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SUMMARY & DELIVERABLES.

There were four broad objectives stated in the original proposal. With the modification of the number of treatments evaluated, all objectives were met. However, the range of soil impacts assessed is less due to the illness of my Co-PI, Clive David – he had to take a medical retirement in March, 2004 and was unable to help with the project after Sept., 2003. Furthermore, most of the infiltration data were lost when he moved out of his office. Briefly, the answer to these four questions are:

1) The low intensity strip-head fire brought about modest reductions in the fuel load. The Herbicide+Mechanical treatment reduced the litter layer to the same approximate degree as the prescribed burns, but caused a notable *increase* in woody fuels – primarily fuel pieces less than 7.6cm diameter.
2) Low-to-moderate intensity fire can be used safely and for a variety of purposes in this [mesic white pine] forest type. The key determinant of severity is probably the moisture level of the lower half of the litter layer, and in 1000-hr fuels.
3) Prescribed fires implemented by Menominee Tribal Enterprises in the late 1990's caused an unacceptable level of overstory mortality, presumably because of high residence times in the thicker-than-average litter (and perhaps some duff) that has built up around the base of large pines due to fire exclusion for 100+ years. We documented that moderately high temperatures (> 530° C) are generated *within* the litter layer, but that removal of the fresh litter largely prevented combustion around the pines. The four burns conducted as part of this study *did not cause* any increase in overstory mortality.
4) A range of effects on the vegetation and soil were documented, with much greater effects, in general, on the vegetation. The prescribed burns had moderately strong effects on the hardwood sapling layer and the understory stratum. Arboreal seedling composition was largely unaffected by the fires and Herbicide+Mechanical treatments. Given the intensity of the burns, the magnitude of the impact on herb-layer cover was striking. Very large changes occurred in the second year after treatment and we cannot tell how long it might take for the understory to 'recover' to a state similar to pre-treatement conditions.

<u>Deliverables</u>. The products that we have produced include 1) a completed masters thesis by Betsy Galbraith (2005); 2) a tri-fold brochure for use with the general public; 3) a tri-fold brochure for use with resource managers; and 4) a web site (www.uwsp.edu/forestry/fireresearchproject.htm) that describes the basic methods and important results. In addition, results from the study served as the basis for a number of presentations in a variety of venues. Students at UWSP used the first- year understory response data and the second-yr soil nutrient data for presentations at the UW-Stevens Point, College of Natural Resources Undergraduate Research Symposium in 2003 and

2004. B. Galbraith presented the pre-treatment understory data at the Ecological Society of America annual meeting in 2002. J. Cook made a presentation on the forest management implications to the UW-SP Student Chapter of the Soc. Amer. Foresters in April, 2005. Cook also presented at the North American Forest Ecology Workshop (June, 2005) in Ottawa, Canada, on fire effects on the understory.

Manuscripts. J. Cook and B. Galbraith have a complete draft of a manuscript on fire behavior variation that will be submitted to International Journal of Wildland Fire by 8-31-05. J. Cook, N. Jensen and B. Galbraith have a manuscript on fire effects (approximately 70% complete) on vegetation that will be submitted by 10-15-05 to Canadian Journal Forest Research. This opportunity is available due to the presentation by Cook at the N. American Forest Ecology Workshop in June, 2005. B. Galbraith and J. Cook plan to submit a manuscript to the Canadian Journal of Botany on the seed bank component of Galbraith's thesis.

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I. STUDY OBJECTIVES

As stated in the original proposal, the general objectives for this study were :

1. How do three site preparation treatments affect fuel loading in this system?

2. How should fire be implemented to aid in the management of an important forest resource?

3. Why are the eastern white pine on Menominee lands suffering extensive damage from fires that they should be able to readily withstand?

4. Are there important ecological effects when fire is re-introduced to this largely neglected system?

Because we did not have the burning window we needed in 2002 or 2003, only one prescribed burn treatment was included in the study. This resulted in an additional year of pre-treatment data. This had several positive effects in that we could collect a greater breadth of data and a more in-depth foundation from which the treatments could be evaluated. Two examples of the additional types of data we have generated are 1) evaluation of the density and composition of the seed bank, and 2) detailed analysis of the treatment impacts on the early growing season understory layer.

II. OVERVIEW of DESIGN and METHODS

A. STUDY SITES

Our study site were two 140-year old white pine stands on the Menominee Reservation in northeastern Wisconsin, USA. The even-aged forests had an average overstory diameter at breast height (dbh) of 40.6 cm and 26.3 m^2 basal area per hectare; 87% of which was pine (Table 1). The original proposal called for three treatments and a control; one of the prescribed fire treatments (Mechanical + Backing Fire) was not accomplished because of the limited burning window in this region and because it requires very dry conditions to get a backing fire to burn readily through these mesic forests.

B. FIELD METHODS

<u>Experimental Design.</u>

Four, 0.81 hectare burn units were established within one stand in Compartment 219. Three other units that would have been burn are also in this compartment; they became additional controls. Nested within the burn treatment was a ‘litter removal’ treatment. Five-to-six treated (litter raked away) and control (no raking) overstory pine were randomly selected in each burn unit. This sub-treatment was a test of heat generation in the litter layer and an assessment of the suitability of fuel removal as a means to protect residual seed trees. Four units for herbicide plus mechanical (M+H) treatment were established in Compartment 344; immediately adjacent were two controls. An additional pair of control units was also set up about 1 km from the M+H units.

A minimum of 20 m separated adjacent treatment units to provide a buffer. The overstory was cut to 70% (Compt. 344) or 55% (Compt. 219) canopy cover 10 years prior; slash from these harvests was left in place. We collected data using a 15.2 x 15.2 m grid (four rows with four posts/row) in the center of each unit. A metal post was driven in the ground at each grid point to provide permanent sampling locations.

<u>Treatments</u>

Prescribed fires were completed within four units on April 29, 2003, with ignition of the first unit at 12:30 pm [Unit 2]. The other units were burned in the order 3, 1 and then 4, with the ignition of Unit 4 beginning at 6:40 pm. A strip head fire ignition pattern was used in all units, with the distance between strips of 5-10 meters. It had been 9 days since a rainfall event > 1 cm. Weather conditions on-site were approximated using a belt weather kit supplemented by data from a U.S. Weather Service station in Keshena, WI, approximately 16 km south of the burn unit. Conditions during the burns were as follows:

Temperature: 14-18ºC

Wind speed: 0 - 11.3 kph, averaging approximately 3.2 kph

Relative humidity: 27-40%, averaging approximately 31%

The mechanical-plus-herbicide treatment was implemented in 2002. A broad spectrum herbicide was applied in August, and the mechanical portion completed approximately one month later. The mechanical portion consisted of large anchor chains pulled by a medium size bulldozer.

<u>Vegetation Inventory</u>

Overstory

A complete census of all *P. strobus* and *P. resinosa* greater than 20.3 cm in each treatment unit was completed during the summer of 2001 or 2002. Each tree was tagged and assigned a unique number and were measured for basal scarring, insect damage, dbh, and height to base of live crown.

Intermediate Vegetation

The intermediate size vegetation [≥1.37 m tall but less than 20.3 cm dbh with a tree-like form] was inventoried by species and 2.5 cm diameter classes. This stratum was inventoried in eight, 404. 7 m^2 (radius = 11.34 m) plots per treatment unit (Burn Units) or 4 plots per unit (Control, M+H) [Fig. 1, Appendix A].

Shrub Component

This life form was assessed independently (i.e., it was included in the understory cover inventory) via the line intercept method. In 2001, 7.6 m lines were used; in all subsequent years, we extended the length to 15.2 m. We used the same location as the planar intercept transects (see Fuel Inventory). The typical sample size was 4 samples per unit for the M+H and Controls, and 8 samples/unit in the Burn treatment.

Understory Vegetation

Sixteen circular 1 m^2 quadrats were marked per treatment unit for the seedling inventory. These were placed in pairs approximately 2.5 m in opposite directions from eight of the permanent posts (Fig. 1, Appendix A). All arboreal seedlings less than 1.37 m tall were recorded in early June and mid-August 2002. Occasionally it was not possible to identify the very small seedlings to species and thus were recorded by genus (e.g., *Acer, Betula*).

Seed Bank

Thirty-two seed bank samples were collected from each of four treatment units within Compartment 219 and from two treatment units within Compartment 344 during the summer of 2001, for a total of one hundred and ninety-two samples. Two samples were obtained at all 16 posts within treatment units, using a random azimuth and distance, between 1 and 5 m, from the post. Soil sample size was 7.5 cm wide and 21 cm deep. .

<u>Fuel Inventories</u>

For two years before (2001-02) and two years after (2003-04), the down woody fuels were sampled by time-lag classes along eight, 15.24 m transects per unit (Brown et al. 1982). The transects started from the permanent posts that served as the center of the intermediate vegetation plot (Fig. 1, Appendix A).

Litter samples were collected 2001-04 in 0.09 m^2 quadrats which were referenced to the permanent sampling posts. In 2001, the litter samples were collected approximately 0.3 m north and south from the post. Within Compartment 219, litter+duff depth (the duff layer is almost non-existent in this system) was measured and litter samples were collected at 14-16 locations within each of seven treatment (all intended Burn) units. Within Compartment 344, samples were taken at twelve locations in four of the Control units. During the summer of 2002, only 64 litter samples were collected. All seven treatment units in Compartment 219 were re-inventoried and one Control unit in Compartment 344 was re-sampled. Litter weight and litter+duff depth were assessed at eight permanent sample points, one randomly chosen direction per post, and the data collected approximately 1 m from the post. For 2003, the same 8 posts utilized in 2001 were used to collect post-treatment litter samples for determining mass in the Burn units. For the other units, the sampling intensity was lower; the number of samples per unit were: Unit 9 (8), Unit 10(12), Unit 11(11), Unit 12 (7), Unit 13 (8) and Unit 14 (8). The sampling intensity in 2004 was lower (4-11 samples/unit) and we utilized different posts to provide an 'independent' assessment of post-treatment litter layer mass.

Soil Measurements

Infiltration rates. We used the cylinder infiltrometer method (Bouwer 1986) to make a comparative assessment of the effects of the treatments on water intake rates. Despite the limitations of the method, the logistics make this the most practical. Measurements were made during the growing season preceding the application of treatments, and in June, 2003. Within each unit, 24 sample points were located mid-way between the metal fence posts.

Basic Cations. These soil variables were measured in the upper 15 cm of mineral soil. Sampling was done in June of each year following the treatments. We collected 6 soil cores (15 cm deep by 5 cm diameter) from each unit; these were arrayed in a diagonal across the treatment units.

Available Nitrogen, Carbon.. Available nitrogen (ammonium form, 2003) and total nitrogen and carbon (2004) in the mineral soil were determined from the same samples as used for determination of basic cation conccentrations.

Soil Acidity. Two samples were obtained at all 16 posts within 6 treatment units, using a random azimuth and distance, between 3.2 and 16.4 feet (1 and 5 m), from the post. A standard soil sample size of 7.5 cm wide and 21 cm in length was used. A 25 gram subsample of ~ 30 samples from each unit was used (n = 183) to test for soil pH.

Fire Behavior Monitoring & Measurements

Temperatures above-ground were estimated using heat sensitive paints ("Tempilac", Big Three Industries, South Plainfield, NJ) applied to metal tree tags and attached to each post in the grid at five heights (0.15, 0.30, 0.60, 0.91, and 1.22 meters above ground). Use of heat sensitive material (paint or crayons) has been successfully used in a variety of ecosystems including heath shrublands (Hobbs et al. 1984), white pine-broadleaf mixed (Clinton et al. 1998), oak savanna (Fonteyn et al. 1984), prairie (Cole et al. 1992) and oak forest (Cole et al. 1992). This arrangement documented the variation in fire intensity in horizontal and vertical dimension within the treatment units. In Unit 2, we only had time to put tags on 12 posts; for all other units tags were placed on all 16 posts. Each tag contained a small swath of paint representing each of the following temperatures: 79, 135, 204 and 288ºC; this range was selected based on the data for an oak woodland (Cole et al. 1992).

