Herpetological Conservation and Biology 13(3):551–557.
Submitted: 10 May 2017; Accepted: 27 July 2017; Published: 16 December 2018.

Prescribed Fire Affects Diurnal Vertebrate Use of Gopher Tortoise (*Gopherus polyphemus*) Burrows in a Longleaf Pine (*Pinus palustris*) Forest

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***Abstract.*—Frequent fires are essential for maintaining the Longleaf Pine (*Pinus palustris*) ecosystem and are beneficial to the Gopher Tortoise (*Gopherus polyphemus*), a Longleaf Pine specialist that excavates burrows used by many commensal species. Presumably, burrows offer important refugia to commensals both during and after fires, but no published studies have confirmed this. Therefore, the objective of this study was to examine how prescribed fire influences diurnal vertebrate use of Gopher Tortoise burrows. We deployed trail cameras in 46 burrows before a prescribed fire and monitored vertebrate activity until we removed cameras 11 d after the fire. We compared vertebrate burrow use before and during the prescribed fire and also used data from a previous study to compare vertebrate use of burrows on an unburned site to that of our recently burned site. We observed one vertebrate commensal at 43 monitored burrows (0.02 vertebrates per camera) on the day before the burn and nine vertebrates at 41 burrows (eight species, 0.22 vertebrates per camera) during the burn. In addition, we observed 8.5 times more vertebrates using burrows at the recently burned site than at an unburned site (51 individuals of seven species versus six individuals of three species, respectively). Our results suggest that Gopher Tortoise burrows offer important diurnal refugia to commensals from direct (risk of mortality) and indirect (perceived risk of predation and/or injury) effects of fire. Additional studies would be beneficial on nocturnal vertebrate burrow use, longer-term trends as vegetative cover regenerates following fire, and relative importance of other refugia for vertebrates.**

Key Words.—behavioral ecology; commensal; refugia; trail camera; wildlife management

Introduction

The Longleaf Pine (*Pinus palustris*) ecosystem is one of the most diverse in North America with over 40 species of plants per square meter in the ground cover and more than 200 vertebrate species (Walker and Peet 1984; Peet and Allard 1993; Means 2006; Peet 2006). This ecosystem was once the dominant land cover across the southeastern U.S. but has declined since the 1800s from an estimated 37 million ha to approximately one million ha in 2000 (Jose et al. 2006). Among the causes for this decline are land-use change (silvicultural and urban development) and fire-suppression (Gilliam and Platt 2006; Jose et al. 2006). Frequent fires are an essential natural disturbance in the Longleaf Pine ecosystem. Fire removes pine litter and herbaceous vegetation, exposing the mineral soil required for Longleaf Pine seedling establishment and development (Walker and Peet 1984; Peet and Allard 1993). Frequent fire also promotes biodiversity through creating an open-canopy by reducing hardwoods and promoting growth of herbaceous ground cover vegetation (Peet and Allard 1993; Kirkman et al. 2001). Today, remaining tracts of Longleaf Pine are primarily managed using prescribed fire.

A species frequently associated with the Longleaf Pine ecosystem is the Gopher Tortoise (*Gopherus polyphemus*). Gopher Tortoises require an open canopy with herbaceous ground cover on loose, well-drained sandy soils, which allow tortoises to burrow, forage, nest, and thermoregulate (Diemer 1986; Ashton et al. 2008). However, Gopher Tortoise populations have declined due to loss of Longleaf Pine forests, fire-suppression, and historically, from human predation (Auffenberg and Franz 1982; Diemer 1986; Ashton et al. 2008). Gopher Tortoise burrows promote faunal diversity by providing shelter, mating habitat, and foraging opportunities for other species (Eisenberg 1983; Lips 1991; Birkhead and Tuberville 2008; Catano and Stout 2015). Specifically, over 300 species of invertebrates and 60 species of vertebrates have been observed using Gopher Tortoise burrows (Jackson and Milstrey 1989; Lips 1991), which average 4.5 m in length (Hansen 1964) and range from 1–3 m deep (Hallinan 1923; Young and Goff 1939).

