United States Department of Agriculture
Forest Service

North Central Research Station

Research Note NC-381
2003

Alternative Fuel Reduction Treatments in the Gunflint Corridor of the Superior National Forest:

Second-year Results and Sampling Recommendations

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ABSTRACT.—Fuel loadings need to be considered in two ways: 1) the total fuel loadings of various size classes and 2) their distribution across a site. Fuel treatments in this study affected both. We conclude that 1) mechanical treatments of machine piling and salvage logging reduced fine and heavy fuel loadings and 2) prescribed fire was successful in reducing fine fuel loadings (fuels less than 3 inches in diameter) but less successful than salvage logging and mechanical piling in reducing heavy fuel loadings (fuels greater than 3 inches in diameter).

KEY WORDS: Fuel reduction, prescribed burn, salvage harvest, silviculture, wind disturbance.

Figure 1.—*Untreated jack pine blowdown.*

On July 4, 1999, unprecedented thunderstorm downbursts, also known as derechos (wind speeds of 75 to 110 mph), caused wind damage to approximately 477,000 acres of sub-boreal forest in the Superior National Forest, including the Boundary Waters Canoe Area Wilderness and adjacent Gunflint Corridor (fig. 1). To reduce the risk of wildfire and protect the public, four management alternatives were considered with varying degrees of management intensity. After extensive public review, the management alternative selected for implementation by the USDA Forest Service includes three fuel reduction treatments on 4,714 acres in the Gunflint Corridor: (a) prescribed burning, (b) salvage harvesting, and (c) piling of down trees with and without burning (USDA Forest Service 2000). The purpose of this paper is to provide second-year results on the efficacy of these fuel reduction treatments and provide recommendations for future sampling in similar situations.

METHODS AND MATERIALS

Study Area

The Gunflint Corridor of the Superior National Forest is surrounded by the Boundary Waters Canoe Area Wilderness in northeastern Minnesota (fig. 2). Latitude ranges from 48° 00′ to 48° 05′ and longitude ranges from 90° 25′ to 90° 55′. Climate is mid-continental with

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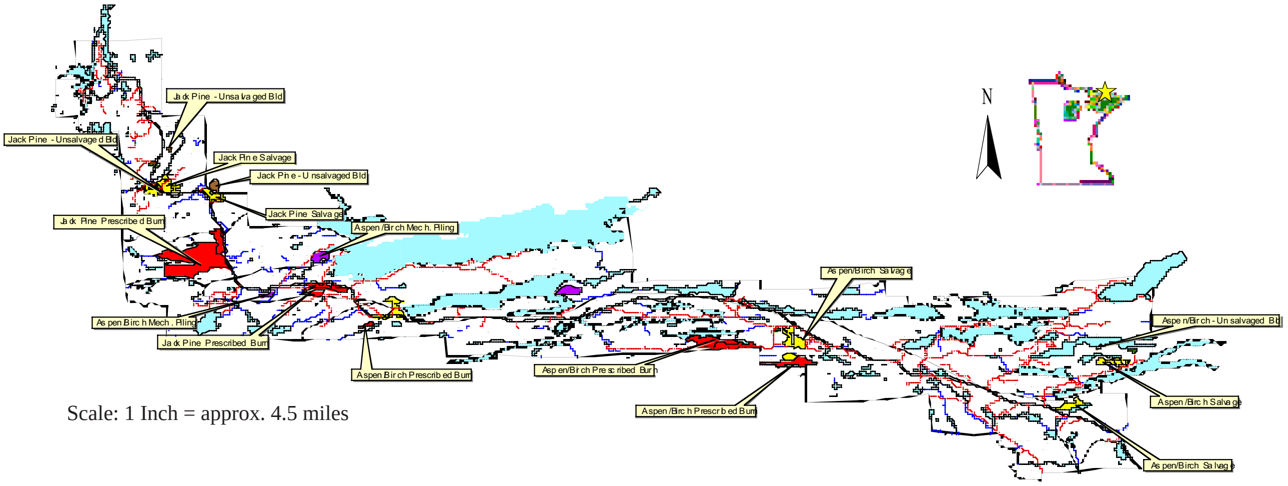