The temperatures generated in the litter layer were quantified with heat sensitive paint applied to clay tiles; the tiles measured 11.5 x 7.5 cm and had been fired to 1400ºC. Four tiles were installed along two radii on opposite sides of the tree at 0, 25, 50 and 100% of the distance to the drip line, with 0% representing at the base of the tree. Paint temperatures applied were: 79, 135. 163, 204, 288, 371, 454 and 538ºC.

We also utilized trained observers and 1.5 m tall posts painted with contrasting colors every 0.30 m to get estimates of flame height while the burns were in progress. These posts were installed immediately adjacent to the posts with the heat tags. Due to low wind speed and somewhat erratic winds, these observations were often difficult to make due to the smoke.

IIC. LAB METHODS

Seed Bank Composition & Density

The samples were split into a greenhouse portion and a growth chamber portion. The former were placed in the UW-SP greenhous,. Samples were placed in a room with temperatures ranging from 12 to 31° Celsius (J.Hardy, Personal Communication 2002) and watered as often as necessary to keep the soil moist. Light levels fluctuated throughout the germination period with overcast days experiencing light levels varying from 100 -210 µmol m^{-2} s^{-1} and sunny days ranging from 210-1000 µmol m^{-2} s^{-1} (B. Galbraith, unpublished data). The samples remained in the greenhouse and growth chamber for approximately four months.

A sub-sample of seed bank samples was germinated in a standard growth chamber. Temperatures were adjusted to 6.7° Celsius during 12 nighttime hours and 17.8° Celsius during 12 daytime hours, temperatures necessary to induce germination of spring ephemerals (Godman and Mattson no date). Samples were watered as often as necessary to retain soil moisture.

Soil Chemical Analyses

In treatment year #1 (2003), soil was analyzed for NH_4^+ concentrations by means of extraction with 2M KCl. For the second growing season, total nitrogen concentration was determined with a CE2100 C/N Autoanalyzer. Total carbon in the mineral soil was determined simultaneously with the Autoanalyzer.

The analytical method for cations was a standard one used in soil analysis (Sparks et al. 1996) and was performed by the Environmental Task Force in the College of Natural Resources, UW-SP.

Soil acidity (pH) was determined by mixing the soil with 25 ml of distilled water, creating a 1:1 solution. Values were recorded following calibration of the Orion® digital pH meter using 4.0 and 7.0 pH buffering solutions.

IID. COMPUTATIONS & ANALYSES

Fire behavior variation

We developed histograms and temperature profiles to depict the variation in temperatures within and between units (Hobbs et al. 1984, Cole et al. 1992). These methods present the temperature variation in a clear, easy-to-understand manner, as well as providing direct, meaningful comparisons between burns. To statistically compare the behavior among the four burn units, a chi-square analysis was done based on the frequency of temperatures recorded at 0.15 m above-ground. The hypothesis tested was that the frequency of the temperatures was independent of burn unit.

The data distributions (behavior metrics, fire effects and response variables) were often non-normal (right skewed, typically); therefore, we used the median as the most representative value for all metrics except char height and temperature in the litter layer.

Estimation of flame-front intensity from direct observation

The sample size (# of observations) is less than ideal, and we believe the precision and accuracy of the estimate is sub-standard. Nonetheless, these data were summarized, and used to derive a crude estimate of flame-front intensity (I) from the equation:

$$I \text{ (kW/m)} = 259.83 * L^{2.174},$$

where L = average flame length in meters (Alexander 1982).

Statistical Analyses – Fuel and Vegetation

Though spatially clumped, each burn and M+H treatment unit was ecologically independent of the others with the possible exception of a small amount of seed movement by wind or animal vectors. Thus, each unit was treated as an independent sample and ANOVA (fixed effects model) was employed as the primary means of analysis. Several variants of ANOVA (MANOVA, Repeated Measures, ONE-WAY) were used depending on the number of dependent variables and the degree of temporal dependence of the response variables. One exception to this generality was the woody fuel variable. Typically, this would be analyzed with the pre-treatment variable as a covariate (e.g., Knapp et al. 2005). However, I chose not to do this because the control values exhibited a moderate level of fluctuation over time due to slight differences in sampling, and this variation would weaken the ability of the test to identify treatment-induced changes. Therefore, I opted to analyze each treatment separately with a paired sample t-test. This approach is suitable when there is a direct effect of the pre-treatment level (value) on the post-treatment value. For this approach, the differences between the two measurements are the response values; utilizing these, as opposed to the values, provides a more powerful test than a two-sample t-test (Zar, 1986).

IIIA. PRE-TREATMENT CONDITIONS, VEGETATION - 2001

Overstory. Across all treatment units, overstory basal area (BA) was dominated by pine but had a small-to-modest broadleaved component (Table 1, Appendix B). White pine was the dominant species in all units; pine BA ranged from 16.0 to 34.3 m^2/ha, whereas the broadleaf species contributed 0.8 to 5.7 m^2/ha. There was a minor, sporadic component of hemlock – it was present in 7 of 12 treatment units (TU) and amassed 0.13 to 1.04 m^2/ha. According to MTE records the overstory age was 140-150 years. The pine were about twice the average diameter of the broadleaved species.

Intermediate Layer. A dense and diverse intermediate layer (size range 2.5 to 21.3 cm, diameter) existed on all units, but exhibited a wide range of stems densities (Table 1, Appendix B). The units in Compartment 219 ranged from 1485 to 2208 tr/ha, whereas Units #9-11 in Compt. 344 had a narrower range of densities (1569 – 1878 tr/ha) and the 'Control' units had fewer stems (636 - 1093 tr/ha). This layer included a large number of species typical of mesic sites, as well as a few shrubs. All units had at least 9 species in this stratum, and the dominant taxa were Acer, Betula and Prunus. Species with a relative density (Rel. Dens.) of 10 % or more in the Control and Burn units were: A. saccharum (.32), B. alleghanensis (.18), A. rubrum (.12) and B. papyrifera (.11). For Burn units only, the ranking was different and included one Prunus: B. alleghanensis (.23), A. saccharum (.22), A. rubrum (.15), and P. pensylvanica (.11).

The Intermediate Layer was dominated by the trees less than 5 cm in diameter; in all units these stems constituted more than 90% of all stems in this stratum (Table 2).

Shrub Layer. The percent cover by the shrubs (NOT including Rubus) in 2001 ranged from 1.7% (Unit 5) to 24.9% in Unit 16. This latter value is clearly an anomaly (statistically speaking), as the next largest value was 6.6. The average cover for this life form was 4.2% (without Unit 16) and 6.5% (all units). The two most frequent species were Hamamelis virginiana and Corylus cornuta.

Arboreal Seedlings. As is typical for many mesic temperate systems, arboreal seedling density was highly variable across the landscape (range: 22.5 – 89.7 M/ha). Both Burn and Control treatment areas included units with very high and very low densities (Table 1, Appendix B). The three Mechanical units were different in that they 1) had much less variation among them, 2) all were on the low end of the range, and 3) they had a lower degree of domination by maple species. One of the three species of maple was the dominant seedling species in every unit, and the dominant often represented greater than 50% of the total; sugar and red maple were roughly equivalent on this basis.

Understory Layer. The understory was inventoried initially in Aug., 2001, for all Burn and Control units. This group of units was also inventoried in late May/early June,

2002. However, the Mechanical units were not surveyed for the first time until Aug., 2002. The total (all species) percent cover across all units in August, 2001 and 2002 was 24.1% (range: 10.8 – 51.2%; Table 1, Appendix B). In contrast to the seedling pattern, the Mechanical units (#9-11) had a noticeably higher level of understory cover (mean = 37.0%). Both substantially below- and above-average values were found in both compartments and in units that were very close together. The Mechanical units also differed from the others in terms of richness of the understory; the average value for #9-11 was 32.3, whereas both Burn and Control averaged 37.8 species per unit.

Table 2. Intermediate stem counts and relative density by size class for Units 1, 3, 5, 9, and 13 (left to right, respectively). Sample size was 8 plots for Units 1,3 and 5; and 4 plots for Units 9 and 13. All counts made in 2001, except Unit 9 which was inventoried in 2002.

Size Class (midpoint, cm)	Count	Rel. Dens.	Count	Rel. Dens.	Count	Rel. Dens.	Count	Rel. Dens.	Count	Rel. Dens.	Avg. Rel. Dens.
2.5	593	.829	400	.787	454	.875	245	.894	132	.846	.846
5.0	77	.108	71	.140	59	.114	19	.069	16	.103	.107
7.5	45	.063	31	.061	5	.010	7	.026	4	.026	.037
10	0	0	6	.012	1	.002	2	.007	2	.013	.007
12.5	0	0	0	0	0	0	1	.004	2	.013	.003
TOTL	715		508		519		274		156		

IIIB. SEED BANK

A total of 824 germinants, representing 46 taxa, emerged from the 192 seed bank samples. The most abundant group of species was the alien/weedy herbs (35%), followed closely by native herbs (30%). The representation of other groups was: grasses and sedges (19%), shrubs (11%), unidentified species (5%), and trees (.01%). Germinants from the genus *Carex* were the most abundant member of the grass and sedge category as well as the largest taxa (16%) found in the seed bank (Tables 3-5). The average viable (i.e., germinated) dormant seed density across all samples and units was 2044/m^2 ; the average densities among units was 1131 (#5) – 4299 (#13) seeds per square meter.

The number of native woodland herbaceous species in the seed bank varied by a factor of 4 (16 to 66) among the six treatment units sampled (Table 3). The five most abundant taxa were Polygonum cilinode, Viola spp., Oxalis stricta, Conzya Canadensis, and Maianthemum canadense, out of a total of 23 taxa identified.

For the alien species and native weedy species, the variation among treatment units was even greater because one unit (#14) only had three species in these two categories, resulting in a 10-fold difference (Table 4). The total number of alien/weedy germinants was 48 (24%) greater than the native woodland herbs, though the number of species found was less (9 vs. 23). The alien/weedy component of the seed bank was strongly dominated by three species: Cerastium fontanum, Chenopodium album, and Solanum ptycanthum – which collectively constituted 91% of the germinated seeds.

Shrubs were moderately common in the seed bank (total of 89 seeds germinated), but trees were rare (total count = 5) [Table 4]. Three shrub taxa were common: Diervilla lonicera, Sambucus racemosa ssp. pubens, and Rubus spp. This latter taxa is technically not a shrub because it does not have a secondary cambium; however the form of the species in the genus is more like that of a shrub than an herb.

IIIC. PRE-TREATMENT CONDITIONS, FUEL

Litter depth for 11 treatment units averaged 3.2 centimeters (Figure 2). Adjacent units 2 and 3, separated by only a 30 m buffer, contained the lowest (2.4 cm) and highest (4.0 cm) amounts of litter, respectively (Galbraith 2005). The weight of the litter layer was relatively consistent across the landscape, ranging from 1 to 2 tons/ac with an average of 1.32 (Table 6).

High spatial variability characterized the woody fuel component (Table 6). The 7 units in Compt. 219 had total woody loadings ranging from 7.5 to 29.9 t/ac. The units measured in Compt. 344 had a slightly smaller range of values: 10.3 to 26.2 t/ac. This range, however, is still quite large - approximately 250%. The ‘1000-hr Sound had the highest degree of variability (see Coefficient of Variation, Table 6), whereas the 1-hr size class had the least. The ‘1000-hr Sound and 1000-hr Rotten components dominated the loadings in 7 units, whereas in 4 units (#1, 4, 13, & 14) the 1000-hr Rotten class was much more important than 1000-hr Sound. On average, the 1000-hr Rotten component contributed the largest amount (7.9 t/ac, 40%) to the total fuel load.

