CHARACTERIZING MECHANICAL AND PRESCRIBED FIRE TREATMENTS FOLLOWING CLEAR-CUTTING OF JACK PINE AND SHORT-TERM TREATMENT EFFECTS ON INSECT COMMUNITIES

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ABSTRACT

Effects of post-harvest mechanical treatment, prescribed fire, and mechanical treatment followed by prescribed fire in jack pine (*Pinus banksiana*) were characterized on 0.4-ha treatment areas on the Baraga Plains in the Upper Peninsula of Michigan. The effects of these treatments on ground-dwelling arthropod communities were investigated. Differences in mean basal area and diameter at breast height among treatments prior to harvest were not significant.

Fuel loading assessments showed that prescribed fire reduced smaller size classes (<5 cm diameter) of fuels, although prescribed fire did not significantly reduce total fuel loading. The percentage of closed jack pine cones was lower in burned areas (0% in prescribed fire–only treatments, 9.6% in mechanical treatment followed by prescribed fire) than in non-burned areas (55.1% in untreated areas and 23.4% in mechanical treatment–only areas). Burn coverage was less in areas that had mechanical treatment followed by prescribed fire than in areas that received only prescribed fire.

In the first post-treatment growing season, prescribed fire decreased the taxonomic richness and Shannon–Wiener diversity of ground-dwelling arthropods. Mean pitfall trap catches for ants (Hymenoptera: Formicidae) were significantly higher in prescribed fire–only areas (64.6 individuals/trap) than in untreated control areas (12.1 individuals/trap). Mean pitfall trap catches for leaf beetles (Coleoptera: Chrysomelidae) and plant bugs (Hemiptera: Miridae) were significantly lower in prescribed fire–only areas (0.0 and 0.7 individuals/trap, respectively) compared with untreated controls (0.5 and 8.1 individuals/trap, respectively). Lower numbers of arachnids and ground beetles (Coleoptera: Carabidae) were trapped in areas treated with a combination of fire and mechanical treatments (2.3 and 2.4 individuals/trap, respectively) than in untreated control areas (7.0 and 5.1 individuals/trap, respectively), and lower numbers of wingless long-horned grasshoppers (Orthoptera: Gryllacrididae) were caught in both of the treatments that included fire (0.1 individuals/trap in both treatments) compared with untreated control areas (0.5 individuals/trap). Continued monitoring of these sites will enable management recommendations to be made with respect to impacts on ground-dwelling arthropod communities.

keywords: fuels, ground-dwelling arthropod, jack pine, mechanical treatment, Michigan, *Pinus banksiana*, prescribed fire.

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INTRODUCTION

Jack pine (*Pinus banksiana*) is widely distributed throughout Canada and the northeastern and north-central United States (Rudolph and Laidly 1990), including the well-drained, sandy outwash of the Baraga Plains in the Upper Peninsula of Michigan (Berndt 1988). Fire can be important to the jack pine ecosystem for stand replacement (Chapman 1952, Ahlgren 1959, Chrosciewicz 1959), and for mineral cycling, seed dispersal, and management of forest pests and diseases (Rouse 1986, Desponts and Payette 1992). Periodic stand-replacing fires occur naturally in jack pine (Beaufait 1962, McRae 1979, Cayford and McRae 1983), when seeds encased in serotinous cones are released when heated to at least 45°C (Keeley and Zedler 1998). Fire-scarified mineral soils are ideal for jack pine seed germination (Smith et al. 1997), but seeds can be destroyed by overly intense fires (Chrosciewicz 1959, Smith et al. 1997). Therefore, stand-replacing fires may be more detrimental to jack pine regeneration in some cases than low-intensity prescribed fires, which may be used for slash removal, soil scarification, and seed distribution following harvesting (Beaufait 1962, Chrosciewicz 1970, Cayford and McRae 1983).

The jack pine barrens ecosystem in Michigan's Upper Peninsula has been characterized as fragmented, due to land use and fire exclusion (Pregitzer and Saunders 1999). Clear-cutting on a 50-y rotation is a common management practice for jack pine (Houseman and Anderson 2002), and mechanical treatments are often utilized in post-harvest jack pine management to control logging slash to enhance natural regeneration. Examples of these mechanical treatments include anchor-chaining, manual collection–slash removal, and using a whole-tree cutting system instead of a cut-to-length system (Smith et al. 1997). The natural fire regime in jack pine of the Baraga Plains is a 25- to 100-y interval (Van Wagner 1978, Heinselman 1981, Whit-

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ney 1986, Pregitzer and Saunders 1999). The last major fire on the Baraga Plains was an escaped campfire in the 1980s (M. Nelson, Michigan Department of Natural Resources, personal communication).

In jack pine, high-intensity crown fires help in seed dispersal and do not decrease seed viability (Beaufait 1960). Prescribed burning exposes and scarifies mineral soil, enhancing regeneration (Chrosciewicz 1970), and can be used to decrease slash, prepare mineral seedbeds, and control forest pests in jack pine (Beaufait 1962, McRae 1979). Branch age is an important determinant of serotiny, and differences in serotiny may be caused by the variation in the fire regime (Gauthier et al. 1993, Radeloff et al. 2004). Fire can be used to enhance jack pine regeneration, but fire intensity is often too low in small jack pine slash fires and too high in large, stand-replacing crown fires (Chrosciewicz 1959). Indeed, in a comparison of vegetation changes between burned and unburned areas of post-harvest jack pine in northern Lower Michigan, there was a lack of natural jack pine regeneration in response to fire (Abrams and Dickmann 1984).

