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Short term response of herpetofauna to oak regeneration treatments on the mid-Cumberland Plateau of southern Tennessee

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ABSTRACT

We examined the short term response of herpetofauna to two treatments designed to regenerate oak in upland hardwood forest: (1) shelterwood (30–40% BA retention), and (2) oak-shelterwood (midstory removal by use of herbicide), along with controls. Research was conducted 1 and 2 years post treatment within an oak-hickory forest within the mid-Cumberland Plateau of southern Tennessee. Reptiles and amphibians were captured using drift fences equipped with double-ended funnel traps and pitfall traps. The shelterwood treatment had the least canopy cover and greatest amount of light at the forest floor relative to oak shelterwood or control. These changes were the main drivers for increasing the complexity of forest vegetation within the stands. Fowler's toads, eastern-narrow mouthed toads, northern slimy salamanders, eastern five-lined skinks, eastern fence lizards, northern black racers and smooth earth snakes were most abundant in the shelterwood treatment. Broad-headed skinks were most abundant in oak-shelterwood stands. Amphibian and reptile species richness was higher in the shelterwood stands than in oak-shelterwood or control. Reptile diversity was higher in the shelterwood treatment than controls. No negative responses for herpetofaunal abundance, richness, or diversity were detected in either treatment. These findings will provide forest resource managers and private forest land owners with better knowledge for conserving herpetofaunal species when implementing these oak regeneration methods in upland hardwood forests of the Cumberland Plateau.

1. Introduction

Herpetofauna are an important component of forest ecosystems because of their critical role in ecosystem function, complex position within the food chain (Bhatt et al., 1999), and as indicators of ecosystem health and forest biodiversity (Davic and Welsh, 2004; Welsh and Droege, 2001; Wilson and McCranie, 2003). Understanding herpetofaunal responses to forest management practices is important because some of these species may be vulnerable to habitat or microclimate alteration (Bartman et al., 2001; Harpole and Haas, 1999; Herbeck and Larsen, 1999; Petranka et al., 1993). Complex vegetation structure such as multiple tree strata (canopy, understory, and shrub layers), down coarse woody debris, and dead standing trees (snags) provides habitat and foraging sources for many reptile and amphibian species (Lanham and Guynn, 1996). Changes in the availability and distribution of these forest features can potentially affect herpetofaunal species richness, diversity, and relative abundance of individual species and alter herpetofaunal community composition (Felix, 2007; Wang et al., 2006).

Oak is an important tree species both ecologically and economically (Guyette et al., 2004); however, forest managers report difficulty regenerating oak in upland hardwood forests, especially in moist, higher quality sites (Aldrich et al., 2005; Jackson and Buckley, 2004; Schuler and Miller, 1995; Schweitzer and Dey, 2011). The application of shelterwood prescriptions (SW) to regenerate oak on productive upland hardwood sites has resulted in several promising recommendations, including the use of herbicides (oak shelterwood method, OSW) (Hannah, 1987; Johnson et al., 2009; Loftis, 1990; Parker and Dey, 2008; Sander, 1979; Schweitzer and Dey, 2011) and fire (Brose and Van Lear, 1998; Keyser et al., 1996; Van Lear and Waldrop, 1989). Shelterwood harvests remove a portion of the forest canopy with subsequent increases in direct light to the forest floor that promote growth of oak seedlings or saplings; prescribed burns after a few years are recommended to reduce hardwood competition and promote oak recruitment (Brose et al., 1999; Miller et al., 2004; Motsinger et al., 2010; Schweitzer and Dey, 2011). In contrast, the OSW method removes the midstory to increase indirect light with the goal of enhancing growth rates of existing oak seedlings to a competitive size before

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removing the overstory after several years (Janzen and Hodges, 1987; Lockhart et al., 2000; Loftis, 1990; Stringer, 2005).

Several studies have shown that different methods of regeneration harvests affect amphibian and reptile communities (Bartman et al., 2001; Harpole and Haas, 1999; Herbeck and Larsen, 1999; Knapp et al., 2003; Morneault et al., 2004; Perison et al., 1997; Russel et al., 2002), with responses differing among species. Abundances of some salamander species may decline in response to canopy removal, and the resulting changes in forest features (Bartman et al., 2001; Harpole and Haas, 1999; Herbeck and Larsen, 1999; Petranka et al., 1993), whereas abundance of some reptile species may increase (Perison et al., 1997; Russel et al., 2002). Todd and Andrews (2008) found a higher abundance of small-bodied snakes in thinned pine stands within the South Carolina Coastal Plain, however the abundances were greatly reduced within clearcuts. Pike et al. (2011) suggested that canopy removal increased reptile species richness and benefits species that thrive in habitat that receives direct sunlight while reducing species that are adapted to a closed canopy environment. McKenney et al. (2006) reported that abundance of eastern red-backed salamanders (*Plethodon cinereus*) was not affected by group or single tree selection treatments but suggested an association between eastern red-backed salamanders and specific structural habitat features associated with treatment stands, such as having a higher abundance associated with well-decayed coarse woody debris (CWDs).

Several studies have evaluated the response of salamanders to understory and midstory removal using herbicide (Felix, 2007; Knapp et al., 2003; Harpole and Haas, 1999; Homyack and Haas, 2009). Felix (2007) reported lower reptile abundance and richness in OSW compared to stands with 50% basal area (BA) retention, but no detectable change in amphibian abundance. Other studies report higher salamander abundance in control stands and in stands where understory was removed via herbicide than in stands with varying levels of canopy removal (Harpole and Haas, 1999; Homyack and Haas, 2009). Factors such as location, forest type, treatment scale, stand type, and weather conditions, as well as initial composition of herpetofauna play important roles in the herpetofaunal responses to a particular treatment.