A subset of Burn/Control units, plus all Mechanical units, were inventoried in

Table 3. Number and identity of native herbs germinated from the soil seed bank by treatment unit (adapted from Galbraith, 2005).

	1	*3*	*4*	*5*	*13*	*14*	*Total*
Native herbs							
Arisaema triphyllum			1				1
Aster spp.					1		1
Circaea alpina ssp. canadensis				1			1
Conyza canadensis			1	9	7		17
Corydalis sempervirens	1	4			1		6
Dicentra spp.			3				3
Epilobium ciliatum			1		2		3
Erechtites hieracifolia					1		1
Euthamia graminifolia						1	1
Galium triflorum		1	1				2
Geranium bicknellii		1					1
Geranium maculatum			1				1
Hepatica acutiloba			1				1
Hieracium spp.		1		1			2
Hydrophyllum virginianum			2				2
Maianthemum canadense	3	3			1	1	8
Oxalis stricta		1	3		19		23
Polygonum cilinode	46	40	5			3	94
Potentilla norvegica		2			1		3
Ranunculus spp.	2			1		1	4
Solidago spp.		1	1				2
Uvularia sessilifolia			1				1
Viola spp.	5	11	10	4	5	26	61
Unknowns		1					1
Total for Herbs	57	66	31	16	38	32	240

2002. The purpose for the re-measurement of the Burn/Control was to double-check the 2001 values, and to see if winter damage had substantially increased the fuel load. The data indicate greater than expected yr-to-yr variation in some units (Table 7); this occurred even though we used permanent starting points and the same bearing for the transects in both years. Despite variation between years at the transect and unit level, the

Table 4. Number and identity of trees, shrubs and alien/weedy taxa germinated from the soil seed bank by treatment unit (adapted from Galbraith, 2005).

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	1	*3*	*4*	*5*	*13*	*14*	*Total*
Alien/weedy herbs							
Cerastium fontanum		4			90		94
Chenopodium album	10	51	6	14	8	2	91
Chenopodium glaucum	2	1	1	2	1	1	8
Plantago major			1		5		6
Rumex obtusifolius					1		1
Solanum ptycanthum	40	4	32	1			77
Sonchus oleraceus			6	1			7
Taraxacum officinale		1	2				3
Trifolium repens		1					1
Total for alien/weedy	52	62	48	18	105	3	288
Shrubs							
Diervilla lonicera	8	2	1	3	4	18	36
Lonicera canadensis			1				1
Rubus spp.	4	5	4	6	3	2	24
Rubus idaeus ssp. strigosus					1		1
Sambucus racemosa ssp. Pubens		4	8	11	3	1	27
Total for shrubs	16	15	17	12	8	21	89
Trees							
Acer rubrum					1		1
Betula spp.						2	2
Prunus pensylvanica						1	1
Prunus virginiana						1	1
Total for trees					1	4	5

overall (across all units) Woody Fuel Load in 2002 differed from 2001 by only 10.6% (17.9 vs. 16.0 t/ac). Using fluctuation of ± 15% as the criterion, 5 of 7 re-measured units exhibited roughly constant woody fuel loadings between years.

PRE-TREATMENT CONDITIONS – SOIL

Soil pH did not vary significantly among treatment units in 2001 (Figure 3). Average pH was 5.0, with the lowest and highest pH found in unit 14 (4.69) and unit 4 (5.19), respectively (Galbraith 2005).

Table 5. Number and identity of grasses, sedges and rushes germinated from the soil seed bank by treatment unit, plus total densities and richness for all life forms (adapted from Galbraith, 2005).

	1	**3**	**4**	**5**	**13**	**14**	**Total**
Grasses and Sedges							
Agrostis perennans			1		2		3
Carex spp.	25	47	30	18	2	8	130
Digitaria ischaemum				1			1
Juncus spp.						1	1
Oryzopsis asperifolia						1	1
Unidentified	2	1	15	1	2		21
Total for graminoids	27	48	46	20	6	9	156
Unidentified germinants	11	10	10	5	3	7	46
Total germinants – all life forms	163	202	152	70	161	76	**824**
Total no. of taxa/treatment unit	12	22	26	15	23	16	

Figure 2. Litter depth by treatment unit in 2001.

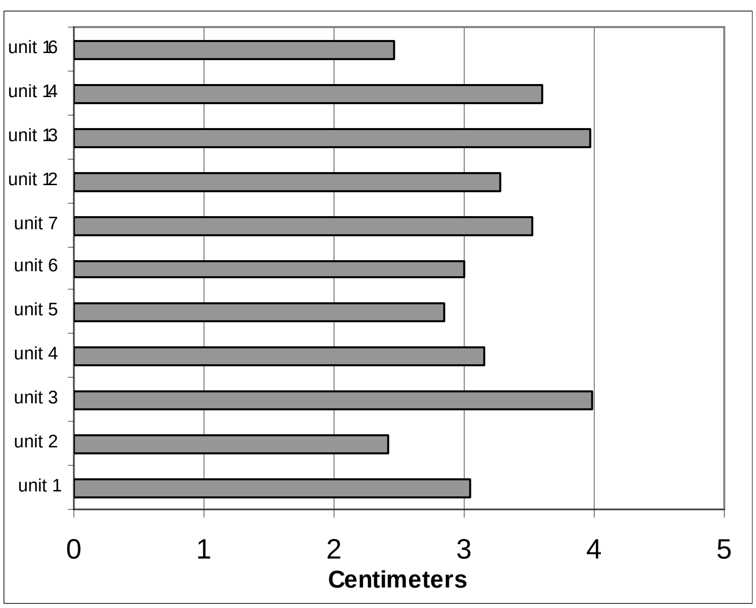


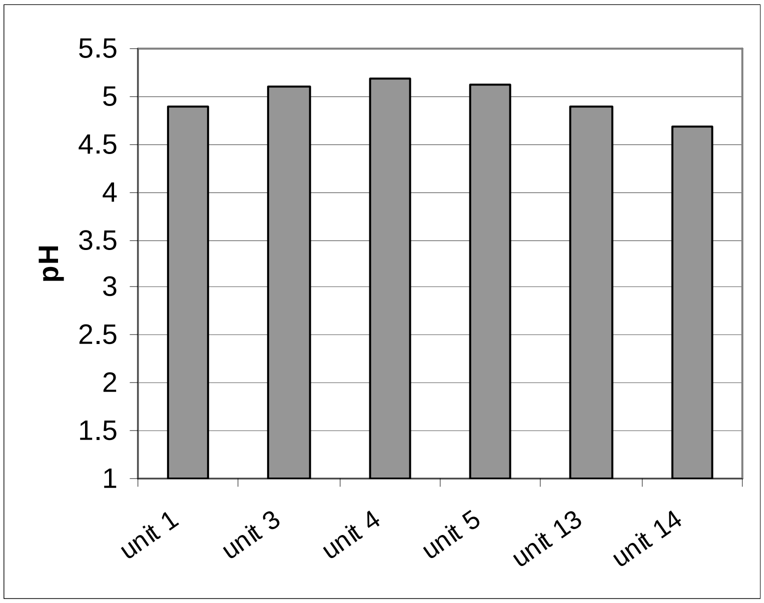
Table 6. Fuel load (t/ac) by treatment unit in Compartments 219 & 344, 2001.

TRT UNIT	TOTAL FUEL LOAD	WOODY FUEL LOAD	1-hr	10-hr	100-hr	1000-hr, Sound	1000-hr, Rotten	LITTER
1	13.3	11.1	0.47	1.62	1.26	1.32	6.42	1.43
2	21.1	19.4	0.69	2.51	1.15	6.98	8.07	0.92
3	23.0	21.1	0.74	2.98	1.49	8.4	7.5	1.14
4	9.3	7.5	0.49	1.53	1.15	0.96	3.41	1.02
5	23.4	22.2	0.7	2.94	0.57	8.05	9.9	1.15
6	15.5	13.0	0.79	5.36	1.38	1.29	4.19	1.71
7	31	29.9	0.67	6.34	2.07	9.46	11.4	1.07
12	28.4	26.2	0.45	1.87	1.94	10.15	11.81	1.36
13	17.0	14.2	0.69	1.70	1.39	1.43	8.99	2.01
14	12.3	10.3	0.50	1.53	1.16	0.55	6.55	1.21
16	24.1	21.8	0.34	2.21	2.08	8.41	8.81	1.45
Avg.	19.9	17.9	.59	2.78	1.42	5.18	7.91	1.32
CV	.35	.40	.25	.58	.32	.77	.34	.22

Table 7. Fuel load (t/ac) by treatment unit and year in Compartment 219, and initial (pre-treatment) values for units in Compartment 344.

TRT	WOODY FUEL LOAD (t/ac)	WOODY FUEL LOAD (t/ac)	DIFFERENCE (t/ac)	DIFFERENCE (% of '01)
UNIT	2001	2002	(01-02)	
1	11.1	8.9	2.2	19.8
2	19.4	19.9	-0.5	2.6
3	21.1	19.7	1.4	6.6
4	7.5	10.8	-3.3	44.0
5	22.2	20.2	2.0	9.0
6	13.0	12.3	0.7	5.4
9	----	10.6		
10	----	16.6		
11	----	9.5		
16	21.8	19.9	1.9	8.7
Avg. (1-6,16)	17.9	16.0		
Avg. (all)	----	14.8		

Figure 3. Soil pH for a subset of the treatment units; units 1, 3 and 4 are Burn units and the others are Controls.



PRE-TREATMENT CONDITIONS, VEG. – REPEAT MEASUREMENTS, 2002
Arboreal Seedlings.

The average arboreal seedling density late in the 2002 growing season differed by approximately 11,800 per ha between the burn units and the controls (Table 8); if one unit with an average > 66% higher than all others (#13) is not considered, the burns and controls differed by about 2500 seedlings/ha. The mechanical units were notably different than the other two treatments with approximately 50% lower density. In comparison to 2001, the densities were less for Burn treatment and similar for the Control treatment (averaged across all units; Burn = 6.03 seedlings/m^2; Control = 5.41 seedlings/m^2).

One of the three native Acer species dominated the seedling bank in every unit; in Compartment 219 (units 1-6) it was always sugar maple (Table 8). In the three control units in Compt. 344, red maple was the dominant species. The mechanical units stood out in this regard also; each was dominated by a different species, and the level of domination was much lower than the other units (0.35 vs. 0.70 in the burn units and 0.66 for the controls).

Table 8. Arboreal seedling density and dominant species by unit and intended treatment, August 2002. Acru = Acer rubrum; Acsa = A. saccharum; Acsp = A. spicatum.

	Unit	#/m²	Dom. Spp.	Rel. Abund.
BURNED UNITS				
	1	4.75	Acsa	0.58
	2	2.81	Acsa	0.69
	3	4.31	Acsa	0.54
	4	5.38	Acsa	0.97
	Mean	4.31		0.695
CONTROLS				
	5	6.06	Acsa	0.88
	6	3.12	Acsa	0.62
	12	4.42	Acru	0.53
	13	10.92	Acru	0.76
	14	3.75	Acru	0.64
	16	4.69	Acru	0.52
	Mean	5.49		0.66
	[average w/o #13 = 4.57]			
MECHANICAL UNITS				
	9	1.94	Acsp	0.42
	10	2.56	Acsa	0.29
	11	1.81	Acru	0.34
	Mean	2.10		0.35

IV. FIRE BEHAVIOR

Fire Behavior - All Burns

For all units combined, the average flame height was 0.78 m (range = 0.3-1.4) [Table 9] and the flame-front intensity was roughly 153 kW m^{-1} (but see caution in Methods). This shows the relatively low intensity of the burns; nevertheless, the observers (PI included) occasionally noted hot spots in which the flames exceeded 2 m.

The maximum temperatures recorded and heat sums indicated that Unit 3 burned hotter than the other three units (Table 9). Unit 3 had at least 25% more posts reaching the maximum temperature and the median heat sum was 22-47% higher than units 1, 2 and 4. In contrast, the average flame heights indicated that Unit 4 was slightly more intense than Units 1 and 3.

