Forest Ecology and Management 257 (2009) 1939–1944

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Response of soricid populations to repeated fire and fuel reduction treatments in the southern Appalachian Mountains

Charlotte E. Matthews[a,*], Christopher E. Moorman[a], Cathryn H. Greenberg[b], Thomas A. Waldrop[c]

[a] *North Carolina State University, Box 7646, Raleigh, NC 27695, United States*
[b] *USDA Forest Service, Southern Research Station, Bent Creek, Experimental Forest, Asheville, NC 28806, United States*
[c] *USDA Forest Service, Southern Research Station, Clemson, SC 29634, United States*

ARTICLE INFO

Article history:
Received 6 November 2008
Received in revised form 29 January 2009
Accepted 2 February 2009

Keywords:
Fire surrogates
Prescribed fire
Shrews
Soricids
Southern Appalachian Mountains
Understory cutting

ABSTRACT

Fuel hazards have increased in forests across the United States because of fire exclusion during the 20th century. Treatments used to reduce fuel buildup may affect wildlife, such as shrews, living on the forest floor, especially when treatments are applied repeatedly. From mid-May to mid-August 2006 and 2007, we used drift fences with pitfall traps to capture shrews in western North Carolina in 3 fuel reduction treatment areas [(1) twice-burned (2003 and 2006), (2) mechanical understory cut (2002), and (3) mechanical understory cut (2002) followed by 2 burns (2003 and 2006)] and a control. We captured 77% fewer southeastern shrews (*Sorex longirostris*) in mechanical + twice-burned treatment areas than in mechanical treatment areas in 2006, but southeastern shrew captures did not differ among treatment areas in 2007. Total shrew captures did not differ among treatment areas in either year. Decreases in leaf litter, duff depth, and canopy cover in mechanical + twice-burned treatment areas may have decreased ground-level moisture, thereby causing short-term declines in southeastern shrew captures. Prescribed fire or mechanical fuel reduction treatments in the southern Appalachian Mountains did not greatly affect shrew populations, though the combination of both treatments may negatively affect some shrew species, at least temporarily.

As a result of fire exclusion across the United States during the 20th century, forests have accumulated large fuel loads. In the southern Appalachian Mountains, down woody fuels can be heavy across all topographic positions, and vertical fuels, which consist of mostly mountain laurel (*Kalmia latifolia*) and rhododendron (*Rhododendron maximum*), are common and dense where they occur (Waldrop et al., 2007). More recently, prescribed fire has been used with increasing frequency as a land management tool to return land to historical conditions, control growth of understory plants, reverse succession, affect vegetative species composition, improve wildlife habitat, and reduce fuel accumulation. However, because of the risks to property and air quality associated with fire, mechanical or manual fire surrogates may be used to thin vegetation and remove potential fuels (Johnson and Hale, 2000; Van Lear and Harlow, 2000). Fuel reduction treatments have not been used as extensively in the southern Appalachian Mountains as in the western United States, although prescribed fire, thinning, or a combination of these treatments may be beneficial in reducing fuel loads and returning these forests to historical conditions (Gorte, 2000). Historically, many forests in the southern Appalachian Mountains were fire-maintained mixed oak forests with a sparse understory (Lorimer, 1985; Abrams, 1992; Delcourt and Delcourt, 1997; Brose et al., 2001, 2002).

Shrews (soricids) have small home ranges and high food and moisture requirements, and therefore may be sensitive to treatments that affect forest floor microhabitats (Chew, 1951; Pruitt, 1959; Getz, 1961; Ochocińska and Taylor, 2005). Shrews are important as a prey base and as predators and have been used as indicators of the ecological effects of forestry practices (Hamilton, 1941; Buckner, 1966; Carey and Harrington, 2001; Ochocińska and Taylor, 2005). Soricid populations generally do not change following prescribed fire or other disturbances that leave some canopy cover (Ford et al., 1999; Ford and Rodrigue, 2001; Greenberg and Miller, 2004). However, heavy disturbances that substantially reduce forest canopy cover or consume litter and duff may affect shrew populations (Menzel et al., 2005; Greenberg et al., 2007a).

Most studies of shrew response to disturbances have been short-term and address initial responses after a single disturbance (e.g., prescribed fire). Yet, multiple prescribed burns likely result in additional changes in leaf litter, canopy cover, and understory density. With these additive habitat changes, the effects of multiple fuel reduction treatments on shrews may differ from

---

[*] Corresponding author. Tel.: +1 919 513 7558; fax: +1 919 515 5110.
E-mail addresses: cematthe@ncsu.edu, charematthews@yahoo.com
(C.E. Matthews).

0378-1127/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2009.02.006

the effects shortly after 1 treatment. Little is known about longer-term effects of fuel reduction treatments on soricids, including shrew response to multiple prescribed burns.

