Available online at www.sciencedirect.com
ScienceDirect
Forest Ecology and Management 243 (2007) 231–236
Forest Ecology and Management
www.elsevier.com/locate/foreco

Short-term response of shrews to prescribed fire and mechanical fuel reduction in a Southern Appalachian upland hardwood forest

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Received 23 January 2007; received in revised form 2 March 2007; accepted 7 March 2007

Abstract

As part of the multidisciplinary National Fire and Fire Surrogate study, we used drift fences with pitfall traps from May to September 2003 and 2004 to determine how three fuel reduction techniques affected shrews in the Southern Appalachian Mountains of North Carolina. Ground-dwelling macroarthropods also were collected from a subset of pitfall traps to assess relative prey availability among the treatments. 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; (4) forested controls. Mechanical understory felling treatments were conducted in winter 2001–2002, and prescribed burning was conducted in March 2003. High-intensity fires and high tree mortality increased canopy openness in mechanical felling + burn treatment compared to the others. Burning reduced leaf litter depth in both the burned treatments (burn only and mechanical felling + burn), whereas mechanical understory felling alone increased leaf litter depth in that treatment. Dry biomass of ground-dwelling macroarthropods was similar among the treatments and control. We collected a total of 269 shrews of four species during 2003 and 2004, including northern short-tailed shrews (*Blarina brevicauda*), smokey shrews (*Sorex fumeus*), pygmy shrews (*S. hoyi*), and southeastern shrews (*S. longirostris*). Relative abundance of all shrews combined and pygmy shrews was lowest in the mechanical felling + burn treatment, but differed significantly only from the mechanical understory felling treatment where the contrast in leaf litter depth was high. Our results indicate that low-intensity fuel reduction treatments, with minimal change to canopy cover or leaf litter depth, have little impact on shrews. However, high-intensity disturbance, such as prescribed burning that kills trees and dramatically reduces shade and leaf litter depth, can reduce the abundance of some shrew species and all shrews combined, at least in the short term.

Keywords: Burn; Fire surrogate; Fuel reduction; Prescribed fire; Shrews; Soricids; Southern Appalachians

1. Introduction

The Southern Appalachian Mountains support a high species richness and abundance of shrews. Shrews are important predators on other small vertebrates and invertebrates, serve as prey for many vertebrate predators (Van Zyll de Jong, 1983), and are an important component of the small mammal community (Laerm et al., 1999). Among the nine species occurring in the Blue Ridge Physiographic portion of the Southern Appalachians (Ford et al., 1997), three (pygmy shrews (*Sorex hoyi*), rock shrews (*Sorex dispar*), and water shrews (*Sorex palustris*)) are rare, and considered of conservation concern (Ford and Rodrigue, 2001). Despite this, information on shrew habitat requirements and response to forest management is scant because they are elusive, and because the most effective method for trapping shrews, pitfall trapping with drift fences, involves considerable time and effort (Kirkland and Sheppard, 1994; Handley and Kalko, 1993).

In the Southern Appalachians, elevation, forest type (Laerm et al., 1999; Ford et al., 2006), and competition among shrew species (Kirkland, 1991; McCay et al., 2004) are thought to influence their distribution and relative abundance. Microhabitat features such as coarse woody debris also may be weakly associated with the abundance of some shrew species (Ford et al., 1997). Moisture levels in soil and leaf litter, and the invertebrate prey base it supports often are suggested as

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0378-1127/$ – see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.foreco.2007.03.003

important determinants of shrew diversity and abundance (Getz, 1961; Kirkland, 1991).

Forest management practices that dramatically alter light conditions, leaf litter depth and cover, and subsequently soil or leaf-litter temperature and moisture might be expected to impact shrew communities. However, studies of shrew response to natural or silvicultural disturbance show results that often are contradictory. Some studies report increases in shrew captures after timber harvests (Ford et al., 2000; Healy and Brooks, 1988; Kirkland, 1990), whereas others show little numerical response to silvicultural (Klein and Michael, 1984; Ford and Rodrigue, 2001; Ford et al., 2002) or natural (Greenberg and Miller, 2004) disturbances.

Prescribed burning and mechanical understory reductions are common silvicultural practices used to reduce the risk of wildfire (Graham et al., 2004), and for ecosystem restoration, oak regeneration, understory control, and wildlife conservation (Brawn et al., 2001). During the past decade prescribed fire has become a common forest management practice in Southern Appalachian hardwood ecosystems. The impact of various fuel reduction treatments on shrew communities is likely to correspond with the type and intensity of disturbance, and changes in macro- and microhabitat. However, few studies address the response of shrews to prescribed burning or other fuel reduction methods.

