ABSTRACT

MATTHEWS, CHARLOTTE ESTHER. Response of Herpetofauna and Soricids to Repeated Prescribed Fire and Fuel Reduction Treatments in the Southern Appalachian Mountains. (Under the direction of Christopher E. Moorman.)

Recent use of prescribed fire and fire surrogates to reduce fuel hazards has spurred interest in their effects on wildlife. Studies of fire in the southern Appalachian Mountains have documented few effects on reptiles and amphibians. However, these studies were conducted after only 1 fire and for only a short time period (1 to 3 years) after the fire. From mid-May to mid-August 2006 and 2007, we used drift fences with pitfall traps to capture reptiles, amphibians, and shrews in a control and 3 replicated fuel reduction treatments: 1) twice-burned (2003 and 2006), 2) mechanical understory cut (2002), and 3) mechanical understory cut (2002) followed by 2 burns (2003 and 2006). We captured fewer salamanders in mechanical + twice-burned treatment areas than in twice-burned and control treatment areas, but more lizards in mechanical + twice-burned treatment areas than in other treatment areas. Higher lizard captures in mechanical + twice-burned treatment areas likely was related to increased ground temperatures and greater thermoregulatory opportunities. Higher and more variable ground temperatures and faster drying of the remaining litter and duff may have led to fewer salamander captures in mechanical + twice-burned treatment areas. 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 and canopy cover in mechanical + twice-burned treatment areas may have decreased ground-level moisture, thereby causing declines in southeastern shrew captures. Our long-term results, after 2 prescribed burns, differ from results after 1 prescribed burn at the same site when fence lizard (*Sceloporus undulatus*) captures were greater in mechanical + burn treatment areas but salamander captures did not differ among treatment areas. Prescribed fire or mechanical fuel reduction treatments in the southern Appalachian Mountains do not appear to greatly affect reptile, amphibian, or shrew populations. However, multiple (≥2) fuel reduction treatments that decrease canopy cover may benefit lizards but negatively affect salamanders and some shrew species.

Response of Herpetofauna and Soricids to Repeated Prescribed Fire and Fuel Reduction Treatments in the Southern Appalachian Mountains

by
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DEDICATION

In memory of

Raymond and Manie Sue Horn

BIOGRAPHY

Charlotte Esther Matthews was born in Galveston, Texas, and grew up in a small town in west Texas – Eastland. She is the daughter of Dr. Robert and Mary Matthews. Charlotte has one younger brother, Ben Matthews, and one younger sister, Anna Matthews. She graduated from Eastland High School in May 2000 as the Valedictorian of her class. She then graduated with a B.S. in Biology in June 2004 from Furman University in Greenville, South Carolina. During the summer of 2003, she researched inter and intra specific competition of an endangered plant on the campus of Furman University. After college, she worked as an intern at Laguna Atascosa National Wildlife Refuge in South Texas for 6 months, then as a Bald Eagle Biologist with the North Carolina Wildlife Resources Commission for 6 months. Charlotte began her graduate study at North Carolina State University in January 2006. While preparing for her Master's defense, she assisted on a similar graduate research project in the southern Appalachian Mountains. Charlotte hopes to continue working with wildlife and contributing to the field for the rest of her life.

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multiple (≥2) fuel reduction treatments that decrease canopy cover may benefit lizards but negatively affect salamanders.

KEY WORDS amphibians, fire surrogates, fuel reduction treatments, prescribed fire, reptiles, southern Appalachian Mountains.

INTRODUCTION

Historically, forests of the Americas burned fairly frequently; fires were ignited by Native Americans and by lightning (Komarek 1981, Delcourt and Delcourt 1997, Van Lear and Harlow 2000, Johnson and Hale 2000, Brose et al. 2001). Native Americans set fires to clear land, to hunt, to provide vegetation for prey, to facilitate acorn collection, and to induce berry production (Pyne 1982, Brose et al. 2001). Early settlers also burned forests to clear land, to expose nuts for collection, and to provide food for livestock (Van Lear and Harlow 2000). Because of the large tracts of forest unbroken by roads or development, fire spread easily and was not ended by human intervention or fire breaks.

Southern Appalachian Mountain hardwood forests historically burned less frequently than Coastal Plain forests and Piedmont forests in the southeastern United States, yet fire also was an important disturbance in these ecosystems (Van Lear and Waldrop 1989). Natural and anthropogenic fires helped to create the mixed oak (*Quercus* spp.) forests of the region (Lorimer 1985, Abrams 1992, Delcourt and Delcourt 1997, Brose et al. 2001). After severe and devastating wildfires in the western United States in the early 1920s, federal and local government agencies initiated a national campaign to end forest fires (Pyne 1982), resulting in widespread fire suppression during most of the 20th century.

Consequently, forests accumulated large fuel loads, increasing their susceptibility to wildfire.

In recent decades, prescribed fire has been used with increasing frequency as a land management tool to return land to its historical state, affect vegetative species composition, improve wildlife habitat, and reduce fuel accumulation. However, because of risks to property, human safety, and air quality associated with fire, mechanical or manual fuel reduction methods may be used instead of prescribed burns (Johnson and Hale 2000, Van Lear and Harlow 2000). Also termed "fire surrogates," these fuel treatments include thinning vegetation or the mechanical removal or cutting of potential fuels.

The herpetofaunal diversity in the southern Appalachian Mountains rivals or is greater than that anywhere else in the United States (Kiester 1971, Conant and Collins 1991), so an understanding of land management influence on reptile and amphibian populations is central. Several studies indicate that salamanders are adversely affected by forest management practices that reduce canopy cover, such as clearcutting (Pough et al. 1987, Petranka et al. 1993, 1994, Harpole and Haas 1999). Conversely, disturbances that retain full canopy cover do not appear to affect salamander populations (Harpole and Haas 1999). Studies in upland hardwood southern Appalachian Mountain forest indicate that a single prescribed burn has a positive effect on reptiles but does not affect amphibians, at least in the short-term (Ford et al. 1999, Greenberg and Waldrop 2008). Therefore, the more intense or frequent fuel reduction treatments (e.g., periodic prescribed fire) that eventually result in canopy reduction may be detrimental to herpetofauna, especially salamanders. However, relatively little is known about longer-term effects of fuel reduction treatments on reptiles and amphibians.