An earlier study of short-term shrew response to 3 fire and fire surrogate treatments (before a second prescribed burn) and a control was conducted at our study site during 2003 and 2004. Fuel reduction treatments were a single prescribed burn, a mechanical understory cut, and a mechanical understory cut + burn treatment. Captures of pygmy shrews (*Sorex hoyi*) and total shrews were lower in mechanical + burn treatment areas than in mechanical treatment areas, indicating that shrews were not affected in the short-term by low-intensity fuel reduction treatments, but that high-intensity disturbance that reduces canopy cover and leaf litter may negatively affect shrews (Greenberg et al., 2007a). Our study was designed to examine longer-term effects on shrews following a second burn at the same study site. We hypothesized that after 2 prescribed burns, shrew relative abundance would be lower in mechanical + twice-burned treatment areas than in all other treatment areas, but unaffected in twice-burned and mechanical treatment areas.

1. Study objectives

The National Fire and Fire Surrogate Study was initiated in 2000 in 13 different ecosystems across the United States to assess the effects of prescribed fire and fire surrogate treatments on vegetation, wildlife, pathogens, soil, and the forest floor and to evaluate such variables as fire behavior, fuel, smoke, economics, and wood product utilization. Management objectives at our study site were to restore the area to an open woodland structure, reduce potential wildfire severity, and increase oak regeneration (Waldrop et al., 2008). The objective of this paper was to determine the effects of 2 successive prescribed fires, a mechanical fire surrogate treatment, and a combined mechanical + prescribed fire treatment on soricids.

2. Study area

Our study was conducted on the 5481-ha Green River Game Land (GRGL) in the southern Appalachian Mountains of Polk County, North Carolina. The southern Appalachian Mountains harbor a high diversity of shrews and are an appropriate location to research their response to fuel reduction treatments (Ford et al., 2005). Elevation on the GRGL ranged from 366 to 793 m. Two of our sites (35°17′9″N, 82°19′42″W) were located approximately 2.9 km NW of our third site (35°15′42″N, 82°17′27″W). Forest stands consisted of xeric and mesic oak species (*Quercus* spp.) mixed with hickories (*Carya* spp.) and pine (*Pinus* spp.). Pitch pine (*P. rigida*) and Table Mountain pine (*P. pungens*) were located sporadically on ridgetops and white pine (*P. strobus*) was in moister cove areas. Chestnut oak (*Q. prinus*), black oak (*Q. velutina*), northern red oak (*Q. rubra*), scarlet oak (*Q. coccinea*), white oak (*Q. alba*), yellow-poplar (*Liriodendron tulipifera*), sourwood (*Oxydendrum arboreum*), blackgum (*Nyssa sylvatica*), mockernut hickory (*C. tomentosa*), and red maple (*Acer rubrum*) were located on all sites.

The understory was composed primarily of mountain laurel, rhododendron, flame azalea (*Rhododendron calendulaceum*), and blueberry (*Vaccinium* spp.). Before 2003, the site had not been burned in over 50 years (Dean Simon, North Carolina Wildlife Resources Commission, personal communication), and stands varied in age from 80 to 120 years.

3. Methods

Our experimental design followed the National Fire and Fire Surrogate Study guidelines. Three blocks of 4 treatment areas were implemented in a randomized complete block design for a total of 12 treatment areas. The 4 treatments were randomly assigned to areas within each block. Treatments, representing different fuel reduction options, consisted of an untreated control, a twice-burned treatment, a mechanical understory cut, and a combined mechanical understory cut + twice-burned treatment. Each treatment area was 10 ha with a surrounding buffer, 20 m wide.

4. Treatments

Mechanical understory cut treatments were conducted between December 2001 and February 2002, 1 year before the first prescribed burn. Trees $\geq$1.8 m tall and $<$10.2 cm diameter at breast height (dbh) and shrubs regardless of size were cut using chainsaws and left on site. The first burns were conducted in March 2003. Treatment areas within 2 blocks were ignited by helicopter using spot fires and within 1 block by hand using spot fires and strip-headfires (Greenberg et al., 2007a). Maximum temperatures were recorded with thermocouples located 30 cm above the ground, with 38–40 thermocouples spaced throughout each treatment area. The mean maximum temperatures for burn and mechanical + burn treatments in 2003 were 180 and 370 °C, respectively (Waldrop et al., 2008). Phillips et al. (2006) provided a description of this fire behavior in more detail.

Hot fires in the mechanical + burn treatment killed overstory trees and opened the canopy the first summer after burning, and overstory mortality continued to increase in mechanical + burn treatment areas 3 years after the burn (Waldrop et al., 2008). Burning alone did not cause substantial overstory mortality (Waldrop et al., 2008).