Figure 2.—*Location of study sites in the Gunflint Corridor, Superior National Forest, Minnesota.*

relatively long, cold winters and warm summers. Mean annual precipitation is around 28 inches and temperature ranges between -46˚ F and 100˚ F (Ahlgren 1969). The mean annual temperature is 36˚ F with mean July and January temperatures of 62˚ F and -5˚ F, respectively (Baker and Strub 1965). The soils of the area are characterized by grayish brown tills, outwash, and lacustrine deposits from the Rainy glacial lobe of the Laurentide Ice Sheet. Depth to bedrock, an import factor in determining species composition and productivity, varies from several inches to greater than 40 inches with numerous rock outcrops (USDA Forest Service 2001). Ecosystems are fire dependent relying on periodic fire to “drive nutrient cycling, energy pathways, and help maintain the diversity, productivity, and long-term stability of the ecosystem” (Heinselman 1973). Historical tree species composition on the landscape included jack pine (*Pinus banksiana*), eastern white pine (*P. strobus*), red pine (*P. resinosa*), black spruce (*Picea mariana*), white spruce (*P. glauca*), balsam fir (*Abies balsamea*), paper birch (*Betula papyrifera*), and trembling aspen (*Populus tremuloides*).

The percent composition of these species has changed over the last 100 years due to fire suppression, timber harvesting, and other natural disturbances such as wind and insect outbreaks (Frelich and Reich 1998). In the pre-fire suppression era, the interaction between the disturbances of fire, wind, and insect outbreaks occurred frequently. The jack pine cover type still covers a large proportion of the landscape, but the white pine and red pine cover types have been shrinking as the area occupied by the aspen/birch cover type has continued to increase (Freidman and others 2001).

Data Collection

The umbrella experimental design for the project included two factorial levels of cover types (aspen/birch or jack pine), and fuel reduction treatments: non-blowdown control, blowdown-control, prescribed burn (fig. 3), salvage harvest (fig. 4), and machine piling (fig. 5). Material piled in the machine piled treatment is scheduled for burning in future years. Plots were established using a systematic grid pattern modified to fit within stand boundaries (Gilmore and others 2002). Assuming a square

Figure 3.—*Prescribed burning.*

Figure 4.—*Salvage harvested blowdown.*

Figure 5.—*Machine piled treatment.*

grid pattern, this represented a 5- to 8-ac sampling area per stand. Plots were located in areas where severe wind throw (67 to 100 percent wind damage) had occurred and where fuel reduction treatments were most likely to be implemented (USDA Forest Service 2000).

A planar intersect sampling method was used to inventory fuel loadings (Brown 1974). The method is rapid, easy to use, and applicable to naturally fallen debris and slash. In brief, 52.5 ft fuel sampling transects were established across permanent 0.05 ac plots installed using a systematic grid pattern as part of a long-term monitoring program (Gilmore and others 2002). The 52 ft transects included two smaller nested transects to measure diameter classes that correspond to 1 hr, 10 hr, and 100 hr average moisture time lag classes for many wood materials incorporated into the National Fire-Danger Rating System. In the first 6.5 ft of each transect, 1 hr (0 to 0.25 in. diameter) and 10 hr (0.25 to 1.0 in. diameter) fuels and larger were tallied. In the first 13 ft of each transect, 100 hr (1.0 to 3.0 in. diameter) fuels and larger were tallied. Total fine fuels were the sum of the 1 hr, 10 hr, and 100 hr fuels. Fuels greater than 3.0 in. in diameter—1,000 hr fuels or heavy fuels—were measured along the entire transect.

