FINAL REPORT TO THE JOINT FIRE SCIENCE PROGRAM

PROJECT #06-3-1-26

COMPILING, SYNTHESIZING AND ANALYZING EXISTING BOREAL FOREST FIRE HISTORY DATA IN ALASKA

JULY 14, 2011

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I. Abstract

Wildland fires play a critical role in maintaining the ecological integrity of boreal forests in Alaska. Identifying and maintaining natural fire regimes is an important component of fire management. There are numerous research projects that directly or indirectly address historical fire regimes in the Alaskan boreal forest, but many are unpublished, have many unprocessed dendrochronological (tree age and fire scar) samples, or their data were used for other purposes. Furthermore, no assessment of these data exists to understand how fire has historically affected the boreal forest ecosystems of Alaska. The goal of this project was to compile and synthesize existing Alaska boreal-forest fire-history literature and datasets (http://frames.nbii.gov/alaska/borealfirehistory). We include a literature review and synthesis of publications related to fire regimes in boreal forests in Alaska (the pending general technical report "Fire Regimes of the Alaskan Boreal Forest"), and incorporate the reference information into the Alaska Fire Effects Reference Database (http://frames.nbii.gov/alaska; funded by JFSP as part of project 05-4-2-03: Expanding FIREHouse to Alaska). Fourteen published and unpublished fire-history or stand-age datasets were compiled and processed into the Alaska Fire History Database (http://frames.nbii.gov/documents/alaska/fire_history/ak_fire_history_db.zip), and data summarized by plot are available through a dynamic map interface (within the Alaska Fire and Fuels Research Map; http://afsmaps.blm.gov/imf/imf.jsp?site=firehouse). Data compiled in the Alaska Fire History Database have also been submitted to the International Multiproxy Paleofire Database (IMPD). Finally, some of the project funds were used to clean up and improve data within the Alaska Large Fire Database, a database started in the early 1990s that includes reported fire locations since 1939 and fire perimeters since 1942 (http://afsmaps.blm.gov/imf/imf.jsp?site=firehistory).

II. Background and Purpose

In Alaska, the boreal forest occupies 32 percent of the total land area (about 47 million ha) and wildland fire is the primary disturbance (fig. 1). High-intensity crown fires are common, and during active fire years, area burned may be on the order of millions of ha. For example, in 2004 and 2005, two of the largest fire seasons recorded in Alaska, roughly 5 percent of the total area of the boreal forest burned each year (Alaska Interagency Coordination Center 2004, 2005). Fire has been an important process for thousands of years and paleoecological studies suggest the contemporary boreal forest has been maintained by fire for the past 5,000 years (Hu et al. 2006).

The boreal fire regime in Alaska is outwardly simple, given the biological homogeneity of the boreal forest (Hillebrand 2004) and prevalence of large stand-replacing crown fires (Johnson 1992), but complex in the context of land management. Interactions between fire and the environment are difficult to identify with high levels of confidence. Inter-annual and decadal changes in weather also have a profound influence on area burned, thus the fire regime may appear to shift dramatically over short time periods. Fire dynamics vary at different temporal and spatial scales. These complexities make it difficult to understand how management will affect ecological processes and introduce uncertainty into future planning.

Federal agencies own a majority of boreal forest in Alaska and are mandated to promote ecosystem health by restoring the natural process of fire (Interagency Federal Wildland Fire Policy Review Working Group 2001). The Alaska Interagency Wildland Fire Management Plan (Alaska Wildland Fire Coordinating Group 1998), which governs federal agencies and other major landholders in the Alaskan boreal forest, including state and tribal organizations, also recognizes the inherent ecological value of fire. Since the 1980s, fire management has allowed natural fires to burn when life and sensitive property are not threatened (Todd and Jewkes 2006).

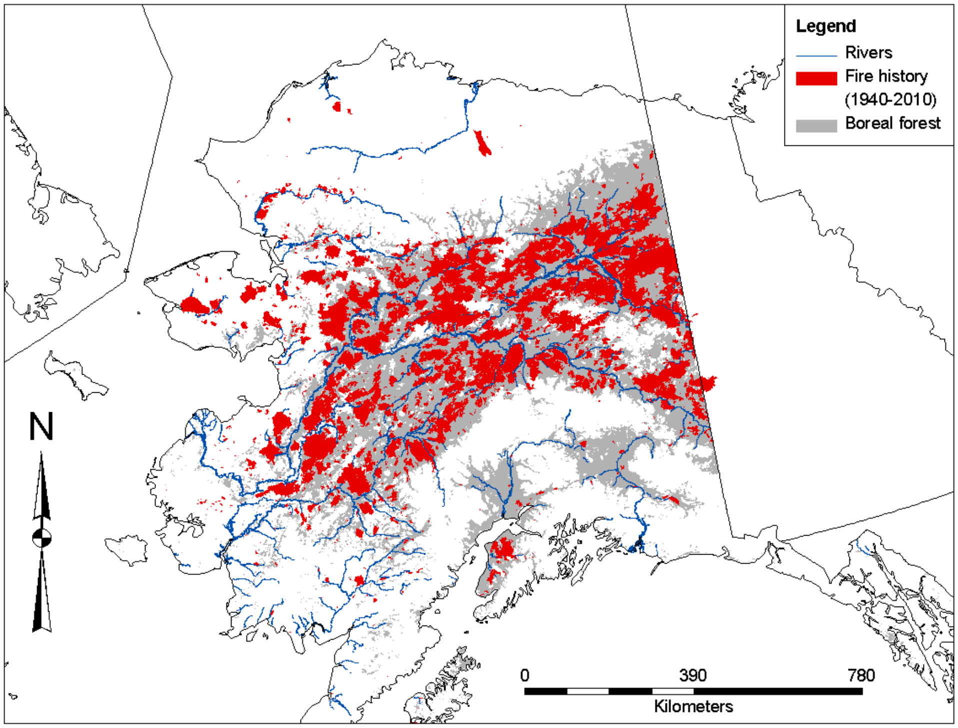

Figure 1. Distribution of fires (1940-2010) and boreal forests in Alaska.

To successfully manage for natural fire regimes, succinct and relevant information about local fire regimes is necessary. This includes information on what constitutes natural fire regimes, how far contemporary fire regimes have departed from natural fire regimes, the ecological consequences of altered fire regimes, and the scale and type of management required to move ecosystems toward desired states. There are several barriers to obtaining this information. In some instances, research has yet to address questions about fire regimes. Although a number of publications address fire regimes in Alaska, significant gaps in such knowledge still exist. There are problems with information accessibility, because even if available, agency reports and graduate-student work are not widely disseminated. In other instances, data were collected but never analyzed or published. Without a central repository of information, it can be cumbersome for fire managers and planners to sift through the literature and find information that is tailored to meet their needs.

This project was developed in response to Joint Fire Science Program AFP 2006-3, Task 1, and addresses the gap between information and fire management agencies. The overall goal was to provide comprehensive access to information about fire regimes in the boreal forest of Alaska. Such a compilation of fire history information was identified as a research goal by the Alaska Wildland Fire Coordination Group, specifically, the request for a "compilation of fire return intervals for the entire state," which "would enable fire managers and resource managers to make more informed decisions about fire and fuels treatment."

We had three primary objectives:

1. Publish a literature review and synthesis of fire regimes in boreal Alaska "Fire Regimes of the Alaskan Boreal Forest." This review covers all relevant publications about fire regimes in boreal forests of the northern hemisphere; an appendix provides summaries of each fire-history publication in Alaska.

2. Develop a fire-history database (the Alaska fire-history database) as a clearinghouse for fire-history data, including sample data from unpublished and published datasets that have not been fully utilized to document fire history.

3. Revise and update the Alaska large-fire database by adding missing attribute information, improving fire perimeters, adding missing fires, and extending the dataset farther back in time.

A secondary goal was to conduct large-scale spatial and temporal analyses of Alaskan boreal forest fire history, providing that the compiled datasets were of sufficient spatial and temporal resolution. This was originally proposed to be considered "Part 2" of the project, and supplemental funding would have been required.

III. STUDY DESCRIPTION

Literature Review and Synthesis

"Fire Regimes of the Alaskan Boreal Forest" reviews publications that describe fire regimes of the Alaskan boreal forest. Considerable effort was made to identify all sources, including work outside of peer-reviewed literature such as government reports and graduate thesis work. We used scientific literature search engines and libraries at Yale University, University of Alaska, Fairbanks, University of Washington, and the U.S. Forest Service. Land managers and researchers in Alaska were also requested to identify additional documents.

The literature review covers 378 references, including 28 references (table 1) that are individually summarized because they address fire history in the boreal forest of Alaska.

We focused on boreal forest as opposed to other major cover types in Alaska because fire is an important component of the natural fire regime but rare outside of the boreal forest (Gabriel and Tande 1983). One exception is tundra, which has been receiving increased attention due to recent large tundra fires and concern over the potential impacts of climate change on the tundra fire regime. Significant tracts of alpine tundra also exist within the boreal forest and play a role in the spatial distribution of fire regimes. Consequently the review and synthesis include information about fire's role in tundra.

