1
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Abstract:

Fire and fuels management goals in Alaska are hindered by a limited understanding of fire history and the controls of fire regimes. Nowhere is this statement more accurate than in tundra ecosystems that cover nearly one-third of the state. Over 60 communities and 348 native allotments are located within this fuel type, and as in any region, fire and land managers working with tundra face decisions on fuels management, suppression tactics and pre-suppression staffing. However, unlike other regions, these decisions are currently made in the absence of long-term fire history records and limited empirical knowledge on the relationships between fire, climate and vegetation. Current and future climatic change also challenge land managers as they consider the impacts of increasing temperatures on tundra fire regimes and the cascading effects this could have on other ecosystem processes.

The treeless tundra presents difficulties for reconstructing fire histories with traditional tools such as dendrochronology. This study capitalizes on the ability to reconstruct both vegetation and fire history with lake-sediment records. Using macroscopic charcoal from well-dated lake sediments we will reconstruct the frequency component of fire regimes at two sites in two tundra types across the Seward Peninsula and within the Noatak River watershed. Fossil pollen from each of these eight sites will allow us evaluate large-scale changes in the vegetation communities over the span of the fire-history records. Our sampling design facilitates inferences into the relative importance of climate and vegetation on the frequency component of tundra fire regimes. Results from this study will provide managers with quantitative estimates of fire-return-interval distributions over the past several centuries to several thousand years. This information will immediately prove useful for classifying fire regimes, understanding the historic range of variability in these systems, and participating in National fire initiatives such as Fire Regime Condition Class (FRCC) and LANDFIRE.

Fire-history data in addition to vegetation classifications and modern climate data will also serve to refine the Boreal version of the Alaskan Frame-based Ecosystem Code (Boreal ALFRESCO), a model specifically designed to simulate climate-vegetation-fire linkages in Alaskan biomes. With prior funding from the Joint Fire Science Program (JFSP 01-1-1-02 and 05-2-1-07) Boreal ALFRESCO has increasingly been adopted by Alaskan fire managers as a tool for assessing fuels and fire hazards. This study will provide the observations required to add representations of different tundra fuel types and climatic regimes to Boreal ALFRESCO. Development and parameterization of this new fuel component should substantially improve Boreal AFRESCO's ability to simulate tundra fire dynamics. Our proposal thus addresses the Board’s interest in understanding fire history in regions where fire regimes are not currently well defined, and it integrates this knowledge into a landscape model that is increasingly used within the Alaskan fire-management community.

1. INTRODUCTION

Fire mangers in Alaska face significant challenges unique to this vast region. Alaska contains extensive ecosystems that are rare or absent from the contiguous United States. Arctic and subarctic tundra, for example, cover nearly one-third of the state, encompassing over 60 communities and 348 native allotments. Under warm, dry conditions tundra fuels are highly flammable, and over the past fifty years more than 1.7 million hectares (4.1 million acres) of Alaskan tundra have burned (Alaska Fire Service, 2005). Despite the abundance of this fuel type, the empirical information on fire regimes required for fire and resource management in tundra is lacking. National fire initiatives such as LANDFIRE and Fire Regime Condition Class (FRCC) require knowledge of historic fire return intervals (FRIs) to make landscape-level fire and fuels management decisions, yet even this basic information is missing in virtually all tundra ecosystems.

Alaskan fire managers also face the unique challenge posed by climate-induced changes in vegetation and physical processes across tundra regions (e.g. Hinzman et al., 2005). Increases in shrub density documented over the past several decades (Silipaswan et al., 2001; Stow et al., 2004), for example, represent an important change to the fuel characteristics in tundra. Recent paleoecological evidence, which indicates high flammability of shrub tundra in the past (Higuera et al., 2005b), also suggests the possibility that increasing shrub density could lead to increased area burned in tundra regions.

Thus not only are tundra fire regimes poorly understood, but also their key vegetation and climate controls appear to be changing. These unknowns impose a major challenge to fire management efforts to anticipate the impacts of future vegetation and climate change on tundra fire regimes.

1.1 Project Objectives

The unique qualities of Alaskan tundra and our relative ignorance about this ecosystem pose special challenges for the design and implementation of landscape-level fire and fuels management. Confronting these challenges requires managers to understand the relationships between fuels, climate and fire and to consider landscapes in the context of historic variability. The proposed study address AFP 2006-3, Task 1 through two components. **First, we will provide long-term records of fire history in two of the most flammable tundra-dominated regions in Alaska (Seward Peninsula and Noatak River watershed). Second, we will use these records to infer relationships between climate, vegetation, and flammability. This understanding will be employed to refine the tundra component of an increasingly-used ecosystem model designed to aid Alaskan land managers in assessing fuels and fire hazards.**

Our specific research goals are to:

(1) **Use macroscopic charcoal from lake-sediment records to characterize the frequency component of fire regimes in two dominant tundra types in northwestern Alaska over the past 5000 years.** Quantitative fire-return interval data, stratified by tundra type and study region, will immediately allow fire and resource managers to make informed decisions about fire and fuels management. National fire initiatives such as LANDFIRE and FRCC depend upon this information to facilitate management decisions at the project and landscape scale.