Diameter, condition class (sound, rotten), timing of fall (before or after July 4, 1999), and life stage (dead or alive) were recorded for 1,000 hr fuels only. At 16.4, 19.7, 32.8, and 36.1 ft intervals along each transect, duff and litter depths were recorded. Height of the fuel above the ground was measured at the maximum aboveground height within each of the following categories: 0 to 12 in., 12 to 24 in., and 24 to 36 in.

Data Analyses

Field data were converted to tons ac^{-1} using techniques described by Brown (1974). In brief, tons ac^{-1} of fine fuels were estimated with the equation:

$$\text{tons ac}^{-1} = (11.64 \bullet n \bullet d^2 \bullet S_g \bullet a \bullet c)/(N \bullet l)$$

where

n = total tally of pieces for size class

d^2 = average diameter class squared in imperial units of measure (0.0151 in^2; 0.289 in^2; 2.76 in^2)

S_g = specific gravity

a = nonhorizontal angle correction factor

c = slope correction factor

N = number of transects

l = transect length in feet

Tons ac^{-1} of heavy fuels were estimated with the equation:

$$\text{tons ac}^{-1} = (11.64 \bullet n \bullet \Sigma d^2 \bullet S_g \bullet a \bullet c)/(N \bullet l)$$

where all variables are previously defined except that Σd^2 represents a sum of the actual squared diameters.

Two-factor analyses of variance (ANOVAs) were used to test for differences in fuel loading between cover types and treatment. ANOVAs were performed using the general linear model:

$$Y = CT + TRT + CT{*}TRT + \varepsilon$$

where

CT = forest cover type (aspen-birch or jack pine)
TRT = fuel reduction treatment (none, prescribed burn, salvage logging, machine piling)
CT*TRT = the interaction term
ε = error NID~ $(0,\sigma^2)$.

The mechanical piling treatment was not duplicated in the jack pine cover type; thus, to balance the ANOVA, this treatment was excluded from all ANOVAs. SYSTAT (SPSS, Inc. 2000) was used for all statistical analyses.

RESULTS AND DISCUSSION

Average fuel loadings by cover type and fuel reduction treatment are presented in table 1. Separate ANOVAs testing the effects of cover type and fuel reduction treatment on the alternative fuel reduction treatments did not detect any interaction between cover type and treatment (table 2). The main effects of cover type and treatment on total fine fuels did not differ among cover types but were affected by treatment. Heavy fuels (> 3 in. diameter) were influenced by treatment. Total (combined fine and heavy) fuel loadings were affected by both cover type and treatment.

Because our sample plots were semi-permanent and our data are from repeated samples at the same location, our results were influenced by lack of uniformity within treatments. As expected there were fire skips in prescribed burns, areas that were not harvested or slash piles in the salvage logging, and piles of downed material were placed on seven of the sample transects in the mechanical piling

Table 1.—*Average fuel loadings, standard error of the mean (SE), standard deviation of the sample (SD), lower and upper confidence limits (LCL and UCL at a 95 percent confidence interval) by fuel reduction treatment and classes and by forest cover type*

