# Final Report – Project 06-2-1-39

## Quantifying the Effects of Fuels Reduction Treatments on Fire Behavior and Post-fire Vegetation Dynamics


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***Abstract***

Concerns about wildland fuel levels and a growing wildland-urban interface (WUI) have pushed wildland fire risk mitigation strategies to the forefront of fire management activities. Mechanical (e.g., shearblading) and manual (e.g., thinning) fuel treatments have become the preferred strategy of many fire managers and agencies. This Joint Fire Science Program funded project seeks to document and quantify mechanical and manual fuel treatment effects on fire behavior. Alaska's Federal and State fire management agencies have identified this "data gap" as their most important fire science research need and priority.

The Nenana Ridge Ruffed Grouse Project Area is 6,000 acres of typical interior Alaska boreal forest located 30 miles southwest of Fairbanks, Alaska. The experimental burn site is approximately 930 acres with approximately 550 acres of relatively homogenous closed black spruce with a typical understory of moss, lichen and ericaceous shrubs. The experimental design calls for paired burn measurements to facilitate direct comparisons between the control vegetation matrix and the treatments. We are testing 8 x 8 ft thinning pruned to 4 ft under two different fuel removal strategies: (1) haul away, (2) burn piles on site; additionally we are testing mechanical treatments with and without windrowing and burning on site. We inventoried the existing vegetation, including ground vegetation, understory and overstory trees and tree crowns, organic layer, and dead-down woody surface fuels throughout the control vegetation matrix. Following treatments we inventoried understory and overstory trees and tree crowns, organic layer, and dead-down woody surface fuels. Fire behavior was monitored extensively from the time of ignition until steady state behavior ceased using a combination of cameras, video, direct observations, and thermal dataloggers. Consumption plots were located in both treatment units and the control vegetation.

This research has lead to the first quantified test of the effects of fuel reduction treatments on fire behavior in Alaska. Our results provide the first set of data required by fire behavior models, fuels characterization systems, and fire effects models. In addition, we are providing guidelines directed at design and methodology that can be used to assist in carrying out other experimental burns in Alaska when opportunity arises.

***Background and Purpose***

Fire research in both the US and Canada has focused on the prediction of wildland fire behavior. The emphasis in Canada has focused primarily on empirical wildfire observations, while US efforts have focused on theory and laboratory-based experiments (Stocks et al. 2004b). Both research programs have resulted in fire danger rating and fire behavior prediction systems (see Andrews et al. 2003 for US; see Forestry Canada Fire Danger Group 1992 for Canada). Both systems have documented relationships between natural (and a limited number of harvested) stand conditions and fire behavior (Stocks et al. 2004b, Peterson et. al. 2005).
The emergence and extension of the WUI phenomenon has greatly complicated the management of wildland fires (Winter et al. 2002). Prescribed fire has been shown to be effective in reducing general fire behavior, but broad-scale use as a mitigation strategy has met strong resistance from the public due to concerns about escapement, smoke, and aesthetics (Fernandes and Botelho 2003). Fuels reduction treatments are increasingly being used across the United States as a primary mitigation strategy to reduce fire risk in the WUI (Agee 2000, Johnson and Peterson 2005). Research continues to document relationships between various fuel treatments and fire behavior (Johnson et al. 2005). However, the effectiveness of various thinning treatments has largely been analyzed using fire behavior models (van Wagtendock 1996, Graham et al. 1999), with few empirical observations (although these observations are slowly growing).

Findings from JFSP project **00-2-34** "Fuels treatment demonstration sites in the boreal forests of interior Alaska" by Ott and Jandt caught the attention of the Alaska fire management agencies due to adverse changes documented in surface fuelbeds and model predictions of higher rates of spread in treated areas. Shaded fuelbreak treatments in Interior boreal forest have substantial ecological effects on the forest floor, permafrost and surface fuels (Jandt, et al. 2005), including increase of fine downed woody and grass fuels, increased midflame wind speed, and dryer forest floor moss layers. The fire behavior modeling tools used to compare treated and untreated fuels have not been field-validated in Alaska.

Alaska's fire managers have recommended **and funded** fuel treatments, including shaded fuel breaks and shearblading, **without** demonstrable evidence that they work. This project provides the first empirical observations of fuel treatment effects on fire behavior in Alaska. This project also provides important empirical observations on duff consumption.

***Study Description and Location***

The primary goal of this project is to quantify the effects on fire behavior of two different shearblading techniques and 8 x 8 ft thinning treatments, under two different fuel removal strategies; and transfer that information to the Federal and State fire management community. We focus our research on the following specific objectives:

a. Document changes in fuel loading and vegetation structure in treated areas.
b. Document site specific weather observations and associated fire danger indices.
c. Quantify differences in fire behavior between treated and control plots.
d. Quantify fuel consumption in both treated and control plots.
e. Document the initial response of vegetation to burning in treated versus control plots.
f. Develop guidelines regarding study design and methods for use by managers to streamline future opportunities for experimental burns in Alaska.

**Study Site**

The Nenana Ridge Ruffed Grouse Project Area is 6,000 acres of typical interior Alaska boreal forest located 30 miles southwest of Fairbanks, Alaska. The area includes a mix of deciduous and spruce forest distributed across both uplands and lowlands. Various ruffed grouse habitat projects have been conducted in the past including prescribed burning. This site is an ideal location for our proposed experimental burn because (1) it is in close proximity to Fairbanks and offers good access via an existing road network, (2) the site is owned by the State of Alaska and has a burn plan in place that can be modified to include the proposed experimental burns, and (3) the area offers a large homogenous fuel type to allow for limited replication.

The proposed experimental burn site is approximately 930 acres with approximately 550 acres of relatively homogenous closed black spruce with a typical understory of moss, lichen and ericaceous shrubs. The site is located on a 0-10% slope with a southerly aspect and approximately 200 ft. elevation gradient. Prevailing summer winds are from the southwest.

**Sampling Design**

We plan to take advantage of the knowledge gained from the International Crown Fire Modeling Experiment (ICFME) carried out between 1995 and 2001 in the Northwest Territories (Stocks et al. 2004a). The ICFME was designed to improve the physical modeling of crown fire propagation and spread and provides a fully tested design for quantifying fire behavior (Stocks et al. 2004b). That basic design calls for experimental plots of 150 x 150 m (approximately 5 acres), which represents an area large enough to provide unbiased observations of fire behavior (Stocks et al. 2004b). The square design accommodates fluctuations in wind direction. In contrast to the ICFME our plots will not be surrounded by a cleared fireline, but instead will be surrounded by an uncleared black spruce fuel matrix. This deviation from the ICFME design will allow us to specifically address our research question regarding the effect of fuel treatments on fire behavior. It should be noted that we are **not** attempting to simulate a landscape-level fuelbreak; rather we are quantifying changes in fire behavior between treated and control vegetation.

Our sample design provides for 3 experimental burn units, each approximately 185 acres. Each burn unit will be separated by a fireline cleared to mineral soil. Within each burn unit 4 fuel treatment plots (150 x 150 m) will be established (Figure 1). Individual treatments will be spaced in a manner such that each treatment is surrounded (minimum of 150 m on all sides) by sufficient control vegetation, and will not affect fire behavior in neighboring plots.

We propose testing two primary treatment strategies that reflect the actual treatment types currently being implemented by Federal and State agencies in Alaska. Each burn unit will have two shearblading treatments and two thinning treatments. Burn unit A consists of two 8 x 8 ft thinning treatments. In both thinnings the fuels have been removed from sight and remaining trees have been pruned to 4 feet. In addition, burn unit A has one shearbladed treatment where the fuels have been windrowed and burned and one treatment where the fuels remain on the ground. Burn unit B consists of two 8 x 8 thinning treatments pruned to 4 feet. Instead of fuels being removed from the site they will be burned in piles. In addition, burn unit B has one shearbladed treatment where the fuels have been windrowed and burned and one treatment where the fuels remain on the ground one year after shearblading. Burn unit C was held in reserve for future potential use. In all instances we will conduct **paired burn** measurements to facilitate direct comparisons between a control and the treatments. The paired measurements will eliminate any confounding effects of varied burn years. Quantification of fire behavior will be limited to the thinning treatments. Consumption measurements will be collected in all the treatments as well as the control vegetation. Direct observations (but no instrumentation) of fire behavior will be made in the shearblading treatments. Our primary interest in the shearblading treatments will be to evaluate basic fire behavior as well as the effect on post-fire plant succession. Temporary conversion of spruce-dominated sites to hardwood species is important from a fuels management perspective.