(2) **Develop a mechanistic representation of climate-vegetation-fire relationships and integrate this into a management tool for assessing fire and fuels hazards in tundra ecosystems.** We will use the FRIs derived from sediment records in addition to modern climate data and vegetation classifications (Walker et al., 2005) to refine the Boreal version of the Alaskan Frame-based Ecosystem Code (Boreal ALFRESCO), a model specifically designed to simulate climate-vegetation-fire linkages in Alaskan biomes (Rupp et al., 2000a). Boreal ALFRESCO has increasingly been

adopted by Alaskan fire managers as a tool for assessing fuels and fire hazards. This study will expand the scope of the Joint Fire Science Program-funded (JFSP) Boreal ALFRESCO version (JFSP **01-1-1-02** and **05-2-1-07)** through the development of additional vegetation types (i.e. "frames") to specifically simulate tundra.

1.2 Management Needs

Assessing fire hazard, determining fuel treatment methods, and evaluating the impacts of fire suppression on fire regimes all require basic information on FRIs and the relationships between fuels, climate, and fire occurrence. While fire and resource managers throughout most of western North America have access to such information, managers working in tundra ecosystems lack even basic fire history records. As recognized by the JFSP Board and Alaskan land managers (Appendix C), this lack of information on tundra fire regimes represents a serious limitation to fire and fuels management.

The impacts of fire suppression in Alaska are thought to be negligible because suppression efforts have only been in place since the 1940's and the majority of the state's public lands (67%) are under limited suppression. Tundra represents a contrast to this generalization because large areas have been managed with active fire suppression to protect reindeer range lands. Studies tracking tundra vegetation after fires indicate that lichen is negatively impacted, with little lichen recovery up to 15 years post-fire (Racine et al., 2004). As a result of the negative impacts of fire on lichen and thus reindeer range lands, only 27% of the 5.7 million hectares (14 million acres) of tundra on the Seward Peninsula, for example, are managed under limited fire suppression. The Resource Management Plan (1994) of Bering Land Bridge National Preserve (BLBNP, Seward Peninsula) recognizes the potential conflict between its goal of preserving the role of fire as "a dynamic natural process" and a Congressional mandate to protect reindeer range lands. With respect to fire, the overall goal in the Resource Management Plan is "to allow natural processes to continue within the preserve to the greatest extent possible." Without knowledge of historic FRIs it is impossible to assess whether current management under the Full and Modified fire suppression options of this plan is altering fire regimes.

The proposed study will provide quantitative descriptions of FRIs coving the last several hundred to several thousand years for areas within BLBNP (section **2.5, 2.7**). This information will give land managers a critical baseline from which to measure the impacts of past management practices and to develop future management goals. Fire history information for the Noatak River watershed will serve a similar purpose and will aid several other identified research needs in that region (see attached letter of support from Neitlich, Appendix C). Integrating insights gained from our tundra fire-history records into the Boreal ALFRESCO model will provide the ability to spatially model the effects of climate, fuels and suppression on fire within this ecosystem (section **2.8**). In addition, the two components of our study also address two fire research needs recently identified by the Alaska Wildland Fire Coordinating Group (AWFCG): (1) Empirical data documenting historic FRIs in tundra ecosystems (ID # 11, 16); (2) Information on and tools to evaluate the potential changes in fire regimes under changing climate scenarios (ID # 1; see letter of support from the AWFCG, Appendix C).

1.3 Controls of Tundra Fire Regimes

The current ignorance about the patterns, controls, and effects of fire in tundra ecosystems reflects the difficulty of reconstructing fire history in treeless landscapes rather than an insignificant role of fire in tundra communities. The limited studies that have addressed fire in tundra ecosystems (e.g. Hall et al., 1978; Racine et al., 1985; Higuera et al., 2005b) highlight familiar relationships among climate, fuels, and fire occurrence that have important implications for fire and fuels management in Alaskan tundra.

Both data on the location and timing of recent fires in tundra and evidence from new paleoecological records emphasize the important role of woody fuels (e.g. birch, willow, and/or alder shrubs) and specific climatic conditions for fire occurrence and spread. The majority of Alaskan tundra fires over the past 50 years have occurred in tussock- and shrub-tundra in two regions: the Noatak River watershed and the Seward Peninsula (Racine et al., 1985; Racine et al., 1987). Fire rotation periods in the Noatak River region span from as little as 100 years to > 500 years, and fire rotation periods on the Seward Peninsula are speculated to be even shorter (Racine et al., 1985). However, given the short time interval and small spatial scale of the existing fire database, inferences about fire rotation periods in tundra must be made with caution. The abundance of tundra fires on the Seward Peninsula and in the Noatak Valley coincides with an abundance of shrub-dominated tundra in these regions, relative to other arctic and subarctic tundra in Alaska (Alaska Fire Service2005; Walker et al., 2005). This relationship suggests that woody biomass is an important fuel source for tundra fires (although graminoid tussocks on the Seward Peninsular are also quite flammable). Regional climatic difference between the Seward Peninsula, Noatak Valley, and other areas in Alaska almost certainly play an important, but as of yet unknown, role in controlling fire occurrence.