		Aspen-birch cover type						**Jack pine cover type**					
Treatment	**Fuel class**	**N**	**Average tons ac^{-1}**	**SE**	**SD**	**LCL tons ac^{-1}**	**UCL tons ac^{-1}**	**N**	**Average tons ac^{-1}**	**SE**	**SD**	**LCL tons ac^{-1}**	**UCL tons ac^{-1}**
None	1 hr	60	1.12	0.147	1.140	0.83	1.41	60	1.16	0.133	1.035	0.90	1.43
	10 hr	60	3.37	0.415	3.216	2.54	4.21	60	2.92	0.336	2.606	2.25	3.59
	100 hr	60	3.17	0.453	3.511	2.27	4.08	60	2.28	0.281	2.182	1.71	2.84
	Total fine	60	7.68	0.831	6.437	6.01	9.34	60	6.37	0.600	4.649	5.17	7.57
	Heavy fuels	60	33.04	3.181	24.641	26.67	39.40	60	31.45	3.329	25.793	24.79	38.11
	Total fuels	60	40.72	3.500	27.112	33.71	47.72	60	37.82	3.682	28.520	30.46	45.19
Prescribed burn	1 hr	30	0.70	0.133	0.731	0.43	0.98	5	0.25	0.041	0.092	0.14	0.36
	10 hr	30	2.14	0.312	1.713	1.50	2.78	5	1.05	0.222	0.497	0.43	1.67
	100 hr	30	3.05	0.685	3.754	1.65	4.45	5	3.87	0.431	0.963	2.68	5.07
	Total fine	30	5.90	0.804	4.405	4.25	7.54	5	5.19	0.662	1.482	3.34	7.03
	Heavy fuels	30	26.42	2.60	14.259	21.09	31.74	5	45.59	9.381	20.977	19.54	71.63
	Total fuels	30	32.32	2.910	15.943	26.36	38.27	5	50.78	9.629	21.532	24.04	77.51
Salvage harvest	1 hr	32	0.84	0.116	0.656	0.60	1.08	26	0.93	0.139	0.710	0.64	1.21
	10 hr	32	3.30	0.455	2.579	2.37	4.23	26	2.54	0.351	1.790	1.82	3.26
	100 hr	32	4.24	0.613	3.471	2.99	5.49	26	1.90	0.379	1.934	1.12	2.68
	Total fine	32	8.39	1.022	5.782	6.30	10.47	26	5.38	0.778	3.967	3.78	6.98
	Heavy fuels	32	21.15	4.184	23.668	12.61	29.68	26	18.68	3.512	17.911	11.45	25.92
	Total fuels	32	29.54	4.229	23.927	20.91	38.16	26	24.07	4.148	21.153	15.52	32.61
Mechanical piling	1 hr	32	1.30	0.204	1.158	0.88	1.71						
	10 hr	32	4.15	0.675	3.818	2.77	5.53						
	100 hr	32	6.43	1.104	6.249	4.17	8.68						
	Total fine	32	11.88	1.636	9.259	8.54	15.22						
	Heavy fuels	32	78.05	30.388	171.901	16.08	140.03						
	Total fuels	32	89.64	30.928	174.956	89.94	956.73						

Table 2.—*Results of Analysis of Variance (ANOVA) testing the effects of cover type (CT), fuel reduction treatment (TRT), and their interaction (CT*TRT) on fuel loadings per fuel size class in the Gunflint Corridor of the Superior National Forest*

	P-values for effects from ANOVAs		
Fuel size class	**CT**	**TRT**	**CT*TRT**
1 hour	0.553	0.012	0.554
10 hour	0.123	0.069	0.861
100 hour	0.170	0.556	0.121
Total fine fuels	0.100	0.551	0.550
1,000 hour sound	0.130	0.011	0.229
1,000 hour rotten	0.054	0.001	0.156
Total heavy fuels	0.255	0.001	0.192
Total fuel loading	0.048	0.005	0.206

Note: Analyses excluded the mechanical piling treatment because there was no replication in each cover type.

treatment. Only two aspen-birch stands for which we had pre-burn data actually had prescribed burns implemented and two aspen-birch stands had mechanical piling treatments implemented. We had no pre-burn data for any jack pine stands but did have post-burn data for five transects.

Figures 6 through 8 show the variability in fuel loading at our sample plot locations in greater detail. Pre-treatment data and data from plots where no treatments were planned were combined in the construction of table 1 and in the data set used for all ANOVAs to test the effects of cover type and treatment on fuel loadings. Some pre-treatment data were compared to post-treatment data in figure 8. Therefore, data are presented differently in figures 6 through 8 than in the formal ANOVAs. Pre-treatment data and data from locations where no treatments were planned were separated in the construction of all figures but not in the ANOVAs.

