



# Effects of fuel reduction treatments on movement and habitat use of American toads in a southern Appalachian hardwood forest



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## ABSTRACT

Prescribed fire is a commonly used management technique for maintaining fire-adapted ecosystems, yet empirical data regarding its effects on amphibians are limited and contradictory. Anurans (frogs and toads) may be the amphibian taxa most negatively affected by fire due to their extensive use of the forest floor; however, short-term abundance studies suggest that terrestrial toads (e.g., *Anaxyrus* [*Bufo*] *americanus*) may benefit from fire-based ecosystem management. We used radio-telemetry to examine the effects of prescribed fire on movements, home range characteristics, mortality, and habitat selection of *A. americanus* in a southern Appalachian upland hardwood forest. We tracked 26 adult *A. americanus* between 27 January and 30 May 2012. Toads exhibited high non-breeding site fidelity and traveled 993.5 m ( $\pm 265.9$  m) mean ( $\pm$ SD) route distance between the breeding ponds and the last recorded location within their summer habitat. We found no evidence of direct mortality of *A. americanus* from a prescribed fire that occurred on 13 February 2012. Forward stepwise discriminant analysis (DA) revealed that the availability of coarse woody debris (CWD) was a significant discriminator between microhabitats used (i.e., location plots) and random plots (Wilk's lambda = 0.9852,  $F_{1, 661} = 9.9414$ ,  $p = 0.002$ ). Forward stepwise DA revealed that burned and unburned location plots were significantly different (Wilk's lambda = 0.2713,  $F_{1, 221} = 593.6863$ ,  $p < 0.001$ ) based on the percent of plot ground cover comprised of charred material (%char). When %char was excluded from the analysis due to its short-term nature, the percent of plot ground cover comprised of deciduous leaves, a cover item commonly used by toads in unburned locations, was the variable with the most discriminatory power (Wilk's lambda = 0.4243,  $F_{1, 221} = 299.8741$ ,  $p < 0.001$ ). Toads maintained greater distances from CWD in the unburned (mean  $\pm$  SD = 119.50  $\pm$  109.64 cm) than in the burned locations (mean  $\pm$  SD = 86.05  $\pm$  104.81 cm;  $\chi^2_1 = 9.7055$ ,  $p = 0.002$ ). Our results indicate that prescribed fire as implemented in this study did not cause direct mortality, nor did it appear to inhibit migratory movements of adult *A. americanus*. However, fire reduced the diversity and availability of refugia, especially deciduous leaves, though the availability of alternative cover objects (e.g., CWD) in burned treatments allowed toads to inhabit those areas, suggesting the importance of noncombustible or semi-permanent refugia for *A. americanus* in fire-managed forests.

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## 1. Introduction

Fire has been a predominant force influencing the structure and function of many ecosystems (Noss, 1989; Spetich et al., 2011). Methods of prescribed burning have been developed to restore and maintain native fire-adapted ecosystems (Stanturf and Madson, 2002). Fire as a management tool is commonly used to maintain a specific ecosystem type (Boyer and White, 1990; Waldrop et al., 1992), enhance habitat for wildlife (Kern et al., 2012), reduce

fuel loads and the associated risk of damaging wildfire (McCandliss, 2002; Agee and Skinner, 2005; Agee and Lolley, 2006; Waldrop et al., 2008), and eradicate exotic or invasive species (Higgins et al., 1989; Miller et al., 1999; Miller, 2003; Kyser et al., 2008). Numerous empirical studies and reviews conducted to elucidate the effects of fire on wildlife have yielded equivocal results that were largely dependent on species, life history, and fire frequency, extent, and intensity (Russell et al., 1999; Ford et al., 2000; Moritz et al., 2011). Vegetation responses to fire largely structure long-term population responses for many wildlife species, but the immediate effects of a burn are less understood (Russell et al., 1999). Movement and habitat selection studies of wildlife species in response to fire are rare and most wildlife-fire studies assess species presence or population-level changes. Among vertebrates,

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birds and mammals are best studied in relation to fire; until recently little information was available for reptiles and amphibians (Russell et al., 2009; Zwolak, 2009).

Amphibians may be vulnerable to the negative effects of fire due to their limited vagility and susceptibility to desiccation, a characteristic associated with their dependence on moisture and their sensitive, permeable skin (Pilliod et al., 2003; Greenberg and Waldrop, 2008). However, fire-maintained ecosystems, such as longleaf pine savannas, harbor a variety of amphibian species considered habitat specialists, demonstrating that fire in some ecosystems can enhance amphibian habitat and, by extension, populations (Means, 2006). Studies examining the effects of prescribed fire on amphibians report conflicting results which may reflect differences in species' life histories in relation to fire, but may also in part be due to limitations associated with study design (Bury, 2004; Greenberg and Waldrop, 2008; Matthews et al., 2010). For example, many relevant studies have been limited to comparisons of pre- and post-fire abundance and/or richness estimates (e.g., Kirkland et al., 1996; Schurbon and Fauth, 2003; Greenberg and Waldrop, 2008; Matthews et al., 2010). Because many prescribed burns are implemented in the winter or spring, pre- and post-burn amphibian sampling is often conducted in the fall prior to and in the summer following the burn (e.g., Ford et al., 1999; Greenberg and Waldrop, 2008). The results of such studies may be confounded by seasonal differences in abundance and/or detection rates as many amphibians undergo seasonal migrations and changes in activity states (e.g., torpor; Conant and Collins, 1998; Wells, 2007). Furthermore, the short-term duration of abundance and richness studies will not elucidate the longer-term effects of fire that may result from indirect impacts (e.g., the effects of changes in the distribution of fine-scale structure that serve as amphibian habitat; Matthews et al., 2010; Perry et al., 2012). Complementary studies that examine amphibian movement patterns, use of space, and post-fire habitat selection provide critical information regarding longer-term and/or sublethal effects (e.g., behavioral response to disturbance) of prescribed fire on amphibians, yet such studies are rare (but see Guscio et al., 2008; Hossack et al., 2009).

Anurans (i.e., frogs, toads) may be among the amphibian taxa most likely affected by fire as many anuran species travel extensively across the forest floor and occupy shallow burrows or cavities during times of inactivity (Baldwin et al., 2006; Elliott et al., 2009). Research targeting the effects of fire on anurans has shown that fire may have no effect, positive effects, or negative effects. For example, Moseley et al. (2003) found no significant differences in anuran abundance, diversity, or richness between burned and unburned bottomland hardwood forest in the upper Coastal Plain of Georgia. Kirkland et al. (1996) found that amphibian abundance, driven to a great extent by the presence of American toads (*Anaxyrus [Bufo] americanus*), was greater in a burned than in an unburned oak forest in Pennsylvania. However, because the burn was the result of wildfire, Kirkland et al. (1996) did not have pre-burn capture data to establish whether the observed patterns of amphibian abundance were preexisting or a result of the fire. The effects of fire on boreal toad (*Anaxyrus boreas*) breeding habitat revealed that *A. boreas* selected wetlands subjected to higher severity fires over wetlands exposed to lower severity fires (Guscio et al., 2008; Hossack et al., 2009). The authors concluded that the selection of wetlands subjected to higher severity fires may have been due to possible fitness benefits (e.g., higher growth rate, greater fertility) associated with higher burrow temperatures observed in the wetlands subjected to higher severity burns. In contrast, Humphries and Sisson (2012) found that a gopher frog (*Lithobates capito*) undergoing spring migration from its breeding habitat suffered direct mortality from a prescribed burn in North Carolina.

