Short-Term Response of Ground-Dwelling Arthropods to Prescribed Fire and Mechanical Fuel Reduction in a Southern Appalachian Upland Hardwood Forest

Cathryn H. Greenberg, T. G. Forrest, and Thomas Waldrop

Abstract: As part of the multidisciplinary National Fire and Fire Surrogate Study, we used drift fences with pitfall traps to determine how three fuel reduction treatments affected ground-dwelling macroarthropods in the southern Appalachian Mountains of North Carolina. Four experimental units, each >14 ha, were contained within each of three replicate blocks. Treatments were (1) prescribed burning, (2) mechanical felling of shrubs and small trees, (3) mechanical felling + burning, and (4) untreated controls. Mechanical understory felling was conducted in winter 2001–2002, and prescribed burning was conducted in March 2003. Mechanical felling + burning resulted in greater canopy openness compared with the other treatments as a result of hotter fires and elevated levels of subsequent tree mortality. Burning reduced leaf litter depth in both burned treatments by >80%. We captured 6,776 individual macroarthropods (460 g of dry biomass) within 22 identified orders and 59 identified families. Coleoptera and Hymenoptera were numerically dominant (27.3 and 25.9%, respectively); Lepidoptera larvae also were a dominant component of dry biomass (37%). We found no differences among treatments in the relative abundance or dry biomass of total ground-dwelling macroarthropods or within most orders; Hymenoptera (predominantly Formicidae) dry biomass was greater with mechanical felling + burning than with mechanical felling. Total relative abundance and dry biomass were low in spring and higher in late summer. Our results indicate that prescribed burning and mechanical fuel reduction treatments conducted in winter or early spring have little impact on the community composition, relative abundance, or biomass of total arthropods or most arthropod orders and families, at least in the short term. However, because we did not use a killing agent, our trapping method probably undersampled macroarthropods that could climb or fly from traps, and results for those groups should be interpreted cautiously. Our study suggests that the fuel reduction methods studied may be used as a land management tool in upland hardwood forest with little effect on macroarthropod communities or the ground-dwelling arthropod prey base for vertebrates. FOR. SCI. 56(1):112–121.

Keywords: burn, fire surrogate, fuel reduction, macroarthropods, southern Appalachians, upland hardwoods

IN THE SOUTHERN Appalachians widespread, frequent burning was historically used by native Americans to maintain an open understory and improve conditions for travel and game. Later, fire was used by European settlers to improve grazing for livestock (Van Lear and Waldrop 1989, Lorimer 1993, Brose et al. 2001, Stanturf et al. 2002). Fire frequencies and intensities in southern Appalachian forests before human influence are largely unknown. Lightning-caused fires are infrequent (Harmon 1982), but their frequency varies with topography and associated forest types (Delcourt and Delcourt 1997). In the 1930s forest fires began to be viewed as destructive and were suppressed or excluded (Lorimer 1993). Fire exclusion led to higher mid- and understory densities of shade-tolerant trees and shrubs, especially on mesic upland sites (Brose et al. 2001). During the past decade prescribed burning and mechanical understory reductions have become common silvicultural practices in upland hardwood forest and are used for reduction of fuels and the risk of wildfire (Graham et al. 2004), ecosystem restoration, oak regeneration, understory control, and wildlife conservation (Brawn et al. 2001).

Arthropods represent a large proportion of biological diversity and support invertebrate and vertebrate diversity by serving as an important food resource (Greenberg and Forrest 2003). They also play key ecological roles as herbivores (Wilson 1987) and pollinators (Campbell et al. 2007) and in decomposition and nutrient cycling (Coleman and Rieske 2006). Because they depend on structural and microclimatic features of the forest floor such as coarse woody debris, leaf litter, and soil moisture (Sanderson et al. 1995), ground-dwelling macroarthropods may be sensitive to fuel reduction treatments that alter forest floor conditions.

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Burning may have an impact on ground-dwelling macroarthropod communities by direct mortality or indirectly by altering forest floor conditions (Mitchell 1990). Effects may be greater after hot burns that kill overstory trees, thus increasing light and heat at ground level. However, direct impacts on arthropods may be mitigated by their life history traits, mobility, and behavior. Similarly, incomplete burns that leave patches of leaf litter and other suitable forest floor conditions could mitigate or mask potentially adverse impacts to ground-dwelling macroarthropods. The impact of various fuel reduction treatments on ground-dwelling macroarthropod communities is likely to correspond with the type, intensity, and timing of disturbance and subsequent changes in macro- and microhabitat. However, few studies address the response of ground-dwelling macroarthropods to prescribed burning or other fuel reduction methods in upland hardwood forests (e.g., Kalisz and Powell 2000, Dress and Boerner 2004). Clearly, land managers need more information about how prescribed burning and other fuel reduction methods affect the community composition, relative abundance, and biomass of macroarthropods as an important component of and prey base for biological diversity, while managing wildfire risk and achieving other forest management objectives.

As part of the multidisciplinary National Fire and Fire Surrogate study (Youngblood et al. 2005), we assessed how macroarthropod density and community composition changed in response to fuel reduction by prescribed burning, mechanical understory reduction, or mechanical understory reduction followed by burning. Specifically, we examined differences in the relative abundance of ground-dwelling arthropod orders, families, and total individuals among these three fuel reduction treatments and untreated controls in the southern Appalachians shortly after all three treatments were implemented.

Study Area and Methods

Study Area

Our study was conducted on the 5,841-ha Green River Game Land (35°17′9″N, 82°19′42″W, blocks 1 and 2; 35°15′42″N, 82°17′27″W, block 3) in Polk County, North Carolina (Figure 1). Elevation within the study area ranged from 366 to 793 m. The area is managed by the North Carolina Wildlife Resources Commission and lies on the escarpment of the Blue Ridge Physiographic Province, near its interface with the South Carolina Piedmont. Soils were primarily of the Evard series (fine-loamy, oxidic, mesic, Typic Hapludults), which are very deep and well-drained in mountain uplands (US Department of Agriculture Natural Resources Conservation Service 1998). The study site also contained areas of rocky outcrops. Forest stands were composed mainly of oaks (*Quercus* spp.) and hickories (*Carya* spp.). Shortleaf (*Pinus echinata* Miller) and Virginia (*P. virginiana* Miller) pines were found on ridge tops, and white pine (*P. strobus* L.) and yellow-poplar (*Liriodendron tulipifera* L.) occurred in moist coves. Stand ages varied from 80 to 120 years. Thick shrub layers occurred throughout much of the study area. Predominant shrubs were mountain laurel (*Kalmia latifolia* L.) along ridge tops and on upper

