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Management and Conservation Article

Response of Reptiles and Amphibians to Repeated Fuel Reduction Treatments

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ABSTRACT 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 (USA) have documented few effects on reptiles and amphibians. However, these studies were conducted after only one fire and for only a short time (1–3 yr) after the fire. From mid-May to mid-August 2006 and 2007, we used drift fences with pitfall and funnel traps to capture reptiles and amphibians 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 we captured 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 remaining litter and duff may have led to fewer salamander captures in mechanical + twice-burned treatment areas. Our longer term results, after 2 prescribed burns, differ from shorter term results. After one prescribed burn at the same site, eastern fence lizard (*Sceloporus undulatus*) captures were greater in mechanical + burn treatment areas but salamander captures did not differ among treatment areas. Our results indicate that multiple ($\geq$2) fuel-reduction treatments that decrease canopy cover may benefit lizards but negatively affect salamanders.

KEY WORDS amphibians, fire surrogates, forest management, fuel reduction, herpetofauna, prescribed fire, reptiles, salamanders, southern Appalachian Mountains.

Historically, forests of the Americas burned frequently; fires were ignited by Native Americans and by lightning (Komarek 1981, Delcourt and Delcourt 1997, Johnson and Hale 2000, Van Lear and Harlow 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 through a flush of herbaceous growth (Van Lear and Harlow 2000). Because of the large tracts of forest uninterrupted 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 was also an important disturbance in these ecosystems (Van Lear and Waldrop 1989). The historical interval between fires in the region prior to 1940 was approximately 10 years (Harmon 1982). 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 (e.g., Smokey Bear, Dixie Crusaders), resulting in widespread fire suppression during most of the 20th century (Pyne 1982). 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. 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.

Salamander species richness in the southern Appalachian Mountains is greater than that anywhere else in the United States (Kiester 1971, Lannoo et al. 2005); therefore, the southern Appalachian Mountains are an appropriate location to research land management influence on herpetofaunal populations. 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 negatively affect, and may even positively affect, salamander populations (Harpole and Haas 1999, Knapp et al. 2003, Homyack and Haas 2009). Studies in upland hardwood southern Appalachian Mountain forest indicate that one prescribed burn has a positive effect on reptiles but does not affect amphibians, at least in the short term (Ford

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et al. 1999, Greenberg and Waldrop 2008). Therefore, more intense or frequent fuel-reduction treatments (e.g., periodic prescribed fire) that eventually result in canopy reduction may be detrimental to reptiles or amphibians, especially salamanders. However, little is known about longer term effects of fuel-reduction treatments on reptiles and amphibians in hardwood forests.

An earlier study of short-term reptile and amphibian response to 3 fire and fire surrogate treatments (before a second prescribed burn) was conducted at our study sites on the Green River Game Land from 2001 to 2004 (Greenberg and Waldrop 2008). Fuel-reduction treatments were one prescribed burn, a mechanical understory cut, and a mechanical understory cut + burn treatment. We designed our study to assess longer term reptile and amphibian 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.

The National Fire and Fire Surrogate Study, spanning 13 study sites across the United States and supported by the United States Department of Agriculture and United States Department of the Interior Joint Fire Science Program and the National Fire Plan, was initiated in 2000. The purpose of the study was to assess 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 effects of the original prescribed fire, a mechanical fire surrogate treatment, and a combined mechanical + prescribed fire treatment on reptiles and amphibians for a longer time period after initial treatments and to determine effects of a second prescribed burn applied in the same treatment areas.

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, USA (Fig. 1). Elevation on the GRGL ranged from 366 m to 793 m. Two of our replicate sites (35°17′9″N, 82°19′42″W) were located 2.9 km northwest 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. alba*), 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 >50 years, and stands varied in age from 80 years to 120 years (D. Simon, North Carolina Wildlife Resources Commission, personal communication).