The treatments removed and redistributed the fuels throughout the study sites. It would be misleading to look at site averages without explaining what happened to individual plots. Perhaps the best way to illustrate this point is by using the machine piling treatment as an example. This fuel reduction treatment simply rearranged the blowdown trees from a more or less uniform distribution to a highly aggregated or clumped distribution—the piles. This is indicated by the large standard deviation in this treatment relative to the other treatments (table 1). When all of the post-treatment fuel transects were included in the site average, the total fine and heavy fuel loadings were greater than the untreated control (fig. 6a). If we exclude the seven fuel transects that included the piled fuel from the data, the post-treatment fuel loadings are different in that total fine and total fuel loadings are reduced (fig. 6b). These differences also occurred in the salvaged logged treatment, but they were less pronounced as indicated by the standard deviation of the samples and in a graphical depiction of the data (table 1; figs. 6a, b). The jack pine site had a prescribed burn treatment as opposed to the mechanical piling, but similar patterns are evident in the salvage logged treatment (figs. 7a, b). All transects in the prescribed burn

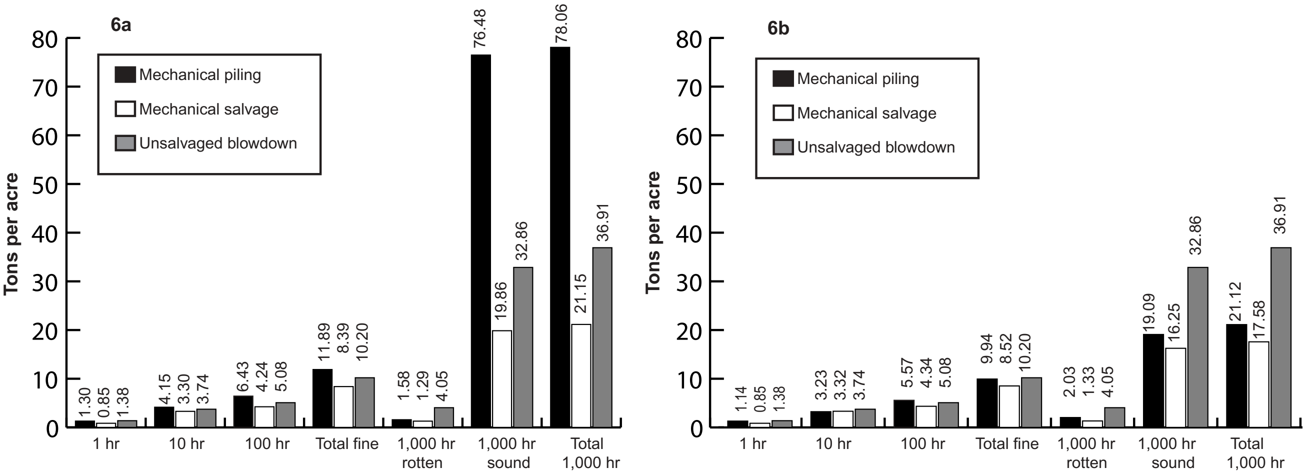

Figure 6.—*Average plot (a) and affected plot (b) fuel loadings by size class in the aspen-birch cover type for two fuel reduction treatments. Data were collected from aspen-birch stands indicated in figure 2.*