A second prescribed burn was implemented in February 2006 in burn and mechanical + burn treatment areas. Another mechanical understory cut was not implemented because shrubs had not grown tall enough to become a fuel risk. Fires in all replicates were ignited from the ground. Maximum temperatures were recorded with thermocouples located 30 cm above the ground, spaced throughout all burn treatment areas. Average maximum fire temperatures in the second prescribed burn were higher in the mechanical + twice-burned treatments (222 °C) than in the twice-burned treatments (155 °C) (Waldrop et al., 2008).

Live-tree basal area declined and canopy cover decreased as overstory mortality increased in mechanical + twice-burned treatment areas immediately after the second burn. However, the relative abundance of tree species was not substantially altered, as mortality was consistent among all species (Waldrop et al., 2008). In contrast, live-tree basal area in twice-burned-only treatment areas remained similar to control and mechanical treatment areas (Waldrop et al., 2008).

5. Soricid sampling

The 2 drift fence arrays per treatment area installed in 2001 were reopened from 17 May to 16 August 2006. We installed 1 additional array in each treatment area, $\geq$100 m from original arrays; these were opened concurrently on 11 July so that 3 arrays per treatment area were operational from 11 July to 16 August 2006. In 2007, all 3 drift fence arrays per treatment area were opened from 15 May to 13 August. The tri-arm ('Y' formation) arrays (Kirkland and Sheppard, 1994), constructed of 50-cm aluminum flashing, had 7.6-m array arms buried 10–15 cm in the soil and 19-L buckets in the center of the array and at the end of each arm for a total of 4 pitfall traps. We drilled holes in the bottoms of pitfalls to prevent flooding, buried buckets flush with the ground, and cut buckets so flashing ran into pitfalls. We placed double-ended funnel traps, made from aluminum screening, along both sides of each arm for 6 funnel traps total per array. Each pitfall and funnel trap was covered by a small board for shade and contained a wet sponge to provide moisture that was rewet every time traps were checked. Frequently flooded buckets also contained a small piece of styrofoam for cover and flotation.

We checked all arrays every 1–3 days and every day following a rain event. Dead shrews (83% of all shrew captures) were labeled and kept for later measurement and identification. Live shrews (17% of all shrew captures) were released without marking and identified to species in the field if possible in 2007, but not in 2006. Shrew specimens were deposited with the North Carolina Museum of Natural Sciences. We handled all animals according to protocol approved by the North Carolina State University IACUC (Project Number 06-025-O). Animal collection was permitted by the North Carolina Wildlife Resources Commission in 2006 and 2007 (Permit Number 0996, 1050).

6. Habitat data

Habitat variables were measured in all treatment areas during the summer of 2006, the first summer after the second burn. Variables recorded were density, volume, and percent cover of coarse woody debris, litter depth, duff depth, basal area of live and dead trees, percent herbaceous cover, and percent shrub cover. Shrubs were recorded in 2 height categories: < or ≥1.4 m.

We established permanent gridpoints spaced at 50-m intervals throughout each treatment area. Leaf litter and duff depth were measured at each gridpoint along 3 randomly oriented 15.2-m transects that were separated by 45°. Measurements were made at 3, 7.6, and 12.2 m along each transect (Greenberg et al., 2007a,b). One 4-m × 20-m strip plot was located at every other gridpoint. The density, volume, and percent cover of coarse woody debris (≥1 m in length and ≥15 cm diameter at widest point) were recorded within these strip plots. Coarse woody debris, shrub, and herbaceous cover were categorized as <1%, 1–10%, 11–25%, 26–50%, 51–75%, and >75% (Greenberg et al., 2007a).

Ten 50-m × 20-m plots were established at randomly selected gridpoints in each treatment area. Each plot was divided into ten 10-m × 10-m subplots, each of which contained two 1-m × 1-m quadrats, located at the upper right and lower left corners of each subplot. Shrubs ≥1.4 m were recorded in 5 of the 10 subplots. Shrubs <1.4 m and herbaceous cover were measured in the quadrats (Greenberg et al., 2007b; Waldrop et al., 2007).

Percent tree cover at each array was recorded in July of 2006 and 2007 using a spherical densiometer at breast height held over the center bucket of the array (Greenberg et al., 2007a). We measured distance from each array to nearest water, defined as any water source that would have standing or moving water during a summer with average rainfall (e.g., large puddles, streams, and seepages).

7. Analyses

We defined relative abundance as the number of shrews captured per 100 array nights. Live and dead shrews were combined in analyses. Shrew relative abundance was compared among treatments using a randomized complete block design ANOVA (SAS v.9.1.3, Cary, NC). We also compared relative abundance per 100 array nights for the most common species, the southeastern shrew (*Sorex longirostris*). Treatment means of relative abundance were compared using Tukey's Honestly Significant Different (HSD) test. Distance to nearest water and percent canopy cover at each array originally were included in the models as covariates, but were left out of final models because they were not significant. For all analyses, years were analyzed separately because of possible differences in detection probabilities associated with differences in rainfall between the years. Relative abundance was log-transformed to correct for non-normality. Habitat data was compared among treatments using a randomized complete block design ANOVA; individual treatments were compared using Tukey's HSD test (SAS v.9.1.3, Cary, NC).