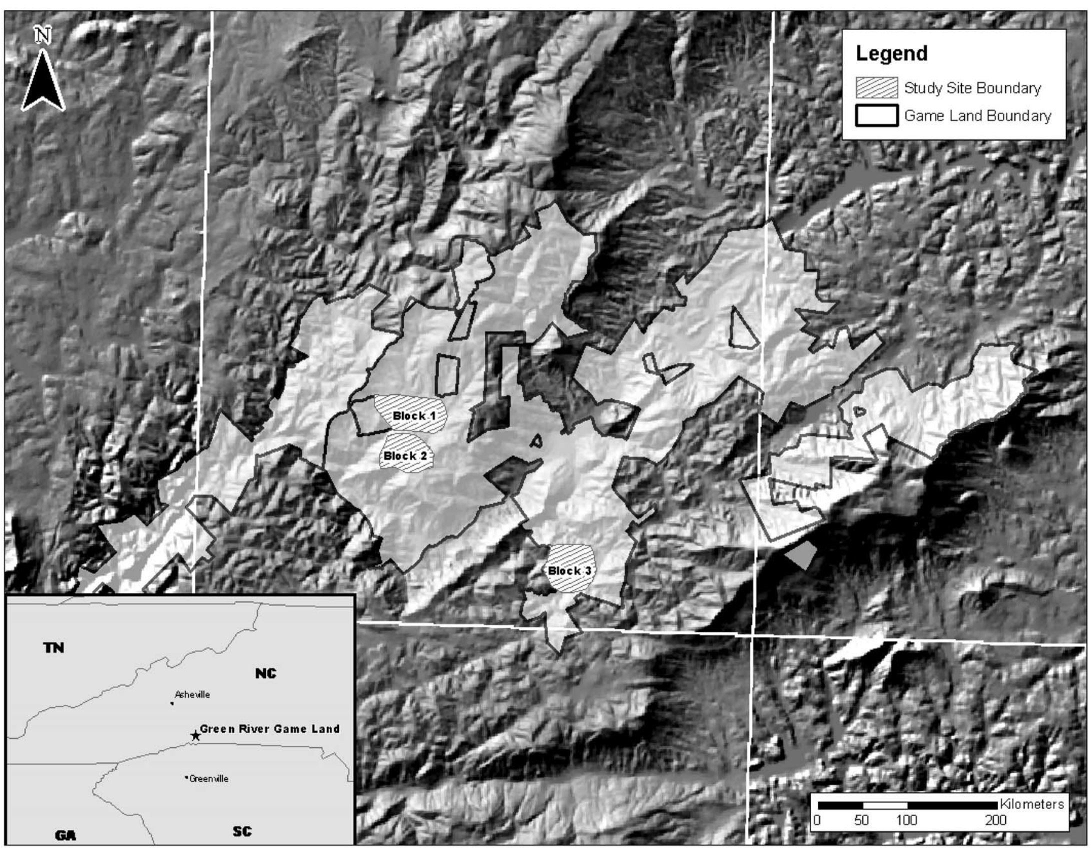

Figure 1. Study area location at the Green River Game Land, Polk County, North Carolina, USA.

southwest-facing slopes and rhododendron (*Rhododendron maximum* L.) in mesic areas. None of the sites had been thinned or burned for at least 50 years (Dean Simon, North Carolina Wildlife Resources Commission, pers. comm., Jan. 23, 2007).

Study Design

Our experimental design was a randomized complete block. Three blocks were selected based on stand size (large enough to accommodate all four treatments), stand age, cover type, and management history to ensure that baseline conditions were consistent among the treatments. First- and second-order streams bordered and/or traversed all three blocks. Four experimental units, each >14 ha, were contained within each block. This unit size allowed for 10-ha treatment core areas, each surrounded by a 20-m buffer.

Three treatments and an untreated control (C) were randomly assigned to the four experimental units within each block. Treatments were fuel reduction by mechanical understory felling in winter 2001–2002 (M), fuel reduction by prescribed burning in March 2003 (B), and fuel reduction by mechanical understory felling in winter 2001–2002 and prescribed fire in March 2003 (MB). The understory mechanical treatment (for M and MB) consisted of cutting all mountain laurel, rhododendron, and trees >1.8 m tall and <10.0 cm in dbh with chainsaws. Removing fuels was cost prohibitive, but felled stems were cut repeatedly to reduce piles to less than 1.2 m tall. Prescribed burns were conducted in all B and MB treatments across the three blocks on March 12 or 13, 2003. Burning in MB was done 1 year after felling to allow curing and decomposition of some fuels to reduce fire intensity. Each B and MB experimental unit had a complete set of fire lines, and each was burned as an individual unit. Those in one block were burned by hand ignition using spot fire and strip-headfire techniques. The two other blocks were ignited by helicopter using a plastic sphere dispenser. Backing fires were set along fire lines by hand followed by spot fires set from the air. The objective of all treatments was to reduce ladder fuels by substantially reducing the shrub layer.

Habitat and Fire Temperature Measurements

We measured habitat variables in all experimental units before and immediately after treatments (in 2002 for M and in 2003 for C, B, and MB). Thirty-six to 40 permanent gridpoints were spaced at 50-m intervals throughout treatment areas. Trees and snags (≥10 cm dbh) were measured within 10 0.05-ha plots that originated at a randomly predetermined subset of the numbered gridpoints, with plot origins spaced 200 m apart. Coarse woody debris (≥1 m in length and ≥15 cm large-end diameter within transect) was measured within 4 × 20 m belt transects originating at alternate gridpoints throughout treatment areas. Depth of leaf litter and duff was measured at three locations (3.6, 7.6, and 12.2 m) along each of three randomly oriented, 15-m transects originating at each grid point. Herbaceous plant cover was estimated in 200 1-m^2 subplots within each 10-ha treatment plot (Phillips et al. 2007). We used a concave spherical densiometer held at breast height (1.4 m) to measure percent canopy openness in 2002 (before canopy disturbance) and 2003. We used the average of four densiometer readings (one per cardinal direction), taken at the midpoint of each drift fence array (two arrays) within each experimental unit during summer (leaf on). Maximum temperatures (°C) were recorded by 68 thermocouples located 30 cm aboveground and placed systematically throughout each B and MB experimental unit.