An earlier study of short-term herpetofauna response to 3 fire and fire surrogate treatments (before a second prescribed burn) and a control was conducted at our study area from 2001 to 2004 (Greenberg and Waldrop 2008). Fuel reduction treatments were a single prescribed burn, a mechanical understory cut, and a mechanical understory cut + burn treatment. Results did not indicate a negative effect on amphibians and reptiles after a single application of fuel reduction treatments (Greenberg and Waldrop 2008). Total reptiles and fence lizards (*Sceloporus undulatus*) were more abundant in mechanical + burn treatment areas than in burn treatment areas. Total anurans were more abundant in burn and mechanical + burn treatment areas than in control and mechanical treatment areas. Relative abundance of salamanders did not differ among treatment areas (Greenberg and Waldrop 2008). Our study was designed to assess longer-term herpetofaunal response to these same 3 fuel reduction treatments, including a second prescribed burn in the burn and mechanical + burn treatments, at the same study site.

Study Objectives

The National Fire and Fire Surrogate Study, spanning 13 ecosystems across the US and supported by the USDA/USDI Joint Fire Science Program and the National Fire Plan, was initiated in 2000. The purpose of the study was to assess the effects of fire and fire surrogate treatments on vegetation, wildlife, pathogens, insects, 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). Our objective was to determine the effects of 2 successive prescribed fires, a mechanical fire surrogate treatment, and a combined mechanical + prescribed fire treatment on reptiles and amphibians for a longer time period after initial treatments.

STUDY AREA

We conducted our study on the 5,481-ha Green River Game Land (GRGL) in the southern Appalachian Mountains of Polk County, North Carolina. Elevation on the GRGL ranged from 366 to 793m. Two of our replicate sites (35°17'9"N, 82°19'42"W) were located 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 (*Q. prinus*), black (*Q. velutina*), northern red (*Q. rubra*), scarlet (*Q. coccinea*), and white oaks (*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 (*Kalmia latifolia*), rhododendron (*Rhododendron maximum*), flame azalea (*R. calendulaceum*), and blueberry (*Vaccinium* spp.). Before 2003, none of our study sites had been burned in over 50 years (Dean Simon, NC Wildlife Resources Commission, personal communication), and stands varied in age from 80 to 120 years.

METHODS

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

Treatments

Mechanical fuel reduction treatments occurred between December 2001 and February 2002, 1 year before the first prescribed burn. Chainsaw crews cut trees ≥1.8 m tall and <10.2 cm diameter at breast height (dbh) and shrubs regardless of size and left debris on site. The first burns were conducted in March 2003. Two blocks were ignited by helicopter using spot fires and 1 block was ignited from the ground by hand using spot fires and strip-headfires (Greenberg et al. 2007, Greenberg and Waldrop 2008). Maximum temperatures were recorded with thermocouples located 30 cm above the ground, with 38 to 40 thermocouples spaced throughout each burn treatment area. The mean maximum temperatures in burn and mechanical-burn treatments in 2003 were 180° C and 370° C, respectively (Waldrop et al. 2008). Phillips et al. (2006) provided a description of 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 the 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 the burn and mechanical + burn treatment areas. Another mechanical understory cut was not implemented because shrubs had not grown tall enough to be a fuel risk. The second burns 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 again 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).

Habitat Data

We measured habitat variables in all treatment areas during the summer of 2006 (the first summer after the second burn). Measured variables included density, volume, and percent cover of coarse woody debris, litter depth, duff depth, basal area of live and dead trees, percent herb cover, and percent shrub cover. We recorded shrubs in 2 height categories (< or ≥ 1.4 m).

We established permanent gridpoints spaced at 50-m intervals throughout each treatment area. We measured leaf litter and duff depth at each gridpoint along 3 randomly oriented 15.2-m transects that were separated by 45°. Leaf litter and duff depth were measured at 3, 7.6, and 12.2 m along each transect. One 4-m × 20-m strip plot was located at every other gridpoint. Within these strip plots, we recorded the density, volume, and percent cover of coarse woody debris (≥1 m in length and ≥15 cm diameter at widest point). We recorded coarse woody debris, shrub, and herb cover in cover classes (<1%, 1 to 10%, 11 to 25%, 26 to 50%, 51 to 75%, and >75%).

At randomly selected gridpoints in each treatment area, we established 10 50-m × 20-m plots. We divided each plot into 10 10-m × 10-m subplots, each of which contained 2 1-m × 1-m quadrats, located at the upper right and lower left corners of each subplot. In 5 of the 10 subplots, we recorded shrubs ≥1.4 m in height and live and dead tree basal area (≥10 cm dbh). We measured shrubs <1.4 m in height and herbs in the quadrats.

We measured percent tree canopy cover at the center bucket of each array (arrays described below) in July of 2006 and 2007 using a spherical densiometer. 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, including large puddles, streams, and seepages.

Herpetofaunal Sampling

We reopened the 2 drift fence arrays per treatment area installed in 2001 from 17 May to 16 August 2006. We installed 1 additional array in each treatment area, ≥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, constructed of 50-cm aluminum flashing, had 7.6-m array arms buried 10 to 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 had a small board for shade and contained a wet sponge to provide moisture for amphibians that was wet every time we checked traps. Frequently flooded buckets also contained a small piece of styrofoam for cover and flotation.

We checked all drift fence arrays every 1 to 3 days and every day following a rain event. All reptiles and amphibians were identified to species, weighed, measured (snout-vent length and total length), sexed (if possible), aged as juvenile or adult, and marked. We marked amphibians with Visible Implant Elastomer (Northwest Marine Technology, Inc., Shaw Is., Washington, USA) (Davis and Ovaska 2001); reptiles were scale-clipped (snakes), toe-clipped (lizards), or scute-notched (turtles). We sterilized injection syringes and scissors between marking different individuals and marked animals according to drift fence array so that each recapture could be identified back to the location of original capture. We recorded free-ranging reptiles and amphibians that we observed within treatment areas, but did not mark them. We included animals caught while traveling to and from arrays in species richness analyses, but not in analyses of relative abundance. 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).