Table 9 . Fire behavior characterization for 4 prescribed burns in a mature white pine forest. Each unit was 0.81 ha and burned on the same day with a strip-head fire ignition pattern. Temperatures were recorded with a series of heat-sensitive paints attached to metal posts at 0.15, 0.30, 0.61, 0.91 and 1.22 m above ground. N/A = not enough observations to calculate.

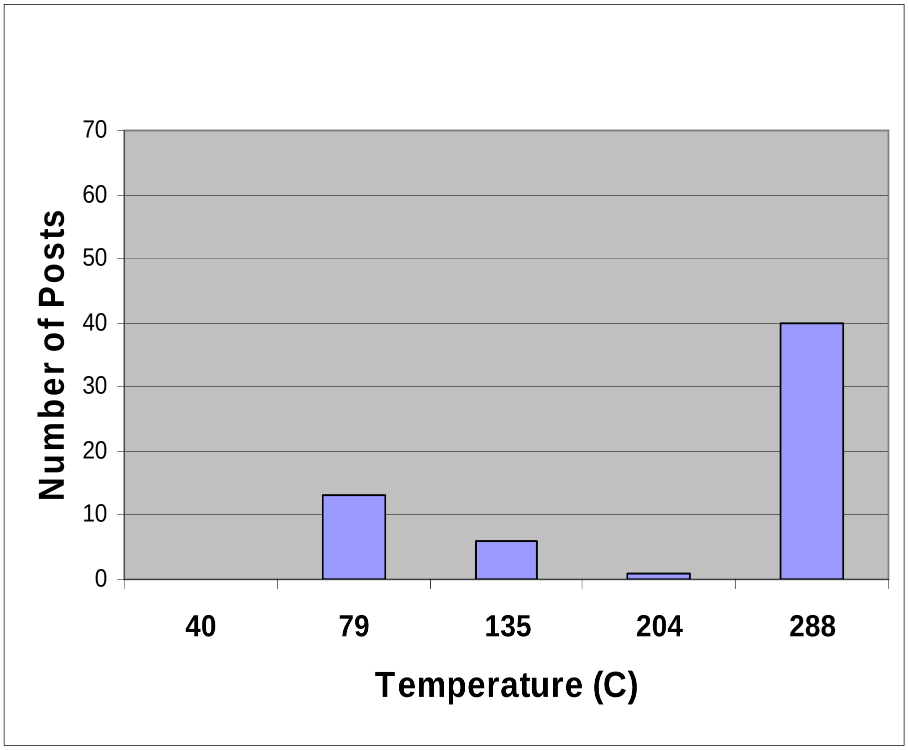
Unit	Percent of Posts with Temp. > 288C	Median Total Heat Sum	Median Heat Sum for 0.15 and 0.30 m	Average Flame Ht. (m)
1	69	814	492	0.79
2	50	683	346	N/A
3	94	993	575	0.70
4	50	677	325	0.91
				Mean = 0.78

The distribution of temperatures changed rapidly with height above-ground. At 0.15 m, 66% of the posts reached or exceeded 288ºC, whereas by 1.22 m above-ground only 1.7% reached the maximum temperature (Fig. 4a-d). The temperatures at 0.3 m exhibited a bi-modal pattern with approximately equal numbers of locations reaching the lowest temperature [79ºC] and the highest [288ºC]. The patterns for 0.61 and 0.91m were almost identical with over half of the locations only reaching 79° C and sharply declining numbers at the higher temperatures. Because there was very little difference between 0.61 and 0.91, and because the pattern for 0.91 falls between the 0.61 and 1.22 patterns, all other data summaries exclude the 0.91 height data.

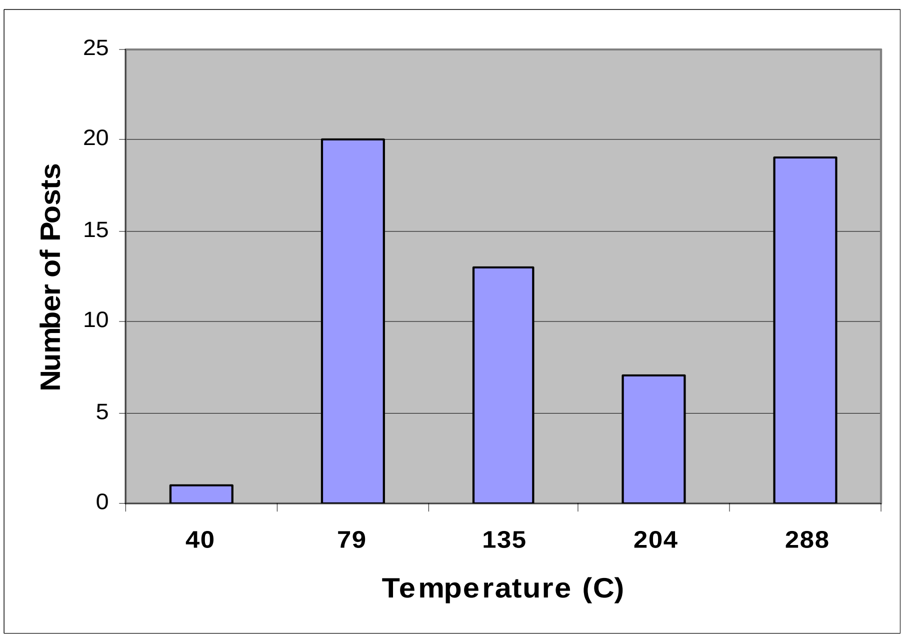
Temperatures noted in the litter layer were typically much higher than those immediately above-ground; the overall average was 407.2ºC ($\pm$ 191.8). Over half (57.1%) of the locations (n=161) recorded a temperature of $\geq$ 538ºC and an additional 11.7% reached 454°C (Figure 5). At the other extreme, 13.7% of the tiles did not reach the lowest paint temperature (i.e., either the spot did not burn or the fire barely burned through the upper-most portion of the litter in the vicinity of the tile). There was no consistent pattern in litter-layer temperature with distance from the bole of the

Figure 4. Frequency of temperatures (C) at four heights above-ground in four prescribed burns (a) Temperatures at 0.15 m; (b) Temperatures at 0.30 m; (c) Temperatures at 0.61 m; (d) Temperatures at 1.22 m.

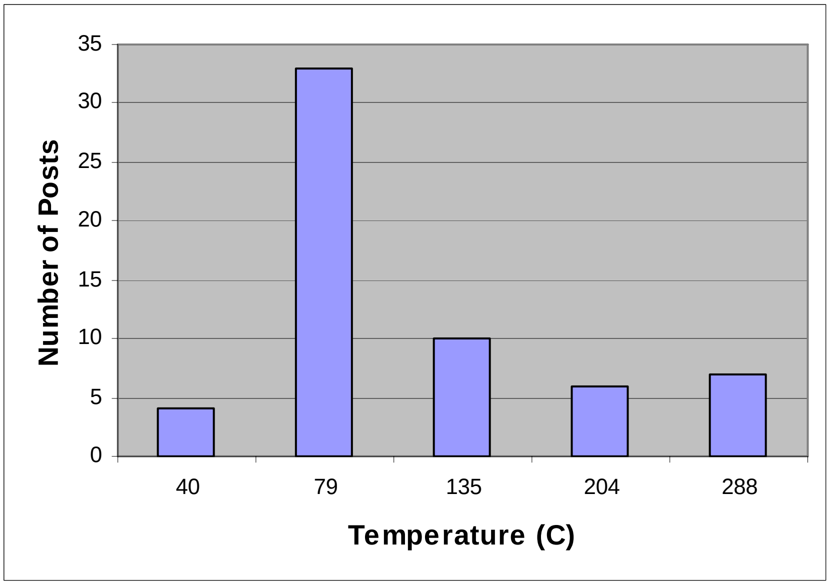
A.



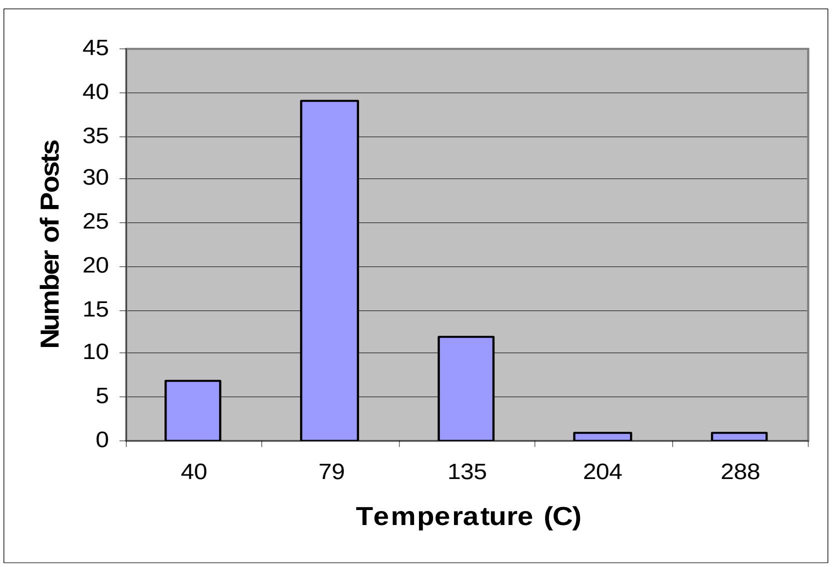
B.



C.



D.

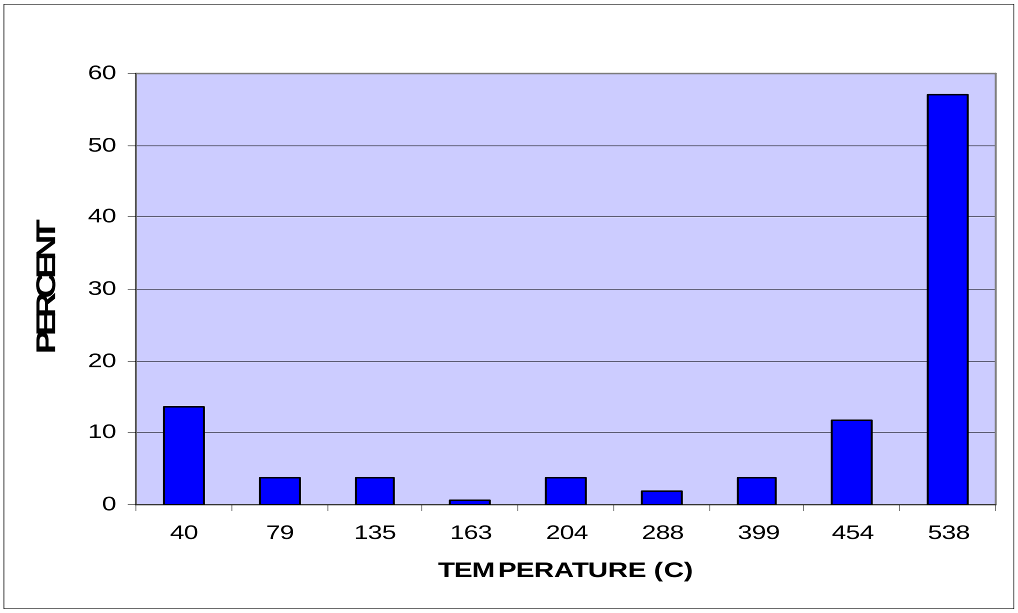


overstory pine (Figure 6; note overlap of bars representing two standard deviations). The averages ranged from 366.3ºC (± 223.7) at the 50% location to 426.7ºC (± 177.5) at the 25% location.

Fire Behavior - Comparisons among Units

The chi-square analysis resulted in the null hypothesis being accepted (.50 > p > .25), suggesting that the distribution of temperatures at 0.15 m was similar across all four units.