Ground-Dwelling Macroarthropod Sampling

We established two drift fence arrays ≥100 m apart in each experimental unit. Arrays were constructed with three 7.6-m sections of aluminum flashing positioned at approximately 120° angles (in a Y shape), with one 19-L bucket (~28 cm opening) buried at each section end such that its rim was flush with the ground surface. A fourth pitfall was shared by all three "arms" in the center of the Y. The arrays were designed to capture reptiles and amphibians, but also effectively captured ground-dwelling macroarthropods. Because we did not use a killing agent, our trapping method probably undersampled macroarthropods that could climb or fly from traps, and some macroarthropods were probably consumed by small mammals, herpetofauna, or other macroarthropods in the same traps. However, because of the low capture rates of vertebrates in pitfall traps (Greenberg et al. 2007, Greenberg and Waldrop 2008), we assume that these potential biases were consistent among treatments and hence should not bias comparisons. Because habitat structure and microclimate, which differed among the treatments, can affect both arthropod activity and relative abundance, our pitfall trapping method provided an "activity-density" index (Spence and Niemela 1994) as an indicator of treatment effects.

Ground-dwelling arthropods were collected (hand-scooped) every 14 days from all pitfall traps at one of the two drift fence arrays (the other was not used for macroarthropod sampling) in each treatment during spring (May 26, June 9, and June 23) and again during late summer (August 11, August 25, September 8, and September 22). Traps were closed during most of July for logistical reasons. Traps were cleared of macroarthropods and debris 2 weeks before the first collection for both periods (May 12 and July 28). Macroarthropods were preserved in 70% ethyl alcohol. We later sorted and counted macroarthropods by morphospecies

Table 1. Percentage of each experimental unit burned at different temperature categories and mean maximum temperature in the Green River Game Land, Polk County, North Carolina

		Percentage of unit burned			
Block	Treatment	0–300°C	301–600°C	601–900°C	Mean max(°C)
1	B	45.3	32.8	21.9	396.4
	MB	18.4	35.4	46.2	568.8
2	B	44.1	50.0	5.9	333.5
	MB	26.4	51.5	22.1	426.3
3	B	70.6	23.5	5.9	232.7
	MB	20.6	30.9	48.5	556.1

that were identified to the order and family level. Specimens were then oven-dried at 50°C to a constant mass and weighed to obtain an estimate of average dry biomass.

Statistical Analyses

We used one-way randomized complete block design analyses of variance (ANOVAs) (SAS Institute, Inc. 1990) to compare the relative abundance and dry biomass of each order and family and of total macroarthropods, as well as richness of orders and families, among treatments (SAS Institute, Inc. 1990). We applied a two-way ANOVA with repeated measures over the seven sample periods (May–September) to compare relative abundance of ground-dwelling macroarthropods (by order) among treatments and over time and to test for treatment × time interactions. We used the type III sum of squares and associated mean squares as the error term for treatment effects. Post hoc tests were performed using a Tukey's multiple comparison procedure (Zar 1984). Adults and larvae (including all subadult forms) were analyzed separately. Only orders or families having ≥30 specimens were included in data analyses of relative abundance and biomass by order or family. All taxa were included in analyses of total relative abundance, biomass, and richness. Data were natural log-transformed for analysis to reduce heteroscedasticity.

We also used ANOVAs to test for pre- and posttreatment differences in habitat features among treatments. Percentage data (coarse woody debris and canopy openness) were square root arcsine-transformed for ANOVAs. Post hoc tests were performed using Tukey multiple comparison procedures (Zar 1984).

Results

Fire temperatures varied within and among sites but were generally moderate (300–600°C) to high (600–900°C) (Table 1). Flame lengths of 1 to 2 m occurred throughout all burn units, but in one block, flame lengths reached up to 5 m where topography or intersecting flame fronts contributed to erratic fire behavior. Mean maximum temperature at 30 cm above the forest floor was 321°C in B but exceeded 500°C in two MB experimental units (Table 1). Greater fuel loads resulting from understory felling treatments, lower fuel moisture, and topography contributed to hotter fires in MB (Phillips et al. 2006).

Hot fires of 600°C or more killed overstory trees in B and MB within a few months after burning (Waldrop and Yaussy 2007). Fires of these temperatures covered an average of 11% of the area in B and 39% of the area in MB experimental units (Table 1). Approximately 5% of the trees were killed in B and approximately 25% of the trees were killed in MB (Table 2). Canopy openness was greatest in MB but differed significantly only from that in C in 2003 (Table 2). Leaf litter depth was significantly lower (reduced by >80%) in both burned treatments (B and MB) after burning, but increased in M because of the addition of dead leaves during understory felling. Duff depth (treatment range 3.0–5.4 cm), percent cover of coarse woody debris, and percent cover of herbaceous plants did not differ among the treatments (Table 2).

We captured 6,776 individual macroarthropods (460 g of dry biomass) within 22 identified orders and 59 identified families (Table 3). Dominant (>10%) orders, based on relative abundance and dry biomass were Coleoptera (27.3 and 32.2% respectively), Hymenoptera (25.9 and 1.1% respectively), and Lepidoptera larvae (6.3 and 37.0% respectively).

The number and dry biomass of total macroarthropods did not differ among treatments (Table 3). Among the orders analyzed, only Hymenoptera (predominantly Formicidae) dry biomass was greater in MB than in M. Among the families analyzed, Formicidae (order Hymenoptera) dry biomass was greater in MB than in M, and Corinnidae (order Araneae) relative abundance and dry biomass were greater in MB than in B and M. In the order Coleoptera, Curculionidae relative abundance was marginally higher in MB than in M; Scarabaeidae relative abundance was greater in MB than in C and greater in B than in C and M, and

Table 2. Mean ± SE habitat measurements before (first line) and immediately after (second line) three treatments (B, M, and MB) and controls (C) in the Green River Game Land, Polk County, North Carolina