8. Results

Leaf litter depth was lower in twice-burned and mechanical + twice-burned treatment areas than in mechanical or control treatment areas; duff depth was lower in mechanical + twice-burned treatment areas than in all other treatment areas (Table 1). Live-tree basal area was 43% lower and basal area of snags was 245% greater in mechanical + twice-burned treatment areas than in mechanical treatment areas because of higher tree mortality (Table 1). Percent cover of shrubs ≥1.4 m was 96% lower in mechanical + twice-burned treatment areas than in control treatment areas (Table 1). Percent cover of shrubs <1.4 m was 182% greater in mechanical treatment areas than in twice-burned treatment areas (Table 1). Other variables did not vary among treatment areas (Table 1).

9. Soricids

We captured 5 species of shrews over both years: 13 least shrews (*Cryptotis parva*), 53 northern short-tailed shrews (*Blarina brevicauda*), 23 pygmy shrews, 51 smoky shrews (*Sorex fumeus*), and 130 southeastern shrews. Least shrews were not captured in twice-burned treatment areas in 2006. Pygmy shrews were not

Table 1
Habitat data (mean ± S.E.) from the Green River Game Land in Polk County, North Carolina, from 3 replicates of 4 treatments: twice-burned (2B), control (C), mechanical understory cut (M), and mechanical understory cut followed by 2 prescribed burns (M2B). All data is from the summer of 2006, the first year following a second prescribed burn, except for percent canopy cover, for which means are given for both 2006 and 2007. *F* and *P*-values are results from a 2-way ANOVA. Differences among treatments are indicated by letters following means.

Habitat variable	Treatment				F	P_{trt}
	2B	C	M	M2B		
Coarse woody debris density (logs/ha)	281.8 ± 56.3	282.7 ± 108.2	247.4 ± 56.5	354.4 ± 192.0	0.98	0.464
Coarse woody debris volume (m^3/ha)	12.5 ± 3.0	9.0 ± 3.0	13.5 ± 7.5	13.2 ± 2.6	0.64	0.614
Coarse woody debris cover (%)	2.0 ± 0.4	1.6 ± 0.7	1.7 ± 0.7	2.4 ± 1.7	0.80	0.539
Litter depth (cm)	1.1 ± 0.6A	5.4 ± 0.3B	6.3 ± 0.8B	0.5 ± 0.1A	69.08	<0.001
Duff depth (cm)	2.2 ± 0.2A	3.0 ± 0.4A	2.9 ± 0.3A	1.3 ± 0.5B	18.99	0.002
Live-tree basal area (m^2/ha)	25.9 ± 6.6AB	27.6 ± 1.3AB	29.0 ± 2.5A	16.5 ± 5.9B	6.07	0.030
Dead tree basal area (m^2/ha)	3.1 ± 2.2AB	3.0 ± 0.9AB	2.0 ± 0.5A	6.9 ± 2.3B	5.56	0.036
Shrub cover >1.4m (%)	3.6 ± 3.8AB	14.2 ± 6.5A	4.4 ± 2.5AB	0.5 ± 0.6B	6.42	0.027
Shrub cover <1.4m (%)	6.6 ± 3.1A	9.5 ± 2.4AB	18.6 ± 3.8B	12.5 ± 4.5AB	7.03	0.022
Herbaceous cover (%)	3.8 ± 1.0	5.0 ± 4.7	3.2 ± 2.4	7.5 ± 3.1	3.02	0.116
Canopy cover (%), 2006	96.7 ± 4.1	99.2 ± 1.0	96.9 ± 3.4	74.1 ± 25.3	3.58	0.086
Canopy cover (%), 2007	93.1 ± 7.3	98.6 ± 1.5	96.1 ± 3.8	70.2 ± 30.5	3.05	0.114

Table 2
Mean number of shrew captures per 100 array nights (±S.E.) from drift fence arrays on the Green River Game Land in Polk County, North Carolina (2006–2007). Captures were from 3 replicates of 4 treatments: twice-burned (2B), control (C), mechanical understory cut (M), and mechanical understory cut followed by 2 prescribed burns (M2B). *F* and *P*-values are results from a randomized complete block design ANOVA. Differences among treatments are indicated by letters following means.