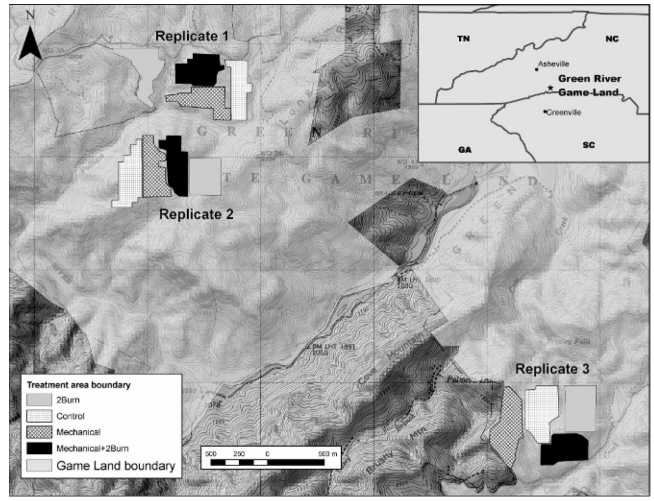

Figure 1. Location of the study site on the Green River Game Land, Polk County, North Carolina, USA, 2006–2007. There were 3 replicates of 4 forest management treatments: twice-burned (2Burn), control, mechanical understory cut (Mechanical), and mechanical understory cut followed by 2 prescribed burns (Mechanical + 2Burn).

Our experimental design followed the National Fire and Fire Surrogate Study guidelines. We implemented 3 blocks of 4 10-ha treatment areas in a randomized complete block design for 12 treatment areas. We randomly assigned 4 treatments 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 20-m buffer.

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 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 one 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 38–40 thermocouples spaced throughout each burn treatment area. 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) provides 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. Second burns in all replicates were ignited from the ground. 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, relative abundance of tree species was not substantially altered, because 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).

METHODS

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 described duff as a combination of the F (fermentation) layer and the H (humus) layer. We recorded shrubs in 2 height categories ($<$1.4 m or $\geq$1.4 m). We categorized coarse woody debris (CWD) into 5 decomposition classes (Thomas 1979). Decay class 1 included CWD with intact bark and twigs, sound wood texture, a round shape, and original wood color. Decay class 2 included CWD with intact bark, no twigs, sound or slightly soft wood texture, a round shape, and original wood color. Decay class 3 included CWD with bark falling off, no twigs, sound or slightly soft wood texture, a round shape, and faded wood color. Decay class 4 included CWD with no bark or twigs, soft wood texture with blocky pieces, an oval shape, and faded to light yellow or gray wood. Decay class 5 included CWD with no bark or twigs, soft and powdery wood texture, an oval shape, and faded to light yellow or gray wood.

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

At randomly selected grid-points 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 $\geq$1.4 m in height and live and dead tree basal area ($\geq$10 cm dbh). We measured shrubs $<$1.4 m in height and herbs in the quadrats.

We measured elevation at each array and 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, because distance to water could be a correlate of soil moisture and an important influence on salamander movement.

Reptile and Amphibian Sampling

We reopened the 2 drift-fence arrays per treatment area installed in 2001 from 17 May to 16 August 2006. We installed one additional array in each treatment area, $\geq$100 m from original arrays; we opened these concurrently on 11 July so that 3 arrays per treatment area were operational from 11 July to 16 August 2006. In 2007 we opened all 3 drift-fence arrays per treatment area 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 10–15 cm in the soil and 19-L buckets in the center of the array and at the end of each arm for 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 that we wet every time we checked traps to provide moisture for amphibians. Frequently flooded buckets also contained a small piece of styrofoam for cover and flotation.

We checked all drift-fence arrays every 1–3 days and every day following a rain event. We identified all reptiles and amphibians to species and weighed, measured (snout–vent length and total length), sexed (if possible), aged as juvenile or adult, and marked them. We classified salamanders as adults or juveniles using published snout–vent lengths for each species (Petranka 1998, Lannoo 2005). We marked amphibians with Visible Implant Elastomer (Northwest Marine Technology, Inc., Shaw Island, WA; Davis and Ovaska 2001); we scale-clipped snakes, toe-clipped lizards, and scute-notched turtles. We sterilized injection syringes and scissors between marking individuals and marked animals according to drift-fence array so we could identify each recapture 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 Institutional Animal Care and Use Committee (Project no. 06-025-O). Animal collection was permitted by the North Carolina Wildlife Resources Commission in 2006 and 2007 (Permit no. 0996, 1050).