As part of the multidisciplinary National Fire and Fire Surrogate study (Youngblood et al., 2005), we used a replicated experimental design to determine if and how shrew species and communities respond to fuel reduction by prescribed burns, mechanical understory reductions, or mechanical understory reductions followed by prescribed burns. Specifically, we examined differences in the relative abundance of species and total individuals among these three fuel reduction treatments and untreated controls in the Southern Appalachians, both immediately after and 1 year after all three treatments had been fully implemented.

2. Study area and methods

2.1. Study area

Our study was conducted on the 5841-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, western North Carolina. 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 (USDA Natural Resources Conservation Service, 1998). The study site also contained areas of rocky outcrops in steeper terrain. Forest stands were composed mainly of oaks (*Quercus* spp.) and hickories (*Carya* spp.). Shortleaf (*Pinus echinata*) and Virginia (*P. virginiana*) pines were found on ridgetops, and white pine (*P. strobus*) and yellow-poplar (*Liriodendron tulipifera*) 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*) along ridge tops and on upper southwest-facing slopes, and rhododendron (*Rhododendron maximum*) in mesic areas. Elevation ranged from approximately 366–793 m. None of the sites had been thinned or burned for at least 50 years (Dean Simon, North Carolina Wildlife Resources Commission, personal communication).

2.2. Study design

Our experimental design was a complete randomized block design with repeated measures over years. We selected three study areas (blocks) within the Game Land. Study blocks were selected based upon stand size (large enough to accomodate all four treatments), stand age, cover type, and management history to ensure that baseline conditions were consistent among the treatments (see Greenberg et al., 2006). First and second order streams bordered and (or) traversed all three replicate 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 treatment regimes and an untreated control (C) were randomly assigned to the four experimental units within each block. Treatments were (1) fuel reduction by mechanical understory felling in winter 2001–2002 (M); (2) fuel reduction by prescribed burning in March 2003 (B) and; (3) 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 diameter at breast height (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 B and MB treatments on 12 or 13 March 2003; burning was done 1 year after felling to allow decomposition of some fuels so that fire intensity would be reduced. One block was burned by hand ignition using spot fire and strip-headfire techniques. The two other blocks were burned as a single unit. Backing fires were set along fire lines by hand followed by spot fires set by a helicopter using a plastic sphere dispenser. See Phillips et al. (2006) for methods used to measure fuel loadings, fire temperature, and fire behavior.

Fire intensities varied within and among sites but were generally moderate to high. Flame lengths of 1–2 m occurred throughout all burn units but in one block reached up to 5 m in localized spots where topography or intersecting flame fronts contributed to erratic fire behavior. Measured temperatures at 30 cm above the forest floor were generally below 120 °C in B sites but sometimes exceeded 800 °C in MB. Higher fuel loads from the understory felling treatment, lower fuel moisture, and topography contributed to higher-intensity fires in MB (R.J. Phillips, US Forest Service, personal communication). A detailed description of fire behavior in this study is given by Phillips et al. (2006).

2.3. Shrew and 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 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.'' Double-ended funnel traps were placed on both sides of each arm for a total of six funnel traps at each array, but these generally did not capture shrews. A moist sponge was placed in each bucket to provide moisture and cover for captured animals. The arrays were designed to capture reptiles and amphibians, but also effectively captured shrews.

Arrays were open continuously and concurrently from 5 May to 2 July and 28 July to 1 October 2003, and from 10 May to 2 August and 20 August to 1 October 2004 for a total of 123 nights in 2003 and 125 nights in 2004. Shrews also were captured, but not systematically collected, during 2001 (15 August–10 October) and 2002 (7 May–1 October) while trapping herpetofauna; therefore, we used none of those data in this study. All traps were checked three times weekly.

Dead shrews were bagged, labeled by date and location, and frozen for later identification. We recorded and released live shrews (24% of total captures, possibly including recaptures), but we did not identify them to species or include those captures in analyses. The proportion of live, released shrews to total captures (live and dead) did not differ among the treatments (ANOVA; $F_{3,6} = 1.29$; $P = 0.3611$), and therefore did not likely bias our data. All shrews collected were measured (mass; total, tail, hind foot, and ear lengths), dried, de-fleshed in *Dermestes lardarius* L. (larder beetle) colonies, and identified using keys to body measurement, dental, and cranial characters (Hall, 1981; Junge and Hoffmann, 1981) in the laboratory. We determined sex and reproductive status (e.g., lactating; swollen testes) by dissection if body condition was adequate. All shrew specimens were assigned a unique catalogue number and deposited in the Bob & Betsy Campbell Museum of Natural History at Clemson University (Accession # 1026) after identification.