The effects of mechanical treatment alone, or with small-scale prescribed fire, may mimic certain aspects of natural wildfire, such as seed release from serotinous cones and exposure of mineral soil. Comparing effects of mechanical treatments (such as anchor chaining) and prescribed fire is useful for forestry in the Upper Great Lakes area, and in other jack pine–dominated systems. However, the short- and long-term ecological costs of these practices on the Baraga Plains are not known. One of these ecological costs could be the reduction in biodiversity of ground-dwelling arthropods. Ground-dwelling arthropods are important, as they typically account for a large proportion of the species composition in a given area (Schowalter 2000, Hanula and Wade 2003), and many ground-dwelling arthropod taxa are sensitive to disturbance. In this small-scale study we examined the short-term impacts of fire and mechanical treatments on ground-dwelling arthropod communities. Characterizing the effects of fire and mechanical treatments on jack pine slash will assist in the post-harvest site-preparation decision-making process for land managers.

The objectives of this project were to 1) characterize the effects of prescribed fire and mechanical treatment on fuel load, closed cone percentage, and burn coverage in a post-harvest jack pine site; and 2) determine the differences in biodiversity of ground-dwelling arthropods resulting from prescribed fire and mechanical treatment in a post-harvest jack pine site.

STUDY AREA

The study area was approximately 20 ha and located in the Michigan Technological University Ford Center Research Forest, Baraga County, Michigan (WGS84: lat 46°38′41.6″N, long 88°31′51.9″W). This area was generally characterized by excessively drained soils and level sandy outwash that was dominated by jack pine and associated vegetation types (Berndt 1988). The study site was surrounded by land managed for blueberry (*Vaccinium* spp.) production, other softwood stands (mostly comprising red pine [*Pinus resinosa*] and jack pine), and mixed hardwood–softwood stands. Mean tree age prior to harvest was 50 y.

Baseline forest inventory data were collected in May–June 2003 from each of five 0.04-ha plots in each treatment area (see Methods). Data recorded included species and diameter at breast height (DBH) of trees that were within the plot, and the height of every fifth live tree. Basal area (BA) per tree was determined, and mean BA per plot was calculated in square meters per hectare (Avery and Burkhart 1994).

METHODS

Study Design

The study site was divided into 16 treatment units, with four treatments applied randomly in each of four treatment areas so that each treatment was replicated four times. Treatments were untreated (i.e., control), mechanical site preparation by anchor chaining, prescribed fire, and prescribed fire following anchor chaining. Treatment areas were 0.40 ha, but each extended into a 12-m-wide buffer–firebreak. Including the buffer–firebreak, each treatment area was approximately 0.64 ha. Treatments were installed in the study site randomly with the constraint that one treatment area of each treatment type would be located in one of the four treatments abutting a road to the north so that the study site could be used as a demonstration site (Figure 1).

Inside each 0.40-ha treatment area, five circular 0.04-ha plots were established. The corners of the treatment areas and buffers, and the centers of the 0.04-ha plots were marked with pieces of reinforcing rod with numbered aluminum tags. Following harvest and mechanical treatment, the reinforcing rod markers were found with a metal detector, or corners and centers were relocated and marked again.

The entire study site was clear-cut from September to November 2003. Mechanical site preparation was achieved by anchor chaining in May 2004, prior to any pre-fire data collection. Firelines were installed in May 2004, and prescribed fires occurred in July 2004 under the direction of the Michigan Department of Natural Resources (Figure 2).

Ground-Dwelling Arthropods

Pre-harvest pitfall trapping of ground-dwelling arthropods was carried out in June 2003. Following harvest and mechanical treatment, pre-fire trapping was carried out in May–June 2004, and post-fire trapping was carried out in July–August 2004. A transect of five pitfall traps was installed in each treatment area, for a total of 80 pitfall traps. Azimuth and distance of each transect from the center of each treatment area were determined randomly. Traps were installed at 5-m intervals along the same transect (Ward et al. 2001). Traps consisted of two plastic cups with an 8.3-cm-diameter opening and 12.4-