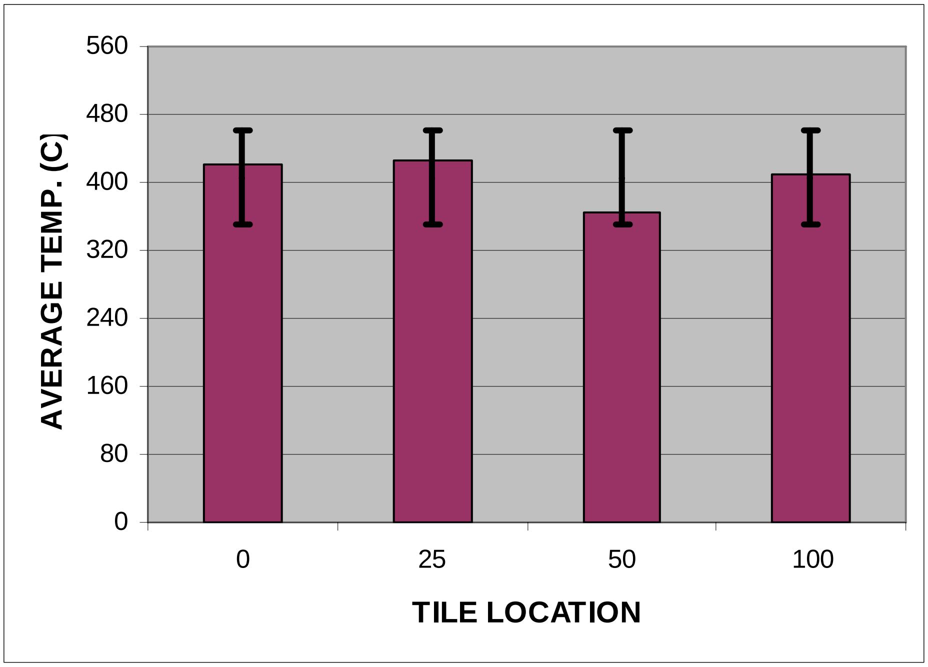
Figure 5. Percent of tiles that were heated to various maximum temperatures (C) for four prescribed burns. Tiles were placed in the litter layer beneath mature pines.



The temperature profiles [<u>sensu</u> Cole et al. 1992] summarize the representative temperatures in the vertical dimension and indicate a clear ranking of the burns, from hottest to coolest: Unit 3 > Unit 1 > Unit 2 ~ Unit 4 (Fig. 7). Thus, the temperature profile corroborates the summary statistics based on the heat sensitive paints. However, they also show probable differences in the upward heat pulse. For example, the temperature reached at increasing heights above-ground decreased steadily but less rapidly in Unit 1 compared to Units 2 and 4. Further evidence of the greater heat output in Unit 3 is shown by the fact that it is the only unit that had potentially biologically lethal temperatures at 0.61 m above the forest floor.

The temperature presentation by post and height shows the vertical and horizontal variation within a unit (Fig. 8a-d). The value of these figures is their ability to document

Figure 6. Average maximum temperature (C) of tiles in the litter layer as a function of location. 0 = at base of tree, 100 = at drip line; 25 and 50 represent 25% and 50% of the distance from base of the tree to the drip line. Bars represent two standard deviations.



across-unit changes in fire intensity at a specific horizontal scale (15 m in this case), to 'capture' isolated hot spots, and to provide an easy-to-read representation of patterns for the entire burn unit. For example, in Unit 1, the side of the unit containing posts 1-4 was notably cooler than the rest of the unit (Fig. 8a). In Unit 2, posts 13-16 were substantially hotter than other portions of the unit (Fig. 8b).

V. TREATMENT EFFECTS

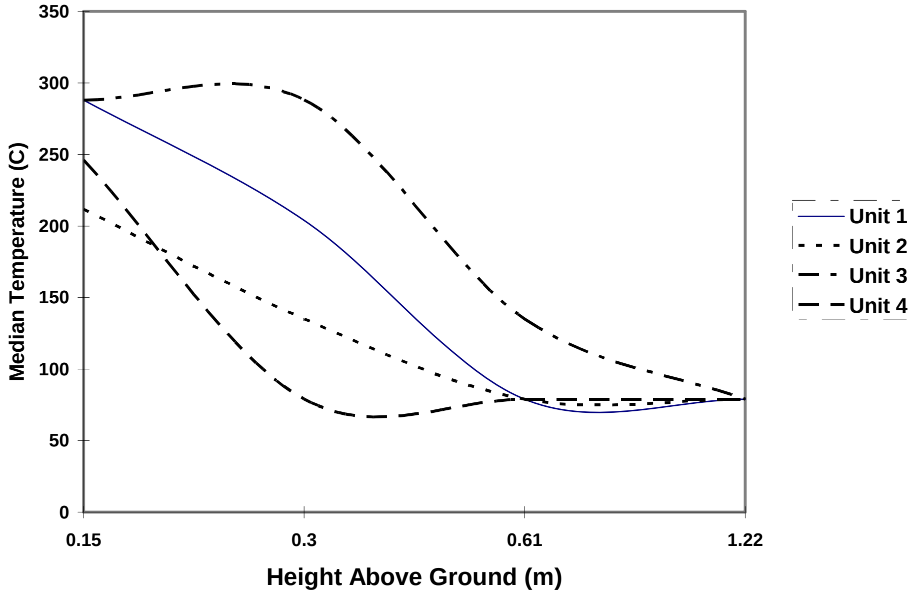
A. VEGETATION – OVERSTORY

Neither the prescribed burns nor the Mechanical site prep caused overstory mortality greater than the background rate, as indicated by the rate in the Control Units (Table 10). The burn also resulted in very little crown scorch, with only a total of f 9 trees, out of 175 assessed showing any signs of fire-induced foliage mortality. The majority were in Unit 3.

A. VEGETATION – INTERMEDIATE LAYER

The treatments resulted in very different levels of intermediate stem mortality during the first year post-treatment; there was approximately 2 1/2 times greater mortality rate due to mechanical + herbicide treatment than the burns (Table 10). The Controls

Figure 7. Median temperature by height above-ground ('temperature profile') for four prescribed burns.



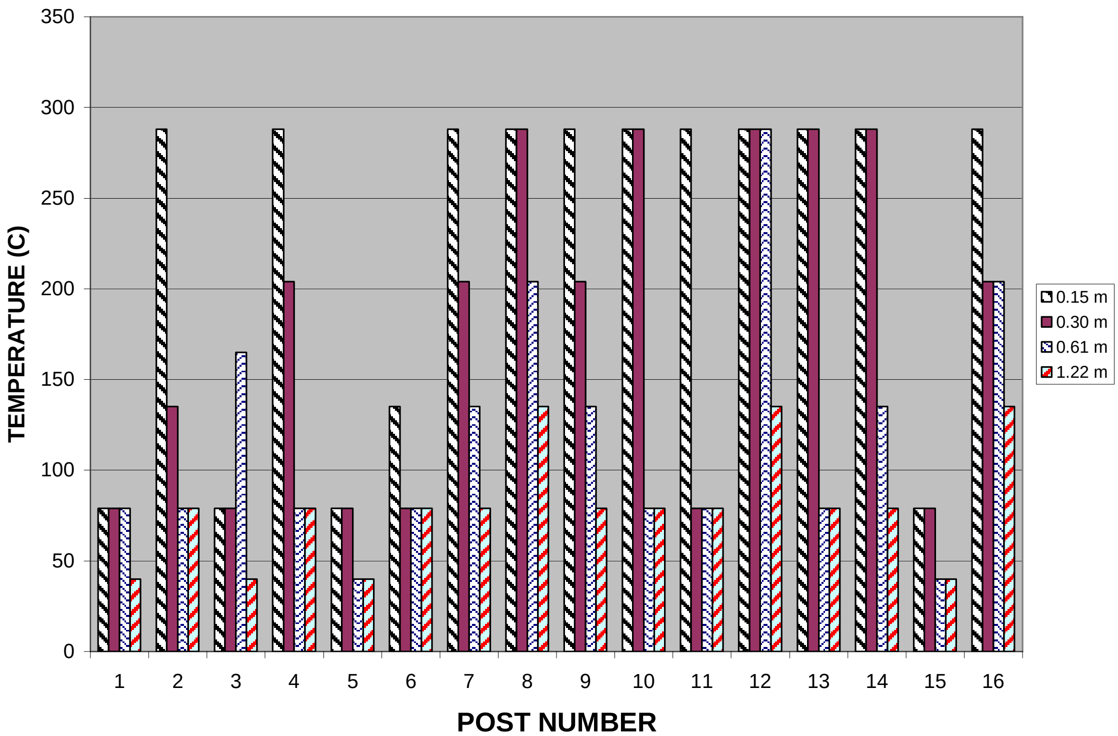
exhibited surprising variability among units, ranging from a loss of 11% to a gain of 31%, with an average net increase of 9%. In additional to direct mortality, the Mechanical treatment also resulted in the majority of stems being pushed towards a horizontal position; between 53 and 75% were leaning at least 45º from vertical in 2003.

Three burn units and all M+H units were re-surveyed in 2004. This turned out to be an important decision as very significant levels of 'delayed' mortality occurred in the burned units, with the second year mortality greater than the first year in all 3 units. The '03-04 mortality rates were 59.4% (Unit 2), 59.0% (Unit 3), and 47.1% (Unit 4, Fig. 9). Thus, the average cumulative (2-yr) mortality rate due to burning was 63.7%. The M+H units also reflected some delayed mortality; the average cumulative (2-yr) mortality rate due to this form of site prep was 80.3%.

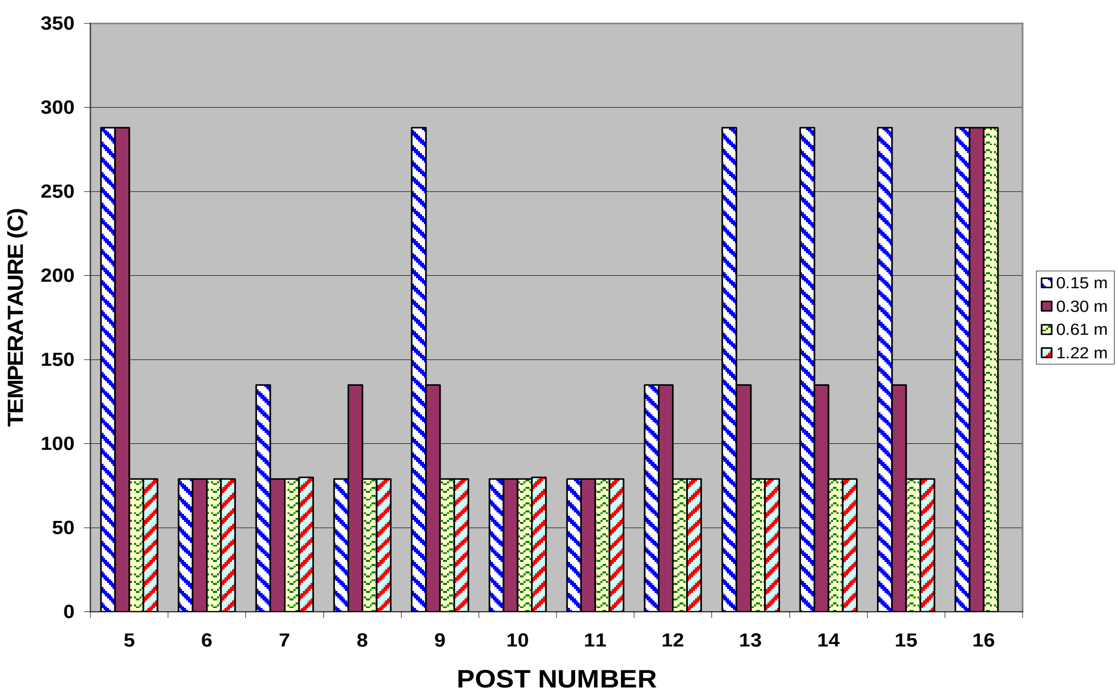
A sub-sample of stems in Units 2 & 3 (n=368) that died by 2004 were assessed in 2004 for sprouting. The overall (all species) average was 49.9%; however, very significant differences among taxa were found. Based on those with a sample size > 50, the per-taxon rates were: Acer – 84.7%; Betula – 8.7%; and Prunus – 3.6%. A smaller

Figure 8. Maximum temperature by height above-ground and post in four prescribed burns. Posts were arrayed on a 15 x 15 m grid in the center of 0.8 ha burn unit. A-D represent units 1-4, respectively.