Analyses

We estimated species richness using totals from the 3 arrays and opportunistic captures in each treatment area. For analyses, we combined reptile and amphibian species. We compared species richness among treatments using a randomized complete block design ANOVA (SAS Institute, Cary, NC). We defined relative abundance as the number of animals captured per 100 array nights (excluding opportunistic captures) in 8 categories: total reptiles, lizards, snakes, turtles, total amphibians, salamanders, toads, and frogs. We also compared relative abundance per 100 array nights for species with >30 captures in each year: five-lined skink (*Eumeces fasciatus*), fence lizard, and northern slimy salamander (*Plethodon glutinosus*). Using distance to nearest water and percent canopy cover at each array as covariates, we compared relative abundance among treatments using a randomized complete block design with subsampling ANCOVA (SAS Institute, Cary, NC). Percent canopy cover at each array was not correlated with any captures in 2006 or 2007, so it was not included in final models. We compared treatment means of species richness and relative abundance using Tukey's Honestly Significant Different (HSD) test. For all analyses, we analyzed years separately because of possible differences in detection probabilities due to differences in rainfall between years. To approximate normality with equal variances, we log-transformed relative abundance and species richness data. We compared habitat data among treatments using a randomized complete block design ANOVA and treatment means using Tukey's HSD test (SAS Institute, Cary, NC).

RESULTS

Habitat

Leaf litter depth was at least 80% lower in twice-burned and mechanical + twice-burned treatment areas than in mechanical or control treatment areas; duff depth was at least 41% lower in mechanical + twice-burned treatment areas than in all other treatment areas (Table 1.1). 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 1.1). Percent shrub cover of shrubs ≥1.4 m was 96% lower in mechanical + twice-burned treatment areas than in control treatment areas (Table 1.1). Percent shrub cover for shrubs <1.4 m in height was 182% greater in mechanical treatment areas than in twice-burned treatment areas (Table 1.1).

Herpetofauna

We captured 28 species total during 2006 and 2007, including 16 species of reptiles and 12 species of amphibians (one of these species - black racer, *Coluber constrictor* - was observed but not captured in traps) (Table 1.2). We captured 605 reptiles and amphibians in arrays in 2,616 array nights during 2006 (Table 1.2). Total lizard captures were at least 200% greater in mechanical + twice-burned treatment areas than in other treatment areas (Table 1.3). Five-lined skinks were 415% and 250% more abundant in mechanical

+ twice-burned treatment areas than in twice-burned and mechanical treatment areas, respectively, and fence lizards were 1900% more abundant in mechanical + twice-burned treatment areas than in control treatment areas (Table 1.3). We captured 72% fewer total salamanders in mechanical + twice-burned treatment areas than in twice-burned treatment areas (Table 1.3).

During 2007, we captured 488 reptiles and amphibians in 3,240 array nights (Table 1.2). As in 2006, we captured more lizards in mechanical + twice-burned treatment areas than in other treatment areas (Table 1.3). Five-lined skink captures were similar among treatments, but fence lizards were at least 200% more abundant in mechanical + twice-burned treatment areas than in all other treatment areas (Table 1.3). As in 2006, we captured the fewest salamanders in mechanical + twice-burned treatment areas (Table 1.3). Additionally, we captured 80% fewer northern slimy salamanders in mechanical + twice-burned treatment areas than in twice-burned treatment areas (Table 1.3). Captures of salamanders and northern slimy salamanders were negatively correlated to distance to nearest water (Table 1.3).

Captures showed the same trends in 2006 and 2007 (Fig. 1). Species richness did not differ among treatment areas in 2006 or 2007 ($F_{3,6} = 3.11$, $P_{trt} = 0.110$; $F_{3,6} = 1.78$, $P_{trt} = 0.251$). Total reptile, snake, turtle, toad, and frog captures were not different among treatment areas in either year (Table 1.3).

DISCUSSION

Our results indicate that the mechanical + twice-burned treatment benefited lizards but adversely affected salamanders; reptiles and amphibians showed little response to other fuel reduction treatments. These responses were likely due to a combination of reduced litter and duff depth and a more open canopy in mechanical + twice-burned treatment areas, resulting from hot fires and substantial overstory mortality (Waldrop et al. 2008).

Other studies also report greater lizard abundance following high-intensity disturbances such as clearcuts (McLeod and Gates 1998), large canopy gaps (Greenberg 2001), and burns (Mushinsky 1985, Moseley et al. 2003, Keyser et al. 2004). Although Greenberg and Waldrop (2008) did not detect significantly greater abundance of total lizards in mechanical + burn treatment areas at our site after the first burn, they did detect more total reptiles and fence lizards in mechanical + burn treatment areas. Habitat in mechanical + burn treatment areas changed after the first burns in 2003, but continued to change over the years as a result of delayed overstory mortality and understory growth. Additional overstory mortality occurred following second burns (Waldrop et al. 2008). Decreased litter and duff depths and a more open canopy in mechanical + twice-burned treatment areas likely increased ground temperatures and created greater thermoregulatory opportunities for lizards (Moseley et al. 2003). These conditions likely persisted from the first burn, with continued favorable conditions after the second burn.

Salamanders were less abundant in mechanical + twice-burned treatment areas, though they were not completely absent. Previous studies have reported no change in salamander captures following prescribed burns (Ford et al. 1999, Floyd 2003, Moseley et al. 2003, Greenberg and Waldrop 2008). Salamander captures in our twice-burned treatment areas were not different from those in control treatment areas, indicating that the relatively less intense fires did not affect salamander populations. Similarly, salamander captures in mechanical treatment areas were not different than captures in other treatment areas, as was also reported in another study in the southern Appalachian Mountains (Harpole and Haas 1999).

