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Ecology of Upland Snake Communities in Managed Montane Longleaf Pine Habitats of Georgia

Miranda Gulsby
Kennesaw State University

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Miranda Louise Gulsby

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Kennesaw State University

1000 Chastain Road

Kennesaw, Ga 30144

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Major Advisor: Thomas McElroy, Ph. D.

Committee Members:

Joel McNeal, Ph. D.

Lisa Ganser, Ph. D.

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Ecology of Upland Snake Communities in Managed Montane Longleaf Pine Habitats of Georgia

Miranda Gulsby, Thomas McElroy, Ph.D.

Department of Ecology, Evolutionary, and Organismal Biology, Collect of Science and Mathematics, Kennesaw State University, Kennesaw, GA, 30144, USA

ABSTRACT

Longleaf pine ecosystem decline in the Southeast United States has led to intensive land management implementation with the goal to benefit both the ecosystem and at-risk species. Addressing at-risk snake populations in these longleaf pine ecosystems, for instance, requires understanding both community and species level ecology of snakes in these managed forests. Data for snakes in the montane (mountain) longleaf pine habitats remains unclear since management practice implementation. Currently, intensive restoration of montane longleaf pine habitats is taking place within two Wildlife Management Areas (WMA) in the Raccoon Creek Watershed of Northwest Georgia, Sheffield and Paulding Forest. These areas differ in both historic forest management and intensity of restoration for longleaf pine habitats. To survey these areas for snake diversity and abundance, we used drift fence trap arrays at six locations within the two WMAs, yielding a total of 85 captures representing nine species, including the five most frequently trapped species: Black racers (*Coluber constrictor*), copperheads (*Agkistrodon contortrix*), corn snakes (*Pantherophis guttatus*), Eastern hognose (*Heterodon platirhinos*), and timber rattlesnakes (*Crotalus horridus*). Northern pine snake (*Pituophis melanoleucus melanoleucus*), a taxon of concern in Georgia, was detected within both WMAs, along with evidence of recruitment of new individuals. Montane longleaf pine habitats in Sheffield WMA were found to support a significantly greater diversity of upland snake species than similar habitats in Paulding Forest. This study collected baseline data for the upland snake communities in this ecosystem and will inform restoration of this ecosystem.

KEYWORDS: snake communities, longleaf pine forests, restoration ecology, snake activity

INTRODUCTION

Longleaf pine (*Pinus palustris*) forests have experienced significant range-wide declines in the Southeastern United States due to anthropogenic activities (Frost, 1993; Ware et al., 1993). Additionally, the wildlife species that depend on these habitats have suffered similar declines, including gopher tortoises (*Gopherus polyphemus*) and eastern indigo snakes (*Drymarchon couperi*), leading to increased protections. High priority conservation efforts for this unique ecosystem and its wildlife require implementing intensive land management regimes that will benefit targeted species.

Anthropogenic disturbances, especially agriculture and urbanization detrimentally affect biodiversity in ecosystems by changing the availability of resources to organisms (Sala et al., 2000). Only 7% of United States forests are considered old-growth (100 -149 years old), and even these are still impacted indirectly by anthropogenic activities (USDA-FA, 2000). Development has had many unintended consequences on forests, either because the effects at the time were unknown or the potential effects were known and disregarded. Land development caused invasions of exotic pests, displacement of natural communities, and, in extreme cases, caused extinctions of species on local and global scales. Extinctions are growing at an exponential rate because of a variety of human-caused problems, including disease, intentional killing, pollution, habitat destruction, and deforestation (Gibbons et al., 2000). Human activities have disrupted the natural environment, directly leading to declines in species diversity and habitat loss (Cardinale et al., 2012). Subsequently, anthropogenic interventions are necessary to mitigate the negative impacts of previous disturbances. Anthropogenic ecosystem restoration activities, such as prescribed fire, help to reclaim lost ecosystem functions and benefit wildlife.

Forest management techniques in upland coastal plain habitats will often include clearcutting timber, initially resulting in negative impacts on snake species but eventually followed by recovery (Russell et al., 2002). These clearcutting practices and the effects on reptile species mimic historically intense wildfires (Greenberg et al., 1994a). Though fire and forest management practices can benefit the communities as whole, the specific species responses can vary (Greenberg et al., 1994a; McLeod and Gates, 1998). The goal of this management is to reduce hardwood encroachment in upland habitat through prescribed burning, mechanical thinning, and herbicide treatments that will maintain open, savannah-like upland habitats. The influences of these practices on snake community ecology in many different managed habitats, however, are largely unstudied compared to studies on mammals and birds (Parker and Plummer, 1987; Dodd, 1993;Vitt, 1987).