Ground-dwelling arthropods were collected (hand-scooped) bi-weekly from all pitfall traps at one of the two drift fence arrays in each treatment from 12 May 2003 through 22 September 2003 except when traps were closed (3 July through 27 July 2003). Macroarthropods were preserved in 70% ethyl alcohol before being oven-dried to a constant mass and weighed in the lab.

2.4. Habitat measurements

We measured habitat variables in all experimental units immediately after treatments (2002 for M, and 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 ten 0.05-ha plots that originated at a randomly pre-determined 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 m × 20 m belt transects originating at alternate gridpoints throughout treatment areas. Depth of leaf litter and duff was measured at three locations (3.6 m, 7.6 m, and 12.2 m) along each of three randomly oriented; 15-m transects originating at each grid point. We measured percent canopy openness at both drift fence arrays within each experimental unit during summer (leaf on) 2003 and 2004 using a concave spherical densiometer held at breast height.

2.5. Statistical analyses

We used a two-way ANOVA with repeated measures over years on post-treatment data (2003–2004), to compare the relative abundance of each shrew species and all shrews combined among treatments and years, and to test for treatment × year interactions (SAS, 1990). 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 multiple comparison procedure. These data were natural log-transformed for analysis to reduce heteroscedasticity. We used a log-likelihood ratio *G*-test (Zar, 1984) to determine whether the male:female ratio differed from 1:1 for each species, using data from all sites and years combined.

We used one-way ANOVAs to test for post-treatment (2003) differences in natural log-transformed total arthropod biomass, and to test for 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's multiple comparison procedure. We considered $P < 0.05$ to be statistically significant for all analyses.

3. Results

Immediately after treatment, live tree density was lower in MB than other treatments; snag density and canopy openness also tended to be higher in MB than other treatments due to high tree mortality from the high-intensity burns (Table 1). Leaf litter depth was lower in both burned treatments (B and MB) than the other treatments, and highest in M. Duff depth and percent cover of coarse woody debris did not differ among the treatments (Table 1). Total biomass of macroarthropods did not differ among treatments ($F_{3,6} = 0.94$, $P = 0.4775$).

We collected a total of 269 shrews from pitfall traps during 2003 and 2004; 262 were identified to species. Shrew species were northern short-tailed shrews (*Blarina brevicauda*) (123; 99 sexed), smokey shrews (*Sorex fumeus*) (36; 26 sexed), pygmy shrews (45; 40 sexed), and southeastern shrews (*S. longirostris*) (58; 45 sexed) (Table 2). An additional 86 shrews (possibly including recaptures) were captured alive and released. Other small mammal species captured in pitfalls included star-nosed moles (*Condylura cristata*), pine voles (*Microtus pinetorum*), and white-footed mice (*Peromyscus leucopus*).

Table 1
Mean (±S.E.) post-treatment density of live trees and snags (≥10 cm dbh), percent cover of coarse woody debris, duff and leaf litter depth (cm), and percent canopy openness, in three treatments: burned (B), mechanical understory felling (M), and mechanical understory felling followed by burning (MB), and controls (C) ($n = 3$ each), Green River Game Land, Polk County, North Carolina

Habitat feature	Treatment				ANOVA	
	C	B	M	MB	P_{block}	P_{trt}
Live trees (ha)	550.7 ± 15.0 A	539.3 ± 30.0 A	588.0 ± 11.0 A	379.3 ± 43.5 B	0.349	0.007
Snags (ha)	68.0 ± 9.0 AB	72.7 ± 19.0 AB	52.7 ± 4.4 A	152.0 ± 25.3 B	0.740	0.031
Coarse woody debris (% cover)	0.9 ± 0.3	1.2 ± 0.3	1.0 ± 0.2	1.2 ± 0.5	0.088	0.852
Litter depth (cm)	4.2 ± 0.5 A	0.9 ± 0.1 B	5.5 ± 0.2 C	0.5 ± 0.1 B	0.139	<0.001
Duff depth (cm)	3.5 ± 0.6	3.6 ± 0.3	5.4 ± 1.0	3.0 ± 0.4	0.877	0.187
Canopy openness (%)	1.6 ± 0.4 A	2.6 ± 1.1 AB	3.0 ± 0.8 AB	12.8 ± 5.0 B	0.205	0.028

Differences among treatments are denoted by different letters within rows.