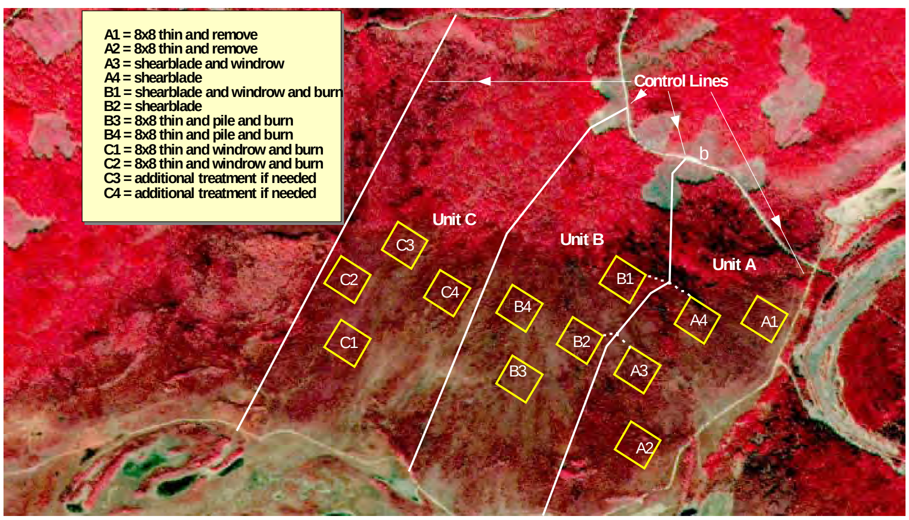


***Figure 1. Layout of treatment plots dispersed within control vegetation matrix.***

## Methods

### *Vegetation/Fuels*

We will inventory the existing vegetation, including ground vegetation, understory and overstory trees and tree crowns, organic layer, and dead-down woody surface fuels, throughout the control vegetation matrix. These measurements will serve as baseline data for post-treatment and post-burn comparisons. We will not make direct measurements within the treatment plots prior to treatment to minimize trampling and its potential effects on fire behavior. Following treatments we will inventory understory and overstory trees and tree crowns, organic layer, and dead-down woody surface fuels within the treated plots. All vegetation measurements will be re-measured post-burn. Existing ground vegetation will be characterized by establishing 32 randomly located 1 x 1 m sampling quadrats throughout the control vegetation (Alexander et al. 2004).

This ground vegetation sampling will serve to characterize species density, composition, and cover. A grid of permanently marked plot centers (30 x 30 m spacing; n=16) will be established within each treatment unit to sample the understory and overstory trees and tree crowns, and to

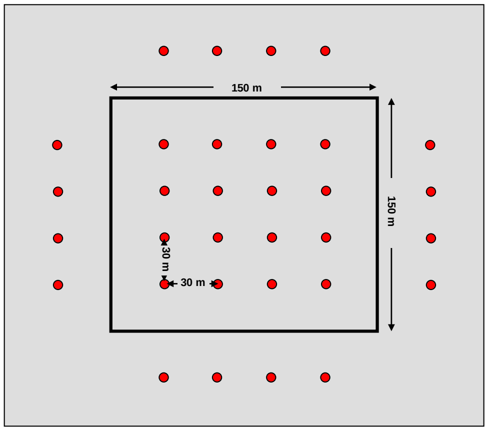


***Figure 2. Sampling grid following the methodology of Alexander et al. (2004). Treatment units measure 150 x 150 m. Grid points (red dots) are spaced 30 x 30 m inside treatment unit and around control vegetation borders.***

locate the consumption plots and dead-down woody surface fuel transects; permanent plot centers (n=16) will also be established in the surrounding control vegetation (Figure 2). A point-centered quarter method (Cottam and Curtis 1956, Alexander et al. 2004) will be used to sample overstory trees (DBH $\geq$ 3.0 cm) at each grid point. These measures will be used to calculate density and basal area and to characterize tree crown geometry. In addition, we will use a point intersect method and densitometer to quantify canopy cover. Understory trees (DBH< 3.0 cm) will be sampled using 2-m radius fixed area plots at every other grid point (n=8).

***Fuel Consumption***

Sixteen forest floor depth and consumption plots were systematically located inside and outside each of the A1, A2, B3, and B4 thinned treatment blocks established for the study (Figure 1). Forest floor reduction was measured as the dependent variable according to procedures adapted from Beaufait et al. (1977). Within each plot, 16 forest floor pins were inserted 0.5 meters apart into the forest floor and clipped flush with the lichen, moss, or duff surface (Figure 2). Because the forest floor is often very deep, lightweight welding rod >60 cm in length was used as forest floor reduction pins. No data was collected on the pre-burn loading or consumption of the shrub, grass and woody fuels because very little mass existed of those fuelbed categories.

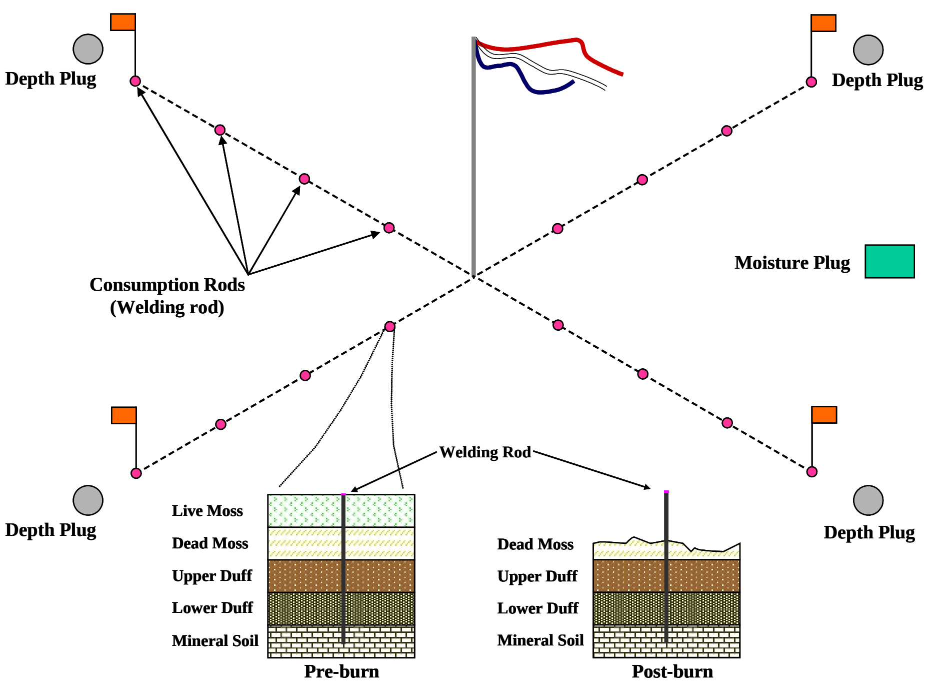


***Figure 3. Individual forest floor and consumption plot layout.***

Forest floor layer depths and fuel moisture content were measured as independent variables. Four forest floor plugs approximately 10 $cm^2$ was removed from near each plot and the depth of the live moss, dead moss, upper duff, and lower duff was measured (Figure 3). Just prior to the burn, a final plug was collected to determine fuel moisture content, separated into live moss, dead moss, upper duff, and lower duff categories and placed into labeled and sealed plastic bags. All samples were oven dried at 70 °C for 96 hours and weighed before and after drying to determine fuel moisture content by forest floor category.

After the smoldering combustion was complete, each plot was relocated, and the depth of the burn was measured at each forest floor reduction pin. A measurement from the top of the pin to mineral soil provided a total forest floor depth.