	Treatment				ANOVA	
Habitat feature	C	B	M	MB	$F_{3,6}$	P_{trt}
Live trees/ha	566.0 ± 10.6	568.7 ± 29.3	602.0 ± 18.1	506.7 ± 33.8	2.4	0.17
	550.7 ± 15.0^{a}	539.3 ± 30.0^{a}	588.0 ± 11.0^{a}	379.3 ± 43.5^{b}	11.6	0.01
Snags/ha	74.0 ± 8.3	62.7 ± 6.7	55.3 ± 4.7	67.3 ± 14.1	0.7	0.59
	68.0 ± 9.0^{ab}	72.7 ± 19.0^{ab}	52.7 ± 4.4^{a}	152.0 ± 25.3^{b}	6.0	0.03
Canopy openness (%)	6.8 ± 1.0	6.2 ± 0.3	8.3 ± 1.2	8.5 ± 2.6	0.8	0.56
	1.6 ± 0.4^{a}	2.6 ± 1.1^{ab}	3.0 ± 0.8^{ab}	12.8 ± 5.0^{b}	6.3	0.03
Litter depth (cm)	5.0 ± 0.1	4.8 ± 0.3	5.0 ± 0.2	5.1 ± 0.3	0.2	0.90
	4.2 ± 0.5^{a}	0.9 ± 0.1^{b}	5.5 ± 0.2^{c}	0.5 ± 0.1^{b}	116.1	<0.01
Duff depth (cm)	3.5 ± 0.5	4.6 ± 0.8	4.1 ± 0.7	4.5 ± 0.9	2.1	0.20
	3.5 ± 0.6	3.6 ± 0.3	5.4 ± 1.0	3.0 ± 0.4	2.2	0.19
Coarse woody debris (%)	1.0 ± 0.3	1.2 ± 0.3	1.1 ± 0.2	1.7 ± 0.7	1.2	0.40
	0.9 ± 0.3	1.2 ± 0.3	1.0 ± 0.2	1.2 ± 0.5	0.3	0.85
Herbaceous cover (%)	3.6 ± 1.6	3.5 ± 1.3	1.8 ± 0.9	3.3 ± 2.0	0.9	0.49
	2.8 ± 1.6	2.1 ± 0.4	2.4 ± 1.3	2.0 ± 0.6	0.1	0.97

Differences among treatments are denoted by different letters within rows.

Table 3. **Total and mean ± SE number (first line) and dry biomass (g; second line) of common (≥30 specimens) arthropods collected by pitfall trapping after three treatments (B, M, and MB), and controls (C) at the Green River Game Land, Polk County, North Carolina**

		Treatment				ANOVA	
Order and Family	Total	C	B	M	MB	$F_{3,6}$	P_{trt}
Araneae	402	35.3 ± 13.5	33.0 ± 9.7	24.0 ± 6.0	41.7 ± 2.0	0.67	0.60
	15.8	1337.6 ± 640.8	1343.9 ± 419.7	1090.5 ± 389.3	1511.2 ± 165.5	0.23	0.87
Corinnidae	171	14.3 ± 3.9^{ab}	11.3 ± 0.9^{a}	9.0 ± 1.5^{a}	22.3 ± 1.2^{b}	6.06	0.03
	2.1	179.9 ± 49.3^{ab}	142.3 ± 11.1^{a}	112.9 ± 19.2^{a}	280.3 ± 15.1^{b}	6.07	0.03
Cyrtaucheniidae	119	11.0 ± 8.0	16.0 ± 10.7	5.7 ± 3.7	7.0 ± 3.5	0.29	0.83
	5.8	539.8 ± 393.6	785.1 ± 524.7	278.1 ± 182.1	343.5 ± 170.0	0.29	0.83
Lycosidae	60	4.3 ± 2.3	3.0 ± 2.1	5.7 ± 2.6	7.0 ± 3.1	0.81	0.54
	6.3	453.6 ± 244.2	314.0 ± 217.9	593.1 ± 272.5	732.7 ± 319.8	0.91	0.49
Thomisidae	51	5.7 ± 0.7	2.3 ± 1.5	3.7 ± 0.9	5.3 ± 1.9	1.54	0.30
	1.5	164.3 ± 19.3	67.7 ± 42.1	106.3 ± 25.6	154.7 ± 53.8	1.34	0.35
Archaeognatha	77	5.0 ± 2.1	7.0 ± 0.6	4.7 ± 3.7	9.0 ± 1.5	1.51	0.31
	0.5	35.4 ± 14.7	49.5 ± 4.1	33.0 ± 25.9	63.6 ± 10.8	1.33	0.35
Machilidae	77	5.0 ± 2.1	7.0 ± 0.6	4.7 ± 3.7	9.0 ± 1.5	1.51	0.31
	0.5	35.4 ± 14.7	49.5 ± 4.1	33.0 ± 25.9	63.6 ± 10.8	1.51	0.30
Blattodea (adult)	42	3.3 ± 0.9	2.3 ± 0.7	2.0 ± 0.6	6.3 ± 2.7	1.15	0.40
	2.9	269.3 ± 55.8	169.9 ± 79.3	273.1 ± 78.9	269.9 ± 131.0	0.66	0.61
Blattodea (larvae)	106	8.3 ± 1.9	9.3 ± 4.1	5.0 ± 0.6	12.7 ± 3.5	1.43	0.32
	1.4	111.7 ± 24.9	125.1 ± 54.9	67.0 ± 7.7	169.7 ± 47.3	1.45	0.32
Blattellidae (larvae)	106	8.3 ± 1.9	9.3 ± 4.1	5.0 ± 0.6	12.7 ± 3.5	1.43	0.32
	1.4	41.7 ± 16.7	33.3 ± 8.3	0.0 ± 0.0	133.3 ± 54.7	1.42	0.33
Coleoptera (adult)	1849	117.7 ± 12.2	182.7 ± 54.9	126.3 ± 25.8	189.7 ± 32.1	0.79	0.54
	147.9	9977.6 ± 1337.4	11,107.7 ± 4,673.6	14,386.0 ± 3,601.9	1,3843.9 ± 3,852.2	0.42	0.75
Carabidae	683	41.7 ± 8.5	82.0 ± 39.3	51.3 ± 23.4	52.7 ± 8.4	0.31	0.82
	44.5	3279.4 ± 594.9	4778.1 ± 2182.2	3738.3 ± 1368.9	3047.4 ± 260.6	0.06	0.98
Curculionidae	124	9.7 ± 4.4^{ab}	12.3 ± 2.8^{ab}	4.0 ± 1.2^{a}	15.3 ± 3.5^{b}	3.53	0.09
	1.0	98.0 ± 52.6	84.5 ± 7.5	27.7 ± 12.0	108.0 ± 26.3	2.76	0.13
Elateridae	55	5.3 ± 2.0	5.3 ± 1.9	2.7 ± 0.7	5.0 ± 1.7	0.50	0.69
	0.7	67.8 ± 25.8	67.8 ± 23.6	33.9 ± 8.5	63.5 ± 22.0	0.50	0.69
Endomychidae	44	2.7 ± 1.2	2.3 ± 0.3	3.3 ± 1.5	6.3 ± 1.8	1.09	0.42
	0.2	10.2 ± 4.6	9.0 ± 1.3	12.8 ± 5.6	24.3 ± 6.8	1.08	0.42
Histeridae	191	15.3 ± 4.3	16.3 ± 4.2	11.3 ± 4.7	20.7 ± 8.3	2.06	0.21
	2.0	160.7 ± 45.4	171.2 ± 43.8	118.8 ± 48.9	216.6 ± 86.5	2.06	0.21
Nitidulae	83	5.0 ± 2.1	2.7 ± 1.8	1.3 ± 0.7	18.7 ± 9.9	3.03	0.11
	0.1	3.3 ± 1.4	1.8 ± 1.8	0.9 ± 0.4	12.5 ± 6.6	3.33	0.10
Phengodidae	184	10.7 ± 3.0	12.0 ± 6.1	23.7 ± 10.1	15.0 ± 3.5	0.85	0.52
	11.3	657.8 ± 182.7	740.0 ± 376.8	1459.5 ± 623.2	925.1 ± 213.7	0.91	0.49
Scarabaeidae	114	4.0 ± 0.6^{a}	16.3 ± 2.6^{b}	6.7 ± 3.2^{ac}	11.0 ± 1.0^{bc}	6.48	0.03
	5.3	192.2 ± 124.3	562.8 ± 78.6	670.9 ± 551.5	345.5 ± 37.1	1.59	0.29
Silphidae	45	4.3 ± 1.5	1.3 ± 0.9	5.7 ± 4.3	3.7 ± 2.3	0.44	0.73
	63.9	4497.8 ± 2175.4	2882.7 ± 1906.7	7380.5 ± 4541.4	6535.7 ± 3787.8	0.17	0.91
Staphylinidae	71	6.7 ± 3.8	8.0 ± 4.4	4.3 ± 2.8	4.7 ± 2.0	0.16	0.92
	1.5	183.1 ± 123.8	160.4 ± 92.3	124.9 ± 111.3	21.5 ± 10.1	0.13	0.94
Tenebrionidae	190	10.7 ± 2.7^{ab}	16.3 ± 0.3^{a}	10.3 ± 3.5^{a}	26.0 ± 4.9^{b}	3.50	0.09
	9.0	596.0 ± 184.7	779.7 ± 149.8	337.2 ± 95.6	1274.5 ± 562.7	2.21	0.19
Coleoptera (larvae)	79	5.0 ± 3.5	7.3 ± 2.2	4.7 ± 2.7	9.3 ± 5.5	0.56	0.66
	4.3	36.6 ± 29.4	1044.8 ± 667.5	244.8 ± 202.3	259.1 ± 215.2	1.24	0.37
Diptera (larvae)	410	34.3 ± 2.0	51.3 ± 46.4	47.3 ± 37.9	3.7 ± 1.5	0.62	0.63
	0.5	41.6 ± 24.8	65.8 ± 62.1	66.9 ± 38.3	8.1 ± 2.2	0.67	0.60
Psychodidae (larvae)	180	21.7 ± 3.7	5.3 ± 3.5	33.0 ± 30.1	0.0 ± 0.0	2.60	0.15
	<0.1	5.4 ± 0.9	1.3 ± 0.9	8.3 ± 7.5	0.0 ± 0.0	2.57	0.15
Sarcophagidae (larvae)	89	6.0 ± 4.0	8.3 ± 7.8	14.0 ± 8.1	1.3 ± 0.3	0.79	0.54
	0.4	24.0 ± 16.0	33.3 ± 31.4	56.0 ± 32.3	5.3 ± 1.3	0.78	0.55
Hymenoptera	1753	111.7 ± 54.2	164.3 ± 57.7	69.7 ± 13.0	238.7 ± 10.3	2.94	0.12
	5.2	347.6 ± 121.0^{ab}	496.4 ± 203.2^{ab}	179.9 ± 4.7^{a}	727.0 ± 22.7^{b}	5.24	0.04
Formicidae	1624	99.0 ± 49.1	156.0 ± 55.8	65.7 ± 13.9	220.7 ± 13.9	2.88	0.13
	4.2	236.0 ± 81.7^{ab}	419.2 ± 195.8^{ab}	148.7 ± 10.9^{a}	582.4 ± 24.8^{b}	4.62	0.05
Mutilidae	95	9.7 ± 5.7	5.7 ± 2.6	2.0 ± 0.6	14.3 ± 2.7	2.40	0.17
	0.8	79.6 ± 46.9	46.6 ± 21.4	16.5 ± 4.8	118.0 ± 22.4	2.40	0.17
Julida/Spirobolida	610	24.3 ± 17.0	26.0 ± 11.0	61.0 ± 25.8	92.0 ± 27.0	1.89	0.23
	43.0	1716.0 ± 1195.6	1833.5 ± 776.8	4301.7 ± 1817.6	6487.9 ± 1904.1	1.89	0.23