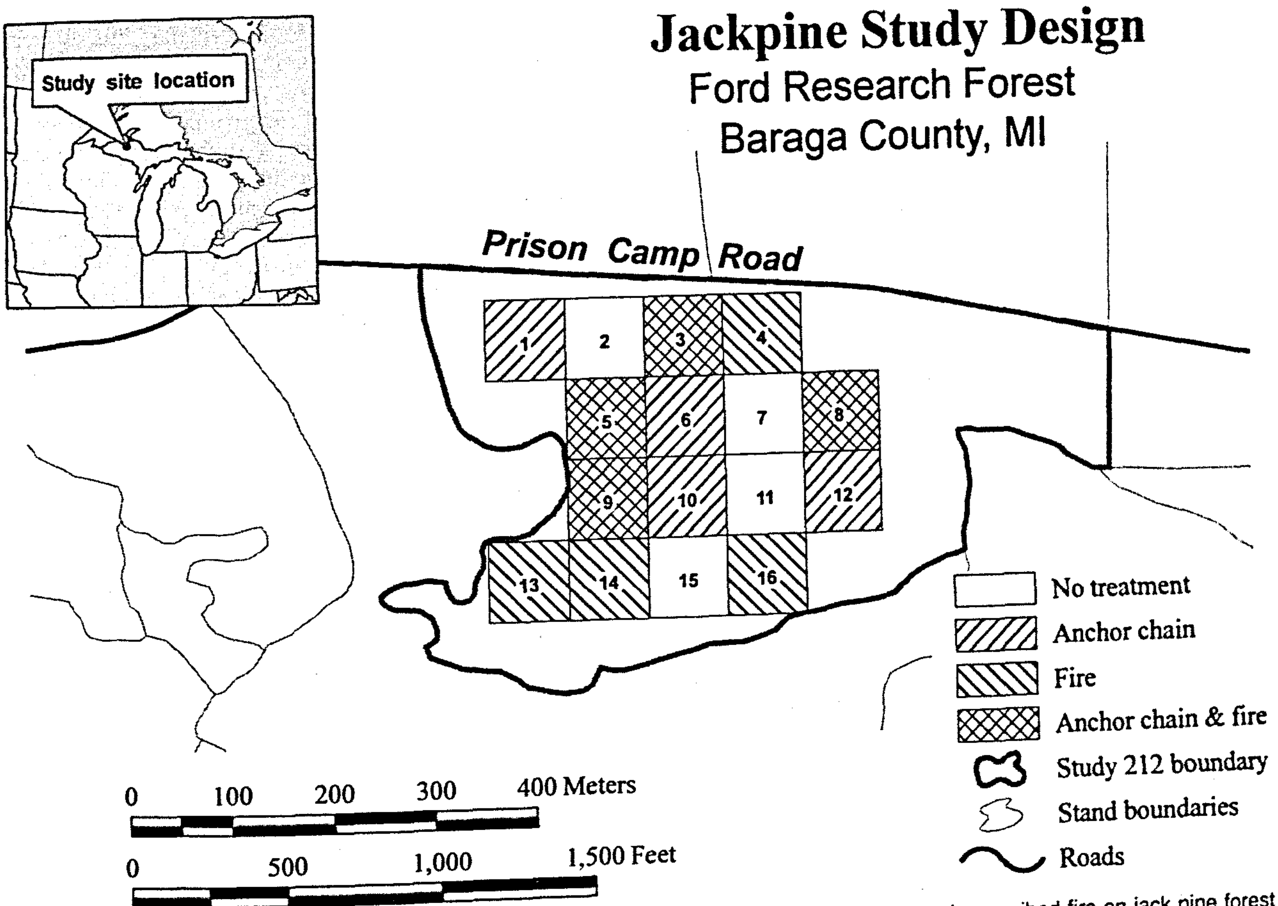

Fig. 1. Treatment installation in a study of the post-harvest effects of mechanical treatment and prescribed fire on jack pine forest biodiversity, Ford Center Research Forest, Baraga County, Michigan. Source: Michael D. Hyslop, Michigan Technological University.

cm depth, one inside the other, inserted into a hole in the ground. A Styrofoam plate was placed above each trap to prevent rainwater from entering. A gap of 2.5 cm was maintained between the plate and the cup by using nails as spacers. The top of the cups in each trap was level with the surface of the forest floor, and each was filled up to 5 cm with a 50% propylene glycol (Prestone® LowTox™ antifreeze) solution. Traps were left open for 1 week, the contents collected, and then the process was repeated, for a total of two rounds of pitfall trap catches per data collection period. Once trap contents were collected, insects were counted and identified to family, and arachnids were counted. Data from the five traps in each treatment area at each collection time were pooled.

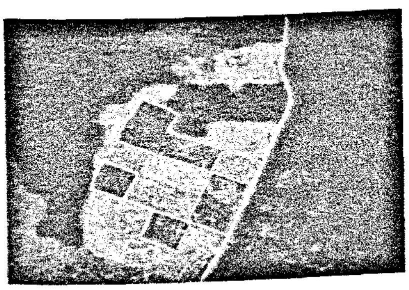

Fig. 2. Aerial photograph of the study site following mechanical treatment and prescribed fire (July 2004) in a study of the post-harvest effects on jack pine forest biodiversity, Ford Center Research Forest, Baraga County, Michigan. Source: Michigan Department of Natural Resources.

Fuel Loading

Pre-fire fuel-loading data were collected following mechanical treatment in May 2004 and post-fire fuel-loading data were collected in August 2004. Both fuel loading and closed cone percentage assessments were done using a line-intercept method modified from McRae et al. (1979), which was developed specifically for the jack pine forest type in the Upper Great Lakes area. Fuel loading was assessed by measuring coarse woody debris intersecting fire triangle lines, and classified into one of 24 fuel categories, depending on the size, species, and condition of the fuel. Based on McRae's (1979) procedure, for the first 2 m of a triangle side, all size classes were recorded. For the next 2 m, everything >0.49 cm was recorded. For the next 2 m, everything >0.99 cm was recorded. For the next 2 m, everything >2.99 cm was recorded. For the next 2 m, everything >4.99 cm was recorded. For the last 2 m of a triangle side, everything >7 cm was recorded. Go/no-go gauges made from sheet metal were used to quickly assign fuel to size classes (McRae et al. 1979).

Mean tonnes per hectare was calculated per plot

Table 1. Multiplication factors to determine fuel loading[a] in post-harvest jack pine. Modified from McRae et al. (1979).

Fuel diameter (cm)	Fuel type[b] Jack–Red pine	White spruce	Red–Sugar maple
0–0.49	0.0015	0.001	0.00175
0.50–0.99	0.00275	0.00275	0.003
1.00–2.99	0.011	0.01675	0.015
3.00–4.99	0.0395	0.04325	0.052
5.00–6.99	0.08325	0.0825	0.084
>7	0.0015	0.0015	0.002
Rotten	0.001	0.001	0.001

[a] To calculate fuel loading in kilograms per square meter, multiply number of intersects of each fuel size and type along triangular transects (each side 12 m long) by the multiplication factor in the table.
[b] Jack pine, *Pinus banksiana*; red pine, *Pinus resinosa*; white spruce, *Picea glauca*; red maple, *Acer rubrum*; sugar maple, *Acer saccharum*.

for each size class, as well as for total fuels. Only pieces of fuel whose midpoint intersected the line were counted. Twelve-meter transects were used as fuel triangle sides and final results were then converted from kilograms per hectare to tonnes per hectare (Table 1). Three triangles were randomly located in each treatment area for pre-fire and post-fire assessments, and mean fuel loads per treatment area were calculated. Species results were combined and classified into one of six size categories.

Burn Coverage and Closed Cone Percentage

Percent burn coverage of prescribed fire treatment areas was assessed in August 2004 along six randomly placed 20-m transects into each burned area. The distance (in centimeters) burned or unburned along each transect was measured to calculate mean percent burn coverage.