Snake biodiversity and other reptile and amphibian populations are declining globally on an unprecedented scale (Dodd, 1987; Gibbons et al., 2000). Affects from human activities, disease, invasive species, poaching, and intentional killing have led to population declines and multiple extinctions. The Yangtze giant softshell turtle, for example, was threatened by the illegal meat trade in its native Asian countries. In April 2019, the last female died, leaving this species functionally extinct with only three males remaining. Likewise, the sharp decline and eventual extinction of the Rabbs' fringe-limbed tree frog in 2016 was precipitated by the spread of deadly chytridiomycosis across South America. Many of the snake species native to the historical range of longleaf pine forests are also declining (Guyer and Bailey, 1993; Dodd, 1995;

Tuberville et al., 2000), necessitating the snake community surveys in longleaf pine forests presented in the current study.

Snakes are vital members of the Southeastern ecosystems and are impacted by forest management practices. Currently, little data exists that assess the status and population trends of snake communities in these managed long leaf pine forests (Parker and Plummer, 1987; Vitt, 1987). Even basic ecological information is limited for snake communities (Parker and Plummer, 1987; Dodd, 1987; Dodd, 1993; Dodd, 1995). The Southeastern United States contains the highest concentration of at-risk snake species in the country (Dodd, 1987). Though studies suggest reptile diversity increases with prescribed fire in pine sandhills (Means et al., 2004) and bottomland hardwoods (Moseley et al., 2003), followed by quick recolonization (Cavitt, 2000), these improvements have not been measured in upland montane longleaf pine habitats. Regional studies have addressed effects on some individual species [e.g., timber rattlesnake (*Crotalus horridus*) (Steen et al., 2007; Howze et al., 2012), Eastern hognose snake (*Heterodon platirhinos*) (Plummer and Mills, 2000), copperhead (*Agkistrodon contortrix)* (Cross and Petersen, 2001), gray rat snake (*Pantherophis spiloides*) (Mullin et al., 2000; Howze et al., 2019), pine snake (*Pituophis melanoleucus*) (Beane and Pusser, 2012; Miller et al., 2012)], underscoring the need for the current study to fill gaps in these previous data.

Historically, longleaf pine forests caught fire every 2-8 years (Ware et al., 1993); thus, forests managers mimic this natural cycle when conducting prescribed burns. In longleaf pine habitats, a patchwork of burned and unburned parcels is ideal to provide a variety of habitats (Setser and Cavitt, 2003), supporting the hypothesis that a mosaic of disturbance-maintained habitats may lead to increases in reptile diversity (McLeod and Gates, 1998). This increase in spatial heterogeneity facilitates an increase in snake species richness (Vitt, 1987). Thus, restoration and forest management efforts to perpetuate fire-adapted wildlife species should result in an increase in snake species richness and community diversity.

BACKGROUND INFORMATION AND LITERATURE REVIEW

Decline of Longleaf Habitats

The longleaf pine ecosystem is among the most biologically diverse ecosystems outside of the tropics partially due to the extensive land area it once covered (Noss et al., 2015). This ecosystem has a distinctive habitat structure of open-canopy with low density of mature pine trees, little midstory, and one of the most diverse herbaceous understories. Many insects, reptiles, amphibians, and small mammals have adapted to habitat characteristics that the longleaf ecosystem provides. Ranges of certain amphibians and reptiles are restricted to suitable longleaf pine habitats (Guyer and Bailey, 1993). Several reptiles and amphibian species, such as the flatwoods salamander and the gopher tortoise, are longleaf pine ecosystem specialists that depend on the characteristics of longleaf pine habitats (Fenolio et al., 2014). The frosted flatwoods salamander (*Ambystoma cingulatum*) and reticulated flatwoods salamander (*Ambystoma bishopi*) are among the most imperiled salamander species in the United States and are only found in the flatwood longleaf pine habitats of the Southeast coastal plain (Fenolio et al., 2014). Both species rely on the seasonal inundation of wetlands to reproduce, but have experienced an 86.8% population decline, because fire suppression allows encroachment of competing vegetation and increasing leaf litter layers (Semlitsch et al., 2017). Likewise, the gopher tortoise, an endemic longleaf pine reptile, relies on the sandy soils to excavate their burrows. The gopher tortoise is a keystone species of the longleaf pine forests, but habitat loss and degradation have reduced populations by 80 percent (Dziadzio and Smith, 2016). Population declines in this keystone species impact hundreds of other vertebrate and invertebrate species that depend on gopher tortoise burrows for refuge (Earley, 2004).

