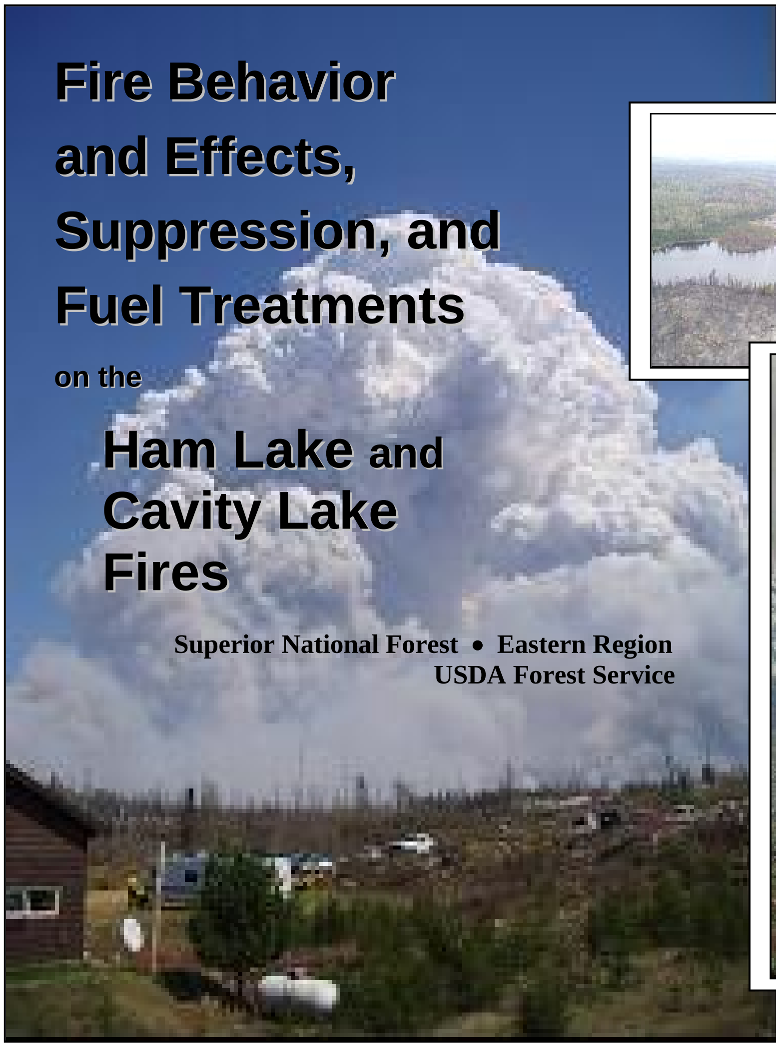

Fire Behavior and Effects, Suppression, and Fuel Treatments

on the

Ham Lake and Cavity Lake Fires

Superior National Forest • Eastern Region
USDA Forest Service

Prepared for the Washington Office By

The Fire Behavior Assessment Team

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This report presents findings derived from evaluating the use and effectiveness of fuel treatments and fire behavior inside treated and untreated areas on the Ham Lake and Cavity Lake fires. It is based on interviews with firsthand observers of fire behavior and suppression as well as follow-up post-fire surveys of fire behavior evidence and effects.

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Fire behavior and suppression during the Ham Lake Fire, Superior National Forest and adjacent lands, May 2007.

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Executive Summary

Fire Behavior, Suppression, and Fuel Treatments

Background

Ham Lake Fire

- On May 5, 2007, an escaped campfire ignited the Ham Lake Fire that burned approximately 75,000 acres on the Superior National Forest. (Nearly half of the fire spread into Canada.)
- Dead litter, branches, and boles fueled the fire—plants were not yet leafed out.

Cavity Lake Fire

- During summer 2006, the lightning-ignited Cavity Lake Fire, encompassing 31,500 acres, burned directly west of the 2007 Ham Lake Fire area in heavy blowdown fuels.
- Plants had leafed out and helped reduce fire behavior in treated areas, but fire spread rapidly elsewhere.

Key Findings

Ham Lake Fire

1. Treated areas had evidence of less intense fire behavior and lower severity than untreated areas. Depending on the information source, however, these results varied.

    (a) Satellite imagery taken during the end of the fire, before green-up (Burned Area Rehab Map), showed significantly lower severity in areas treated with prescribed fire or mechanically than untreated areas. When areas that had been mapped as having blowdown were separated from those that had not, the treated areas had significantly lower severity than untreated areas mapped with blowdown. Other imagery taken after the fire and green-up (Differenced Normalized Burn Ratio [DNBR] and canopy change maps) showed significantly higher canopy change solely in mechanically treated areas.

    (b) Mean crown consumption was lower in treated (35 percent/prescribed fire and 19 percent/mechanical-manual) than in untreated areas (50 percent). High variability in effects and fire characteristics made differences statistically insignificant for areas treated with prescribed fire but significant for those treated mechanically.

    (c) Previous monitoring showed a marked reduction in surface fuels due to prescribed fire treatments in blowdown—undoubtedly contributing to less-intense fire behavior and less-severe fire effects than if left untreated.

2. Treated areas were utilized during suppression along several flanks of the fire.

   a) Mechanically and prescribed fire-treated fuels around the Seagull Guard Station aided in successful structure protection using sprinklers and spot fire attack.

   b) Prescribed fire treatment areas—where fuels had been significantly reduced in blowdown areas—were targeted for suppression burn out operations. Utilizing these pre-treated areas for tactical operations allowed for safe and effective use fire suppression.

   c) Treated areas near Iron Lake aided successful suppression efforts to constrain eastward progression of the fire toward homes.

Cavity Lake Fire

1. When the fire reached large prescribed fire treated areas, it was extinguished and became readily suppressed with direct attack. Treatments were concentrated to the west of the Gunflint Trail wildland-urban interface area, resulting in stopping the fire's progression toward homes.

2. According to monitoring conducted by the Superior National Forest, soil organic material consumption was reduced in treated areas compared to untreated areas.

Overall

In both fires, treated areas were utilized during suppression that successfully modified fire behavior. Fire behavior was decreased in treated areas to a greater degree during the Cavity Fire in the summer than during the Ham Lake Fire in early spring.

Because the Ham Lake Fire occurred in the wildland-urban interface, nearly all areas with concentrations of blowdown were treated—according to mapping conducted by the state of Minnesota and the Superior National Forest—resulting in less contrast between treated and untreated areas.

Despite the minimal difference in pre-fire fuels between treated and untreated areas (because most concentrations of blowdown were treated), untreated areas had significantly greater fire severity than treated areas.

Observations by firefighters as well as Superior National Forest monitoring data strongly support the belief that without treatment, fire behavior in treated areas would have been much more intense and fast moving.

The goal of this evaluation is to assess fire behavior and effects in fuel treatments in the context of suppression and weather.

I INTRODUCTION

Substantial money and time are invested in designing and implementing fuel treatments while simultaneously managing for wildlife and other resource values. It is important to evaluate the effectiveness of treatments to gauge whether these investments provided positive results and to determine if future treatments should be modified for increased effectiveness.

BACKGROUND

The Ham Lake Fire ignited May 5, 2007 on the Superior National Forest. It burned a total of approximately 75,000 acres, including areas treated for fuel hazard reduction, untreated areas, and developed wildland-urban interface along the Gunflint Trail.

Winds during the fire were often high. Gusts up to 28 miles per hour were common. Wind direction shifted dramatically, starting from the southwest, then switching rapidly more west, and, finally, from the north. Major fire runs were sustained in each wind direction.

The fire burned after a dry winter and spring, with early snow and ice melt. Leaves had not come out yet (prior to green up) and the primary fuels of down litter, sticks and wood burned intensely and rapidly in low and varied humidities.

The Cavity Lake Fire, in contrast, burned after green-up and the fire stopped in treated areas.

In 1999, the Superior National Forest experienced a severe blowdown event that resulted in extensive areas of high concentrations of fuels in the Boundary Water Canoe Wilderness and adjacent developed areas along the Gunflint Trail[1]. Extensive fuel treatments were conducted to reduce this fuel hazard.

This report contains an evaluation of the use and effectiveness of these fuel treatments and the resultant fire behavior that occurred in both treated and untreated areas during the May 2007 Ham Lake Fire on the Superior National Forest, located in northern Minnesota. A synthesis of previous reports on the Cavity Lake Fire, which occurred during the summer of 2006, is used to compare with Ham Lake Fire behavior and effects. Together, the two fires provide insight into use and effectiveness of fuel treatments during two different fire season phases---pre-leaf out or “green up” and post- leaf out.

This report’s analysis is based on:

- Interviews with firefighters regarding direct observations during the fire;
- Synthesis of previous monitoring and analyses, and
- A quantitative post-fire assessment of fire behavior evidence and immediate post-fire effects to forests, understory vegetation, and soils.

[1] The Gunflint Trail (Cook County Highway 12) is a 57-mile paved roadway that begins in Grand Marais, MN and ends at Seagull Lake in the Boundary Waters Canoe Area Wilderness near the U.S. border with Ontario, Canada. Originally a foot path for travellers from inland lakes to Lake Superior, the trail was eventually widened into a road. It now serves as a route to lodges, outfitters, hiking trails, and the lakes and rivers of the Boundary Waters Canoe Area Wilderness. A small number of people, numbering in the hundreds, have full-time residences or businesses along the Gunflint Trail, though thousands have cabins or other part-time residential properties here.

The goal of this report's evaluation is to assess fire behavior and effects in fuel treatments and protected areas in the context of suppression and weather.

Report Organization

This report is divided into four key sections:

1. Fuel Treatments

Chapters I and II summarize the fuel treatments planned and implemented by the Superior National Forest to address the fuel hazard posed by the 1999 blowdown event.

2. Fire Behavior and Suppression

Chapter III provides a summary of information gained through direct observation of fire behavior and suppression.

3. Fire Behavior Effects Post-Fire Survey

Chapter IV outlines a more detailed post-fire survey of fire behavior evidence and effects.

4. Comparing Fire Behavior, Suppression, and Fuel Treatments on the Cavity Lake and Ham Lake Fires

Chapter V compares fire behavior, suppression, and fuel treatments on the Cavity Lake fire with the Ham Lake Fire. Overall, this comparison provides insight into contrasts in fire behavior and fuel treatments during different fire seasons.

For the most part, blowdown was rated in the "high damage" category in the area burned in the Cavity Lake Fire. The blowdown rating was more variable in the area burned by the Ham Lake Fire.

II BLOWDOWN AND FUEL TREATMENTS TO REDUCE HAZARD

In 1999, the Superior National Forest experienced a severe blowdown event that caused extensive damage in the Boundary Waters Canoe Area Wilderness (BWCAW) and adjacent areas (figs. 1, 2).

An extensive network of strategically placed fuel reduction treatments were implemented to reduce the potential fire hazard, especially within the developed areas along the Gunflint Trail.

The Blowdown Event

During this 1999 high wind event, trees were snapped in half and thousands of acres were covered with various amounts of jack-strawed tree boles (fig. 1). While the blowdown was centered in the BWCAW, it included areas outside of the wilderness along the Gunflint Trail and extended into Canada. The blowdown was not uniform. Satellite and aerial surveys were conducted to map the presence of damage (fig. 2).

Figure 1 – Severe blowdown in the Boundary Water Canoe Area Wilderness and adjacent areas.