Analyses

We estimated species richness for reptiles and amphibians using totals from the 3 arrays and opportunistic captures in each treatment area. We compared reptile and amphibian species richness among treatments using a randomized complete block design analysis of variance (ANOVA; SAS Institute, Cary, NC). We defined relative abundance as the number of animals captured/100 array-nights (excluding opportunistic captures) in 7 categories: total reptiles, lizards, snakes, turtles, total amphibians, salamanders, and anurans. We also compared relative abundance/100 array-nights for species with >30 captures in each year: common five-lined skink (*Plestiodon fasciatus*), eastern fence lizard (*Sceloporus undulatus*), white-spotted slimy salamander (*Plethodon cylindraceus*), and American toad (*Anaxyrus americanus*). We analyzed white-spotted slimy salamanders independently but grouped all salamander species together, terrestrial and streamside, in the overall salamander analyses. In many of our arrays, terrestrial species were numerically dominant and, therefore, our analyses may better reflect terrestrial salamander abundance. Because our objective was to determine differences among discrete treatments, we compared relative abundance among treatments using a randomized complete block design with subsampling analysis of covariance using elevation and distance to nearest water as covariates (SAS Institute). We excluded covariates from final models when $P > 0.05$. 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 and percent of juvenile salamanders in the population among treatments using a randomized complete block design ANOVA and separated treatment means using Tukey's HSD test (SAS Institute). To approximate normality with equal variances, we arcsine-transformed percentage data from 2006 and square root–transformed percentage data from 2007.

RESULTS

Leaf litter depth was ≥80% lower in twice-burned and mechanical + twice-burned treatment areas than in mechanical or control treatment areas; duff depth was ≥41% 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 for shrubs ≥1.4 m in height was 96% lower in mechanical + twice-burned treatment areas than in control treatment areas (Table 1). Percent cover for shrubs <1.4 m in height was 182% greater in mechanical treatment areas than in twice-burned treatment areas (Table 1). Coarse woody debris volume and percent cover for decay class 5 were ≥69% and ≥50% greater in mechanical treatment areas (Table 1). Coarse woody debris percent cover for decay class 3 was 100% greater in control treatment areas than in mechanical treatment areas (Table 1).

During 2006 and 2007, we captured 16 species of reptiles and 12 species of amphibians (we observed but did not trap one of these species, North American racer [*Coluber constrictor*]; Table 2). We captured 605 reptiles and amphibians in 2,616 array-nights during 2006 (Table 2). Total lizard captures were ≥200% greater in mechanical + twice-burned treatment areas than in other treatment areas (Table 3). Common 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 eastern fence lizards were 1,900% more abundant in mechanical + twice-burned treatment areas than in control treatment areas (Table 3). We captured 72% fewer salamanders in mechanical + twice-burned treatment areas than in twice-burned treatment areas (Table 3).

During 2007 we captured 488 reptiles and amphibians in 3,240 array-nights (Table 2). As in 2006, we captured ≥205% more lizards in mechanical + twice-burned treatment areas than in other treatment areas (Table 3). Common five-lined skink captures were similar among treatments, but eastern fence lizards were ≥200% more abundant in mechanical + twice-burned treatment areas than in all other treatment areas (Table 3). As in 2006, we captured ≥68% fewer salamanders in mechanical + twice-burned treatment areas than in twice-burned and mechanical treatment areas (Table 3). Additionally, we captured 80% fewer white-spotted slimy salamanders in mechanical + twice-burned treatment areas than in twice-burned treatment areas (Table 3). Captures of amphibians, salamanders, and white-spotted slimy salamanders were negatively correlated with distance to nearest water in 2007; only total amphibian captures were negatively correlated with distance to nearest water in 2006 ($P < 0.05$; Table 3). In 2006 snake captures decreased at higher elevations and fence lizard captures increased at higher elevations ($P < 0.05$; Table 3).

