Managing Fire with Fire in Alaskan Black Spruce Forests: Impacts of fire severity on successional trajectory and future forest flammability

Final Report to the Joint Fire Science Program

Project # 05-1-2-06

Principal Investigators:
Teresa Hollingsworth, Boreal Ecology Cooperative Research Unit, PNW Research Station, US Forest Service
Jill Johnstone, Institute of Arctic Biology, University of Alaska Fairbanks

Co-Investigators:
F.S. Chapin III, Institute of Arctic Biology, University of Alaska Fairbanks
Michelle Mack, Department of Botany, University of Florida
Edward (Ted) Schuur, Department of Botany, University of Florida
David Verbyla, Department of Forest Sciences, University of Alaska Fairbanks

Contact information (phone and email):
Teresa Hollingsworth: (907) 474-2424; t.hollingsworth@fs.fed.us
Jill Johnstone: (306) 966-4421, jill.johnstone@usask.ca

October 31st, 2007

Introduction:

Wildfires are the dominant large-scale disturbance in the Alaskan boreal forest and highly flammable black spruce forests cover over 40% of interior Alaska. In the summer of 2004, Alaskans experienced the largest fire year in recorded history; 6.7 million acres burned mostly in the interior of Alaska (i.e. north of the Alaska Range and south of the Brooks Range). All of the 2004 wildfires were associated with large areas of black spruce forest. The 2004 Alaska fires presented a unique opportunity for research on fire effects for a variety of reasons. Firstly, many of the fires occurred along roads (an unusual condition given the sparse Alaskan road system). Secondly, the fires burned across 14 sites with intensive vegetation studies prior to burning. Finally, 2004 exhibited unusually dry and warm fire weather (Figure 1), conditions that may become more common in the future under climate change. Our Joint Fire Science project used data from the 2004 fires in Alaska to link pre-fire vegetation composition and soil conditions with patterns of fire severity and post-fire trajectories of ecosystem rehabilitation. An understanding of these linkages allows us predict the conditions that lead to altered fuel configurations in black spruce forests. In this project we explicitly address the following hypotheses:

Hypothesis 1: Variations in pre-fire vegetation, site conditions (slope, aspect, drainage), and fire weather interact to affect patterns of fire severity. Under moderate fire weather, vegetation and site conditions have a strong influence on severity level, while areas that burn under extreme fire weather are likely to experience a consistently high level of fire severity.

Hypothesis 2: The level of fire severity determines the strength of pre-fire vegetation legacies, and therefore the degree to which the post-fire vegetation composition resembles pre-fire vegetation composition at a site.

Hypothesis 3: Sites with high levels of fire severity have an increased recruitment potential for deciduous trees and shrubs. This is caused by increased rates of establishment from seed and more rapid growth of deciduous species on sites with high fire severity.

Methods:

This JFSP project was initiated in May of 2005. We established 90 sites in burned black spruce forests within three large 2004 fire complexes along the Dalton, Taylor, and Steese Highways (Figure 2). Approximately 10 sites were located in Caribou/Poker Creek Research Watershed (owned by the University of Alaska Fairbanks) part of the Bonanza Creek Long-Term Ecological Research (BNZ-LTER) program. Another 5 sites were located at the Poker Flats Research Range (owned by the University of Alaska Fairbanks) part of the Geophysical Institute. The remaining sites were located on Bureau of Land Management (including the Steese National Conservation Area) and State of Alaska land. These sites were permitted for continuing use, and the permit is on file with the BNZ-LTER site manager (Jamie Hollingsworth: (907) 474-7470; fsjh@uaf.edu). The closest towns to our sites are Livengood, Circle Hot Springs, Chena Hot Springs, Fairbanks, Tok, and Chicken (Figure 2).

When established, the 90 sites were rapidly assessed for site moisture and fire severity (initially estimated based on the % mineral soil exposed in the site). We then selected 32 of these sites for intensive study. These “intensive sites” were selected to include combinations of high vs. low site moisture and high vs. low fire severity, and also included 7 sites at elevational treeline. Detailed pre-fire stand data (including stand density, pre-fire organic layer depths, full vascular and nonvascular species composition, and soil characteristics) were available for 14 sites. These 14 “pre-fire” sites became a subset of our intensive sites, and reconstruction of pre-fire conditions was done at the remaining intensive sites using the 14 sites to compare our reconstructions. Each site was sampled within a 30 x 30 m plot, which was selected to represent the size of a single pixel of LANDSAT satellite data.