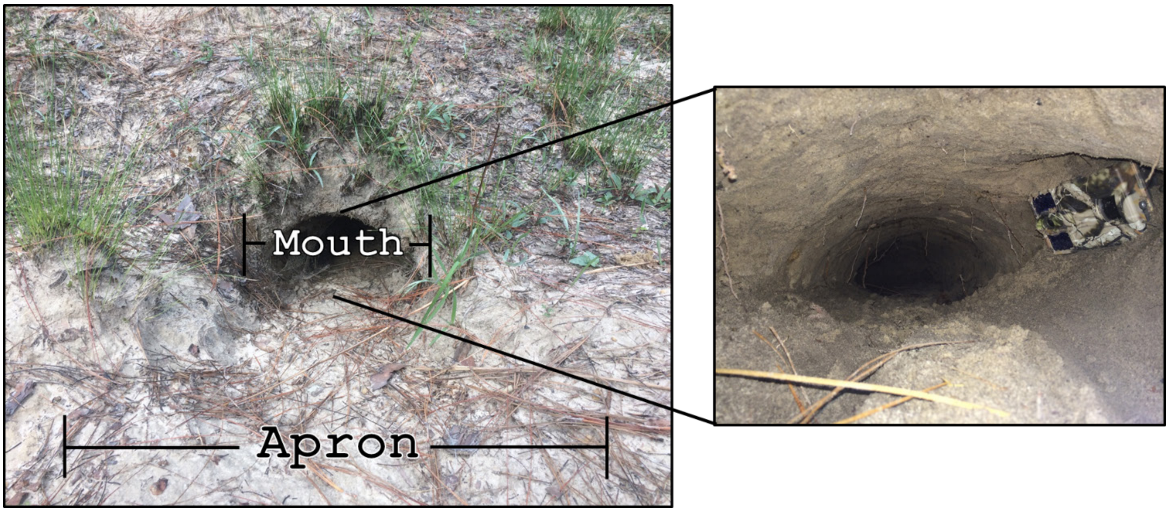

Figure 1. Photograph of the burrow entrance (left) of a Gopher Tortoise (*Gopherus polyphemus*) and a trail camera mounted inside a burrow facing the mouth of the burrow (right) to capture animals entering and exiting. (Photographed by Daniel D. Knapp).

Consequently, a secondary, but potentially important, effect of declines in tortoise populations is the decline in shelter provided by their burrows.

Gopher Tortoise burrows maintain a constant temperature under the most extreme conditions (Pike and Mitchell 2013) and it has been hypothesized that burrows provide an important refuge to other organisms during fires (Jackson and Milstrey 1989; Lips 1991; Russell et al. 1999). In addition, burrows might offer refugia after a fire due to the burning of the ground cover. For example, Kinlaw (1999) wrote that the lack of vegetative refugia promote the importance of underground burrows as they provide additional shelter options available for vertebrates. Nonetheless, very few studies have examined vertebrate use of tortoise burrows to escape fire, nor has increased use of burrows following a fire been reported. Therefore, the objective of this study was to examine how prescribed fire influences vertebrate use of Gopher Tortoise burrows. More specifically, we hypothesized that diurnal vertebrate use of Gopher Tortoise burrows would increase during a prescribed fire and the number of vertebrate commensals using tortoise burrows would be greater at a recently burned site than at an unburned site. To test this, we placed trail cameras in Gopher Tortoise burrows to monitor diurnal vertebrate activity before, during, and after a fire event. As our pre-burn data were limited, we compared our post-burn results to those of Dziadzio and Smith (2016) to serve as a baseline for an unburned site.

Materials and Methods

Study site.—We conducted this study at Ichauway, the 11,736-ha research site of the Joseph W. Jones Ecological Center located in Baker County, Georgia, USA. Approximately 5,700 ha of the site was in mature Longleaf Pine forest with a native ground cover understory, and Longleaf Pine forests were managed with prescribed fire on a 1–2 y interval. Gopher Tortoises and their burrows were common on upland soils on the property (Smith et al. 2006). We sampled a 139-ha research site burned on a 2-y rotation and last burned in March 2014. The site was comprised of Longleaf Pine with a Wiregrass (*Aristida stricta*) understory (78%), hardwoods (*Quercus* spp., 19.8%), wildlife food plots (1.8%), and woody shrubs (0.4%). The soil was principally composed of Troup series sand (somewhat excessively drained) and Albany series sand (somewhat poorly drained).