The USDA Forest Service Southern Research Station, Upland Hardwood Ecology and Management Research Work Unit 4157 initiated a regional multidisciplinary study (the regional oak study) in 2008 with partners to compare the efficacy of three different proposed, but not widely tested methods to regenerate oak and other hardwood species. Longer-term treatments include: (1) SW harvest followed by prescribed fire, (2) OSW, and (3) prescribed fire alone. The second phase of these shelterwood treatments will be conducted 11 years following initial treatment, and will involve the removal of all residual trees. We compared the short-term response of herpetofaunal communities to initial SW and OSW treatments, and untreated controls, on the mid-Cumberland Plateau of southern Tennessee. We examined how microhabitat and microclimate features varied by treatment type and how changes in these features related to changes in reptile and amphibian species relative abundance, richness, and diversity.

1.1. Study site description

The study site was located on the mid-Cumberland Plateau in Grundy County, in southern Tennessee (N 35.38, W 85.85). The elevation of the site is approximately 390–550 m above sea level. The forest stands are located on the eastern escarpment of Burrow's Cove, drained by Laurel Creek; stands are located to the north and south of Mill Hollow. The site is just east of the Eastern Highland rim in a true plateau with strongly dissected margins (Smalley, 1982), and in the Cliff section of Mixed Mesophytic Forest region (Braun, 1950). The site index is 23–24 m for upland oak and 30 m for yellow-poplar (*Liriodendron tulipifera* L.) (Smalley, 1982). Soil is deep and well drained, consisting of 30–75% rocky slopes and classified as Bouldin series, a stony loam formed in colluviums weathered from interbedded sandstone, siltstone and shale (USDA, 2007). The dominant overstory trees at the site include yellow poplar, sugar maple (*Acer saccharum* Marsh.), white oak (*Quercus alba* L.), pignut hickory (*Carya glabra* Sweet), and northern red oak (*Q. rubra* L.). The stands on average had a BA of 22.5 m^2/ha and 164 stems per hectare (SPHA).

2. Materials and methods

The field experimental design was a completely randomized design (CRD) with three oak regeneration treatments and one control replicated five times resulting in 20 experimental stands ($\sim$5 ha each). Most stands were adjacent to one another, separated by $\geqslant$20 m buffers. Treatment stands had mature closed canopies with trees >70 years old and had not encountered major anthropogenic or natural disturbances within the last 15–20 years. Treatment stands were similar in elevation, slope, aspect and forest composition. For this paper, we examined 18 total stands; 10 controls, five OSW, and three SW. Other stands were omitted at this time due to staggered implementation of treatments.

2.1. Silviculture treatments

The SW harvest prescription followed the guidelines of Brose et al. (1999). The treatments removed 60–70% BA using chainsaw felling and grapple skidding along pre-designated trails. Residual trees were based on species, diameter and quality: many dominant and co-dominant oak species were retained. Trees harvested had their crown, limbs, and branches removed on site leaving the majority of slash within the unit, creating potential wildlife habitat due to increased amounts of woody debris and lessened forest floor exposure. Harvesting was conducted in fall-winter of 2008–2009.

The OSW treatment followed the guidelines of Loftis (1990) and removed mid-story trees (5–25 cm) using a Garlon 3A Trichlopyr herbicide solution injected using the hack and squirt method. The initial treatment in 2008 did not kill targeted midstory trees, and was successfully reapplied in the fall/winter of 2009.

2.2. Herpetofaunal trapping

The herpetofaunal community was sampled using drift fences with pitfall and box funnel traps (Corn, 1994). In each stand four drift fences of 7.6 m long aluminum flashing were installed: two in the lower slope (bottom 1/3 of the stand) and two at the upper slope (top 1/3 of the stand). A pitfall trap (19 L bucket) was buried at both ends of each drift fence such that opening edge was flush with the ground surface. A double funnel box trap ($91.4 \times 30.5 \times 30.5$ cm) was positioned at the center of both sides of each drift fence.

Sampling was conducted from mid-May through the end of September in 2009 and 2010. Traps were open continuously except for a few days at the end of August and beginning of September each year. All traps were checked 4–6 days per week. Each time a single drift fence was checked it was recorded as being a single trap night. Captured amphibians and lizards were marked by toe-clips, snakes were marked by scale clips, and turtles were marked by scute filing (Kilpatrick et al., 2004). The clip and filing corresponded to treatment and year in which the individual was caught.

2.3. Microhabitat data collection

During the 2010 field season microhabitat data were quantified at each drift fence using two 10 m line transects at each drift fence, starting 2 m away from the middle of the fence. Direction of the first transect was randomly determined between 0° and 360° compass bearing, and the second transect was the polar opposite the first transect on the opposite fence side. Variables recorded along the transect included: litter depth, percent ground cover, volume of CWD and slash, and forest stratification. Litter depth was measured every 2 m along each transect to the nearest millimeter using a ruler. Percent ground cover was recorded within a square (0.5 × 0.5 m) frame plot at 5 m intervals along each transects. Ground cover categories included leaf litter, bare ground, CWD, slash, rock, and herbaceous and woody vegetation. Percent cover of each category was recorded as cover within or directly above the sampling plots up to 2 m. Forest strata were assigned the following categories during visual surveys at each 5 m interval: ground cover (⩽2 m); (2) understory (>2 m–⩽4 m); (3) midstory (>4 m–below canopy); and (4) overstory (any vegetation in the main canopy ranging from intermediate to dominant; categories modified from Sutton (2010)). Volume of CWD and slash piles, slash being the treetops and branches left behind after logging or natural disturbance, that intersected transects were assessed by recording the length and diameter of CWD (⩾10 cm in diameter at the point it contacted the transect). Volume of CWD was calculated using the formula of $V = (3.14^2 \Sigma d^2/8L)$ (Van Wagner, 1968), where d = diameter (cm), and L = length of the transect (m). The volume of slash was measured if any portion of a slash pile intersected with the transect (Hardy, 1996). Canopy cover was estimated at the middle of each drift fence using a hand-held spherical densiometer during mid-summer of 2009 and 2010 field seasons when the canopy foliage was full. Basal area and photosynthetically active radiation (PAR) readings were collected by the USDA Forest Service. The USDA Forest Service installed six 0.05 ha circular plots in which all live trees ⩾25 cm were, tagged, and measured for diameter at breast height (dbh); diameters were then used to calculate an average stand BA. We measured above and below canopy PAR using an AccuPar LP-80 ceptometer (Decagon Devices, Inc., Pullman, WA). Photosynthetically active radiation measurements were collected after full leaf expansion. Below-canopy PAR was sampled at 1.4 m above ground around the entire circumference of the 0.05 ha overstory vegetation plot. In concert with these measurements, a second ceptometer recorded unobstructed ambient PAR in an adjacent open area. The percent of PAR reduction in the understory compared to open conditions was calculated from these data.