Fire played a primary role in shaping the species composition and structure of hardwood forests of the eastern United States for thousands of years (Spetich et al., 2011). In the southern

Appalachian Mountains, oak-dominated hardwood forests were historically common due to the frequent fires that occurred as a result of Native Americans' activities (Waldrop et al., 2008). Fire resulted in open woodland and early successional forest habitats (Waldrop et al., 2008). However, land use changes and fire suppression policies resulted in altered species composition, denser forests, and higher fuel loads that increased the likelihood of catastrophic wildfire (Spetich et al., 2011). One of the best documented cases of the use of forest management techniques, including prescribed fire, to restore open woodland habitats and decrease fuel loads in the southern Appalachian Mountains is the result of the National Fire and Fire Surrogate (NFFS) study. The NFFS study is a nationwide program designed by an interdisciplinary team of government, university, and private scientists and land managers to quantify the ecological and economic effects of fire across a variety of forest types (Youngblood et al., 2005). The goals for the southern Appalachian Mountains NFFS site are to decrease the severity of wildfires through fuel reduction, increase oak regeneration, and improve wildlife habitat including creating early successional habitat (Waldrop et al., 2008). These goals are expected to be achieved by restoring open woodland habitats through prescribed fire, mechanical understory removal, and a combination of the two techniques (Waldrop et al., 2008). The NFFS program provides the opportunity to study the effects of forest management techniques, used alone and in combination, on a variety of species including amphibians. Previous studies at the southern Appalachian Mountain NFFS site revealed no differences in relative abundance of amphibian species with the exception of *A. americanus*, following mechanical understory removal and a prescribed burn (Greenberg and Waldrop, 2008). *A. americanus* were more abundant in treatments subjected to fire, but the authors warned that the result may not have been an effect of treatment but rather proximity to breeding habitat and study timing corresponding with juvenile dispersal as the majority of individuals captured were juveniles (Greenberg and Waldrop, 2008). A subsequent study following a second prescribed fire yielded no significant differences in capture rates among treatments for all anuran species pooled or *A. americanus*, but lower salamander abundance in treatments that received both mechanical understory removal and prescribed fire relative to control and burn-only treatments (Matthews et al., 2010). As a third prescribed fire was scheduled for 2012, we sought to extend these studies by examining the effects of fuel reduction treatments on the movements, home range, mortality, and habitat selection of the most abundant and terrestrial anuran species at the site, *A. americanus*. As toads are habitat generalists, we predicted that toads would not avoid burned areas as they moved through the landscape. As toads are relatively hardy to arid conditions and have behavioral adaptations that would allow them to avoid and survive low intensity fires, we predicted that few, if any, toads would suffer direct mortality from fire. We predicted that habitat selection analyses would reveal that toads may select for microhabitat features (e.g., refugia) that provided security from predators and/or allowed them to better regulate their physiological status and that these features may differ between burned and unburned locations. As in all fine-grained radio-telemetry analyses, we sought to add to general natural history and movement knowledge, and apply that to forest management.

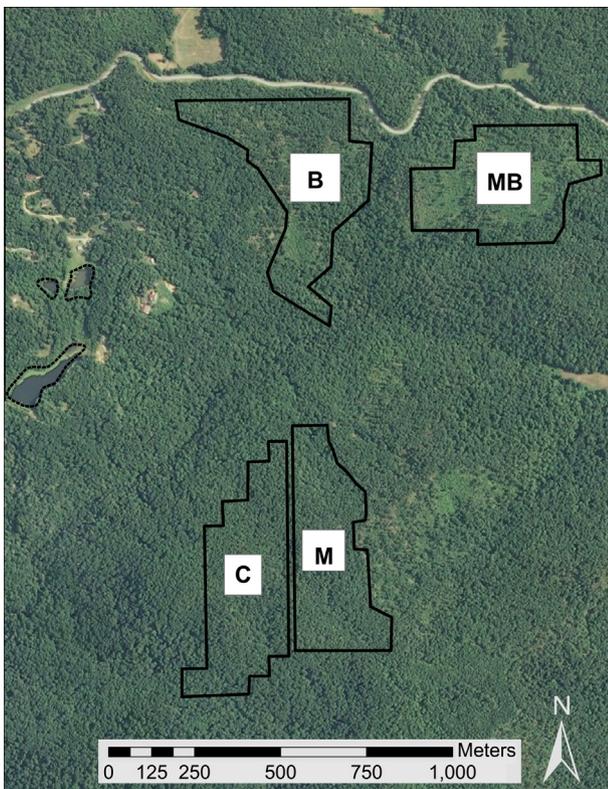
## 2. Methods

### 2.1. Study area

The Green River Game Land (GRGL), Polk County, North Carolina (35°17'9"N, 82°19'42"W), located in the southern Appalachian Mountains, is a 5841-ha mixed-use recreation area. The area is pri-

marily upland hardwood forest consisting of oaks (*Quercus* spp.) and hickories (*Carya* spp.), with shortleaf pine (*Pinus echinata*), pitch pine (*Pinus rigida*) and Virginia pine (*Pinus virginiana*) located on ridgetops (Greenberg and Waldrop, 2008). Common understory shrubs are mountain laurel (*Kalmia latifolia*), rhododendron (*Rhododendron maximum*), and blueberry (*Vaccinium* spp.; Greenberg and Waldrop, 2008; Matthews et al., 2010). The GRGL has been part of the NFFS study since 2001 when three experimental blocks were selected to receive four 14-ha treatments each: prescribed burn (B), mechanical understory removal (M), prescribed burn + mechanical understory removal (MB), and control (C; Greenberg and Waldrop, 2008). Prior to the implementation of our study, the appropriate treatment areas within the GRGL received one round of mechanical understory removal and two rounds of prescribed burns. Mechanical removal was performed in the winter 2001–2002, and prescribed burns were conducted in March 2003 and February 2006.

Due to the intensive character of individual movement and habitat selection studies, we targeted our sampling to one replicate of each treatment type, with sampling in block one treatments B and MB and block two treatments M and C (Fig. 1). The four targeted treatment areas were selected based on the higher relative abundance of adult *A. americanus* captured at those sites in previous studies (Greenberg and Waldrop, 2008; Matthews et al., 2010). Prescribed burns in the B and MB treatments were conducted on 13 February 2012. The maximum mean temperature ( $\pm$ SD), as measured by thermocouples placed 30 cm above the forest floor, of the fire was  $170.0 \pm 107.6$  °C (range = 51.9–376.9 °C;  $n = 18$ ) in the B treatment and  $167.8 \pm 121.2$  °C (range = 46.9–515.6 °C;  $n = 17$ ) in the MB treatment (R. Phillips, U.S. Forest Service, pers. comm).



**Fig. 1.** Forest management treatments areas used in the Green River Game Land, Polk County, North Carolina, USA. Treatments include prescribed burn (B), prescribed burn + mechanical understory removal (MB), mechanical understory removal (M), and control (C).

## 2.2. Capture methods

From 23 January to 26 January 2012 we installed numbered, geo-referenced drift fence/pitfall trap arrays following the protocols described by Corn (1994) in each of the four target areas to capture *A. americanus*. The ‘Y’-shaped arrays consisted of three 10-m sections of fabric silt fencing spaced at approximately 120° angles from each other around a central 19-L bucket. Each array arm led to a 19-L bucket at its outer end. We drilled holes in the bottoms of the buckets to allow for drainage and inserted sticks to allow non-target species (e.g., small mammals) to escape. Arrays were checked daily and left open until we captured our target sample size for the study of 20 *A. americanus*. At initial capture, we recorded the date, time, pitfall trap number, and weather conditions and collected data on toad sex and morphometrics. We measured snout-vent length (SVL) to the nearest 1.0 mm using calipers and weighed each individual to the nearest 0.1 g using an Ohaus pocket scale ( $\pm 0.1$  g; Ohaus Corporation, Pine Brook, NJ).

## 2.3. Radio-telemetry

Toads were outfitted with a BD-2 or PD-2 transmitter (Holohil Systems Ltd., Carp, Ontario) attached by a belt following the protocol of Baldwin et al. (2006) as modified by L. Groff (pers. comm.). To construct the transmitter attachment we threaded Stretch Magic bead cord (Pepperell Crafts, Pepperell, MA) through a channel attached to the transmitter and a short piece of 3/32 heat shrink tubing. Using the appropriately sized portion of a dowel as a reference, we created the belt by making a square knot and sliding and shrinking the tubing over the knot to reduce abrasion potential. Total mass of the transmitter and cord attachment harness was  $\leq 7.4\%$  of body mass,  $< 10\%$  recommendation by Richards et al. (1994). We released tagged individuals at site of capture. We tracked radio-tagged toads using a R-1000 receiver (Communications Specialists, Orange, CA) and RA-23K VHF rubber ducky ‘‘H’’ type antenna (Telonics, Inc., Mesa, AZ). We located animals 1–2 times per week between 0800 and 1900 h with visual confirmation for terrestrial habitats or local triangulation within 3 m of the toad for aquatic habitats.