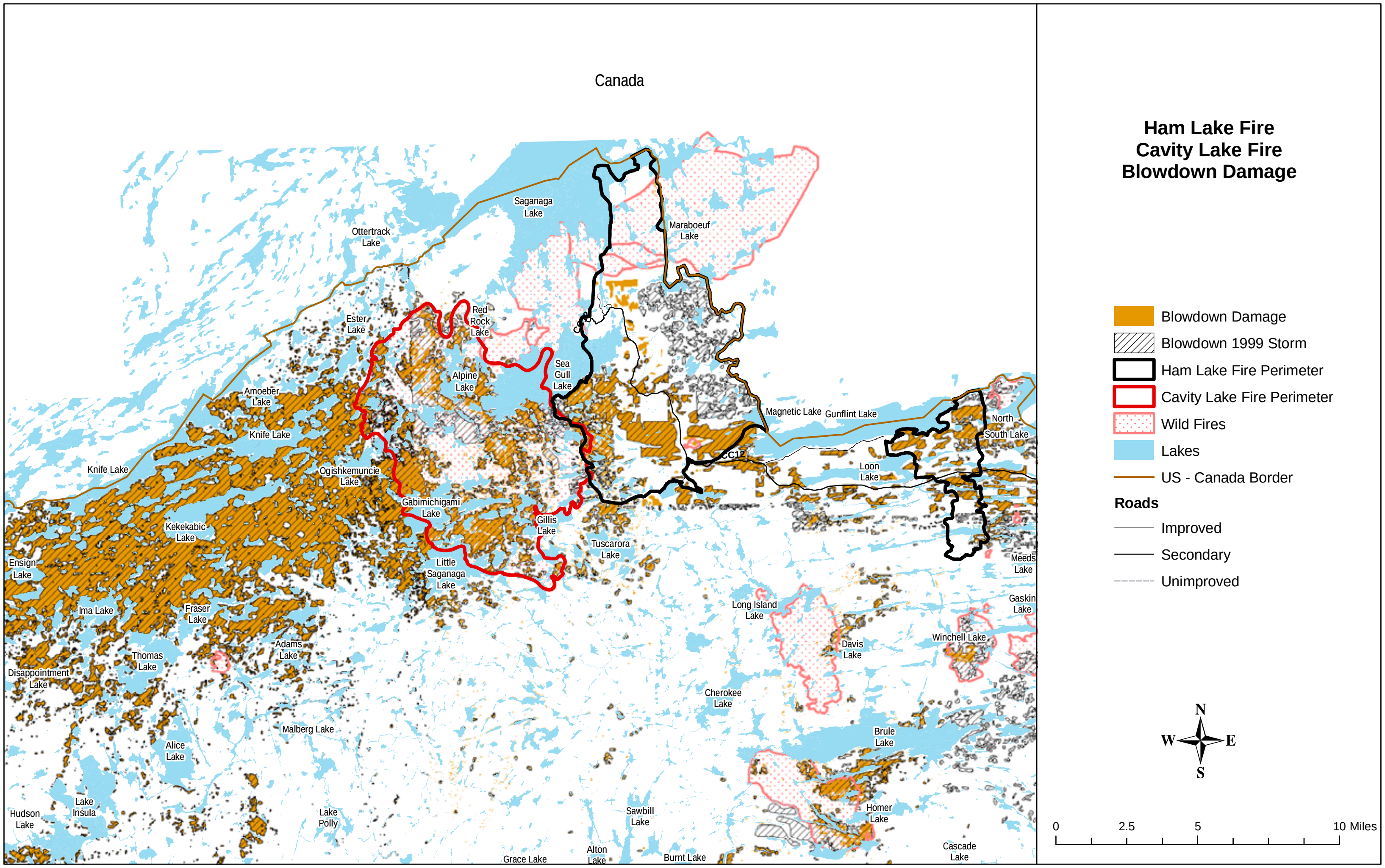

Figure 2 – Map of blowdown across northern Minnesota in the area of the Ham Lake and Cavity Lake fires, near the Gunflint Trail.

Within the areas with various levels of blowdown, in addition to added dead and down surface fuels from the blown down trees, a change in live fuels also occurred: an increased establishment and growth of balsam fir in the understory. Balsam fir can be highly flammable. Additionally, its crowns are low to the ground, making this species readily available as a ladder into crown fire in the overstory—or as crown fire fuel on its own.

Figure 3 – A large landscape prescribed burn in the Ham Lake Fire area, conducted several years before the fire to reduce the fuel hazard caused by the 1999 blowdown windstorm.

Fuel Treatments in Blowdown

The 1999 blowdown event confronted Superior National Forest managers with an extensive area of very high fuel concentration. These managers quickly consulted with the USDA Forest Service Missoula Fire Laboratory regarding the most effective means of characterizing and reducing the potential fire hazard (Leuschen and others 2000). In particular, Dr. Mark Finney provided detailed potential fire behavior predictions and state-of-the-art strategic fuel treatment placement recommendations.

Based on a review of fires in similar blowdown conditions documented in Canada, Dr. Finney indicated that without treatment, fires were likely to be very high intensity and potentially fast spreading with extensive and long-range spotting. The team from the Missoula Fire Laboratory indicated that very high fuel loads—as great as 100+ tons/acre, arranged in depths up to 20 feet deep—were accumulated across the area.

Dr. Finney recommended a network of strategically placed area fuel treatments in the landscape affected by the blowdown to reduce (but not stop) fire behavior. This included numerous large patches of the landscape adjacent to non-flammable lakes or rock outcrops—arranged to slow progression of fire.

Acknowledging the likelihood of long-range spotting, the size of these treated areas recommended by Dr. Finney were relatively large (thousands of acres). The Superior National Forest implemented such a network of strategically placed fuel treatments relatively rapidly (within six years of blowdown event) across a large portion of the area affected by blowdown. In particular, treatments were placed around the Gunflint Trail area, an important developed recreation area with numerous vacation homes, lodges, and residences.

Most of the resultant fuel hazard reduction treatments were large, landscape prescribed burns (fig. 3). The large landscape burns were conducted primarily through aerial ignition, with concentrations of blowdown targeted.

Essentially, the prescribed burns resulted in a mosaic of levels of fuels and fire effects. It would have been difficult to safely burn the entire treatment blocks more uniformly (resulting in too much intense fire).

Figure 4 – Area along the Gunflint Trail in the foreground was mechanically treated to remove blowdown and then reforested with pine seedlings.

In addition, burning these widespread areas could have resulted in adverse impacts to scenic, wildlife, and soil resources. According to forest and district fire personnel, the degree of fuel reduction within the individual treatment blocks or projects varied—depending on time of year as well as plant and soil moisture levels.

Numerous more intensive mechanical and hand-based treatments were also conducted in the greatest concentrations of blowdown in accessible areas along the Gunflint Trail—located outside of wilderness (fig. 4). In some areas, nearly all blowdown tree boles were removed and residual litter and branches were piled/burned or burned. These treatments occurred in small areas (10-100 acres) in relation to the larger, landscape prescribed fire treatments.

Monitoring Fuel Reductions in Treated Areas

The Superior National Forest has conducted detailed monitoring of fuels prior to and after treatment. Although this work is ongoing, preliminary analysis reveals that treatments substantially reduced fuel loads (table 1).

After prescribed fire, 1-hour fuels were reduced by more than 50 percent and 10- and 100-hour fuels by more than 30 percent. Average fuel depth decreased over 50 percent. The number of 1,000-hour fuels (>3” diameter, including down tree boles) decreased by 24 percent. The levels of the fuels were high pre-treatment—undoubtedly from blowdown. These fuels were substantially reduced with treatment.

Smaller size classes of fuels and fuelbed depth are especially important in fire spread rates and intensity. These monitoring data show a substantial reduction in fuel hazard.

Summary of Fuels for all Plots					
	1 hour	**10 hour**	**100 hour**	**1000 hour**	**Avg. Fuel Depth**
	Tons/acre (or % as indicated)			**Number of pieces (or % change as indicated)**	**Feet**
Percent Reduction from Fuel Treatment	53%	36%	38%	24%	56%
Percent Reduction after Ham Fire	92%	88%	73%	4% *increase*	30%
Overall Reduction	**96%**	**92%**	**83%**	**21%**	**69%**

Table 1 – Summary of surface fuel conditions in Superior National Forest monitoring plots: before treatment, after treatment, and after the Ham Lake Fire.

III Fire Behavior and Suppression in Relation to Weather and Fuel Treatments

Ham Lake Fire Chronology

The Ham Lake Fire, ignited May 5th 2007 after a dry winter and spring, was largely a wind-driven fire. Snow and ice had recently melted.

The day the fire started, winds were generally greater than 10 mph at the Seagull weather station (in the center of the fire area), including gusts up to 28 mph (fig. C-1: Appendix C). These winds caused the fire to spread rapidly toward the west and northwest (fig 6). Spots from the fire traveled up to an estimated ¾ mile. By 2:30 p.m., the fire had grown to approximately 480 acres. By the next morning it had traveled an estimated 3 miles (fig. 6).

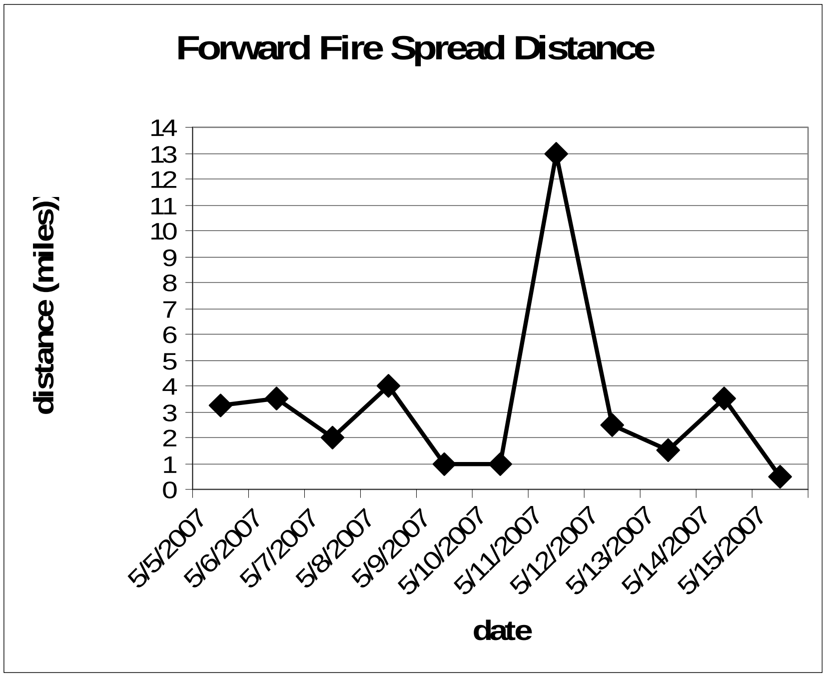

Figure 5 – Daily forward progression of main head of Ham Lake Fire.

The next morning (May 6th), low relative humidities dried fuels and contributed to active fire behavior (fig C-1, table C-1; see appendix C). Again, average winds generally exceeded 12 mph; gusts over 25 mph were common. Wind direction shifted, eventually moving more from the south, with the fire progressing rapidly more to the northwest—again, close to three miles' fire spread distance. On May 7th, the fire's third day, high winds continued with a more northwest progression of 2 miles fire spread.

On May 8th, winds from the south and southwest early and late in the day exceeded 20 mph. The fire spread 4 miles to the north with active spotting. On both May 7th and 8th, the area burned included the most extensive wildland-urban interface affected by the fire.

On May 9th and 10th, winds moderated (averaging less than 10 mph) and humidity increased, resulting in slower fire progression. On May 11th, winds increased again as the fire's direction switched to a south direction (from the north) bringing very dry air from Canada and pushing the fire south toward Iron Lake. The fire burned with very high intensity and progressed nearly 10 more miles.