Newly developed fire-history records from two lakes in northern Alaska support the hypothesis that dense shrub cover facilitates tundra burning. Specifically, birch tundra 11,000-14,000 years ago appears to have been highly flammable, as modal fire-return intervals inferred from sediment-charcoal records are < 100 years (Fig. 1 row (d), Higuera et al., 2005b).

The timing of fires in the past c. 50 years indicates the necessity of warm, dry weather conditions for large areas of tundra to burn. From 1956-1983 ignitions resulting in notable tundra fires occurred during short periods in June and July, and the largest tundra fires on record occurred during the unusually warm, dry summer of 1977 (Hall et al., 1978; Racine et al., 1985). At larger temporal scales, the paleo record also suggests that dry climatic conditions facilitate tundra burning. Climatic conditions from 11,000-14,000 years ago, when charcoal records indicate a flammable shrub tundra (Fig. 1), were cooler but most likely drier than present (Anderson and Brubaker, 1993, 1994). Thus, both modern and paleo records of tundra fires are consistent with the hypothesis that tundra burns more frequently with both woody fuels and dry weather conditions.

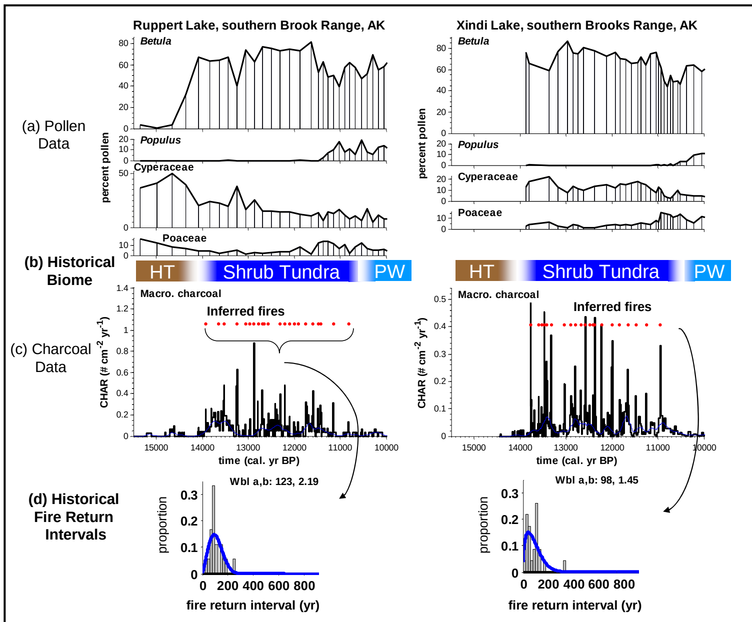

Figure 1. Historical vegetation and fire history records from northern Alaska illustrating (1) methods used to infer vegetation and fire history from lake-sediment records, and (2) high fire frequencies experienced from 11,000-14,000 years before present (ybp), when northern Alaska was dominated by (birch) shrub tundra. Prior to c. 14,000 ybp, herb tundra dominated by grass and sedge (**HT**) did not support frequent fires, nor did the *Populus* woodland (**PW**) that covered the region after c. 11,000 ybp. These records are the first to indicate a highly flammable tundra community existed in the past in northern Alaska, and the relationships between vegetation and fire history point to an important role of fuel characteristics in supporting fire occurrence. FRIs are fit with a Weibull model (Wbl, with two parameters, *a* [scale (yr)] and *b* [shape])via maximum likelihood techniques (see section 2.5). Describing fire return intervals parametrically facilitates statistical comparisons and integration into the Boreal ALFRESO model. The fire frequencies at the two sites above are not statistically different.

1.4 The Potential for Future Change in Tundra Fire Regimes

Recent and predicted changes in the controls of tundra fires (Fig. 2) suggest the possibility that tundra fire regimes will differ in the near future. Trends and predictions of climatic warming in Alaska (e.g. Serreze et al., 2000), modeling and empirical work suggesting increased area burned with increased temperatures (Rupp et al., 2000b), and studies documenting increased shrub densities across arctic and subarctic tundra within the last several decades (e.g. Silipaswan et al., 2001; Stow et al., 2004) all suggest that fire occurrence in tundra ecosystems will increase with climatic warming. Anticipating and assessing the impacts of this change depends upon understanding historical fire regimes and improving ecosystem models that incorporate the dynamic relationships between fire, vegetation, and climate. Our study will make significant progress towards reaching both of these requirements by reconstructing tundra fire history in the most flammable regions of Alaska and utilizing these data to expand and parameterize the Boreal ALFRESCO model (section **2.7, 2.8**).