2.4. Microclimate data collection

Three microclimate variables were assessed. Relative humidity and ambient temperature were recorded by H8 Hobo Data Loggers© (Onset Computer Corporation Bourne, MA) in 2010. Data loggers were installed on wooden stakes approximately 1 m above the ground and were housed in plastic containers with an open area on the bottom for air circulation. A single data logger was placed in the upper slope portion (top 1/3 of the stand) and the other within the lower slope portion (bottom 1/3 of the stand) of each treatment stand (total 36 data loggers for 18 stands). Data loggers were set to record data four times daily at: 0300, 0900, 1500, and 2100 h (CST) concurrently with the herpetofaunal sampling periods. Precipitation data during each field season was downloaded from the Coalmont, TN weather station COOP: 401887, which is <14 km away from the research site, via the NOAA database (National Weather Service, 2012).

2.5. Statistical analysis

Herpetofaunal species richness and diversity measurements were calculated using Estimate S V. 8.2.0 (Colwell, 2009). Species richness (S_{obs}) was the actual number of species captured. Shannon–Wiener diversity index with natural logarithms was used to calculate observed species diversity by treatment (Magurran, 2004). General linear model (GLM) analysis of variance (ANOVA) for a repeated measurement design was used to test the effect of treatment (main plot factor), year (repeated factor), and their interactions on herpetofaunal species abundance, species richness and diversity. Microhabitat data was analyzed using one way ANOVA to determine if any differences among treatments were present. Post Hoc least significant difference test (LSD) was used to identify differences between specific treatments if ANOVA tests were significant. A constrained ordination technique, canonical correspondence analysis (CCA), was used to explore the relationship between the herpetofaunal community and microhabitat variables using habitat and herpetofaunal data collection in 2010 (McGarigal et al., 2000). All stands, with the exception of the pre-burn stands were used for CCA analysis. Similarities of herpetofaunal communities among treatments were estimated using Morisita's similarity index (Krebs, 1999). To control the effect of sampling effort variation (different number of replications) among the three treatments on estimating Morisita's similarity index, three stands each of OSW and control treatments were randomly selected to compare with the three SW units. Species with <5 captures in each year were excluded from all analyses (except species richness and diversity) to avoid the effect of small sample bias. All analyses used $\alpha = 0.05$ to test for statistical significance.

3. Results

3.1. Microhabitat

Control, SW, and OSW had an original BA of 22.9 ± 3.37 m^2/ha, 22.04 ± 1.02 m^2/ha, and 23.32 ± 2.98 m^2/ha respectively. The initial phase of the SW treatment reduced the BA to 9.48 ± 1.91 m^2/ha BA, a 41% BA retention. The OSW, following treatment, had a BA of 24.09 ± 3.37 m^2/ha, a 4% increase. Canopy cover was higher in control and OSW stands than in SW stands in 2009 and 2010 (Table 1). Oak-shelterwood and control stands had higher litter depth, litter cover, and presence of overstory than SW stands (Table 1). Shelterwood stands had a higher amount of slash and slash pile volume and abundance of woody and herbaceous vegetation in the ground cover than control and OSW treatment stands. Shelterwood stands also had more bare ground that OSW and control stands. Understory and midstory structures were reduced in SW and OSW stands compared to controls.

3.2. Microclimate

Microclimate variables differed among treatment types (Table 1). Shelterwood stands had a higher maximum temperature and lower minimum temperature than OSW and control stands, which resulted in a greater range and higher average of temperature in that treatment. Minimum and maximum relative humidity had similar patterns, and the average humidity was higher in control stands than in SW and OSW stands. Precipitation during data collection season was 85.7 cm in 2009 and 19.1 cm in 2010.

3.3. Herpetofaunal species composition

We captured 1661 individuals (excluding recaptures) of 29 herpetofaunal species in 6984 trap nights (97 days) during 2009. In

Table 1
Means (+SD) of microhabitat and microclimate variables in recently harvested shelterwoods with 30–40% BA retention, oak shelterwoods (midstory removal by herbicide), and undisturbed controls in Grundy County, Tennessee (2009 and 2010).