Reptile species richness did not differ among treatment areas in 2006 or 2007 ($P \geq 0.204$; Table 3). Amphibian species richness was 55% greater in twice-burned treatment areas than in mechanical + twice-burned treatment areas in 2006, but was not different among treatment areas in 2007 ($P = 0.109$; Table 3). Total reptile, snake, turtle, anuran, and American toad captures were not different among treatment areas in either year ($P \geq 0.127$, 0.224, 0.596, 0.304, 0.241; Table 3). Percent of juvenile salamanders in the population was not different among treatments in either 2006 or 2007 ($P = 0.331$, 0.783; Table 4).

Table 1. Habitat data from the Green River Game Land in Polk County, North Carolina, USA, from 3 replicates of 4 forest management treatments: twice-burned (2B), control (C), mechanical understory cut (M), and mechanical understory cut followed by 2 prescribed burns (M2B). All data are from 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 with associated standard errors. *F*- and *P*-values are results from a 2-way analysis of variance. Differences among treatments are indicated by letters following means.

	Treatment									
Habitat variable	**2B**	**2B SE**	**C**	**C SE**	**M**	**M SE**	**M2B**	**M2B SE**	***F***	***P***
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
Decay class 1	195.4	33.5	191.0	51.4	270.8	95.5	204.6	44.7	1.37	0.338
Decay class 2	125.0	125.0	83.3	72.2	83.3	144.3	145.8	36.1	0.36	0.785
Decay class 3	152.8	48.1	158.3	57.7	125.0	0.0	157.3	28.0	0.81	0.534
Decay class 4	269.0	64.9	221.3	51.2	205.8	45.5	221.8	94.6	1.17	0.397
Decay class 5	222.2	31.8	184.6	24.9	203.1	29.8	173.6	67.0	0.77	0.549
Coarse woody debris vol, m^3/ha	12.5	3.0	9.0	3.0	13.5	7.5	13.2	2.6	0.64	0.614
Decay class 1	12.7	2.1	8.8	3.1	22.0	24.8	17.6	7.1	0.77	0.551
Decay class 2	10.4	13.9	8.8	9.0	8.4	14.6	4.9	3.1	0.15	0.925
Decay class 3	22.7	11.8	21.7	13.0	10.0	4.2	16.3	14.2	1.20	0.388
Decay class 4	20.0	4.9	11.0	2.6	11.1	3.4	16.9	1.4	4.03	0.069
Decay class 5	7.3A	3.1	12.3A	5.9	20.8B	7.4	11.7A	3.5	9.68	0.010
Coarse woody debris cover, %	2.0	0.4	1.6	0.7	1.7	0.7	2.4	1.7	0.80	0.539
Decay class 1	1.4	0.6	1.0	0.5	1.9	0.8	1.3	0.5	2.32	0.175
Decay class 2	1.2	1.6	0.7	0.7	0.8	1.3	0.5	0.2	0.24	0.868
Decay class 3	1.1AB	0.2	1.4A	0.2	0.7B	0.2	1.0AB	0.3	4.73	0.051
Decay class 4	2.1	0.8	1.2	0.2	1.3	0.6	1.8	0.9	1.73	0.261
Decay class 5	0.9A	0.4	1.0AB	0.3	1.5B	0.5	1.0A	0.4	5.27	0.041
Litter depth, cm	1.1A	0.6	5.4B	0.3	6.3B	0.8	0.5A	0.1	69.08	<0.001
Duff depth, cm	2.2A	0.2	3.0A	0.4	2.9A	0.3	1.3B	0.5	18.99	0.002
Live tree basal area, m^2/ha	25.9AB	6.6	27.6AB	1.3	29.0A	2.5	16.5B	5.9	6.07	0.030
Dead tree basal area, m^2/ha	3.1AB	2.2	3.0AB	0.9	2.0A	0.5	6.9B	2.3	5.56	0.036
Shrub cover >1.4 m, %	3.6AB	3.8	14.2A	6.5	4.4AB	2.5	0.5B	0.6	6.42	0.027
Shrub cover <1.4 m, %	6.6A	3.1	9.5AB	2.4	18.6B	3.8	12.5AB	4.5	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