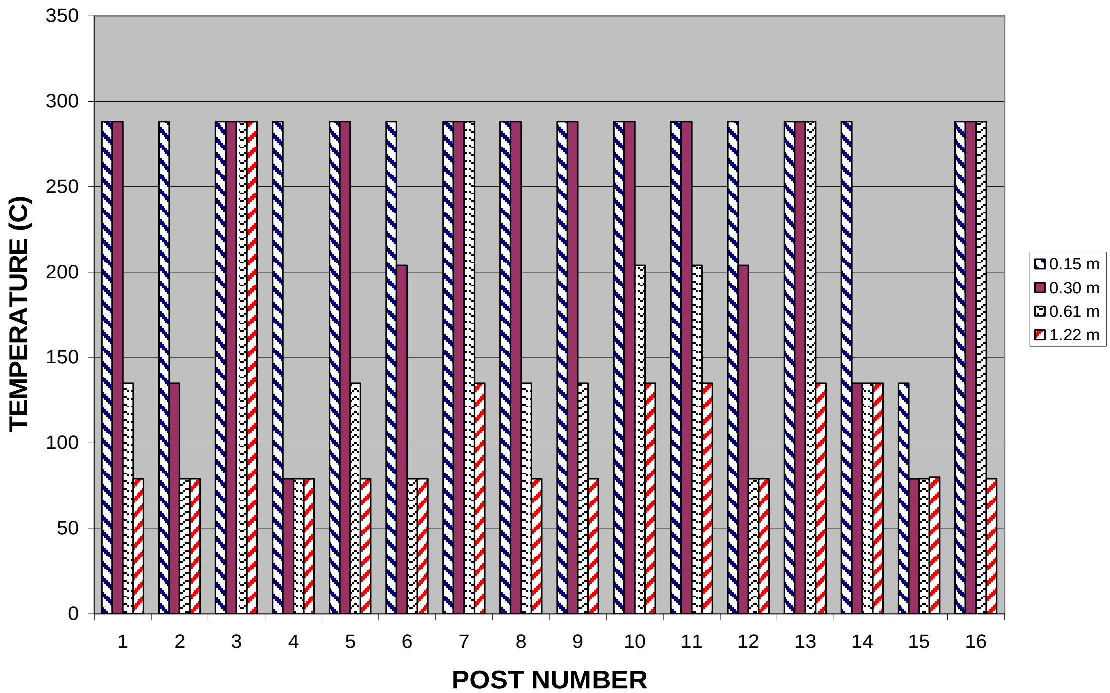
A.



B.

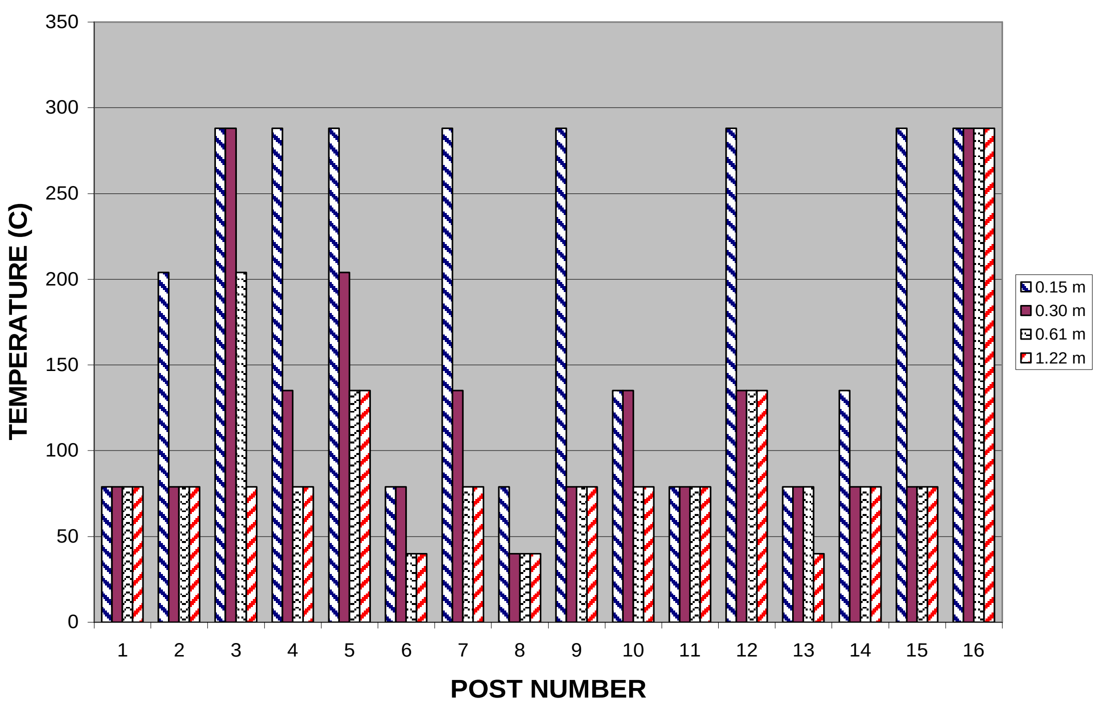


C.



350
300
250
200
150
100
50
0
TEMPERATURE (C)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
POST NUMBER
0.15 m
0.30 m
0.61 m
1.22 m

D.



350
300
250
200
150
100
50
0
TEMPERATURE (C)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
POST NUMBER
0.15 m
0.30 m
0.61 m
1.22 m

Table 10. Representative fire effects on vegetation and the variation in these effects within and among units. No measure of variation is presented for Seedling Mortality because each quadrat typically had too few stems present to make a percentage meaningful. NS = not sampled.

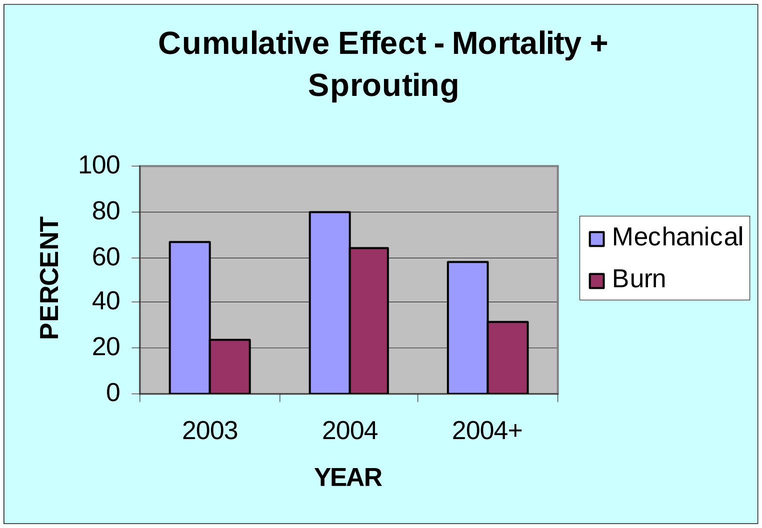
Unit	Overstory Mortality (# / unit)	Overstory Scorch (# / unit)	Char Height (m) Mean (SD)	Seedling Mortal.(%) (Aug.02-03)	Intermediate Mortality (%) ['01 – 03; range]
1	1	0	0.65 (.58)	89.4	15.8 (7.90-94.9)
2	4	1	0.55 (.65)	84.3	15.2 (17-70.5)
3	1	7	1.66 (1.31)	87.0	48.7 (24.6-92.6)
4	2	2	0.84 (.78)	86.1	17.9 (28.5-71)
MEAN			0.79	86.7	24.4
5	5	N/A	N/A	22.6	1.9
6	0	N/A	N/A	48.1	10.9
7	12	N/A	N/A	NS	NS
12	1	N/A	N/A	25.1	10.7
13	1	N/A	N/A	74.3	+21.2
14	0	N/A	N/A	3.2	+26.6
16	2	N/A	N/A	NS	+31.1
MEAN				34.7	+9.2
9	0	N/A	N/A	16.5	60.7
10	0	N/A	N/A	75.8	79.3
11	1	N/A	N/A	17.1	62.0
MEAN				34.5	67.3

but notable level of sprouting was found in the M+H units. The net effect of mortality plus sprouting is depicted in Figure 9.

A. VEGETATION – SHRUB LAYER

To represent the 'total' effect of the treatments, the 2004 data are utilized. The Burns did not result in a change in shrub cover for all taxa except *Rubus*. The average cover in 2004 was 3.5%. The average for the same group of Control units measured in 2001 was 20.5%, which is more than twice the 2001 value. There was an increase in every unit, but this was not due to new species flourishing or rare species expanding a lot – the same two taxa (Corylus spp., Hamamelis virginiana) were dominant. The non-Rubus cover in the M+H units average 13.3% but ranged from 2.6 – 29.2%.

Figure 9. Effects of treatment induced mortality (2003, 2004) and the combined effect of mortality and sprouting (2004+) on stems in the intermediate layer.



The treatments resulted in greater cover of Rubus. The percent cover of Rubus was 25.1%, 20.7% and 11.0% for the Burns, M+H and Controls, respectively.

A. VEGETATION – ARBOREAL SEEDLINGS

The prescribed burns resulted in 2X+ mortality rate for seedlings by the end of the first growing season, whereas the M+H treatment, on average, was identical to that of the Controls (Table 10). One M+H units (#10) had a very high mortality rate [more than four times greater] in comparison to the other two. If this one unit is set aside, the M+H treatment had a mortality rate *only one-half* that of the Controls.

Arboreal seedling density sharply rebounded in the treated units in 2004. The density in the burned units doubled and the density in the M+H units increased approximately six-fold. Given that the Control units exhibited a 12.8% increase, the patterns in the treated units is clearly an ecologically significant treatment effect. The ANOVA (years 2002-04) indicated a significant 'Time' effect (p=.003), no Treatment effect (p=.12) and a marginal 'Time-x-Treatment' interaction (p=.06). The 2004 densities represent numbers of seedlings that were 3-times smaller (Burns) and 3.5 times larger (M+H) than the August, 2002 values. These comparisons, plus the trend in the control units (collectively and individually) point to the highly dynamic and ephemeral nature of this vegetative component.

From an ecological and management perspective, the composition of the seedling bank can be of paramount importance. One aspect of this highlighted earlier (and in the tables) is the level of dominance (Relative Density) by red or sugar maple. The ANOVA of this response variable indicated no Time effect (p=.70), no Treatment effect (p=.30), and a marginal Time-x-Treatment effect (p=.07). To summarize this facet, I compare the combined dominance of these two maples in August, 2002 to the situation in August, 2004. For the Burns, there was a modest drop (0.82 to 0.66), whereas the M+H units exhibited a doubling (0.36 to 0.78). The background pattern was a very small decrease in maple dominance (0.83 to 0.78, average of all Controls). Thus, the two treatments had divergent effects in this regard also.

A second dimension of the seedling composition component is the identity of new stems established in response to the treatments; in general, this cohort was dominated by red and/or sugar maple. Given the environment-altering effect of site preparation, it was expected that intolerant [pioneer-type] species would increase. Of 77 seedlings alive in the Burn units in August, 2004, only four (5%) were intolerant or intermediately tolerant. In the M+H units, we found 356 seedlings in August, 2004, only 12 (3.4%) of this class (group included white pine, paper birch, aspen, pin cherry and black cherry). The situation in the Controls was 8 'intolerants' out of 348 (2.3%). Thus, the site preparation had a very small effect on this group of species.