The review and synthesis are approached from two angles: (1) traditional review and synthesis of existing literature, and (2) a compendium of all fire history studies conducted in Alaska. The body of the document is divided into three main chapters. Chapter 2 reviews each component of the Alaskan boreal fire regime. Chapter 3 takes a look at the spatial distribution of fire regimes by vegetation type. Chapter 4 describes the temporal variability of fire regimes across multiple scales. Since fire frequency is the most common measure of how fire regimes change over time and space, chapters 3 and 4 concentrate on measures of frequency, such as the fire cycle and fire-return interval. There is also an appendix that provides more extensive summaries of all Alaskan fire-history studies. Each entry presents pertinent fire-history data graphically, followed by a short written summary.

Alaska Fire History Database

Fourteen existing published and unpublished fire history (or stand age) tree-ring datasets (table 2) were identified through either the literature review or conversations with Alaska researchers and land managers. For five of the datasets, samples had already been processed and we did not re-process them. For the rest of the datasets, samples were re-processed using dendrochronological methods. Whenever possible, samples were visually crossdated using standard dendrochronological techniques (Stokes and Smiley 1968), and if necessary, samples were measured and reviewed for accuracy using a crossdating software program (COFECHA; Holmes 1983). If a sample could not be crossdated, then a ring count is provided (and noted) for that sample. Crossdating ensures the accuracy of fire-date and tree-age reconstructions and enables comparisons between samples at annual scales. Once the sample re-processing was complete, the datasets were compiled into the Alaska fire history database.

Alaska Large Fire Database

The Alaska large-fire database was originally developed during the early 1990s by Nancy French and others from the Environmental Research Institute of Michigan, with the cooperation of Don Barry (the Alaska Interagency Coordination Center's Intelligence Coordinator at the time). Its purpose was to compile and standardize perimeter information for large fires dating back to 1950 derived from historical fire reports (please refer to Kasischke et al. 2002 for more details about the original database). Since its original development, it has been maintained by the Bureau of Land Management's Alaska Fire Service, including the addition of each successive year's fire point and perimeter data, and supplemented by occasional improvements to existing data. By leveraging funding from this project and resources at the Alaska Fire Service, the database has been improved by extending the dataset to include fire perimeters since 1942, identifying and digitizing missing fire perimeters from remotely sensed imagery in conjunction with historical maps, updating existing fire perimeters, and adding missing attribute information. The current version of the database can be viewed at http://afsmaps.blm.gov/imf/imf.jsp?site=firehistory.

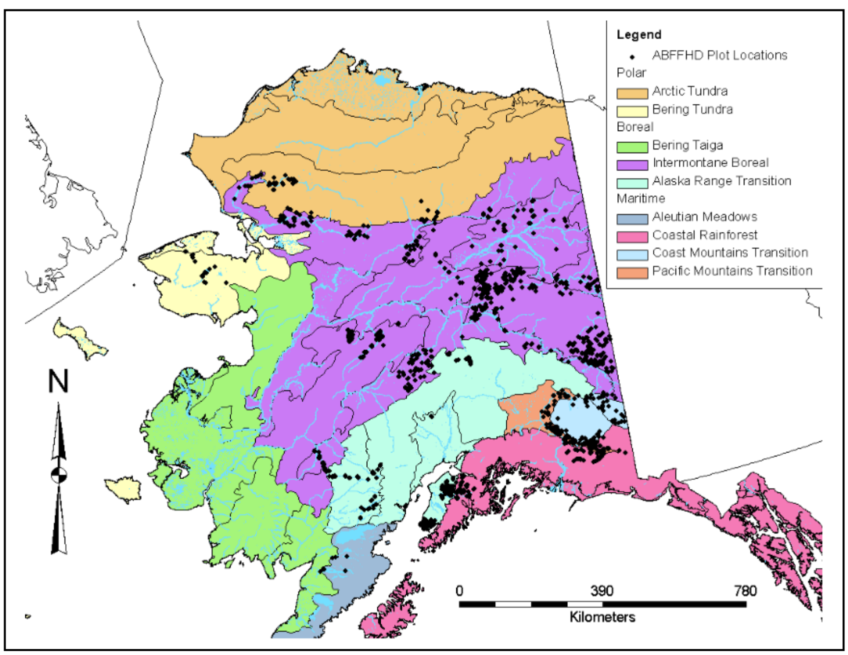

Figure 2. Map of Alaska Fire History Database plot locations. (ecoregion base map from Nowacki *et al*. (2001).

Table 1—Alaskan boreal forest fire-history studies. See Literature Cited for full citations.

Anderson et al. 2006	Paleoecological sediment core data collected from three lakes in boreal forest on the Kenai Peninsula were used to infer fire history, climate, and vegetation interactions for the past 13,000 years.
Barney 1971	Investigates the relationships between fire regimes and geographic characteristics for Alaska using fire management records for the period 1940-69.
Berg and Anderson 2006	Paleoecological soil data were sampled at 121 locations on the Kenai Peninsula to infer fire history for the past 2,500 years in Lutz and white-spruce forest.
Christiansen 1988	As part of a broader study to examine interactions between fire and spruce-lichen woodlands, dendrochronological samples, including 13 fire scars and 57 stand-origin dates, were collected across a small study area located in spruce-lichen woodland in the south-central brooks Range and used to infer fire history for a 220 year period.
De Volder 1999	Dendrochronological samples, including fire scars, stand-origin dates, and outer-ring dates, were collected at 171 sites at two study sites (90,000 ha and 8,200 ha) within the Kenai National Wildlife Refuge and used to describe spatial and temporal trends in fire history for the period 1708-1947.
DeWilde and Chapin 2006	Fire perimeter data for the period 199-2001 was used to investigate the effects of fire suppression on characteristics of the fire regime in interior Alaska.
Drury and Grissom 2008	Dendrochronological samples were collected at 27 points within the 4.5 million-ha Yukon Flats National Wildlife Refuge in northeast interior Alaska and stand origin dates and fire scars were used to identify temporal trends and differences in fire frequency among forest types.
Earle et al. 1996	Paleoecological sediment core data for a lake located in the boreal forest of interior Alaska was used to describe a 14,000 year period of vegetation development and fire history.
Fastie et al. 2002	Dendrochronological samples, including fire scars, outer ring dates, and stand origin dates, were collected from 43 sites in boreal forest of the Caribou-Poker Creek Research Watershed and combined with fire perimeter data to describe fire history for the period 1750-1999.
Gabriel and Tande 1983	Investigates the relationships between fire regimes and geographic characteristics for Alaska using fire perimeter data for the period 1957-79.
Goldstein 1981	Primarily dedicated to the influence of climate on white spruce near treeline, dendrochronological samples were used to reconstruct stand age and describe the history of disturbance for treeline stands of white spruce in the southcentral Brooks Range.
Higuera et al. 2008	Examines fire history during period of shrub tundra dominance between 14,000 and 10,000 years ago based on paleoecological sediment cores from two lakes in the southcentral Brooks Range.
Higuera et al. 2009	Paleoecological sediment core data from four lakes in the southcentral Brooks Range provides a record of fire history and vegetation for the past 14,300 years.
Hu et al. 1993	Paleoecological sediment core data for a lake located in the boreal forest of interior Alaska was used to describe a 12,000 year period of vegetation development and fire history.
Hu et al. 1996	Paleoecological sediment core data for a lake located in the boreal forest of interior Alaska was used to describe an 11,000 year period of fire history and interactions with climate and vegetation.