At all sites, we characterized fire severity by measuring the Composite Burn Index (CBI), and reconstructing the proportion of biomass loss from the tree canopy (using allometric equations) and forest floor (using our adventitious root method, described below). We classed each site into one of six categories of site moisture (sub-hygric to mesic) based on topography, soil texture, and presence of permafrost, and compared those classes to direct measurements of mineral soil moisture taken with a TDR moisture probe in July 2006. Pre-fire vegetation conditions at the site were characterized by measuring the size, density, age, and composition of the trees killed in the fires. We characterized post-fire vegetation and site conditions using a full floristic survey, density of natural tree regeneration, and intensive measurements of residual organic depth.

At our intensive sites, we increased sampling intensity and conducted more detailed measurements to characterize pre-fire and post-fire conditions. We established 14, 1 m^2 permanent vegetation plots at each site for long-term monitoring of vegetation recovery. We also conducted experimental trials of potential post-fire tree regeneration using a combination of seed sowing treatments and planted seedlings (Figure 3). The regeneration trials included planting seeds and seedlings of black spruce (*Picea mariana*), white spruce (*Picea glauca*), lodgepole pine (*Pinus contorta*), paper birch (*Betula neoalaskana*), and trembling aspen (*Populus tremuloides*). The soil measurements at these sites were also expanded to include measures of soil bulk density, carbon and nitrogen pools, and nitrogen availability (using ion exchange resins).

Synopsis of results:

Our results deal specifically with both **FIRE SEVERITY** and **SITE MOISTURE**, both of which can have various meanings. For this project, we have defined these terms as follows:

Fire severity: The amount of canopy or soil biomass consumed by a fire, measured as a proportion of (reconstructed) pre-fire biomass. Most of the stands we studied experienced 100% canopy mortality in the 2004 burns, so we did not use % mortality as an indicator of fire severity.

Site moisture: The potential moisture available for plant growth. Our classification of site moisture incorporates effects of both soil porosity and topographic drainage at a given site.

Fire severity is tightly linked to both pre-fire site characteristics and burning conditions.

- We developed a new method for using adventitious roots to estimate surface fire severity. Black spruce trees produce adventitious roots that grow near the top of the soil organic layer and these roots tend to track the height of the soil organic layer as it accumulates with increased time since fire. When a stand burns, these adventitious roots are generally still visible on the burned spruce trunks. Using our pre-fire data and data from unburned stands, we found that adventitious root height was a good proxy for pre-fire organic soil depth. Deeper burning does occur at trees, and we developed a correction factor that estimates the “offset” between root and organic soil surface height. This method, with the correction factor, can now be used in the field by managers to estimate amount of soil organic layer that has been consumed by fire in black spruce forests.

- The amount of carbon lost from a site was a function of pre-fire soil organic depths, site moisture, and pre-fire stand structure.

- CBI was a good estimator of overall (canopy and surface) % mass lost and a fairly good estimator for carbon emissions in Alaskan black spruce forests. CBI explains between 45-64% of the variation in organic soil mass lost and C emissions.

- We found that the relationship between CBI and ΔNBR (Normalized Burn Ratio, a remotely-sensed index of fire severity) for the 2004 wildfires was very low, where ΔNBR only captured 36% of the variation in CBI. This is attributed to the extreme fire season of 2004 where the summer temperature was high and summer precipitation was low. Therefore, most of the sites sampled in 2005 were from the "high end" of fire severity, and the remotely sensed index (ΔNBR) did not work well within this small range of severity. We suggest that ΔNBR estimates of fire severity are best across wide ranges of fire severity, and poorly differentiate between sites with varying surface severity once all of the canopy trees have been killed (high canopy severity).

- There was a consistent relationship between sites that we classified as high severity and the time of season the fire passed through that site, where late season fires (late July and August) were more likely to lead to high fire severity, indicating the importance of burn conditions in determining post-fire rehabilitation and ecosystem recovery.