Variable	Control n = 10	Shelterwood n = 3	Oak-shelterwood n = 5	F[a]
Canopy cover (2009)	92.6 ± 3.1 A[b]	58.4 ± 14.1 B	91.7 ± 2.9 A	145.55***
Canopy cover (2010)	92.3 ± 3.0 A	67.4 ± 9.9 C	86.1 ± 5.2 B	101.12***
Litter depth	3.2 ± 1.2 A	2.2 ± 0.8 B	3.4 ± 1.1 A	4.61*
Litter cover	62.5 ± 12.5 A	23.3 ± 9.9 B	60.2 ± 8.9 A	58.95***
Bare ground cover	0.9 ± 1.8 AB	2.3 ± 2.4 A	0.7 ± 0.9 B	3.386*
Slash	4.0 ± 2.1 B	7.9 ± 4.3 A	4.0 ± 1.7 B	12.31***
Slash piles (volume)	0.0 ± 0.0 B	87.61 ± 98.3 A	0.0 ± 0.0 B	24.91***
Woody vegetation	13.0 ± 8.5 B	30.2 ± 11.9 A	14.4 ± 9.2 B	16.25***
Herbaceous vegetation	8.9 ± 8.1 B	24.1 ± 10.5 A	9.9 ± 6.8 B	16.55***
Understory	0.6 ± 0.3 A	0.2 ± 0.2 B	0.1 ± 0.2 B	23.58***
Midstory	0.7 ± 0.2 A	0.4 ± 0.3 B	0.2 ± 0.2 B	37.87***
Overstory	01.0 ± 0.1 A	0.8 ± 0.2 B	1.0 ± 0.1 A	10.28***
Rock	5.7 ± 8.2	5.8 ± 7.9	5.6 ± 5.3	0.002
Coarse woody debris	4.8 ± 4.0	6.5 ± 3.9	5.6 ± 4.6	0.786
Ground cover	0.9 ± 0.2	1.0 ± 0.0	0.9 ± 0.1	2.042
Coarse woody debris (volume)	48.7 ± 63.1	90.1 ± 63.9	76.5 ± 98.5	1.85
Minimum temperature	21.3 ± 0.4 A	20.6 ± 0.5 B	21.3 ± 0.7 A	3.48*
Maximum temperature	27.9 ± 1.0 C	33.2 ± 2.3 A	29.3 ± 0.9 B	41.12***
Range temperature	6.6 ± 0.7 C	12.5 ± 2.6 A	8.1 ± 0.6 B	56.11***
Average temperature	24.2 ± 0.6 B	26.2 ± 1.0 A	24.7 ± 0.6 B	20.35***
Minimum relative humidity	55.5 ± 4.4 A	38.9 ± 5.1 B	44.9 ± 11.3 B	16.03***
Maximum relative humidity	78.9 ± 3.2 AB	82.0 ± 5.6 A	68.5 ± 19.3 B	4.20*
Range relative humidity	23.4 ± 3.4 B	43.2 ± 7.0 A	23.5 ± 8.8 B	25.98***
Average relative humidity	68.5 ± 3.3 A	61.6 ± 5.3 AB	58.0 ± 16.2 B	4.80*

All results are from 2010, with the exception of canopy cover in 2009.
[a] F statistics from repeated measure factorial (treatment by year) ANOVA with significance level.
[b] Different letters among treatment means within a row indicate significant difference (LSD, $P < 0.05$).
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

2010, we captured and 4108 individuals of 28 species in 6912 trap nights (96 days), for a total of 33 species (18 reptile and 15 amphibian species. American toads (*Anaxyrusamericanus*), green frogs (*Lithobates clamitans melanota*), northern slimy salamanders (*P. glutinosus*), Fowler's toads (*A. fowleri*), and pickerel frogs (*L. palustris*) were the most commonly captured amphibian species (Table 2). Eastern garter snakes (*Thamnophis sirtalis sirtalis*), eastern five-lined skinks (*Plestiodon fasciatus*), northern copperheads (*Agkistrodon contortrix mokasen*), Midwest worm snakes (*Carphophis amoenus helenae*), and eastern fence lizards (*Sceloporus undulatus*) were the most commonly captured reptile species. American toads, Fowler's toads, eastern spadefoot toads (*Scaphiopus holbrookii*), and pickerel frogs had the highest recapture rate in 2009, and eastern spadefoot toads, broad-headed skinks (*P. laticeps*), eastern fence lizards, and American toads in 2010.

3.4. Herpetofaunal communities and treatment relationships

Amphibian and reptile species richness was higher in SW than in OSW or control stands (Table 3), but richness did not differ between years and no interaction effect was detected. Observed amphibian diversity did not differ among treatments, but diversity was lower in 2010 than 2009. Observed reptile diversity was higher in SW than in control, but did not differ from OSW, but diversity in OSW stands did not differ from SW or controls. No treatment with year interactions were detected for species richness or diversity for either reptiles or amphibians.

Several species showed an overall treatment effect (Table 2). Among amphibians, Fowler's toads, eastern-narrow mouthed toads (*Gastrophryne carolinensis*), and northern slimy salamanders were higher in abundance in SW. Among reptiles, eastern five-lined skinks, eastern fence lizards, northern black racers (*Coluber c. constrictor*), and smooth earth snakes (*Virginia valeriae*) were more abundant in SW. Broad-headed skinks were more abundant in OSW.

Fowler's toads, eastern narrow mouthed toads, northern slimy salamanders, and American bullfrogs (*L. catesbeianus*) were more abundant in 2009, whereas American toads and southern leopard frogs (*L. sphenocephalus*) more abundant in 2010. Northern slimy salamander was the only species that had a treatment with year interaction, with lower abundance in 2010 than in 2009, especially within SW treatments (Table 2). Morisita's similarity index for herpetofaunal community composition was similar among the treatments for both 2009 and 2010 (Table 4).