Hu et al. 2006	Synthesis of earlier paleoecological lake-sediment studies of Holocene fire-climate-vegetation interactions in the boreal forest of Alaska.
Kasischke and Turetsky 2006	Builds on earlier research using fire perimeter data from interior Alaska (Kasischke et al. 2002) by adding fire perimeter data from Canada and examining trends in fire history for boreal North America from 1959-99.
Kasischke et al. 2010	Investigates relationships between fire regime, vegetation, and climate by reviewing annual area burned data from fire perimeter data and annual area burned estimates based on climate reconstructions. These datasets show annual area burned in Alaska from 1860-2009.
Kasischke et al. 2002	Investigates the relationships between the fire regime and geographic characteristics in interior Alaska using fire perimeter data for the period 1959-99.
Lutz 1956	Observational data describes fire history for the boreal forest of interior Alaska.
Lynch et al. 2002	Paleoecological sediment core data collected from five lakes in boreal forest of Alaska were used to infer general measures of fire activity for the past 1,000 years. Sediment core data from one of these lakes located in interior Alaska was used to infer patterns of fire history and vegetation for the past 9,000 years.
Lynch et al. 2004	Paleoecological sediment core data collected from two lakes in boreal forest of the Copper Plateau were used to infer fire history, climate, and vegetation interactions for the past 7,000 years.
Mann et al. 1995	As part of a broader study to examine forest succession on floodplains, dendrochronological samples, including fire scars and stand-origin dates, were collected from 446 spruce trees across an 850-ha study area located in riparian boreal forest and muskeg in interior Alaska and used to infer fire history for a 500 year period for the entire sample area and stratified by forest type.
Mann and Plug 1999	Dendrochronological data, including fire scars and stand-origin dates collected from a small site in boreal forest was stratified by substrate age and differences in a 250 year record of fire history were examined among substrate age classes.
Quirk and Sykes 1971	Dendrochronological samples were used to reconstruct stand age for six white spruce stringer forest stands and adjacent upland boreal forest in interior Alaska and fire history, representing a 200 year period, was compared between the two forest types.
Tinner et al. 2008	Paleoecological sediment core data collected from a lake near treeline in the Copper Plateau region of Alaska provides decadal resolution of fire history, climate, and vegetation for the past 700 years.
Tinner et al. 2006	Paleoecological sediment core data collected from two lakes in boreal forest to the south and north Alaska Range were used to infer fire history and vegetation for the past 14,700 and 9,600 years, respectively.
Yarie 1981	Dendrochronological samples were used to reconstruct stand age at 371 sites within a 3.6 million-ha study area in boreal forests of northeast interior Alaska and fire history was reconstructed based on stand age distribution models for the entire study area and based for individual forest types.

Table 2—Datasets included in the Alaska fire history database

Dataset	Plots	Sample type	Trees	Samples	Scar dates	Processing
Anchor River Watershed Spruce Bark Beetle Project (Alaska Natural Heritage Program): Tree cores were collected from white and Lutz spruce affected by spruce bark beetles. Sampling occurred during 2004-2005 in the Anchor River Watershed on the Kenai Peninsula. Data contact: Keith Boggs (ankwb@uaa.alaska.edu)						
	136	cores	770	770	3	Samples crossdated by measuring; counted if unable to crossdate.
Chena Lakes F-Unit and Remote Arm Burn Severity and Forest Succession Projects (Bureau of Land Management): Both of these Chena Lakes projects were designed to determine fuel treatment effectiveness, prescribed burn severity, and post-burn vegetative succession. Incident to the sampling, some tree cross-sections were collected in 2001 to determine approximate stand ages, and in one case to determine a fire date for a fire-scarred black spruce. Data contact: Randi Jandt (randi.jandt@gmail.com)						
	4	cross-sections	32	32	17	Samples crossdated by measuring.
Fire and Climate History of Lowland Black Spruce Forests, Kenai NWR (US Fish and Wildlife Service and Northern Arizona University): This detailed fire and climate history study was undertaken during 1997 and 1998 to define the fire regime in black spruce forests on the Kenai National Wildlife Refuge. A total of 1,022 cross-sections and 771 increment cores were collected at two study sites and cross-dated in order to describe spatial and temporal trends in fire history for the period 1708-1947. Data contact: Andrew De Volder (andy_devolder@fws.gov)						
	160	cross-sections and cores		1,793		Samples processed by De Volder.
Fire Effects Paired Plots Study (National Park Service): This project was initiated in 1982, to assess vegetation change and succession as a result of fire. In 9 different parks in Alaska, fire teams established paired vegetation plots in burned and representative unburned habitat adjacent to the burned area. Burned sites of varying ages were identified and selected for study from historical fire reports, aerial photography, and aerial reconnaissance. Some plots were established in front of active wildfires and control plot pairs were not established. Plot data that was collected included tree cores and cross-sections, many of which included fire scars. Data contact: Jennifer Barnes (jennifer_barnes@nps.gov)						
	535	cross-sections and cores	3813	3,815	467	Scarred samples (281) crossdated either visually or by measuring (as necessary), rest of samples were dated by NPS personnel.
Fire History Disturbance Study of the Kenai Peninsula Mountainous Portion of the Chugach National Forest (US Forest Service): Cores were collected during 1995-1996 to reconstruct the fire history of three isolated, mature forest areas on the mountainous portion of the Chugach NF using the age distributions of living trees. Twenty-four historical burns were also examined. The ages of living Lutz spruce and mountain hemlock within the mature forests sampled are greater than 200 years old. Data contact: Rob DeVelice (rdevelice@fs.fed.us)						
	46	cores	1,139	1,137	0	Samples counted.
Fire History and Lichen Study in Eastern Alaska (Alaska Dept. of Fish and Game): Tree cross-sections (primarily spruce) were collected during 2000-2001 in eastern Alaska to determine the relationships between fire history, lichen, and caribou. Data contact: Bill Collins (william.collins@alaska.gov)						
	232	cross-sections	277	277	100	Samples crossdated visually; counted if unable to crossdate.
How Succession Affects Fire Behavior in Boreal Black Spruce Forests of Interior Alaska (Bureau of Land Management and Yale University): This project assessed the relationship between stand age and fire behavior in the black spruce forest type of interior Alaska. Forest-canopy and substrate data were collected from sites with stand ages from 2 to 227 years. These data were used in fire behavior prediction models to estimate flammability for three weather scenarios. Black spruce cross-sections were collected during 2004 and 2005, and were used to determine stand ages, and when applicable, fire dates (based on fire scars or tree death dates). Data contact: Jim Cronan (JFSP Project Number 04-2-1-96) (jcronan@uw.edu)						
	29	cross-sections	545	547	449	Scarred samples crossdated either visually or by measuring (as necessary).

Dataset	Plots	Sample type	Trees	Samples	Scar dates	Processing
Interactions Among Climate, Fire and Vegetation in the Alaskan Boreal Forest (University of Alaska, Fairbanks): As part of a study designed to calibrate and validate a model of interactions among weather, fire, and vegetation (Boreal ALFRESCO), stand-age distributions were developed by collecting tree cross-sections (including fire-scarred cross-sections) from more than 900 plots (250 clusters of plots) across 5 study areas located throughout the boreal forest region of Alaska (during 2002-2004). Data contacts = Scott Rupp (tsrupp@alaska.edu) and Paul Duffy (paul.duffy@neptuneinc.org) (JFSP Project Number: 01-1-1-02)						
	905	cross-sections	3,853	3,853	556	Samples processed by the University of Alaska.
Kanuti NWR Fire History Study (US Fish and Wildlife Service): As part of the refuge's inventory program, tree cross sections and cores were collected along the edges of old burns during a pilot project in 1999, then a system of "mini-grids" systematically located on the refuge were sampled from 2004-2008. At least 2 samples were collected from each plot. The study area is dominated by black spruce, but when plots contained multiple species, attempts were made to get at least one sample from each species. In some cases, particularly during the 2006 sampling, there were numerous old burn poles in the plots. Data contact: Lisa Saperstein (Lisa_Saperstein@fws.gov)						
	171	cross-sections and cores	464	361	260	Samples crossdated by measuring; counted if unable to crossdate.
Quantifying Variability in the Alaskan Black Spruce Ecosystem: Linking Vegetation, Carbon, and Fire History (US Forest Service and University of Alaska, Fairbanks): Tree cores were collected during 2000-2002 from black and white spruce at 146 sites throughout central interior Alaska as part of a study addressing questions about the regional variability and biodiversity of the black spruce forest type. Ninety of the sites burned during the 2004 fire year. Data contact: Teresa Hollingsworth (thollingsworth@fs.fed.us)						
	146	cores	693	693	0	Samples processed by the University of Alaska.
White Mountains Fire History (Bureau of Land Management): Black spruce and white spruce tree cross-sections and cores were collected during 2001, 2003, and 2007 in the Steese Conservation Area and the White Mountain National Recreation Area of interior Alaska. Data contact: Jim Herriges (jim.herriges@blm.gov)						
	164	cross-sections and cores	878	879	364	Samples crossdated visually or by measuring (as necessary); counted if unable to crossdate.
Wrangell-St. Elias Ground Truth Study (National Park Service): Between 1983 and 1988, tree cores and cookies were collected as part of a project to create and ground truth land-cover maps. Vegetation type and percentage cover, landform, drainage, slope, aspect, and soils data were collected for more than 1200 plots. Tree cookies or cores were collected for a sub-set of the sites (186 plots). Data contact: Jennifer Barnes (jennifer_barnes@nps.gov)						
	186	cross-sections and cores	318	318	4	Samples processed by the National Park Service.
Wrangell-St. Elias Spruce Bark Beetle Study (National Park Service): Tree cores were collected during 1997-1998 as part of a spruce bark beetle study in the Wrangell-St. Elias National Park and Preserve (eastern Alaska). Data were collected from every tree on a 20-m x 20-m plot or the three largest trees were cored (at increment bore height on tree base). Presence/absence of evidence of fire was recorded for each plot. Data contact: Jennifer Barnes (jennifer_barnes@nps.gov)						
	45	cores	725	725	0	Samples crossdated visually; counted if unable to crossdate.
Yukon Flats NWR Fire History Study (US Fish and Wildlife Service): This project analyzed fire-history patterns within the Yukon Flats National Wildlife Refuge in northeast interior Alaska. Tree-ring samples were collected between 1997-1999 from 27 points within the refuge boundaries. Standard dendrochronological methods were used to date 40 fires and to determine stand origin dates. Data contact: Stacy Drury (sdrury@sonomatech.com)						
	27	cross-sections				Samples processed by Drury.