Taxa	Year	Treatment ($n = 3$)				$F_{3,6}$	P_{trt}
		2B	C	M	M2B		
Total shrews	2006	3.0 ± 2.4	4.3 ± 3.8	5.7 ± 3.3	2.9 ± 3.2	1.62	0.282
	2007	2.7 ± 1.9	4.9 ± 2.3	4.4 ± 3.5	2.7 ± 1.5	1.46	0.316
Southeastern shrew	2006	1.2 ± 1.4AB	1.6 ± 1.6AB	3.9 ± 2.9A	0.9 ± 1.4B	3.48	0.090
	2007	2.1 ± 2.0	3.0 ± 1.8	2.7 ± 2.2	1.9 ± 1.2	0.38	0.770

captured in mechanical + twice-burned treatment areas in 2006 or in twice-burned treatment areas in 2007. All other species were captured in all treatments both years. We captured 13 live shrews and 124 shrews that died in traps in 2006 and 38 live shrews and 120 shrews that died in traps in 2007. Total shrew captures were not significantly different among treatment areas in 2006 or 2007 (Table 2). We captured 77% fewer southeastern shrews in mechanical + twice-burned treatment areas than in mechanical treatment areas in 2006 ($P_{trt} = 0.090$) (Table 2). Captures were not different among treatment areas in 2007 (Table 2).

10. Discussion

Our results indicate that shrew response to fuel reduction treatments was minimal, even after 2 prescribed burns and 4–5 years after initial treatments. Shrew abundance differed only between mechanical and mechanical + twice-burned treatment areas. These longer-term results indicate that shrew response to these treatments was consistent with the shorter-term response that was documented soon after initial treatments in the previous study (Greenberg et al., 2007a). During the first 2 years after initial fuel reduction treatments, total shrew and pygmy shrew captures were greater in mechanical treatment areas than in mechanical + burn treatment areas (Greenberg et al., 2007a); immediately after the second burn, southeastern shrew captures were greater in mechanical treatment areas than in mechanical + twice-burned treatment areas. Though not significant, southeastern shrew captures also were at least 144% greater in mechanical treatment areas than control and twice-burned treatment areas.

In our study, leaf litter and duff depth differed between mechanical and mechanical + twice-burned treatment areas, which may have affected shrew abundance. This difference was because of leaf litter additions to mechanical treatment areas during 2002 (cut trees and shrubs were not removed from the site) and litter and duff reductions from burning in mechanical + twice-burned treatment areas; leaf litter results were similar to results at the same study site after only a single burn (Greenberg et al., 2007a). Duff depth did not differ among treatment areas after a single burn (Greenberg et al., 2007a). In contrast, duff depth was lower in mechanical + twice-burned treatment areas than in all other treatment areas after the second burn, likely because of reduced litter input and repeated litter removal in this treatment area.

Leaf litter and duff depth may be important in regulating microhabitat and soil moisture levels. Because shrews have high moisture requirements and high rates of evaporative water loss, they may be sensitive to treatments that dry the soil or leaf litter (Chew, 1951; Pruitt, 1959; Getz, 1961). The mechanical + twice-burned treatment areas had a more open canopy and lower leaf litter and duff depths compared to other treatment areas. These conditions likely caused more extreme temperatures and higher frequency and intensity of wetting and drying cycles, as occur in recently clearcut sites (Blair and Crossley, 1988). Southeastern shrews favor heavy herbaceous cover and/or thick leaf litter (French, 1980). Whitaker and Feldhamer (2005) reported that southern short-tailed shrews (*Blarina carolinensis*) were positively correlated with litter depth. Brannon (2000) showed that litter depth, litter moisture, certain sizes of coarse woody debris, number and size of invertebrates, and number of salamanders were all important factors in predicting the abundance of some shrew species. On GRGL, coarse woody debris density, cover, and volume did not differ among treatment areas and therefore did not explain differences in captures of shrews.

Shrews have high metabolism rates and therefore may be affected by food availability (Pearson, 1947; Ochocińska and Taylor, 2005). Ground-occurring macroarthropods have been reported to be more abundant in closed canopy forests than in canopy gaps (Greenberg and Forrest, 2003) or in clearcuts (Blair and Crossley, 1988). Greater litter depths, as in our mechanical treatment areas, create a more complex environment and consequently may increase arthropod diversity (Metz and Dindal, 1975). However, macroarthropod biomass did not differ among treatment areas at our study site after the first burn, suggesting that it did not affect shrew abundance in the short-term (Greenberg et al., 2007a). If arthropod populations were negatively affected by the second burn, they may have recovered by the second growing season after the burn (Coleman and Rieske, 2006), thereby also allowing shrew populations in mechanical + twice-burned treatment areas to recover.

We captured 77% fewer shrews in mechanical + twice-burned treatment areas than in mechanical treatment areas only during the first year after the second burn. Shrew populations could have recovered quickly, so that differences were not noticeable the second year after the burn. Kirkland et al. (1996) documented decreases in shrew abundances lasting only 8 months after burning in the central Appalachian Mountains. Understory and seedling growth, though not recorded, increased the second year after burns at GRGL, likely reducing the amount of sunlight reaching the forest floor and aiding in moisture retention in leaf litter (C. Matthews, personal observation). This may have ameliorated microhabitat quality for shrews 2 years after the second burn in mechanical + twice-burned treatment areas.