There are strong relationships between pre-fire vegetation, fire severity, site moisture, post-fire vegetation composition, and nitrogen (N) availability for plant growth.

- Burn severity and site moisture appear to be highly correlated with overall post-fire species composition. In addition, site moisture was tightly linked with pre-fire vegetation and post-fire residual and resprouting vegetation. For example, wet or moist sites showed a significantly higher tendency to exhibit patches of residual vegetation and resprouting of vascular plants.

- When comparing pre- and post-fire composition in the 14 "pre-fire" sites, there was a larger change in overall species composition in dry sites and sites that experienced high severity burns, as compared to wet sites or sites that experienced low severity burns. An unexpected result was that the amount of change in species composition at a site was correlated to location (i.e. the highway the sites was adjacent to). We interpret this as an indication of the role of wildfire conditions, which differed among the three fire complexes, in driving post-fire vegetation composition.

- High severity sites lost more N than low severity sites and absolute N loss was positively related to pre-fire N pools in dry, high severity sites. In addition relative N loss was negatively related to pre-fire N pool size across all sites. It appears that in Alaskan black spruce forests, substantial N loss in the 2004 fires mines N pools accumulated over centuries even in low severity burns.

Wildfires can act as a conduit for invasive species colonization in interior Alaska and are occurring along interior Alaska road systems.

- Exotic plants were found along all three highways (Dalton, Taylor, and Steese) where the 2004 wildfires were road accessible. In particular, exotics occurred in significantly higher amounts along the Dalton Highway than the other two highways, possibly due to the large human influence along this highway.

- In the greenhouse, burned soil cores showed higher germination, survival, and biomass of three sown invasive species as compared to unburned soil cores. However there was no significant effect of fire severity or site moisture on germination, survival, and biomass. Therefore, exotic species management should extend into all recent burns regardless of severity.

Fire severity and site moisture significantly affect the rates of establishment and growth of deciduous tree and shrubs, forbs, mosses, and lichens.

- Comparing pre-fire and post-fire vegetation, there was an increase in the presence and abundance of key moose browse species following fire, especially in high severity and high moisture sites. These species included *Salix pulchra*, *Salix alexensis*, *Salix bebbiana*, and *Salix scouleriana*. Conversely, there was almost a 100% loss in lichen species, including *Cladonia spp.*, which provide winter forage for caribou.

- Conversely, there was a decrease in moss abundance and diversity, and in particular *Sphagnum spp. Sphagnum* plays a strong role in the development and maintenance of permafrost in Alaska black spruce forests, which in turn affects the site's moisture availability. Therefore, current burn severity, which was relatively high, could affect the future flammability of that site through the modification of site moisture.

- We found that the drivers of tree regeneration were specific to functional groups (deciduous versus coniferous), where deciduous species were most sensitive to the depth of the residual organic layer and conifers were most responsive to variations in site moisture.

- At sites that have moderate to low site moisture, fire severity can play an important role in determining whether black spruce forests return to black spruce after fire, or shift to an alternate, deciduous-dominated successional trajectory. Although similar shifts can occur following a severe fire at moist sites, such changes are less likely because of the reduced chance of burning away the thicker organic layers at moist sites.

Acknowledgements:

We would like to acknowledge the additional support we received for this project from both the USDA Forest Service PNW Research Station and the University of Alaska Fairbanks, in particular we are grateful for the support of the Bonanza Creek Long-Term Ecological Research Program (BNZ-LTER). BNZ-LTER donated field support (Jamie Hollingsworth), office/logistical support (Julie Benioff), and web support (Jason Downing). Emily Tissier was the research technician on this project and contributed to all aspects of the work. Thanks to Tom Paragi (AK Fish and Game) who contributed to the intellectual development of this project and the successional trajectories workbook. Finally, we would like to acknowledge the Alaska Wildland Fire Coordinating Group (AWFCG) for their continued support of this project.

Table 1: Deliverables cross-walk table for proposed knowledge transfer and deliverables.