IV. KEY FINDINGS

Literature Review and Synthesis

"Fire Regimes of the Alaskan Boreal Forest" provides a comprehensive review of information about fire regimes in Alaska and is presented in the context of current knowledge about patterns of fire in boreal forests of the northern hemisphere. Three major subject areas have emerged from the literature review of fire regimes: the complexity of environmental interactions, temporal trends, and spatial trends. Some of the highlights of each are reviewed below.

Fire, Vegetation, and Climate Interactions

Despite the relative simplicity of the boreal biome, fire regimes and interactions with the broader environment are still sufficiently complex that certain patterns have defied explanation. Over the past 60 years of fire history research in Alaska, methods have progressed dramatically from the observations and historical accounts documented by Harold Lutz (1956). Fire history studies currently document the past 14,000 years, while providing extensive geospatial analysis of contemporary fire regimes. Figure 3 summarizes the shifting dominance of vegetation types *vis a vis* changing fire frequency estimated from paleoecological records. Dominant vegetation and fire both respond to changing climate, and vegetation can provide negative or positive feedbacks to fire frequency and severity (Higuera et al. 2009).

Substantial progress has also been made documenting other fire-environment interactions and including them in ecological models that project future fire regimes and vegetation composition under various scenarios of management and climate. There are three key components to fire-environment interactions in the Alaskan boreal forest.

1. Scale. Interactions between fire and environmental variables must be understood at appropriate scales, because as one moves between scales, either in time or space, these relationships may change.
2. Variability. Variability is inherent to fire regimes in North America, but it is a defining aspect of the Alaskan boreal fire regime, notably at short temporal scales (Kasischke et al. 2006).
3. Synergy. Rarely do fire-environment interactions occur in a vacuum. Factors that influence patterns of fire frequently interact with each other. Thus, relative contributions of individual drivers of the fire regime are difficult to ascertain.

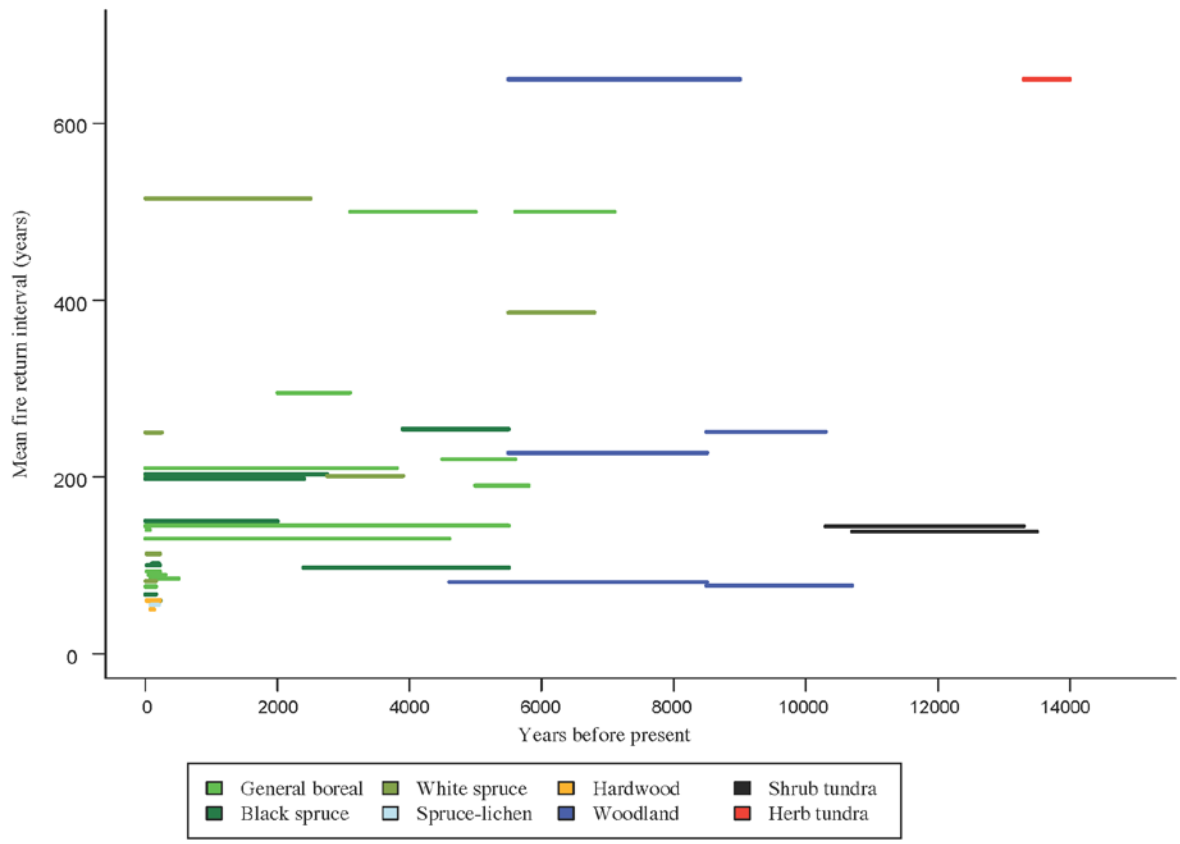

Figure 3. Temporal distribution of measured fire return intervals for vegetation types in boreal Alaska

Temporal Trends in Fire Regimes

During the last century, the primary drivers of area burned in the North American boreal forest at regional and continental scales were annual-to-decadal atmospheric teleconnections (e.g. the Pacific Decadal Oscillation and the El Nino Southern Oscillation. Positive phases of these teleconnections increase the probability of extended periods of warm and dry conditions, which in turn can cause substantially above average annual area burned. Fire-perimeter data have been frequently used to determine short-term patterns of fire (Kasischke and Turetsky 2006; Kasischke et al. 2002; Kasischke et al. 2010) and climate reconstructions have established strong correlations between area burned and teleconnection indices in boreal Alaska (Duffy et al. 2005; Hess et al. 2001).

Despite high variability at interannual to decadal scales, larger trends occur at the centennial scale. A widespread trend found in dendrochronological studies across boreal Canada has been the decrease in fire frequency following the end of the Little Ice Age in the mid 19th century (Brassard and Chen 2006). Dendrochronological and paleoecological data from boreal Alaska have been equivocal, with some studies showing increased fire frequency (De Volder 1999; Lynch et al. 2002) and other reporting a decrease, as seen across Canada (Tinner et al. 2006). It is unclear what caused these trends but some interaction between climate and settlement is often cited. Studies focused on centennial trends do show that landscape-scale vegetation patterns can be substantially altered by changes to the fire regime.

Millennial-scale patterns of the fire regime are revealed in studies documenting 14,000 years of fire history in boreal Alaska. At this scale changes in climate, vegetation, and the fire regime are dramatic. There is debate over the relative strength of interactions between climate, vegetation, and fire. One argument is that climate-induced vegetation shifts change the flammability of the landscape, which in turn controls the fire regime (Brubaker et al. 2009; Higuera et al. 2009; Hu et al. 2006). The other is that fire regimes respond to changes in climate and vegetation adapts to fluctuations in the fire regime (Anderson et al. 2006; Carcaillet et al. 2001). Both arguments can be supported in the literature we surveyed.

Information gained from fire-history studies will be applied to understanding the impact of climate change. Ecological disturbance models for the boreal region have consistently forecast that a warming climate will increase fire activity (Flannigan and Van Wagner 1991; McCoy and Burn 2005; Stocks et al. 1998; Tymstra et al. 2007; Wotton and Flannigan 1993; Wotton et al. 2010), and cause large-scale vegetation shifts from conifer to deciduous boreal forest (Calef et al. 2005; Potter 2004; Rupp et al. 2001) and from herb to shrub tundra (Euskirchen et al. 2009). These forecasts are consistent with recent analyses of regional- to continental-scale changes of fire regimes (Kasischke and Turetsky 2006; Soja et al. 2007) and stand-level changes in the boreal forest (Johnstone and Kasischke 2005; Johnstone et al. 2010). Uncertainty remains substantial within these models, however (Hinzman et al. 2005; Rupp et al. 2007), and more work is needed to understand and quantify the effects of teleconnections, which are important decadal-scale drivers of fire (Macias Fauria and Johnson 2008).