A. VEGETATION – UNDERSTORY

The understory layer exhibited dramatic responses to the treatments; however, the magnitude of the response varied by season, treatment, response variable and year. The general patterns included: i) much greater response in cover than in richness, ii) cover of the early season assemblage was reduced in 2003 but increased in 2004, iii) whereas the late-season assemblage showed almost no response in 2003 but a sharp increase in 2004, and iv) the M+H affected the early season assemblage more and the late-season assemblage less.

<u>Cover.</u>

The changes in cover from June, 2002 to June, 2003 were small in absolute magnitude but notable in relative terms. The cover in the Burns was reduced 29% and in the M+H units it declined by approximately 80% (Table12). In the second growing season, early season cover exploded in the Burned units, increasing 9-fold in comparison to the 2003 value. The M+H units showed a similar level of change.

Table 11 . Post-treatment arboreal seedling densities and dominant species by unit, August 2003 and 2004.

Unit	#/m²		Dom. Spp.		Rel. Abund.	
	2003	2004	2003	2004	2003	2004
1	0.50	1.06	Acru	Acru	0.38	0.47
2	0.44	1.81	Acru	Acru	0.88	0.41
3	0.56	0.88	Prpe	Acsa	0.56	0.50
4	0.75	1.06	Acsa	Acsa	0.67	0.65
Mean =	**0.56**	**1.20**				**0.51**
5	4.69	4.94	Acsa	Acsa	0.89	0.94
6	1.62	1.12	Acsa	Acsa	0.96	0.61
12	3.31	3.56	Acru	Acru	0.62	0.51
13	2..81	2.75	Acru	Acsa	0.58	0.50[1]
14	3.63	NM	Acru	--	0.72	--
16	NM	4.56	---	Acru	---	0.44
Mean =	**3.21**	**3.62**				**0.60**
9	1.62	8.12	Acer[2]	Acru	0.27	0.62
10	0.62	2.44	Acru	Acru	0.60	0.60
11	1.50	11.69	Acsp	Acru	0.29	0.91
Mean =	**1.25**	**7.42**				**0.71**

[1] Red maple was essentially a co-dominant with 0.48 Rel. Abund.
[2] Both red and sugar maple had a Rel. Abund. of 0.27

For the late season assemblage, the M+H caused a significant reduction (31%) the first year, but the Burns only a small one (10%; Table 12). These values may not indicate the full effect of the treatments, though they were calculated in the same manner as the other changes reported previously. Over this same time period (Aug. 2002 – Aug. 2003) the Controls exhibited a > 50% reduction in cover, thus there may have been a positive effect of the burns that translated into a much smaller reduction than would have occurred. This assessment is corroborated by the ANOVA which indicated a significant Time effect ($p<.001$), a significant Treatment effect ($p=.003$), and a significant Time-x-Treatment interaction ($p=.04$). By the end of the second growing season, the treatments resulted in a doubling (Burns) or tripling (M+H) of cover. The Control also rebounded to their 2002 level of cover.

Table 12. Cover of all understory plants by period, year and treatment; 2002 represents the pre-treatment benchmark.

	JUNE 02	AUG. 02	JUNE 03	AUG. 03	JUNE 04	AUG. 04
BURN	7.9	48.3	5.6	44.3	51	95.6
M + H*	14.5	37	2.8	25.4	31	64.1
CONTROL	14.5	50.5	27	23.8	32.8	51.6

*The M+H units were not surveyed in June, 2002. The Control value is being used as the benchmark.

Richness.

Overall, richness was less affected than cover; however, the early season assemblage (hereafter vernal species) appears to have been reduced an ecologically significant amount in 2003, especially by the M+H treatment (Table 13). By 2004, the vernal species rebounded vigorously and were at (M+H) or above (Burns increased by ~ 60%) the June, 2002 level.

There was a small decrease in richness of the late season assemblage in all three treatments; therefore, there was no site preparation induced effect (Table 13). In contrast, a sharp increase was noted in 2004. The ANOVA consistently corroborates these, indicating a strong Time effect ($p<.001$), a significant treatment effect ($p=.04$), but no Time-x-Treatment interaction ($p=.52$).

Table 13. Richnes of the understory layer by period, year and treatment; 2002 represents the pre-treatment benchmark.

	JUNE 02	AUG. 02	JUNE 03	AUG. 03	JUNE 04	AUG. 04
BURN	26.5	38.7	22	35.5	43	46.2
M + H*	34.3	33.3	17	28	36.3	40.3
CONTROL	34.3	35	37	31	36.5	37.5

Compositional Turnover.

The number of species at a particular time is a function of the total number previously, the number lost since the previous census, plus any new arrivals. To more completely assess the impacts of disturbance, this turnover should be examined. The two site preparation treatments induced significant changes; for the vernal species in 2003 the major impact was the loss of species (Table 14). In 2004, the treatments resulted in significantly higher rates of invasion at both times of the growing season.

Table 14. The number of species lost between sample periods and the number of new arrivals by year, time period and treatment.

	Turnover (new/lost) By Time Period		
Treatment	June02-03	June03-04	Aug03-04
Burn	7.5/11.5	19.7/2.5	22.2/14.5
M+H	CND*	24.3/5.0	------------
Control	7.0/7.0	7.4/7.0	12.7/7.5

* = Could not determine due to lack of June, 2002 data

B. FUEL

Litter.

Given the difference in sampling intensity, the litter mass values showed high consistency between 2003 and 2004. The weight of the Controls was twice as high as the Burns and 75% higher than the M+H units (Table 15). The sampling intensity was lower in 2004, which is reflected in the higher standard deviations. The purpose of the 2004 re-measurement was to confirm the 2003 values and to detect any major changes (though none were expected) that might have occurred. The Repeated Measures ANOVA confirms the consistency between years (Time effect, p=.47) and the Treatment effect (p=.04).

The changes in litter mass induced by the burns averaged 39% (range 22 – 54%) [compare Tables 6 and 15]. The reliability of the litter estimates was acceptable, which is documented by the changes in the Controls -- the average change from 2001 to 2003 (or 2004 for Units 5,6 & 16) was 15%. With two values excluded (Units 6 and 12), the average change was only 3.2%

Woody Fuels.

The change in Total Woody Fuel Load caused by the treatments were diametrically opposite; 3 of 4 burns reduced the woody load about 27% whereas the *M+H treatment increased* the woody load 61% on average (Table 16). The paired sample t-test suggested a significant difference ($.05 > p > .01$) in the Burn units, but no significant effect ($.20 > p > .10$) from the Mechanical treatment. By comparing the values in Table 16 for 'Total' and '1000-hr', it can be seen that the majority of the increase due to the Mechanical treatment was in fuels less than 7.6 cm (i.e., 1-hr to 100-hr classes). In one Burn unit, the fire resulted in a 40% increase in woody fuel load. As noted in the pre-treatment measurements, a rather large amount of temporal variation was noted in a few units.

A. TREATMENT EFFECTS, SOIL

Though no data can be presented, I can report that there was no general indication (in qualitative terms) that either treatment resulted in reduced infiltration rates (C. David, pers. comm., August, 2003)

The treatments resulted in some surprising effects on the nutrient pools (mostly available pools) in these systems. In 2003 (approximately 7 weeks after the burns), the amount of ammonium (the dominant form of available N in most forest systems) was 3-times greater in the M+H units than the Burns (Table 17). Given that the Controls had an intermediate level of NH_4^+, the fires apparently reduced ammonium and the M+H increased its availability in the soil. The 1-WAY ANOVA indicated a marginally significant ($p=.09$) treatment effect.

The various 'metallic' ions tested showed a range of rankings amount units. For these nutrients, the Control units are presented by Compartment because there were often very large differences between them. Based on spatial arrangement, Units 5 & 6 would be the most suitable controls for the Burns and Units 12-14, 16 more suitable for the M+H treatment. There are very few consistent (across the nutrients) patterns in these data. One of the few we noted was that for 4 of the 5 with moderate differences among treatments, one of the Controls had the highest level; the exception is sulfur. ANOVA indicated that calcium ($p=.02$), manganese ($p=.02$) and sulfur ($p=.002$) varied significantly among treatments.

Table 15. Litter weights (t/ac) means and standard deviations (SD) in 2003 and 2004 (1- and 2-yr post treatment) by unit and treatment.

2003

BURN		M+H		CNTRL	
Unit	Mean	Unit	Mean	Unit	Mean
1	.66	9	.62	12	.92
2	.72	10	.72	13	1.77
3	.64	11	1.0	14	1.24
4	.65				
Mean	.67	Mean	.75	Mean	1.31
SD	9.95	SD	13.60	SD	13.02

2004

BURN		M+H		CNTRL	
Unit	Mean	Unit	Mean	Unit	Mean
1	NM	9	0.77	5	1.08
2	.85	10	0.67	6	0.95
3	.42	11	1.05	12	1.14
4	.65			13	1.24
				14	0.91
				16	1.50
Mean	.69	Mean	.83	Mean	1.12
SD	10.55	SD	18.34	SD	23.33

Table 16. Woody fuels (total and 1000-hr only) by year, unit and treatment. Data are tons/ac. NM = not measured that year; CND = could not determine. 2001 was used as the most appropriate pre-treatment value for the Burns (Units 1-4) and Controls (units 5-6, 12-14, 16) because of larger sample size. Changes were calculated as 'Pre-' minus 'Post', thus a negative value indicates a fuel load increase.

UNIT	2001 TOTAL	2001 1000	2002 TOTAL	2002 1000	2003 TOTAL	2003 1000	Post TOTAL	2004 TOTAL	2004 1000	% Change pre- vs. post
1	11.1	7.7	8.9	5.2	8.4	3.7	2.7	6.9	4.4	0.243
2	19.4	14.1	19.9	15.4	13.7	9.5	5.7	13.8	11.7	0.294
3	21.1	15.9	19.7	14.8	15.2	6.3	5.9	16.4	11.9	0.280
4	7.5	4.4	10.8	6.8	[16.1]*	[3.6]*	-3	13.8	9.9	-0.400
									Avg.	**0.272**
5	22.2	18	20.2	17.9	NM	NM	2	13.8	11.1	CND
6	13	5.5	12.3	5.5	NM	NM	0.7	7.4	4	CND
12	26.2	22	NM	NM	22.1	18.4	4.1	13.3	6.8	0.156
13	14.2	10.4	NM	NM	11.3	4.7	2.9	7.6	3.6	0.204
14	10.3	7.1	NM	NM	8.8	3.1	1.5	8.7	6	0.146
16	21.8	17.2	19.9	12.8	NM	NM	1.9	7.8	4.7	CND
9	NM	NM	10.6	6.7	22.8	0.7	-12.2	24.6	11.3	-1.151
10	NM	NM	16.6	12.3	21.2	9.8	-4.6	14.5	6.9	-0.277
11	NM	NM	9.5	5.2	13.2	5.8	-3.7	22.2	7.8	-0.389
									Avg.	**-0.606**

* Estimate is based on transects that differ in location from 2002 and 2004, and thus are not a suitable comparison.

Table 17. Soil ammonium concentration in June, 2003 by treatment and unit.

Unit	Conc. (mg/kg)	Unit	Conc. (mg/kg)	Unit	Conc. (mg/kg)
1	71.0	9	320	5	64.5
3	70.2	10	223	6	75.0
4	104.3	11	162	12	252
Mean	81.8	Mean	234.7	13	114
				14	215
				Mean	144.2

Table 18. Soil nutrient concentrations (mg/kg) by treatment in June, 2003. Data are means (above) and standard deviation (below). The Controls are separated by Compartment.