## 2.4. Data collection

At each toad location event, we recorded date, time, GPS coordinates, and weather conditions. For locations within 20 m of the previous location, we measured bearing using a Silva model 515 Ranger compass (Johnson Outdoors Inc., Racine, WI) and distance to last location in cm using a measuring tape (Keson Industries, Aurora, IL). For distances greater than 20 m, we calculated distance using the movement.pathmetrics command in Geospatial Modeling Environment (GME) Version 0.7.1.0 (Beyer, 2012). We estimated activity state based on posture (e.g., tucked/inactive, alert, active) as described by Duellman and Trueb (1994), and categorized and recorded diurnal refugia (e.g., dry leaf, saturated leaf, log). We measured the distance from each toad to the closest coarse woody debris (CWD;  $\geq 10$  cm diameter as defined by Harmon and Sexton, 1996), a semi-permanent cover object that would survive the prescribed fire. To assess microhabitat selection, we measured microsite and macrosite slope and aspect, soil moisture, microhabitat and macrohabitat relative humidity, microhabitat and macrohabitat temperature, relative abundance of tree species, light levels, canopy and understory openness, and ground cover composition at each individual’s location (i.e., location plot) and at two neighboring nonlocation (i.e., random plot) sites 2 m and 20 m in a random direction determined by blindly rotating the bevel on a compass, from the location site. The distances of the nonlocation sites from the location site were chosen to represent

two within-macrohabitat spatial scales at which toads could select habitat (Baldwin et al., 2006; Forester et al., 2006). Location and random plots were 1 m<sup>2</sup> in size, with the location plots centered at the toad's location. We measured slope and aspect using a Silva model 515 Ranger compass with declinometer (Johnson Outdoors Inc., Racine, WI). Microsite slope and aspect were measured as the slope and aspect within the 1-m<sup>2</sup> plot. Macrosite slope and aspect were measured as the slope and aspect of the major landscape feature (e.g., hillside) upon which the 1-m<sup>2</sup> plot was located. We measured soil moisture using a Field Scout TDR 100 with 12 cm probes (Spectrum Technologies, East Plainfield, IL) within 10 cm of the individual's location. We used an Extech Precision Psychrometer (Extech Instruments, Waltham, MA) to measure microhabitat relative humidity and air temperature <3 cm from each individual *A. americanus* and the macrohabitat relative humidity and temperature of the air while standing at the center of each location plot. We measured relative abundance of tree species while standing at the center of 1-m<sup>2</sup> location and random plots using a 10 BAF cruising prism (GHC Specialty Brands, LLC.). We measured forest floor light levels 3 cm immediately above each individual *A. americanus* with an Extech Foot Candle/Lux Light Meter (Extech Instruments, Waltham, MA). We measured canopy and understory openness using a Model-A Spherical Densitometer (Forest Densitometers, Bartlesville, OK). We estimated percent ground cover within each 1-m<sup>2</sup> plot (1–5, 6–25, 26–50, 51–75, >75%) of tree trunk/root bole, shrubs, standing water, deciduous leaf litter, saturated leaf litter, leaf fragments, moss, lichen, grass/sedge, fern, sticks (<10 cm diameter), soil, bare rock, gravel, constructed trail, CWD by decay class (1–5; Thomas, 1979), other non-woody herbaceous vegetation, conifer needles, bark, charred material, and other (e.g., acorns).

### 2.5. Spatial and statistical analyses

We mapped all locations in ArcMap 10.0 (ESRI, Redlands, CA). We calculated total straight-line distance traveled between location events using GME. We calculated home range using the minimum convex polygon method (MCP) in Biotas 2.0a (Ecological Software Solutions LLC, Hegymagas, Hungary).

We used the nonparametric Wilcoxon signed-rank tests to compare the macrohabitat temperature ( $n = 229$ ) with the microhabitat temperature ( $n = 229$ ) and the macrohabitat relative humidity ( $n = 229$ ) with the microhabitat relative humidity ( $n = 229$ ) for all location plots pooled, regardless of treatment, to determine if toads maintained abiotic conditions within their microhabitats that differed from the conditions of the surrounding air. To assess differences in habitat use between toads in burned and unburned plots, we compared the distance from each toad to the closest CWD in burned ( $n = 85$ ) and unburned ( $n = 138$ ) locations using a Kruskal–Wallis test. We used a chi-square contingency analysis to determine whether types of structures (e.g., leaf form, preexisting cavity) used by toads for diurnal refugia in terrestrial settings were different in burned and unburned location plots.

To evaluate habitat selection, we used a discriminant analysis (DA) to compare the location plots ( $n = 223$ ) with the 2 m and 20 m random plots pooled ( $n = 440$ ). DA is a multivariate statistical technique that allows for the discrimination of predefined groups (e.g., location plots, random plots) by revealing dominant gradients of variation among groups by maximizing among-group variation and minimizing within-group variation (McGarigal et al., 2000). Additionally, DA can be used in an exploratory manner to identify variables that most strongly differentiate groups (McGarigal et al., 2000). The habitat selection technique we applied follows the site attribute design described by Garshelis (2000). Of the 56 original habitat variables for which we collected data, we retained 46 vari-

ables in our analyses. Three variables, percent of plot ground cover comprised of standing water and CWD decay class 5, and number of alder (*Alnus* spp.), were removed from the analyses due to lack of data. Six variables, microaspect, microhabitat relative humidity and temperature, understory openness, and percent of plot ground cover comprised of soil and conifer needles, were removed from the analyses due to high correlation ( $|r| \geq 0.7$ ) with other variables. One variable, macroaspect, was removed due to missing values associated with macroslope values equal to “zero” (level ground). Eight location plots and 20 random plots were excluded from the analyses due to missing data associated with the plots' location relative to water bodies as not all variables were measured for points located within water bodies. We performed a DA using all retained habitat variables, followed by a forward stepwise DA to determine which variables were the best discriminators between location and random plots. We also used independent sample *t*-tests or nonparametric Kruskal–Wallis tests if assumptions for parametric analyses were not met to determine whether the habitat variables were significantly different between the location and random plots. Additionally, to identify trends that may be relevant at different spatial scales, we performed a multiple DA using all retained habitat variables to compare the location plots ( $n = 223$ ), 2 m random plots ( $n = 221$ ), and 20 m random plots ( $n = 219$ ), followed by a forward stepwise multiple DA to determine which variables were the best discriminators among plots. We used one-way ANOVA or nonparametric Kruskal–Wallis tests followed by post hoc analyses to determine whether habitat variables were significantly different among location plots, 2 m random plots, and 20 m random plots.

To evaluate the effects of fire on toad habitat, we used a DA to compare the burned ( $n = 83$ ) and unburned ( $n = 140$ ) location plots of the toads. Of the 56 original habitat variables for which we collected data, we retained 48 variables in our analyses. Three variables, percent of plot ground cover comprised of standing water, CWD decay class 5, and constructed trail, were removed from the analyses due to lack of data. Three variables, microaspect, microhabitat relative humidity and temperature, were removed from the analyses due to high correlation ( $|r| \geq 0.7$ ) with other variables. One variable, macroaspect, was removed due to missing values associated with macroslope values equal to “zero” (level ground). One variable, understory openness, was removed due to sampling inconsistencies. Data from all but eight location plots were included in the DA. The eight excluded location plots had missing data due to their locations relative to water bodies as not all variables were measured for points located within water bodies. We conducted a DA with all remaining habitat variables retained, followed by forward stepwise DA to determine which variables were the best discriminators between burned and unburned location plots. Following initial examination of results, we removed the variable percent of plot ground cover comprised of charred material (%char) from the analysis as it was the strongest discriminator between burned and unburned location plots, but ultimately a short-term effect of the fire. We hypothesized that the inclusion of %char might have obscured the longer-term effects of fire (e.g., microstructure diversity and availability) that would serve as more ecologically significant discriminators between toad habitats in burned and unburned location plots. The resultant model retained 47 habitat variables which we analyzed using a DA, followed by forward stepwise DA to determine which of the remaining variables were the best discriminators between burned and unburned location plots. We also used independent sample *t*-tests or Kruskal–Wallis tests to determine whether the habitat variables were significantly different between the burned and unburned location plots.