Spatial Heterogeneity

Spatial heterogeneity of fire regimes has been well documented in Alaska, where patterns are evident at fine to broad scales, with variability ubiquitous across scales (Kasischke et al. 2002). Synergistic interactions between spatial and temporal controls and short-term variability in annual area burned obscure evidence of stable spatial patterns in the boreal forest, but broad-scale gradients and fine-scale are still observed. For example, at the boreal-biome scale, there is a west-to-east increase in fire frequency across interior Alaska (Kasischke et al. 2002), with less frequent fire south of the Alaska Range (Lynch et al. 2002). Possible influences include lightning-strike density and precipitation. At the stand level, terrain features such increasing mean waterbreak distance, decreasing elevation (except lowlands), and south aspects are associated with frequent fire (Kasischke et al. 2002). Forest type also seems to influence the fire regime. Deciduous upland forests are associated with more frequent but less severe fire (Alexander 2010; Alexander and Lanoville 1989; Allen and Sorbel 2008; Duffy et al. 2007; Hely et al. 2001; Mann and Plug 1999; Yarie 1981; Quintillo et al. 1991) than boreal spruce. Distinct fire regimes occur in spruce stringer forests in wet depressions (Quirk and Sykes 1971) and alpine tundra (Kasischke et al. 2002), both of which have substantially less frequent and severe fire than adjacent boreal forest.

The relative influence of spatial controls can be unclear. For example, with increasing elevation the weather is cooler and wetter and less conducive to fires, and at treeline flammable spruce forest is replaced by less flammable alpine tundra. In this case climate and fuels act together to reduce the frequency, intensity, and severity of fires. In other cases drivers may have opposing effects. South-facing slopes generally have more frequent and severe fire, but they are also associated with deciduous forest types, in which fires are less severe than in conifer forest, though still more frequent. At the broadest scale (across Alaska), there are sharp geographic boundaries among fire regimes caused by spatial variation in fuels and climate (Gabriel and Tande 1983; Kasischke et al. 2002). For instance, most fire activity in Alaska is confined to interior Alaska (i.e., where the majority of the boreal forest biome in Alaska occurs), where fuels and climate are conducive to very large intense fires.

Alaska Fire History Database

The fourteen datasets compiled into the Alaska fire history database comprise 2,786 plots and 13,585 samples. We processed 5,095 of the samples, from nine of the datasets. The samples have been returned to the respective data contacts, and each dataset will also be sent to the data contact for use in their local fire and landscape management. The Alaska fire history database can be downloaded from: http://frames.nbii.gov/documents/alaska/fire_history/ak_fire_history_db.zip. Plot summary data will also be accessible through the Alaska Fire and Fuels Research Map layer hosted by the AICC ArcIMS mapping website (http://afsmaps.blm.gov/imf/imf.jsp?site=firehouse). The database has been sent to Gary Schmunk at AICC, and he expects to post the changes to the map layer during May or June 2011. This will enable users to select a plot on an online map and view the summary of disturbances recorded for the plot, as well as the earliest establishment date recorded for the plot.

As expected, conducting a broad-scale analysis of this compilation of datasets posed a challenge, primarily due to the different sampling intensities and design for each study. Some studies include multiple sample points per plot, whereas others sampled just one tree. Some studies targeted multiple age classes of trees, whereas some targeted only the oldest trees. Some studies targeted fire-scarred or fire-killed trees within stands that appeared to represent old burn scars, whereas others followed transects with the intent to not be biased toward sampling old burns. Perhaps most importantly, plots were not evenly distributed throughout the landscape. Because of these uncertainties, we limited our analysis of the data to a general review of the average earliest tree-establishment dates for plots within Nowacki et al. (2001) ecoregions, and the percentage of plots estimated to have burned, by decade and ecoregion.

For each of the plots in the database, fire dates, possible fire dates, and tree establishment dates were summarized (as applicable) for all the samples collected from the plot. Each plot was also assigned an ecoregion, which was then cross-referenced to a Stafford et al. (2000) climatic zone. Review of the average earliest tree-establishment dates by ecoregion and climatic zone revealed that the ecoregions in the South Central climatic zone had the earliest average establishment dates, and it appears that establishment dates in eastern ecoregions are earlier than in western ecoregions (table 3).

Appendix 1 provides a more detailed breakdown of the data summarized in fig. 4. It specifies whether percentage data represented probable fires or possible fires, and whether fires (or possible fires) were known to have occurred in specific decades, or if the decades were estimated (based on clustering of tree establishment dates).

Table 3—Average earliest tree establishment dates by Nowacki et al. (2001) ecoregion

Ecoregion	Average earliest tree estab.	Number of plots with estab. dates	Number of plots per eco-region	Stafford et al. (2000) climatic zone (modified by relative geographic location in italics)
Maritime: Coast Mountains Transition: Kluane Range	1787	27	31	*eastern* South Central
Maritime: Coastal Rainforests: Chugach-St. Elias Mountains	1793	95	101	*central and eastern* South Central
Maritime: Coast Mountains Transition: Wrangell Mountains	1812	30	35	*eastern* South Central
Boreal: Alaska Range Transition: Alaska Range	1812	41	55	*northern* South Central
Boreal: Alaska Range Transition: Lime Hills	1815	138	145	*eastern* West Coast
Boreal: Bering Taiga : Bristol Bay Lowlands	1838	3	6	*southeastern* West Coast
Maritime: Pacific Mountains Transition: Copper River Basin	1844	236	243	*eastern* South Central
Polar: Arctic Tundra: Brooks Range	1850	22	70	*southern* Arctic
Boreal: Intermontane Boreal: Ray Mountains	1851	31	32	*central* Interior
Boreal: Intermontane Boreal: Yukon-Tanana Uplands	1853	414	438	*eastern* Interior
Boreal: Intermontane Boreal: Tanana-Kuskokwim Lowlands	1859	170	197	*southern* Interior
Boreal: Intermontane Boreal: Davidson Mountains	1861	70	70	*northeastern* Interior
Boreal: Intermontane Boreal: Yukon-Old Crow Basin	1864	176	203	*northeastern* Interior
Maritime: Aleutian Meadows : Alaska Peninsula	1871	7	8	*southeastern* West Coast
Boreal: Intermontane Boreal: Yukon River Lowlands	1874	20	20	*western* Interior and *eastern* West Coast
Boreal: Alaska Range Transition: Cook Inlet Basin	1880	133[2]	300	*central* South Central
Boreal: Intermontane Boreal: Kobuk Ridges and Valleys	1883	219	287	*northwestern* Interior and *northern* West Coast
Boreal: Intermontane Boreal: Kuskokwim Mountains	1886	463	463	*southwestern* Interior and *eastern* West Coast
Boreal: Intermontane Boreal: North Ogilvie Mountains	1887	35	42	*eastern* Interior
Polar: Bering Tundra: Kotzebue Sound Lowlands	1947	2	2	*northern* West Coast
Polar: Bering Tundra: Seward Peninsula	1950	16	21	*northern* West Coast

[2] We don't have the tree establishment data for the DeVolder plots. The average earliest fire date for all DeVolder plots is 1800, suggesting the average earliest tree establishment value for the Cook Inlet Basin ecoregion is likely earlier than 1880.