3.5. Herpetofaunal and habitat association

Canonical correspondence analysis (CCA) for amphibians (Fig. 1) accounted for 51.7% of amphibian species data (Axis 1: 19.7%, Axis 2: 14.1%, Axis 3: 9.5%, and Axis 4: 8.4%) and 81.6% of cumulative percentage variance of species–environment relationship (Axis 1: 31.0%, Axis 2: 22.3%, Axis 3: 15.1%, and Axis 4: 13.2%). The first axis was positively correlated to the presence of ground cover, understory, and woody and herbaceous vegetation but negatively with litter cover and depth, and overstory. The second axis was positively correlated to BA, canopy cover, and rock coverage and negatively correlated with presence and volume of CWD, bare ground, light, and the presence and volume of slash. Species such as the green frog, Fowler's toad, and eastern spadefoot toad were positively associated with cover of herbaceous and woody vegetation, slash, and light. Cave salamanders were positively associated with the second axis with rock and canopy cover. Southern leopard frogs and eastern spotted newts were associated with the presence of understory. Pickerel frogs were most associated with CWD and bare ground. Northern slimy salamanders and eastern narrow-mouthed toads were negatively associated with the presence of overstory, litter and litter depth represented by the

Table 2
Mean (+SD) number of amphibian and reptile captures in recently harvested shelterwoods with 30–40% BA retention, oak shelterwoods with midstory removal by herbicide, and undisturbed controls in Grundy County, Tennessee (2009 and 2010).

	Treatments						ANOVA[a]		
Species	Year	Captures (excluding recaptures)	Recaptures	Control	Shelterwood	Oak-shelterwood	Treatment	Year	Year X treatment
Amphibians									
Anaxyrus americanus	2009	815	63	22.7 ± 8.7	31.5 ± 6.4	17.2 ± 7.22	0.24	60.07***	1.58
	2010	3477	120	94.2 ± 37.0	80.7 ± 32.2	110.7 ± 48.7			
	Total	4292	183	116.9 ± 87.5	112.17 ± 64.8	127.9 ± 110.6			
A. fowleri	2009	66	4	3.4 ± 2.8	6.3 ± 1.2	2.6 ± 1.5	4.10*	4.46*	1.18
	2010	36	1	0.6 ± 0.7	1.8 ± 1.2	1.3 ± 1.6			
	Total	102	5	2.3 ± 2.3B[b]	5.0 ± 2.1A	2.6 ± 2.0B			
Eurycea lucifuga	2009	12	0	0.5 ± 1.3	1.0 ± 1.0	0.8 ± 1.3	0.58	0.18	0.60
	2010	11	0	0.3 ± 0.6	0.0 ± 0.0	0.6 ± 1.1			
	Total	23	0	0.5 ± 1.1	0.5 ± 0.8	1.0 ± 1.5			
Gastrophryne carolinensis	2009	26	1	1.2 ± 2.0	4.0 ± 1.7	0.4 ± 0.6	7.12**	6.88*	2.16
	2010	8	0	0.1 ± 0.3	0.7 ± 0.8	0.2 ± 0.4			
	Total	34	1	0.7 ± 1.5B	2.67 ± 1.9A	0.4 ± 0.5B			
Lithobates catesbeianus	2009	11	0	0.8 ± 0.8	0.3 ± 0.6	0.4 ± 0.6	0.82	7.46*	0.815
	2010	0	0	0	0	0			
	Total	11	0	0.4 ± 0.7	0.17 ± 0.4	0.2 ± 0.4			
L. clamitans melanota	2009	157	2	10.2 ± 5.6	5.0 ± 2.7	8.0 ± 5.0	0.79	0.58	0.159
	2010	183	3	5.6 ± 6.9	4.7 ± 1.9	4.3 ± 2.5			
	Total	340	5	10.7 ± 8.2	7.17 ± 3.3	8.3 ± 4.2			
L. palustris	2009	53	3	3.4 ± 3.9	1.3 ± 1.5	3.0 ± 3.9	0.67	0.43	0.259
	2010	34	0	0.9 ± 1.4	0.5 ± 0.6	1.4 ± 1.7			
	Total	87	3	2.55 ± 3.1	1.17 ± 1.0	2.9 ± 3.3			
L. sphenocephalus	2009	4	0	0.2 ± 0.4	0.0 ± 0.0	0.4 ± 0.6	2.17	6.38*	0.839
	2010	16	0	0.3 ± 0.5	0.3 ± 0.5	0.8 ± 0.9			
	Total	20	0	0.4 ± 0.5	0.33 ± 0.5	1.0 ± 1.4			
Notophthalmus v.viridescens	2009	22	0	1.4 ± 1.2	0.3 ± 0.6	1.4 ± 0.9	1.00	0.66	0.07
	2010	28	0	0.8 ± 1.3	0.5 ± 0.55	0.9 ± 1.1			
	Total	50	0	1.5 ± 1.6	0.67 ± 0.5	1.6 ± 1.1			
Plethodon glutinosus	2009	173	4	6.3 ± 5.3B	23.7 ± 9.0A	7.8 ± 6.2B	8.24**	17.63***	5.94**
	2010	80	2	2.2 ± 2.7A	2.8 ± 4.2A	1.9 ± 1.6A			
	Total	253	6	5.3 ± 4.7B	14.67 ± 11.7A	5.8 ± 4.8A			
Pseudotriton r. ruber	2009	8	0	0.4 ± 0.7	0.3 ± 0.6	0.6 ± 1.3	1.00	0.11	1.91
	2010	7	0	0.2 ± 0.5	0.7 ± 1.0	0.0 ± 0.0			
	Total	15	0	0.35 ± 0.7	0.83 ± 1.0	0.3 ± 0.9			
Scaphiopus holbrookii	2009	35	2	1.8 ± 2.9	2.7 ± 2.3	1.8 ± 2.2	0.25	3.15	0.05
	2010	12	2	0.4 ± 0.8	0.5 ± 0.6	0.2 ± 0.6			
	Total	47	4	1.3 ± 2.3	1.8 ± 1.7	1.1 ± 1.7			
Reptiles									
Agkistrodon c. mokasen	2009	46	0	1.5 ± 1.3	0.3 ± 0.5	1.5 ± 1.1	1.18	0.88	1.42
	2010	28	0	0.7 ± 1.2	0.8 ± 0.8	0.9 ± 0.9			
	Total	74	0	2.15 ± 1.9	1.17 ± 1.0	2.4 ± 1.5			
Carphophis a. helenae	2009	38	0	2.0 ± 1.8	1.0 ± 1.0	3.0 ± 3.7	0.29	1.14	0.97
	2010	21	0	0.6 ± 0.7	0.8 ± 1.3	0.5 ± 0.7			
	Total	59	0	1.55 ± 1.5	1.33 ± 1.2	2.0 ± 2.7			
Coluber c. constrictor	2009	5	0	0.2 ± 0.4	1.0 ± 1.0	0.0 ± 0.0	3.65*	0.00	0.70
	2010	7	0	0.3 ± 0.6	0.3 ± 0.5	0.0 ± 0.0			
	Total	14	0	0.35 ± 0.6AB	0.83 ± 1.0A	0.0 ± 0.0B			
Diadophis p. edwardsi	2009	7	0	0.4 ± 0.7	0.3 ± 0.6	0.8 ± 0.8	0.22	0.82	1.50
	2010	10	0	0.3 ± 0.4	0.5 ± 1.2	0.2 ± 0.4			
	Total	17	0	0.4 ± 0.7	0.5 ± 1.2	0.6 ± 0.7			
Plestiodon fasciatus	2009	48	1	2.2 ± 2.5	2.3 ± 2.5	2.01±.2	6.21**	2.50	0.26
	2010	30	2	0.6 ± 0.8	1.8 ± 1.0	0.8 ± 1.0			
	Total	78	3	1.65 ± 1.9B	4.5 ± 2.1A	1.8 ± 1.2B			
Plestiodon laticeps	2009	22	3	0.9 ± 1.1	2.0 ± 1.7	1.4 ± 1.1	3.79*	0.01	1.34
	2010	10	2	0.2 ± 0.5	0.7 ± 0.8	1.2 ± 1.8			
	Total	32	5	0.6 ± 0.9B	1.67 ± 1.2AB	1.9 ± 1.8A			
Sceloporus undulatus	2009	26	0	0.2 ± 0.4	8.0 ± 1.7	0.0 ± 0.0	50.58***	0.69	0.28
	2010	33	2	0.1 ± 0.3	4.3 ± 3.8	0.5 ± 0.5			
	Total	59	2	0.2 ± 0.4B	8.33 ± 4.3A	0.5 ± 0.7B			
Thamnophis s. sirtalis	2009	66	0	3.5 ± 2.6	2.3 ± 0.6	4.8 ± 2.2	0.25	0.50	2.20
	2010	48	0	1.2 ± 1.2	2.2 ± 1.7	1.1 ± 0.9			
	Total	114	0	2.95 ± 2.3	3.33 ± 2.3	3.5 ± 2.2			
Virginia valeriae	2009	5	0	0.2 ± 0.4	1.0 ± 1.0	0.0 ± 0.0	4.73*	0.15	0.39
	2010	5	0	0.2 ± 0.4	0.3 ± 0.5	0.0 ± 0.0			
	Total	10	0	0.25 ± 0.4B	0.8 ± 1.0A	0.0 ± 0.0B			