Although the mechanical treatments did not occur during our study, we hypothesized that treatment history may have an effect on toad habitat, so we conducted a multiple DA to assess differ-

ences in location plots among treatments ( $n_{\text{burn}} = 89$ ,  $n_{\text{mechanical}} = 18$ ,  $n_{\text{mechanical burn}} = 11$ ,  $n_{\text{control}} = 31$ ,  $n_{\text{outside of treatment area}} = 74$ ) to assess whether recent (fire) and historical (mechanical removal and previous prescribed burns) management influenced toad habitat. Of the 56 original habitat variables for which we collected data, we retained 47 variables in our analyses. Four variables, number of alder and percent of plot ground cover comprised of standing water, CWD decay class 5, and trail, were removed from the analyses due to lack of data. Three variables, microaspect, microhabitat relative humidity and temperature, were removed from the analyses due to high correlation ( $|r| \geq 0.7$ ) with other variables. One variable, macroaspect, was removed due to missing values associated with macroslope values equal to “zero” (level ground). One variable, understory openness, was removed due to sampling inconsistencies. Eight location plots were excluded from the analyses due to missing data associated with the plots' location relative to water bodies as not all variables were measured for points located within water bodies. We removed the variable %char from the analysis so as not to obscure longer-term discriminators of toad habitat among treatments. The resultant model retained 46 habitat variables. We performed a multiple DA using all retained habitat variables, followed by a forward stepwise multiple DA to determine which variables were the best discriminators among treatments.

Radio-telemetry studies yield datasets based on multiple observations of each of the individuals sampled. If an individual represents a disproportionately high number of the observations for the entire sample, it may unduly bias the results of statistical analyses. We calculated the percentage of the total number of observations comprised by each individual to determine if any individual represented a disproportionately high number of the observations.

Statistical analyses were conducted using JMP 10.0.0 (SAS Institute, Inc., Cary, NC) with a significance level of  $\alpha = 0.05$ .

### 3. Results

#### 3.1. Movement and home range

We captured and radio-tagged 21 adult *A. americanus* between 27 January and 5 February 2012, prior to the prescribed burn. Due to a reduction in sample size associated with transmitter loss and mortality, we captured and radio-tagged 5 additional *A. americanus* (one individual each on 21 and 23 February, three individuals on 6 April). Movement patterns indicated that toads were migrating directionally immediately following capture/release suggesting that toads were initiating their breeding migration as early as 27 January 2012. All individuals ( $n = 13$ ) that migrated to a breeding pond went to the same pond complex (Fig. 2a), arriving 24 February–5 March 2012. Mass breeding events occurred on 1–2 March 2012. A few individuals were heard calling at the pond complex as late as 5 March 2012. Post-breeding migration began as early as 2 March 2012. Individuals ( $n = 6$ ) that we were able to follow on their post-breeding migration returned to their original capture treatment area (Fig. 2b) as early as 26 March 2012. Mean ( $\pm$ SD) straight-line distance from the breeding ponds to the summer habitat (i.e., geographical distance not distance of route traveled) was  $863.4 \pm 162.2$  m (range = 723.4–1152.7 m). Mean ( $\pm$ SD) total route distance traveled post-breeding between the breeding ponds and the last recorded location within the toad's summer habitat based on observed locations for each individual was  $993.5 \pm 265.9$  m (range = 796.3–1497.8 m). One male from the B treatment and one female from the MB treatment did not undergo breeding migrations and remained in their respective treatments, though the female was found dead outside of the MB treatment on 12 March 2012. We were able to track a total of seven individuals

for a time period that included pre- and post-burn and pre- and post-breeding movements (Table 1). Mean ( $\pm$ SD) minimum home range used from 27 January to 30 May was  $83,999 \pm 65,424$  m<sup>2</sup> ( $n = 7$ ; Table 1).

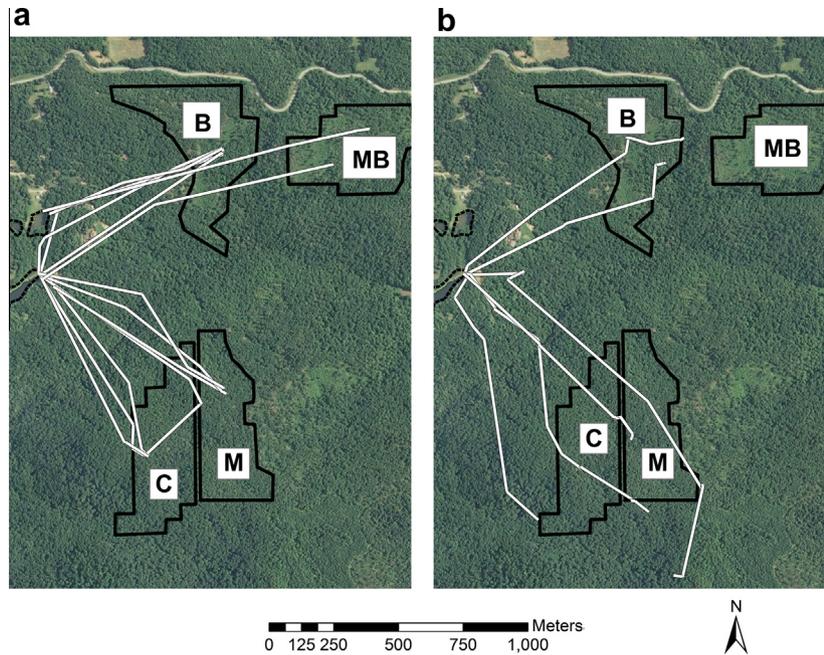
#### 3.2. Mortality

As of the date of the prescribed burn (13 February 2012), four of the 21 radio-tagged *A. americanus* remained within the burned treatments (B, MB; Table 1). On 14 February 2012, three of the four were located in the same shallow burrows they were in prior to the burn. Although the radio transmitters were destroyed by the fire, the toads survived the burn, had no visible injuries (Fig. 3), and were subsequently outfitted with new radio-transmitters for continued tracking. Remains of the fourth transmitter were recovered from a cavity inside a smoldering log in which the toad had been located prior to the burn. The transmitter was no longer functional, but no remains or evidence of the toad were found. Additionally, the interior of the log where the destroyed transmitter was found remained moist and seeds and nuts cached within the log remained unburned. There were five confirmed cases of predation where the transmitters and/or toad remains were found in the predator or the predator's scat and one additional loss that was likely due to predation as the transmitter, which bore bite marks, was found in a partially buried, 0.5-m-diameter drainage pipe (Table 1). An additional toad was found dead and had portions of its snout removed by small mammals, but the cause of death was unknown as the damage may have happened post-mortem as a result of scavenging rather than predation (Table 1).

#### 3.3. Habitat selection

The mean ( $\pm$ SD) microhabitat temperature ( $21.14 \pm 7.38$  °C) was significantly greater than the mean ( $\pm$ SD) macrohabitat temperature ( $19.54 \pm 6.83$  °C;  $S = -8833.5$ ,  $p < 0.001$ ). The mean ( $\pm$ SD) microhabitat relative humidity ( $61.53 \pm 20.37\%$ ) was significantly higher than the mean ( $\pm$ SD) macrohabitat relative humidity ( $49.86 \pm 21.53\%$ ;  $S = -10,157$ ,  $p < 0.001$ ). The distance individual toads were observed from CWD was significantly greater in the unburned locations (mean  $\pm$  SD =  $119.50 \pm 109.64$  cm) than in the burned locations (mean  $\pm$  SD =  $86.05 \pm 104.81$  cm;  $\chi^2_1 = 9.7055$ ,  $p = 0.002$ ). The types of structures (e.g., leaf form, preexisting cavity) used by toads for diurnal refugia were significantly different in burned and unburned location plots ( $\chi^2_7 = 69.6829$ ,  $p < 0.001$ ) with toads located in unburned areas typically using burnable structures (e.g., leaves) and toads located in burned areas typically using preexisting cavities and other semi-permanent features (e.g., logs; Table 2).