Pre-fire closed cone percentage data (collected following mechanical treatment in May 2004) and post-fire percentage closed cone (percent serotinous) data (collected in August 2004) were collected by recording all cones attached to woody debris that intersected fuel transect lines in each treatment area. The mean percentage of closed cones was calculated for each treatment area.

Statistical Analyses

For all data collected, means per treatment area at each time of data collection were calculated, with the exception of burn coverage data. For burn coverage data, one-way analysis of variance and least significant difference tests were used to test for differences in mean percent burn coverage between prescribed fire areas and areas treated mechanically prior to prescribed fire. For ground-dwelling arthropod data, taxonomic richness (S) and Shannon–Wiener diversity (*H*) were calculated per trap for each treatment area, using taxa that were identified from the trap catches (Hayek and Buzas 1997). Differences among the four treatments were tested using one-way analysis of variance. Arcsine transformations of proportional data were used for the closed cone percentage assessments and burn coverage assessment, square-root transformations were used for tree diameter data, and log transformations were used for ground-dwelling arthropods in the Formicidae and Arachnida. Where treatment effects were significant, pairwise comparisons between the treatments were made using least significant difference tests. Comparisons of trap catches between dates were not made because of seasonal differences in the data, and data for the two rounds of trapping that occurred post-fire were pooled. Data were analyzed with Statistix 8.0 (Analytical Software 2003). All transformed data were back-transformed for presentation.

RESULTS

Forest Inventory

In the baseline forest inventory, jack pine accounted for 97% of tree species found at the study site. Of the standing jack pines, 19.0% were dead. The mean BA of the study site was 18.22 m^2/ha (SE = 1.13), the mean DBH was 19.8 cm (SE = 0.30), and mean tree height was 16.6 m (SE = 0.93). From data collected prior to the harvest, differences in mean BA between treatments were not significant ($F = 1.65$, df = 3, 12, $P = 0.230$) nor were differences in mean DBH ($F = 0.38$, df = 3, 12, $P = 0.767$).

Fuel Loading

In the pre-fire survey, only the fuel loading in the 0.5–1-cm size class differed significantly between treatments (Figure 3). In the post-fire survey, fuel loading was different among treatments for the four smallest size classes (respectively: $F = 25.73$, df = 3, 12, $P < 0.001$; $F = 18.23$, df = 3, 12, $P < 0.001$; $F = 17.60$, df = 3, 12, $P < 0.001$; $F = 5.58$, df = 3, 12, $P = 0.012$). In the post-fire survey, all non-control treatments reduced the fuel loading in the <0.5 cm, 0.5–1-cm, 1–3-cm size classes while fire treatments reduced fuel loading in the 3–5-cm size class (Figure 3). Post-fire differences between treatments in the larger fuel classes and total fuel loading were not significant (Figure 3).

Burn Coverage and Closed Cone Percentage

Burn coverage was 94% in fire-only areas and 61% in areas with mechanical treatment followed by prescribed fire. The difference in mean burn coverage between these two treatments was significant ($F = 11.42$, df = 1, 6, $P = 0.015$).

Differences in mean closed cone percentage among treatments were not significant in the pre-fire assessment ($F = 0.76$, df = 3, 12, $P = 0.537$). However, differences in mean closed cone percentage among treatments were significant in the post-fire assessment ($F = 30.27$, df = 3, 12, $P < 0.001$) (Figure 4). The percentage of closed cones was lowest in fire-only treatments and highest in control areas.