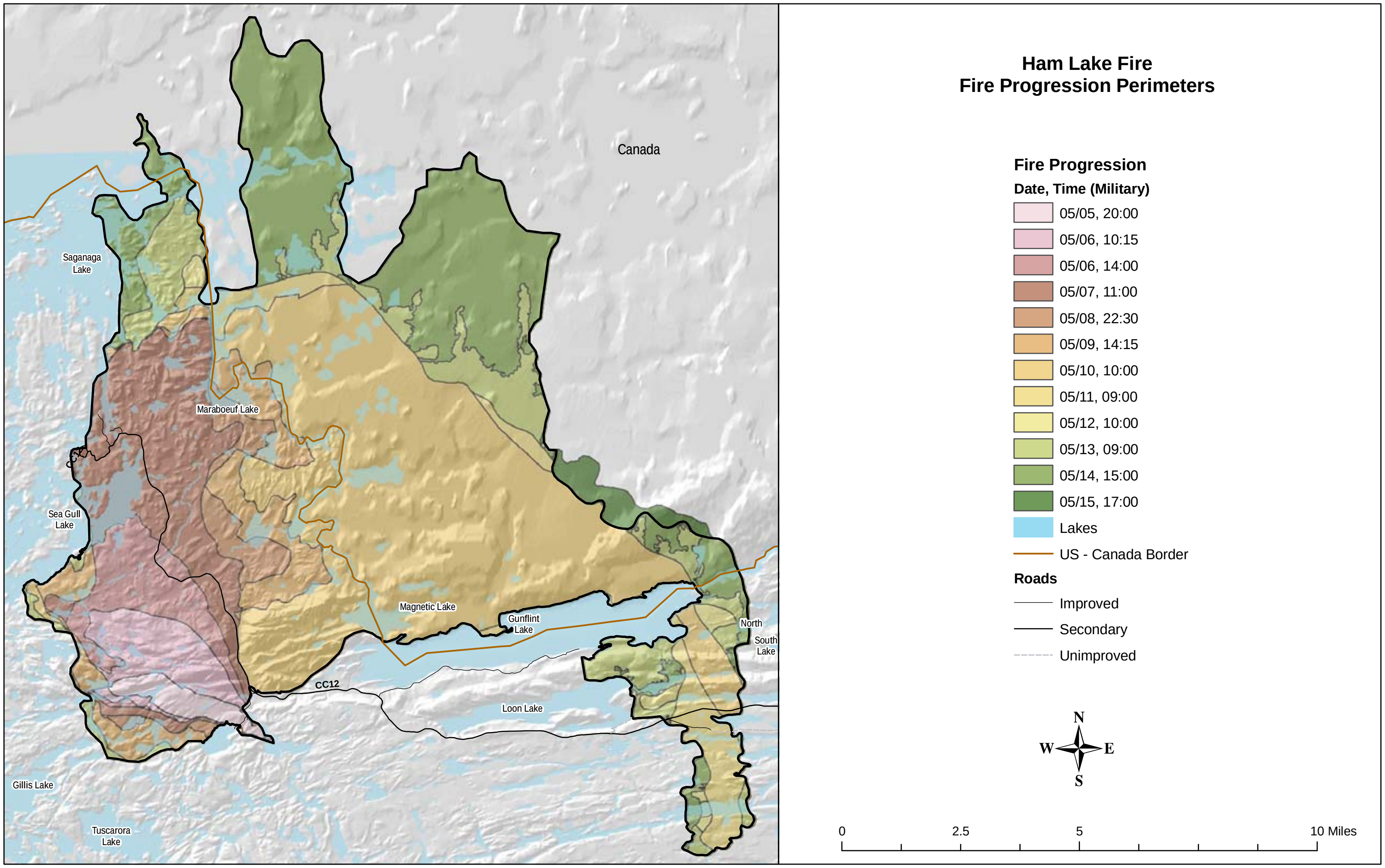

Figure 6 – Ham Fire progression map.

For the duration of the fire, from May 12th through the 15th, when it was declared contained, for the most part, average winds remained below 10 mph. While humidities dropped below 30 percent at times, they were generally greater. On the last two days of the fire, humidities generally exceeded 70 percent, greatly reducing fire behavior.

During much of the fire, when it was driven by winds, it burned as a fast moving fire. Where there were trees present, it often burned as a crown fire (fig. 7). Across much of the landscape where blowdown had occurred, particularly in uplands, blowdown not only resulted in increased dead and down fuels, this condition also resulted in "release"—or increased establishment and growth—of balsam fire in the understory.

Figure 7 – The Ham Lake Fire. Foreground area indicates evidence of crown fire, with extensive areas of complete crown consumption.

As is typical for this species, balsam fir burned readily during the Ham Lake Fire (fig. 8). It often served as a key fuel component in fire spread. Live fuel moistures were low, near 100 percent (fig. C-4, table C-1; see Appendix C). Because of the previously dry winter and spring, even wetlands that rarely burn proceeded to burn on this fire. This occurred, in part, because the new shoots of sedges and grasses had not yet emerged. Dead leaves and stems from the previous year's growth was the only fuel available to burn. Normally, this time of year here, standing water in the wetlands prevents this available dead material from burning. The dry year of 2007, however, was the exception.

Figure 8 – Crown fire in balsam fir in the wildland-urban interface along the Gunflint Trail.

Past Treatments Aid Ham Lake Fire Suppression Efforts

Because the Ham Lake Fire was generally fast-moving and wind-driven, suppression was difficult (fig. 9). Where trees were present, the fire often burned as a crown fire with high flamelengths (figs. 9 and 10). Based on interviews with firefighters, the previous fuel treatments aided fire suppression in several ways.

First, fire was moderated in treated areas where blowdown had been reduced (fig. 11). Without this prior treatment, it had been predicted—as observed in previous fires—that fire behavior would be much more intense and fast spreading in heavy blowdown.

Secondly, in many instances, direct use of treated areas assisted suppression actions.

For instance, near the Seagull Guard Station where intensive mechanical and prescribed fire treatments had been applied, firefighters were able to successfully put out numerous spot fires. Sprinklers around the station were also effective because of the limited—post treatment—surrounding fuels. Because of these reduced fuels and the resulting lower radiant heat, suppression forces were able to safely fight fire in this area.

Figure 9 (above) – Fast-moving crown fire—evident from the large smoke plume—burns southeast of the Seagull Guard Station along the Gunflint Trail (Cook County Highway 12).

Figure 10 (left) – Crown fire in an untreated area outside of a treated area (foreground) during the Ham Lake Fire.

Firefighters said that without the prior fuel treatment they might not have been able to utilize this important fire suppression tactic.

Figure 11 – Moderated fire behavior in an area treated mechanically to reduce blowdown.

Fuel treatments positioned along the Gunflint Trail were also used to increase safety for conducting burn operations to the south of the Seagull Guard Station (fig. 12).

Without treatment, blowdown fuels would have made these suppression activities unsafe and greatly increased the likelihood of generating more fire across the road.

Figure 12 – Burn operation along the Gunflint Trail is aided by reduced fuels in this area that had been previously treated mechanically for fuel hazard reduction

Similarly, a large burn operation between Loon Lake and Gunflint Lake was aided by previous prescribed fire treatments. Firefighters stated that it would have been far riskier to conduct their burn operation if the area hadn't already been treated. They said that without the prior fuel treatment they might not have been able to utilize this important fire suppression tactic—both ground and aerial burn operations were able to be conducted (figs. 13,14,15).

Figure 13 – Firefighter monitors fire spread and intensity during burn operation on Ham Like Fire.

Finally, as the fire progressed south in the vicinity of Iron Lake, numerous intensive mechanical and manual—as well as less intensive prescribed fire treatments—aided in effective use of aircraft and ground firefighting resources to limit eastward progression of the fire toward a number of dispersed homes (figs. 14 and 15).

Figures 14 and 15 – Ham Lake Fire aerial operations, water drop from helicopter (left), and removing fuels to place a fire hose or wet line near the fire (right).

The Fire Behavior Assessment Team conducted detailed fire behavior/fuels and post-fire effects measurements—in particular, those areas that had previously undergone fuel treatments. Examining the effects of treated areas on suppression operations and the wildfire behavior in these treated areas served as the emphasis of this assessment.

IV Post Fire Survey of Fire Behavior Evidence and Effects

Quantitative evidence of fire behavior and effects framed the emphasis of the Ham Lake Fire's post-fire survey. Two complementary post-fire evidence data sets on fire behavior and effects were compiled: one from field plots and the other from satellite imagery.

Data layers of treatment history and fire history were compiled to allow a comparison of treated and untreated areas. Data analysis included both descriptive analysis with summary of data in graphs, as well as formal statistical analysis using General Linear Models and Contingency Tables.

Data from Field Plots

For the first data set, data were gathered in the field. (See Appendix A for details on sampling approach and protocols.) Emphasis was on sampling as many of the treated areas—as well as representative untreated areas—as possible. Information was gathered on fire behavior evidence and effects, including:

- Tree crown consumption and scorch,
- Basal bole scorch on hardwoods,
- Needle freeze and color,
- Soil cover consumption and effects,
- Understory vegetation consumption and effects, and
- Evidence of fire suppression actions.

Tree crown consumption is a critical indicator of crown fire. When tree crowns are not consumed by fire, needle color and "freeze" in the crowns provide an indication of the direction and intensity of fire spread. Needle freeze occurs when the fire is burning intensely, often moving in a specific direction with enough speed to "freeze" the needles in the direction the fire is burning. Black needles indicate higher-intensity fire. Light-brown needles—with some green remaining—indicate lower-intensity fire.

Visible evidence of suppression actions on the Ham Lake Fire was limited because vegetation had re-grown after the fire and covered up ground disturbance. In addition, many of the suppression tactics used (aircraft water drops or hoselays from lakes) are not visible after the fact (figs. 14 and 15). Where fire suppression evidence was observed, it was noted. Information on suppression actions for this assessment came primarily from interviews with firefighters assigned to the fire.

These data were summarized into four separate variables used in the analysis:

1. The average proportion of crown consumption computed from tree data;
2. The modal soil severity rating (5 classes) (see table 2);
3. The modal understory severity rating (5 classes) (see table 2); and
4. A composite rating of fire behavior (see table 2).

Code	Definition for fire behavior rating	Definition for soil rating (based on NPS system but with rating levels reversed to correspond with fire behavior ratings	Definition for understory rating (based on NPS system but with rating levels reversed to correspond with fire behavior ratings)
0	**Unburned**	**Unburned**	**Not applicable, not present prior to fire**
1	Low intensity surface fire, overstory little or no effects.	Very low: Litter charred, little to no consumption.	Unburned
2	Moderate intensity surface fire (understory trees all scorched, overstory trees <50% scorched) or all poles or seedlings scorched if younger stand	Low: Litter partially consumed, duff unaffected	Foliage scorched.
3	High intensity surface fire, all crowns consumed on pole trees, up to 50% crown consumption or 80% scorch in overstory trees	Moderate: Litter consumed, duff unaffected or slight.	Lightly burned, with some foliage and smaller twigs partially consumed. Branches mostly intact.
4	High intensity fire with at least some crowning; heavy crown consumption on most trees, some scorched trees remain.	High: Duff consumed but not completely (<50% depth or patchy); some rocks may be exposed but patchy exposure.	Moderate with all foliage and some small twigs consumed.
5	Very high intensity with all crowns consumed.	Very high: Very heavy (>50%) to complete duff consumption, many roots and rocks exposed.	Heavily burned, consumed to stobs > 1cm diameter

Table 2 – Severity Rating Levels Applied to Each Plot. The fire behavior rating, developed by the Fire Behavior Assessment Team, is based on a similar rating system developed by Omi and Kalabokidis (1991). The soil and understory severity ratings are based on the National Park Service's Western Monitoring Handbook. The criteria for soil severity rating was modified to incorporate key visible effects to organic soils more applicable to northeastern soils, such as organic matter consumption and exposure of underlying roots or rocks.

Data From Satellites

Satellite-derived information on immediate post-fire severity produced by the Remote Sensing and Application Center and the U.S. Geological Survey Earth Observing System Center staff served as important sources of data evidence for the Fire Behavior Assessment Team. These data are based on a nationally adopted process using LANDSAT satellite imagery. Several different satellite data sources were analyzed. The Burned Area Emergency Rehabilitation Classification (BARC) maps (fig. 16) and both the defined categories and continuous BARC index values were also used in this analysis. While these data are developed primarily for the purpose of assessing severity to soils, they also detect changes to vegetation above the soil. These data were gathered just before the fire ended, after most acres had burned, before green-up. Additional post-fire and post-green up satellite data was also used. This included the Differenced Normalized Burn Ratio (DNBR) index and associated composite burn index and change in canopy cover estimates.