Discriminant analysis including all retained habitat variables revealed a significant difference between the location and random plots (Wilk's lambda = 0.8955,  $F_{46, 616} = 1.5619$ ,  $p = 0.012$ ) suggesting habitat selection, with 35.9% ( $n = 238$  of 663) misclassification of data points and 10.4% of the total canonical variation explained by group differences [canonical correlation coefficient ( $R_c$ ) = 0.3232]. Forward stepwise DA revealed a significant difference between the location and random plots (Wilk's lambda = 0.9852,  $F_{1, 661} = 9.9414$ ,  $p = 0.002$ ) when only one variable, percent of plot ground cover comprised of CWD decay class 4, was considered, however the misclassification rate was minimized to 34.4% ( $n = 228$  of 663) when 24 variables, percent of plot ground cover comprised of CWD decay classes 4 and 3, tree trunk/root bole, stick, other, deciduous leaf, lichen, moss, bark, fern, and trail, microslope, light, soil moisture, and number of maple (*Acer* spp.), beech (*Fagus* spp.), oak, sumac (*Rhus* spp.), Carolina silverbell (*Halesia carolina*), dead, flowering dogwood (*Cornus florida*), pine, hemlock (*Tsuga caroliniana*), and birch (*Betula* spp.) trees, were included in the analysis (Wilk's



**Fig. 2.** Movements of American toads (*Anaxyrus americanus*) in the Green River Game Land, Polk County, North Carolina, USA. (a) Illustrates movements from capture location to the breeding pond complex. (b) Illustrates movements from the breeding pond complex to the summer habitat. Breeding ponds are indicated by dashed-line polygons.

**Table 1**  
Capture date, last date confirmed alive, date of final location attempt, status at final location, total distance traveled, and home range of American toads (*Anaxyrus americanus*) radio-tracked in the Green River Game Land, Polk County, North Carolina, USA. Total distance traveled was calculated as the sum of distances among locations recorded for each individual.

Toad ID	Date of initial capture	Last date confirmed alive	Date of final location attempt	Status	Total distance traveled (m)	Home range (m <sup>2</sup> )
BF1	1/27/2012	3/20/2012	3/27/2012	Transmitter apparatus slipped off	760	–
BF2	1/27/2012	2/28/2012	3/27/2012	Dead; Predation by snapping turtle ( <i>Chelydra serpentina</i> )	593	–
BF3	4/6/2012	5/21/2012	5/21/2012	Alive; Released due to laceration	79	–
BM1	1/27/2012	2/4/2012	3/7/2012	Transmitter found in pipe; evidence of predation	107	–
BM2	1/27/2012	1/31/2012	3/7/2012	Transmitter apparatus slipped off	7	–
BM3	1/27/2012	1/31/2012	3/7/2012	Transmitter apparatus slipped off	24	–
BM4 <sup>a</sup>	1/27/2012	5/10/2012	5/10/2012	Alive; Released due to laceration	1614	72,422
BM5	1/27/2012	5/16/2012	5/16/2012	Alive; Released due to laceration	1441	47,206
BM6	1/27/2012	2/5/2012	3/7/2012	Transmitter apparatus slipped off	341	–
BM7 <sup>a</sup>	1/27/2012	5/30/2012	5/30/2012	Alive; Released due to abrasion	309	7320
BM8	4/6/2012	5/16/2012	5/21/2012	Dead; Predation by hognose snake ( <i>Heterodon platirhinos</i> )	50	–
BM9	4/6/2012	5/16/2012	5/16/2012	Alive; Released due to laceration	168	–
CF1	1/27/2012	4/2/2012	4/2/2012	Dead; Predation by garter snake ( <i>Thamnophis sirtalis</i> )	1436	115,421
CF2	1/27/2012	5/30/2012	5/30/2012	Alive; Released due to laceration	2082	212,525
CF3	2/5/2012	5/30/2012	5/30/2012	Alive; Released due to laceration	1722	76,532
CM1	1/27/2012	1/28/2012	3/1/2012	Dead; Predation by mammal	369	–
CM2	2/2/2012	3/19/2012	5/30/2012	Transmitter offline	610	–
MBF1 <sup>a</sup>	1/27/2012	2/4/2012	2/14/2012	Transmitter apparatus slipped off due to prescribed fire	69	–
MBF2 <sup>a</sup>	2/5/2012	3/5/2012	3/12/2012	Dead; Unknown cause	293	–
MBF3	2/21/2012	2/27/2012	3/13/2012	Transmitter apparatus slipped off or toad died in water	1066	–
MBF4	2/23/2012	2/27/2012	3/13/2012	Transmitter apparatus slipped off	1056	–
MF1	1/27/2012	3/2/2012	3/7/2012	Transmitter apparatus slipped off	681	–
MF2	2/5/2012	2/20/2012	3/6/2012	Transmitter apparatus slipped off in stream	135	–
MM1	1/27/2012	3/20/2012	3/27/2012	Dead; Predation by avian	718	–
MM2	1/27/2012	5/30/2012	5/30/2012	Alive; Released due to laceration	1383	56,565
MM3	1/27/2012	2/24/2012	3/7/2012	Transmitter apparatus slipped off	710	–

<sup>a</sup> Denotes individuals located in areas subjected to prescribed burn during the burn event.



**Fig. 3.** An American toad (*Anaxyrus americanus*) that remained in the Green River Game Land, Polk County, North Carolina, USA during a prescribed burn. The toad survived the burn by occupying a shallow (<2 cm) excavated earthen cavity but the transmitter (indicated by arrow) was destroyed by the fire.

lambda = 0.9008,  $F_{24, 638} = 2.9283$ ,  $p < 0.001$ ). Univariate analyses revealed that the only statistically significant differences between the location and random plots were for the variables light ( $\text{mean}_{\text{location}} \pm \text{SD} = 13432.3 \pm 20700.1$  lux,  $\text{mean}_{\text{random}} \pm \text{SD} = 16840.8 \pm 22873.8$  lux,  $\chi^2_1 = 8.3995$ ,  $p = 0.004$ ), soil moisture ( $\text{mean}_{\text{location}} \pm \text{SD} = 13.16 \pm 7.90\%$ ,  $\text{mean}_{\text{random}} \pm \text{SD} = 14.16 \pm 8.05\%$ ,  $\chi^2_1 = 4.4541$ ,  $p = 0.035$ ), and percent of plot ground cover comprised of CWD decay class 4 ( $\text{mean}_{\text{location}} \pm \text{SD} = 0.86 \pm 1.48$ ,  $\text{mean}_{\text{random}} \pm \text{SD} = 0.52 \pm 1.19$ ,  $\chi^2_1 = 9.3077$ ,  $p = 0.002$ ), tree trunk/root bole ( $\text{mean}_{\text{location}} \pm \text{SD} = 1.13 \pm 1.59$ ,  $\text{mean}_{\text{random}} \pm \text{SD} = 0.85 \pm 1.34$ ,  $\chi^2_1 = 4.0226$ ,  $p = 0.045$ ), stick ( $\text{mean}_{\text{location}} \pm \text{SD} = 2.81 \pm 0.92$ ,  $\text{mean}_{\text{random}} \pm \text{SD} = 2.65 \pm 0.85$ ,  $\chi^2_1 = 3.8695$ ,  $p = 0.049$ ), and other ( $\text{mean}_{\text{location}} \pm \text{SD} = 0.04 \pm 0.30$ ,  $\text{mean}_{\text{random}} \pm \text{SD} = 0.15 \pm 0.63$ ,  $\chi^2_1 = 5.0061$ ,  $p = 0.025$ ). Multiple DA including all retained habitat variables revealed a significant difference among location plots, 2 m random plots, and 20 m random plots (Wilk's lambda = 0.7898,  $F_{92, 1230} = 1.6747$ ,  $p < 0.001$ ), with 48.9% ( $n = 324$  of 663) misclassification of data points. The first canonical function explained 72.2% of the total differentiation among plots (Eigenvalue = 0.1830,  $R_c = 0.3933$ ) and the second canonical function explained the remaining 27.8% of the total differentiation