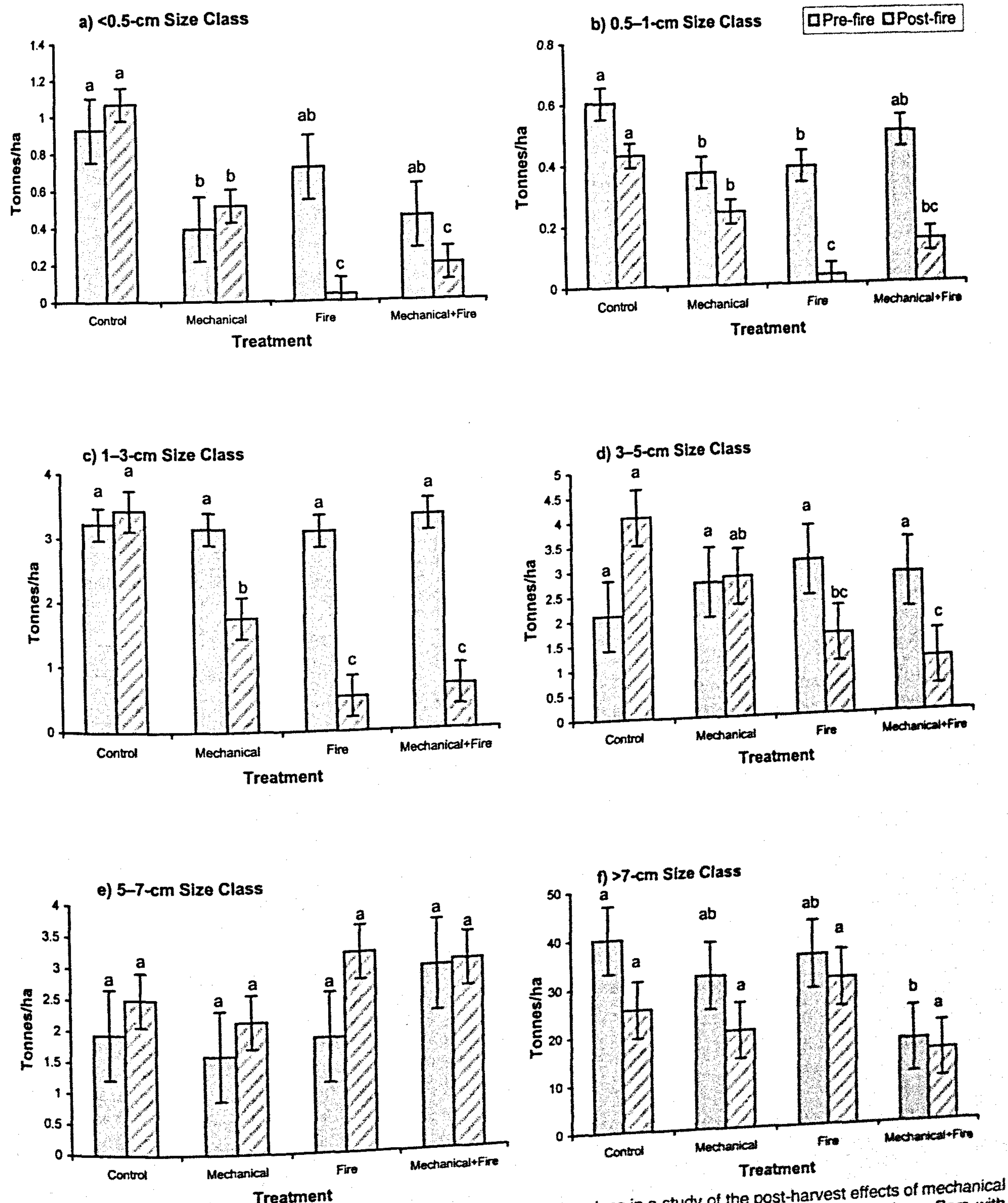

Fig. 3. Pre-fire (May 2004) and post-fire (August 2004) fuel loading by size class in a study of the post-harvest effects of mechanical treatment and prescribed fire on jack pine forest biodiversity, Ford Center Research Forest, Baraga County, Michigan. Bars with different lowercase letters within each data collection period differ significantly.

Ground-Dwelling Arthropods

We identified 22 arthropod taxa that were caught in the 480 pitfall traps installed at the study site. The five most common arthropod taxa in both the pre-harvest (Table 2) and post-harvest, pre-fire (Table 3) surveys were Carabidae, Chrysomelidae, Curculionidae, Formicidae, and Arachnida. The five most common arthropod taxa in the post-fire survey were Carabidae, Formicidae, Miridae, Acrididae, and Arachnida (Table

Table 2. Pre-harvest arthropod mean pitfall trap catch (June 2003) in a study of the post-harvest effects of mechanical treatment and prescribed fire on jack pine forest biodiversity, Ford Center Research Forest, Baraga County, Michigan.

Taxon	Treatment[a]				SE
	None	Mechanical	Fire	Mechanical + Fire	
Insecta					
Coleoptera					
Anthicidae	0.00	0.05	0.05	0.05	0.04
Buprestidae	0.00	0.00	0.50	0.00	0.03
Carabidae	2.70a	0.95b	1.80ab	1.70ab	0.44
Cerambycidae	0.00	0.00	0.05	0.00	0.03
Chrysomelidae	1.10	0.85	0.65	0.70	0.25
Curculionidae	0.90	1.00	2.15	3.05	0.80
Elateridae	0.35	0.05	0.40	0.05	0.12
Histeridae	0.00	0.05	0.00	0.00	0.03
Pedilidae	0.00	0.05	0.00	0.00	0.03
Scarabaeidae	0.00	0.05	0.00	0.00	0.03
Scolytidae	0.00	0.05	0.00	0.05	0.04
Staphylinidae	2.60	0.95	1.15	1.65	0.54
Tenebrionidae	0.00	0.00	0.05	0.05	0.04
Hymenoptera					
Formicidae	16.10	11.39	19.84	9.66	0.66
Orthoptera					
Acrididae	0.25	0.40	0.50	0.40	0.19
Tettigoniidae	0.70	0.60	0.65	0.55	0.32
Arachnida					
Acarina, Araneida, and Phalangida	48.09	32.30	45.84	45.51	0.18

[a] Results from one-way analysis of variance, with SE ($\alpha = 0.05$). For each order or family, treatment types with different letters differ significantly. Pairwise comparisons between the treatments were made using least significant difference tests (Statistix 8.0; Analytical Software 2003). Data for Formicidae and Arachnida were log-transformed to meet the assumption of homogeneity of variance.

4). In the post-fire arthropod trapping period, more ants (Hymenoptera: Formicidae) and fewer leaf beetles (Coleoptera: Chrysomelidae) and plant bugs (Hemiptera: Miridae) were trapped in the fire-only treatment areas compared with untreated controls. Lower numbers of arachnids and ground beetles (Coleoptera: Carabidae) were trapped in the areas treated with a combination of fire and mechanical treatments than in untreated control treatment areas, and lower numbers of wingless long-horned grasshoppers (Orthoptera: Gryllacrididae) were caught in both of the treatments that included fire compared with the untreated control treatment areas (Table 4).

Differences in taxonomic richness among treatments were not significant in both the pre-harvest ($F = 0.44$, df = 3, 12, $P = 0.729$) and pre-fire ($F = 3.33$, df = 3, 12, $P = 0.057$) trapping periods. However, differences in taxonomic richness among treatments were significant in the post-fire trapping period ($F = 3.80$, df = 3, 12, $P = 0.040$) (Figure 5). Taxonomic richness was lowest in fire-only treatment areas compared with control and mechanical-only treatment areas.

Differences in Shannon–Wiener diversity among treatments were not significant in both the pre-harvest ($F = 0.01$, df = 3, 12, $P = 0.999$) and pre-fire ($F = 0.39$, df = 3, 12, $P = 0.761$) trapping periods. However, differences in Shannon–Wiener diversity among treatments were significant in the post-fire trapping period ($F = 4.62$, df = 3, 12, $P = 0.023$) (Figure 5), being lower in fire-only treatment areas than in all other treatments.