Proposed	Delivered	Status	Attachments
Website	Although we had not listed a website as a deliverable in our proposal, it soon became clear to us that this was an important tool for organizing and disseminating information about the project. Our project website was initiated in **2005**, and can be found at: http://www.becru.uaf.edu/JFSP.htm	Done	n/a
Demonstration Sites	For our demonstration sites, we selected four sites that were easily accessible and covered a range of fire and vegetation conditions. The sites are located on land managed by the Bonanza Creek LTER, and are well-suited for long-term use in demonstrating the different post-fire successional trajectories that are possible in Alaskan black spruce forests. The sites have already been used in tours for managers and scientists (JFSP governing board, LTER site review) and were the focus of a Denali Elementary School educational field trip that had 50 first-graders visiting the plots and learning about fire.	Done	n/a
Fire Successional Trajectory Workbook	We have developed a successional trajectories workbook that is a tool for managers to predict future forest composition as a function of pre-fire vegetation, site moisture, and fire conditions in burned black spruce forests. The workbook follows the general structure of a dichotomous key, and uses a rule-based decision tree to predict successional trajectories after the fire. We have added in an additional section for fire planning in unburned forests. This section helps identify the fire conditions that would likely be necessary to result in a shift to a given alternate successional trajectory. The workbook also includes a key for identifying general categories of available site moisture. Photographs are provided to provide a visual reference to different fire conditions and successional trajectories. At the time of this	In progress	Draft of workbook

	report, the workbook is in its final draft. We expect to publish it as a small, spiral bound workbook by **December 2007.**		
Maps of Successional Trajectory	We developed maps of predicted succession trajectory for one of the large fire complexes studied in our project, the 2004 Boundary Fire. These maps were derived from analyses of remote sensing data to estimate pre-fire vegetation and fire severity. We then used the ALFRESCO landscape simulation model to predict future forest cover as a function of pre-fire vegetation and fire severity. Because feedbacks between forest cover and future flammability are a major focus of this project, we also used the ALFRESCO model to examine how changes brought about by differences in severity in one fire cycle can affect burning in a subsequent fire cycle. The maps and simulations for this component of the project were completed in **September 2007**.	Done	Summary presentation (pdf) www.becru.uaf.edu/Research/JFSP/Boundary_Fire_simulations.pdf
Maps of Projected Succession in Unburned Landscapes	This component of the project has been changed from our original proposal. We decided that it would be more valuable to managers if, instead of making a map for a specific area, we expanded the successional trajectories workbook to include a section for unburned forest. This new section in the workbook provides a list of general fire and landscape conditions that are likely to result in a return to forest types similar to the pre-fire stand, or a switch to an alternate successional trajectory.	Done	see Succession Workbook
Meetings with Managers	Our meetings with fire and land managers in Alaska have take two forms: 1) providing short presentations on our research at meetings organized by the managers, and 2) holding small meetings with managers that focused specifically on our JFSP project. • **May 2005,** presentation at the North American Boreal Fuel Consumption working group, Ann Arbor, MI. • **November 2005**, presentation to the Alaskan Northern Forest Cooperative, Fairbanks, AK. • **April 2006,** project meeting with	Done (except one upcoming presentation)	Manager presentations (ppt files) www.becru.uaf.edu/JFSP_October2007_Meeting.htm

	managers from Alaska Division of Natural Resources, Fairbanks, AK. • **August 2006,** presentation and field visit to demonstration sites with local fire managers and the JFSP Governing Board, Fairbanks, AK. • **August 2006,** full-day symposium for fire managers to summarize the results of this JFSP and other fire research projects at the University of Alaska. Symposium attended by managers from Alaska Fire Service and Alaska Division of Natural Resources. Fairbanks AK. • **October 2006**, poster presentation at the 7th Annual Alaska Statewide Noxious and Invasive Plants Management Workshop, Anchorage, Alaska. • **March 2006,** research update at the North American Boreal Fuel Consumption working group, Edmonton, Alberta. • **October 2007,** final project meeting with managers, Fairbanks, AK. At this meeting, we presented a summary of the project results and deliverables, and concluded with a round-table discussion. The meeting was attended by managers representing the major land management agencies in Alaska, including Alaska Division of Natural Resources, Bureau of Land Management, U.S. Park Service, U.S. Forest Service, and U.S. Fish and Wildlife Service. • **March 2008:** We have been invited to provide a summary presentation on the project at the spring meeting of the Alaska Wildland Fire Task Group.		
Annual Reports	Our annual progress report for research conducted from the start of the project in June 2005 to August 2006 was submitted to JFSP in 2006. This final report updates our progress for the second and final year of the project.	Done	n/a
Presentations at Scientific Conferences	We have presented several oral and poster presentations on our project results at international and national scientific	Done	Presentation abstracts and PDF copies