Longleaf pine habitats range from Virginia, along the Southeast United States, and West to Louisiana and Texas. Throughout the range, this ecosystem is divided into five types based on differences in soils and topography that influence environmental factors such as fire regimes, ground cover plants, and animal species. These types are sandhills, rolling hills, flatwoods, savannahs, and montane (Outcalt, 2000). Savannah and flatwoods habitats have minimal surface drainage and receive abundant rainfall. These habitats are seasonally inundated with water. Sandhill habitats have soil dominated by sand but have a hilly topography. In the coastal regions, the sandhill and savannah habitats are the most common while the rolling hill habitats occur in the Gulf Coastal Plain ecoregions. The montane longleaf pine habitats range from middle to high elevations around 2000 ft. within Northwest Georgia and Eastern Alabama (Varner et al., 2003). They are atypical compared to the other longleaf pine habitat types because they consist of a matrix of upland habitats that are dissected by well-developed drainage networks, creating a complex topography (Peet, 2006). These regions experience greater loss of longleaf pine habitat due to their close proximity to developed, agricultural, and fire-suppressed landscapes (Cipollini et al., 2012). Most of the information about longleaf pine ecosystems comes from studies done in the sandhill and coastal plain habitat types with far fewer studies of the montane longleaf pine habitats.

The longleaf pine ecosystem was once the most extensive forest ecosystem in North American (Jose et al., 2006), covering more than 90 million hectares (ha), of the Southeastern United States before the arrival and spread of European settlers (Figure 1). Frequent fire in the Southeast maintained this ecosystem by preventing competing woody and herbaceous species

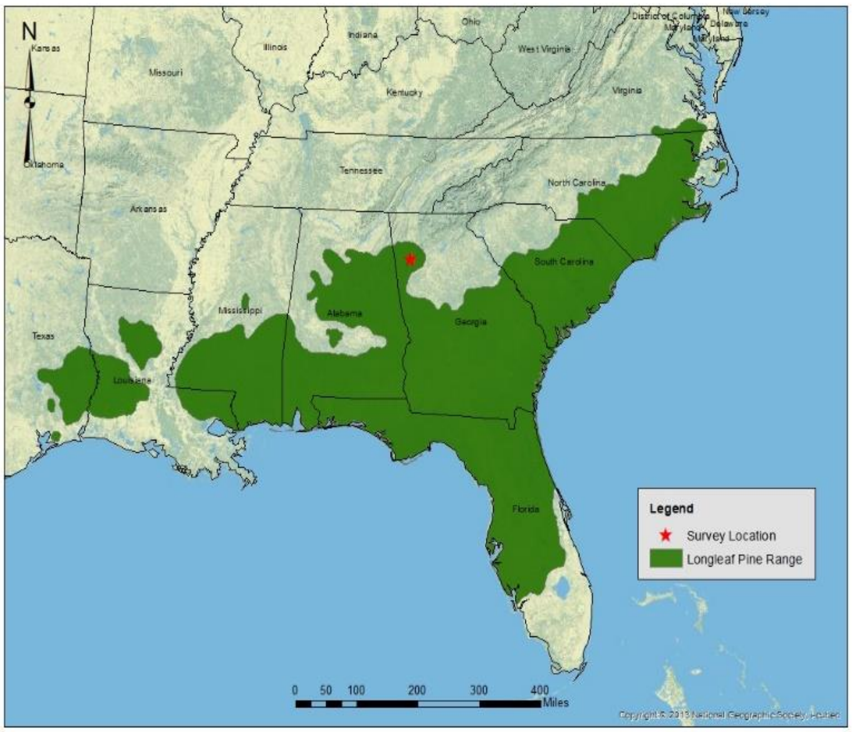

Figure 1. The historical range of longleaf pine ecosystem in the Southeastern United States. The study location is visually represented by the star symbol located northwest of metro-Atlanta in Georgia. This location is within with limited range of montane longleaf pine habitats that occur in northern ecoregions of north Georgia and North Alabama.

from establishing (Outcalt, 2000). Longleaf pine was a valuable source of lumber to 19th and 20th century settlers, resulting in large scale logging operations that depleted longleaf pine populations. Longleaf pines are slow growing, taking around 10 to 15 years to reach the sapling stage. Due to this slow growing nature of longleaf pines, faster growing pine species, loblolly (*Pinus taeda*) and slash (*Pinus elliotti*), were planted in their place to increase timber yields (Lander et al., 1995). Forests converted to loblolly pine are superficially similar to longleaf habitats; however, they lack the fire adapted traits longleaf pines have evolved. Loblolly pine silviculture practices require a high density of pines, often not allowing for understory plants adapted to grow in open, savannah-like habitats. European settlements led to anthropogenic fire suppression, altering forest structure by allowing fire-intolerant hardwood species to invade and dominate the forest, (Mitchell et al., 2006). Altogether, anthropogenic activities have left only 1.33% (equaling 1.2 million ha) of the original longleaf forest (Alavalapati et al., 2002). The upland habitats in montane longleaf pine forests are adjacent to lower riparian forests and wetland communities (Jose et al., 2006). These riparian habitats are critical for bisecting the uplands to create the habitats needed for many species that require both habitats (Jose et al., 2006). Both plants and animals that depend on the specific habitat characteristics of longleaf pine habitats show concurrent declines in biodiversity (Brunjes et al., 2003). The longleaf pine ecosystem is now considered an endangered ecosystem in the United States (Noss et al., 1995) and is included on the IUCN Red List (Farjon, 2013).