***Fire Behavior***

Fire behavior will be monitored, in both the treatment plots and the surrounding control matrix, extensively from the time of ignition until steady state behavior ceases. Two fire proof systems were deployed: 1) the Fire Behavior Package (FBP) and 2) the in-fire video system. The FBP contains a fine gauge type K thermocouple to sense air kinetic temperature, a narrow angle radiometer that senses radiosity of the flames in the field of view, a hemispherical heat sensor that senses both total and radiant energy flux incident on the surface of the sensor, and horizontal and vertical flow sensors. The digital video cameras are housed in fire resistant cases and can be triggered by a wireless signal from the FBP initiated by heating on the sensors. Images from the cameras can be used to characterize fire behavior in terms of flame geometry, flame rate of spread, and local burning properties. Fire behavior sensors and in-fire video recorders were deployed as described in Table 1 and shown in Figure 4.

**Table 1—Description of distribution of sensors and cameras and burn notes.**

| Unit | Treatment | Sensor Box # | Camera # | General location | Notes |
|---|---|---|---|---|---|
| A-1 | Thinned and burned offsite | 1, 6, 13 | 1, 8, 9 | In unit | Sensor #1 failed, 13 did not trigger, and 6 did not see any significant fire. Fire burned up to edge of treatment. |
| A-1 control | | 4, 14 | 10, 13 | South of unit | Max temp >1150C, 240kW/m^2 |
| A-2 | Thin and burned offsite | 7, 9, 10 | 11, 14 | In unit | Only sensor 10 recorded heating from local ping pong ball ignition. |
| A-2 control | | 8, 12 | 4, 5 | South of unit | Did not burn-no data or video |
| A-3 | Shearblade no windrows | 5 | 6 | In unit | Very low intensity burn |
| A-4 | Shearblade w/ windrows | 2 | 2 | In unit | Very low intensity |

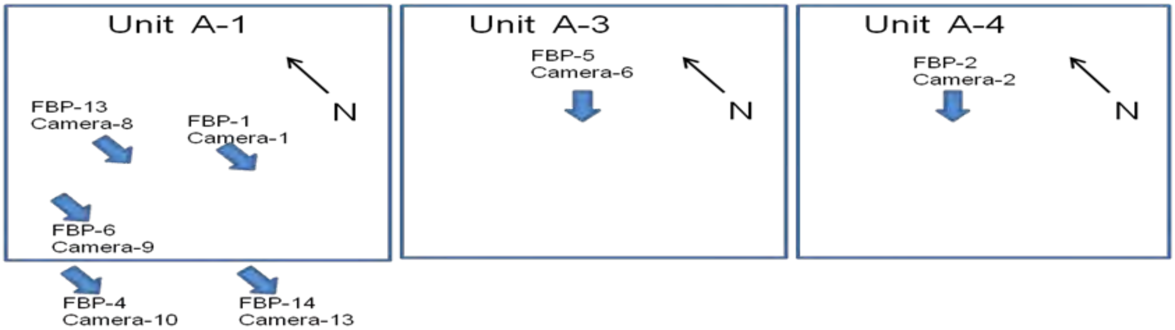


***Figure 4 – Layout of sensors in burn unit.***

***Weather***

A fully instrumented hourly remote automated weather station (RAWS; Figure 5) will be located at the burn site to quantify fire weather. Hourly weather observations will be recorded from snowmelt through September each year. Hourly weather data will be utilized to calculate fuel moisture codes and fire behavior indices of the Canadian Forest Fire Weather Index System. In addition, two Hobo weather stations will be deployed to capture all relevant weather fields throughout the burning operations at 2 minute intervals. Prior to burning operations, but following treatments one Hobo weather station (Figure 5) will be deployed in the control matrix and one in the treatment for a one week period to document plot-level differences in wind speed, temperature, and relative humidity.

***Figure 5 – RAWS and Hobo stations.***

## <u>**Data Analysis**</u>

The objective of this study is to document differences in fire behavior and fuel consumption between treated and untreated vegetation. Due to budget constraints we have limited replication (n=2), but in all cases we have **<u>paired plot</u>** measurements for comparison. This design is not ideal, but it is the reality of today's budget climate and the tenuous nature of fire behavior measurements. We will follow the methodology of Alexander et al. (2004) for analysis of vegetation characteristics. Species composition, cover, frequency, and prominence of the understory vegetation will be characterized for the control vegetation matrix and will be assumed to apply to the treatment plots prior to the actual treatments (see methods section above). Similarly, the understory and overstory tree and tree crown characteristics will be summarized including post-treatment. Surface fuel loads will be calculated following standard procedures (Brown 1974, McRae et al. 1979, Alexander et al. 2004). Pre-burn organic layer depth, load, and total and organic bulk density will be calculated from the post burn measurement and a unit average with standard errors calculated. Woody fuel loading and consumption will be determined using the line intersect inventory methodology and calculation procedures outlined by Brown (1974).

All consumption data was input into the FERA Data Reduction and Analysis Program (DRA) to summarize the mean, median, standard deviation, and standard error of the fuel moisture contents by fuelbed categories, pre-burn forest floor depths by forest floor layer and forest floor consumption by layer. A standard Fuel Characteristic Classification System (FCCS) (Ottmar et al. 2007) fuelbed representing a boreal forest spruce stand that closely matched the Nenana site was customized with measured forest floor depths. The custom fuelbed was imported into Consume and measured weather variables and fuel moisture contents were entered. Consumption was predicted and compared to measured forest floor consumption.

Fire progression observations will be used to characterize changes in fire behavior between the control vegetation matrix and the fuel treatment plots (Stocks et al. 2004b). Fire behavior will be characterized through flame geometry calculations and energy release rates. Video images collected from digital video cameras deployed in fire proof enclosures will be analyzed to determine flame height, depth and angle. Direct measurements of energy release will be collected by calibrated total and radiant energy sensors.

***Results and Key Findings***

Attempts to burn Unit A and B were unsuccessful in both 2007 and 2008 due to weather and/or resource limitations. The project successfully burned Unit A on June 17, 2009, but was unsuccessful in burning Unit B on June 18 due to unfavorable wind direction. Because of limited available funding for fire operations we were unable to attempt another ignition in Unit B. Additional attempts to burn Unit B in 2010 and 2011 were also unsuccessful due to weather and additional funding challenges. In September 2011 it was decided that no additional efforts would be made to burn Unit B in the upcoming 2012 fire season due to continued funding constraints for fire operations and the ending of this JFSP sponsored research grant.

**Fuels**

We measured tree spacing, density, basal area, and canopy cover in both the control and treatments (Unit A only). Average tree spacing in the control units ranged from 1.15-1.61 m and the thinning resulted in spacing of 2.06 m and 2.78 m for treatment A1 and A2, respectively (Figure 6). Average stem density in the control units ranged from 3849-7531 stems/ha and the thinning resulted in density of 2359 and 1290 stems/ha for treatment A1 and A2, respectively (Figure 7). Average basal area in the control units ranged from 11.83-31.53 $m^2$/ha and the thinning resulted in basal area of 10.76 and 16.32 $m^2$/ha for treatment A1 and A2, respectively (Figure 8). Black spruce trees composed at least 95% of stems in both control and treatments. Overstory canopy cover in the control units ranged from 29-50% and the thinning resulted in cover of 11 and 41% for treatment A1 and A2, respectively (Figure 9). Canopy cover estimates were influenced by both differences in tree height and canopy structure across sites.