Capture rates of pygmy shrews and all shrews combined were lower in MB than in M but did not differ from C or B (Table 2). Abundances of all shrews combined and each species except southeastern shrews were higher in 2003 than in 2004. No treatment × year interactions or repeated measures effects were detected. The proportion of males to females did not differ from the expected 1:1 ratio for any species ($P \geq 0.5$) except southeastern shrews, where males outnumbered females by 3.1:1 ($n = 45$; $P < 0.0001$).

4. Discussion

Our results indicate that the abundance of all shrews combined and pygmy shrews was lower in MB, although among treatment differences were statistically significant only between MB and M. High-intensity fires and high tree mortality markedly increased canopy openness in MB compared to the other treatments, whereas burning reduced leaf litter depth in both MB and B. In contrast, litter depth in M was higher than in the other treatments due to the addition of dead leaves after mechanical understory felling. Although we did not measure temperature or moisture levels in the leaf litter and soil, it is likely that temperatures increased and moisture decreased at ground level in MB, as canopy cover was substantially reduced. Differences in microhabitat and microclimate among the treatments may have affected shrew abundance, given their high moisture requirements (Getz, 1961; Kirkland, 1991) and strong association with leaf litter.

Ford et al. (1999) reported that a high intensity community restoration burn in a xeric pitch pine (*P. rigida*) forest in the Southern Appalachians did not affect the relative abundance of masked shrews (*S. cinereus*), smokey shrews, pygmy shrews, and northern short-tailed shrews (they did not capture southeastern shrews). Shrews likely avoid direct effects of prescribed fire by their semi-fossorial habits. Mole tunnels, runways beneath leaf litter, stump or root holes, and spaces within coarse woody debris likely provide shelter from heat (Ford et al., 1999). Incomplete or patchy burns that create a mosaic of shrub cover and tree mortality also could dampen potentially detrimental post-fire effects of burning on shrew abundance.

Several studies report little relationship between most measured microhabitat variables and capture rates of most shrew species (e.g., Getz, 1961; Healy and Brooks, 1988; Pagels et al., 1994; Ford et al., 1997; McCay et al., 1998). Ford et al. (1997) reported a weak association between leaf litter depth and abundance of northern short-tailed shrews and

Table 2
Total captures and mean (±S.E.) number of shrew captures in three fuel reduction treatments: prescribed burn (B), mechanical understory reduction (M), and mechanical + burn (MB), and controls (C) ($n = 3$ each) during 2003 and 2004, Green River Game Land, Polk County, North Carolina

Species	Total Captures	Year	Treatment				ANOVA			
			C	B	M	MB	$P_{rep(trt)}$ (d.f. = 6, 8)	P_{trt} (d.f. = 3, 6)	P_{year} (d.f. = 1, 8)	$P_{trt \times yr}$ (d.f. = 3, 8)
B. brevicauda	93	2003 A	10.3 ± 3.3	6.0 ± 2.1	8.3 ± 1.2	6.3 ± 1.2	0.436	0.435	0.019	0.518
	30	2004 B	3.0 ± 1.5	2.3 ± 0.3	3.0 ± 0.6	1.7 ± 1.2				
Sorex fumeus	28	2003 A	1.7 ± 0.8	1.7 ± 1.7	3.7 ± 2.3	2.3 ± 0.3	0.072	0.868	0.021	0.400
	8	2004 B	0.7 ± 0.7	1.0 ± 1.0	0.7 ± 0.7	0.3 ± 0.3				
S. hoyi	35	2003 A	2.0 ± 1.2 AB	3.7 ± 1.7 AB	4.7 ± 1.3 A	1.3 ± 0.9 B	0.650	0.035	0.030	0.831
	10	2004 B	0.3 ± 0.3	1.7 ± 1.2	1.3 ± 0.3	0.0 ± 0.0				
S. longirostris	43	2003	4.7 ± 2.0	3.7 ± 1.5	4.3 ± 1.5	1.7 ± 1.7	0.188	0.125	0.211	0.261
	15	2004	1.0 ± 0.6	1.3 ± 0.3	2.0 ± 0.6	0.7 ± 0.3				
Total shrews	206	2003 A	19.3 ± 0.3 AB	15.0 ± 2.5 AB	22.3 ± 4.7 A	12.0 ± 3.6 B	0.966	0.004	0.001	0.643
	63	2004 B	5.0 ± 2.1	6.3 ± 1.2	7.0 ± 0.0	2.7 ± 1.2				

Different letters between years (rows), or among treatments within rows (without respect to year) indicates significant differences.

smokey shrews in a Southern Appalachian cove hardwood forest. Ford and Rodrigue (2001) reported little effect of a partial overstory removal harvest on masked shrews, smokey shrews, and northern short-tailed shrews in the Central Appalachians, despite decreased leaf litter, canopy cover and (likely) soil moisture. Northern short-tailed shrews may be weakly associated with coarse woody debris (McCay et al., 1998). However, this likely did not affect our results because coarse woody debris cover was similar among all treatments and controls. Shrew responses to silvicultural practices, such as thinning or timber harvests, and associated changes in microhabitat features may vary geographically with regional precipitation, soils, and other edaphic factors that govern soil moisture. Shrew species captured within our study area were habitat generalists (Laerm et al., 2000; Ford et al., 2006), and apparently tolerated a wide range of habitat conditions.