(Eigenvalue = 0.0704,  $R_c = 0.2564$ ). Forward stepwise multiple DA revealed a significant difference among plots (Wilk's lambda = 0.9769,  $F_{2, 660} = 1.6747$ ,  $p < 0.001$ ) when only one variable, percent of plot ground cover comprised of CWD decay class 4, was considered. However the misclassification rate was minimized to 48.6% ( $n = 322$  of 663) when all but four variables, macroslope, canopy openness, and number of magnolia and hemlock trees, were included in the analysis (Wilk's lambda = 0.7951,  $F_{84, 1238} = 1.7805$ ,  $p < 0.001$ ). Univariate analyses revealed that the only statistically significant differences among the location plots, 2 m random plots, and 20 m random plots were for the variables light ( $\text{mean}_{\text{location}} \pm \text{SD} = 13432.3 \pm 20700.1$  lux,  $\text{mean}_{2\text{m}} \pm \text{SD} = 15954.2 \pm 22207.5$  lux,  $\text{mean}_{20\text{m}} \pm \text{SD} = 17735.4 \pm 23544.1$  lux,  $\chi^2_2 = 8.7655$ ,  $p = 0.012$ ) and percent of plot ground cover comprised of CWD decay class 4 ( $\text{mean}_{\text{location}} \pm \text{SD} = 0.86 \pm 1.48$ ,  $\text{mean}_{2\text{m}} \pm \text{SD} = 0.67 \pm 1.33$ ,  $\text{mean}_{20\text{m}} \pm \text{SD} = 0.37 \pm 1.02$ ,  $\chi^2_2 = 14.5177$ ,  $p < 0.001$ ), CWD decay class 3 ( $\text{mean}_{\text{location}} \pm \text{SD} = 0.57 \pm 1.26$ ,  $\text{mean}_{2\text{m}} \pm \text{SD} = 0.50 \pm 1.19$ ,  $\text{mean}_{20\text{m}} \pm \text{SD} = 0.28 \pm 0.87$ ,  $\chi^2_2 = 6.9076$ ,  $p < 0.032$ ), stick ( $\text{mean}_{\text{location}} \pm \text{SD} = 2.81 \pm 0.92$ ,  $\text{mean}_{2\text{m}} \pm \text{SD} = 2.77 \pm 0.87$ ,  $\text{mean}_{20\text{m}} \pm \text{SD} = 2.53 \pm 0.82$ ,  $\chi^2_2 = 13.8240$ ,  $p = 0.001$ ), and other ( $\text{mean}_{\text{location}} \pm \text{SD} = 0.04 \pm 0.30$ ,  $\text{mean}_{2\text{m}} \pm \text{SD} = 0.10 \pm 0.52$ ,  $\text{mean}_{20\text{m}} \pm \text{SD} = 0.20 \pm 0.72$ ,  $\chi^2_2 = 5.0061$ ,  $p = 0.025$ ). Post-hoc analyses revealed that light was significantly lower in location plots compared to either 2 m or 20 m random plots ( $z_{\text{location:2m}} = -2.2469$ ,  $p_{\text{location:2m}} = 0.025$ ;  $z_{\text{location:20m}} = -2.7664$ ,  $p_{\text{location:20m}} = 0.006$ ) which were not significantly different from each other ( $z_{2\text{m}:20\text{m}} = -0.6456$ ,  $p_{2\text{m}:20\text{m}} = 0.518$ ). The 20 m plots had significantly lower amounts of CWD decay class 3 ( $z_{20\text{m}:location} = 2.5511$ ,  $p_{20\text{m}:location} = 0.011$ ;  $z_{20\text{m}:2\text{m}} = 2.0700$ ,  $p_{20\text{m}:2\text{m}} = 0.039$ ;  $z_{\text{location:2m}} = 0.5099$ ,  $p_{\text{location:2m}} = 0.610$ ) and 4 ( $z_{20\text{m}:location} = 3.8059$ ,  $p_{20\text{m}:location} < 0.001$ ;  $z_{20\text{m}:2\text{m}} = 2.465$ ,  $p_{20\text{m}:2\text{m}} = 0.014$ ;  $z_{\text{location:2m}} = 1.4213$ ,  $p_{\text{location:2m}} = 0.155$ ) and sticks ( $z_{20\text{m}:location} = 3.2271$ ,  $p_{20\text{m}:location} = 0.001$ ;  $z_{20\text{m}:2\text{m}} = 3.1989$ ,  $p_{20\text{m}:2\text{m}} = 0.001$ ;  $z_{\text{location:2m}} = 0.1598$ ,  $p_{\text{location:2m}} = 0.873$ ) than location or 2 m random plots which were not significantly different from each other.

Discriminant analysis revealed a significant difference between the burned and unburned location plots when all variables including %char were included in the analyses (Wilk's lambda = 0.0992,  $F_{48, 174} = 32.9214$ ,  $p < 0.001$ ), with 1.3% ( $n = 3$  of 222) misclassification of data points and 90.1% of the total canonical variation explained by group differences ( $R_c = 0.9491$ ). Forward stepwise DA revealed a significant difference between the burned and unburned location plots (Wilk's lambda = 0.2713,  $F_{1, 221} = 593.6863$ ,  $p < 0.001$ ) when only one variable, %char, was considered, with 5.8% misclassification rate ( $n = 13$  of 222) and 72.9% of the total canonical variation explained by group differences ( $R_c = 0.8537$ ). When %char was excluded from the DA, the burned and unburned location plots remained significantly different (Wilk's lambda = 0.1668,  $F_{47, 175} = 18.5928$ ,  $p < 0.001$ ), with 2.7% ( $n = 6$  of 222)

**Table 2**

Microhabitats used diurnally by American toads (*Anaxyrus americanus*) in the Green River Game Land, Polk County, North Carolina, USA.

Form type	Unburned locations		Burned locations	
	N	%	N	%
Excavated cavity	49	33.8	21	24.4
Preexisting cavity	2	1.4	27	31.4
Excavated depression	3	2.1	3	3.5
Preexisting depression	3	2.1	0	0
Burnable structure (e.g., leaf form)	47	32.4	4	4.6
In/under log	7	4.8	12	14.0
In rock pile	0	0	2	2.3
In water	4	2.8	0	0
In open	30	20.7	17	19.8

misclassification of data points and 83.3% of the total canonical variation explained by group differences ( $R_c = 0.9128$ ). Forward stepwise DA revealed a significant difference (Wilk's lambda = 0.4243,  $F_{1, 221} = 299.8741$ ,  $p < 0.001$ ) when only one variable, percent of plot ground cover comprised of deciduous leaf litter, was considered, with 12.6% misclassification rate ( $n = 28$  of 222) and 57.6% of the total canonical variation explained by group differences ( $R_c = 0.7588$ ). However, misclassification rate was minimized to 1.8% when 30 variables, percent of plot ground cover comprised of deciduous leaf, leaf fragments, saturated leaf, moss, lichen, shrub, CWD decay classes 1 and 3, bark, soil, gravel, and other, number of dead, hickory, yellow poplar, silverbell, magnolia (*Magnolia* spp.), birch, sourwood, pine, dogwood, rhododendron, maple, sumac, mountain laurel, and oak trees, microslope, soil moisture, canopy openness, and light, were included in the analysis (Wilk's lambda = 0.1829,  $F_{30, 192} = 29.3360$ ,  $p < 0.001$ ,  $R_c = 0.9040$ ). Univariate analyses revealed the macroslope, microslope, air temperature, canopy openness, percent of plot ground cover comprised of leaf fragment, tree trunk/root, bare rock, gravel, CWD decay class 4, soil, herb, and charred material, and number of oak, yellow poplar, and dead trees were significantly greater in the burned than the unburned location plots (Table 3). Relative humidity, soil moisture, percent of plot ground cover comprised of deciduous leaf, saturated leaf, lichen, and pine needles, and number of all species of trees pooled, mountain laurel, pine, rhododendron, silverbell, and magnolia were significantly greater in the unburned than the burned plots (Table 3).