Salamander captures did not differ among treatments after the first burn (Greenberg and Waldrop 2008), but captures were lower in mechanical + twice-burned treatment areas after the second burn. Little direct salamander mortality would be expected from a winter burn at our study site because most of the salamander species we captured would be underground or in streams. However, habitat alterations following a burn could decrease survival rates, leading to decreased captures 3 to 4 years later. Plot-wide canopy cover was reduced in our mechanical + twice-burned treatment areas, probably resulting in higher and more variable ground temperatures and less moisture in the remaining litter and duff (Ash 1995, Waldrop et al. 2008). Also, though fires in the mechanical + burn treatment were hotter during the first burn than the second burn, duff depths in these treatment areas were lower than all other treatments after the second burn, but not after the first burn (Greenberg and Waldrop 2008). Most of the salamander species we captured lack lungs and breathe through their skin; maintaining moist skin is extremely important for all salamander species and individuals are generally only active when microhabitats are moist. Salamanders are consequently sensitive to changes in prevailing temperature, humidity, and soil moisture regimes (Petranka et al. 1993). Salamanders tend to completely disappear from clearcut areas for a decade or more (Ash 1997, Petranka 1993). In contrast, twice-burned treatment areas retained most of their canopy cover (Waldrop et al. 2008), which likely reduced temperature fluctuations on the forest floor, moisture loss from litter and duff, and the potential for salamander desiccation relative to mechanical + twice-burned treatment areas.

Habitat alterations following the first burn could have reduced oviposition sites and consequently reduced salamander reproduction, a response that would not be detected immediately. *Plethodon* salamanders in the southern Appalachian Mountains reproduce and lay eggs in the spring. Juveniles hatch in late summer and spend their first year underground (Hairston 1983), where they are not likely to be captured in traps. Female *P. jordani* do not reach sexual maturity until at least 3 years of age and do not lay eggs until after nearly 4 years of age (Hairston 1983). Red salamanders (*Pseudotriton ruber*) lay eggs in early autumn in the southern Appalachian Mountains and larvae, not likely to be captured in terrestrial traps, do not metamorphose until around 3 years of age (Bruce 1978). Female red salamanders do not reproduce until they are at least 5 years old (Bruce 1978). Therefore, effects on terrestrial salamander reproduction might not be easily detected during the first year after initial treatments, but effects would become increasingly evident 3 or more years later.

Immigration or emigration also could cause differences in salamander or lizard captures. However, if this were the case, an immediate change in captures following the first treatments would have been expected. No immediate response was observed for salamanders, but lizard captures did increase soon after the mechanical + burn treatment (Greenberg and Waldrop 2008). There is little evidence for long-distance dispersal of salamanders, except for breeding purposes in some species; this would not be the case for most plethodontids. Plethodontid salamanders generally have small home ranges and are not easily led to disperse from those home ranges (Duellman and Trueb 1994). Conversely, the short-term response by lizards to the first treatment may indicate movement into mechanical + twice-burned treatment areas from surrounding areas, possibly because of the better microhabitat conditions. However, we did not recapture any individual lizards in a treatment plot different than that of its original capture, which suggests that lizard emigration or immigration was limited during our study.

Detection probabilities could differ among treatment areas and lead to differences in herpetofauna captures. We were unable to accurately calculate detection probability because of low recapture rates. Most herpetofaunal studies assume that sampled individuals represent the entire population (deMaynadier and Hunter 1995). This assumption is unlikely for salamanders because surface populations represent only very small percentages of the total population (Bailey et al. 2004a). Conditions in mechanical + twice-burned treatment areas may have been more stressful for salamanders than conditions in twice-burned treatment areas and caused individuals to retreat underground for longer periods of time, becoming less detectable than in other treatment areas. Conversely, more open understory conditions in twice-burned treatment areas, compared to mechanical and control treatment areas, may have increased detection probability of salamanders. However, in this case, we should have observed similar increases in detection probability in mechanical + twice-burned treatment areas, and we did not. If possible, estimates of detection probability should be made to more accurately determine the effects of habitat changes on salamander populations (Bailey et al. 2004a, Bailey et al. 2004b). Regardless of the mechanisms, our mechanical + twice-burned treatment appears to create favorable conditions for lizards and unfavorable conditions for salamanders. Response of reptiles and amphibians to fire and fire surrogate treatments should continue to be monitored, especially over longer time periods and after multiple fire and mechanical treatments.

MANAGEMENT IMPLICATIONS

Our results indicate that fuel reduction by mechanical understory cut or multiple, low intensity prescribed fires has little effect on reptile or amphibian communities of southern Appalachian Mountain hardwood forest. However, high intensity, multiple burns, such as those in our mechanical + twice-burned treatment, may impact herpetofaunal populations by decreasing salamander abundances and increasing lizard abundance. Our results suggest that the decision to use the combination of mechanical treatment followed by 2 prescribed fires must be considered within a landscape context to avoid large-scale impacts to salamander communities. Further, our findings that salamanders are negatively affected in mechanical + twice-burned treatment areas contrast with the results of an earlier study of these fuel reduction treatments at the same study site after a single burn, suggesting that effects may be delayed. This emphasizes the need for long-term studies to assess reptile and amphibian responses to fuel reduction treatments after multiple burns.

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LITERATURE CITED

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

Ash, A. N. 1995. Effects of clear-cutting on litter parameters in the southern Blue Ridge mountains. Castanea 60:89-97.

Ash, A.N. 1997. Disappearance and return of plethodontid salamanders to clearcut plots in the southern Blue Ridge Mountains. Conservation Biology 11:983-989.

Bailey, L. L., T. R. Simons, and K. H. Pollock. 2004a. Estimating detection probability parameters for plethodon salamanders using the robust capture-recapture design. Journal of Wildlife Management 68:1-14.

Bailey, L. L., T. R. Simons, and K. H. Pollock. 2004b. Spatial and temporal variation in detection probability of Plethodon salamanders using the robust capture-recapture design. Journal of Wildlife Management 68:14-24.

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

Bruce, R. C. 1978. Reproductive biology of the salamander *Pseudotriton ruber* in the southern Blue Ridge Mountains. Copeia 1978:417-423.

Conant, R., and J. T. Collins. 1991. A field guide to reptiles and amphibians: eastern and central North America. Houghton Mifflin, Boston, Massachusetts, USA.

Davis, T. M., and K. Ovaska. 2001. Individual recognition of amphibians: effects of toe clipping and fluorescent tagging on the salamander *Plethodon vehiculum*. Journal of Herpetology 35:217-225.