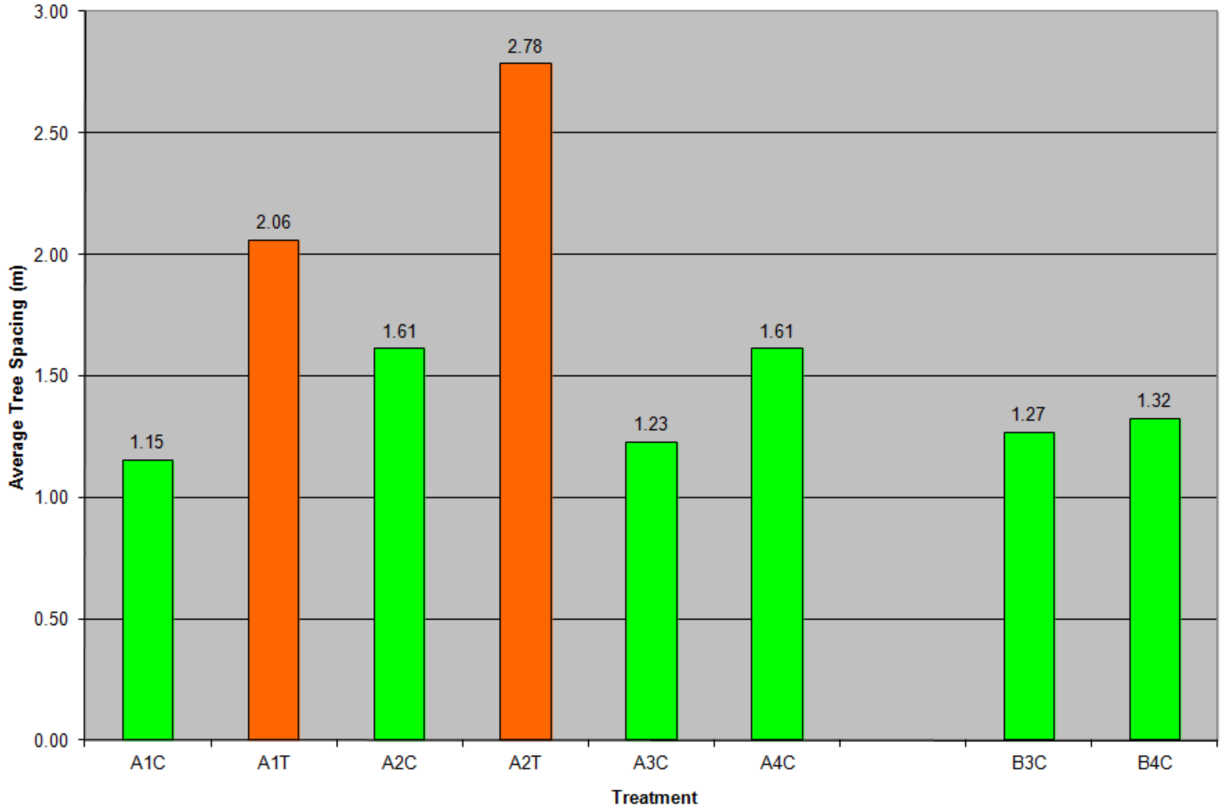


**Figure 6. Average tree spacing (m) in control (green) and treatments (red).**

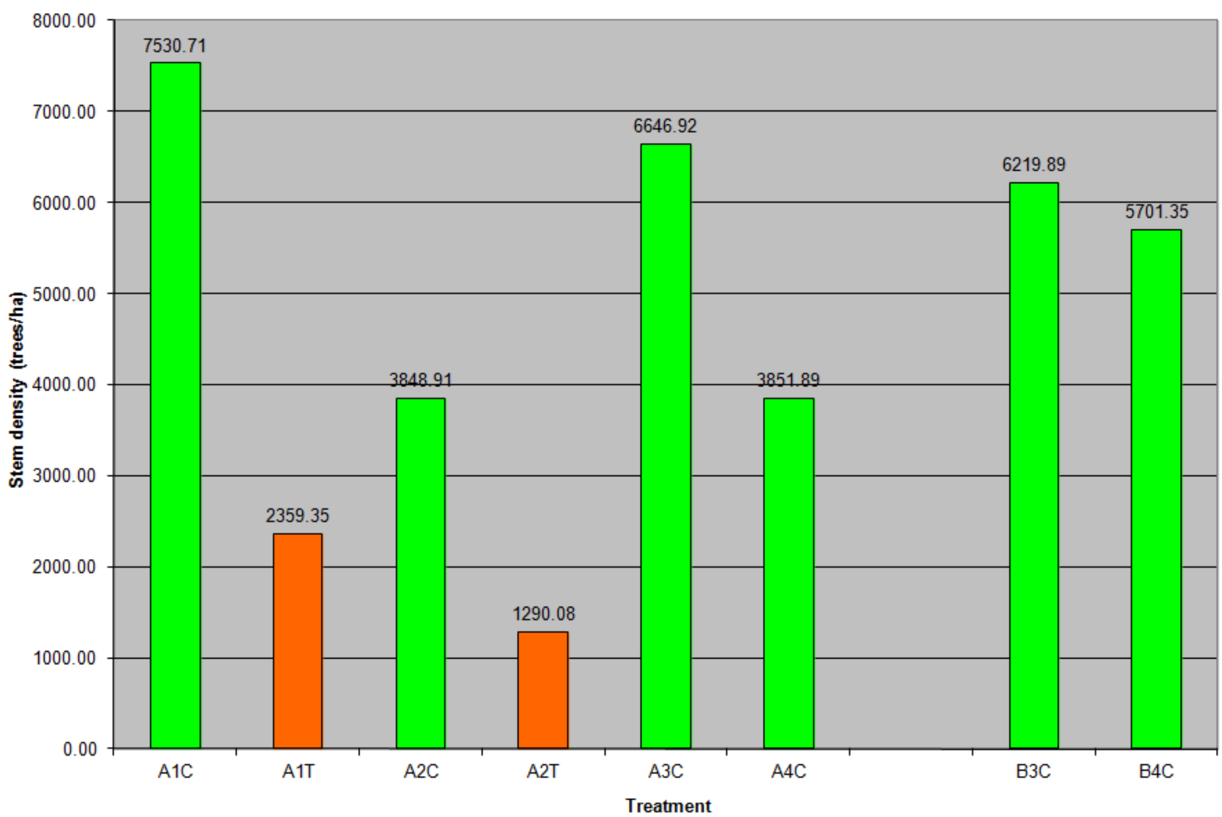


**Figure 7. Average tree density (stems/ha) in control (green) and treatments (red).**

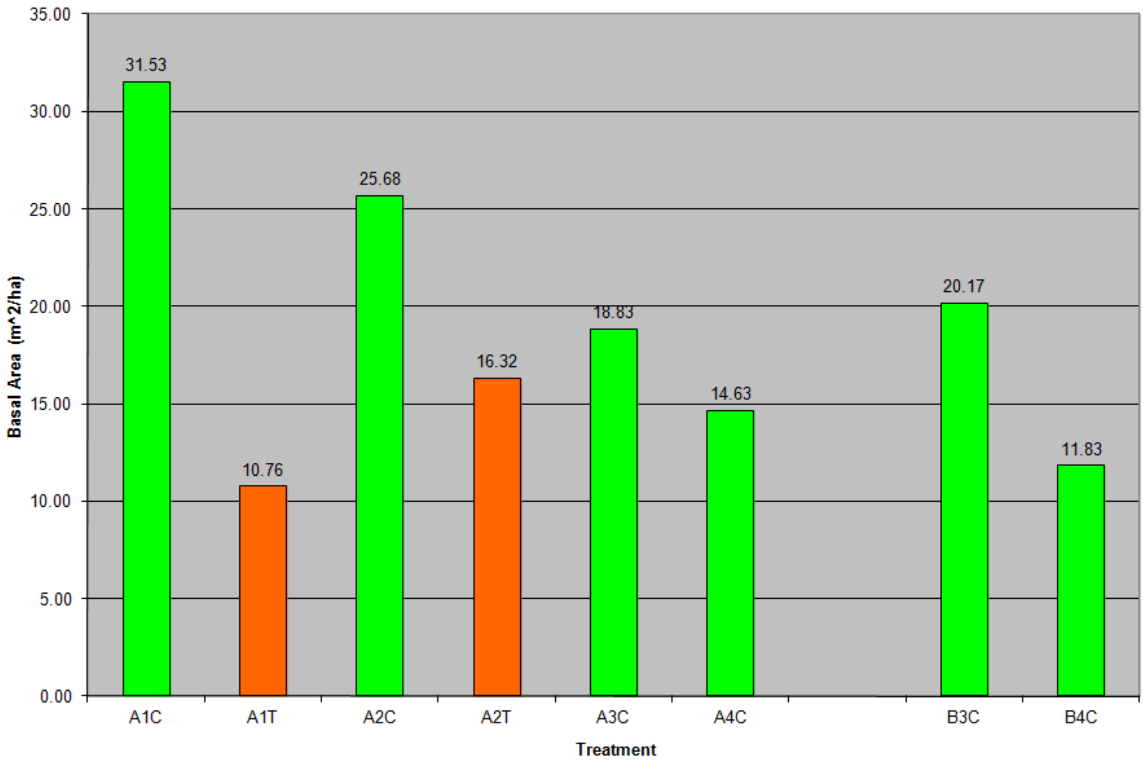


**Figure 8. Average basal area ($m^2$/ha) in control (green) and treatments (red).**

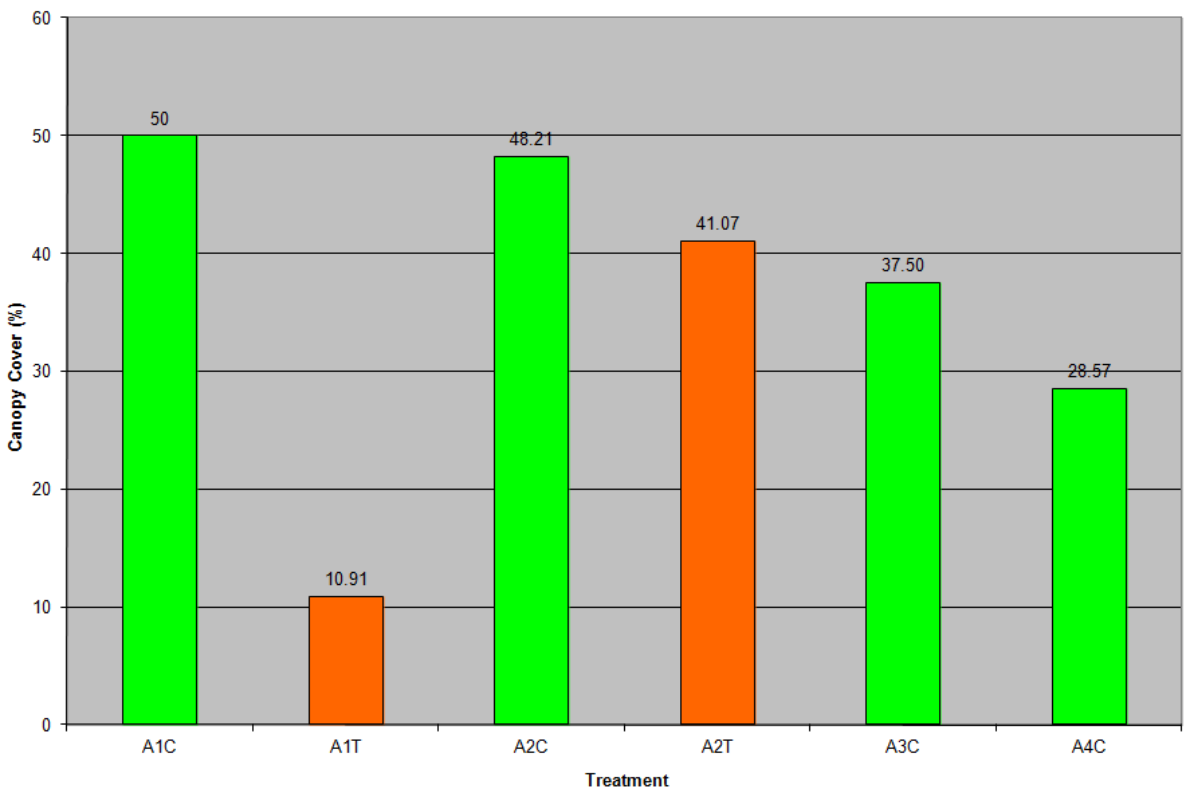


**Figure 9. Overstory tree canopy (%) in control (green) and treatments (red).**

Mean tree age across both Unit A and B was 82 yr (n=47) with a maximum tree age of 99 yr and a minimum tree age of 66 yr. Understory seedling/stem densities (Unit A only) were also quantified. Seedling density represents pre-treatment density only as all understory stems were removed during thinning operations in treatments. Total seedling density ranged from 3680-34915 stems/ha and were composed primarily of black spruce, with a component of willow, and some birch (Figure 10).

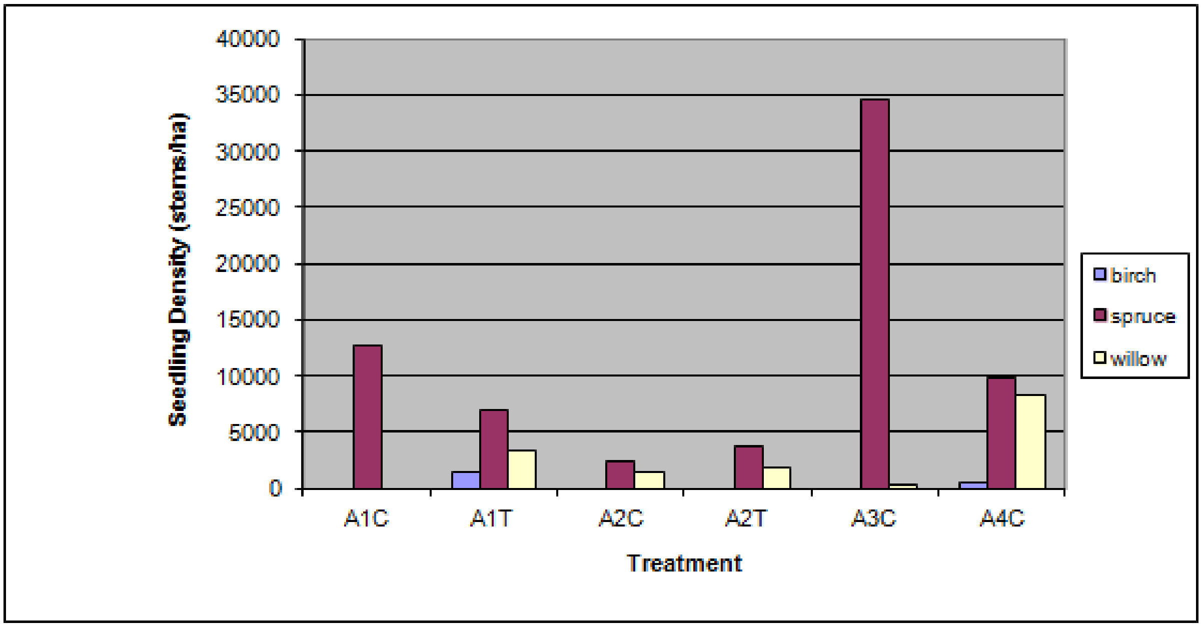


**Figure 10. Average seedling density (stems/ha) across control and treatment (prior to thinning) and species distribution.**

Understory vegetation was composed of primarily ericaceous shrubs (lowbush cranberry and Labrador tea) and some grasses and sedges. Live mosses – primarily feather mosses, but also sphagnum mosses) – were the dominant ground cover with some lichen. Immediate post-treatment response to thinning was minimal. However, substantial changes in understory species composition in the shearbladed treatments were identified 3 years after the treatment operation. The typical distribution in the control was as described above, but post-shearblade the mosses had declined by approximately 50% and grasses and sedges had increased by approximately 4000%. Long-term post-thinning observations were not made, but other research in interior Alaska (JFSP project **00-2-34**; Ott and Jandt, 2005) has documented similar shifts in species distribution.

## Weather

Pooled data pairs (control and treatment) were analyzed during the fire seasons 2007-2010 in the unburned Unit B. We tracked average wind speed, maximum wind gust, air temperature, and relative humidity (Figure 11). The black vertical lines at 0 represent what the pooled differences should be if there is no difference between treatment and control. The red vertical lines represent the averaged pooled differences. In all cases differences existed between the control and treatment (i.e., thinned) weather variables suggesting increased mean and maximum wind speeds and air temperature in the treatment; and suggesting decreased relative humidity in the treatment. In addition, the data suggest increased variability and magnitude of weather observations in the treatment. For example, the treatment site can be up to approximately 7 degrees C warmer, but only 4 degrees C cooler; likewise the treatment experienced up to a 60% reduction (i.e., drier) in RH, but only a 30% increase (i.e., wetter). To summarize, the treatment experienced windier, warmer, and drier conditions than the control.