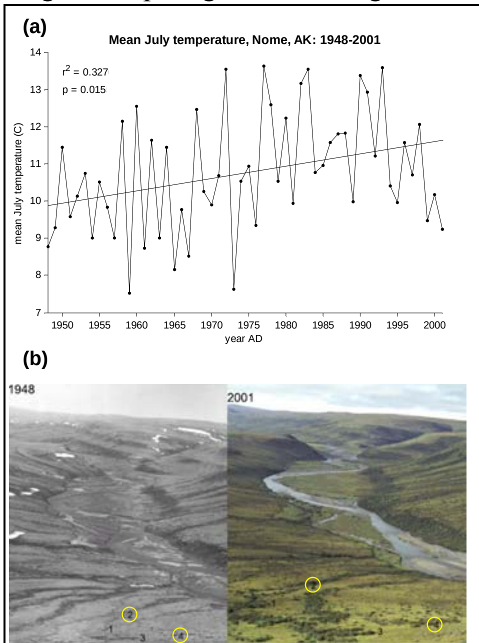

Figure 2. Examples of recent changes in temperature (a) and fuel structure (b) in northern Alaska. Temperature data in (a) come from Nome, on the Seward Peninsula. Photographs in (b) are from Stow et al. (2003) and illustrate an increase in shrub density along the Chandler River on the North Slope. Numbers and circles represent the same areas in the 1948 and 2001 photos.

1.5 Reconstructing Fire Regimes in Non-forested Landscapes

Tree-ring records and fire atlases have proven extremely valuable for understanding the spatial and temporal patterns of fire within forested ecosystems. These methods are inadequate, however, for studying fire regimes in tundra communities, where modern fire-return intervals are long relative to the length of historical records and where trees are absent.

Fortunately, reconstructing fire history in tundra ecosystems is possible through the use continuously-sampled, high-resolution records of macroscopic charcoal (Fig. 1; Higuera et al., 2005b; section **2.5**). The temporal pattern of charcoal accumulation in lake sediments provides a unique proxy of fire occurrence spanning thousands of years, and charcoal records integrate information on fire size, location, intensity, fuels, and weather conditions. Methodological advances and empirical studies over the past two decades have helped develop a conceptual and analytical framework supporting the use of macroscopic charcoal records to resolve local fire occurrence through the identification of distinct charcoal peaks (e.g. Whitlock and Anderson, 2003; Lynch et al., 2004).

The limitations of macroscopic charcoal analysis stem from the inherent nature of fire regimes, variations in charcoal transport processes, and the variable quality of sediment records. A fire may go undetected in a sediment record if it is small, downwind of the lake, or temporally close to another fire. However, these limitations are minimized if sediment accumulation rates are high and fires are large and infrequent. Although inherently ambiguous, the spatial scale represented by macroscopic charcoal records is critical to consider when designing a fire history study. Theoretical and empirical evidence suggests that such records most accurately represent fire occurrence within ~ 500 m of a lake (Gavin et al., 2003; Higuera et al., 2004). Even though some fires at greater distances can create charcoal peaks in a record, and some fires within this range can go undetected, studies matching charcoal peaks with known fires (Lynch et al., 2003; Lynch et al., 2004) and simulation models (Higuera et al., 2004) suggest that these inaccuracies are negligible when fire occurrence is summarized over long time periods (e.g. 5-10 FRIs). Thus the sediment in a single lake records fire occurrence for a restricted area (< 1 km^2) over long time periods (centuries to thousands of years). Assuming that most area is burned by large fires, a sediment charcoal record can be interpreted analogously to a stand-level fire history reconstructed by tree rings, for example.

1.6 Linking Paleo-fire Records and the Ecosystem Model Boreal ALFRESCO

Paleoecological records of fire are valuable to managers and researchers in their own right because they provide an important historical context and facilitate inferences into the processes controlling fire regimes (e.g. vegetation type, climate). When such records are placed into a larger framework such as Boreal ALFRESO, which describes relationships between climate, vegetation, and fire occurrence, they become even more relevant and valuable to land management. We will use the distributions of FRIs derived from our sediment charcoal records to parameterize the flammability of different tundra vegetation types in Boreal ALFRESCO (section **2.5, 2.8**). Informing Boreal ALFRESCO with FRI data from sediment charcoal records is feasible because of the equivalent spatial scales of sediment charcoal records and the 1 km^2 pixel size in Boreal ALFRESCO.

ALFRESCO was originally designed to simulate the response of subarctic vegetation to changing climate and disturbance regimes (Rupp et al., 2000a; Rupp et al., 2000b). With the benefit of prior (**01-1-1-02)** and current **(05-2-1-07)** JFSP funding, the Boreal ALFRESCO model now simulates five major ecosystem/fuel types: upland tundra, black spruce forest, white spruce forest, deciduous forest, and grassland-steppe. Each ecosystem type in ALFRESCO responds to climate, vegetation, and time-since last fire (TSLF) based on an empirical understanding of these relationships. Flammability in the upland tundra ecosystem type, for example, is controlled by climate and conifer cover, with the probability of burning increasing with TSLF (to represent changing fuel loads; Rupp et al., 2000a). We know, however, that tundra ecosystems lacking conifer cover can and do burn (section **1.3**), but an absence of empirical data on the probability of burning with TSLF and climate-fire relationships in tundra vegetation precludes these ecosystems from inclusion in the current Boreal ALFRESCO version. Our work reconstructing FRIs in tundra vegetation will allow Boreal ALFRESCO to include the influence of TSLF, tundra type, and climatic parameters on the probability of tundra fire occurrence (section **2.8**). More accurate representations of tundra ecosystems in the Boreal ALFRESCO model will broaden the utility and applicability of this tool to Alaskan fire managers and help assess the potential response of tundra systems to future climatic change.