Upland Longleaf Pine Restoration

Naturally occurring fire maintains species diversity in longleaf pine ecosystems while also preventing forest fuel loads from accumulating to hazardous levels. As part of restoration, forest managers intentionally set prescribed fires and monitor the burns to control their location and intensity. Restoring fire to montane longleaf pine ecosystems facilitates an open canopy, and in degraded habitats, prescribed fire is used in combination with mechanical removal of fire-intolerant hardwoods and pines. Montane longleaf habitats are commonly dominated by mature longleaf and shortleaf pines and dotted with occasional oaks (*Quercus spp.*). In unmanaged montane longleaf pine habitats, the diversity of species in the herbaceous layer of plants and grasses is lost but can be restored by prescribed burns (Cipollini et al., 2012). Herbaceous vegetation in these habitats includes blackberries (*Rubus spp.),* bluestem grasses (*Andropogon spp.*), and a variety of other grass species (Poaceae). Studies have suggested that the burning and its effects on the vegetation communities benefit the herpetofauna by opening habitat structure and increasing ground temperature (Moseley et al., 2003).

Restoration of longleaf pine ecosystems varies depending on the type of habitat and degree of degradation. Upland montane longleaf pine habitats dominated by an overstory of longleaf pine that are poorly managed are quickly overtaken by an unnaturally dense hardwood midstory and canopies co-dominated by other Southern pines and hardwoods. Restoration of these habitats includes multiple years of cyclical prescribed fires to reduce fuel levels and competing vegetation (Brockway et al., 2005). After the reintroduction of multiple seasons of fire, mechanical thinning of competing southern pines and hardwoods is done to reduce the overstory (Brockway et al., 2005). Some upland montane longleaf pine habitats have become very degraded due to land conversion to loblolly pine plantations, making these habitats more difficult to restore due to the significant soil disturbance and alteration of vegetation (Brockway et al. 2005). Restoration still begins with cyclical prescribed fires to reduce fuels loads and reduce the woody and hardwood vegetation in the understory, followed by mechanical thinning of the loblolly pines to create canopy gaps that allow grasses and forbs to grow in the understory (Brockway et al., 2005). The final step of restoration includes clear cutting the remaining loblolly pines and planting longleaf pine seedlings. Continuing cyclical prescribed fires maintains the recovered upland montane habitats.

Southeastern United States Snake Communities in Longleaf Pine Habitats

Aside from providing a unique ecosystem, longleaf pine forests support a significant amount of vertebrate diversity, with many reptiles and amphibians that are considered specialists (Means, 2006). The decline of upland longleaf pine habitats and subsequent forests management practices has undoubtably affected many snake communities. Snakes, along with other reptiles and amphibians, fill crucial ecological roles in the trophic food webs of most ecosystems, representing links as both predators and prey to a wide variety of species (Grant et al., 1991).

Even though the ecological significance of snakes is well documented, there is surprisingly limited knowledge and research on general snake ecology (Grant et al., 1991). Conservation concerns surrounding snake communities are often anecdotal, and the limited literature makes determining accurate assessments of population and communities difficult (Dodd, 1987; Dodd, 1993; Parker and Plummer, 1987). Snakes are difficult organisms to study in general, presenting many obstacles to compiling a data set to address conservation concerns. Snakes are notoriously cryptic, often resulting in low detectability rates and perceived low densities. As ectotherms, their activity is highly dependent on thermoregulation needs, and resulting irregular foraging behaviors contribute to the frustrations and scarcity in data collection (Parker and Plummer, 1987; Gibbons et al., 2000). Habitat selection by snakes involves a complex model from macrohabitat selection to microhabitat selection (Reinhert, 1993; Smith et al. 2013). Snakes select habitats based on their physiological condition, such as reproductive condition, foraging/digestive stage, ecdysis, disease/injury status, social relationships, and site fidelity (Reinert, 1993).

The Southeastern United States has the greatest diversity of reptiles and amphibians in the United States, and within the longleaf pine ecosystem they are a considerable contributor to the vertebrate biomass (Kiester, 1971; Means, 2006). There are 30 ectothermic species that are considered longleaf pine ecosystem specialists (6 salamanders, 11 frogs, and 13 reptiles) while there are only five species of bird and three species of mammal that are longleaf pine specialists (Means, 2006). In this region, many studies have be done on spatial ecology, activity patterns, and population trends of many snake species such as timber rattlesnake (*Crotalus horridus*)