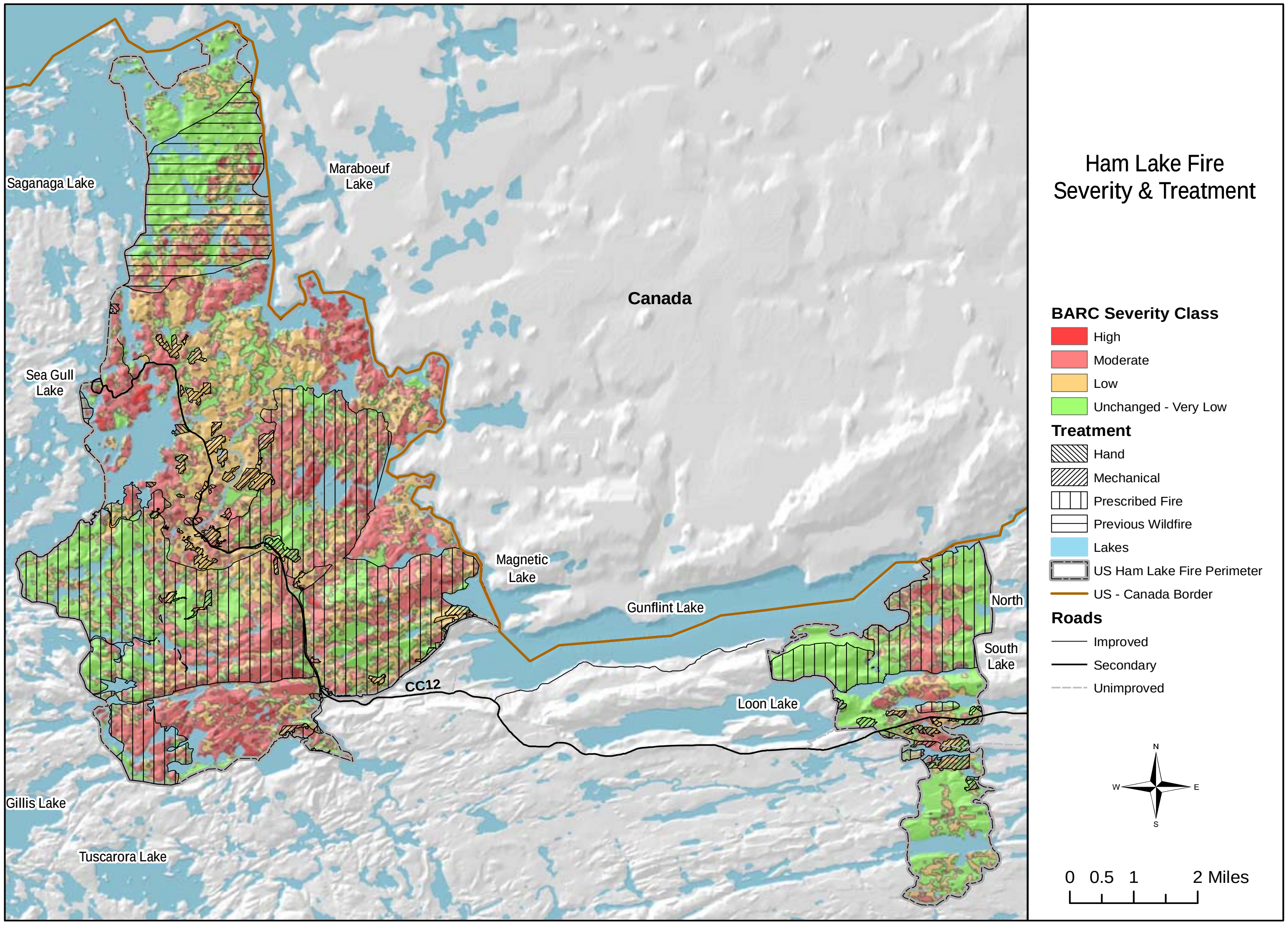

Figure 16 – Map of post-fire severity to soils (Burned Area Rehabilitation Code) from LANDSAT satellite imagery with fuel treatments overlaid on top.

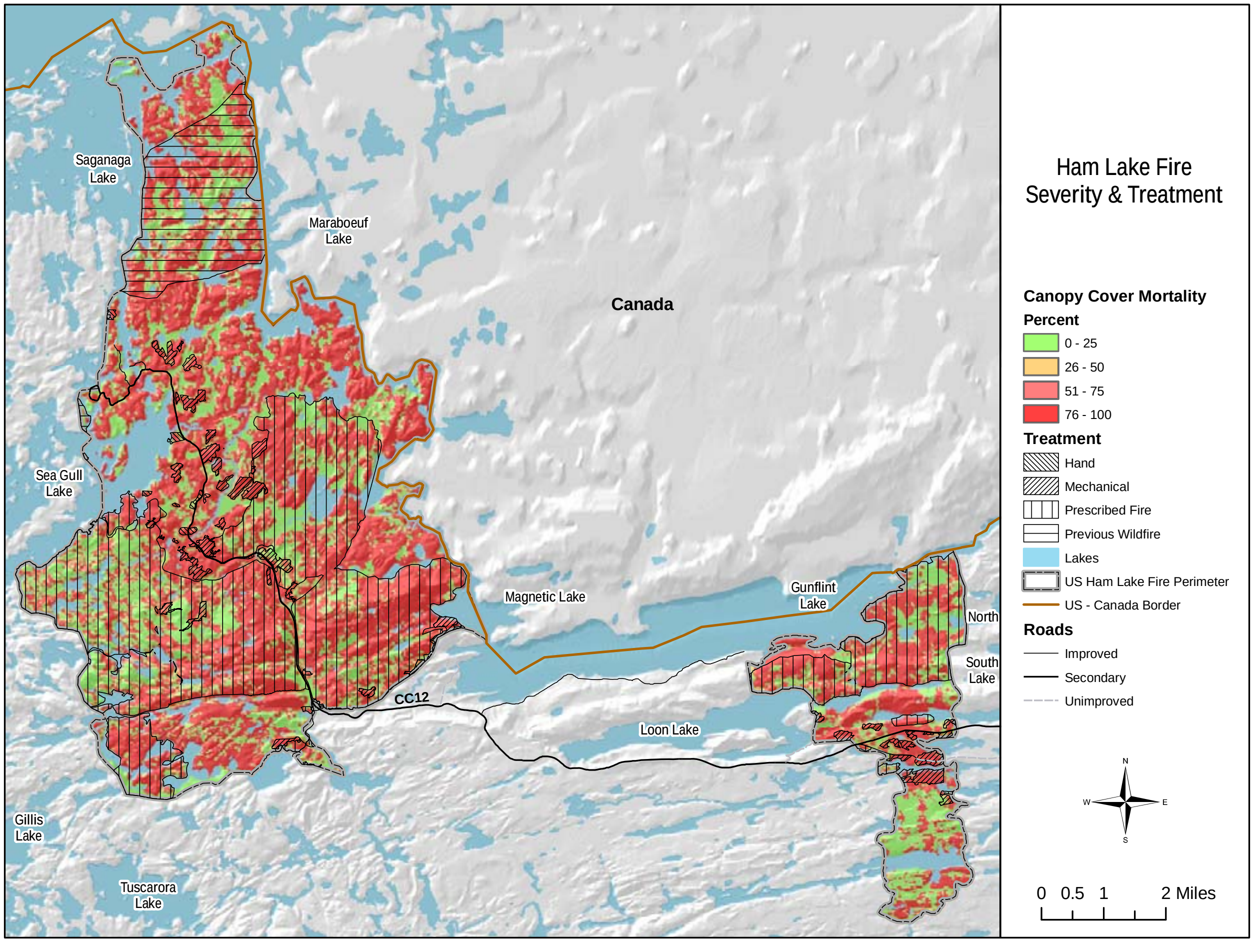

Figure 17 – Map of post-fire severity depicting changes in vegetation canopy cover from LANDSAT satellite imagery overlaid with fuel treatment areas.

Findings

Overall

Overall, treated areas had lower—but highly variable evidence—of fire behavior and severity levels than untreated areas. Observations by firefighters and both plot and satellite-based data all indicate that fire behavior was reduced in areas intensively treated mechanically.

Treated areas had lower but highly variable evidence of fire behavior and severity levels than untreated areas.

Results varied depending on the satellite data used. The BARC data, which was collected on May 12th after most of the fire had burned, exhibited significantly lower evidence of fire behavior and severity in areas treated with prescribed fire or mechanically. (table 3).

For some analyses, areas that had burned significantly were included. Areas recently burned in wildfires had significantly lower severity than those treated mechanically or manually. The Sag Corridor Fire occurred in the northernmost portion of the Ham Lake Fire area. It burned in 1995, resulting in fewer trees to blowdown—and reduced fuels overall. This portion of the landscape was omitted for other comparisons of treated and untreated areas because the greater effects of a recent wildfire obscured detection of differences in other parts of the landscape

From the plot data on the ground, on average, there was lower tree crown consumption (fig. 20, table 4) in areas treated with prescribed fire than untreated areas. The difference, however, was not statistically significant. Areas treated mechanically did have significantly lower crown consumption than in untreated areas or areas treated with prescribed fire.

Based on plot data, mean individual tree crown consumption was 50 percent in untreated areas, 36 percent in areas with prescribed fire, and 19 percent in areas with mechanical or manual treatments.

With other satellite data there were only significant differences between areas treated mechanically or manually and other categories (untreated, treated with prescribed fire, recent wildfires) (see Appendix B). There were significantly greater effects in mechanically and manually treated areas with these data. These satellite data were taken on May 20th, eight days after the fire was out. This data focused on other indices relating to effects to vegetation (DNBR, canopy cover change) or combined vegetation and soil effects (composite burn index).

Land Status	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	*Upper Bound*
Untreated	137[a]	2.0	137.0	145.0
Recent Wildfire	118[b]	5.5	117.1	138.6
Prescribed fire	131[c]	1.6	127.9	134.2
Mechanical /manual	136[a]	3.0	130.9	142.8

Table 3 – Summary of mean fire severity levels from BARC index satellite data among treated (prescribed fire and mechanical/manual, untreated areas, and those recently burned by wildfires). Under the land status column, categories denoted with different letters in the superscript have significantly (p<.05) different means. See Appendix B for details on statistical test results.

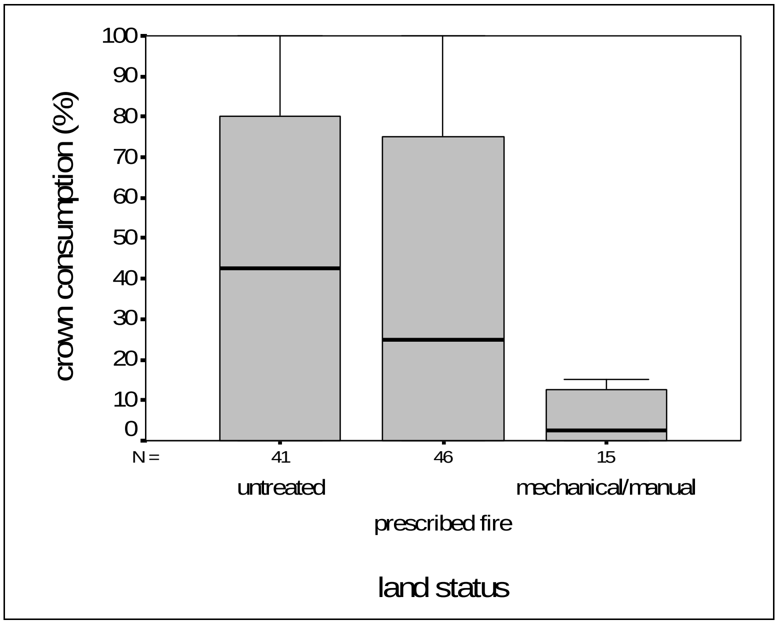

Figure 18 – Box plot of tree crown consumption in untreated and treated areas (prescribed fire or mechanical/manual) based on field plots. The center line, the median and lower and upper box represent the 25th and 75th percentiles respectively.

Land status	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	*Upper Bound*
Untreated	50[a]	6.3	37.6	62.5
Prescribed fire	36[a]	5.7	24.3	47.0
Mechanical/manual	19[b]	10.0	-.5	39.3

Evaluated with covariates in the model: topographic position, swamp or marsh, and blowdown or not.

Table 4 – Summary of mean post-fire crown consumption from field plots among treated (prescribed fire and mechanical/manual) and untreated areas. Under the land status column, categories denoted with different letters in the superscript have significantly (p<.05) different means. See Appendix B for details on statistical test results.

Explaining the Differences in Data
There are several reasons for the varied results from different sources of data, either different satellite data or the plot data. This includes a high variability in fire patterns in the prescribed burn treatments, focus of treatments on areas of most severe blowdown, time of the fire prior to hardwood “green-up”, and timing of satellite data after green-up had occurred.