(continued)

Table 3. (continued)

Order and Family	Treatment					ANOVA	
	Total	C	B	M	MB	$F_{3,6}$	P_{trt}
Lepidoptera (larvae)	428	11.0 ± 1.5	73.3 ± 52.8	29.7 ± 17.2	28.7 ± 7.5	1.33	0.35
	170.0	4391.8 ± 1653.6	28,573.1 ± 20,330.3	14,153.7 ± 7,634.2	10,817.3 ± 4433.6	1.28	0.36
Noctuidae (larvae)	57	2.7 ± 1.8	6.0 ± 2.6	5.3 ± 2.3	5.0 ± 2.6	0.82	0.53
	51.3	2401.2 ± 1588.3	5402.9 ± 2382.4	4802.5 ± 2101.1	4502.3 ± 2382.4	0.94	0.48
Saturniidae (larvae)	314	4.3 ± 2.4	60.0 ± 47.6	22.0 ± 16.7	18.3 ± 8.8	0.97	0.47
	115.1	1646.1 ± 913.1	22,708.5 ± 18,000.4	8149.0 ± 6276.2	5873.4 ± 3180.2	0.88	0.50
Opiliones	206	9.0 ± 3.1	27.0 ± 10.1	14.7 ± 11.2	18.0 ± 4.4	1.05	0.44
	8.8	386.4 ± 131.2	1159.4 ± 432.2	629.8 ± 480.9	772.9 ± 187.2	1.05	0.44
Phalangidae	206	9.0 ± 3.1	27.0 ± 10.1	14.7 ± 11.2	18.0 ± 4.4	1.05	0.44
	8.8	386.4 ± 131.2	1159.4 ± 432.3	629.8 ± 480.9	772.9 ± 187.2	1.05	0.44
Orthoptera	267	17.7 ± 4.3	32.0 ± 11.2	20.7 ± 5.0	18.7 ± 3.5	0.62	0.63
	31.1	1608.7 ± 712.2	4176.2 ± 1478.4	2479.5 ± 617.7	2115.6 ± 498.0	1.27	0.37
Gryllidae	36	6.0 ± 3.8	0.7 ± 0.3	3.0 ± 1.5	2.3 ± 0.9	0.30	0.82
	0.3	45.6 ± 28.8	8.4 ± 5.1	42.6 ± 21.4	40.8 ± 15.4	0.39	0.76
Rhaphidophoridae	204	9.0 ± 4.2	29.3 ± 10.3	14.7 ± 4.1	15.0 ± 3.5	1.84	0.24
	27.3	1205.0 ± 557.5	3927.5 ± 1383.5	1963.7 ± 543.0	2008.2 ± 470.2	1.84	0.24
Polydesmida	81	6.7 ± 4.2	10.0 ± 4.4	5.7 ± 4.7	4.7 ± 2.9	0.62	0.63
	20.9	911.8 ± 631.1	2813.6 ± 1004.9	1291.4 ± 1257.9	1946.4 ± 1172.7	0.54	0.67
Scolopendromorpha	155	7.0 ± 1.7	18.7 ± 8.1	13.0 ± 5.1	13.0 ± 4.6	0.53	0.68
	3.3	150.2 ± 37.2	400.4 ± 173.5	278.9 ± 110.1	278.9 ± 98.3	0.53	0.68
Cryptopidae	155	7.0 ± 1.7	18.7 ± 8.1	13.0 ± 5.1	13.0 ± 4.6	0.53	0.68
	3.3	150.2 ± 37.2	400.4 ± 173.5	278.9 ± 110.1	278.9 ± 98.3	0.53	0.68
Total[1]	6776	415.0 ± 56.4	694.3 ± 180.7	448.0 ± 127.4	701.3 ± 26.2	1.39	0.33
	459.8	21.5 ± 1.4	53.9 ± 22.9	38.5 ± 11.8	39.3 ± 2.7	0.95	0.47