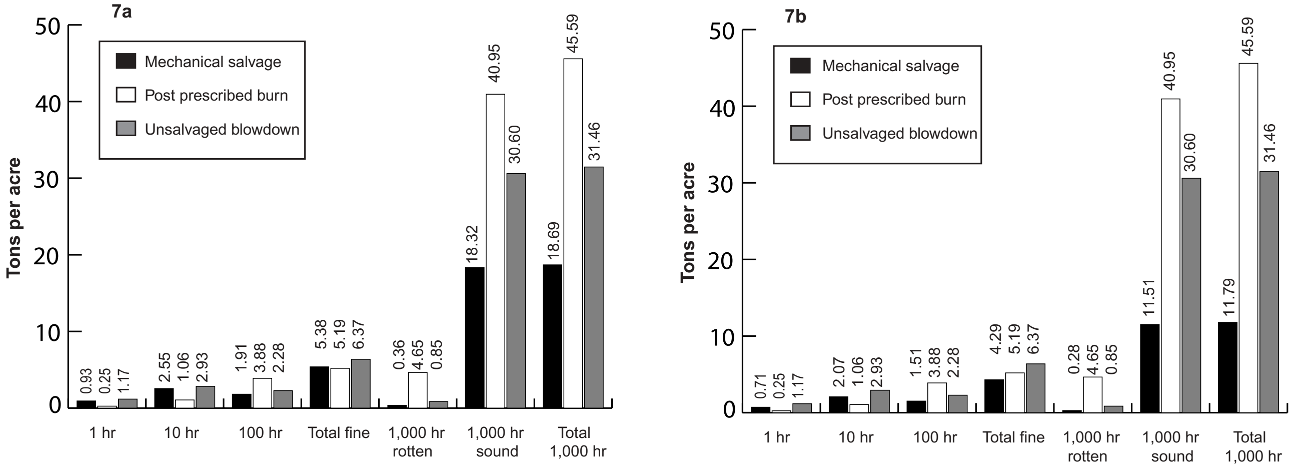

Figure 7.—*Average plot (a) and affected plot (b) fuel loadings by size class in the jack pine cover type for two fuel reduction treatments. Data were collected from jack pine stands indicated in figure 2.*

sites (five total) were affected so there are no differences in fuel loadings for the prescribed burn treatment in figures 7a and 7b.

The effect of the prescribed burn treatment in the aspen-birch cover type is illustrated in figure 8 using pre- and post-treatment data collected from permanent fuel sampling transects at two sites. Fifteen of the thirty permanent sampling transects were affected by the prescribed burn. It is important to note, however, that at some points along various transects not all size classes were affected. When all post-treatment data were averaged, total fine fuel loadings increased because of our multi-year sampling scheme and the continued wind throw of residual trees (fig. 8a). Trees falling across sampling transects after the burn would increase fuel loadings. If we examine transects that were burned to some degree only (fig. 8b), fine fuel loadings were decreased. The prescribed burn treatments were successful in that the easily combustible fine fuel loadings were reduced (figs. 7b, 8b). The salvage harvest treatment, however, was more effective in reducing fine and heavy fuel loadings (figs. 6 and 7).

Statistical power is the probability of non-rejection of a false hypothesis (Type II error) and is a concern when statistical differences are not detected in ANOVAs. In such instances, statisticians recommend re-evaluation of an experiment in order to determine if a larger sample size is needed. Using the variance displayed for the combined fine and heavy fuels data, preliminary estimates of the sample size required to detect differences in total fuel loadings between cover types and treatments exceed 7,200 fuel