First, it is likely that the treatments resulted in less contrast in fuels between treated and untreated areas. Prior to the treatments, greater amounts of blowdown fuels existed within the areas planned for treatment. However, the monitoring data collected by the Superior National Forest clearly demonstrate that the prescribed fire treatments substantially reduced (>50 percent) surface fuels. This corroborates claims by the firefighters, as well as predictions by researchers (e.g. Dr. Finney), that fire behavior and effects would have been much greater if the blowdown had not been treated.

Because the Ham Lake Fire burned in the spring, its seasonal timing resulted in challenges for measuring and interpreting evidence of fire behavior and effects. This fire burned prior to plants leafing out or “green up”. Common measures of crown fire include crown consumption and fire effects, and crown scorch.

When this fire occurred, numerous hardwood trees had not yet leafed out. Therefore, there were no crowns to scorch or consume which—where hardwoods were prevalent—made it difficult to detect pre- to post-fire changes via satellite.

The blowdown left many areas without minimal—and sometimes no—overstory tree cover. Because there were no crowns to burn, this also made detection of fire behavior evidence and effects difficult.

In addition, by the time the fire was ending, plants and leaves were emerging. This caused further obscuring of evidence of fire with remote sensing data for ash, charred, or consumed plant stems and foliage. This is why all or most wetlands show no change in canopy cover, despite the fact that many burned at least partially (fig. 17).

In the field plots, while it was possible to document evidence of fire, challenges occurred in discerning soil organic material or plant or tree consumption where previous prescribed burn treatments had also consumed fuels and vegetation.

The field survey was conducted in the early fall. If it had been conducted immediately after the fire, discerning the differences between evidence from the Ham Lake Fire and previous prescribed fire treatments would have been more straightforward. For example, there still would have been ash on the ground.

Soil and Understory Effects
Soil and understory severity based on plot data did not vary significantly among treated and untreated areas. The reliability of soil and understory severity from plot data was lessened because of the timing of the survey in early fall—after a growing season with ash washed away and vegetation growth obscuring effects. In addition, because plants had not leafed out at the time of the Ham Lake Fire, the typical indicators of crown scorch and consumption were less useful because of the prevalence of hardwoods in the area and lack of crown effects.

Effect of Prescribed Fire Intensity
According to Superior National Forest fire managers, the intensity and spatial pattern of prescribed fires varied, depending on the location in the landscape and time of year, or weather conditions when fire was applied. The Arc Lake and Honker projects (fig. 20) both burned hotter than other prescribed burns, with greater reduction in blowdown and other fuels. This is partly due to a higher proportion of drier, rocky terrain with more Jack pine and balsam fir that—because of their flammability—enable greater fuel reduction during prescribed fires. In both the satellite-based severity maps, substantially lower levels of severity occur within these treated areas (figs. 16 and 17). In contrast, the 2004 Larch Lake prescribed burn project did not yield as much fuel reduction. It was conducted in the fall when fuels and weather were wetter and cooler. Also, its overall landscape is lower in elevation with more wetlands and less flammable vegetation. In this area, fire behavior evidence and severity was more severe.

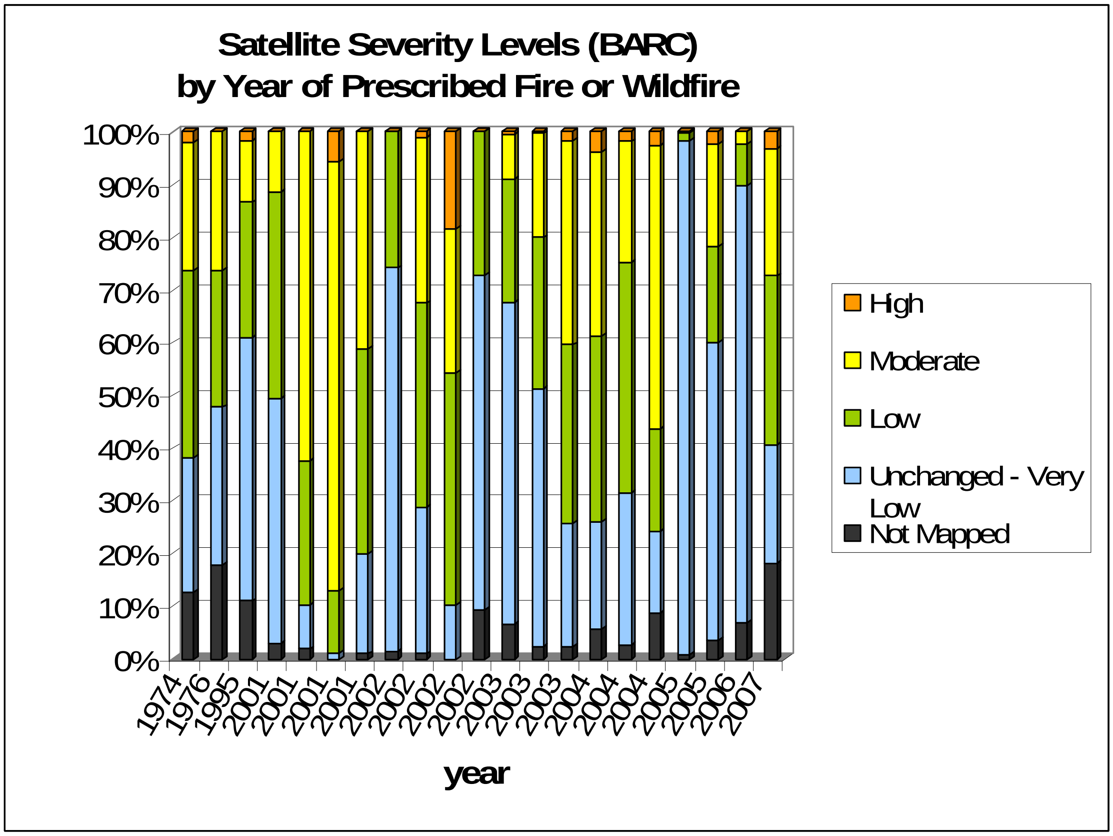

Figure 19 – Fire severity from satellite data (Burned Area Recovery Condition) in the Ham Lake Fire within individual prescribed fire project areas or recent wildfires. Data are arranged by year in which the prescribed fire or wildfire occurred. Wildfires occurred in 1974, 1976, 1995, and 2006.

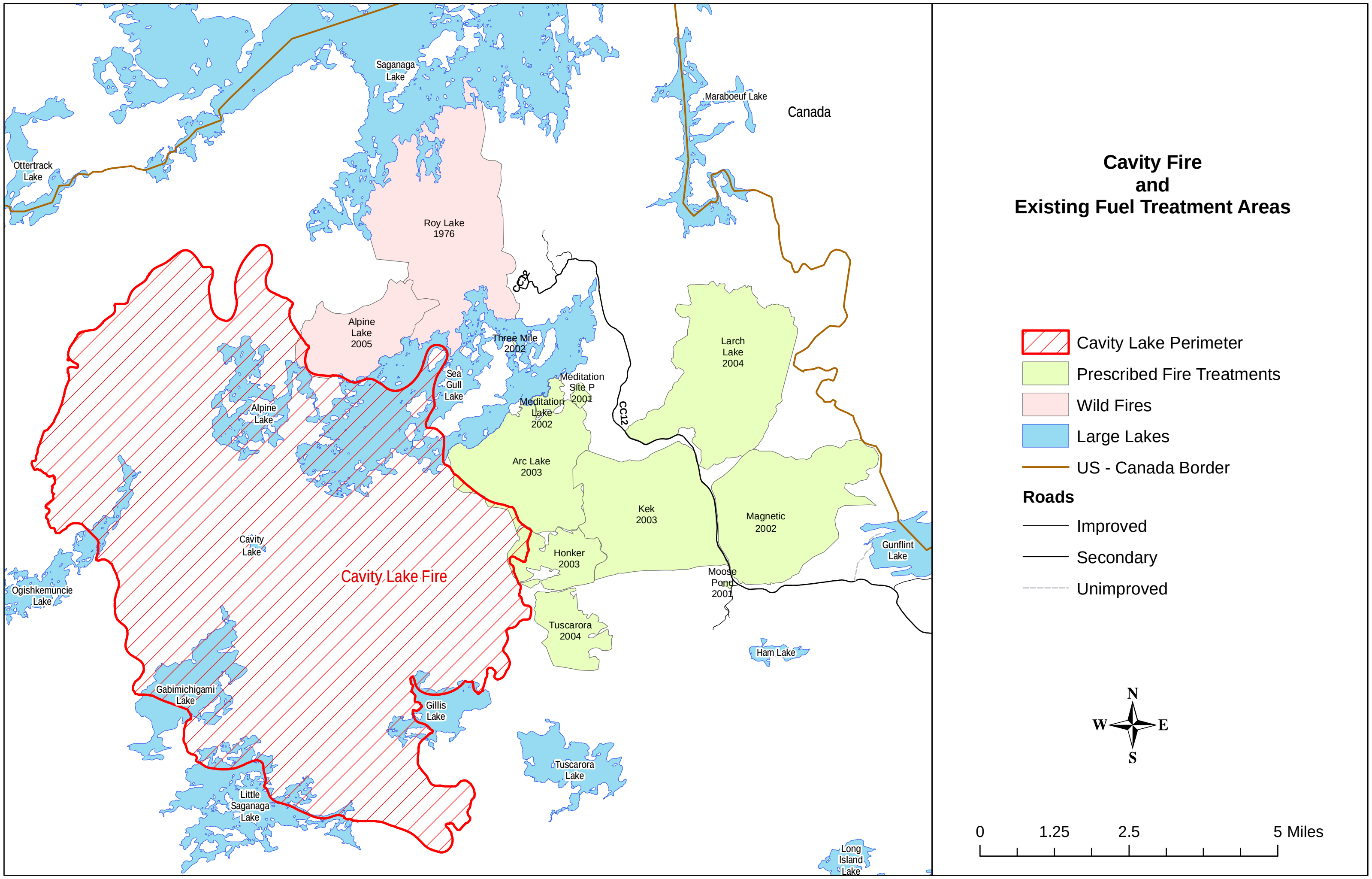

Figure 20 – Map of prescribed fire treatments and recent wildfires that aided in reduced forward progression of the Cavity Lake Fire.

Due to seasonal timing and effects—mainly the occurrence of green-up—fuel treatments had a greater emphasis in reducing fire behavior on the summertime Cavity Lake Fire than during the springtime Ham Lake Fire.

V COMPARING FIRE BEHAVIOR AND FUEL TREATMENTS ON THE CAVITY LAKE AND HAM LAKE FIRES

While lessened fire behavior and effects were observed on both the Ham Lake and Cavity Lake fires when influenced by prior fuel-treated areas, the magnitude of this influence depended on the season in which the fire occurred.

The Cavity Lake Fire burned in the summer *after* vegetation had leafed out. The Ham Lake Fire burned in the spring, *before* this green-up occurred. Thus, dead fuels and conifer trees served as the primary fuels for this springtime fire.

Prior to the severe 1999 wind/blowdown event, most areas with blowdown were dominated by a conifer overstory. This condition tended to result in low levels of herbaceous or deciduous plants in the understory. In many areas after the 1999 blowdown event, understory deciduous species increased in amount as well as the in-growth of young, highly flammable balsam fir. One of the major effects of the prescribed fire treatments on this new layer of vegetation was the substantial reduction of the flammable balsam fire component.

Comparison fire behavior and effects in treated areas between wildfires in the spring (prior to leaf out) and summer (after leaf out) reveal variation in the magnitude of effects/change that fuel treatments bestowed on fire behavior.

Fire was moderated by treatment areas to a much greater degree during the summertime Cavity Lake Fire compared to the springtime Ham Lake Fire. A map of the Cavity Lake Fire showing prior prescribed fire treatments and relatively recent wildfires confirms that the fire did not progress very far into these treated and fire-impacted areas (fig. 20).

According to firefighters on both of these fires, the green vegetation that was present during the Cavity Lake Fire had a dampening effect on fire in treated areas. During the Ham Lake Fire, fire behavior was also apparently reduced by prior fuel treatment areas, but not as extensively. This effect was due, in part, to the absence of (prior to green-up) understory vegetation.

Additional differences could exist between the Ham Lake and Cavity Lake fires. A more detailed comparison, however, is beyond the scope of this assessment.