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 reported greater lizard abundance following high-intensity disturbances such as clearcuts, large canopy gaps, and burns (Mushinsky 1985, McLeod and Gates 1998, Greenberg 2001, 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 eastern 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 the 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 salamanders were not completely absent. Previous studies, including the study conducted after initial treatments at our study site, 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 less intense fires did not affect salamander populations. Similarly, salamander captures in our mechanical treatment areas that did not disturb the canopy were not different than captures in other treatment areas, as was also reported following midstory removal using herbicide treatments in the southern Appalachian Mountains (Harpole and Haas 1999, Knapp et al. 2003, Homyack and Haas 2009). Distance to nearest water was not significant in salamander models in 2006. Our study area received more rainfall in 2006 than in 2007, so it is possible that environmental moisture was more important to salamanders during the drier year and, thus, was only significant in the 2007 model. Greenberg and Waldrop (2008) did not detect any pretreatment differences in reptile and amphibian captures

Table 2. Total reptile and amphibian species distribution across 2 years and 3 replicates of 4 forest management 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 the Green River Game Land in Polk County, North Carolina, USA.

	Treatments 2006				Treatments 2007			
Species	**2B**	**C**	**M**	**M2B**	**2B**	**C**	**M**	**M2B**
Lizards, Lacertilia	18	18	26	70	39	32	45	88
Broad-headed skink, *Plestiodon laticeps*		1	1	2	1	8	4	5
Coal skink, *Plestiodon anthracinus*	2	1	2	2	2	3	10	3
Common five-lined skink, *Plestiodon 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			
Little brown skink, *Scincella lateralis*		1	1		2			3
Snakes, Serpentes	28	20	12	9	13	20	6	10
Copperhead, *Agkistrodon contortrix*	1	5	1	2		2		
Common gartersnake, *Thamnophis sirtalis*	2[a]		2[a]		1	7	1	
Eastern hog-nosed snake, *Heterodon platirhinos*		1			1	2		1
North American racer, *Coluber constrictor*[a]			1					
Eastern ratsnake, *Pantherophis alleghaniensis*		1[a]	1[a]					1
Eastern wormsnake, *Carphophis amoenus*	23	12	5	5	8	7	3	6
Ring-necked snake, *Diadophis punctatus*	2	1	2[a]		2	1	2	2
Timber rattlesnake, *Crotalus horridus*				2[a]	1[a]	1[a]		
Turtles, Testudinides		1	2	1	6	1	2	2
Snapping turtle, *Chelydra serpentina*		1						
Eastern box turtle, *Terrapene carolina*			2[a]	1[a]	6[a]	1[a]	2[a]	2[a]
Frogs, Anura	10	7	4	4	7	5	3	6
American bullfrog, *Lithobates catesbeianus*		1	1	1				
Gray treefrog, *Hyla versicolor chrysoscelis*		1				1		
Green frog, *Lithobates clamitans*	8	4	2	3	6	2	3	5
Pickerel frog, *Lithobates palustris*	2		1			1		1
Wood frog, *Lithobates sylvaticus*		1			1	1		
Salamanders, Caudata	69	31	25	16	47	43	20	14
Blue Ridge two-lined salamander, *Eurycea wilderae*	13	15	12		2	8	2	
Eastern newt, *Notophthalmus viridescens*	12	7	5	5	4	5	4	2
Southern gray-cheeked salamander, *Plethodon metcalfi*	7				7	2		4
Red salamander, *Pseudotriton ruber*	14	3	1	8	10	4	2	3
White-spotted slimy salamander, *Plethodon cylindraceus*	21	6	7	3	24	24	12	5
Seal salamander, *Desmognathus monticola*	2							
Toads, Anura	112	24	30	78	49	16	9	17
American toad, *Anaxyrus americanus*	112	24	30	78	49	16	9	17

[a] We caught these species or individuals by hand only in treatment areas, not in traps.

among treatment areas in 2001 or 2002, suggesting that environmental variation among treatment areas did not significantly affect our posttreatment results.