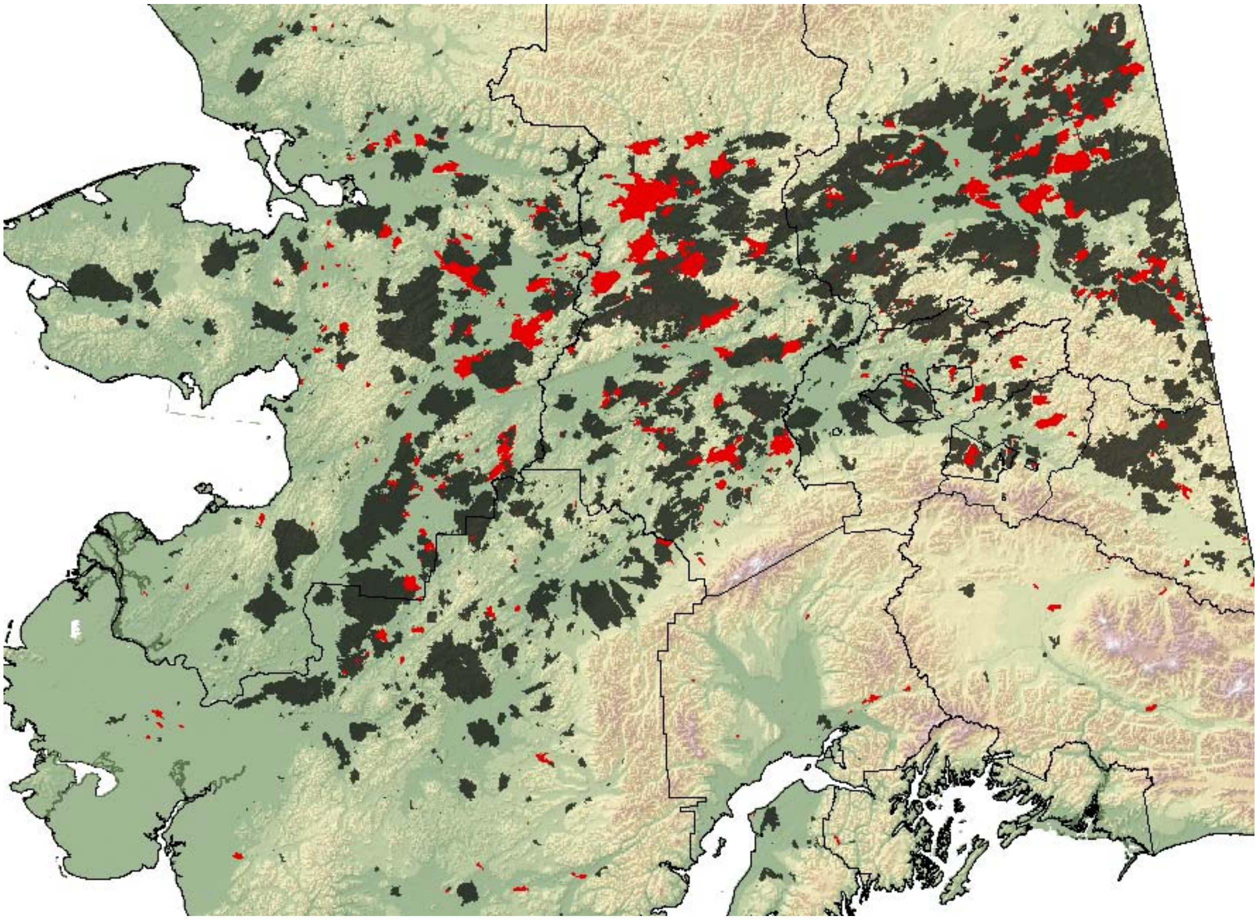

Figure 4—Map of Alaska large fire database perimeters since 1942. Red perimeters represent the missing fires added during this project. The entire database can be accessed at: http://afsmaps.blm.gov/imf/imf.jsp?site=firehistory

Alaska Large Fire Database

By leveraging funding from this project and resources at the Alaska Fire Service, the large-fire database has been extended to include fire perimeters since 1942, identifying and digitizing missing fire perimeters from remotely sensed imagery in conjunction with historical maps, updating existing fire perimeters, and adding missing attribute information. Over the course of this project, 417 missing fire perimeters were identified and digitized adding approximately 5.8 million acres of burned area to the landscape. The additional fire-attribute information includes fire name, management office, management option, latitude, longitude, origin owner, origin administrative unit, start date, out date, estimated acres, cause, origin township, origin range, origin section, origin meridian, AFS fire number, State fire number, USFS fire number, and import notes and comments. Lastly, we georeferenced a point location for every fire start reported in Alaska since 1939.

We conducted a quick internet search to identify studies that used previous versions of the Alaska Large Fire Database. Twenty-six journal articles were identified, with topics including remote sensing, effects of climate change on fire regimes, fire-season severity and atmospheric-ocean variability, fire's impact on birch defense and snowshoe-hare browse, and the influence of fire regime on caribou habitat. This dataset continues to be used to monitor climate and habitat change in interior Alaska, and other programs as diverse as BLM's Soil, Water, and Air program provided additional maintenance funding in 2010.

V. MANAGEMENT IMPLICATIONS

The compilation of multiple existing fire scar and tree age tree-ring datasets into a single Alaska fire history database provides the fire research community the opportunity to identify underrepresented regions and to conduct broad-scale analyses of spatial and temporal patterns. This helps the management community by obviating data collection in certain areas and freeing more resources to analyze fire-regime patterns and their implications for land management. By our processing samples from those datasets, their owners (often land management agencies) now have more complete and specific fire-history information for their landscapes.

The Alaska large fire database has already been used in multiple studies, and requests for it continue. It has also been instrumental to the development of two tools:

> Boreal ALFRESCO (Alaska Frame Based Ecosystem Code http://www.snap.uaf.edu/downloads/boreal-alfresco), which projects the impacts of changing climate on fire regimes for five major subarctic boreal ecosystem types: upland tundra, black spruce forest, white spruce forest, deciduous forest, and grassland-steppe.
>
> Paul Duffy's "Experimental forecast of area burned for Interior Alaska" (http://www.snap.uaf.edu/fire_prediction_tool/) which forecasts area burned in Interior Alaska for the upcoming fire season for fire managers.

By providing online searchable access to the tree-ring based plot disturbance and tree age summary data in a map layer, alongside the layer containing fire perimeters since 1942 and points since 1939, we give managers and researchers access to summarized fire history data. Specifically, users can add the large fire database data as layers in the fire and fuels research theme on the AICC ArcIMS mapping website (http://afsmaps.blm.gov/imf/imf.jsp?site=firehouse) by expanding the "Fire History" folder and selecting the desired map layers. This online map interface to both databases facilitates and streamlines access to fire history data for use in developing fire management plans."

VI. RELATIONSHIP TO OTHER RECENT STUDIES

The literature review provides an account of all recent published findings related to fire regimes in the boreal forest of Alaska. Of the 28 fire history studies for which individual summaries have been developed (table 1), 11 were published since the submission of our proposal. Included in these individual reviews are recent paleoecological studies that have described changes in fire for the late Quaternary Period at numerous sites across boreal Alaska (Higuera et al. 2008, 2009; Hu et al. 2006; Tinner et al. 2006, 2008). These studies have expanded knowledge of the interactions among fire, vegetation, and climate at long temporal scales. The recent dendrochronological study in the Yukon Flats National Wildlife Refuge (Drury and Grissom 2008) is also summarized, as are recent studies by Kasischke et al. (2006, 2010), which use fire-perimeter data to describe spatial and temporal trends of boreal fire regimes.

This project is directly linked to the following JFSP-funded projects either by providing data, or in the case of FIREHouse, capitalizing on the online map interface already developed at AICC:

- Development of a Computer Model for Management of Fuels, Human-Fire Interactions, and Wildland Fires in the Boreal Forest of Alaska (Rupp, Jandt; 01-1-1-02)

- Refinement and Development of Fire Management Decision Support Models Through Field Assessment of Relationships Between Stand Characteristics, Fire Behavior and Burn Severity (Camp, Omi, Cronan, Huffman; 04-2-1-96)
- Managing Fire With Fire in Alaskan Black Spruce Forests: Impacts of Fire Severity on Successional Trajectory and Future Forest Flammability (Johnstone, Hollingsworth; 05-1-2-06)
- Post-Fire Studies Supporting Computer-Assisted Management of Fire and Fuels During a Regime of Changing Climate in the Alaskan Boreal Forest (Rupp, Mann, Murphy; 05-2-1-07)
- Expanding FIREHouse (the Northwest Fire Research Clearinghouse) to Alaska (Olson, Barnes, Jandt, Peterson; 05-4-2-03)
- Reconstructing Fire Regimes in Tundra Ecosystems to Inform a Management-Oriented Ecosystem Model (Higuera, Rupp, Barnes; 06-3-1-23)

VII. FUTURE RESEARCH NEEDS

The literature review focused on Alaskan boreal forests, because as climate change impacts the region, there is a high potential for more fire in tundra ecosystems. Relative to boreal forests, fire in tundra ecosystems is not well understood, and a synthesis of existing literature would help identify baseline information and focus future research in the most pressing knowledge gaps. The literature review also revealed two limitations to our understanding of boreal fire regimes in Alaska: (1) the focus on fire frequency as the primary measure of the historical fire regime, to the exclusion of severity and spatial pattern, and (2) the lack of regional information on centennial-scale trends in fire.

Fire frequency by itself does not necessarily capture the complexity of historical fire regimes. The lack of research in other aspects of historical fire regimes (such as severity, seasonality, intensity, vegetation succession, etc.) is largely understandable given the difficulty of measuring those variables. Methods are available to measure these other aspects of historical fire regimes are either indirect (e.g., using pollen data to measure severity) or provide low resolution (e.g., using tree ring data to measure seasonality). Identifying new methodologies to measure properties of historical fires would help develop frameworks for historical, current, and future fire-environment interactions.

The lack of centennial-scale data on fire history in Alaska reflects the development of fire-history studies in the state. Initially, dendrochronology was frequently used to document fire history, but nearly all of these studies focused on findings for very small sampling areas. Recently, efforts have focused on fire-perimeter data from historical fire reports, and paleoecological data, such as sediment charcoal, pollen, and macrofossils. This research has provided rigorous data about decadal-scale and millennial-scale trends, respectively, but there is still a gap at the intermediate temporal scale. Widespread stand-replacing fire regimes limit the geographic coverage of fire-scar data. Some paleoecological studies have analyzed sediment charcoal and pollen samples at a higher temporal resolution (e.g., annual), but due to the intense sampling effort required, they lack the spatial resolution available from the more spatially extensive dendrochronological studies. Innovative approaches to centennial-scale fire history would help in understanding pre-settlement and pre-suppression fire regimes, and in determining possible impacts of climate change on vegetation and fire over the next century.