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

deMaynadier, P. G. and M. L Hunter, Jr. 1995. The relationship between forest management and amphibian ecology: a review of the North American literature. Environmental Reviews 3:230-261.

Duellman, W. E. and L. Trueb. 1994. Biology of Amphibians. The Johns Hopkins University Press, Baltimore, Maryland, USA.

Floyd, T. M. 2003. Effects of prescribed fire on herpetofauna within hardwood forests of the upper Piedmont of South Carolina. Master's thesis. Clemson University, Clemson, South Carolina.

Ford, W. M., M. A. Menzel, D. W. McGill, J. Laerm, and T. S. McCay. 1999. Effects of a community restoration fire on small mammals and herpetofauna in the southern

Appalachians. Forest Ecology and Management 114:233-243.

Greenberg, C.H. 2001. Response of reptile and amphibian communities to canopy gaps created by wind disturbance in the southern Appalachians. Forest Ecology and Management 148:135-144.

Greenberg, C. H., A. L. Tomcho, J. D. Lanham, T. A. Waldrop, J. Tomcho, R. J. Phillips, and D. Simon. 2007. 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.

Greenberg, C. H., and T. A. Waldrop. 2008. Short-term response of reptiles and amphibians to prescribed fire and mechanical fuel reduction in a southern Appalachian upland hardwood forest. Forest Ecology and Management 255:2883-2893.

Hairston, N. G., Sr. 1983. Growth, survival, and reproduction of *Plethodon jordani*: tradeoffs between selection pressures. Copeia 1983:1024-1035.

Harpole, D. N. and C. A. Haas. 1999. Effects of seven silvicultural treatments on terrestrial salamanders. Forest Ecology and Management 114:349-356.

Johnson, A. S., and P. E. Hale. 2000. The historical foundations of prescribed burning for wildlife: a southeastern perspective. Pages 11-23 *in* W. M. Ford, K. R. Russell, C. E. Moorman, editors. The role of fire in nongame wildlife management and community restoration: traditional uses and new directions. Proceedings of a special workshop. 15 September 2000, Nashville, Tennessee. U.S. Forest Service General Technical Report NE-288. Northeastern Research Station.

Keyser, P. D., D. J. Sausville, W. M. Ford, D. J. Schwab, and P. H. Brose. 2004. Prescribed fire impacts to amphibians and reptiles in shelterwood-harvested oak-dominated forests. Virginia Journal of Science 55:159-168.

Kiester, A. R. 1971. Species density of North American amphibians and reptiles. Systematic Zoology 20:127-137.

Komarek, E. V. 1981. History of prescribed fire and controlled burning in wildlife management in the south. Pages 285-298 *in* G. W. Wood, editor. Prescribed fire and wildlife in Southern forests. Belle W. Baruch Forest Science Institute, Clemson University, Georgetown, South Carolina, USA.

Lorimer, C. G. 1985. The role of fire in the perpetuation of oak forests. Pages 8-25 *in* J. E. Johnson, editor. Challenges in Oak Management and Utilization. Cooperative Extension Service, University of Wisconsin, Madison, USA.

McLeod, R. F., and J. E. Gates. 1998. Response of herpetofaunal communities to forest cutting and burning at Chesapeake Farms, Maryland. American Midland Naturalist 139:164-177.

Moseley, K. R., S. B. Castleberry, and S. H. Schweitzer. 2003. Effects of prescribed fire on herpetofauna in bottomland hardwood forests. Southeastern Naturalist 2:475-486.

Mushinsky, H. R. 1985. Fire and the Florida sandhill herpetofaunal community: with special attention to responses of Cnemidophorus sexlineatus. Herpetologica 41:333-342.

Petranka, J. W., M. E. Eldridge, and K. E. Haley. 1993. Effects of timber harvesting on southern Appalachian salamanders. Conservation Biology 7:363-370.

Petranka, J. W., M. P. Brannon, M. E. Hopey, and C. K. Smith. 1994. Effects of timber harvesting on low elevation populations of southern Appalachian salamanders. Forest Ecology and Management 67:135-147.

Phillips, R. J., T. A. Waldrop, D. M. Simon. 2006. Assessment of the FARSITE model for predicting fire behavior in the southern Appalachian Mountains. Pages 521-525 *in* K. F. Connor, editor. Proceedings of the 13th Biennial Southern Silviculture Research Conference General Technical Report SRS-92, Asheville, North Carolina, USA.

Pough, F. H., E. M. Smith, D. H. Rhodes, and A. Collazo. 1987. The abundance of salamanders in forest stands with different histories of disturbance. Forest Ecology and Management 20:1-9.

Pyne, S. J. 1982. Fire in America: a cultural history of wildland and rural fire. University of Washington Press. Seattle, Washington, USA.

Van Lear, D. H., and T. A. Waldrop. 1989. History, uses, and effects of fire in the Appalachians. U.S. Forest Service General Technical Report SE-54. Southeastern Forest Experiment Station, Asheville, North Carolina, USA.

Van Lear, D. H., and R. F. Harlow. 2000. Fire in the eastern United States: influence on wildlife habitat. Pages 2-10 *in* W. M. Ford, K. R. Russell, C. E. Moorman, editors. The role of fire in nongame wildlife management and community restoration: traditional uses and new directions. Proceedings of a special workshop. 15 September 2000, Nashville, Tennessee. U.S. Forest Service General Technical Report. Northeastern Research Station.

Waldrop, T. A., D. A. Yaussy, R. J. Phillips, T. A. Hutchinson, L. Brudnak, R. Boerner. 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.

Table 1.1. Habitat data 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. Treatment means are given ± SE. *F* and *P*-values are results from a 2-way ANOVA. Differences among treatments are indicated by letters following means.

	Treatment					
Habitat Variable	B	C	M	MB	F	P_{trt}
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

Table 1.1. Continued

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
Herb 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 1.2. Total reptile and amphibian species distribution across 2 years and 3 replicates of 4 treatments: twice-burned (2B), control (C), mechanical understory cut (M), and mechanical understory cut followed by 2 prescribed burns (M2B). We caught animals using drift fence arrays open for 2,616 array nights during the summer of 2006 and 3,240 array nights during the summer of 2007 on Green River Game Land in Polk County, North Carolina.