	Ca	K	Mg	Mn	P	S
Burn	826.3	345.2	832.7	426.5	317.9	70.6
	322.46	148.40	189.37	230.78	88.13	26.96
Control	988.7	383.8	788.3	739.1	362.4	79.2
(Units 5,6)	371.74	110.19	227.19	595.11	158.22	17.06
Control	822.7	413.9	1155.0	589.8	218.0	119.0
(Units 12-14)	657.78	221.35	445.41	709.61	103.29	68.35
M + H	537.5	391.9	894.3	293.0	295.5	136.5
	351.09	215.71	335.96	254.90	169.56	73.47

The analyses of the soil samples collected in June, 2004, largely corroborated the patterns noted for 2003. For the metallic ions, the treatments were ranked similarly (phosphorus is an exception) [Table 19]. One difference of note, however, was the substantially higher levels in the 2004 samples. The total N analysis produced the same ranking for treatments as the did the ammonium levels in 2003; the percent carbon results were similar though the Burns were noticeably lower than the Controls (Table 20).

Table 19. Soil nutrient concentrations (mg/kg) by treatment in June, 2004. Data are means (above) and standard deviation (below). The Controls are separated by Compartment.

	Ca	K	Mg	Mn	P	S
BURN	1099.2	456.3	877.7	580.4	302.6	284.4
	474.85	181.12	238.74	348.94	97.16	98.01
CONTROL	1066.6	498.0	896.9	554.0	380.6	291.7
(Units 5 & 6)	353.57	235.69	239.20	346.58	90.36	97.23
CONTROL	948.8	541.3	1323.9	418.4	317.0	299.7
(Units 12-14, 16)	630.64	286.19	488.10	237.11	89.88	155.15
M+H	630.2	407.8	1019.3	334.8	260.5	387.0
	374.43	219.80	445.26	268.14	144.54	125.01

Table 20. Total nitrogen (%) and total carbon (%) in the mineral soil, June 2004, by sample, unit and treatment.

Burn	%N	%C	Mech.	%N	%C	Control	%N	%C
Unit 1-1	0.046	1.072	Unit 9-1	0.098	1.609	Unit 5-1	0.081	1.424
1-2	0.036	0.885	9-2	0.129	2.436	5-2	0.05	0.976
1-3	0.056	0.951	9-3	0.099	2.054	5-3	0.086	1.482
1-4	0.061	1.311	9-4	0.084	2.222	5-4	0.039	0.873
1-5	0.045	0.981	9-5	0.089	2.195	5-5	0.168	2.411
1-6	0.074	1.273	9-6	0.229	4.277	5-6	0.045	0.945
Unit 3-1	0.141	2.896	Unit 10-1	0.105	1.651	Unit 6-1	0.064	1.381
3-2	0.067	1.129	10-2	0.267	3.504	6-2	0.026	0.699
3-3	0.072	1.735	10-3	0.113	1.712	6-3	0.088	1.425
3-4	0.069	1.362	10-4	0.065	1.429	6-4	0.118	1.966
3-5	0.013	0.439	10-5	0.081	2.038	6-5	0.073	1.317
3-6	0.089	1.427	10-6	0.075	1.465	6-6	0.081	1.358
Unit 4-1	0.057	1.029	Unit 11-1	0.112	1.941	Unit 12-1	0.17	3.648
4-2	0.199	2.792	11-2	0.129	3.041	12-2	0.063	1.289
4-3	0.149	2.176	11-3	0.088	2.049	12-3	0.132	2.689
4-4	0.09	1.649	11-4	0.096	2.022	12-4	0.111	2.142
4-5	0.099	1.536	11-5	0.114	2.67	12-5	0.096	1.664
4-6	0.038	0.847	11-6	0.129	3.043	12-6	0.079	1.805
Avg.	**0.078**	**1.416**	**Avg.**	**0.117**	**2.298**	**Avg.**	**0.087**	**1.639**

DISCUSSION & IMPLICATIONS

Fuel Loads Changes Due to Treatments & Use of Prescribed Fire

It is clear that these relatively low intensity fires had a modest impact on the fuel loads. However, when re-introducing fire into a system from which it has been excluded for a long period of time, a low intensity fire may be the appropriate first step to avoid unacceptable impacts on the system (e.g., Bastian 2001). Nonetheless, we believe that a more intense (and severe) fire would be safe to utilize. Based on the behavior of the burns, the original prescription (see project proposal) was very close to the conditions that are suitable. More specifically, if we had been able to wait about 2-3 more days, keep the RH at or below 30% and have a steady wind of ~ 6-8 kph, we predict the woody fuel consumption would have been notably higher, sapling layer mortality in 2003 higher, and litter layer reduction greater. Furthermore, it is not likely, given the impacts we found, that other fire effects would have been alarming or unacceptable to the Tribe or MTE. If protection of the overstory is a paramount concern, removal of the fresh litter around the trees is highly effective, at least under the conditions of these burns.

Two other noteworthy results are that the form of mechanical site preparation used (dragging of anchor chains) is definitely not a potential fuel reduction technique for forest systems that have a moderate-high density of sapling, small pole size trees. The net effect was to take a sizable live fuel component and transfer it to 10- and 100-hr dead fuel classes. The second point of note is the fuel increase (Unit 4) caused by burning. Though not the norm, an increase like this has been noted in other burning studies (e.g., Cole et al. 1992). We are confident that the effect was 'real' because our 2004 estimate corroborated the 2003 value. The actual reason [mechanism] for the increase is not clear. There were not any treefalls noted, yet 1000-hr fuels also increased. Therefore, one plausible explanation is a moderate level of large branch damage over the winter (ice, snow build up) or due to summer thunderstorm(s).

Fire Effects on Vegetation

We suggest that this study is illuminating and potentially important for the management (in the broadest sense) of eastern white pine forests in the Great Lakes Region (including the adjacent portions of Canada). This forest type has been regularly characterized as a fire-maintained system with a regime of high intensity events (150-250 yr return interval) separated by 20-40 yr interval low intensity fires (e.g., Frelich 1992, Carey 1996). To our knowledge, no one has investigated the impact or ecological role of the low intensity portion of the regime. Both the vegetative impact/response and the magnitude of the soil impacts we documented are helpful in beginning to fill this information void. Of particular note it is the effect on richness, invasion and species turnover in the understory layer. The variation between time periods and the magnitude of the effect are potentially very important. This type of information is directly relevant to the issue of landscape level bio-diversity and the role that natural disturbance has in shaping it. Though much more than 2-yr of response are needed, as well as varying intensities of fires, these data are a first big step.

The effects of fires such as these on long-term changes in the arboreal component are a bit speculative; however, the suggestions of these prescribed burns deserves a brief description. First, they did not cause any overstory mortality of note, and thus there was no effect through that stratum. The effect on the intermediate layer was quite obvious and striking by 2004, but also a bit mis-leading given the level of re-sprouting. The probable effect, if it is allowed to play out without further disturbance is to increase the maple component at the expense of other genera (Betula, Prunus, and perhaps others). This is noteworthy because the seedling layer composition was not altered, and thus the maples maintained their dominance if this layer as well. The combined, long-term implication is a major shift to maple-dominated overstory. Given the high richness of the intermediate layer, a variety of other species will maintain themselves at low levels. Of practical note is the difference between M+H and the Burns. The M+H treatment resulted in higher intermediate mortality and less sprouting, so the relative dominance of species is likely to be somewhat different.

Soil Nutrient Availability

Because the treated units did not always have the lowest nor highest values, and the order among the units varied, we conclude that meso- or micro-scale differences in other factors (e.g., parent material, micro-topography, vegetation) largely control the levels of the metallic ions tested. However, it appears that the M+H treatment results in short term increases in nitrogen whereas the fires did not. This could be a net effect of 1) less uptake in M+H units due to greater reduction of the intermediate layer density and understory layer cover, 2) greater exposure of the forest floor, and thus higher temperatures in the upper soil layer(s) in M+H units, 3) and volatilization in Burn units. Overall, it seems clear that the treatments cause little-to-no changes in nutrient availability.

Fire Behavior Variation

An array of heat sensitive material such as used in this study provides a wealth of information on fire behavior; it provides estimates of the maximum temperatures, spatial variation in intensity, and an indication of the upward heat flux in the immediate vicinity of the posts. Though the limitations of the methodology are not trivial, some are compensated by the ease of pre-burn preparation, low cost, large amount of data that can be gathered, and the flexibility in the pattern that can be used.

Our results, plus that of others (Hobbs et al. 1984; Cole et al. 1992), show that temperature profiles clearly capture important differences among burns within the same fuel complexes and among community types. Profiles essentially represent two-dimensional summary graphs of temperature that integrate the effects of fuel structure, load and composition; local weather; and ignition pattern. Though they do not indicate the horizontal variation in behavior, they provide an easy-to-interpret form of the vertical variation.

One important benefit of this detailed behavior characterization is its capacity to identify differences between burns that appear to be very similar based on summary type statistics. Neither the average flame heights nor the chi-square analysis indicated that the burn in Unit 3 was significantly hotter than the others; however, the temperature profile clearly indicates it was.

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APPENDIX A

Figure 1. Treatment unit (0.81 ha) showing the arrangement of posts (permanent sampling locations) and intermediate vegetation sub-plots. The woody fuel and shrub cover data were collected along a line originating at a subset of the posts (see Methods for details).

APPENDIX B

Table 1. Pre-treatment vegetation data by treatment unit; measurements taken in 2001 (Units 1-6, 12-16) or 2002 (Units 9-11).

TRT	OVERST. PINE BA	OVERST. HWD BA	PINE	HARDWOOD	INTERM	INTERM.	SEEDL.	SEEDL	SEEDL	UNDER	STORY
UNIT	(m^2/ha)	(m^2/ha)	AVG. DIAM.(cm)	AVG. DIAM (cm)	DENS. (#/ha)	# SPP.	DENS. (1000/ha)	DOM. SPP.	REL. DENS.	AVG. COV.(%)	# SPP.
1	16.3	3.7	69.6	40.6	2208	11	85.5	ACRU	.51	18.6	32
2	28.7	0.8	67.3	32.3	1862	16	48.2	ACSA	.74	12.3	34
3	24.3	3.2	70.9	47.8	1569	13	22.5	ACSA	.64	41.9	44
4	22.6	5.7	75.2	45.0	1603	19	85.0	ACSA	.96	19.7	41
5	16.0	3.8	74.4	43.4	1485	16	63.8	ACSA	.94	20.2	36
6	24.9	3.2	73.9	35.1	1603	14	23.7	ACSA	.76	13.9	45
9	24.5	3.9	67.3	33.3	1693	14	19.4	ACSP	.42	25.5	30
10	27.1	1.9	66.5	32.8	1569	17	25.6	ACSA	.29	51.2	30
11	29.1	2.2	63.5	34.0	1878	17	18.1	ACRU	.34	34.2	35
12	23.5	2.2	62.1	31.0	636	10	25.0	ACRU	.52	19.5	36
13	34.3	2.2	62.7	37.6	963	9	89.7	ACRU	.51	22.1	32
14	23.3	3.8	61.5	33.3	1093	11	67.0	ACRU	.36	10.8	36
16	20.5	1.8	63.0	35.3	655	9	55.6	ACSA	.79	23.8	42

APPENDIX C. Presenter, title, date and location for presentations made with the results generated by this study.

1. Betsy Galbraith. Determinants of understory richness and diversity in old-growth managed white pine stands . Ecological Society of America Annual Meeting, Tucson AZ, August, 2002.

2. Nicholas Jensen. “Short-term understory response to prescribed fire on Menominee Reservations” UW-SP, CNR Undergraduate Research Symposium, April, 2003, Stevens Point WI.

3. J. E. Cook. A comparison of site preparation methods for managing white pine on the Menominee Reservation. April, 2005, Stevens Point WI.

4. Nicholas Jensen and Andrew Pivonka. Soil nutrient response to understory treatments on Menominee Reservation. UW-SP, CNR Undergraduate Research Symposium, April, 2005, Stevens Point WI.

5. J. E. Cook. “Low intensity fire effects on the vegetation of mature eastern white pine forests on mesic sites in northeastern Wisconsin. N. Amer. Forest Ecology Workshop, Ottawa Canada, June, 2005.