Anuran captures did not differ among treatment areas. However, there was a trend for greater anuran captures in twice-burned and mechanical + twice-burned treatment areas in 2006, a pattern similarly demonstrated in other studies of fire effects on anurans (Kirkland et al. 1996, Floyd 2003). Greenberg and Waldrop (2008) reported greater relative abundance of anurans in burn and mechanical + burn treatment areas following the first prescribed burn at our study site. Most of their anuran captures were in burn and mechanical + burn treatment areas of one replicate, which those authors attributed to nearness of breeding sites and to juvenile dispersal (Greenberg and Waldrop 2008). We also captured more anurans at these same sites, though we did not find any water sources exceptionally close to these arrays and distance to nearest water was not significant as a covariate in the model for total anurans or American toads. Toads are more tolerant than salamanders of higher temperatures and are able to store large amounts of water (Duellman and Trueb 1994). Anuran captures decreased from 2006 to 2007 and were more similar among treatments in 2007 than in 2006. Because the 2007 season was dry across the state, puddles and other water sources that normally were wet on our study site were dry most of the summer in 2007, and the drought possibly affected anuran activity and reproduction that year.

Most reptile and amphibian studies assume that sampled individuals represent the entire population, which is unlikely for salamanders because surface populations represent only small percentages of the total population (deMaynadier and Hunter 1995, Bailey et al. 2004). Detection probabilities could differ among treatment areas and lead to differences in reptile and amphibian captures. We were unable to accurately calculate detection probability because of low recapture rates; therefore, our inferences are based on count data and are dependent on the assumption that capture

Table 3. Mean reptile and amphibian species richness and captures/100 array-nights (±SE) in drift-fence arrays on the Green River Game Land in Polk County, North Carolina, USA. Captures were from 3 replicates of 4 forest management 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 analysis of covariance with subsampling. Differences among treatments are indicated by letters following means.

Taxa	Yr	Treatment								$F_{3,6}$	*P*
		2B	2B SE	C	C SE	M	M SE	M2B	M2B SE		
Richness											
Reptiles	2006	4.0	2.0	5.7	0.6	6.7	0.6	5.3	0.6	2.09	0.204
	2007	6.7	1.5	6.3	1.5	6.0	1.7	7.7	1.2	1.06	0.433
Amphibians	2006	7.3A	0.6	6.7AB	1.2	5.0AB	0.0	4.7B	1.2	5.33	0.040
	2007	6.0	0.0	6.0	1.7	4.7	1.2	4.7	0.6	3.12	0.109
Captures											
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	2.8A	3.1	3.5A	2.5	3.7A	3.4	11.3B	4.4	11.95	0.006
	2007	4.6A	2.6	4.0A	2.0	5.1AB	2.6	10.9B	5.0	4.60	0.054
Common five-lined skink,	2006	1.3A	2.1	2.9A	3.0	1.9A	1.7	6.7B	2.3	7.90	0.017
Plestiodon fasciatus	2007	2.3	2.3	2.0	1.3	2.6	1.7	4.3	3.1	0.54	0.672
Eastern fence lizard, *Sceloporus*	2006	1.2A	1.9	0.2A	0.5	1.0A	2.2	4.1B	3.0	11.66	0.007[a]
undulatus	2007	1.7A	1.6	0.6A	0.8	1.2A	1.4	5.2B	2.9	16.41	0.003
Snakes	2006	6.6	15.3	5.1	7.6	2.0	3.6	2.1	3.8	1.41	0.328[a]
	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[b]
	2007	12.7A	8.5	7.9AB	6.7	4.0B	2.2	4.6B	3.9	5.91	0.032[b]
Salamanders	2006	10.7A	6.4	6.8AB	8.4	3.6AB	2.4	3.0B	1.8	5.85	0.033
	2007	5.8A	2.9	5.3A	5.7	2.5AB	1.3	1.7B	2.3	9.38	0.011[b]
White-spotted slimy salamander,	2006	3.1	4.1	0.9	0.9	0.9	1.1	0.6	1.1	3.11	0.110
Plethodon cylindraceus	2007	3.0A	2.4	3.0A	3.4	1.5AB	1.1	0.6B	0.8	5.38	0.039[b]
Anurans	2006	14.9	13.6	3.8	1.9	4.2	2.6	10.0	8.6	1.51	0.304
	2007	6.9	7.7	2.6	2.0	1.5	1.6	2.8	2.6	0.81	0.535
American toad, *Anaxyrus*	2006	20.0	23.9	4.4	3.4	5.9	6.4	13.6	10.7	1.84	0.241
americanus	2007	6.0	6.5	2.0	1.7	1.1	1.4	2.1	2.0	1.51	0.305

[a] Elevation was significant as a covariate ($P < 0.05$) and included in the model.
[b] Distance to water was significant as a covariate ($P < 0.05$) and included in the model.

probability did not vary as a function of fuel-reduction treatment. 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 (e.g., leaf litter and low shrub cover) 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.