	Treatments 2006				Treatments 2007			
Species	B	C	M	MB	B	C	M	MB
Lizards (Lacertilia)	18	18	26	70	39	32	45	87
Broadhead skink (*Eumeces laticeps*)		1	1	2	1	8	4	5
Coal skink (*Eumeces anthracinus*)	2	1	2	2	2	3	10	2
Five-lined skink (*Eumeces fasciatus*)	8	13	14	40	19	16	21	35
Eastern fence lizard (*Sceloporus undulatus*)	8	2	8	26	14	5	10	42
Green anole (*Anolis carolinensis*)					1			
Ground skink (*Scincella lateralis*)		1	1		2			3

Table 1.2. Continued

Snakes (Serpentes)	28	19	11	10	14	18	6	10
Copperhead (*Agkistrodon contortrix*)	1	5	1	2		2		
Eastern garter snake (*Thamnophis sirtalis*)	1		1		1	7	1	
Eastern hognose snake (*Heterodon platirhinos*)	1			1	2			1
Eastern racer (*Coluber constrictor*)*			1					
Eastern rat snake (*Elaphe obsolete*)*		1	1					1
Eastern Worm Snake (*Carphophis amoenus*)	23	12	5	5	8	7	3	6
Ring-necked snake (*Diadophys punctatus*)	2	1	2*		2	1	2	2
Timber rattlesnake (*Crotalus horridus*)				2*	1*	1*		
Turtles (Testudinides)		1	2	1	6	1	2	1
Common snapping turtle (*Chelydra serpentine*)		1						
Eastern box turtle (*Terrapene carolina*)*			2	1	6	1	2	1
Frogs (Anura)	11	7	4	3	7	4	4	6
American bullfrog (*Rana catesbeiana*)	1	1	1					
Gray/Cope’s gray treefrog (*Hyla versicolor/chryscocelis*)		1					1	
Green frog (*Rana clamitans*)	8	4	2	3	6	2	3	5

Table 1.2. Continued

Pickerel frog (*Rana palustris*)	2		1			1		1
Wood frog (*Rana sylvatica*)		1			1	1		
Salamanders (Caudata)	69	31	25	17	47	43	20	14
Blue Ridge two-lined salamander (*Eurycea wilderae*)	13	15	12	1	2	8	2	
Eastern red-spotted newt (*Notophthalmus viridescens*)	12	7	5	5	4	5	4	2
Jordan's salamander (*Plethodon jordani*)	7				7	2		4
Northern red salamander (*Pseudotriton ruber*)	14	3	1	8	10	4	2	3
Northern slimy salamander (*Plethodon glutinosus*)	21	6	7	3	24	24	12	5
Seal salamander (*Desmognathus monticola*)	2							
Toads (Anura)	112	24	30	77	49	16	9	17
American toad (*Bufo americanus*)	112	24	30	77	49	16	9	17

* These species were caught by hand only in the treatment areas, not in the traps.

Table 1.3. Mean reptile and amphibian captures per 100 array nights (± SE) in drift fence arrays on the Green River Game Land in Polk County, North Carolina. 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). Traps were open for 2,616 array nights during the summer of 2006 and 3,240 array nights during the summer of 2007. *F* and *P*-values are results from an ANCOVA with subsampling. Differences among treatments are indicated by letters following means.

		Treatment					
Taxa	Year	B	C	M	MB	$F_{3,6}$	P_{trt}
Reptiles	2006	9.3±16.6	8.9±9.7	5.9±4.6	13.4±6.0	2.86	0.127
	2007	6.9±3.5	6.5±3.4	6.3±2.7	12.2±4.8	2.71	0.138
Lizards	2006	2.8±3.1A	3.5±2.5A	3.7±3.4A	11.3±4.4B	11.95	0.006
Five-lined skink		1.3±2.1A	2.9±3.0AB	1.9±1.7A	6.7±2.3B	7.90	0.017
Eastern fence lizard		1.2±1.9AB	0.2±0.5A	1.0±2.2AB	4.1±3.0B	5.73	0.034