Multiple DA revealed a significant difference in toad habitat among treatments when all variables including %char were included in the analyses (Wilk's lambda = 0.0247,  $F_{188, 689.01} = 5.6009$ ,  $p < 0.001$ ), with 14.8% ( $n = 33$  of 222) misclassification of data points. The first canonical function explained 69.3% of the total differentiation among treatments (Eigenvalue = 5.8001,  $R_c = 0.9235$ ), the second canonical function explained an additional

14.0% of the total differentiation (Eigenvalue = 1.175,  $R_c = 0.7350$ ), and the third canonical function explained 12.8% of the total differentiation (Eigenvalue = 1.0719,  $R_c = 0.7193$ ), while the fourth canonical function explained only 3.8% of the total differentiation (Eigenvalue = 0.3208,  $R_c = 0.4929$ ). Forward stepwise multiple DA revealed a significant difference among treatments (Wilk's lambda = 0.3131,  $F_{4, 218} = 119.5716$ ,  $p < 0.001$ ) when only one variable, %char, was considered, with 64.13% misclassification rate ( $n = 143$  of 222) and 68.7% of the total canonical variation explained by group differences ( $R_c = 0.8288$ ), but the misclassification rate was minimized to 13.5% ( $n = 30$  of 222) when all but one variable, percent of plot ground cover comprised of bark, were included in the analysis (Wilk's lambda = 0.0248,  $F_{184, 692.92} = 5.7469$ ,  $p < 0.001$ ). When %char was excluded from the multiple DA, the treatments remained significantly different (Wilk's lambda = 0.0395,  $F_{184, 692.92} = 4.6993$ ,  $p < 0.001$ ), with 16.6% ( $n = 37$  of 222) misclassification of data points. The first, second, third, and fourth canonical functions explained 57.5% (Eigenvalue = 3.3816,  $R_c = 0.8785$ ), 18.9% (Eigenvalue = 1.1142,  $R_c = 0.7260$ ), 18.2% (Eigenvalue = 1.0700,  $R_c = 0.7190$ ), and 5.4% (Eigenvalue = 0.3201,  $R_c = 0.4924$ ) of the total differentiation, respectively. Forward stepwise DA revealed a significant difference (Wilk's lambda = 0.5708,  $F_{4, 218} = 40.9861$ ,  $p < 0.001$ ) when only one variable, percent of plot ground cover comprised of deciduous leaf, was considered, with 58.3% misclassification rate ( $n = 130$  of 222) and 42.9% of the total canonical variation explained by group differences ( $R_c = 0.6552$ ). However, misclassification rate was minimized to 15.3% ( $n = 34$  of 222) when all but two variables, light, percent of plot ground cover comprised of bark, were included in the analysis (Wilk's lambda = 0.0401,  $F_{176, 700.71} = 4.9361$ ,  $p < 0.001$ ).

The individual located the greatest number of times during the study period accounted for 10.8% of the total number of locations, thus no individual had the opportunity to unduly bias the results of the analyses.

**Table 3**  
Habitat variables that exhibited significant differences in the burned and unburned location plots of American toads (*Anaxyrus americanus*) in the Green River Game Land, Polk County, North Carolina, USA.

Variable	Unburned locations		Burned locations		$\chi^2$	DF	P
	N	Mean $\pm$ SD	N	Mean $\pm$ SD			
Macroslope (°)	140	22.6 $\pm$ 13.8	83	28.5 $\pm$ 8.2	8.76	1	0.003
Microslope (°)	140	16.6 $\pm$ 13.1	83	24.7 $\pm$ 15.7	14.38	1	<0.001
% Relative humidity	140	53.0 $\pm$ 21.4	83	43.7 $\pm$ 19.4	9.25	1	0.002
Air temperature (°C)	140	17.9 $\pm$ 6.1	83	22.7 $\pm$ 7.0	26.46	1	<0.001
Soil moisture (vwc)	140	15.0 $\pm$ 8.4	83	10.0 $\pm$ 5.9	33.60	1	<0.001
Canopy openness (%)	140	12.4 $\pm$ 23.8	83	35.0 $\pm$ 27.5	38.98	1	<0.001
% Leaf fragment	140	0.0 $\pm$ 0.0	83	0.9 $\pm$ 1.7	38.84	1	<0.001
% Deciduous leaf	140	5.5 $\pm$ 0.9	83	2.5 $\pm$ 1.7	126.27	1	<0.001
% Saturated leaf	140	0.7 $\pm$ 1.6	83	0.2 $\pm$ 0.9	4.95	1	0.026
% Tree trunk or root	140	0.9 $\pm$ 1.4	83	1.5 $\pm$ 1.8	8.99	1	0.003
% Lichen	140	0.8 $\pm$ 1.0	83	0.2 $\pm$ 0.6	26.13	1	<0.001
% Bare rock	140	0.3 $\pm$ 0.9	83	0.6 $\pm$ 1.1	7.44	1	0.006
% Gravel	140	0.1 $\pm$ 0.4	83	1.4 $\pm$ 1.5	71.00	1	<0.001
% Coarse woody debris decay class 4	140	0.5 $\pm$ 1.2	83	1.4 $\pm$ 1.7	15.63	1	<0.001
% Soil	140	1.1 $\pm$ 1.4	83	3.7 $\pm$ 1.7	89.48	1	<0.001
% Herb	140	1.0 $\pm$ 1.2	83	1.5 $\pm$ 1.3	8.11	1	0.004
% Char	140	0.2 $\pm$ 0.7	83	4.2 $\pm$ 1.7	162.99	1	<0.001
% Needles	140	1.1 $\pm$ 1.5	83	0.1 $\pm$ 0.6	27.18	1	<0.001
# Trees (all species)	140	11.1 $\pm$ 5.2	83	9.2 $\pm$ 4.5	10.61	1	0.001
# Mountain laurel	140	0.1 $\pm$ 0.5	83	0.0 $\pm$ 0.0	6.83	1	0.009
# Oak	140	6.1 $\pm$ 4.2	83	3.4 $\pm$ 2.3	23.39	1	<0.001
# Yellow poplar	140	1.2 $\pm$ 2.4	83	1.7 $\pm$ 2.1	8.22	1	0.004
# Pine	140	0.7 $\pm$ 1.2	83	0.0 $\pm$ 0.3	31.36	1	<0.001
# Rhododendron	140	0.1 $\pm$ 0.4	83	0.0 $\pm$ 0.1	3.95	1	0.047
# Silverbell	140	0.1 $\pm$ 0.3	83	0.0 $\pm$ 0.0	7.49	1	0.006
# Magnolia	140	0.1 $\pm$ 0.3	83	0.0 $\pm$ 0.0	6.83	1	0.009
# Dead trees	140	0.7 $\pm$ 1.1	83	1.7 $\pm$ 2.1	18.19	1	<0.001

## 4. Discussion

### 4.1. Movement

Prescribed fire appears to have little effect on the movements of adult *A. americanus* at this study site as toads did not avoid recently burned areas in their movements to and from the breeding pond complex or within their summer habitat. The toads that we tracked both pre- and post-breeding exhibited strong site fidelity and returned to their initial capture treatments. Due to transmitter loss and mortality, we were unable to evaluate post-breeding movements of toads initially captured in MB that underwent a breeding migration. Although the sample size of individuals in our study that retained transmitters both pre- and post-breeding is small ( $n_{\text{burned treatments}} = 3$ ,  $n_{\text{unburned treatments}} = 4$ ), these results suggest that adult *A. americanus* exhibit terrestrial site fidelity. Furthermore, we captured two additional adult females in MB approximately one week after the prescribed burn (pre-breeding), and three additional individuals (2 males and 1 female) in B the same week that previously tagged toads returned to their original capture plots (post-breeding), indicating that adult *A. americanus* do not avoid burned areas. Philopatry or site fidelity in amphibians is common in relation to breeding ponds (Semlitsch, 2008) and some evidence suggests terrestrial site fidelity for a variety of species (Dole and Durant, 1974; Ringler et al., 2009; Heemeyer et al., 2012; Humphries and Sisson, 2012), though terrestrial site fidelity appears less important for some species depending on the season, habitat quality, and resource availability (Wells, 2007). In our study, because we captured toads immediately after leaving hibernacula, we were able to demonstrate that adult *A. americanus* returned to the same areas post-breeding. The exhibited terrestrial site fidelity regardless of whether an area was burned may indicate that the use or selection of a habitat by adult *A. americanus* may be more strongly influenced by site fidelity than changes in macro and microhabitat as a result of fire. However, the same patterns may not hold for naive juveniles dispersing from the natal pond as Rothermel and Semlitsch (2002) found that dispersing juvenile *A. americanus* avoided open canopy in favor of more forested habitat.