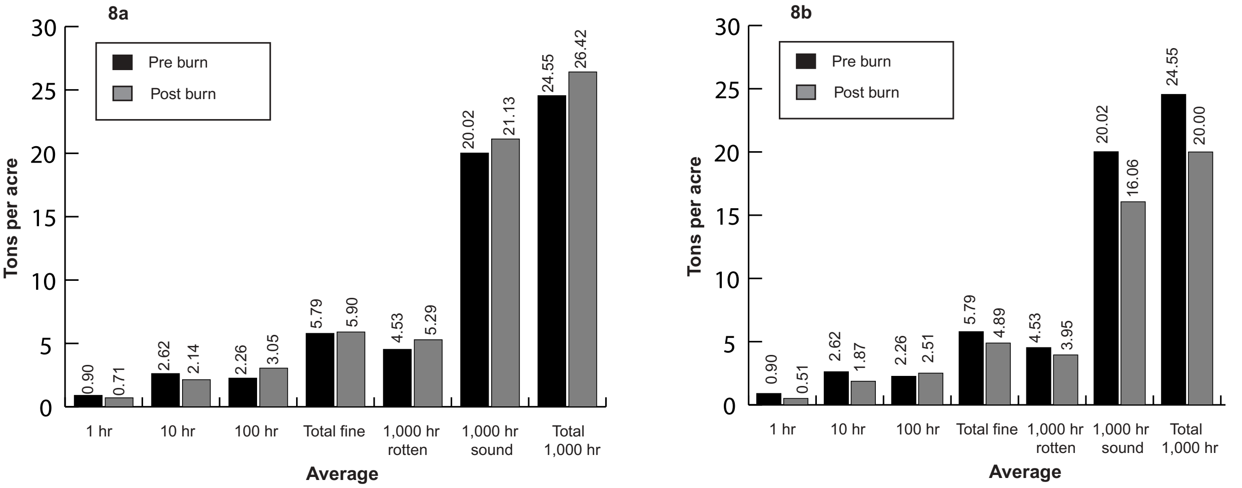

Figure 8.—*Composition of before and after fuel loadings by size class for average (a) and affected (b) plots in two stands in the aspen-birch cover type.*

transects. Resources do not allow this intensity of sampling. ANOVAs are used to test for statistical differences between one or more treatments. This is of interest in an experimental context. Variation of mean fuel loading, expressed by the standard error (SE) of the mean, values per transect is a measure of variation incorporated in ANOVAs. A clearer depiction of variation between samples can be expressed by the simple statistic, the standard deviation (SD) of the sample (table 1). Consider the SD for total fine and heavy fuels (table 1). The total fine fuel SDs are relatively similar between the four treatments indicating that although these fuels are obviously affected by treatments, their spatial distribution is similar. The heavy fuels, on the other hand, were more variable due almost entirely to the piling treatment.

From a pragmatic perspective, however, the question "how many fuel transects are necessary?" often arises for a given site. To our knowledge there has been little work to provide guidance on the number of samples needed to obtain fuel loading estimates for the following treatments in this study. Therefore, we summarize sampling intensity recommendations made by others.

The *USDA Forest Service Handbook for Inventorying Downed Woody Material* (Brown 1974) recommends 15 to 20 sampling transects per location. The Canadian Forest Service (Taylor 1997) recommends a minimum of 15 sampling transects per location. In a seminal paper on the design of fuel sampling inventory procedures Van Wagner (1968) referred to by Brown (1994) and Taylor (1997), recommends 20 sampling transects per location. All of these references consider a sample location to be homogenous, a criterion that is particularly important in post-treatment assessment analyses. It is not possible to precisely determine or predict which sample transect will be included in salvage harvesting and mechanical piling treatments. Prescribed burning treatments are less predictable in their uniformity and intensity (fig. 9). We illustrate the impact of averaging or separating transects affected by fuel reduction treatments in figures 6 through 8. The permanent nature of our sampling transects incorporated into our study design (Gilmore and others 2002) in most instances precluded an adequate post-treatment sampling intensity, particularly in the prescribed burns. The issue surrounding the spatial location of sampling transects can be resolved by using temporary sampling transects. Forest managers can use temporary sampling transects to compare pre- and post-treatment fuel loading conditions by locating approximately the same number (15 to 20) of sampling transects in treated and untreated locations throughout a treated site.

Figure 9.—*Illustration of the spatial variation in the prescribed burn treatment and fuel consumption patterns.*

ACKNOWLDGEMENTS

Staff from the LaCroix Ranger District of the Superior National Forest provided insightful comments on the use and application of the results of this study. Patty Johnson, Fuels Planner, and Myra Theimer, Silviculturist of the Gunflint Ranger District of the Superior National Forest, and Chris Woodall, Inventory Forester, St. Paul provided technical review. Denise D. Plonis, of the University of Minnesota, North Central Research & Outreach Center, assisted with manuscript preparation.

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