[a] F statistics from repeated measure factorial (treatment by year) ANOVA with significance level.
[b] Multiple comparisons among treatments based on LSD test using two year averages when treatment with year interaction was not significant or individual years separately (*Plethodon glutinosus*) when the interaction was significant. Means in the same row with different letters are different ($P < 0.05$).
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

Table 3
Mean (+SD) species richness and diversity of amphibian and reptile in recently harvested shelterwoods with 30–40% BA retention, oak shelterwoods with midstory removal by herbicide, and undisturbed controls in Grundy County, Tennessee.

Test[a]	Treatments					ANOVA[b]	
	Year	Control	Shelterwood	Oak-shelterwood	Year	Treatment	Year X Treatment
Amphibians							
S_{obs}	2009	7.8 ± 1.0	8.0 ± 1.0	8.0 ± 1.2	0.03	3.36*	2.86
	2010	6.7 ± 2.1	10.0 ± 1.0	6.8 ± 1.3			
	Total	7.25 ± 1.7 B[c]	9.0 ± 1.4A	7.4 ± 1.4			
Shannon	2009	1.28 ± 0.2	1.27 ± 0.2	1.34 ± 0.2	105.93***	0.46	0.86
	2010	0.48 ± 0.2	0.67 ± 0.2	0.48 ± 0.1			
	Total	0.88 ± 0.5	0.97 ± 0.4	0.91 ± 0.4			
Reptiles							
S_{obs}	2009	5.4 ± 1.8	7.33 ± 1.5	6.0 ± 1.0	0.02	9.06***	1.42
	2010	4.6 ± 1.8	9.0 ± 1.7	5.4 ± 0.9			
	Total	5.0 ± 1.8B	8.17 ± 1.7A	5.72 ± 0.9B			
Shannon	2009	1.41 ± 0.4	1.67 ± 0.2	1.53 ± 0.2	0.11	3.48*	0.27
	2010	1.36 ± 0.4	1.83 ± 0.1	1.54 ± 0.1			
	Total	1.39 ± 0.4B	1.75 ± 0.2A	1.49 ± 0.3AB			

[a] S_{obs} = species richness by actual species observed, Shannon = Shannon Weiner diversity index.
[b] *F* statistics from repeated measure factorial (treatment by year) ANOVA with significance level.
[c] Multiple comparisons among treatments based on LSD test using two year averages. Means in the same row with different letters are different ($P < 0.05$).
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

Table 4
Morisita's similarity index results for herpetofauna in recently harvested shelterwoods with 30–40% BA retention, oak shetlerwoods (midstory removal by herbicide), and undisturbed controls in Grundy County, Tennessee (2009 and 2010). Values noted with no asterisk represent values for 2009 and values with asterisk represent 2010.