DISCUSSION

The fuel load data, cone serotiny data, and burn coverage data suggest that the prescribed fire treatments and the mechanical treatments followed by fire had sufficient fire intensity to reduce smaller size classes of slash, expose bare mineral soil, and open many of the closed cones in the slash. Post-fire fuel loading differed between treatments in the four smallest size classes but was not significantly different in the largest two size classes. Because prescribed fire had a significant effect on smaller size classes only, total fuel loading was not affected. The smaller size classes were likely consumed rapidly, whereas the larger fuels, although charred, were not entirely consumed.

Over time, jack pine cones naturally open when exposed to heat, so cones that were more exposed to sunlight were more likely to open naturally (Keeley and Zedler 1998). As expected, there was no difference in closed cone percentage between treatments prior to implementation of prescribed fire treatments. The closed cone percentage in the non-burn treatments declined during the study, probably as a result of exposure to sunlight. The heat from the prescribed fire either opened or consumed cones. Percentage of closed cones in all non-control treatments declined during the study, and the percentage of closed cones in the fire-only treatment areas approached zero.

The percentage of area burned was higher in fire-only treatment areas than areas mechanically treated prior to the prescribed fire. Mechanical treatment created more piles of larger fuels, whereas fuels were

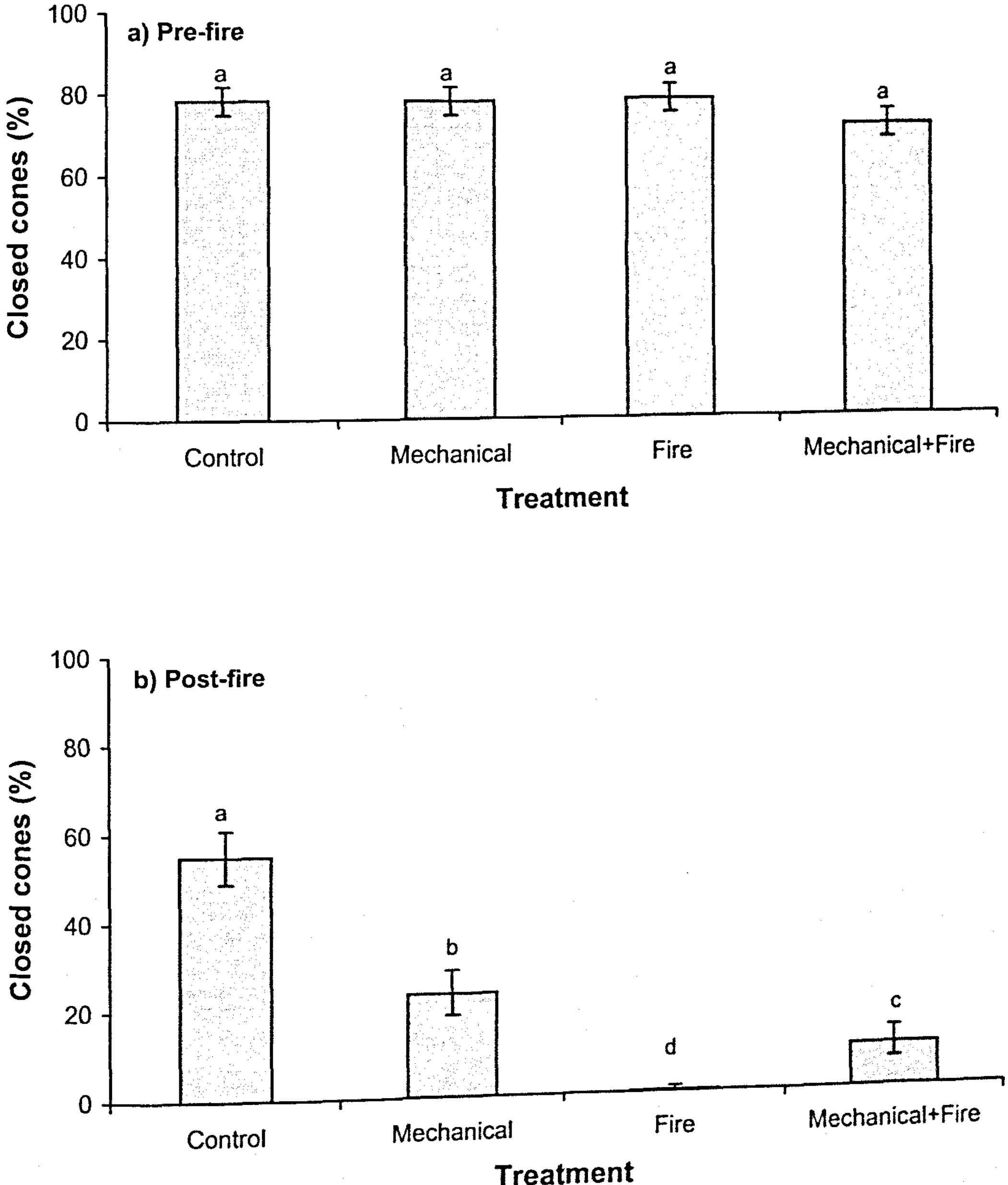

Fig. 4. Jack pine closed cone percentage (a) pre-fire (May 2004) and (b) post-fire (August 2004) in a study of the post-harvest effects of mechanical treatment and prescribed fire on jack pine forest biodiversity, Ford Center Research Forest, Baraga County, Michigan.

more evenly distributed in areas that did not receive mechanical treatment. That even distribution of fuel allowed the fire to carry more completely in fire-only areas than in areas mechanically treated prior to the prescribed fire. Also, soil and slash compaction by heavy machinery was more likely to occur in mechanical-treatment areas than in fire-only areas. By compacting fuels, less air space was available and fuels were not as likely to carry fire. In fire-only treatment areas, more evenly distributed, less compacted fuels allowed for more air space and likely allowed for a more intense burn (Pyne et al. 1996).