(Steen et al., 2007; Howze et al., 2012) black racer (*Coluber constrictor*) (Plummer and Congdon, 1994), Eastern hognose snake (*Heterodon platirhinos*) (Plummer and Mills, 2000), copperhead (*Agkistrodon contortrix)* (Cross and Petersen, 2001), corn snake (*Pantherophis guttatus*) (Franz, 1995), gray rat snake (*Pantherophis spiloides*) (Mullin et al., 2000: Howze et al., 2019), and pine snake (*Pituophis melanoleucus*) (Beane and Pusser, 2012; Miller et al., 2012). These studies often take place in the piedmont and coastal plain physiographic regions of Southeastern states, and few studies address similar questions within montane longleaf pine habitats (Dodd et al., 2007; Graham et al., 2015). Studies that have occurred in mountain physiographic regions of the southeast often focus on aquatic systems and their associated reptiles and amphibian species (Barrett and Guyer, 2008). In a study of the montane longleaf pine habitats in the Talladega National Forest, the factors influencing reptile and amphibian habitat preference include the time since the last burn, availability of microclimates, and the proximity to hardwood stands in low drainages (Lequire, 2010).

In the United States, there are 129 species of snakes (Behler and King, 1979), 41 of which occur in Georgia. In Northwest Georgia, there are 26 species that have predicted ranges covering Paulding and Polk Counties. These 26 species inhabit a wide variety of habitats within the longleaf pine system, and the life history at the species level determines microhabitat selections. Seven of those species prefer aquatic and riparian habitats: mud snake (*Farancia abacura*), plain-bellied watersnake (*Nerodia erythrogaster*), Northern watersnake (*Nerodia sipedon*), queen snake (*Regina septemvittata*), Southeastern crowned snake (*Tantilla coronate*), Eastern ribbon snake (*Thamnophis sauritus*), and common garter snake (*Thamnophis sirtalis*) (Jensen et al., 2008). Another seven species of snake inhabit primarily fossorial areas, thus limiting their time above ground: Eastern worm snake (*Carphophis amoenus*), scarlet snake

(*Cemophora coccinea*), ringneck snake (*Diadophis punctatus*), scarlet king snake (*Lampropeltis elapsoides*), brown snake (*Storeria dekayi*), red-bellied snake (*Storeria occipitomaculata*), and smooth earth snake (*Virginia valeriae*) (Jenson et al., 2008). Rough green snake (*Opheodrys aestivus*) is primarily arboreal, spending most of its time in the branches of vegetation (Jenson et al., 2008). The remaining 11 snake species are included in an upland snake community including: black racer (*Coluber constrictor*), corn snake (*Pantherophis guttatus*), gray rat snake (*Pantherophis spiloides*), Eastern hognose snake (*Heterodon platirhinos*), mole kingsnake (*Lampropeltis calligaster*), Eastern kingsnake (*Lampropeltis getula*), coachwhip (*Masticophis flagellum*), Northern pine snake (*Pituophis melanoleucus melanoleucus*), copperhead (*Agkistrodon contortrix*), timber rattlesnake (*Crotalus horridus*), and pigmy rattlesnake (*Sistrurus miliarius*) (Jenson et al., 2008) (Appendix).

In Georgia, two subspecies of pine snake occur- the Florida pine snake (*Pituophis melanoleucus mugitus*) in the Southern portions of the state and the Northern pine snake in the Northern portions of the state. Both subspecies are fairly large bodied snakes reaching 4-6 ft in length. This species of snake is unique because it has four enlarged rostral scales to assist with burrowing, while most other colubrids only have two. Therefore, it is one of very few snakes that will dig its own burrow (Moore, 1893; Zappalorti et al., 1983). They spend a majority of their time below ground, and above ground activity is mainly from May to October.

Pines snakes occur across the Southeastern states but have disjunct populations and are probably extirpated in multiple states. In Georgia, both subspecies are listed as Species of Concern with a ranking of S2-S3 (rare to uncommon) in the State Wildlife Action Plan. The divide between the subspecies occurs along the Piedmont ecoregion of Georgia where neither species is likely to inhabit. Florida pine snake is often associated with sandhill longleaf habitats and is one of many species that will inhabit gopher tortoise burrows. Northern pine snakes occur in a part of Georgia lacking gopher tortoises, and knowledge of their life history is largely unknown. Northern pine snakes prefer habitats that are dry with open canopies in longleaf pine or turkey oak forests (Burger and Zappalorti, 2011). Limited suitable habitat and secretive life history makes them a more difficulty species to detect. Northern pine snakes have been the least surveyed and studied species of pine snakes. This species has remained undetected and is presumed extirpated in multiple counties of North Georgia. Threats that have led to these assumptions include fire exclusion along with habitat fragmentation and degradation.