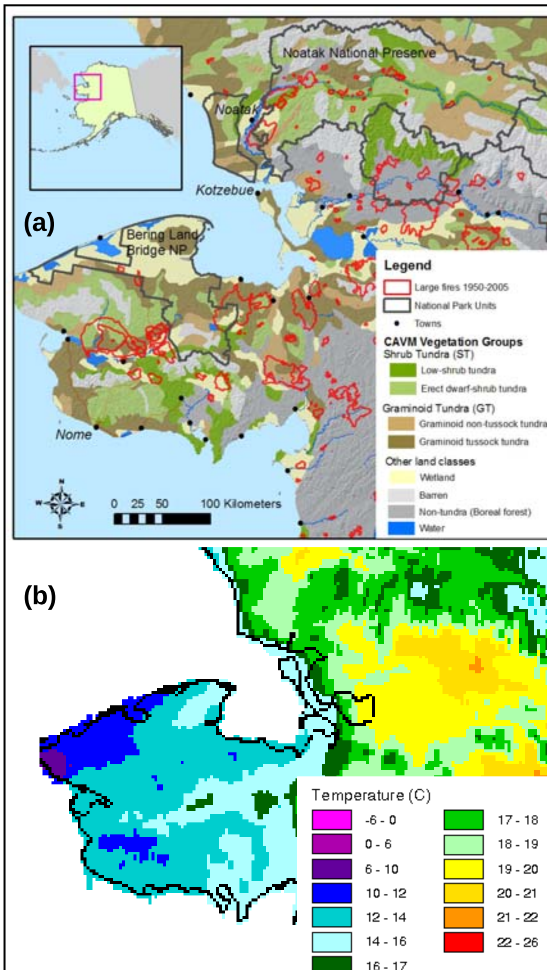

Figure 3. (a) Tundra vegetation types (Walker et al., 2005) and fire perimeters since 1950 (Alaska Fire Service, 2005), and (b) average maximum July temperature across the study region (Spatial Climate Analysis Service, Oregon State University).

2. MATERIALS AND METHODS (ABBREVIATED)

2.1 Study Area

Our study takes place in two study regions, the Seward Peninsula and the lower elevations of the Noatak River watershed (Fig. 3). These regions encompass the most flammable tundra in Alaska and include areas managed by the Department of the Interior within the Bering Land Bridge National Preserve, Noatak National Preserve, Kobuk Valley National Park, and Cape Krusenstern National Monument. Within each region, we focus on two tundra vegetation types: (1) graminoid tundra (GT, dominated by "graminod non-tussock tundra" and graminoid tussock tundra") and (2) erect-shrub tundra (ST, dominated by "low-shrub tundra" and "erect-dwarf-shrub tundra"), which comprise 27% and 28% of the tundra vegetation in our study area, respectively (Fig. 3; Walker et al., 2005). Over the past 50 years, most fires in our study area have burned within GT (c. 49%, Fig. 3). This tundra type is thus a logical focus for our study. We focus on ST vegetation as well because we are also interested in the hypothesis that increased shrub density facilitates fire occurrence and spread.

2.2 Sampling Design and Site Selection
Our sampling design is stratified primarily by region and secondarily by tundra type. This approach facilitates inferences into the relative importance of climate and vegetation on the frequency component of tundra fire regimes. Modern climatic differences between our two study regions (e.g. maximum July temperatures; Fig. 3) allow us to test the hypothesis that past FRIs differed with regional climate (assuming differences in past climate were similar to modern).

We expect, however, that differences in past FRIs may be greater between vegetation types than between study regions, based on the key role of woody fuels in facilitating tundra fires. Within each study region, we will use the recently published Circumpolar Arctic Vegetation Map (CVAM; Walker et al., 2005) to identify two lakes that are surrounded by a 5-km buffer of GT and ST tundra types. The important difference between GT and ST is the presence and abundance of shrubs species (*Betula*, *Salix*, *Alnus*) in ST communities, which creates greater fuel loading and a different fuel structure than in GT. The contrast in shrubs between GT and ST will allow us to evaluate the hypothesis that fire occurrence was higher in shrub-dominated tundra vegetation.

In each of the eight sampling locations, we will collect sediments spanning the past 5,000 years, when modern large-scale vegetation and climatic patterns in northern Alaska were in place (Anderson and Brubaker, 1993). Reconnaissance using USGS maps indicates abundant lakes throughout both study regions in both GT and ST. We will target small (< 15 ha), deep (> 5 m) lakes, which characteristically provide the undisturbed sediments necessary for high-resolution paleoecological studies. Additionally, we will aim to (1) maximize the differences in shrub density between GT and ST sites and (2) sample lakes that fall within or near fires recorded in the Alaska Fire Service large-fire database (Alaska Fire Service, 2005). Final lake selection can be made only after field reconnaissance. At the beginning of each field season we will use fixed-wing aircraft and/or helicopter to identify the final lakes to be sampled. We expect most lakes to be accessed via helicopter, given the small sizes of lakes we are targeting.