VI CONCLUSION

Key Findings

Ham Lake Fire

1. Treated areas had evidence of less intense fire behavior and lower severity than untreated areas. Depending on the information source, however, these results varied.

   a) Satellite imagery taken during the end of the fire, before green-up (Burned Area Rehab Map), showed significantly lower severity in areas treated with prescribed fire or mechanically than untreated areas. When areas that had been mapped as having blowdown were separated from those that had not, the treated areas had significantly lower severity than untreated areas mapped with blowdown. Other imagery taken after the fire and green-up (Differenced Normalized Burn Ratio [DNBR] and canopy change maps) showed significantly higher canopy change solely in mechanically treated areas.

   b) Mean crown consumption was lower in treated (35 percent/prescribed fire and 19 percent/mechanical-manual) than in untreated areas (50 percent). High variability in effects and fire characteristics made differences statistically insignificant for areas treated with prescribed fire but significant for those treated mechanically.

   c) Previous monitoring showed a marked reduction in surface fuels due to prescribed fire treatments in blowdown—undoubtedly contributing to less-intense fire behavior and severe fire effects than if left untreated.

2. Treated areas were utilized during suppression along several flanks of the fire.

   a) Mechanically and prescribed fire-treated fuels around the Seagull Guard Station aided in successful structure protection using sprinklers and spot fire attack.

   b) Prescribed fire treatment areas—where fuels had been significantly reduced in blowdown areas—were targeted for suppression burn out operations. Utilizing these pre-treated areas for tactical operations allowed for safe and effective use of fire suppression.

   c) Treated areas near Iron Lake aided successful suppression efforts to constrain eastward progression of the fire toward homes.

Cavity Lake Fire

1. When the fire reached large prescribed fire treated areas, it was extinguished and became readily suppressed with direct attack. Treatments were concentrated to the west of the Gunflint Trail wildland-urban interface area, resulting in stopping the fire's progression toward homes.

2. According to monitoring conducted by the Superior National Forest, soil organic material consumption was reduced in treated areas compared to untreated areas.

Overall

In both fires, treated areas were utilized during suppression that successfully modified fire behavior. Fire behavior was decreased in treated areas to a greater degree during the Cavity Fire in the summer than during the Ham Lake Fire in early spring.

Because the Ham Lake Fire occurred in the wildland-urban interface, nearly all areas with concentrations of blowdown—according to mapping conducted by the state of Minnesota and the Superior National Forest—resulted in less contrast between treated and untreated areas.

Despite the minimal difference in pre-fire fuels between treated and untreated areas (because most concentrations of blowdown were treated), untreated areas had significantly greater fire severity than treated areas.

Observations by firefighters as well as Superior National Forest monitoring data strongly support the belief that without treatment, fire behavior in treated areas would have been much more intense and fast moving.

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VII APPENDICES

Appendix A – Plot Sampling and Protocol

Data was collected in the Ham Lake Fire area during the first week of October 2007 (approximately five months post fire). A combination of transects along roads, trails, and cross-country were sampled. The influence of roads on fire behavior evidence and effects was avoided.

Plot locations along transects were selected systematically (via mileage in a vehicle or pacing on the ground). Plot centers were located using randomly selected bearings or a blind toss of a center marker.

Information Gathered at Each Detailed Plot

At each detailed plot, the following information was gathered.

The location of each plot was recorded with GPS that could be corrected to less than 1m accuracy. A north-facing photo was taken. For trees, a point-center-quarter sample (Mueller-Dombois and Ellenberg 1974) was utilized where the nearest tree in each cardinal direction quadrant was sampled. For each tree, the following was recorded:

- Species,
- An ocular estimate of the percent crown consumption,
- Percent crown scorch,
- Basal scorch on hardwoods top-killed prior to leafout, and
- measured tree height and best estimate of the height to live crown prior to the fire (using an impulse laser to the nearest 0.1m).

Where present, needle color and freeze direction was also recorded. For understory vegetation and soil effects, the National Park Service severity rating system (NPS 2003) was utilized. This rating was determined occularly within a 20-foot radius area. The rating for soil severity was modified to incorporate information on the amount of organic material consumed.

Appendix B – Statistical Analysis

Both general linear model procedures (GLM) (McCullouch and Searle 2001) and cross-tabulation based Chi-Square tests were used to analyze—depending on data type. Continuous data including crown consumption or satellite indices were analyzed using the GLM procedures. Ordinal data (such as soil severity ratings) were analyzed using the Chi-Square tests.

Two different analyses were conducted that used: 1) Plot data, and 2) Satellite-derived severity mapping data.

1. Analysis with Plot Data

For the analysis with the plot data, five different analyses were conducted. Crown scorch and consumption were analyzed with a GLM, where treatment status, mapped blowdown and a spatial component (to account for the spatial autocorrelation were fixed effects. Blowdown was applied as a binary variable with areas The other three indices (soil and understory severity, and fire behavior) were analyzed using a Chi-Square test in a cross-tabulation procedure. Overall, slightly more than 100 plots were sampled (fig. B-1).

A Generalized Additive Model (GAM) was applied to extract the spatial component (Wood, 2006). The spatial component was estimated using with R-mgcv spline smoother (R 6.2.1, 2008) and the pairwise comparisons were done with the SAS GLM procedure (SAS v.9.1.3, 2003). The Bonferroni approach was used for the Post-hoc tests of the pairwise differences between individual land use interacted with the blowdown effect. The other statistical analyses were done using SPSS (Norusis/SPSS Inc. 1999).

2. Analysis with Satellite Data

The satellite data response BARC was analyzed with the same statistical models and estimating techniques as used for the plot data crown scorch response. However, for this response, besides treatment status, mapped blowdown, and a spatial effects, a topographic position as a second degree polynomial variable was included in the statistical model as well. The Akaike AIC criterion (Burnham and Anderson, 2002) was used to select the explanatory variables for the final statistical model. Topographic position was from a continuous index of position in the landscape calculated with ARC-GIS and DEM data mapped by the State of Minnesota with and without blowdown.

Data for the GLM was derived from random pixel selections, stratified by the land status categories. A target of 500 points was randomly selected in each of untreated, recent wildfire, and prescribed burn treatment areas within the Ham Lake Fire perimeter inside the United States. (The fire spread into Canada.) Because the areas treated by mechanical or manual treatments were too limited to allow a selection of 500 points, 150 points was selected. Points that ended up in the same 30m grid cell were eliminated, resulting in slightly fewer than the target number of points in each type (fig. B-2).

Results of Analysis with Plot Data

Solely statistically significant results are shown (table B-2) for crown consumption. No significant differences existed between the indices for fire behavior, soil severity, or understory severity. The greatest number of plots were sampled in areas treated with prescribed fire, followed by untreated areas (table B-1).

Using the AIC criterion, the topographic position variable as explanatory variable did not improve the model. Therefore, it was not included. Overall, significant differences occurred among treatment status categories, as well as where blowdown existed (mapped prior to treatments) (table B-2).

Although mean crown consumption was lower in areas treated with prescribed fire than in untreated areas, only those treated with mechanical or manual treatment were statistically significantly different (table B-3).

There was higher crown consumption in mechanically or manually treated areas, reflecting the (physically) low stature of seedlings on those sites. With crowns close to the ground and flames, this effect was more prevalent in mechanically treated and reforested areas.

Treatment Status	Number of Field Plots
Untreated	38
Prescribed Fire Treatment	46
Mechanical or Manual Treatment	15

Table B-1 – Number of plots per treatment category from field data.

Effect	Degrees of Freedom	F-Statistic	Significance.
SPATIAL	1	15.37	.0002
LCODE	2	6.73	.0019
BLOWDOWN	1	1.54	.2173
LCODE*BLOWDOWN	2	0.28	.7600

Table B-2 – Overall results of GLM (Type 3 Test of Fixed Effects) of crown consumption from field plot data. Location in mapped blowdown from 1999 (BLOWDOWN) was included as a co-variate both individually and as an interaction term with treatment status (LCODE). SPATIAL is the linear combination of spatial components developed by GAM in R. R^2=0.22.

Parameter	Estimate	Standard Error	t-Value	P-value	Bon-ferroni alpha*	Sig-nifi-cance
In Areas not Mapped with Heavy Blowdown Pre-Fire						
Untreated vs Prescribed Fire Treat	-7.3619	10.4860	-0.70	0.484	0.017	No
Untreated vs Mech/Manual Treat	43.7341	15.1553	2.89	0.005	0.017	Yes
Prescribed Fire vs Mech/Manual Treat	51.0960	17.3822	2.94	0.004	0.017	Yes
In Areas Mapped with Heavy Blowdown Pre-Fire						
Untreated vs Prescribed Fire Treat	-13.6079[1]	17.8897	-0.76	0.449	0.017	No
Untreated vs Mech/Manual Treat	25.4209	20.2881	1.25	0.213	0.017	No
Prescribed Fire vs Mech/Manual Treat	39.0288	15.4520	2.53	0.013	0.017	Yes
Overall Results						
Untreated vs Prescribed Fire Treat	-20.9698	21.2234	-0.99	0.326	0.017	No
Untreated vs Mech/Manual Treat	69.1545	25.6231	2.70	0.008	0.017	Yes
Prescribed Fire vs Mech/Manual Treat	90.1248	24.7608	3.64	0.0005	0.017	Yes

**The mean difference is significant at the Bonferroni adjusted alpha level of 0.05/3=0.017 to conform an experimentwise alpha level=0.05.*

[1]The negative sign indicates that percent crown consumption for Prescribed Fire Treat was higher than for Untreated. However, this difference was not statistically significant. Negative values for the estimate (of difference) mean that the second class has greater evidence of severity than the first listed class).

Table B-3 – Pair-wise comparisons of crown consumption by treatment status based on field plots.

Results of Analysis with Satellite Data

A total of 1573 random points were included in analysis of satellite data (table B-4). When areas with recent fire were cropped from the data set—because they were masking and overwhelming the ability to detect differences among treated and untreated areas—the number of points was reduced to 982. The overall significance of the explanatory variables are shown on table B-5. Only the BARC satellite data showed statistically significant differences among different land status categories (table B-6).

Significant differences were also found in areas of the landscape where heavy blowdown had been mapped prior to treatment and the fire. In this portion of the landscape, areas treated with prescribed fire or mechanical/manual treatment had significantly reduced evidence of fire behavior and effects than untreated areas. Because the treatments focused on concentrations of blowdown, there was less difference between treated and untreated areas where concentrations of blowdown were not previously mapped.

Land status	Number of random points
Untreated	494
Recent wildfire	469
Prescribed fire treatment	466
Mechanical/manual treatment	144
Pre-treatment blowdown status	
No mapped blowdown	1166
Mapped blowdown	407

Table B-4 – Number of random points by land status category used in analysis of satellite data.

Effect	Degrees of Freedom	F-Statistic	Significance.
SPATIAL	1	296.70	<.0001
T.POS	1	18.47	<.0001
$T.POS^2$	1	13.67	0.0002
LCODE	2	0.45	0.6365
BLOWDOWN	1	1.28	0.2586
LCODE*BLOWDOWN	2	3.73	0.0242

Table B-5 – Overall results of GLM (Type 3 Test of Fixed Effects) of crown consumption from field plot data. Location in mapped blowdown from 1999 (BLOWDOWN) was included as a co-variate both individually and as an interaction term with treatment status (LCODE). SPATIAL is the linear combination of spatial components developed by GAM in R. T.POS is the topographic position. R^2=0.27.

Classes Contrasted	Estimate	Standard Error	t-Value	Probability (uncorrected for number of comparisons)
In Areas Where High Concentrations of Blowdown Were not Mapped				
Prescribed fire vs Mech/Manual Treated	3.3212	5.1047	0.6506	0.515
Prescribed fire treated vs Untreated	2.1578	2.5470	0.8472	0.397
Manual/mechanical Treated vs Untreated	-1.1633	5.0295	-0.2313	0.817
Prescribed fire or Mech/Manual vs Untreated	0.9945	6.1244	0.1624	0.871
In Areas Where High Concentrations of Blowdown Were Mapped				
Prescribed fire vs Mech/Manual Treated	1.6379	3.8166	0.4291	0.668
Prescribed fire treated vs Untreated	-10.6123*****	4.0435	-2.6245	**0.009**
Manual/mechanical Treated vs Untreated	-12.2502*****	4.7882	-2.5584	**0.011**
Prescribed fire or Mech/Manual vs Untreated	-22.8625******	7.9992	-2.8581	**0.004**
All Areas- Overall				
Prescribed fire vs Mech/Manual Treated	4.95909	6.4099	0.7736	0.439
Prescribed fire treated vs Untreated	-8.4545	4.8349	-1.74862	0.081
Manual/mechanical Treated vs Untreated	-13.4135	6.9494	-1.93016	0.054
Prescribed fire or Mech/Manual vs Untreated	-21.868	10.112	-2.16255	0.031

** The mean difference is significant at the Bonferroni adjusted alpha level of 0.05/3=0.017for an experiment-wise alpha level=0.05. The negative sign indicates that the response for Untreated was higher than for Prescribed Fire Treat.*

***The mean difference is significant at the .05 level.*

Table B6 – Pair-wise comparisons using a Bonferroni test following a GLM analysis.