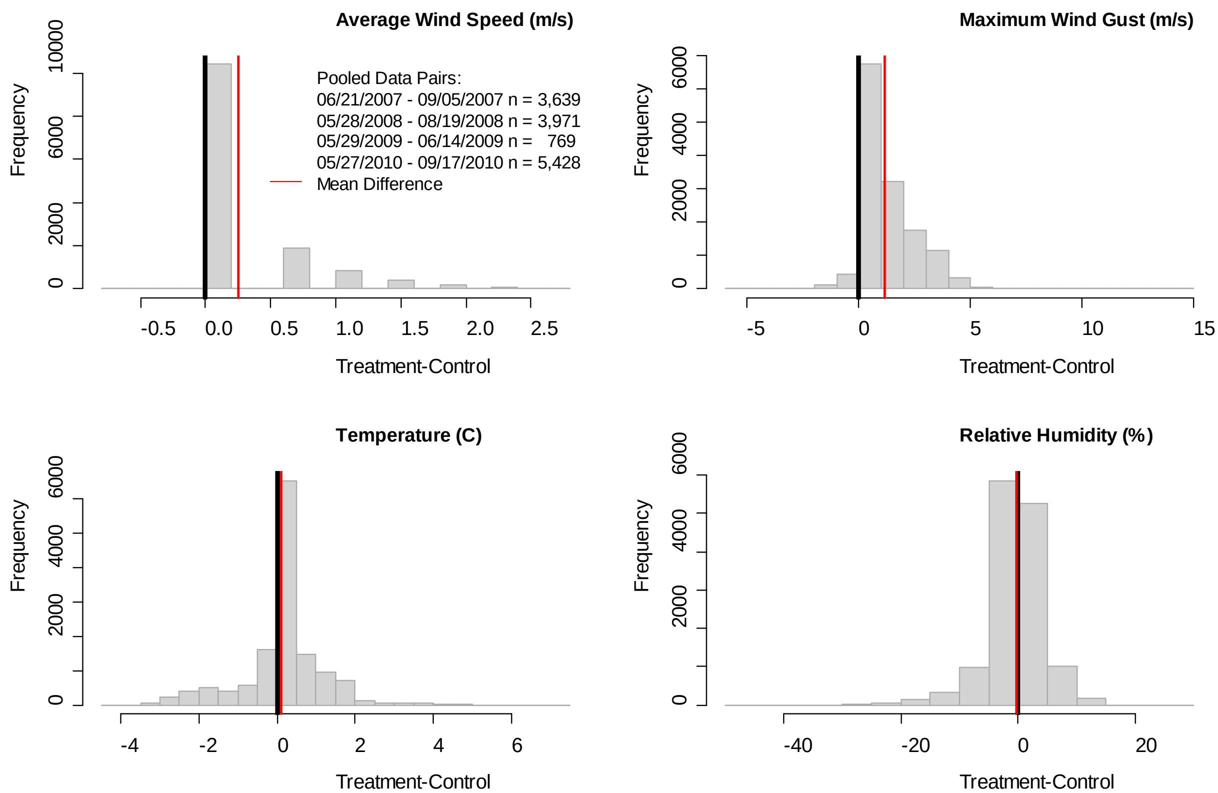


**Figure 11. Pooled weather data pairs identifying differences in average wind speed (m/s), maximum wind gust (m/s), air temperature (C), and relative humidity(%).**

## Fire Behavior

Table 2 summarizes the data collected by the sensors. Fire intensity can be measured using several metrics. They include maximum air temperature, maximum energy flux, heating period (time that temperature spikes above 50 deg C occurred), cumulative fire radiative and total energy (over the heating time), flame length, and fire rate of spread (from evaluation of video images). We attempt to present all of these metrics for each sensor location that saw fire.

**Table 2—Summary of measured quantities.**

| Unit | Heating time (s) | Cumulative total energy load (J) | Max Temperature (C) | Peak total heating flux ($kW/m^2$) | Flame Length (m) | Fire Rate of Spread (m/s) |
|---|---|---|---|---|---|---|
| A-1 | 1100 | 600 | 71 | 2.2 | N/A | N/A |

| | | | | | | |
|---|---|---|---|---|---|---|
| A-1 control sensor 4/14 | 380/450 | 5105/3450 | 1150/780 | 227/50 | 8-11m | 0.6m/s |
| A-2 | 510 | 2600 | 267 | 16 | 0.6m | 0.1-0.3m/s |
| A-3 | 4100 | 2500 | 170 | 51 | 0.3m | N/A |
| A-4 | 5300 | 1800 | 66 | 3 | N/A | N/A |

Helicopter ping-pong ignition was initiated at approximately 1400 hours local time. Ignition followed a roughly head strip fire moving from South to North along East/West aligned lines. Ambient temperature was 25 C and relative humidity 26 %. The ignition began at the southern edge of the A block. Unfortunately the Block did not burn uniformly (Figure 12). The southern half did not burn as completely as the Northern half.

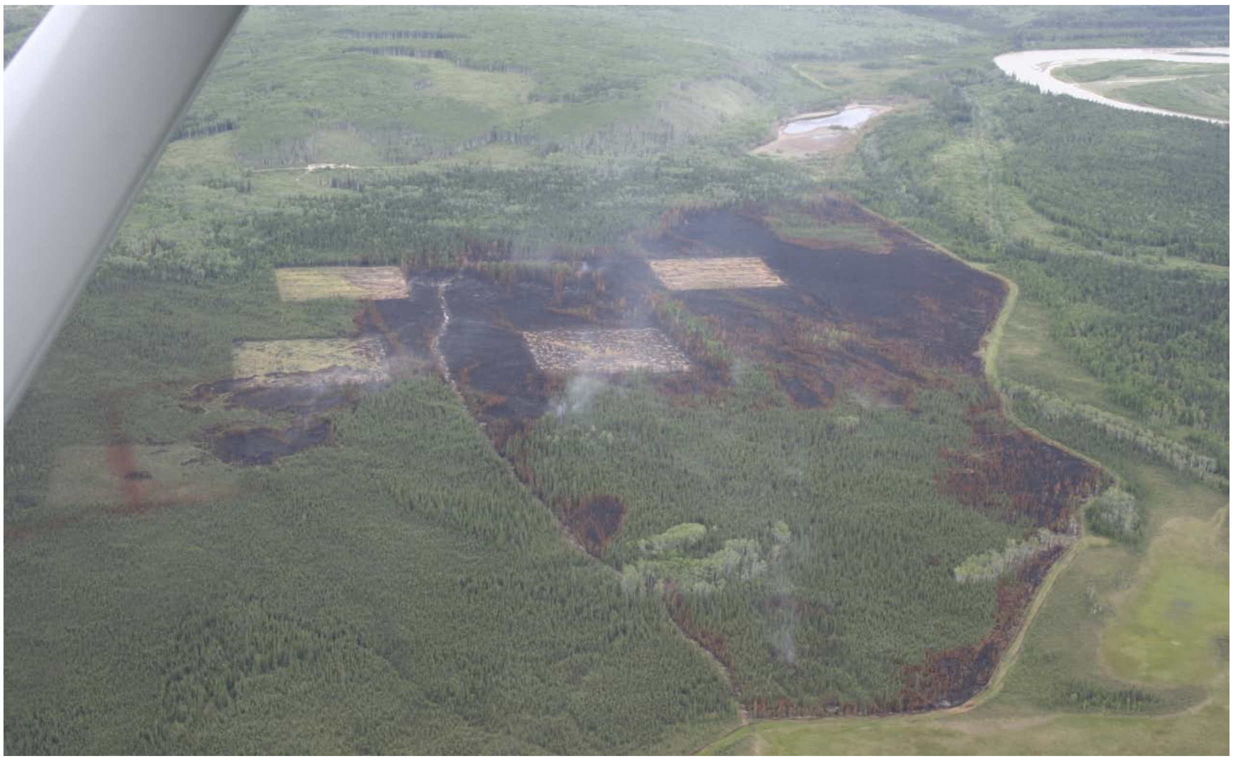

**Figure 12. Photo of block A burn pattern, camera looking north from south of block.**

Unit A-1 was a thinned treatment. It contained three fire behavior sensors and three in-fire video cameras. One sensor package failed and a second did not see high enough energy to begin recording data. The third recorded a maximum heat flux of 2.2 $kW/m^2$ and maximum temperature of 71 C. The heating time was 1100 seconds with a cumulative total energy of 600 J. Evaluation of the video indicated that the fire spread with very low intensity up to the edge of the treatment but very little fire spread occurred in the treated unit, thus no flames were detected. The heating would have been generated by the fire that burned up to the edge of the treatment.