	Control	Shelterwood	Oak-shelterwood
Control		0.95	0.95
Shelterwood	1*		0.99
Oak–shelterwood	1*	0.99*	

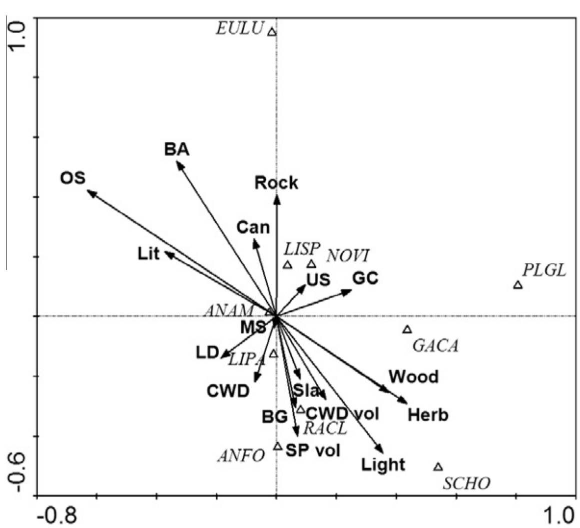

Fig. 1. Canonical correspondence ordination bi-plot of amphibians and microhabitat variables in recently harvested shelterwoods with 30–40% BA retention, oak shelterwoods (midstory removal by herbicide), and undisturbed controls in Grundy County, Tennessee (2010). Amphibian species codes: ANAM = American toad, ANFO = Fowler's toad, EULU = cave salamander, GACA = eastern narrow-mouthed toad, LIPA = pickerel frog, LISP = southern leopard frog, LICL = green frog, NOVI = eastern red spotted newt, PLGL = northern slimy salamander, and SCHO = eastern spadefoot. Microhabitat codes = US = understory, MS = midstory, OS = overstory, GC = ground cover, Lit = litter cover, LD = litter depth, Wood = wood cover, Herb = herbaceous cover, Sla = slash cover, SP vol = slash pile volume, CWD = coarse woody debri, CWD vol = coarse woody debris volume, BG = bare ground cover, Can = canopy cover, and BA = basal area.

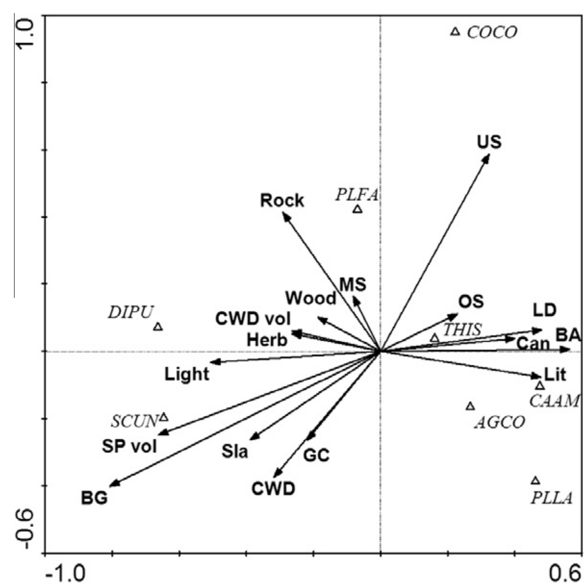

Fig. 2. Canonical correspondence ordination bi-plot of reptiles and microhabitat variables in recently harvested shelterwoods with 30–40% BA retention, oak shelterwoods (midstory removal by herbicide), and undisturbed controls in Grundy County, Tennessee (2010). Species codes AGCO = northern copperhead, CAAM = Midwest worm snake, COCO = black racer, DIPU = northern ringneck snake, PLFA = eastern five-lined skink, PLLA = broad-headed skink, SCUN = eastern fence lizard, and THSI = eastern garter snake. Microhabitat codes = US = understory, MS = midstory, OS = overstory, GC = ground cover, Lit = litter cover, LD = litter depth, Wood = wood cover, Herb = herbaceous cover, Sla = slash cover, SP vol = -slash pile volume, CWD = coarse woody debri, CWD vol = coarse woody debris volume, BG = bare ground cover, Can = canopy cover, and BA = basal area.

first axis. American toads were not closely associated with any structural attribute, and appeared to be a habitat generalist (Fig. 1).

Canonical correspondence analysis for reptiles (Fig. 2) accounted for 54.2% of reptile species data (Axis 1: 21.7%, Axis 2: 12.1%, Axis 3: 10.9%, and Axis 4: 9.5%) and 84.1% of total variance for species–environment relationship (Axis 1: 33.7%, Axis 2: 18.7%, Axis 3: 16.9%, and Axis 4: 14.8%). Axis 1 represented a gradient from higher canopy cover, litter cover and depth, BA, and overstory to areas with higher woody and herbaceous vegetation, light, bare ground, and volume of slash and CWD. Axis 2 represented a gradient from higher presence of understory and midstory, and rock coverage to stands with higher ground cover and presence of slash and CWD. Eastern garter snakes and Midwest worm snakes had a strong positive relationship with the first axis, which included stands with higher canopy cover, BA, litter cover and depth, and overstory. In contrast, eastern fence lizards and northern ring-necked snakes (*Diadophis punctatus edwardsii*) had a strong negative association with the first axis, showing an association with features in more disturbed stands including more light, woody and herbaceous vegetation, and volume of CWD and slash. Northern black racer abundance was positively related to the presence of understory as represented in the first axis. Northern copperheads and broad-headed skinks did not show a clear association with any habitat variable (Fig. 2).