Orders and/or families having <30 specimens were omitted from the table. Sample dates in 2003: May 26, June 9, June 23, Aug. 11, Aug. 25, Sept. 8, and Sept. 22. Differences among treatments are denoted by different letters within rows.
[1] Totals include taxa with <30 specimens that were omitted from the table.

Tenebrionidae relative abundance was greater in MB than in B and M. Discrepancies between relative abundance and dry biomass within orders or families were probably due to differences in the composition or proportions of subtaxa, hence in dry weight, within them (e.g., different family, genus, or species composition within orders). Richness of orders or families did not differ among the treatments or control for adults ($F_{3,6} = 1.21$, $P = 0.38$ and $F_{3,6} = 1.78$, $P = 0.25$, respectively) or larvae ($P = 0.48$, $F_{3,6} = 0.92$ and $P = 0.95$, $F_{3,6} = 0.12$, respectively).

Two-way ANOVA with repeated measures over sample periods indicated that there were no differences among treatments in the relative abundance or dry biomass of total ground-dwelling macroarthropods captured in our study (Table 4; Figure 1). Similarly, we found no differences in treatment effect for relative abundance or dry biomass within orders, with the exception of Hymenoptera, which was marginally significant (Table 4). However, total relative abundance and dry biomass were low in spring sampling and higher in late summer sampling (Table 4; Figure 1). Relative abundance and dry biomass also differed among sample periods for all tested orders except Scolopendromorpha and larval Coleoptera, and temporal patterns of relative abundance and biomass differed among orders (Table 4).

Discussion

In our study, overall richness, relative abundance of orders and families, dry biomass, and general community composition of ground-dwelling macroarthropods were unaffected by mechanical understory removal, prescribed burning, or a combination thereof several months after the completion of all treatments. The few taxa showing a response to treatments all increased in either biomass or relative abundance in response to MB or B relative to at least some of the other treatments or control. Because we did not study macroarthropods at the species level, it is likely that we did not detect some important responses by some species to the fuel reduction treatments. However, our data indicate that arthropods at the order- and family level were little affected, and the prey base (arthropod relative abundance and biomass) for vertebrates was relatively unaltered by the fuel reduction treatments.

Formicidae (ants) may have benefited from reduced leaf litter depth and potentially more bare ground after hot fires in MB, which could have provided better nesting habitat (Campbell et al. 2007). Formicidae relative abundance and biomass also increased in B, where leaf litter was also reduced, although differences were not statistically significant. Increased abundance of Formicidae after burns has also been reported in xeric southern Appalachian pine-oak forests (Love et al. 2007) and in North Florida longleaf pine (*Pinus palustris* Mill.) flatwoods (Hanula and Wade 2003). Several coleopteran families that responded positively to the MB or B treatments, including Curculionidae, Nitidulidae, Scarabaeidae, and Tenebrionidae, tend to be associated with herbaceous plants or dead logs. However, immediately after

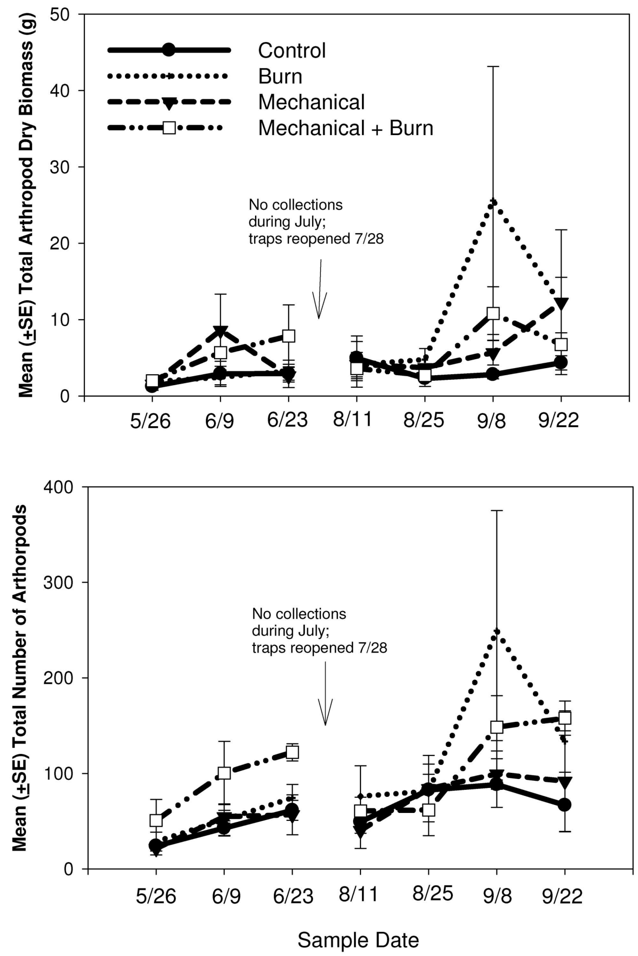

Figure 2. Mean (±SE) number and dry biomass (g) of arthropods collected biweekly with the three treatments (prescribed burn, mechanical understory reduction, mechanical felling + burn) and controls, at the Green River Game Land, Polk County, North Carolina, USA.

prescribed burning (2003), the percent cover of both coarse woody debris and herbaceous plants was similar among the three treatments and the control. In an associated study, Campbell et al. (2007) reported floral visiting insects increased in relative abundance in the MB treatment in 2003–2004, which correlated with reduced basal area of trees and increased herbaceous cover in 2004.