The highest fire intensities were found in the untreated control south of Unit A-1. This location recorded maximum flame temperatures as high as 1150 C and peak total energy fluxes of 227kW/m$^2$. Figure 13 presents the temperature and heat flux time history for this location. The heating period was relative short (approximately 400 seconds) and the cumulative total energy release averaged 4277 J between the two sensors. Flames were 8 to 11m tall, burning through the entire forest canopy of Black Spruce at a nominal spread rate of 0.6m/s.

Unit A-2, a thinned treatment, contained three sensor arrays but did not see consistent fire. Only the easternmost sensor recorded any fire and it was a flanking fire that from the video seemed to originate solely from an ignited ping pong ball. The resultant fire was localized in the vicinity of the FBP and camera. Heating time was 510 s, cumulative total energy release was 2600 J, peak air temperature was 267 C and peak total heat flux was 16 kW/m$^2$. Flame length was 0.6 m and fire rate of spread was 0.1-0.3m/s.

Unit A-3 contained a shearblade treatment with no windrows. One sensor array was deployed near the center of the unit. This sensor recorded fire in the area for 4100 s with a cumulative total energy release of 2500 J. The peak measured air temperature was 170 C and the peak total heat flux was 51 kW/m$^2$. Flame lengths were 0.3m in the distributed slash located near an FBP. No clear fire rate of spread was detected as the fuels were disbursed and did not burn as a uniform front.

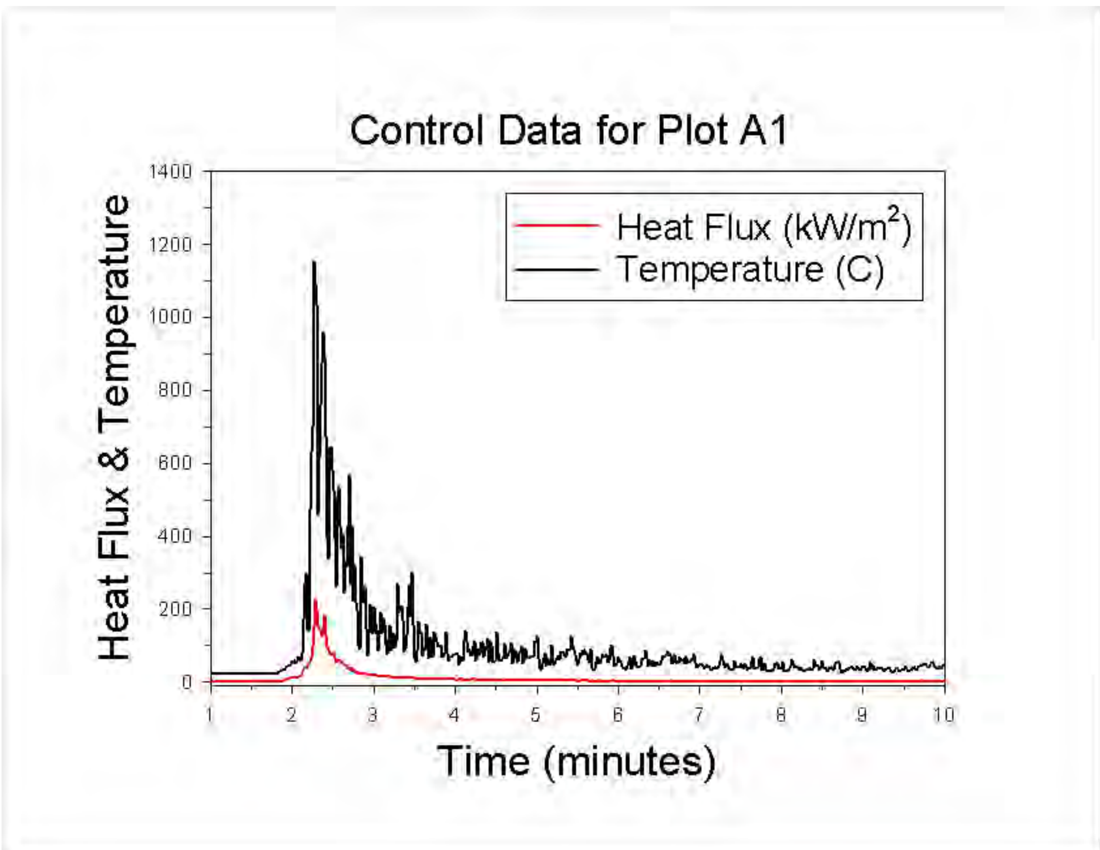


**Figure 13. Temperature and heat flux data from unit A-1.**

Unit A-4 was a shearblade treatment with fuels disbursed in windrows. One sensor array was placed in the center of the unit. This location depicted the presence of fire for 5300 s and a total cumulative energy load of 1800 J but low maximum air temperature of 66 C and minimal total energy flux of 3 kW/m$^2$. No clear flame length or rate of spread was detected. The post burn inspection indicates that the windrows in the unit did not burn completely. The low energy levels were likely due to the burning of slash windrows in a nonuniform low intensity pattern and to energy emitted from the crown fire at the edge of the treatment unit.

**Fuel Consumption**

The forest floor moisture content for the A-1 treatment area averaged 36 % for the live moss, 105 % for the dead moss, 183 % for the upper duff and 247 % for the lower duff (Table 3). The moisture content of the dead grass was 9.3 %, live grass, 293%, and the shrubs, 93 %. Black spruce needle fuel moisture was 151 %. If we consider all 256 pins in the A1 treatment block, regardless if the pin burned or not, the preburn depth was 21.8 cm with a forest floor reduction of 1.2 cm. If we consider only the 60 pins that burned, the preburn forest floor depth was 23.9 cm with a forest floor reduction of 5.4 cm (Table 4).

The forest floor moisture content for the control area averaged 92% for the live moss, 193 % for the dead moss, 132 % for the upper duff and 163 % for the lower duff. Moisture content of the shrub was 93 % while the live black spruce needles were recorded at 95 % (Table 3). No moisture samples were collected for the live and dead grass. Of the 256 forest floor pins located outside the A1 treatment area (control), 249 burned with a pre-burn depth of 24.9 cm and a forest floor reduction of 5.8 cm (Table 4).

Consume 3.0 predicts boreal forest floor consumption using an empirically derived model developed from a set of boreal forest floor consumption data collected between 1990-2004 (Ottmar et al. 2005). Using only the pins that burned, lower duff moisture, and preburn forest floor depths, Consume 3.0 under predicted the measured forest floor consumption by 4% for the treatment block and by 7% for the control (Table 4).

**Table 3. Fuel moisture content by fuelbed categories before the burn.**

| | Fuel Moisture Content (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Unit | Live needles | Live grass | Dead grass | Shrub | Live moss | Dead moss | Upper duff | Lower duff |
| A-1 Treatment | 151 | 293 | 9.3 | 92.6 | 36 | 105 | 183 | 247 |
| A-1 Control | 95 | Not sampled | Not sampled | 161 | 92 | 193 | 132 | 163 |

**Table 4. Preburn depth and reduction of the forest floor and forest floor consumption predictions from Consume.**

| Unit | Pins placed (#) | Pins analyzed (#) | Pins burned (#) | Preburn depth (cm) | Preburn depth SE (cm) | Postburn depth (cm) | Postburn depth SE (cm) | Depth reduction (cm) | Consumption (%) | Consume prediction (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| A-1 Treatment[1] | 256 | 254 | 60 | 21.8 | 0.23 | 20.6 | 0.10 | 1.25 | 6 | 19 |
| A-1 Treatment[2] | 256 | 60 | 60 | 23.9 | 0.24 | 18.5 | 0.09 | 5.4 | 23 | 19 |
| A-1 Control[3] | 256 | 249 | 256 | 24.9 | 0.12 | 19.1 | 0.12 | 5.8 | 23 | 16 |

[1]Two pins were lost or stepped on and were eliminated from the analysis.
[2]Only pins that were burned were analyzed.
[3]Seven pins were lost or stepped on and were eliminated from the analysis.