Data collection.—We located Gopher Tortoise burrows using data from a line transect distance sampling survey (Buckland et al. 2001) conducted in May 2016 (Jennifer Howze, unpubl. data). During the survey, we collected burrow locations using a Nomad 900B global positioning system (Trimble Navigation Ltd., Sunnyvale, California, USA) with a Hemisphere Crescent A101 Smart Antenna (Hemisphere GNSS, Scottsdale, Arizona, USA), and we measured burrow width at 50 cm inside the burrow entrance using calipers (Martin and Layne 1987). Following the survey, we randomly selected 46 adult tortoise burrows (average burrow width = 35 cm; range, 22–47 cm; McRae et al. 1981) within the study site and installed VH400HD trail cameras (UWay Technology LLC., Norcross, Georgia, USA) to record videos of vertebrates using burrows. We placed one camera per burrow approximately 50 cm within the burrow entrance. We placed cameras inside a chamber that we excavated to allow them to sit flush with the wall of the burrow so as not to impede movement of tortoises and other animals (Fig. 1). We positioned cameras facing towards the entrance of the burrow to allow for a wide field of view to detect animals entering and exiting the burrow.

We programmed cameras to capture a 15-s video when the high-sensitivity infrared sensor was triggered by movement and set the illumination to activate as an internally firing infrared to account for low light levels within the burrows. Cameras were operational 0900–1600 to ensure coverage of activity during daylight hours, when the prescribed fire took place. These settings allowed maximum opportunity to record diurnal organisms entering the burrows immediately before, during, and after the prescribed fire. We focused on activity during daylight hours only to extend battery life so we could collect data over a longer period of time. Videos were both date and time stamped, allowing us to compare animal activity in relation to time of fire.

We set cameras two days prior to the fire, on 2 May 2016, and retrieved them 15 May 2016 after the batteries had died (11 d post burn). On the day of the burn (4 May 2016), videos recorded by the cameras indicated that the fire passed monitored burrows from approximately 1116 to 1322. Wind conditions on the day of the burn included a northwest surface wind of 16–23 kph and a transport wind speed of 7 m/s (weather.gfc.state.ga.us/).

For each video, we recorded the date and time of activity and identified vertebrates to species, where possible. For each burrow, we regarded observations of the same species captured within the same day as one individual while observations over a day apart were considered unique individuals. We counted Gopher Tortoise observations as one individual per burrow unless we observed more than one tortoise at the same time.

Data analysis.—To examine whether there was an increase in diurnal vertebrate use of burrows during the fire, we compared the number of all unique vertebrate appearances (including Gopher Tortoises) per camera during the burn window (1100–1330) to the number of appearances on the day before the burn within the same time frame. Due to camera malfunctions or view obstruction, the number of active cameras varied daily. Therefore, we calculated observations in terms of Camera Captures by dividing the number of unique vertebrates captured on camera by the number of active cameras per day.

To examine diurnal vertebrate use of burrows at a burned versus unburned site, we compared our data from the burned site to a data set from a previous (2014), but similar, study at an unburned site (Dziadzio and Smith 2016). The unburned study site was also on Ichauway, approximately 7.5 km from the burned site. Both sites were burned on a 2-y rotation, with the Dziadzio and Smith (2016) site last burned in January 2013. The unburned site had similar vegetation to the burned site: Longleaf Pine with a Wiregrass understory (80.5%), hardwoods (*Quercus* spp., 18.6%), wildlife food plots (0.8%), and roads (0.1%) and similar soil characteristics: Wagram series loamy sand (somewhat excessively drained) and Albany sand (somewhat poorly drained).

In Dziadzio and Smith (2016), cameras were placed outside of burrows between 2 June and 9 October 2014 to capture vertebrate movements within and around burrows. We used only data from the Dziadzio and Smith (2016) study in which vertebrates were observed entering or exiting burrows. Because both methods consistently captured vertebrates of the same species and roughly the same size (Dziadzio and Smith 2016), we believe that detection rates likely did not vary greatly between the two studies. We used a Welch's two-sample *t*-test ($\alpha = 0.05$; R version 3.2.2.; R Core Team 2018) to compare the mean camera capture rate for the period from 0900 to 1660 for the 10-d sample in early May 2016 from our burned-site data to the mean camera capture rate for the same time frame over the 10-d sample in early June 2014 from the unburned site. We did not include tortoise observations in this analysis because they were burrow inhabitants rather than commensals, although we did enumerate tortoise observations.