Our results support other studies that have documented limited shrew response to less intensive habitat disturbances (Ford et al., 1999; Ford and Rodrigue, 2001; Greenberg and Miller, 2004). Although Ford et al. (2002) reported minimal shrew response to habitat disturbances that substantially reduced canopy cover and leaf litter, other studies outside of the Appalachian Mountains indicated that species such as the least shrew may favor more open habitats maintained by disturbance while southeastern shrews more commonly occur in forested areas (Howell, 1954; Wolfe and Esher, 1981; Loeb, 1999; Ford et al., 2001). On our study area, which is lower in elevation and more xeric than many areas in the Appalachian Mountains, a decrease in canopy cover following disturbance may have resulted in lower moisture and food availability levels and consequently a decline in southeastern shrew abundance, at least temporarily.

Detection probability of shrews could differ among treatments because of differing habitat conditions. For example, shrews could be moving less frequently in mechanical + twice-burned treatment areas because of increased availability of prey in the open habitat. However, we did not attempt to make an estimate of detection probability because shrews are difficult to mark and recapture (Rose, 1994). We also did not collect or analyze shrew age or sex differences, but this data could provide additional information on shrew response to fuel reduction treatments (Rychlik, 1998).

Because of small sample sizes, we were not able to analyze the larger shrew species that we captured. However, smaller shrew species (e.g., pygmy shrew and southeastern shrew) may be more affected by substantial reductions in leaf litter depth, as in our mechanical + twice-burned treatment areas. Smaller shrew species often feed on the ground surface and in the litter, whereas larger shrew species, such as the northern short-tailed shrew, are semifossorial and likely less susceptible to surface changes and litter disturbances (George et al., 1986; McCay et al., 2004). Additionally, larger surface-dwelling shrew species, such as the smoky shrew and least shrew, may be more able to exploit different microhabitats than smaller shrew species (Dickman, 1988; Brannon, 2000).

11. Conclusion

Shrew abundance is not greatly affected by prescribed burning for fuel reduction in the southern Appalachian Mountains. However, hot fires that open the canopy may have a slight negative effect on some shrew species, at least immediately after disturbance. On the other hand, treatments that add to the leaf litter layer may benefit shrew populations. Longer-term studies of shrew response to different levels, combinations, and frequencies of fuel reduction treatments could improve our understanding of how shrews are affected by high frequency and (or) canopy-removing forest management practices. The effects of other burn-related habitat variables such as litter depth, soil moisture, cover, and invertebrate abundance on shrews also should be explored to better understand the mechanisms that influence shrew response to prescribed fire and other fuel reduction treatments.

Acknowledgments

This is Contribution Number 193 of the National Fire and Fire Surrogate Project, funded by the US Joint Fire Science Program, the US Forest Service, Southern Research Station (SRS-4156) through the National Fire Plan, and the North Carolina State University, Department of Forestry and Environmental Resources. A US Forest Service team, consisting of R. Phillips, H. Mohr, G. Chapman, C. Flint, and M. Smith assisted in the field and collected all habitat, fuel, and fire data. K. Pollock provided advice on experimental design and statistical analyses, and J. Smith assisted with statistical analyses. L. Gatens and B. Hess assisted with shrew identification. We thank R. Medford, S. Mickletz, and V. Montrone for assistance in establishing and maintaining traps and for sampling soricids and vegetation. D. Simon and the North Carolina Wildlife Resources Commission supervised treatments. S. Bosworth, D. Cooper, K. Frick, A. Matthews, D. Matthews, R. Matthews, M. Sandfoss, A. Savage, C. Shake, and R. Swiers helped with field work. C. Deperno and S. Hutchens provided some supplies.

References

Abrams, M., 1992. Fire and the development of oak forests. Bioscience 42, 346–354.

Blair, J.M., Crossley Jr., D.A., 1988. Litter decomposition, nitrogen dynamics and litter microarthropods in a southern Appalachian hardwood forest 8 years following clearcutting. The Journal of Applied Ecology 25, 683–698.

Brannon, M.P., 2000. Niche relationships of two syntopic species of shrews, *Sorex fumeus* and *Sorex cinereus*, in the southern Appalachian Mountains. Journal of Mammalogy 81, 1053–1061.

Brose, P., Schuler, T., Van Lear, D., Berst, J., 2001. Bringing fire back: the changing regimes of Appalachian mixed-oak forests. Journal of Forestry 99, 30–35.