In our study, ground-dwelling macroarthropod biomass was similar among the treatments, suggesting that arthropod prey availability did not play a key role in affecting relative shrew abundance among the treatments. However, we did not examine possible differences in arthropod species composition among the treatments, which could influence the relative abundance of shrews. Other studies indicate that ground-dwelling macroarthropods are less abundant, and species composition differs between disturbed forest (where canopy and leaf litter cover are lower) and forested controls (e.g., Greenberg and Forrest, 2003; Whitehead, 2003).

Shrew capture rates were lower in 2004 than in 2003 for three of four species, but these declines were independent of treatments. Shrew mortality may have contributed to reduced capture rates in 2004; however, the absence of a repeated measures effect suggests that other factors contributed to the different capture rates. Further, similar numbers of shrews (191 mortalities and 54 alive and released) were captured during 2002 and 2003 from the same drift fence arrays during approximately the same trapping period, suggesting that 2002 shrew mortalities did not reduce capture rates in 2003. McCay and Komoroski (2004) noted that trap mortality in their study (68%) probably represented a small proportion of shrews within their study area due to low capture rates.

We did not capture masked shrews, although they occur in the Southern Appalachians. However, our study area was located at the southern edge of its range. Several studies have reported that southeastern shrews and masked shrews are locally segregated in the Southern Appalachians (Pagels and Handley, 1989; Ford et al., 2001) because of differences in habitat preferences (Laerm et al., 1999) and competitive exclusion between similar-sized shrew species (Fox and Kirkland, 1992). Also, masked shrews tend to occur at higher elevations ($\geq$610 m) than southeastern shrews ($\leq$610 m depending on latitude) (Pagels and Handley, 1989). Greenberg and Miller (2004) found three small-bodied shrew species (southeastern shrews, masked shrews, and pygmy shrews) co-occurring at a nearby site in the Southern Appalachians at a slightly higher elevation and farther north than in this study. Competitive exclusion between same-size shrew species may be most common in xeric forest types, such as that within our study area (McCay et al., 2004; Ford et al., 2006).

5. Conclusions

The abundance of all shrews combined and pygmy shrews decreased in response to MB, where high-intensity burns and high tree mortality increased light and reduced leaf litter depth. The contrast in relative abundance was most marked between MB and M, where leaf litter depth differed considerably due to burning in MB and understory felling in M. Biomass of ground-dwelling macroarthropods was similar among treatments, suggesting that arthropod prey base was not a major factor affecting shrew response to treatments; however, we did not examine differences in arthropod species composition. Changes in relative abundance of shrews were likely a response to the suite of post-treatment habitat conditions in MB, particularly reduced leaf litter cover and associated changes in ground-level microclimatic conditions. Our results indicate that low-intensity fuel reduction treatments, with minimal change to canopy cover or leaf litter depth, have no measurable impact on shrew abundance. However, high-intensity disturbance, such as prescribed burning that kills trees and dramatically reduces shade and leaf litter depth, can reduce the abundance of some shrew species and all shrews combined, at least in the short term.

Acknowledgements

This is contribution number 139 of the National Fire and Fire Surrogate Research (NFFS) project. This research was funded by the US Forest Service through the National Fire Plan. Although the authors received no direct funding for this research from the Interagency Joint Fire Science Program (JFSP), it was greatly facilitated by the JFSP support of existing NFFS project sites. We thank J.D. Lanham for advice on drift fence array design, and J. Baker, A. Livings Tomcho, J. Tomcho, D. Watts, V. Sudilovsky, T. Hayes, G. Graeter, P. Craig, S. Walter, and several volunteers for help in establishing drift fence arrays and (or) sampling shrews. A.L. Tomcho deserves special thanks for many hours of sorting through macroarthropod collections. R. Phillips and others collected and provided habitat data. W.M. Ford, C. Moorman, and C. Matthews, provided useful suggestions to improve an earlier version of this manuscript. We thank the North Carolina Wildlife Resources Commission, especially D. Simon, for support, for permitting this study to be conducted on state Game Lands, and for conducting all fuel reduction treatments.

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