Results

We had 43 cameras recording vertebrate activity from 1100–1330 on the day before the burn (3 May 2016) compared to 41 cameras over the same period during the burn (4 May 2016). The Gopher Tortoise was the most frequently observed species before (n = 8) and during the burn (n = 6). However, we also observed one non-tortoise vertebrate, a Great Crested Flycatcher (*Myiarchus crinitus*), using a burrow the day before the burn (0.02 individuals/camera) and nine non-tortoise vertebrates using the burrows during the burn (0.22 individuals/camera): one Six-lined Racerunner (*Aspidoscelis sexlineata*); one unknown lizard species; one Eastern Gartersnake (*Thamnophis sirtalis*); one Cornsnake (*Pantherophis guttatus*); two Eastern Coachwhips (*Coluber flagellum*); one Hispid Cotton Rat (S*igmodon hispidus*); one unknown mouse (*Peromyscus* sp.); and one unknown mammal species.

The total camera trapping effort differed between the burned (n = 317 camera days in 2016) and unburned (n = 301 camera days in 2014, Dziadzio and Smith 2016) site over the 10-d sampling periods; we recorded 977 and 1,226 videos at the burned and unburned site, respectively. We observed 8.5 times more non-tortoise vertebrates in the burned site (n = 51, mean = 0.16 ± [SE] 0.03 per camera day) compared to the unburned site (n = 6, mean = 0.02 ± 0.01; $t = 4.80$, df = 55, $P < 0.001$; Fig. 2, Table 1). Six-lined Racerunner (n = 34) and Eastern Coachwhip (n = 12) dominated the burned-site camera captures. We also found two Bachman's Sparrows

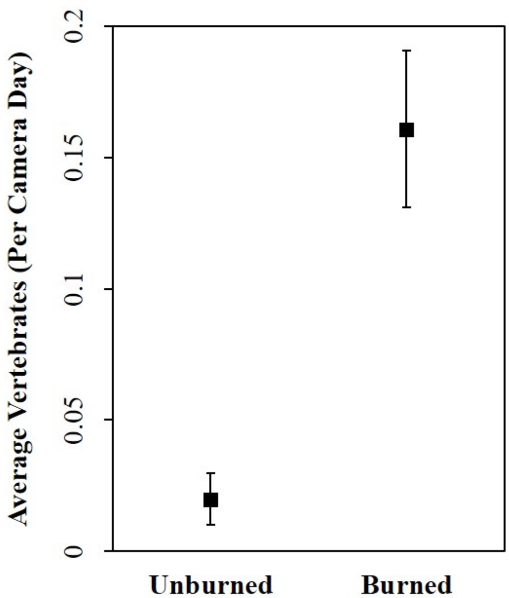

Figure 2. Mean daily observations for a 10-d sample of commensal vertebrates captured on trail cameras within Gopher Tortoise (*Gopherus polyphemus*) burrows at a burned and an unburned site at the Joseph W. Jones Ecological Research Center at Ichauway, Baker County, Georgia, USA. Observations were converted to camera days to account for unequal trap effort between burned (n = 317 camera days) and unburned sites (n = 301 camera days). Error bars are one standard error.

(*Peucaea aestivalis*), three Northern Bobwhites (*Colinus virginianus*), and one Eastern Coachwhip in the unburned site (Table 1).

Discussion

Our study provides evidence of the role of tortoise burrows in a fire-maintained system. Specifically, we report greater diurnal use of Gopher Tortoise burrows by vertebrates during and immediately after a prescribed fire. Of the commensals we observed using burrows in the burned-site, Six-lined Racerunners and Eastern Coachwhips were the most abundant. The Six-lined Racerunner is a small terrestrial lizard commonly found in Longleaf Pine habitat, which forages primarily on invertebrates (Winne 2008). We observed an increase in invertebrate activity during the burn and Six-lined Racerunners could have been attracted to increases in the availability of forage within burrows. Coachwhips are exclusively diurnal snakes that frequently use tortoise burrows, shrubs, and stumps to forage, take shelter, and thermoregulate (Jones and Whitford 1989; Dodd and Barichivich 2007; Howze and Smith 2015). The Eastern Coachwhip is a visual predator that forages primarily on lizards, small mammals, and birds (Tuberville and Gibbons 2008), and recently burned areas with little vegetation may facilitate hunting one of their primary prey, the Six-lined Racerunner (Hamilton and Pollack 1956; Howze and Smith 2015).