	meetings, including: • 3rd International Fire Ecology and Management Congress, **November 2006**, San Diego, CA (1 oral and 2 posters). • Alaska Surveying and Mapping Conference, **March 2007**, Fairbanks, AK (1 oral). • Long Term Ecological Research All-Scientist's Meeting, April 2007, Estes Park, CO (2 posters). • US-IALE 22nd Annual Conference, **April 2007**, Tucson, AZ (1 oral). • VIth International Conference on Disturbance Dynamics in Boreal Forests, **May 2007**, Fairbanks, AK (3 oral). • Ecological Society of America annual meeting, **August 2007**, San Jose, CA (2 oral).		of posters
Scientific Publications	We have several manuscripts that are under review or in preparation for submission to peer-reviewed scientific journals. A core set of scientific papers present the results that were primarily derived from our JFSP project: • Verbyla, D. and R. Lord. Estimating post-fire organic soil depth in the Alaskan boreal forest using the Normalized Burn Ratio. Submitted to *International Journal of Remote Sensing* in **September 2007**. • Boby, L., M. Mack, E. Schuur, J. Johnstone, and D. Verbyla. Fire severity and C and N emissions from Alaska's boreal black spruce forest. In preparation for *Ecological Applications*, expected submission **December 2007**. • Villano, K. C. Mulder, and T. Hollingsworth, 2008. Wildfire burn susceptibility to invasive plant colonization in black spruce forests of interior Alaska. In preparation for *Oikos*, expected submission **January 2008**. • Johnstone, J., L. Boby, F.S. Chapin, III, T. Hollingsworth, M. Mack, E. Schuur,	In progress	Publications will be forwarded to JFSP as they become available.

	and D. Verbyla. The shaping of future forests: Fire effects on tree regeneration and growth in boreal black spruce forests. In preparation for *Ecology*, expected submission **March 2008**. • Mack, M., L. Boby, J. Johnstone, T. Hollingsworth, E. Schuur and F.S. Chapin III. Fire reinforces landscape patterns of C and N accumulation in boreal black spruce forests. In preparation for *Ecosystems*, expected submission **April 2008**. • Hollingsworth, T., J. Johnstone, and E. Bernhardt. Linking below-ground rooting structure and propagule availability to post-fire community composition. In preparation for *EcoScience*, expected submission **August 2008**. In addition, we have been able to provide data and insights from our JFSP project in contribution to several synthesis or summary papers: • Verbyla, D., E. Kasischke, and E. Hoy. Potential bias in mapping fire severity from remotely sensed data due to topographic effects. submitted **April 2007** to *International Journal of Wildland Fire*. • Chapin, F. S., III, S. Trainor, O. Huntington, A. Lovecraft, E. Zavaleta, D. Natcher, A. McGuire, J. Nelson, L. Ray, M. Calef, N. Fresco, H. Huntington, T. Rupp, L. DeWilde, and R. Naylor. Increasing wildfire in the boreal forest: Causes, consequences, and pathways to potential solutions of a wicked problem. Submitted to *BioScience* in **August 2007**. • French, N., J. Allen, R. Hall, E. Hoy, E. Kasischke, K. Murphy, and D. Verbyla. Using Landsat data to assess fire and burn severity in the North American Boreal Forest Region: an overview and summary of results. Submitted to		