Brose, P.H., Tainter, F., Waldrop, T.A., 2002. Regeneration history of three Table Mountain Pine/Pitch Pine stands in northern Georgia. General Technical Report SE-48. Southeastern Forest Experiment Station, USDA Forest Service, Asheville, NC, pp. 296–301.

Buckner, C.H., 1966. The role of vertebrate predations in the biological control of forest insects. Annual Review of Entomology 11, 836–845.

Carey, A.B., Harrington, C.A., 2001. Small mammals in young forests: implications for management for sustainability. Forest Ecology and Management 154, 289–309.

Chew, R.M., 1951. The water exchanges of some small mammals. Ecological Monographs 21, 215–225.

Coleman, T.W., Rieske, L.K., 2006. Arthropod response to prescription burning at the soil–litter interface in oak–pine forests. Forest Ecology Management 233, 52–60.

Delcourt, H.R., Delcourt, P.A., 1997. Pre-Columbian Native American use of fire on southern Appalachian landscapes. Conservation Biology 11, 1010–1014.

Dickman, C.R., 1988. Body size, prey size, and community structure in insectivorous mammals. Ecology 69, 569–580.

Ford, W.M., Dobony, C.A., Edwards, J.W., 2002. Shrews in managed northern hardwood stands in the Allegheny Mountains of West Virginia. In: Proceedings of the Annual Conference Southeastern Association, vol. 56. Fish and Wildlife Agencies, pp. 374–384.

Ford, W.M., McCay, T.S., Menzel, M.A., Webster, W.D., Greenberg, C.H., Pagels, J.F., Merritt, J.F., 2005. Influence of elevation and forest type on community assemblage and species distribution of shrews in the central and southern Appalachian Mountains. In: Merritt, J.F., Churchfield, S., Hutterer, R., Sheftel, B.A. (Eds.), Advances in the Biology of Shrews, II. International Society of Shrew Biologists, Carnegie Museum of Natural History, Pittsburgh, PA, pp. 303–315.

Ford, W.M., Menzel, M.A., McGill, D.W., Laerm, J., McCay, T.S., 1999. Effects of a community restoration fire on small mammals and herpetofauna in the southern Appalachians. Forest Ecology and Management 114, 233–243.

Ford, W.M., Menzel, M.A., McCay, T.S., Laerm, J., 2001. Contiguous allopatry of the masked shrew and southeastern shrew in the southern Appalachians: segregation along an elevational and habitat gradient. Journal of the Elisha Mitchell Scientific Society 117, 20–28.

Ford, W.M., Rodrigue, J.L., 2001. Soricid abundance in partial overstory removal harvests and riparian areas in an industrial forest landscape of the central Appalachians. Forest Ecology and Management 152, 159–168.

French, T.W., 1980. *Sorex longirostris*. Mammalian Species 143, 1–3.

George, S.B., Choate, J.R., Genoways, H.H., 1986. *Blarina brevicauda*. Mammalian Species 261, 1–9.

Getz, L.L., 1961. Factors influencing the local distribution of shrews. American Midland Naturalist 65, 67–88.

Gorte, R.W., 2000. Forest fire protection. CRS Report for Congress, Congressional Research Service, The Library of Congress. Received through the CRS Web.

Greenberg, C.H., Forrest, T.G., 2003. Seasonal abundance of ground-occurring macroarthropods in forest and canopy gaps in the southern Appalachians. Southeastern Naturalist 2, 591–608.

Greenberg, C.H., Miller, S., 2004. Soricid response to canopy gaps created by wind disturbance in the southern Appalachians. Southeastern Naturalist 3, 715–732.

Greenberg, C.H., Miller, S., Waldrop, T.A., 2007a. Short-term response of shrews to prescribed fire and mechanical fuel reduction in a Southern Appalachian upland hardwood forest. Forest Ecology and Management 243, 231–236.

Greenberg, C.H., Tomcho, A.L., Lanham, J.D., Waldrop, T.A., Tomcho, J., Phillips, R.J., Simon, D., 2007b. Short-term effects of fire and other fuel reduction treatments on breeding birds in a southern Appalachian upland hardwood forest. Journal of Wildlife Management 71, 1906–1916.

Hamilton Jr., W.J., 1941. The food of small forest mammals in eastern United States. Journal of Mammalogy 22, 250–263.

Howell, J.C., 1954. Populations and home ranges of small mammals on an overgrown field. Journal of Mammalogy 35, 177–186.

Johnson, A.S., Hale, P.E., 2000. The historical foundations of prescribed burning for wildlife: a southeastern perspective. In: Ford, W.M., Russell, K.R., Moorman, C.E. (Eds.), The Role of Fire in Nongame Wildlife Management and Community Restoration: Traditional Uses and New Directions. Proceedings of a Special Workshop on 2000, September 15, Nashville, TN. General Technical Report NE-288. USDA Forest Service, Northeastern Research Station, pp. 11–23.