VIII. Deliverables

Proposed	Delivered	Status
Alaska fire history database	The Alaska fire history database can be accessed through the following URL: http://frames.nbii.gov/documents/alaska/fire_history/ak_fire_history_db.zip	Complete
Online fire history map	Plot summary data from the Alaska fire history database is accessible through the Alaska fire and fuels research map layer hosted by the AICC ArcIMS mapping website: (http://afsmaps.blm.gov/imf/imf.jsp?site=firehouse)	Complete We expect changes to the map layer during summer 2011
	The improved Alaska Large Fire Database is available through the AICC ArcIMS mapping website: (http://afsmaps.blm.gov/imf/imf.jsp?site=firehistory)	Complete
Incorporation of Alaska fire history data into the international multiproxy paleofire database (IMPD)	The Alaska fire history database was submitted to the International Multiproxy Paleofire Database (IMPD)	We are awaiting word from Michael Hartman about which datasets are accepted into the IMPD
Alaska boreal forest fire history synthesis	*Fire Regimes of the Alaskan Boreal Forest* Draft general technical report http://frames.nbii.gov/documents/alaska/fire_history/fire_regimes_alaskan_boreal_forest_draft_gtr.zip	Ready for submission to PNW
Project website	http://frames.nbii.gov/alaska/borealfirehistory	Complete
Journal publication	Not funded	---------
Final report		Complete

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ADDITIONAL REPORTING

Presentations:

- Olson, D.L. 2006. Compiling, synthesizing and analyzing existing boreal forest fire history data in Alaska [oral presentation]. Alaska Fire Effects Task Group Meeting, September 28, 2006; Anchorage, Alaska.
- Olson, D.L., J.B. Cronan, A.E. Camp, J.L. Allen, D. McKenzie, J. Hrobak, M. Tjoelker, and P.C. Eagle. 2007. Compiling, synthesizing and analyzing existing boreal forest fire history data in Alaska [poster]. 2nd Fire Behavior and Fuels Conference, March 26-30, 2007; Destin, Florida.
- Olson, D.L. 2007. Compiling, synthesizing and analyzing existing boreal forest fire history data in Alaska [oral presentation]. Alaska Fire Effects Task Group Meeting, May 2, 2007; Fairbanks, Alaska.
- Hrobak, J.L. and P. Martyn. 2008. Alaska Large Fire Database [oral presentation]. Monitoring Trends in Burn Severity, Alaska Burn Severity Workshop, February 20-21, 2008; Anchorage, Alaska.
- Hrobak, J.L. 2008. Alaska Large Fire Database [oral presentation]. Alaska Fire Effects Technology Transfer Workshop, March 24-25, 2008; Fairbanks, Alaska.
- Olson, D.L., J.B. Cronan, A.E. Camp, J.L. Allen, D. McKenzie, J.L. Hrobak, M. Tjoelker, and P.C. Eagle. 2008. Compiling, synthesizing and analyzing existing boreal forest fire history data in Alaska [poster]. Alaska Fire Effects Technology Transfer Workshop, March 24-25, 2008; Fairbanks, Alaska.
- Northway, J.L. 2009. Alaska Large Fire Database [oral presentation]. Alaska Fire Effects Technology Transfer Workshop, May 13, 2009; Fairbanks, Alaska.
- Olson, D.L., J.B. Cronan, J.L. Allen, D. McKenzie, A.E. Camp, M. Tjoelker, J.L. Northway, and P.C. Eagle. 2009. Compiling, synthesizing and analyzing existing boreal forest fire history data in Alaska [poster]. Fourth International Congress on Fire Ecology and Management: Fire as a Global Process, November 30-December 4, 2009; Savannah, Georgia.

Agreements:

- Interagency Agreement with the BLM Alaska Fire Service: $16,000
- Cooperative Agreement with Yale University: $91,004
- Cooperative Agreement with University of Washington: $73,000

Appendix 1. Percentages of plots recording (or possibly recording) fires by decade and by Nowacki et al. (2001) ecoregion. Bracketed data denotes that the decade is a best estimate (typically these data reflect clusters of tree establishment dates).

Nowacki et al. (2001) ecoregion, with Stafford et al. (2000) climatic zone in parentheses, modified by relative geographic location in italics.	Maritime: Coast Mountains Transition : Kluane Range (*eastern* South Central)	Maritime: Coastal Rainforests : Chugach-St. Elias Mountains (*central and eastern* South Central)	Maritime: Coast Mountains Transition : Wrangell Mountains (*eastern* South Central)	Boreal: Alaska Range Transition : Alaska Range (*northern* South Central)	Boreal: Alaska Range Transition : Lime Hills (*eastern* West Coast)	Boreal: Bering Taiga : Bristol Bay Lowlands (*southeastern* West Coast)	Maritime: Pacific Mountains Transition : Copper River Basin (*eastern* South Central)	Polar: Arctic Tundra : Brooks Range (*southern* Arctic)	Boreal: Intermontane Boreal : Ray Mountains (*central* Interior)	Boreal: Intermontane Boreal : Yukon-Tanana Uplands (*eastern* Interior)	Boreal: Intermontane Boreal : Tanana-Kuskokwim Lowlands (*southern* Interior)	Boreal: Intermontane Boreal : Davidson Mountains (*northeastern* Interior)	Boreal: Intermontane Boreal : Yukon-Old Crow Basin (*northeastern* Interior)	Maritime: Aleutian Meadows : Alaska Peninsula (*southeastern* West Coast)	Boreal: Intermontane Boreal : Yukon River Lowlands (*western* Interior and *eastern* West Coast)	Boreal: Alaska Range Transition : Cook Inlet Basin (*central* South Central)	Boreal: Intermontane Boreal : Kobuk Ridges and Valleys (*northwestern* Interior and *northern* West Coast)	Boreal: Intermontane Boreal : Kuskokwim Mountains (*southwestern* Interior and *eastern* West Coast)	Boreal: Intermontane Boreal : North Ogilvie Mountains (*eastern* Interior)	Polar: Bering Tundra : Kotzebue Sound Lowlands (*northern* West Coast)	Polar: Bering Tundra : Seward Peninsula (*northern* West Coast)
# plots per ecoregion	31	101	35	55	145	6	243	70	32	438	197	70	203	8	20	300	287	463	42	2	21
avg. earliest establishment	1787	1793	1812	1812	1815	1838	1844	1850	1851	1853	1859	1861	1864	1871	1874	1880	1883	1886	1887	1947	1950
# plots with estab. dates	27	95	30	41	138	3	236	22	31	414	170	70	176	7	20	133	219	463	35	2	16
1500s (fire)																					
1500s (possibly fire)	[3.2]																				
1590s (fire)																					
1590s (possibly fire)		[1.0]																			
1620s (fire)																					
1620s (possibly fire)				[1.8]																	
1650s (fire)																					
1650s (possibly fire)													[0.5]								
1670s (fire)																					
1670s (possibly fire)	[3.2]																				
1680s (fire)																					
1680s (possibly fire)		[1.0]											[0.5]								
1690s (fire)																					
1690s (possibly fire)		[1.0]		[1.8]									[0.5]								
1700s (fire)																7.7					
1700s (possibly fire)				[1.8]			[0.8]												[2.4]		
1710s (fire)																					
1710s (possibly fire)		[1.0]					[0.4]				[1.0]										
1720s (fire)																					
1720s (possibly fire)	[9.7]		[2.9]		[0.7]		[0.4]														
1730s (fire)																					
1730s (possibly fire)	[3.2]		[2.9]		[0.7]		[0.8]						[0.5]						[4.8]		
1740s (fire)																					
1740s (possibly fire)				[1.8]			[0.4]			[0.2]			[1.5]						[2.4]		
1750s (fire)																					
1750s (possibly fire)							[2.9]			[0.2]	[0.5]						[0.3]	[0.4]			
1760s (fire)																20					
1760s (possibly fire)	[3.2]					[16.7]	[1.6]			[0.5]						[0.3]		[0.2]			
1770s (fire)																					
1770s (possibly fire)			[2.9]	[3.6]	[2.1]		[1.2]			[0.5]	[0.5]		[0.5]				[1.0]	0.2 [1.3]			
1780s (fire)																					
1780s (possibly fire)	[3.2]	[1.0]			[0.7]		[1.6]			[0.7]	[1.5]						[1.7]	[0.9]	[2.4]		
1790s (fire)																					
1790s (possibly fire)		[2.0]		[7.3]	[1.4]	[16.7]	[2.9]	[2.9]		[1.4]	[1.5]	[1.4]	[0.5]	[12.5]			[1.4]	[0.4]	[2.4]		
1800s (fire)																					
1800s (possibly fire)				[7.3]	[1.4]		[2.9]			[0.9]	[1.5]		[0.5]				[0.3]	[0.6]			
1810s (fire)																					
1810s (possibly fire)	[6.5]	[2.0]	[8.6]	[7.3]	[2.8]	[16.7]	[5.8]		[3.1]	[2.1]	[3.0]	[2.9]	[1.0]				0.3 [0.7]	[0.6]			
1820s (fire)																5.3					
1820s (possibly fire)	[3.2]	[2.0]		[5.5]			[2.1]			[3.7]	[2.5]	[1.4]	[2.0]		[25.0]		[2.4]	[2.6]	[2.4]		
1830s (fire)										0.2						12					
1830s (possibly fire)		[4.0]			0.7 [4.1]		[3.3]	[4.3]	[3.1]	[0.7]	[1.0]		[1.5]	[12.5]	[5.0]		[0.7]	[1.7]	[2.4]		

Appendix 1. Percentages of plots recording fires (continued).