	International Journal of Wildland Fire in **October 2007**.		
Graduate Theses	There have been three M.Sc. graduate students involved with this project: • Boby, L.A. Fire severity and C and N emissions in Alaska's boreal black spruce forest. School of Natural Resources, University of Florida, Gainesville, FL. Expected completion: **November 2007**. • Villano, K.L. Wildfire burn susceptibility to invasive plant colonization in black spruce forests of interior Alaska. University of Alaska Fairbanks, Fairbanks, AK. Expected completion: **December 2007**. • Bernhardt, E. The effects of fire severity and site moisture on species composition and functional properties of black spruce forests in interior Alaska. University of Alaska Fairbanks, Fairbanks, AK. Expected completion: **April 2008.**	In progress	Thesis abstracts
Unplanned Education and Outreach	Several unplanned opportunities arose during the project to enhance the education and outreach activities of our project. These products were not listed in our original proposal, but have enhanced the educational contributions of our project: • We developed a brochure for the project that describes the main goals, study sites, and our research design. The brochure has been a means to provide information about the project to interested members of the public. Copies were disseminated at agency offices and through visitor centers near our study areas in **2006** and **2007**. • Curriculum development: Katie Villano, a graduate student associated with the project, was able to use seed funding from this JFSP project to start a K-6 curriculum project about fire and invasive species in Alaska. The new curriculum focuses on using hands-on,	Brochure – Done Elementary school curriculum – In progress	Brochure (pdf)

	elementary-level classroom investigations to explore the link between wildfire and exotic plant invasions. This project is expected to be completed in **Spring 2008**.		