Salamander captures did not differ among treatment areas after the first burn, but captures were lower in mechanical + twice-burned treatment areas after the second burn (Greenberg and Waldrop 2008). Little direct salamander mortality would be expected from a winter burn at our study site because most salamander species we captured would be underground or in streams. However, habitat alterations following a burn could cause delayed salamander mortality, leading to decreased captures 3–4 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 treatment areas after the second burn but not after the first

Table 4. Percentage of subadult salamanders from drift-fence arrays on the Green River Game Land in Polk County, North Carolina, USA. Captures were from 3 replicates of 4 forest management 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 summer of 2006 and 3,240 array-nights during summer of 2007. *F*- and *P*-values are results from an analysis of variance.

Taxa	Yr	Treatment								$F_{3,6}$	*P*
		2B	2B SE	C	C SE	M	M SE	M2B	M2B SE		
Total salamanders	2006	0.30	0.17	0.40	0.36	0.13	0.23	0.04	0.07	1.40	0.331
	2007	0.09	0.04	0.19	0.04	0.11	0.19	0.11	0.19	0.35	0.783

burn (Greenberg and Waldrop 2008). Shallower duff may dry more quickly. Most salamander species we captured lack lungs and rely on cutaneous respiration; maintaining moist skin is extremely important for all salamander species and individuals are generally only active when microhabitats are moist (Feder 1983). Salamanders are consequently sensitive to changes in prevailing temperature, humidity, and soil moisture regimes (Petranka et al. 1993, Crawford and Semlitsch 2007). Salamander numbers tend to decrease in areas with removed canopy and in some cases may completely disappear from clearcut areas for a decade or more (Petranka et al. 1993, Ash 1997, Harpole and Haas 1999, Knapp et al. 2003, Homyack and Haas 2009). 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.

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. We observed no immediate response for salamanders, but lizard captures did increase soon after the first mechanical + burn treatment (Greenberg and Waldrop 2008). Adult plethodontid salamanders generally have small home ranges and are not easily led to disperse from those home ranges (Duellman and Trueb 1994). Juvenile plethodontid salamanders may disperse short distances (up to 25 m) through open fields and colonize new habitats, though narrow roads or low-order streams may inhibit dispersal (Marsh et al. 2004, 2005, 2007). Most of our salamander captures were adults, and percentage of subadult salamanders in the population was not different among treatment areas, which suggests that dispersal and recolonization were not a factor for salamanders, at least not during our sampling period. 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.

Habitat alterations following the first burn could have reduced oviposition sites and consequently reduced salamander reproduction, a response that would not be detected immediately. Plethodontid salamanders in the southern Appalachian Mountains generally mate autumn through spring before laying eggs in late spring–early summer. Female red-cheeked salamanders (*P. jordani*) do not reach sexual maturity until $\geq$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 $\geq$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 $\geq$3 years later.

MANAGEMENT IMPLICATIONS

Our results indicate that fuel reduction by mechanical understory cutting or multiple, low-intensity prescribed fires have little effect on reptile or amphibian communities of southern Appalachian Mountain hardwood forests. However, high-intensity, multiple burns, such as those in our mechanical + twice-burned treatment, may impact reptile and amphibian populations by decreasing salamander abundance and increasing lizard abundance. None of our treatments completely restored stand structure to that of the desired open woodland condition, but both burn treatments increased oak regeneration after 2 burns (Waldrop et al. 2008). 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 results of an earlier study of these fuel-reduction treatments at the same study site after one burn, suggesting that effects of multiple treatments may be additive or that the population response to initial treatments may take longer to manifest than has been addressed in prior studies. Our results combined with results from the earlier study emphasize the need for long-term studies to assess reptile and amphibian responses to fuel-reduction treatments after multiple burns.

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