## Fuel Treatments and Fire Operations

Fuel treatments were initiated in the spring of 2006 and completed in early summer 2007. Site preparation and treatment costs totaled approximately $500,000 and were expended primarily by Alaska DNR - Division of Forestry, BLM – Alaska Fire Service, and Alaska Department of Fish and Game. Fire operations costs (for the successful summer 2009 burn in Unit A) totaled approximately $500,000 and were expended by Alaska DNR - Division of Forestry and BLM – Alaska Fire Service. Funding for researchers from UAF and USFS totaled approximately $400,000 and were provided by Joint Fire Science Program ($300,000) as well as in-kind support from UAF ($40,000) and USFS Missoula Fire Lab ($60,000).

### *Management Implications*

All three treatments that burned resulted in significant reductions in fire intensity. While any conclusions from a single data point cannot be conclusive the data suggest that the thin and burn treatments result in substantial reduction in burning time and total cumulative heating energy. If low air temperatures are the desired condition then the shearblade treatment is the most effective, if reduction in peak heating rate or flux is the desired condition then the thin and burn treatment are best. Ignition and flame spread process is complex, but occurs through the presence of flames in the location of unburned but heated fuels. Thus it seems that the most effective deterrent to fire burning across a treatment unit would result from reduction in heating rate as indicated in the thin and burn treatment.

There were consistent multiyear differences in weather observations between the control and thinning treatment. The treatments generally experienced windier (average and gust), warmer (air temperature), and dryer (relative humidity) conditions than the control.

Analysis of the consumption results identified useful anecdotal evidence from this experiment. The fire burned 99% of the forest floor consumption pins located in the control plots outside the A-1 thinned treatment area. This is compared to only 25% of the pins burned within the treatment block. Although we cannot state a scientific conclusion on one treatment site, we can use these data to validate current forest floor consumption models. The 4 to 7 percent under-prediction of consumption by the model compared to the measured forest floor consumption is within the error bounds of Consume.

Although the results of this research experimental burn have produced sparse observations – challenging our ability to report with statistical confidence the effectiveness of these fuel treatments – the observed results and experiences of the fire operations personnel has led to the adoption of rules of thumb related to fuel treatment designs by the State of Alaska Division of Forestry.

### *Recent Findings and Ongoing Work*

This project represents the first operational or experimental test of shaded fuel break and shearbladed fuel treatments. There are no current projects or plans we are aware of that would collect additional observations of this type (see future work section below for recommendations). There are several academic efforts that are interested in vegetation response to mechanical treatments both pre- and post-fire. These efforts are focused at the landscape-level and are looking at interactions with climate change, disturbance regime, and permafrost degradation. This research is part of the Bonanza Creek Longterm Ecological Research (LTER) site (www.lter.uaf.edu). In addition, a major 5 yr Strategic Environmental Research and

Development Program (SERDP) funded project was initiated focusing specifically on the interactions between climate, vegetation, fire and permafrost.

### *Future Work*

As indicated throughout this report the success of this research experimental burn was offset by the inability to captured replicated observations. This presents a significant challenge to developing any rigorous, statistically significant conclusions. However, the anecdotal (n=1) evidence strongly suggests that these treatments are effective in decreasing fire behavior characteristics. These results are the only operational/experimental results for this forest type in Alaska. We highly recommend further studies and research experimental burns to increase observations and the resultant statistical analysis power. We further recognize that there are numerous challenges to carrying out further experiments such as this.

If we can obtain tree densities and grass and shrub characteristics for the A-1 treatment and control areas, we can build FCCS fuel beds and calculate FCCS surface and crown fire potentials and surface fire behavior reaction intensities, flame lengths, and rates of spread. These values could be compared with observations and measurements made by the fire behavior research group and used to validate the FCCS.

### *Deliverables*

This research experimental burn project posed many significant challenges throughout the project period as indicated in previous sections of this report. The challenges of weather, resource availability, and funding for fire operations were significant. In addition, the logistical complexities posed by the primary research groups being based in the lower 48 added to the overall project challenges. Regardless, we were successful in burning Unit A and collecting valuable fire behavior and consumption data. However, due to the delays and added expenses of multiple missed opportunities the final deliverables identified below do deviate from the proposed deliverables. This is an inherent and unavoidable risk with this type of research. The following table summarizes the proposed and realized deliverables:

| Deliverable | Description | Delivery Dates |
|---|---|---|
| Unit A Report | Technical report characterizing results of burn Unit A. | Winter 2011 |
| Unit B Report | Technical report characterizing results of burn Unit B. | Not applicable |
| Unit C Report | Technical report characterizing results of burn Unit C. | Not applicable |
| Technical Report | Guidelines for future experimental burns. | Fall 2010 |
| Manuscripts | Peer-reviewed manuscripts | January 2012 |
| Videos and Photos | Footage from experimental burns. | 2007-2009 |
| Datasets | Datasets from experimental burns. | 2007-2009 |
| Final Report | JFSP final project report. | Winter 2011 |

Because we only successfully burned Unit A the Unit A report and this final report are combined into a single final report document. Results of the Unit A burn have been reported on to the fire management community through a series of public presentations and fact sheets many of which are available for download at the Alaska Fire Science Consortium (AFSC) website (**http://akfireconsortium.uaf.edu**). The technical reporting of guidelines for future experimental burns in Alaska was accomplished with a presentation at the 2nd Annual Alaska Fire Science Consortium Workshop (October 14-15, 2010; see the AFSC website for the presentation and audio (19MB) provided by FMO Robert Schmoll).

The proposed peer-reviewed manuscript(s) presented a unique challenge due to our inability to execute more than one burn and the unsuccessful burning of one of the two treatments within Unit A. This limited burning success effectively provided a single observation point (n=1) that is not compatible with a formal statistical analysis generally required in the peer-review process. However, after long consideration and discussion among our fire research and management colleagues we are now preparing a short paper focused on the projects fire behavior results. Admittedly the data is sparse, but there are almost no similar datasets for this forest type and we therefore believe there will be high interest levels within the fire community. The primary authors of the manuscript titled, "Characterization of wildland fire behavior in Alaskan black spruce," will be Butler and Ottmar with multiple co-authors. The manuscript will be submitted to the Journal of Fire Ecology in January 2012.

This project produced 1+ terabytes of data products including tabular datasets, spatial datasets (GIS and satellite imagery), infrared camera, digital images, raw and edited video, and numerous pdf documents and audio recordings. These data are archived and available through the AFSC upon request. As indicated in the future work section the AFSC is currently developing a new website and once that is complete a project specific page will be available that will host much of this data and/or provide links to the data streams. Currently, the primary products and summaries can be found at the following locations:

**Presentations:**

1. 3 presentations (recordings) on Nenana Ridge given at the JFSP board Visit in 2010 (Rupp, Ottmar, and Butler): http://www.frames.gov/portal/server.pt/community/events/695/2010_jfsp_board_visit/3827
2. 2 Presentations (recordings and pdf's) on Nenana Ridge at the 2010 Alaska Fire Science Workshop (Rupp and Schmoll): http://www.frames.gov/portal/server.pt/community/events/695/2010_fall_workshop/3838
3. ALL 5 presentations can be also be found on the Fuels/Fuels Treatments Presentation Archive page: http://www.frames.gov/portal/server.pt/community/presentation_archive/794/fuels_fuels_treatments/3894

**Summary:**

1. A fact sheet can be found on the 2010 Workshop page (given above) or directly at: http://www.frames.gov/documents/alaska/workshops/Nenana_Ridge_Summary.pdf
2. Rx Burn Narrative (by R. Jandt) is on the 2010 Workshop page or directly at: http://www.frames.gov/documents/alaska/workshops/ENN_2009_RxB_Narrative_condensed_1_.pdf

**Video:**

1. YouTube Video: On the SNAP/ACCAP YouTube Channel: http://www.youtube.com/user/SNAPandACCAP#p/a/u/2/1Qkia5n2g4k

**Photos:**

1. SNAP Flickr: Set of Nenana Ridge Photos (1,539): http://www.flickr.com/photos/snapandaccap/sets/72157626239460636/

**Wiki Page:**

1. Though it was not designed for public use (mainly a workspace for the project collaborators) the wiki page provides access to many data products: http://wiki.snap.uaf.edu/Projects/Nenana_Ridge_Rx_Burn
2. All data products are archived on servers at UAF and maintained by the Scenarios Network for Alaska and Arctic Planning (SNAP; www.snap.uaf.edu).

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