Table 1.3. Continued

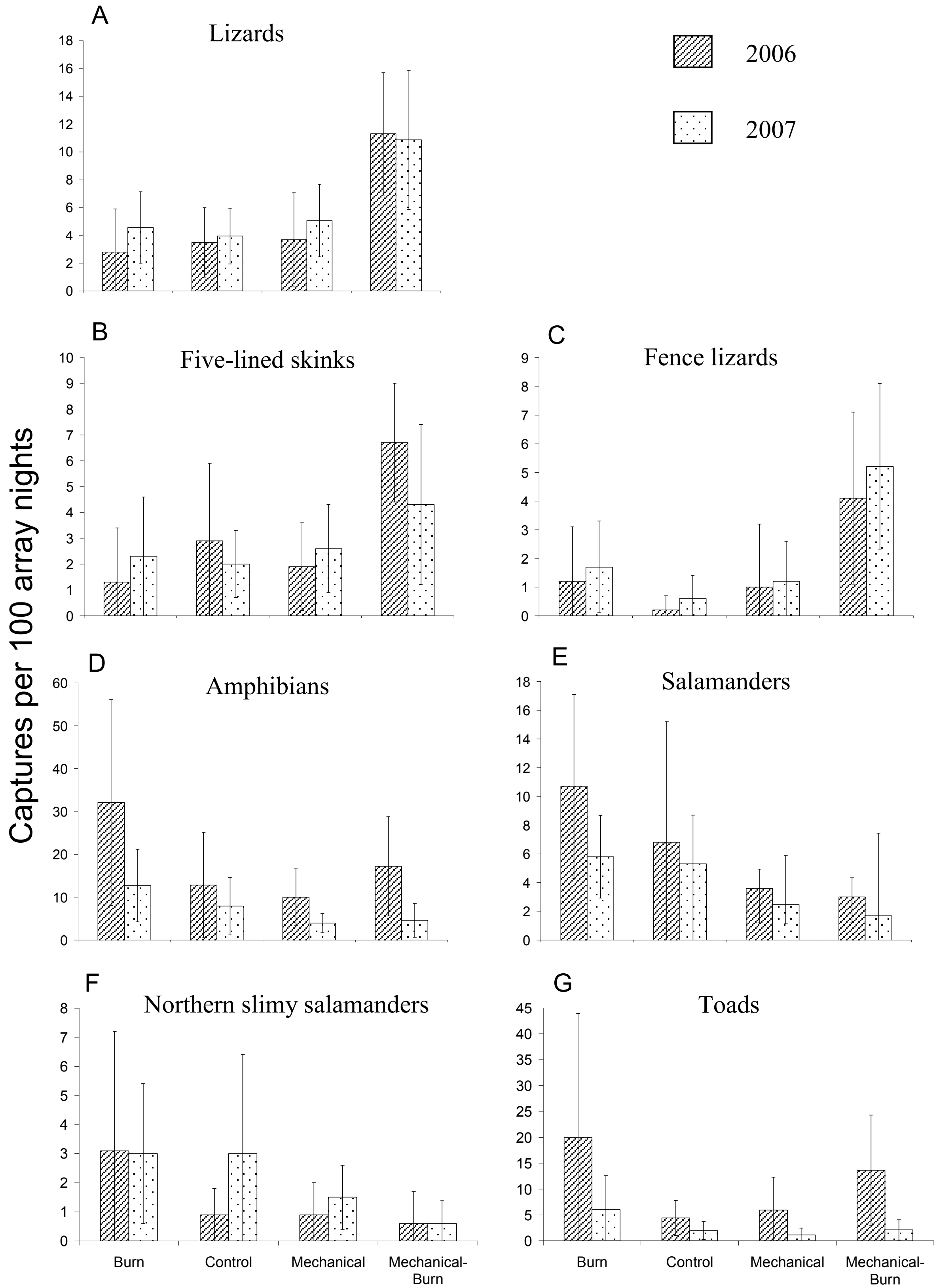
	2007	4.6±2.6	4.0±2.0	5.1±2.6	10.9±5.0	4.60	0.054
Five-lined skink		2.3±2.3	2.0±1.3	2.6±1.7	4.3±3.1	0.54	0.672
Eastern fence lizard		1.7±1.6A	0.6±0.8A	1.2±1.4A	5.2±2.9B	16.41	0.003
Snakes	2006	6.6±15.3	5.1±7.6	2.0±3.6	2.1±3.8	1.91	0.230
	2007	1.6±2.1	2.5±2.0	0.7±1.0	1.2±1.5	1.94	0.224
Turtles	2006	0.0±0.0	0.3±0.9	0.1±0.4	0.0±0.0	0.68	0.596
	2007	0.7±1.5	0.3±0.4	0.0±0.0	0.1±0.4	0.57	0.654
Amphibians	2006	32.1±24.0	12.8±12.3	10.0±6.6	17.2±11.6	3.35	0.097*
	2007	12.7±8.5A	7.9±6.7AB	4.0±2.2AB	4.6±3.9B	5.91	0.032*
Salamanders	2006	10.7±6.4A	6.8±8.4AB	3.6±2.4AB	3.0±1.8B	5.85	0.033
Northern slimy salamander		3.1±4.1	0.9±09	0.9±1.1	0.6±1.1	3.11	0.110
	2007	5.8±2.9A	5.3±5.7A	2.5±1.3AB	1.7±2.3B	9.38	0.011*
Northern slimy salamander		3.0±2.4A	3.0±3.4AB	1.5±1.1AB	0.6±0.8B	5.38	0.039*

Table 1.3. Continued

Toads	2006	20.0±23.9	4.4±3.4	5.9±6.4	13.6±10.7	1.84	0.241
	2007	6.0±6.5	2.0±1.7	1.1±1.4	2.1±2.0	1.51	0.305
Frogs	2006	1.6±2.2	1.6±1.8	0.5±0.8	0.7±1.1	0.87	0.505*
	2007	0.9±1.8	0.6±0.6	0.4±0.8	0.7±1.6	0.33	0.803

*Water was significant as a covariate (P > 0.05) and included in the model.

Figure 1. Mean lizard (A), five-lined skink (*Eumeces fasciatus*) (B), fence lizard (*Sceloporus undulatus*) (C), amphibian (D), salamander (E), northern slimy salamander (*Plethodon glutinosus*) (F), and toad (G) abundance 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). Means are given per 100 array nights ± standard error. Animals were captured in drift fence arrays from on the Green River Game Land in Polk County, North Carolina. Traps were open for 2,616 array nights during the summer of 2006 and 3,240 array nights during the summer of 2007.


A
Lizards
2006
2007
B
Five-lined skinks
C
Fence lizards
D
Amphibians
E
Salamanders
F
Northern slimy salamanders
G
Toads
Captures per 100 array nights
Burn
Control
Mechanical
Mechanical-Burn

RESPONSE OF SORICID POPULATIONS TO REPEATED FUEL REDUCTION TREATMENTS IN THE SOUTHERN APPALACHIAN MOUNTAINS

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 and canopy cover in mechanical + twice-burned treatment areas may have decreased ground-level moisture, thereby causing declines in southeastern shrew captures. Prescribed fire or mechanical fuel reduction treatments in the southern Appalachian Mountains do not greatly affect shrew populations, though the combination of both treatments may negatively affect some shrew species, at least temporarily.

KEY WORDS: fire surrogates, prescribed fire, shrews, soricids, southern Appalachian Mountains, understory cutting

INTRODUCTION

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, Brose et al. 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, Ford et al. 2002, Greenberg and Miller 2004). However, heavy disturbances that substantially reduce forest canopy cover or consume litter and duff may affect shrew populations (Greenberg et al. 2007).

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 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. 2007). Our study was designed to examine longer-term effects on shrews following a second burn at the same study site.

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.

STUDY AREA

Our study was conducted on the 5,481-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. Elevation on the GRGL ranged from 366 to 793m. 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 (*Q. prinus*), black (*Q. velutina*), northern red (*Q. rubra*), scarlet (*Q. coccinea*), and white oaks (*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.

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.