Results from other studies examining the effects of prescribed fire on ground-dwelling macroarthropod richness and relative abundance vary considerably. At another Fire and Fire Surrogate study area in a western Sierra Nevada mixed-conifer ecosystem, Apigian et al. (2006) reported a considerable change in macroarthropod communities and taxon-specific changes in relative abundance in response to treatments but found no general pattern. Interestingly, taxon-specific responses reported in their study differed from those observed in our study. For example, Carabidae, Staphylinidae, and Lycosidae relative abundance decreased in response to their B and/or MB treatments, whereas we found no differences for those taxa. Further, in their study Hymenoptera were unaffected by treatments (Apigian et al. 2006), whereas we found a positive response to MB compared with that to M. Studies of prescribed fire impacts on ground-dwelling macroarthropods vary considerably. Although studies in Jarrah forests of Australia (Abbott et al. 2003), in oak savannas (Siemann et al. 1997), and in southeastern United States longleaf pine forest (New and Hanula 1998) showed negligible or very transient reductions in relative abundance or richness, other studies found substantial impacts (e.g., Paquin and Coderre 1997, Moretti et al. 2006). Hanula and Wade (2003) found that ground-dwelling arthropod species differed in their responses to fire but found few differences at the family level.

The different results reported among some studies may reflect differences in forest ecosystems, timing of prescribed burns, fire intensity and severity, and behavioral and/or physiological adaptations of the macroarthropods sampled. In an upland hardwood forest of the Cumberland Plateau in southeastern Kentucky, Coleman and Rieske (2006) reported that neither single nor multiple prescribed burns had a detectable impact on relative abundance, diversity, or richness of ground dwelling arthropod families or total arthropods captured in pitfall traps. However, burning negatively affected litter-dwelling arthropods sampled by leaf-litter extraction (Coleman and Rieske 2006). Kalisz and Powell (2000) reported a 36% reduction in total dry biomass of soil invertebrates after prescribed fire, primarily due to reductions in coleopteran larvae. The timing of spring (March–May) prescribed fires also could affect various macroarthropod taxa differently in relation to taxon-specific life history traits. Our prescribed burns were in early March, when the overall activity of ground-dwelling macroarthropods is low (Greenberg and Forrest 2003).

In our study, leaf litter depth was significantly reduced in both B and MB treatments after fire. In addition, mortality of overstory trees in the MB treatment increased light and presumably temperature at the forest floor in MB. Given the potential sensitivity of some taxa to temperature, light, moisture, and cover conditions at the forest floor, the negligible effect of B and MB treatments on ground dwelling macroarthropods was somewhat surprising.

Several other studies showed a positive correlation between litter depth and macroarthropod abundance and biomass (e.g., Haskell 2000, Harper et al. 2001, Greenberg and Forrest 2003). Dress and Boerner (2004) reported lower microarthropod relative abundance in an annually burned watershed, where leaf litter mass was reduced, compared with a periodically burned or unburned watershed. In our study, an intact duff layer and relatively high canopy cover (although reduced in MB) may have mitigated the effect of reduced litter depth in the B and MB treatments for many taxa.

Our results showed an increase in arthropod relative abundance and biomass over the entire sampling period (from spring sampling to late summer sampling). However, this increase did not appear to be linked to treatments, as no treatment effects or treatment × time interactions were detected (except marginally for Blattodea adults and Formicidae). In a southern Appalachian hardwood forest, Greenberg and Forrest (2003) also reported peak relative abundance and biomass of ground-dwelling arthropods in summer and lowest in winter. The early spring timing of our prescribed burns may have minimized impacts on most

Table 4. Results of ANOVA with repeated measures on seven sampling dates during spring and summer 2003 on number (first line) and dry biomass (second line) of common arthropods after three treatments (B, M, and MB) and controls (C) at the Green River Game Land, Polk County, North Carolina