Surveying for Snakes Species

Biases exist with all methods of surveying for snake species, meaning that one survey method will not sample every species present (e.g. Gibbons and Semlitsch, 1987; Greenberg et al., 1994b; Enge, 2001; Enge and Wood, 2002). Common methods of sampling snakes include drift fences with pitfalls traps, box traps, or funnel traps, with each trap's biases based on its capability to either allow an animal to enter the trap or to prevent an individual from leaving the trap. Pitfall traps are useful in catching small fossorial snakes that cannot escape the pitfall; however, larger-bodied snakes can easily escape. In order to capture these larger-bodied snakes, modifications were made to a funnel trap design by Burdorf (2005). Biases in these trap captures can occur because active foragers like the black racer and coachwhip can be overrepresented in the sample (Dodd and Franz, 1995). Smaller species, like the arboreal rough green snake or fossorial scarlet kingsnake, can be found in upland habitats but will go undetected with traditional drift fence trapping methods. Other common survey methods for snakes include road cruising, where surveyors drive designated routes at a slow speed to catch snakes crossing roadways (Enge and Wood, 2002). This method greatly depends on when surveys are conducted.

Peak snake activity and highest detection likelihood is generally in the morning, then again at dusk, and sometimes even multiple hours into the night depending on temperature and moisture. Selecting a method to survey snakes depends on the community being studied and includes multiple survey methods to maximize capture diversity and density (Greenberg et al., 1994b; Dodd and Franz, 1995; Kjoss and Litvaitis, 2001).

STUDY AREAS

The historic range of montane longleaf pine habitats includes a relatively small portion of Northwest Georgia and Northeast Alabama, overlapping with more mountainous habitats typical of the North portions of these states (Figure 2). This habitat contains a unique integration of mountainous and coastal plain wildlife and plants. This study was conducted in two wildlife management areas that are undergoing longleaf pine restoration in Northwest Georgia, the Paulding Forest and Sheffield Wildlife Management Areas located at N 34° 01' 94" W 84° 90' 34" in Paulding and Polk Counties, Georgia, USA (Figure 2) at the Southern end of the Appalachian biodiversity hotspot for amphibian and reptile populations (Fouts et al., 2017). These WMAs are positioned at a unique intersection of three physiographic regions in Georgia-Blue Ridge, Ridge and Valley, and Piedmont (Figure 2). The two WMAs are located within the Level III Piedmont Ecoregion and, more specifically, within the Level IV Talladega Upland Ecoregion. The forests of this region are naturally dominated by oak-hickory-pine forests and characterized by dissected hills and tablelands that are generally higher in elevation than the rest of the Piedmont (Griffith et al., 2001).

Additionally, these study regions are located within the Raccoon Creek Watershed, which is a portion of the highly biodiverse Etowah River Watershed (Figure 2). This is area contains one of the largest tracks of remnant montane longleaf pine habitats in Northwest Georgia. The 26 aforementioned snake species have predicted ranges in Polk and Paulding counties and could potentially occur within Paulding Forest and Sheffield WMA; however, this study specifically targets the 11 species included in the upland snake community previously outlined. To determine

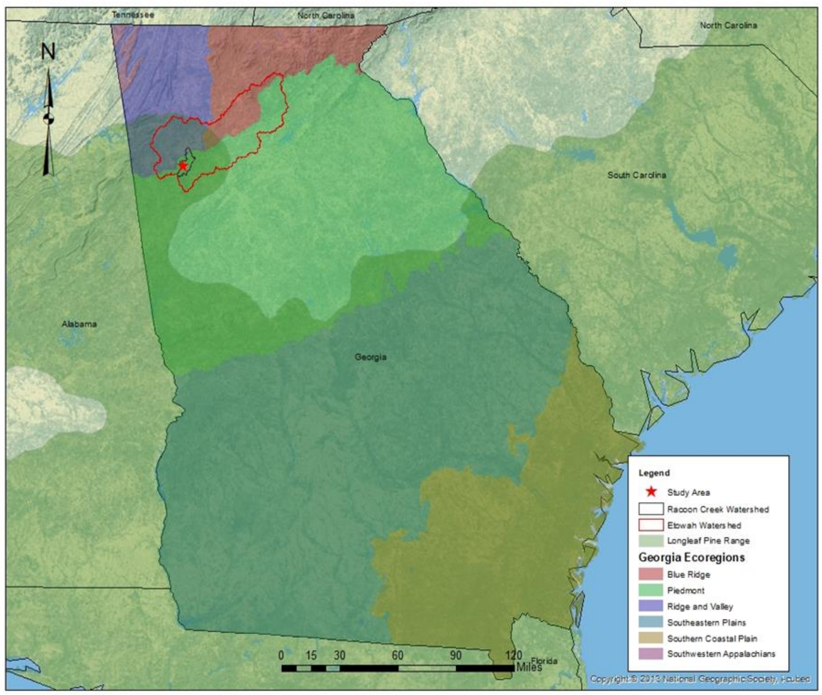

Figure 2. The study areas were at located within a high priority watershed, Racoon Creek, within the biodiverse Etowah River Watershed. This location is also at a unique integration of species from the Blue Ridge, Piedmont, and Ridge and Valley ecoregions.

community assemblages and presence of these 11 snake species, it was important to determine what the predicted diversity of this community should be based on predictive models. Paulding Forest and Sheffield WMAs are located at latitude 34°, and using the linear regression equations from Dalrymple et al. (1991) to determine the diversity and evenness of snake community assemblages, the predicted Shannon-Weiner Diversity (H) should be 1.65, and the Evenness (E) should be 0.66 (Figure 3).