2.3 Sediment Subsampling, and Charcoal and Pollen Analysis
Fire and vegetation history will be reconstructed from continuous records of charcoal accumulation and pollen from overlapping cores collected from each lake. Sediment cores will be sliced at 0.25-0.5 cm intervals (c. 10-20 yr per sample) and subsampled for both charcoal and pollen analysis. Subsamples of 3-5 cm^3 from every level will be washed through a 150-µm sieve and bleached. Charcoal will be identified at 10-40 X magnification (Higuera et al., 2005a). Sediment samples of 1 cm^3 will be prepared for pollen analysis according to standard procedures for arctic sediments (PALE member, 1994). Samples will be counted (400-1000 X magnification; terrestrial pollen sum > 300 grains) at 250- to 500-year intervals to characterize the tundra vegetation.

2.4 Chronological Control
Accurate and precise chronologies are imperative for reconstructing fire history from sediment charcoal records. Chronologies will be based on ^{210}Pb dating of near-surface sediments done at the University of Illinois and AMS ^{14}C dates on terrestrial macrofossils, charcoal fragments or concentrated pollen in deeper sediments done at Lawrence Livermore National Laboratory's Center for Accelerator Mass Spectrometry. One AMS date will be obtained per 500 years of sediment accumulation, with greater resolution if age-depth curves suggest finer-scale changes in accumulation rates. In addition to ^{210}Pb, ^{137}Cs dating will be used to precisely compare charcoal accumulation in the most recent sediment with known fire occurrence documented in the AFS large-fire database.

2.5 Quantitative Treatment of Charcoal Data

Charcoal concentrations will be converted to charcoal accumulation rates (CHAR) based on sediment chronologies. CHAR will be separated into peak and background components, and a threshold selected to identify peaks related to "local" fires will be based on comparisons with documented fires in the Alaskan fire database and a sensitivity analysis (e.g. Lynch et al., 2003). Identified charcoal peaks will be treated as estimates of local fire occurrence, and graphical methods will be used to evaluate temporal changes in fire frequency for each site (Johnson and Gutsell, 1994). Once distinct fire-frequency regimes are estimated, Weibull models will be fit to the FRIs within the identified time period using maximum likelihood techniques (Johnson and Gutsell, 1994). Weibull distributions are commonly used to describe the frequency component of fire regimes, and they allow more powerful statistical tests than other methods (Johnson and Gutsell, 1994). Weibull models are also advantageous because they can be used to express the frequency component of a fire regime in several different ways, including hazard of burning. We feel this provides managers with more useful information than simply reporting a mean FRI.

Comparisons within and between sites, using a likelihood-ratio, will test the null hypothesis that each distribution is identical (Johnson and Gutsell, 1994). Statistically similar distributions will be combined to provide more powerful comparisons between tundra types, regions and/or time periods. Finally, the probability of Type I and II error will be used to evaluate the possibility of changes in fire frequency regimes across space and time. Our results will thus give managers a quantitative description of the frequency component of the fire regimes for a given: (1) site, (2) tundra type, (3) study region, and/or (4) time period.

2.6 Quantitative Treatment of Pollen Data

Our study design is based, but does not depend, upon the assumption that vegetation assemblages have not changed significantly over the period of our fire-history records. Although this assumption is reasonable given previous paleoecological research throughout Alaska (Anderson and Brubaker, 1993), we will test its validity in our study area by quantitatively evaluating the stability (or change) in tundra vegetation over the period of our records. Specifically, we will use the modern-analog approach to evaluate the similarity between fossil samples from our study cores and modern samples from the PAIN pollen database (> 400 sites in Alaska, Bigelow et al., 2003) using standard multivariate techniques (e.g. squared chord distance, discriminant analysis, Prentice, 1980; Oswald et al., 2003). Recent work by Oswald et al. (2003) indicates that graminoid and shrub tundra on the North Slope can be discerned with pollen data, and we will employ similar techniques in our study region to detect any large-scale changes in tundra vegetation.

2.7 Inferring Mechanisms Controlling Tundra Fire Regimes

Inferences into the controls of FRIs will be based mainly upon the spatial scale of any documented differences in FRI distributions (e.g. site, vegetation type, region), and, in the case of temporal changes, upon comparisons to paleo records of environmental variability. For example, if FRIs are similar between two GT sites within a region, and different from the two ST sites within the same region, this would suggest that variables associated with vegetation type (e.g. edaphic characteristics, fuel loading), as opposed to large-scale climate difference, explain the different FRIs. In contrast, if FRIs did not differ between vegetation type but did differ between regions, this would suggest a role for larger-scale variables, such as regional climate, as controls of FRIs. If FRIs show evidence of changes through time, we will consider three alternative hypothesis to explain the pattern(s): (1) climate over the length of our records changed in ways influencing fire occurrence; (2) vegetation changed in ways influencing fire occurrence; (3) both climate and vegetation changed. In the absence of locally-derived paleoclimate record, we will have to rely on previously published paleoclimatic interpretations from the region (e.g. Anderson et al., 2003). The temporal relationships between changes observed in our records and previous paleoclimatic interpretations will be used to infer the potential of climatic mechanisms causing changes in historic FRIs. To evaluate the potential that vegetation change influenced fire occurrence, we will use our pollen-based vegetation reconstructions. As for climate, temporal relationships between FRI and vegetation changes will be used to infer the potential role of vegetation as a control of historic FRIs.