Order	Repeated-measures ANOVA						Treatment effects	Sample effects
	$F_{3,6}$	P_{trt}	$F_{6,48}$	P_{smp}	$F_{18,48}$	$P_{trt \times smp}$		
Archaeognatha	1.4	0.34	4.4	<0.01	1.5	0.13		$2^{a}, 4^{a}, 6^{ab}, 7^{ab}, 1^{ab}, 5^{ab}, 3^{b}$
	1.0	0.46	4.4	<0.01	1.0	0.45		$2^{a}, 4^{a}, 7^{a}, 1^{a}, 5^{a}, 6^{ab}, 3^{b}$
Araneae	0.1	0.93	10.4	<0.01	1.1	0.36		$4^{a}, 5^{ab}, 6^{bc}, 7^{c}, 1^{c}, 2^{c}, 3^{c}$
	0.1	0.95	10.3	<0.01	0.8	0.71		$4^{a}, 5^{a}, 6^{ab}, 7^{bc}, 1^{bc}, 2^{bc}, 3^{c}$
Blattodea (adult)	1.2	0.39	4.3	<0.01	1.8	0.06		$1^{a}, 6^{a}, 7^{ab}, 4^{ab}, 2^{ab}, 5^{ab}, 3^{b}$
	0.6	0.64	3.3	0.01	1.5	0.14		$1^{a}, 6^{a}, 4^{ab}, 2^{ab}, 7^{ab}, 3^{b}, 5^{b}$
Blattodea (larvae)	1.6	0.28	7.7	<0.01	1.3	0.26		$7^{a}, 1^{ab}, 5^{ab}, 6^{ab}, 4^{c}, 3^{c}, 2^{c}$
	1.7	0.27	7.5	<0.01	1.0	0.43		$7^{a}, 1^{ab}, 5^{abc}, 6^{abc}, 4^{bcd}, 3^{cd}, 2^{d}$
Coleoptera (adult)	0.7	0.59	7.8	<0.01	0.9	0.62		$1^{a}, 4^{b}, 7^{b}, 5^{b}, 2^{b}, 3^{b}, 6^{b}$
	0.1	0.98	4.5	<0.01	1.2	0.29		$1^{a}, 7^{ab}, 5^{ab}, 6^{b}, 4^{b}, 3^{b}, 2^{b}$
Coleoptera (larvae)	0.3	0.81	1.8	0.12	0.9	0.55		
	1.9	0.24	0.9	0.50	1.0	0.52		
Diptera (larvae)	1.0	0.44	7.7	<0.01	1.2	0.31		$1^{a}, 2^{a}, 7^{ab}, 3^{ab}, 4^{bc}, 5^{c}, 6^{c}$
	1.2	0.37	2.3	0.05	0.7	0.83		$1^{a}, 2^{a}, 7^{a}, 3^{a}, 4^{a}, 5^{a}, 6^{a}$
Hymenoptera	3.9	0.08	2.4	0.05	1.1	0.05		$1^{a}, 5^{a}, 3^{ab}, 4^{ab}, 2^{ab}, 7^{ab}, 6^{b}$
	3.7	0.08	4.5	<0.01	0.8	0.70	$M^{a}, C^{ab}, B^{bc}, MB^{c}$	$1^{a}, 4^{ab}, 2^{ab}, 5^{ab}, 7^{b}, 3^{b}, 6^{b}$
Julida/Spirobolida	2.2	0.19	8.8	<0.01	1.0	0.51		$4^{a}, 5^{ab}, 3^{b}, 2^{bc}, 6^{bc}, 1^{bc}, 7^{c}$
	3.3	0.10	8.2	<0.01	1.0	0.44		$4^{a}, 5^{ab}, 3^{b}, 2^{b}, 1^{bc}, 6^{bc}, 7^{c}$
Lepidoptera (larvae)	0.4	0.76	12.2	<0.01	0.7	0.75		$3^{a}, 2^{ab}, 4^{b}, 1^{bc}, 5^{bc}, 7^{cd}, 6^{d}$
	0.6	0.62	11.1	<0.01	0.5	0.94		$3^{a}, 2^{ab}, 1^{ab}, 4^{ab}, 5^{bc}, 6^{c}, 7^{c}$
Opiliones	0.6	0.64	14.6	<0.01	1.3	0.20		$3^{a}, 2^{a}, 1^{ab}, 5^{bc}, 7^{bc}, 4^{cd}, 6^{d}$
	0.6	0.66	17.5	<0.01	1.3	0.22		$3^{a}, 2^{a}, 1^{a}, 5^{b}, 7^{b}, 4^{b}, 6^{c}$
Orthoptera	1.0	0.45	5.9	<0.01	0.9	0.54		$2^{a}, 1^{a}, 5^{a}, 4^{ab}, 3^{ab}, 6^{b}, 7^{b}$
	1.1	0.41	5.5	<0.01	1.1	0.35		$2^{a}, 1^{a}, 5^{ab}, 4^{ab}, 3^{abc}, 6^{bc}, 7^{c}$
Polydesmida	0.7	0.58	2.6	0.03	1.4	0.18		$3^{a}, 6^{ab}, 7^{ab}, 2^{ab}, 1^{ab}, 5^{b}, 4^{b}$
	0.7	0.57	2.5	0.03	1.0	0.45		$3^{a}, 7^{a}, 6^{ab}, 2^{ab}, 1^{ab}, 5^{ab}, 4^{b}$
Scolopendromorpha	0.6	0.66	1.5	0.20	1.3	0.25		
	0.6	0.63	1.7	0.14	1.5	0.14		
Total	1.2	0.39	9.31	<0.01	0.8	0.65		$1^{a}, 4^{ab}, 2^{bc}, 5^{bcd}, 3^{bcd}, 7^{cd}, 6^{d}$
	0.6	0.62	5.2	<0.01	0.9	0.64		$1^{a}, 5^{ab}, 4^{ab}, 3^{ab}, 2^{ab}, 7^{b}, 6^{b}$

Sample dates in 2003: 1 = May 26, 2 = June 9, 3 = June 23, 4 = Aug. 11, 5 = Aug. 25, 6 = Sept. 8, and 7 = Sept. 22. Where effects are significant, treatments and sample dates are ordered from least to highest; different letters among treatments or sample periods indicate significant differences.

orders and families of ground-dwelling arthropods because of their relative inactivity, below-ground location, and/or stage of development.

In our study, low treatment replication ($n = 3$) increased the likelihood that we did not detect some responses that did indeed occur (the likelihood of type II error). Further, our conclusions are somewhat limited by our trapping method. Estimates of relative macroarthropod abundance from pitfall trapping may be biased by changes in their activity levels, hence likelihood of being trapped, which could differ among treatments simply because of microhabitat conditions. In our study, for example, higher capture rates of some taxa in B or MB could be a reflection of greater activity levels by those taxa where leaf litter depth was reduced. However, pitfall trapping involves continual trapping over an extended period of time and thus reduces other biases associated with "snapshot" sampling techniques such as collection of soil-litter cores or litter vacuuming.

Low capture rates of individual species (based on our morphospecies data) prohibited us from conducting analyses at lower taxonomic levels that may have revealed more information regarding species-specific responses to the fuel reduction treatments (e.g., Spence et al. 2008). However, most of the studies mentioned above reported significant results based on analyses at the order or family level, possibly because species within families tend to have similar ecological requirements. Our study does not address the ecology or response of individual arthropod species to prescribed fire and other fuel reduction treatments and does not provide information that can be applied to arthropod conservation at the species level. Instead, our study provides information on how ground-dwelling macroarthropods respond to prescribed fire and other fuel reduction treatments at the order, family, and community levels and how these treatments affect an important prey base for vertebrates in southern Appalachian hardwood forest.

Conclusions

Our results indicate that prescribed burning and mechanical fuel reduction treatments conducted in winter or early spring have little impact on the community composition, relative abundance, or biomass of total arthropods or most arthropod orders and families, at least in the short term. Leaf litter depth was significantly reduced in both burn treatments after fire. In addition, hot fires in MB resulted in mortality of overstory trees and reduced canopy cover, increased light, and presumably increased temperature at the forest floor. Among the few taxa showing a response to treatments, all showed increases in either biomass or relative abundance in B or MB after prescribed fire. This result suggests that these changes to the forest floor habitat and microclimate did not adversely affect macroarthropods and may positively affect some. Prescribed burning in early spring, when activity levels are generally low, may mitigate potentially adverse affects to ground-dwelling macroarthropods. Our study suggests that the fuel reduction methods studied may be used as a land management tool in upland hardwood forest with little effect on ground-dwelling macroarthropods.

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