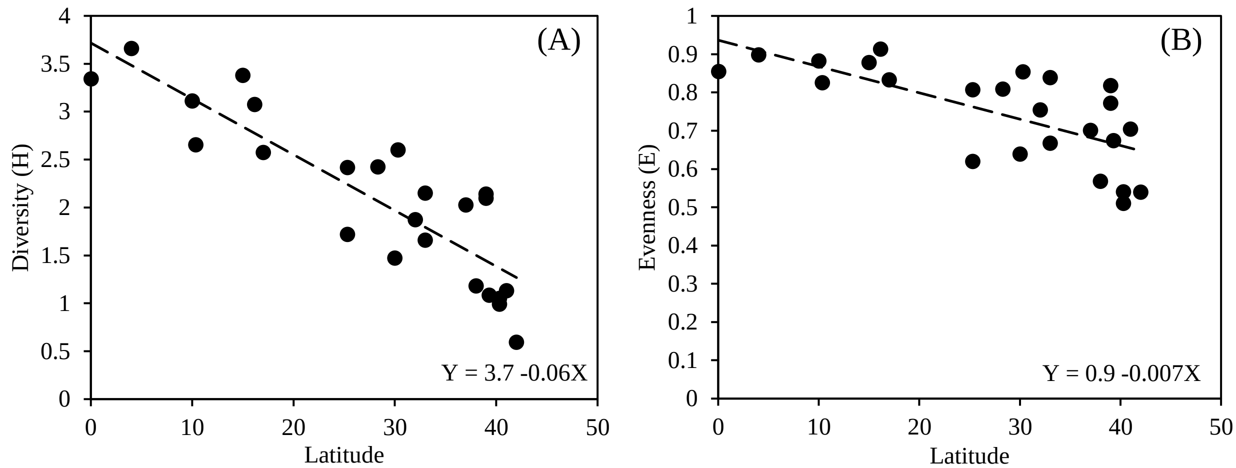

Figure 3. Linear Regression models reproduced from Dalrymple et al. 1991, predicting the relationship between Shannon-Weiner Diversity (A) and Evenness (B) to latitude for snake communities.

The 11 species included in the expected upland snake community of Paulding Forest and Sheffield can be divided into either ubiquitous species or specialists. The ubiquitous snake species are those that have more generalist habitat preferences and have predicted ranges that cover most of the state of Georgia. Ubiquitous species include the corn snake, Eastern hognose snake, Eastern kingsnake, black racer, gray rat snake, copperhead, and timber rattlesnake. These generalist species exhibit adaptability in anthropogenically disturbed habitats and are less vulnerable to local extirpations (Gray, 1989; Segura et al., 2007). The remaining four specialist species include two species associated with Northern piedmont and mountain habitats, the mole kingsnake and the Northern pine snake, while the other two specialist species, coachwhip and pigmy rattlesnake, are more often associated with coastal plain habitats. These specialist species are more sensitive to habitat loss and anthropogenic disturbances than ubiquitous species (Gray, 1989). Although habitat restoration involves some degree of anthropogenic disturbances, the end result aims to reverse habitat degradation by mimicking natural disturbance cycles. Because of the overlap in management and preferred habitats, the upland snake community is likely to be the most heavily impacted.

Public lands managed by State or Federal Governments provide key locations for conservation efforts and managing imperiled species and ecosystems. The Georgia Department of Natural Resources (GaDNR), in partnership with the Georgia Nature Conservancy, are specifically managing the WMAs in which this study was conducted for restoring montane longleaf pine habitats. These WMAs are located near Atlanta, Ga and provide the communities surrounding Atlanta with access to recreational lands for hunting, fishing, and hiking. Portions of the 25,707 acres within the Paulding Forest WMA and 4,850 acres within the Sheffield WMA are being converted and managed for development of a montane longleaf pine ecosystem. Restoration management strategies differ between the two wildlife management areas due to their difference is historic forest management. To restore the ecosystem from mixed-hardwood habitats to upland montane longleaf pine habitats, forest management practices within these two WMAs includes timber harvesting, prescribed fire, herbicide treatments, planting of longleaf pines, and natural regeneration.