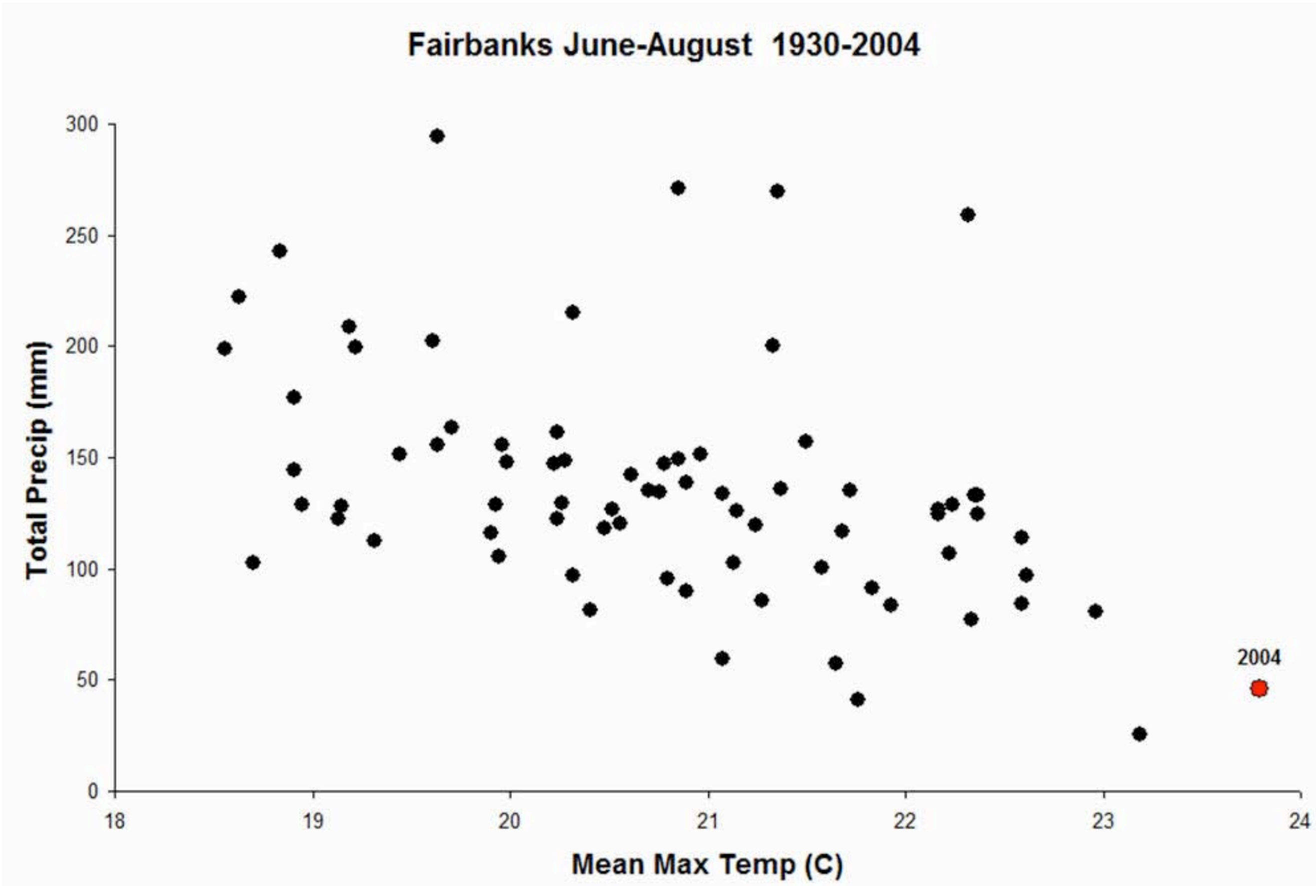

Figure 1. Total annual precipitation and mean maximum temperature for Fairbanks Alaska from 1930-2004. Data taken from www.wrcc.dri.edu/summary/Climsmak.html.

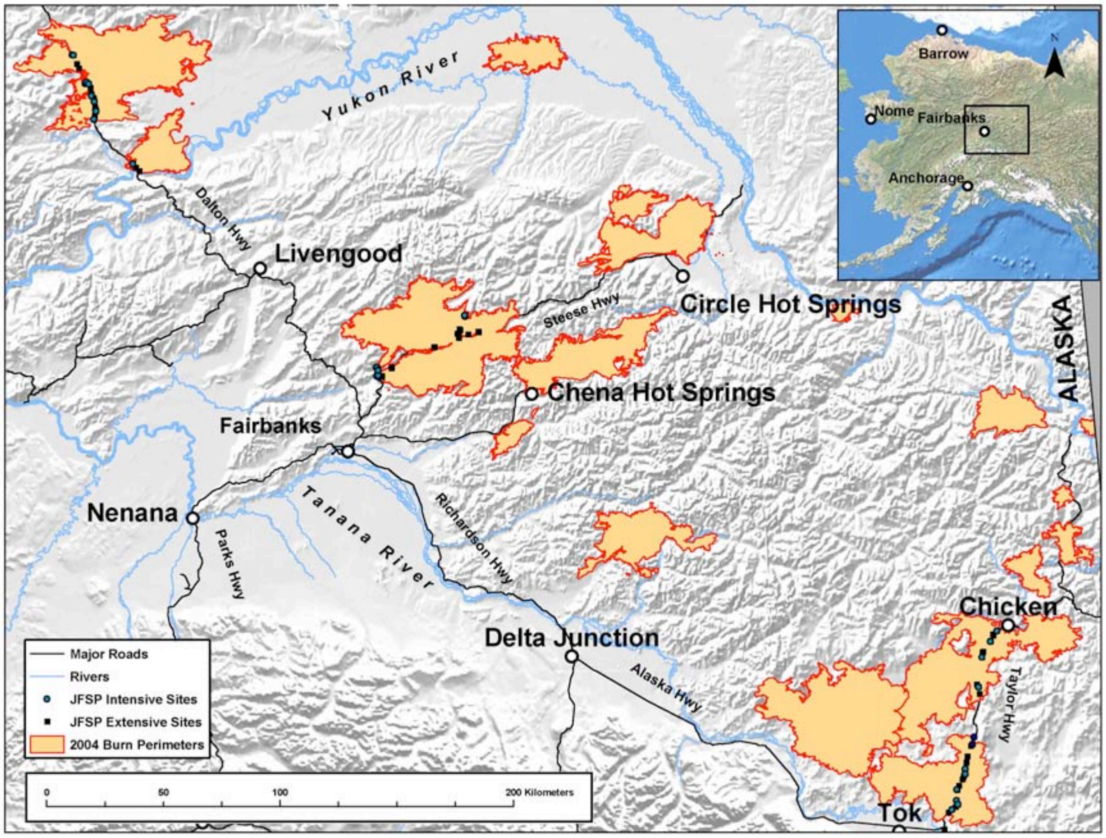

Figure 2. Map of the 90 study sites established in 2005.