2.8 Integrating Fire-history Data with Boreal ALFRESCO

The use of Boreal ALFRESCO to simulate tundra ecosystem dynamics provides opportunities to gain insight into climate-fire-vegetation interactions (e.g., feedbacks, lead-lag relationships) which cannot be determined directly from sediment records. However, the ability to simulate these dynamics has been limited due to a lack of empirical observations of FRIs and information about vegetation and climate controls in tundra ecosystems.

We want to develop simulations that accurately reflect the paleorecords across a range of documented climatic variation (e.g., Region 1 vs. Region 2) and fuel type and structure (e.g., GT vs. ST). Our goal here is to gain a better understanding of past climate-fire-vegetation interactions in tundra and improve the robustness of Boreal ALFRESCO for simulating not only current tundra dynamics, but also future dynamics based on forecasted climatic warming scenarios.

Model development will focus on two primary components: (1) parameterize and calibrate the existing climate weighting algorithm to better represent growing-season climate/weather relationships with fire frequency in tundra ecosystems, and (2) develop a new fuel loading/structure algorithm to represent the influence of shrubs on fire frequency. Currently, the relative effects of growing-season climate on fire were computed using a two-parameter regression analysis similar to that used by Kasischke et al. (2002). This relationship was developed for boreal forest and assumed to hold true for tundra systems as well (due to a lack of fire frequency observations in tundra). Our study will provide the empirical data required to test this assumption. Based on the paleo-derived fire frequency-climate relationships and the model testing results we will re-parameterize the tundra-climate weighting algorithm to reflect historical relationships. We will also develop a new fuel loading/structure algorithm to account for shrub fuels in tundra. Currently, the flammability of tundra systems is based on limited suppositions from the literature. A changing fuel load/structure is simulated in association with colonization by spruce forest, but the shrub vegetation component has been ignored to this point. This study will provide the observations required to add representation of shrub fuels and their effects on fire frequency. Development and parameterization of this new fuel component should substantially improve Boreal AFRESCO's ability to simulate tundra fire dynamics.

3. RESEARCH LINKAGES

Our study is related to several ongoing projects funded by the National Science Foundation and JFSP in both methodology and research goals.

Grant Program	Project Description/Identification	Funding Amount	Completion Date
National Science Foundation	ARC-0112586 to Linda Brubaker, with co-PI P. Anderson, collaborators F.S. Hu and T.S. Rupp, and graduate student P.E. Higuera: *Understanding the Role of Climate-Vegetation-Fire Interactions in Early-Holocene Treeline Dynamics in Alaska*. By coupling paleovegetation, climate and fire history records with the ecosystem model Boreal ALFRESCO, this ongoing project investigates the processes of the early-Holocene fluctuations in white spruce (*Picea glauca*) in northcentral Alaska.	$730 k	2006
JFSP	01-1-1-02 to T. Scott Rupp and Daniel Mann Post-Fire Studies Supporting Computer-Assisted Management of Fire and Fuels During a Regime of Changing Climate in the Alaskan Boreal Forest	$398 K	2008
USFS	05-2-1-07 to T. Scott Rupp Classification and Modeling for FRCC Implementation in Alaska.	$32 K	2006

4. SCIENCE DELIVERY AND APPLICATION

We will use various technology transfer mechanisms to assure the project results and deliverables will be effectively transferred to field managers and other end users. Our field results, analyses, and interpretations will be described in annual reports and presentations to the AWFCG Fire Effects Task Group as well as in several peer-reviewed manuscripts. All fire-history data will be provided to our collaborators on DVD, submitted to the online International Multiproxy Paleofire Database (IMPD: http://www.ncdc.noaa.gov/paleo/impd/paleofire.html), and posted on the investigators web sites and the FireHouse web page (Olson, JFSP 2005). Additionally, online access to the study metadata will be provided through the Alaska Fire Effects Plots Map ArcIMS project (on FIREHouse; http://www.fs.fed.us/pnw/fera/firehouse/index.html). Pollen data will be submitted to the on-line North American Pollen Database (NAPD; http://www.ncdc.noaa.gov/paleo/napd.html).

The Boreal ALFRESCO modeling results will also be described in our annual reports and presentations as well as in peer-reviewed manuscripts. Input datasets, model simulation results, and model software and documentation will be provided to our collaborators on DVD. We will host a one-day workshop at the completion of our project to convey our findings, distribute manuscripts and data, demonstrate software and model improvements, and provide collaborators and land managers (NPS, FWS, BLM, and State) an opportunity to interact with our research team.