We anticipate that the burn intensity will be sufficient to regenerate jack pine in the areas that were burned because of the extent of cone opening and the coverage of the burn. Other studies have suggested that fire intensity is often too low in jack pine slash and too high in large, stand-replacing crown fires to achieve desired levels of regeneration (Chrosciewicz 1959), and in northern Lower Michigan, a designed post-harvest burn yielded only one plot out of 20 that was considered to have adequate jack pine regeneration (Abrams and Dickmann 1984). Future surveys of our treatment areas will enable us to evaluate the success of the treatments for jack pine regeneration.

Post-fire ground-dwelling arthropod taxonomic diversity and Shannon–Wiener diversity in fire areas decreased, due to the initial impact of fire. However, it remains to be seen whether or not fire eventually produces areas with higher arthropod diversity than me-

Table 3. Pre-fire arthropod mean pitfall trap catch (June 2004) in response to post-harvest effects of mechanical treatment and prescribed fire on jack pine forest biodiversity, Ford Center Research Forest, Baraga County, Michigan.

Taxon	Treatment[a] None	Mechanical	Fire	Mechanical + Fire	SE
Insecta					
Coleoptera					
Anthicidae	0.00	0.00	0.10	0.10	0.05
Buprestidae	0.00	0.00	0.00	0.05	0.03
Carabidae	0.55	0.80	0.25	0.55	0.22
Cerambycidae	0.00	0.00	0.05	0.00	0.03
Chrysomelidae	0.90	1.50	0.90	1.00	0.30
Cleridae	0.00b	0.00b	0.00b	0.10a	0.03
Curculionidae	1.05	1.85	1.80	1.20	0.51
Elateridae	0.00	0.00	0.05	0.00	0.03
Pedilidae	0.00b	0.00b	0.00b	0.10a	0.03
Scarabaeidae	0.15	0.25	0.30	0.35	0.13
Scolytidae	0.05	0.10	0.25	0.20	0.08
Staphylinidae	0.20	0.30	0.35	0.30	0.14
Hymenoptera					
Formicidae	9.62	11.83	3.82	11.96	0.49
Hemiptera					
Miridae	0.10	0.00	0.00	0.00	0.05
Orthoptera					
Acrididae	0.45	0.30	0.20	0.35	0.12
Tettigoniidae	0.15a	0.00b	0.00b	0.00b	0.05
Arachnida					
Acarina, Araneida, and Phalangida	38.99	28.81	30.04	27.79	0.51

[a] Results from one-way analysis of variance, with SE ($\alpha = 0.05$). For each order or family, treatment types with different letters differ significantly. Pairwise comparisons between the treatments were made using least significant difference tests (Statistix 8.0; Analytical Software 2003). Data for Formicidae and Arachnida were log-transformed to meet the assumption of homogeneity of variance.

Table 4. Post-fire arthropod mean trap catch (August 2004) in response to the post-harvest effects of mechanical treatment and prescribed fire on jack pine forest biodiversity, Ford Center Research Forest, Baraga County, Michigan.

Taxon	Treatment type[a] None	Mechanical	Fire	Mechanical + Fire	SE
Insecta					
Coleoptera					
Anthicidae	0.30	0.30	0.40	0.55	0.14
Buprestidae	0.05	0.05	0.65	0.60	0.22
Carabidae	5.05a	4.60ab	3.20ab	2.35b	0.79
Cerambycidae	0.10	0.00	0.00	0.05	0.04
Chrysomelidae	0.45a	0.35a	0.00b	0.30ab	0.11
Cleridae	0.00	0.05	0.00	0.00	0.03
Coccinellidae	0.00	0.00	0.00	0.05	0.03
Curculionidae	0.40	0.85	0.35	0.25	0.26
Elateridae	0.05ab	0.00b	0.15b	0.00a	0.04
Pedilidae	0.65	1.25	0.05	0.05	0.69
Scolytidae	0.05	0.05	0.05	0.05	0.05
Staphylinidae	0.25ab	0.45a	0.00b	0.10ab	0.12
Tenebrionidae	0.10	0.20	0.05	0.15	0.12
Hymenoptera					
Formicidae	12.05b	17.78ab	64.60a	14.60ab	0.66
Hemiptera					
Miridae	8.10a	6.80a	0.65b	3.95ab	1.43
Orthoptera					
Acrididae	8.95	9.95	3.35	5.15	2.37
Gryllacrididae	0.50a	0.30ab	0.05b	0.05b	0.11
Gryllidae	0.10	0.45	0.15	0.30	0.13
Tettigoniidae	0.25	0.05	0.05	0.05	0.10
Arachnida					
Acarina, Araneida, and Phalangida	7.03a	5.56ab	3.51ab	2.29b	0.33

[a] Results from one-way analysis of variance, with SE ($\alpha = 0.05$). For each order or family, treatment types with different letters differ significantly. Pairwise comparisons between the treatments were made using least significant difference tests (Statistix 8.0; Analytical Software 2003). Data for Formicidae and Arachnida were log-transformed to meet the assumption of homogeneity of variance.