Nowacki et al. (2001) ecoregion, with Stafford et al. (2000) climatic zone in parentheses, modified by relative geographic location in italics.	Maritime: Coast Mountains Transition : Kluane Range (*eastern* South Central)	Maritime: Coastal Rainforests : Chugach-St. Elias Mountains (*central and eastern* South Central)	Maritime: Coast Mountains Transition : Wrangell Mountains (*eastern* South Central)	Boreal: Alaska Range Transition : Alaska Range (*northern* South Central)	Boreal: Alaska Range Transition : Lime Hills (*eastern* West Coast)	Boreal: Bering Taiga : Bristol Bay Lowlands (*southeastern* West Coast)	Maritime: Pacific Mountains Transition : Copper River Basin (*eastern* South Central)	Polar: Arctic Tundra : Brooks Range (*southern* Arctic)	Boreal: Intermontane Boreal : Ray Mountains (*central* Interior)	Boreal: Intermontane Boreal : Yukon-Tanana Uplands (*eastern* Interior)	Boreal: Intermontane Boreal : Tanana-Kuskokwim Lowlands (*southern* Interior)	Boreal: Intermontane Boreal : Davidson Mountains (*northeastern* Interior)	Boreal: Intermontane Boreal : Yukon-Old Crow Basin (*northeastern* Interior)	Maritime: Aleutian Meadows : Alaska Peninsula (*southeastern* West Coast)	Boreal: Intermontane Boreal : Yukon River Lowlands (*western* Interior and *eastern* West Coast)	Boreal: Alaska Range Transition : Cook Inlet Basin (*central* South Central)	Boreal: Intermontane Boreal : Kobuk Ridges and Valleys (*northwestern* Interior and *northern* West	Boreal: Intermontane Boreal : Kuskokwim Mountains (*southwestern* Interior and *eastern* West Coast)	Boreal: Intermontane Boreal : North Ogilvie Mountains (*eastern* Interior)	Polar: Bering Tundra : Kotzebue Sound Lowlands (*northern* West Coast)	Polar: Bering Tundra : Seward Peninsula (*northern* West Coast)
# plots per ecoregion	31	101	35	55	145	6	243	70	32	438	197	70	203	8	20	300	287	463	42	2	21
avg. earliest establishment	1787	1793	1812	1812	1815	1838	1844	1850	1851	1853	1859	1861	1864	1871	1874	1880	1883	1886	1887	1947	1950
# plots with estab. dates	27	95	30	41	138	3	236	22	31	414	170	70	176	7	20	133	219	463	35	2	16
1840s (fire)													0.5			16.0					
1840s (possibly fire)	[3.2]	[2.0]	[2.9]	[1.8]	[2.8]		[0.4]		[3.1]	0.2 [0.9]	[3.6]		1.0 [3.9]				[2.8]	[1.7]	[4.8]		
1850s (fire)																					
1850s (possibly fire)	[3.2]	[1.0]		[1.8]			[2.1]	[4.3]	[3.1]	[0.5]	[4.1]		[8.4]	[12.5]		[0.3]	[3.5]	[1.7]	[4.8]		
1860s (fire)											0.5					8.0					
1860s (possibly fire)		[1.0]	[2.9]	[3.6]	[4.8]		[0.4]			[1.6]	[2.0]		0.5 [1.5]		[5.0]		[3.1]	[1.1]	[7.1]		
1870s (fire)				5.5							0.5		1.5			0.3					
1870s (possibly fire)		[1.0]	[2.9]	1.8 [1.8]	[0.7]		[2.5]	[1.4]		[0.5]	[4.1]		[4.9]			[0.7]	[6.6]	[0.6]	[2.4]		
1880s (fire)							0.4				1.5		1.5			8.0	0.3				
1880s (possibly fire)	[3.2]	[2.0]		5.5	0.7 [2.1]		[0.4]	[1.4]		[1.1]	[2.5]		[1.0]			[0.7]	[2.4]	0.2 [1.1]	[2.4]		
1890s (fire)							0.4			0.5	0.5		1.5		5.0	3.0					
1890s (possibly fire)			[5.7]		0.7 [2.8]		[0.8]	[5.7]	[9.4]	0.2 [3.7]	[5.1]	1.4 [7.1]	[2.5]		[50.0]		[2.8]	0.2 [1.1]	[2.4]		
1900s (fire)				10.9	2.8		0.4			0.2	3.6		1.0				0.3				
1900s (possibly fire)		[2.0]		1.8 [3.6]	0.7 [2.8]		[2.1]	[2.9]	12.5 [6.3]	[5.5]	[15.7]	[7.1]	[1.0]		[15.0]	[0.3]	0.7 [2.8]	[1.3]	[2.4]		
1910s (fire)				1.8	0.7		0.8				1.0		0.5				0.3	1.3			
1910s (possibly fire)	[3.2]	[5.9]		1.8 [5.5]	2.1 [2.8]		0.4 [4.5]		3.1 [6.3]	0.5 [3.9]	0.5 [13.2]		[3.9]	[12.5]			1.4 [2.1]	1.3 [7.8]	[2.4]		
1920s (fire)				3.6	2.8		0.8		6.3	0.5	2.0		3.9	[12.5]					4.8		
1920s (possibly fire)	[12.9]	[3.0]	[8.6]	3.6 [5.5]	1.4 [2.8]		0.4 [9.1]	1.4 [1.4]	[6.3]	0.2 [3.2]	1.0 [4.1]	[2.9]	[17.7]	[12.5]	5.0		1.4 [2.1]	0.2 [12.1]	[4.8]		
1930s (fire)		1.0			3.4	50.0	0.4				2.5		1.0				1.0	1.9			
1930s (possibly fire)	[3.2]		[8.6]	1.8 [5.5]	1.4 [3.4]		1.2 [1.2]	[1.4]	3.1 [3.1]	0.5 [0.5]	0.5 [1.5]		[3.4]			[1.7]	0.7 [2.1]	1.3 [16.2]	2.4 [2.4]		[9.5]
1940s (fire)				7.3	4.1		0.4				1.5		2.0	25.0			2.1	3.0			
1940s (possibly fire)				1.8 [3.6]	2.8 [0.7]		1.6 [1.2]	[1.4]		0.2 [1.4]	1.0 [2.0]	[8.6]	[1.5]			[2.0]	0.7 [2.8]	1.5 [13.0]	[9.5]	[100.0]	
1950s (fire)				1.8	4.1	33.3				3.7	2.5		2.5				2.8	0.2	4.8		
1950s (possibly fire)	[3.2]	[1.0]			4.8				3.1	0.2 [0.2]	1.5		1.0 [2.5]			[1.3]	1.0 [3.5]	1.5 [5.4]	[4.8]		[19.0]
1960s (fire)					2.1		0.8	1.4	3.1	0.7	5.6		1.0				2.1	0.2	26.2		
1960s (possibly fire)				3.6	3.4		0.4			0.7 [0.2]	0.5 [0.5]		0.5 [0.5]		10.0	[0.3]	1.4 [2.1]	[0.4]	4.8 [7.1]		[19.0]
1970s (fire)				1.8	3.4			21.4		0.9	3.0		0.5				9.1		2.4		14.3
1970s (possibly fire)					1.4		0.8	1.4	12.5	0.7 [0.2]	0.5				10.0		1.4	1.5			[4.8]
1980s (fire)	3.2		2.9	10.9	1.4		1.2	20.0	9.4	1.8	3.6		2.0	12.5			4.5	0.4	19.0		4.8
1980s (possibly fire)				1.8	2.1				3.1	0.9	1.5						0.3 [0.3]	2.2 [1.7]			
1990s (fire)									6.3	1.1			2.5				7.3	2.6			
1990s (possibly fire)					2.8		0.4			1.8	0.5						0.3	0.9 [1.1]			
2000s (fire)								1.4	3.1	2.3	3.6				60.0		16.4	2.2	11.9		
2000s (possibly fire)											2.5	5.7									