5. DELIVERABLES

The goal of our project is to (1) provide fire and land managers with fire history records describing the frequency component of fire regimes in two tundra types in two regions in northwestern Alaska, and (2) integrate fire history information into the management-oriented ecosystem model Boreal ALFRESCO to aid in fire and fuels management decisions (Table 1).

Table 1. Deliverables of the current project.

Deliverable	Description	Delivery Date
Cooperators Meeting	Present fire history records from first field season; request feedback from collaborators.	Winter 2008
Annual Report	Project status report to JFSP and agency partners	Spring 2008
Study Site Data Delivery	Provide preliminary results of fire history records from first field season to agency cooperators.	Spring 2008
Cooperators Meeting	Present fire history records from second field season, present results of model development; request feedback from collaborators.	Winter 2009
Annual Report	Project status report to JFSP and agency partners	Spring 2009
Study Site Data Delivery	Provide preliminary results of fire history records from first field season to agency cooperators.	Spring 2009
Journal Articles	Write and submit fire history results for publication in peer-reviewed journal.	Summer 2009
Journal Articles	Write and submit modified Boreal ALFRESCO results for publication in peer-reviewed journal.	Fall 2009
Tech. Transfer	Workshop with collaborators and land managers (NPS, FWS, BLM, and State) to convey our findings, distribute manuscripts and data, and demonstrate software and model improvements.	Fall 2009
Final Report	Final project report to JFSP and agency partners. Fire history data submission to the IMPD and FIREHouse. Pollen data submission to the NAPD.	Fall 2009

6. BENEFITS TO ALASKAN LAND AND FIRE MANAGERS

Our project has multiple benefits related to both local and National research needs in the fire management community. First, the fire history records developed for tundra ecosystems will benefit land managers in the NPS, BLM, and FWS by providing empirical, rather than speculative, information on fire regimes in tundra ecosystems. Letters of support for our project emphasize the need for fire history information from tundra ecosystems to: (1) participate with National initiatives characterizing fuels and developing fire hazard models (i.e. FRCC and LANDFIRE; BLM: Jandt, Appendix C); (2) develop a management strategy for the Seward-Kobuk Planning area (BLM: Jandt, Appendix C); and (3) help understand the long-term role and impacts of fire and fire management practices on the largest caribou population in Alaska and reindeer populations on the Seward Peninsula (BLM, NPS: Heinlein, Jandt, Neitlich, Appendix C). This study also directly applies to the second theme expressed by Alaskan land and fire managers, concerns over the impacts of climate change and the potential for increased shrub dominance in tundra ecosystems to change tundra fire regimes (Appendix C). Integration of our historic FRI data into Boreal ALFRESCO will provide a tool for land managers to model the impacts of fire management options, climatic change, and vegetational change on fire occurrence. Boreal ALFRESCO will also help managers participate in National initiatives by developing reference landscapes for areas both within and beyond our study sites.

7. QUALIFICATIONS OF INVESTIGATORS

Our study emphasizes paleoecological tools for describing historic tundra fire regimes and it integrates this knowledge with modeling approaches for understanding climate-fire-vegetation relationships. Members of our research team are currently finishing a study of Holocene fire history in the southern Brooks Range that involves a similar integration of paleo and modeling approaches (e.g. Higuera et al., 2005b). Hu has extensive experience and expertise reconstructing paleoenviornmental change throughout Alaska, including fire history (Hu et al., 2005). Higuera will serve as a consultant in the site selection, field work, and data analysis components of this study. He brings expertise in interpreting sediment charcoal records and paleo fire regimes in Alaska. Rupp has extensive experience and expertise with the development and application of Boreal ALFRESCO (JFSP **01-1-1-02** and **05-2-1-07)** and his relationships with Alaskan land managers will facilitate technology transfer from this project. Allen is the Regional Fire Ecologist for Western Arctic National Parklands in Alaska and brings knowledge of local vegetation, fire history, and management needs. The CVs of the each member of the research team are included in Appendix B, and research responsibilities are listed in Table 2.

Table 2. Team members and associated responsibilities.

Personnel	Responsibilities
Feng Sheng Hu	▪ Collection of sediment records, development of charcoal and pollen records and sediment chronologies. ▪ Archiving of sediment records and charcoal and pollen data in National and Agency databases. ▪ Study write up for peer-reviewed journals
Philip Higuera	▪ Assistance in site selection and sampling ▪ Assistance in interpretation of sediment charcoal records and quantification of fire history ▪ Study write up for peer-reviewed journals
Scott Rupp	▪ Development of new tundra “frames” for Boreal ALFRESCO utilizing fire-history data developed by Hu and Higuera ▪ Technology transfer of modified Boreal ALFRESCO to Alaskan fire and land managers ▪ Study write up for peer-reviewed journals
Jennifer Allen	▪ Coordination and assistance in field work ▪ Information transfer to NPS and other relevant fire-management agencies ▪ Study write up for peer-reviewed journals

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