The mean distance traveled by toads migrating from the breeding pond in our study is greater than distances reported in other studies and locations. Furthermore, our calculated mean distance traveled is likely an underestimate as toads were not located daily and our analyses did not account for the high disparity in topography between capture sites and the breeding pond as we calculated straight-line, two-dimensional distances instead of three-dimensional distances that account for elevation. A review by Lemckert (2004) reported the range of post-breeding migrations of *A. americanus* to be 9–594 m from breeding sites. In Maryland, Forester (2006) reported a range of 246–1015 m (mean  $\pm$  SD = 686  $\pm$  245 m). The longer distance traveled post-breeding in our study may reflect the distribution and availability of breeding habitat. All toads that completed a breeding migration in our study traveled to the same human-constructed pond complex located on adjacent private land, a trajectory that required the toads initially captured in C, M, and MB to cross a fast-flowing creek twice on the roundtrip. This pond complex was the only available breeding habitat within a 1000 m buffer of all of the location points in this study identifiable using available digital resources (e.g., aerial photographs, National Wetlands Inventory dataset). Additionally, we did not find alternative breeding habitats during the extensive hours in the field spent backcountry hiking to locate individual toads. Our results indicate that the human-constructed pond

complex may provide critical breeding habitat for toads in our study area. The location of the breeding pond complex on private land and the exclusive use of the breeding pond complex by tracked individuals highlight that organisms do not often conform to jurisdictional boundaries but are dictated by the availability and distribution of critical resources. We recommend that managers take into account the trans-boundary nature of wildlife movements associated with the acquisition of resources and ensure the availability, distribution, and accessibility of critical resources when designing conservation areas and management plans.

### 4.2. Mortality

Many authors consider fire to be an unlikely cause of direct mortality to reptiles and amphibians in fire-adapted ecosystems due to behavioral responses to avoid fire (Means and Campbell, 1981; Russell et al., 1999; Pilliod et al., 2003). Our results support this hypothesis, with visual confirmation of three of the four toads that remained in the burn treatment surviving through the burn with no visible injuries, though their transmitters were destroyed by the fire. We suspect that the fourth toad also survived the fire as we found no evidence of mortality or predation (e.g., carcass; bite marks on the transmitter) and the presence of unburned cached seeds and nuts within the same log that the destroyed transmitter was found indicates that the fire did not burn hot enough in this location to incinerate the remains of the toad. However, previous fuel reduction treatments had reduced the fuel loads in the site resulting in burns of lower intensity in 2012 and 2006 with mean maximum temperatures  $\leq 222$  °C (Matthews et al., 2010). In contrast, the initial burn in the site in 2003 resulted in maximum temperatures  $> 800$  °C in the MB plots (Greenberg and Waldrop, 2008), temperatures that may overpower any behavioral adaptations of herpetofauna to avoid direct mortality from fire.

Adult toads in this study appear to be little affected by prescribed burning, but this may not hold true for other amphibians, as demonstrated by Humphries and Sisson (2012) who observed direct mortality of a migrating *L. capito* as a result of prescribed fire. Toads, being among the most terrestrial of amphibians, have some key adaptations that leave them less vulnerable to desiccation than other amphibians. Anurans have a highly vascularized “pelvic patch” on the ventral surface of the thighs which they can press to a substrate to absorb water and they can store large amounts of water in their bladders (Stille, 1958; Brekke et al., 1991; Zug et al., 2001). The granular skin of toads is more highly vascularized than the relatively smooth skin of other amphibians, resulting in a higher rate of water absorption (Christensen, 1974; Zug et al., 2001). In addition to their thicker, more durable skin, toads have the ability to burrow to reduce evaporative water loss (Wells, 2007). In this study, we observed *A. americanus* excavate a burrow in sandy loam soil and completely disappear below the surface in less than two minutes (J.J. Tavano, pers. obs.).

Timing of the prescribed burn may have furthered the toads' chances for survival. The prescribed burn in our study area was conducted on 13 February 2012 when 7 of the 11 toads we had radio-tagged in B and MB had moved outside of the treatment areas (but had not yet reached the breeding pond complex) on the breeding migration. The timing of the fire also likely limited the chances for direct mortality of other amphibian species as *A. americanus* are among the first amphibians to emerge from their hibernacula in the spring in our study area. We did not observe any other amphibians prior to or immediately following the fire suggesting that other amphibians had yet to emerge. However, the effects of fires occurring later in the spring when more species are active warrant further investigation.

### 4.3. Habitat

Our results suggest that the availability of cover objects or structures is important for toads in general, and the availability of durable cover objects (e.g., logs) or preexisting refugia (e.g., root holes) is important for toads in areas subjected to prescribed fire. Comparison of microhabitat temperature and relative humidity readings with that of macrohabitat temperature and relative humidity revealed that toads' microhabitats were maintained at higher temperatures and relative humidity than the surrounding air. This pattern was achieved by the toads creating or using preexisting microstructures (e.g., earthen cavities, leaf structures, logs; Table 2), suggesting the importance of cover objects or structures for toads. Additionally, the availability of CWD decay class 4 was the most powerful discriminator between toad habitat (i.e., location plots) and available habitat (i.e., random plots) and this trend became more apparent at the 20 m scale. Toads in the burned location plots where alternative microstructure material (e.g., leaf litter) was consumed by the fire maintained shorter distances from CWD than toads in the unburned location plots where alternative microstructure materials were more abundant. In analyses that excluded char due to its short-term nature, percent of plot ground cover comprised of deciduous leaves, a variable that was significantly higher in the unburned than the burned location plots, was the single most powerful discriminator between burned and unburned location plots, yet the lack of deciduous leaf ground cover in the burned areas did not preclude the use of the burned areas by toads. Toads in our study area typically used available deciduous leaves as refugia in unburned location plots, including in B and MB prior to the burn. Reduction of such combustible material following prescribed burns enhanced the importance of other cover objects (e.g., logs) or cavities (e.g., root holes) that were not consumed by the prescribed fire as toads were typically found using such structures in burned areas. Although deciduous leaf litter will once again characterize the forest floor following autumnal leaf drop, availability and use of alternative cover objects may enhance the likelihood of survival or provide a physiological benefit for toads until then. Alternative cover objects may also provide lasting resources if fire severity results in reduction of microstructures provided by partially decomposed leaves and the upper O-horizon. Some authors suggest that the indirect effects of fire, such as reduction in the duff layer, reduction in CWD, and increased canopy openings, likely have a greater effect on amphibians than direct mortality (Means and Campbell, 1981; Russell et al., 1999; Matthews et al., 2010). Our results suggest that the availability of semi-permanent cover objects (e.g., logs) or preexisting refugia (e.g., root holes) is important for toad populations in areas subjected to prescribed fire.

### 5. Conclusions

Prescribed fire, as implemented in this study, did not appear to inhibit migratory movements of adult *A. americanus* nor did it cause direct mortality of radio-tagged *A. americanus*. Fire reduced the diversity and availability of cover objects used for refugia. However, the availability of CWD and preexisting structures in burned plots allowed toads to inhabit the burned areas, suggesting the importance of maintaining structural complexity, including CWD and preexisting structures, on the forest floor for *A. americanus*. Site fidelity and the distribution of critical resources (e.g., breeding habitat) appeared to strongly influence the movement patterns of adult *A. americanus* in this study, a pattern that is consistent with most amphibian movement studies. Amphibian conservation depends on maintaining the availability of and connectivity among critical terrestrial and aquatic resources

(Semlitsch, 2000). Forest managers concerned with anuran populations may need to consider local phenomena (e.g., regular prescribed fire) in the context of seasonal breeding events and landscape-level distribution and configuration of critical habitat resources. When critical resources are not available on public lands, trans-boundary movements and migrations should be expected. As such, we concur with others (e.g., Marsh and Trenham, 2001; Baldwin et al., 2006) that a landscape-scale approach to managing amphibian populations is necessary given the importance and dispersion of aquatic features. Landscape integrity (e.g., lack of barriers to movement) may be more important in maintaining toad populations than regular, managed prescribed fire.

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