4. Discussion

Microhabitat and microclimate features in the SW treatment were markedly different from those in the OSW or controls. Canopy removal in SW changed several habitat features, and resulted in more light availability, higher maximum and range in temperatures, and reduced humidity. The changes in these features due to such treatments have been well documented (Felix, 2007; Harpole and Haas, 1999; Parker and Dey, 2008; Reichenbach and Sattler, 2007; Schweitzer and Dey, 2011). These structural and microclimatic differences likely contributed to higher species richness in amphibians and reptiles in 2010 and higher relative abundance of some species in both years in SW treatment stands.

Among amphibians, eastern narrow-mouthed toads, Fowler's toads, and northern slimy salamanders were more abundant in SW than in OSW or controls. Other studies (Clawson et al., 1997; Perison et al., 1997) also reported a higher abundance of narrow-mouthed toads in clearcut regeneration harvests, indicating that this species can thrive in disturbed habitats. Our results indicated that capture rates of slimy salamanders was higher overall in 2009, with much higher capture rates in SW than in OSW and control stands, however this capture rate was even among treatment stands in 2010, which resulted in a treatment with year interaction. A concurrent study examining the same treatments at the southern Appalachian regional oak study site did not detect any differences in *Plethodon* salamanders among treatments or treatment with year interactions, but capture rates differed among years (Raybuck, 2011). Low recaptures rates across all treatments stands suggests that dispersal from treatment stands did not result in increased abundance of slimy salamanders within SW stands. These findings coincide with several studies that have shown plethodontid salamanders to not increase their dispersal immediately after harvesting (Bartman et al., 2001; Felix, 2007; Raybuck, 2011).

Our short-term results did not correspond with results of some other studies showing that timber harvests have a negative impact on salamanders (Herbeck and Larsen, 1999; Petranka et al., 1993). However, these studies used area- and or time-constrained salamander searches across a chronosequence of different stand age classes, rather than searching the same stands over a longer time period. Their results could be at least in part due to differences in study site localities, landform characteristics, and productivity. Our study and others (Felix, 2007; Raybuck, 2011; Reichenbach and Sattler, 2007) indicate that SW harvests do not adversely affect plethodontid salamanders, but capture rates often differ among years, likely influenced by weather. Reichenbach and Sattler (2007) found SW treatments had no long-term effects on Peaks of Otter Salamanders (*P. hubrichti*) populations. A recent study (Hocking et al., 2013) also found that the western slimy salamanders (*P. albagula*) showed no response to partial thinning, but declined in clearcuts. These findings corroborate our results, indicating that many plethodontid salamanders are able to maintain populations in stands following some canopy removal.

Differences in precipitation levels between 2009 and 2010 might also have affected capture rates, particularly for some amphibian species. For example, certain plethodontid salamanders, narrow-mouthed toads, and many other amphibian species movement and breeding patterns are heavily correlated with rainfall (Grover, 1998; Reichenbach and Sattler, 2007; Saenz et al., 2006; Todd and Winne, 2006). Reichenbach and Sattler (2007) reported higher detection of Peaks of Otter salamanders during rain events that followed several dry days. Rainfall in 2010 was only 22% of the amount in 2009 during the trapping period, and could have affected capture rates. Salamander detection has been found to be low during times of drought (Morneault et al., 2004). Among-year differences in precipitation likely also affected among-year differences in American toad, and slimy salamander captures. Increased road ruts and other water-holding depressions created by timber harvesting activities possibly provided breeding sites and played a role in the sharp increase in capture rates of both adults and juvenile toads. These road ruts and other depressions have been shown to be widely used among certain salamander and Anuran species (Adam and Lacki, 1993).

Abundance of several amphibian species including *Lithobates* spp., American toads, cave and red salamanders, and eastern spadefoot toads were unaffected by OSW or SW treatments. Patrick et al. (2006) found green frogs tolerate canopy removal in partial harvests (reduction of 50% canopy reduction) and clearcuts, suggesting that green frogs are more generalist in their habitat requirements. Our study and others support previous findings that some toads and frogs are more tolerant of increased temperatures (Stebbins and Cohen, 1995).

Our results showing higher abundance of eastern fence lizards and eastern five-lined skinks in the SW treatment supports previous findings that lizards respond positively to forest disturbance (Moorman et al., 2011). This response is likely due to the opening of the forest canopy, resulting in more sunlight and warmth available for thermoregulation. This coincides with other studies that report increased species richness of reptiles and abundance of some species in response to canopy reduction (Felix, 2007; Perison et al., 1997; Sutton, 2010).

5. Conclusions

Our findings will provide forest resource managers and private forest land owners with enhanced knowledge for conserving herpetofaunal species when implementing management practices for oak forest regeneration within this region. Our results indicate that in the short-term, the two oak regeneration treatments examined did not adversely affect any reptile or amphibian species; richness, diversity and relative abundance of some species increased in SW harvests compared to OSW and undisturbed controls. The SW harvests reduced canopy cover, which increased light, temperature, and structural complexity of vegetation, and likely created suitable habitat for some disturbance-adapted species without detectably decreasing suitability for others. In contrast, changes to structural complexity of vegetation or light in OSW were limited to midstory reduction; consequently, herpetofaunal response to this treatment was negligible, with the exception of increased abundance of one lizard species. Because this study only evaluated the short-term response of herpetofauna to the initial treatments of multi-phased silvicultural prescriptions, longer-term studies will provide a more comprehensive understanding of how oak regeneration treatments affect herpetofauna.

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