Table 1. Vertebrates (excluding Gopher Tortoises, *Gopherus polyphemus*) observed over a consecutive 10-d period on trail cameras within Gopher Tortoise burrows at a burned and an unburned site from the Joseph W. Jones Ecological Research Center at Ichauway, Baker County, Georgia, USA. Observations were converted to camera days (in parentheses) to account for unequal trap effort between burned (n = 317 camera days) and unburned sites (n = 301 camera days).

Species	Burned	Unburned
Bachman's Sparrow (*Peucaea aestivalis*)	0	2 (0.007)
Northern Bobwhite (*Colinus virginianus*)	0	3 (0.010)
Carolina Wren (*Thryothorus ludovicianus*)	1 (0.003)	0
Unknown bird	1 (0.003)	0
Hispid Cotton Rat (*Sigmodon hispidus*)	1 (0.003)	0
Eastern Coachwhip (*Coluber flagellum*)	12 (0.038)	1 (0.003)
Six-lined Racerunner (*Aspidoscelis sexlineata*)	34 (0.107)	0
Unknown lizard	1 (0.003)	0
Southern Toad (*Anaxyrus terrestris*)	1 (0.003)	0

We suspect that the relatively moderate numbers of commensals using burrows in our study is a reflection of the abundance of alternative refugia, such as stump holes, coarse woody debris (Russell et al. 1999), Southeastern Pocket Gopher (*Geomys pinetus*) burrows, and additional Gopher Tortoise burrows that were not monitored with a camera at our study site, which is a mature, uneven-aged forest. For example, in a 1994 study in a Longleaf Pine forest in east Texas and Louisiana, radio-telemetered Louisiana Pine Snakes (*Pituophis melanoleucus ruthveni*) sought shelter within Baird's Pocket Gopher (*Geomys breviceps*) burrows (Rudolph et al. 1998). We do not think that the presence of a tortoise in a burrow negatively influenced the occurrence of other vertebrates because commensal species and tortoises often co-occupy a burrow (Kent et al. 1997). Finally, it is possible that the relatively slow rate of spread and low fire intensity at our small, frequently burned site may have allowed many vertebrates to disperse in advance of the fire (Russell et al. 1999).

We also observed 8.5 times more vertebrates using tortoise burrows in the 10 d following the burn as compared to a 10-d period at an unburned site. While this difference could, at least in part, be a reflection of time since fire it is also possible that site- or time-specific attributes such as habitat or weather affected diurnal burrow use. The sites were proximal to one another, and had similar vegetation and soil attributes; however, we cannot rule out potential site differences (i.e., abundance, diversity) or weather effects. Data on abundance and diversity for the two sites were not available. At the unburned site during the 2014 study, the average maximum temperature was 32.4° C, average maximum humidity was 97.7%, and total rainfall was 69.8 mm over the 10-d period. Over the 10-d period during the 2016 study, the average maximum temperature was 28.7° C, average maximum humidity was 87.8%, and there was no rainfall (weather.uga.edu).

Additional research is needed to quantify the importance of tortoise burrows and other refugia during fire, particularly in areas where Gopher Tortoise densities are low. In future studies, we suggest monitoring burrow use at night because our study was restricted to diurnal use. We also suggest monitoring immediately after a burn until ground cover regenerates, which could provide further information on the short-term and long-term effects of fire on vertebrate activity. Collecting more pre-burn data would also be valuable to allow for a direct comparison between pre-burn, during-burn, and post-burn vertebrate activity. Finally, performing similar studies at additional sites where fire shelter structures (i.e., stumps, coarse woody debris; Eisenbies et al. 2009) have been removed might show a greater use of tortoise burrows by commensals.

Acknowledgments.—Work was conducted under Georgia Department of Natural Resources Scientific Collecting Permit 29-WJH-16-58. We thank Elizabeth Parsons for assistance with field work.

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