TREATMENTS

Mechanical understory cut treatments were conducted between December 2001 and February 2002, 1 year before the first prescribed burn. Trees ≥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. 2007). Maximum temperatures were recorded with thermocouples located 30 cm above the ground, with 38 to 40 thermocouples spaced throughout each treatment area. The mean maximum temperatures for burn and mechanical + burn treatments in 2003 were 180° C 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).

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 herb 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. One 4- x 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 herb cover were categorized as <1%, 1 to 10%, 11 to 25%, 26 to 50%, 51 to 75%, and >75%.

Ten 50- x 20-m plots were established at randomly selected gridpoints in each treatment area. Each plot was divided into ten 10- x 10-m subplots, each of which contained two 1- x 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 herbs were measured in the quadrats.

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 (description of arrays to follow). 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).

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, constructed of 50-cm aluminum flashing, had 7.6-m array arms buried 10 to 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 to 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).

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).

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 2.1). 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 2.1). Percent cover of shrubs ≥ 1.4 m was 96% lower in mechanical + twice-burned treatment areas than in control treatment areas (Table 2.1). Percent cover of shrubs < 1.4 m was 182% greater in mechanical treatment areas than in twice-burned treatment areas (Table 2.1). Other variables did not vary among treatment areas (Table 2.1).

SORICIDS

We captured 5 species of shrews over both years: least shrew (*Cryptotis parva*), northern short-tailed shrew (*Blarina brevicauda*), pygmy shrew, smoky shrew (*Sorex fumeus*), and southeastern shrew (Table 2.2). 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 2.3). We captured 77% fewer southeastern shrews in mechanical + twice-burned treatment areas than in mechanical treatment areas in 2006 (P_{trt} = 0.090) (Table 2.3). Captures were not different among treatment areas in 2007 (Table 2.3).

DISCUSSION

Our results indicate that shrew response to fuel reduction treatments was minimal, even after 2 prescribed burns and 4 to 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. 2007). 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. 2007); immediately after the second burn, southeastern shrew captures were greater in mechanical treatment areas than in mechanical + twice-burned treatment areas.

In our study, leaf litter 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 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. 2007). Duff depth also was lower in mechanical + twice-burned treatment areas than in all other treatment areas after the second burn. In contrast, duff depth did not differ among treatment areas after a single burn (Greenberg et al. 2007).

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 often have been associated with heavy ground cover (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.

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). 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. 2007). Coarse woody debris density, cover, or volume did not differ among treatment areas and therefore does not explain differences in captures of shrews.

We captured 77% fewer shrews in mechanical + twice-burned treatment areas only during the first year after the second burn. Shrew populations could have recovered quickly, so that population declines 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, 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 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 some studies have reported minimal shrew response to habitat disturbances that substantially reduce canopy cover (Ford et al. 2002), our study area is more xeric than many areas in the southern Appalachian Mountains. Therefore, a decrease in moisture or canopy cover due to disturbance may result in lower moisture and food availability levels and therefore decreases in shrew populations, at least temporarily.

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 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 smoky shrews and least shrews, may be more able to exploit different microhabitats than smaller shrew species (Dickman 1988, Brannon 2000).

CONCLUSION

Shrew abundance is not greatly affected by cutting shrubs and small trees or 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. 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.

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REFERENCES

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

Blair, J.M., Crossley, D.A., Jr., 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, North Carolina. 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.

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. Proceedings of the Annual Conference Southeastern Association, Fish and Wildlife Agencies 56, 374-384.

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., 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. 2007. 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.

Hamilton, W.J., Jr., 1941. The food of small forest mammals in eastern United States. Journal of Mammalogy 22, 250-63.

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. 2000 September 15, Nashville, Tennessee. General Technical Report NE-288. USDA Forest Service, Northeastern Research Station, pp. 11-23.

Kirkland, G.L. 1996. Impact of fire on small mammals and amphibians in a central Appalachian deciduous forest. American Midland Naturalist 135, 253-260.

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.

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, North Carolina, pp. 521-525.

Pruitt, W.O., Jr., 1959. Microclimates and local distribution of small mammals on the George Reserve, Michigan. Miscellaneous Publications Museum of Zoology, University of Michigan, 109, 1-27.

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. 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. (Ed.), Advances in the Biology of Shrews II. International Society of Shrew Biologists, Carnegie Museum of Natural History, Pittsburgh, PA, pp. 255-263.

Table 2.1. Habitat data (mean ± SE) 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.

	Treatment					
Habitat Variable	B	C	M	MB	F	P_{trt}
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

Table 2.1. Continued

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
Herb 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±4.1AB	99.2±1.0A	96.9±3.4AB	74.1±25.3B	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 2.2. Total number of shrews captured in 3 replicates (combined) of 4 treatments: twice-burned (B), control (C), mechanical understory cut (M), and mechanical understory cut followed by 2 prescribed burns (MB) on Green River Game Land in Polk County, North Carolina (2006-2007). Live and dead captures are included.

	Treatments 2006				Treatments 2007			
Species	B	C	M	MB	B	C	M	MB
Least shrew (*Cryptotis parva*)	0	3	2	1	1	3	1	2
Northern short-tailed shrew (*Blarina brevicauda*)	9	10	2	10	4	6	3	9
Pygmy shrew (*Sorex hoyi*)	3	2	7	0	0	2	6	3
Smoky shrew (*Sorex fumeus*)	3	7	5	8	7	8	10	3
Southeastern shrew (*Sorex longirostris*)	9	13	26	5	17	23	22	15
Total	24	35	42	24	29	42	42	32

Table 2.3. Mean number of shrew captures per 100 array nights (± SE) 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.

		Treatment (n = 3)					
Taxa	Year	B	C	M	MB	$F_{3,6}$	P_{trt}
Total Shrews	2006	3.0±2.4	4.3±3.8	5.7±3.3	2.9±3.2	2.61	0.147
Southeastern shrew		1.1±1.2AB	1.6±1.6AB	3.7±2.7A	0.6±1.1B	4.19	0.064
	2007	2.7±1.9	4.9±2.3	4.4±3.5	2.7±1.5	1.37	0.339
Southeastern shrew		2.1±2.0	3.0±1.8	2.7±2.2	1.9±1.2	0.73	0.572