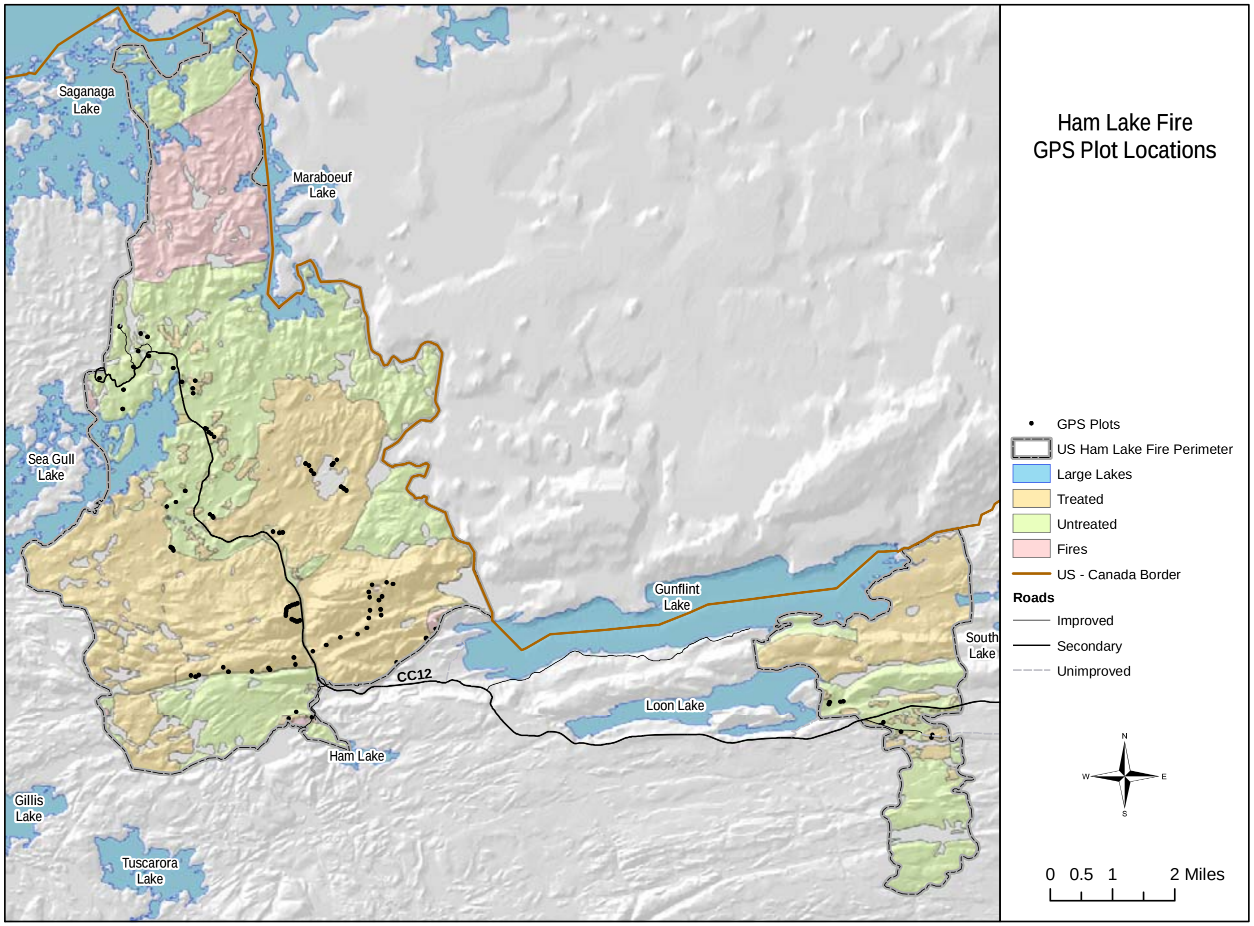

Figure B-1 – Location of field plots sampled in the Ham Lake Fire area.

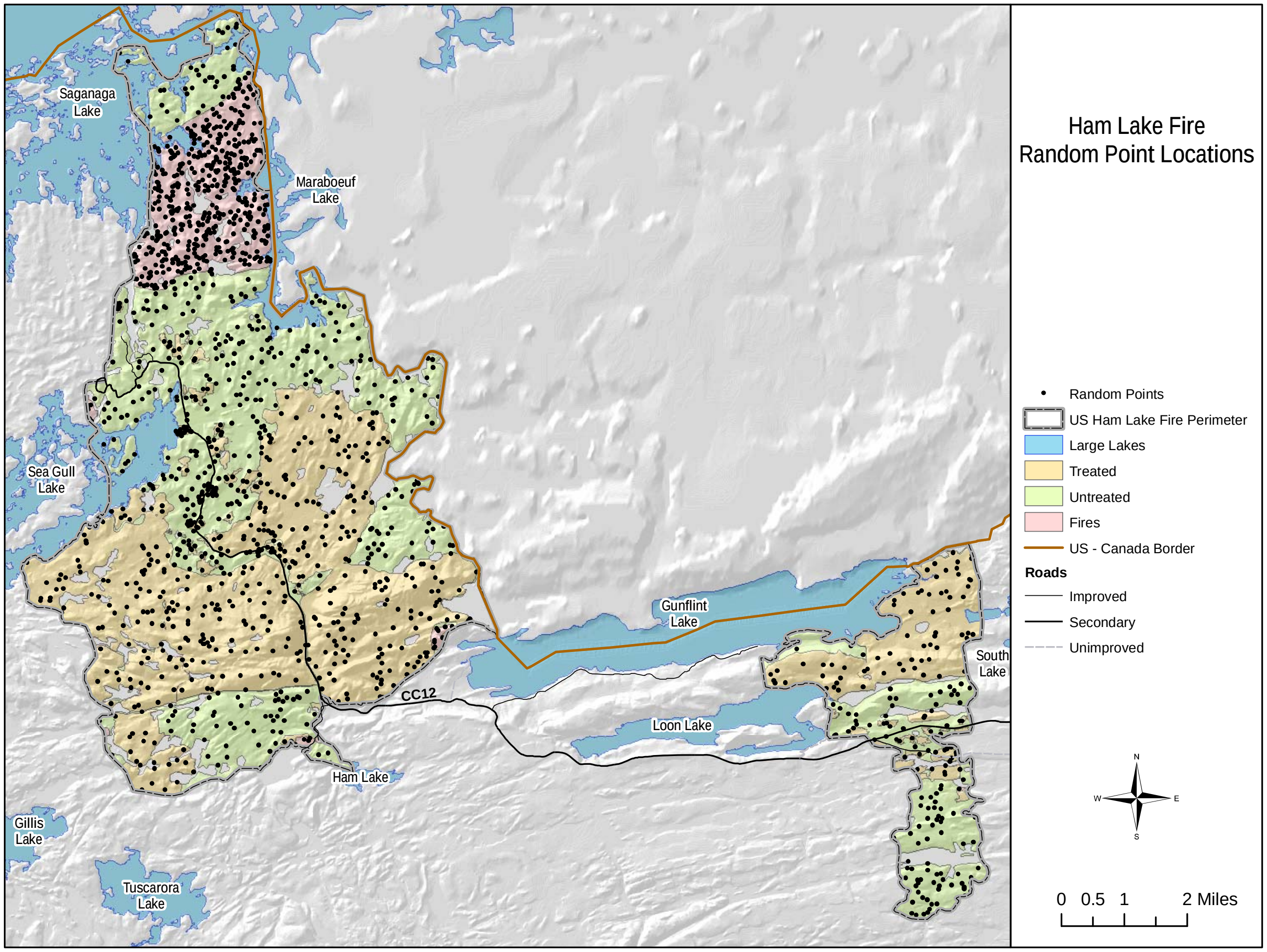

Figure B-2 – Location of randomly selected points for analysis of satellite data.

Appendix C – Weather and Fuel Moisture

Weather data was obtained from the Seagull Remote Automated Weather Station (RAWS) that is located within the Ham Lake Fire area at the Seagull Guard Station along the Gunflint Trail (table C-1, fig. C-1). Fuel moisture levels were obtained from the Superior National Forest (table C-2, fig. C-2).

Table C-1 – Weather data during the Ham Lake Fire from the Seagull Guard Station on the Gunflint Trail, within the Ham Lake Fire Area.

Date/Time	Temper-ature °F	Relative Humidity %	Wind-speed mph	Gusts mph	Direction °	Peak mph	Peak Direction °	Solar radiation W/m*m
5/5/07 0:04	60	18	10	20	107	20	98	219
5/5/07 5:04	53	27	7	15	106	15	114	0
5/5/07 10:04	47	40	9	16	108	16	106	0
5/5/07 15:04	54	31	15	28	102	28	123	462
5/5/07 20:04	56	32	12	28	105	28	126	193
5/6/07 0:04	53	35	11	17	111	17	112	67
5/6/07 5:04	51	33	9	16	125	16	142	0
5/6/07 10:04	50	17	11	25	145	25	128	0
5/6/07 15:04	57	20	13	25	150	25	151	529
5/6/07 20:04	63	18	13	28	162	28	160	448
5/7/07 0:04	63	16	14	27	157	27	153	140
5/7/07 5:04	60	32	16	26	190	26	201	0
5/7/07 10:04	56	38	14	27	194	27	186	0
5/7/07 15:04	61	51	9	15	221	15	226	156
5/7/07 20:04	68	57	10	19	244	19	251	828
5/8/07 0:04	68	54	12	21	245	21	253	224
5/8/07 5:04	54	70	2	5	229	5	277	0
5/8/07 10:04	53	83	6	11	248	11	232	0
5/8/07 15:04	68	43	8	16	280	16	268	639
5/8/07 20:04	78	20	10	22	282	22	264	916
5/9/07 0:04	78	16	5	13	293	13	232	240
5/9/07 5:04	57	52	5	8	160	8	160	0
5/9/07 10:04	44	76	3	5	169	5	155	0
5/9/07 15:04	74	31	3	11	255	11	348	621
5/9/07 20:04	84	16	4	11	297	11	267	693
5/10/07 0:04	80	21	9	18	200	18	198	283
5/10/07 5:04	66	37	11	16	181	16	199	0

Date/Time	Temper-ature °F	Relative Humidity %	Wind-speed mph	Gusts mph	Direction °	Peak mph	Peak Direction °	Solar radiation W/m*m
5/10/07 10:04	62	46	4	10	247	10	248	0
5/10/07 15:04	77	35	12	20	252	20	240	641
5/10/07 20:04	79	32	14	25	336	25	267	874
5/11/07 0:04	70	21	11	21	331	21	340	309
5/11/07 5:04	52	48	7	12	4	12	9	0
5/11/07 10:04	42	66	6	12	46	12	45	0
5/11/07 15:04	50	48	8	14	40	14	34	500
5/11/07 20:04	56	28	7	12	27	12	104	247
5/12/07 0:04	54	38	7	11	187	11	204	100
5/12/07 5:04	46	46	3	7	216	7	15	0
5/12/07 10:04	31	88	1	3	124	3	43	0
5/12/07 15:04	58	30	5	9	227	9	226	649
5/12/07 20:04	66	24	5	14	36	14	295	867
5/13/07 0:04	58	32	9	17	172	17	164	210
5/13/07 5:04	46	51	8	12	155	12	139	0
5/13/07 10:04	47	47	10	16	174	16	175	0
5/13/07 15:04	62	34	9	22	171	22	178	627
5/13/07 20:04	67	30	8	22	161	22	131	860
5/14/07 0:04	57	56	6	15	153	15	129	109
5/14/07 5:04	52	79	7	16	115	16	139	0
5/14/07 10:04	52	94	7	12	110	12	116	0
5/14/07 15:04	64	77	5	12	161	12	73	531
5/14/07 20:04	68	61	6	22	34	22	249	448
5/15/07 0:04	58	77	7	13	325	13	356	54
5/15/07 5:04	55	87	7	12	34	12	350	0
5/15/07 10:04	47	90	4	12	31	12	59	0
5/15/07 15:04	46	89	8	22	29	22	60	189
5/15/07 20:04	48	78	9	15	18	15	27	129