Kirkland Jr., G.L., Snoddy, H.W., Amsler, T.L., 1996. Impact of fire on small mammals and amphibians in a central Appalachian deciduous forest. American Midland Naturalist 135, 253–260.

Kirkland Jr., G.L., Sheppard, P.K., 1994. Proposed standard protocol for sampling small mammal communities. In: Merritt, J.F., Kirkland, Jr., G.L., Rose, R.K. (Eds.), Advances in the Biology of Shrews, vol. 18. Carnegie Museum of Natural History Special Publication, pp. 277–284.

Loeb, S.C., 1999. Responses of small mammals to coarse woody debris in a southeastern pine forest. Journal of Mammalogy 80, 460–471.

Lorimer, C.G., 1985. The role of fire in the perpetuation of oak forests. In: Johnson, J.E. (Ed.), Challenges in Oak Management and Utilization. Cooperative Extension Service, University of Wisconsin, Madison, USA, pp. 8–25.

McCay, T.S., Lovallo, M.J., Ford, W.M., Menzel, M.A., 2004. Assembly rules for functional groups of North American shrews: effects of geographic range and habitat partitioning. Oikos 107, 141–147.

Menzel, M.A., Castleberry, S.B., Ford, W.M., McCay, T.S., Castleberry, N.L., 2005. Effect of a group selection timber harvest on the small mammal community in a southern bottomland hardwood forest. In: Fredrickson, L. (Ed.), Proceedings of the Symposium on Ecology and Management of Bottomland Hardwood Systems: The State of Our Understanding, University of Missouri Press, Columbia, pp. 389–396.

Metz, L.J., Dindal, D.L., 1975. Collembola populations and prescribed burning. Environmental Entomology 4, 583–587.

Ochocińska, D., Taylor, J.R.E., 2005. Living at the physiological limits: field and maximum metabolic rates of the common shrew (*Sorex araneus*). Physiological and Biochemical Zoology 78, 808–818.

Pearson, O.P., 1947. The rate of metabolism of some small mammals. Ecology 28, 127–145.

Phillips, R.J., Waldrop, T.A., Simon, D.M., 2006. Assessment of the FARSITE model for predicting fire behavior in the southern Appalachian Mountains. In: Connor, K.F., (Ed.), Proceedings of the 13th Biennial Southern Silviculture Research Conference General Technical Report SRS-92, Southern Research Station. USDA Forest Service, Asheville, NC, pp. 521–525.

Pruitt Jr., W.O., 1959. Microclimates and Local Distribution of Small Mammals on the George Reserve, Michigan, vol. 109. Miscellaneous Publications Museum of Zoology, University of Michigan, pp. 1–27.

Rose, R.K., 1994. Soricid biology: a summary and look ahead. In: Merritt, J.F., Kirkland, Jr., G.L., Rose, R.K. (Eds.), Advances in the Biology of Shrews, vol. 18. Carnegie Museum of Natural History Special Publication, pp. 455–458.

Rychlik, L., 1998. Evolution of social systems in shrews. In: Wojcik, J.M., Wolsan, M. (Eds.), Evolution of Shrews. Mammal Research Institute, Polish Academy of Science, Bialowieza, pp. 347–406.

Van Lear, D.H., Harlow, R.F., 2000. Fire in the eastern United States: influence on wildlife habitat. In: Ford, W.M., Russell, K.R., Moorman, C.E. (Eds.), The Role of Fire in Nongame Wildlife Management and Community Restoration: Traditional Uses and New Directions. Proceedings of a Special Workshop on 2000, September 15, Nashville, TN. General Technical Report NE-288. USDA Forest Service, Northeastern Research Station, pp. 2–10.

Waldrop, T.A., Brudnack, L., Rideout-Hanzak, S., 2007. Fuels on disturbed and undisturbed sites in the southern Appalachian Mountains, USA. Canadian Journal of Forest Research 37, 1134–1141.

Waldrop, T.A., Yaussy, D.A., Phillips, R.A., Hutchinson, T.A., Brudnak, L., Boerner, R.E.J., 2008. Fuel reduction treatments affect stand structure of hardwood forests in western North Carolina and southern Ohio, USA. Forest Ecology and Management 255, 3107–3116.

Whitaker, J.C., Feldhamer, G.A., 2005. Habitat associations of southern short-tailed shrews (*Blarina carolinensis*) from live trap data in southern Illinois. In: Merritt, J.F., Churchfield, S., Hutterer, R., Sheftel, B.A. (Eds.), Advances in the Biology of Shrews, II. International Society of Shrew Biologists, Carnegie Museum of Natural History, Pittsburgh, PA, pp. 255–263.

Wolfe, J.L., Esher, R.J., 1981. Relative abundance of the southeastern shrew. Journal of Mammalogy 62, 649–650.