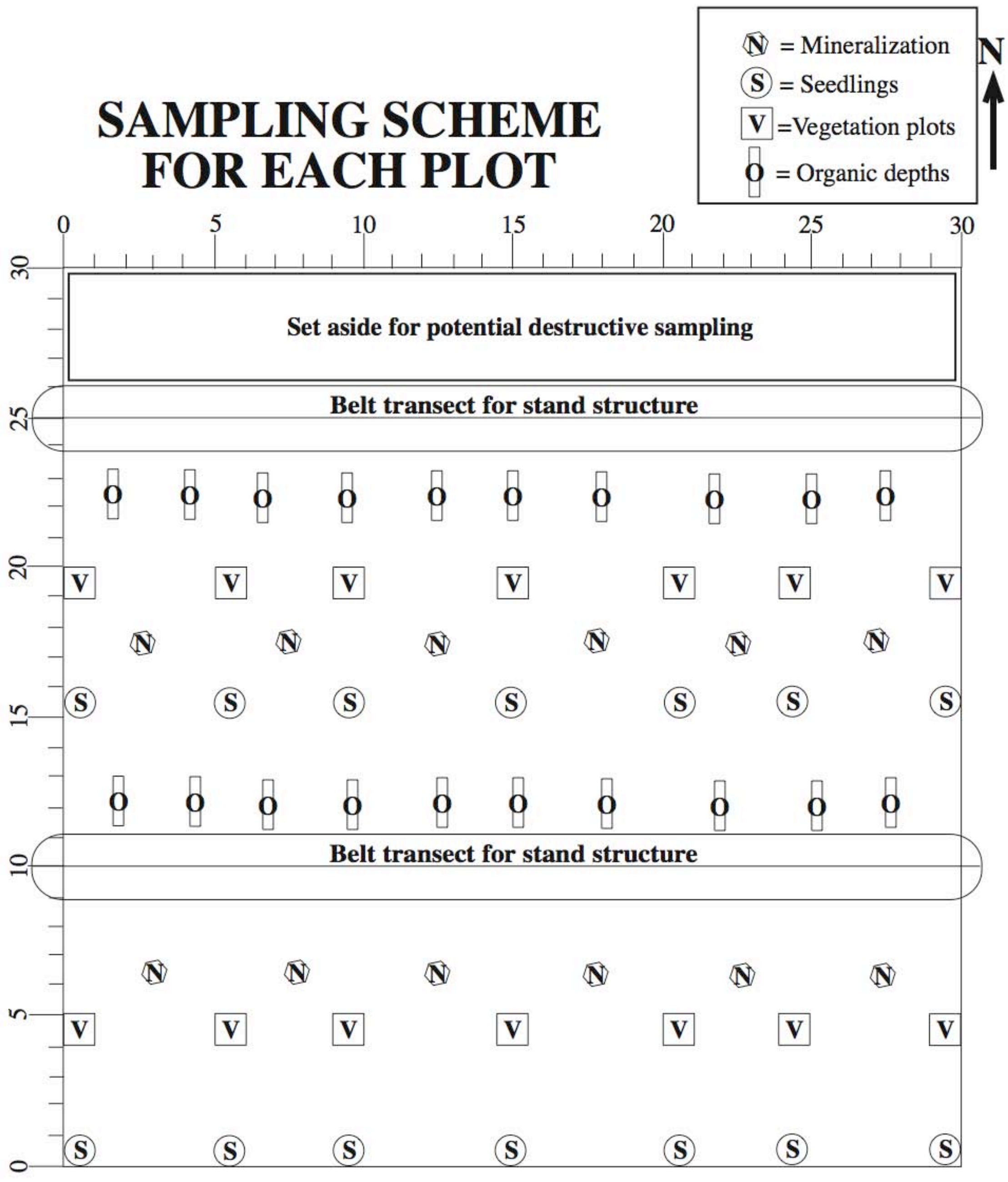

Figure 3. Sampling scheme for the 30x30 m plots used to sample intensive sites. Areas allocated to specific measurements are indicated as follows: O = organic layer measurements, B = 1x1 m permanent vegetation plots, N = soil nitrogen assay using ion exchange resins, S = seedling transplant plots. The corners and center of the plot are indicated with X.