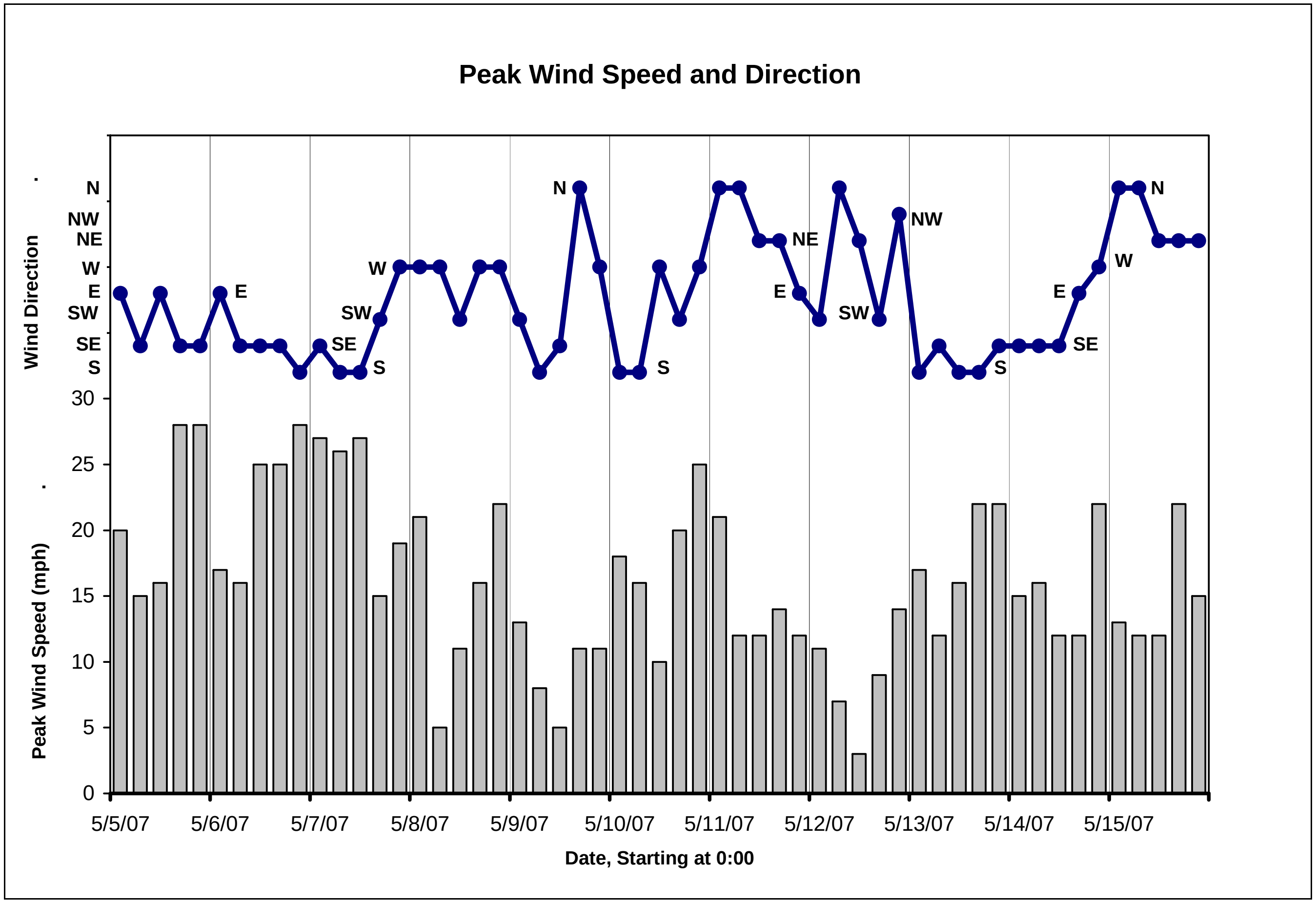

Figure C-1 – Maximum wind gusts and direction recorded from the Seagull Weather Station during the duration of the Ham Lake Fire.

Table C-2 – Fuel moisture levels from the 2007 fire season by location and fuel type (for instance, 1-hour or live foliar moisture).

DATE	LOCATION	SPECIES	1 HR	10 HR	100 HR	1000 HR	LIVE
4/17/2007	Seagull	Jack Pine				22%	
4/17/2007	Seagull	Jack Pine				37%	
4/17/2007	Caribou Rock	Red Pine				23%	
4/17/2007	Caribou Rock	Red Pine				30%	
4/17/2007	Isabella	Spruce				30%	
4/29/2007	Devil Track	Spruce	6%			26%	
4/29/2007	Devil Track	Aspen	8%			33%	
4/29/2007	Devil Track	Red Pine					185%
4/30/2007	Caribou Rock	Balsam	10%	14%		16%	
4/30/2007	Caribou Rock	Birch	12%	150%	39%	52%	
4/30/2007	Caribou Rock	Red Pine					104%
4/30/2007	Midtrail	Jack Pine					98%
5/9/2007	Lima Grade	Jack Pine					107%
5/9/2007	Caribou Rock	Red Pine	9%		11%	15%	
5/9/2007	Caribou Rock	Balsam	4%	11%			
5/9/2007	Caribou Rock	Birch	6%	28%		38%	
5/9/2007	Caribou Rock	Aspen				31%	
6/2/2007	Caribou Rock	Birch	16%			38%	
6/2/2007	Caribou Rock	Balsam	14%				82%
6/2/2007	Caribou Rock	Red Pine	15%			22%	93%
6/2/2007	Midtrail	Jack Pine					153%
6/2/2007	Devil Track	Balsam	16%			54%	78%
6/2/2007	Devil Track	Birch	16%				
6/2/2007	Devil Track	Red Pine					86%
6/9/2007	Wanless Rd.	Birch	17%			36%	
6/9/2007	Wanless Rd.	Balsam	10%			42%	77%
6/9/2007	Wanless Rd.	White Pine					87%
6/9/2007	Blue Moon	Birch	21%			30%	
6/9/2007	Blue Moon	Spruce	9%			21%	
6/9/2007	Blue Moon	Balsam					83%

DATE	LOCATION	SPECIES	1 HR	10 HR	100 HR	1000 HR	LIVE
6/15/2007	Pine Mt. Rd.	Spruce	9%	17%	23%	19%	
6/15/2007	Pine Mt. Rd.	Aspen	9%	10%	18%	20%	
6/15/2007	Pine Mt. Rd.	Balsam					79%
6/15/2007	Pine Mt. Rd.	White Pine					94%
7/1/2007	Caribou Rock	Balsam	11%	14%	12%		139%
7/1/2007	Caribou Rock	Birch	13%	16%	32%	42%	
7/1/2007	Caribou Rock	Red Pine	13%			21%	100%
7/7/2007	Wanless Rd.	Birch	9%	19%	53%	38%	
7/7/2007	Wanless Rd.	Balsam	8%	13%	16%	23%	111%
7/7/2007	Wanless Rd.	White Pine					98%
8/8/2007	Caribou Rock	Balsam	14%	13%	14%		
8/8/2007	Caribou Rock	Birch	10%	15%	29%	37%	
8/8/2007	Caribou Rock	Red Pine	11%	18%	15%	21%	110%
8/8/2007	Midtrail	Jack Pine					130%
8/20/2007	Pine Mt. Rd.	Birch	14%				
8/20/2007	Pine Mt. Rd.	Balsam	11%			49%	129%
8/20/2007	Pine Mt. Rd.	Aspen				14%	
8/20/2007	Grand Portage	Jack Pine	11%	14%			93%
8/20/2007	Grand Portage	Red Pine				28%	
8/20/2007	Grand Portage	Aspen	12%	14%		20%	
8/30/2007	Crocodile	Birch	20%	21%	37%	55%	
8/30/2007	Crocodile	Spruce	16%	23%	21%	26%	
8/30/2007	Crocodile	Balsam					126%
8/30/2007	Caribou Rock	Red Pine	15%	57%	30%	21%	108%
8/30/2007	Midtrail	Jack Pine					121%

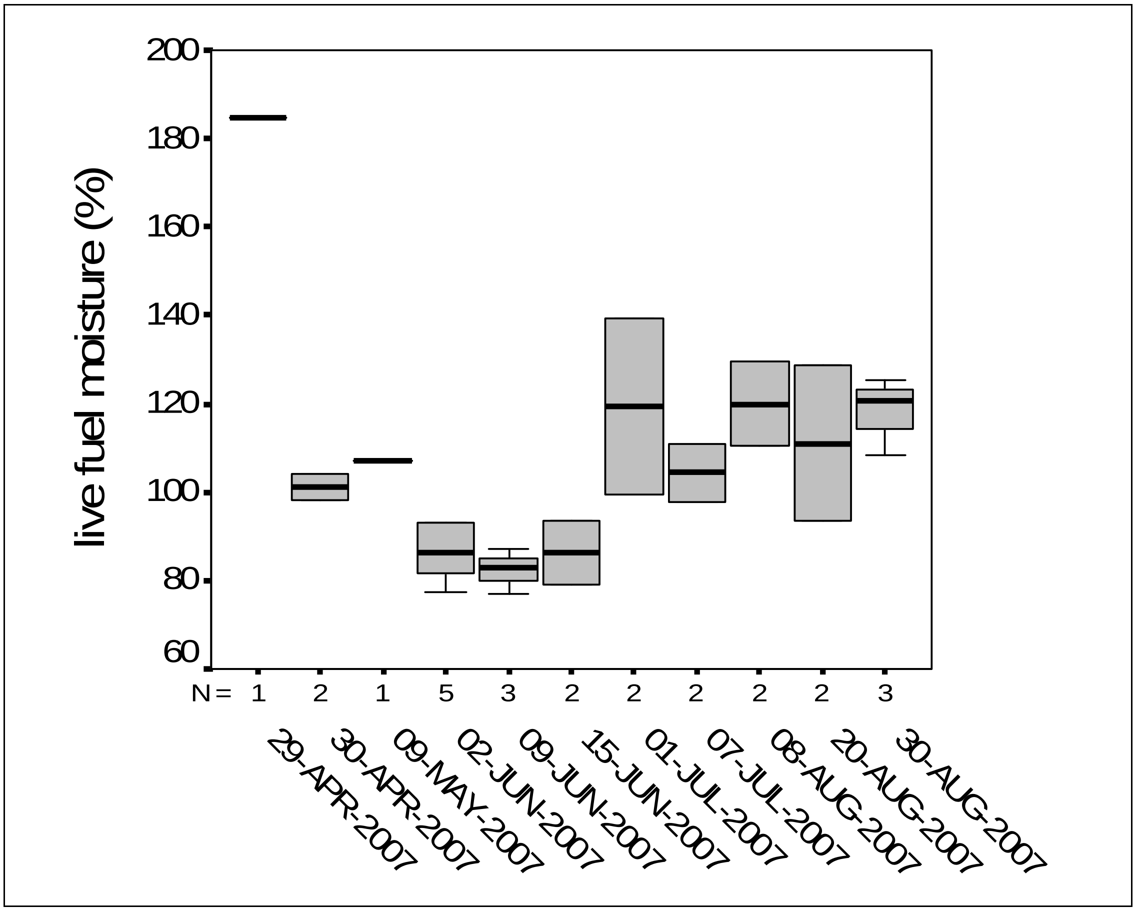

Figure C-2 – Box plot of live fuel moistures collected from conifer trees on the Superior National Forest throughout the 2007 fire season. The box plots depict the median with the horizontal black line the 25th and 75th percentiles as the bottom and top of the gray boxes, respectively.

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