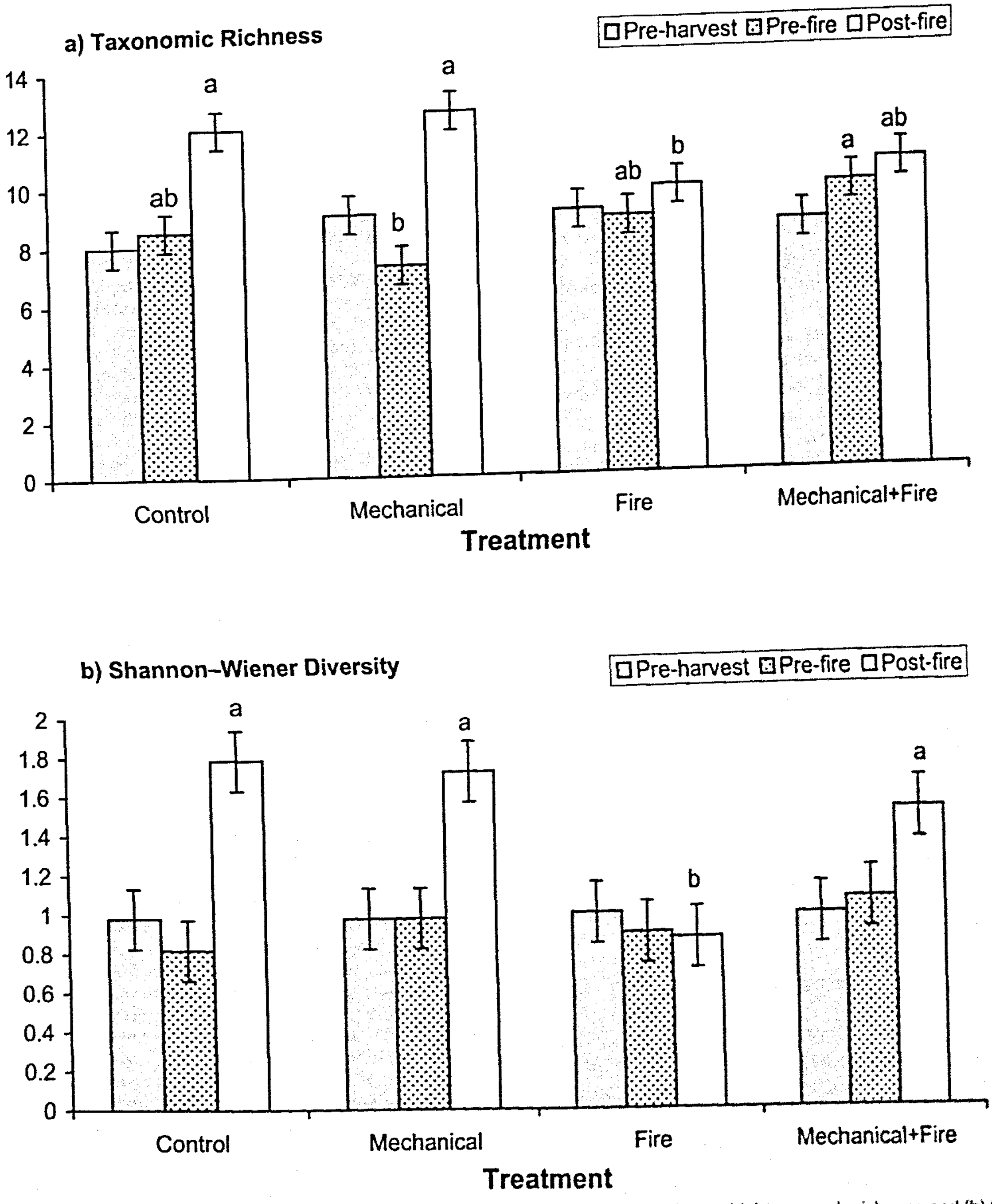

Fig. 5. Pre-harvest (June 2003), pre-fire (June 2004), and post-fire (August 2004) arthropod (a) taxonomic richness and (b) Shannon–Wiener diversity in a study of the post-harvest effects of mechanical treatment and prescribed fire on jack pine forest biodiversity, Ford Center Research Forest, Baraga County, Michigan.

chanically treated or untreated areas. Prescribed fire alone initially decreased arthropod diversity, but further sampling is likely to reveal increased arthropod diversity within 1–2 y as has been documented in prairies (Panzer 2002). Previous studies have indicated that a patchwork of prescribed fires and unburned areas likely results in complete recovery of pre-fire species and could increase abundance of certain species (Beaudry et al. 1997).

Mechanical treatment alone of the study site did not seem to have as much of an effect on arthropod communities as prescribed fire did. Orthopterans were generally more prevalent in non-fire areas than in treatments that included prescribed fire. In other systems, arachnids tend to be more sensitive to fire than are other arthropod taxa (Andersen and Muller 2000), and arachnids decreased in all areas in our study following prescribed fire treatment. Formicidae (ants) are less sensitive to fire than are other arthropod taxa (Andersen and Muller 2000) and increased in fire-only areas following treatment in this study (Table 4).

Insect responses to prescribed fire are often taxon specific (Beaudry et al. 1997) as they were found to be in this study. For example, population sizes of some carabid species increase following prescribed burning in jack pine, while others decrease in abundance (Beaudry et al. 1997). Overall carabid trap catch declined in mechanical treatment followed by prescribed fire treatments in our study, though species determinations were not made. Seasonal differences in arthropod abundance probably had a large effect, as data collection occurred at different periods during the summer. Given the normally late start of warm weather on the Baraga Plains, higher arthropod trap catches should normally occur later in the summer regardless of treatment type. As mechanical treatment was performed early in the summer, it is likely that arthropods were not yet fully active and therefore were not as impacted by mechanical treatment as they were by the fire treatment. Since the fire treatment was applied later in the summer than the mechanical treatment, it is likely that more arthropods were either initially killed by the treatment or that it had more of an initial effect on arthropod habitat than the mechanical treatment did (Panzer 2002, Hanula and Wade 2003). Some insect groups were also likely able to escape from the small treatment areas and subsequently recolonize those areas.

The effects that we have documented here are very short-term post-treatment effects, and will likely change over time as the vegetation changes following the treatments. The data presented here reflect short-term effects of the treatments on ground-dwelling arthropod communities. Continued monitoring of long-term treatment effects will be necessary to fully evaluate the potential ecological costs of the fire and mechanical treatments on these communities and to incorporate this information into management recommendations.

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