Sheffield WMA was previously owned by a private citizen and historically was never converted for silviculture use. Though mature longleaf pine areas persist in upland habitats in this WMA, they were left unmanaged and went through decades of fire suppression. After this property was acquired by the GaDNR, most forest management benefitted hunting opportunities for deer, turkey, and small game. Unmanaged upland habitats in this WMA were mostly closed canopy dominated by a mixture of hardwood and pine tree species with thick layers of fuel loads. Intense longleaf pine restoration management strategies in Sheffield over the past 15 years aims to transition the upland habitats with overgrown and dense overstories dominated by other tree species to open savannah-like montane longleaf pine dominated habitats. Since Sheffield was never converted to silviculture, this provided an ideal site to measure snake populations from recently restored longleaf pine habitats that previously lacked suitable forest management.

The Paulding Forest WMA was previously owned by a timber company and, therefore, most of the upland habitats were converted for silviculture resulting in a monoculture of loblolly pines. As with the Sheffield site, after this property was acquired by the GaDNR most initial forest management benefitted hunting opportunities for deer, turkey, small game, and bears. Habitats are still used for silviculture of loblolly pine interspersed with bottomland mixed hardwood drainages. For the previous 15 years, restoration of upland longleaf pine habitats in Paulding WMA has taken place on the Northern portions of the property, near its boundary with Sheffield WMA. In these upland habitats, the restoration strategies used are to transition the habitats from very degraded upland habitats dominated by other Southern pine species, to longleaf pine habitats. Since Paulding Forest WMA was converted to silviculture, the restoration here provided snake community survey sites in areas where restoration practices are converting silviculture habitats back into montane longleaf pine habitats.

A total of six samples sites were chosen to survey for upland snakes in habitats that have undergone the most intensive longleaf pine restoration. Three sites were chosen within Paulding Forest WMA in upland habitats that are at similar stages in longleaf pine restoration. At these sites, there was an open overstory canopy of loblolly pine and a developed herbaceous layer. Prescribed fire was conducted at all three sites during the winter of 2015-2016 (B. Womack, personal communication, 2017). One site in Paulding Forest WMA was selected adjacent to an area that was clearcut and planted with longleaf pines in winter 2016-2017 (N. Weaver, personal communication, 2017). Three sites within Sheffield WMA were chosen because the habitats are the closest to achieving a climax montane longleaf pine habitat, with an open over-story of longleaf pines and diverse herbaceous layer. Prescribed fire at all three sites was conducted within the previous 3 years and, therefore, the habitats were considered similar in terms of microhabitat availability and resource characteristics.

Though these study sites are regularly managed, dedicated snake community studies are lacking, and most assumptions about the presence and community structure of snake species in these WMAs comes from anecdotal local and GaDNR employee accounts. For the specialist snake species, locals have reported seeing coachwhips regularly, and GaDNR employees report occurrences of pigmy rattlesnakes. Records for mole kingsnakes have been provided to the GaDNR; however, these records date back to the 1970s. Only a few anecdotal accounts of Northern pine snakes have been reported, but GaDNR employees and wildlife managers agreed that this species was unlikely to occur within Paulding Forest and Sheffield WMAs. The Atlanta Herpetology Club conducted a two-day BioBlitz in 2007 in these two WMAs which resulted in 31 new county records for reptiles and amphibians. Some of these county records were for very common species such as five-lined skink (*Plestiodon fasciatus*), Eastern fence lizard (*Sceloporus undulatus*), and ringneck snake (Atlanta Herpetology Club, 2007). This survey and the lack of known populations of any species of concern underscores how little research attention Paulding Forest and Sheffield WMAs have received. This community should be of interest to researchers and wildlife managers alike; therefore, documenting the community and populations present in these habitats will greatly contribute to the limited regional knowledge of snake communities.

RESEARCH OBJECTIVES

The Society for Ecological Restoration identifies many attributes that help determine the success of a restoration, one of which is that the restored ecosystem contains a characteristic assemblage of the species that occur in the reference ecosystem (Jose et al., 2006). Additionally, the restored ecosystem should result in an increase, or at a minimum no decrease, in biodiversity. Restoration of montane longleaf pine habitat requires intensive, rotational prescribed fire and timber thinning to maintain open, savannah- like upland habitat that will influence changes in the community structure and presence of many species, including the upland snakes. Many studies from a variety of habitats and ecosystems suggest that forest management benefits reptile communities.

A systematic survey is needed to determine the current upland snake community within the montane longleaf pine managed habitats as the GaDNR continues restoration of this ecosystem. Due to the lack of baseline data prior to restoration activities, we cannot determine the effects the management has had on the upland snake communities. Instead, we can determine how the upland snake communities differ between Sheffield and Paulding Forest WMAs and associate that with the current structure of managed habitats and forest management history. The first research objective of this study is to determine if restoration practices are influencing expected presence and community structure of upland snake species. If the forest management practices are negatively affecting snake species diversity, then we would expect to find fewer species, and species diversity should be lower than predictive models. The second research objective is to determine if pine habitats at different stages of longleaf restoration between Paulding Forest and Sheffield are supporting similar upland snake species diversity and community structure. We predicted we would detect differences in snake community and diversity between Paulding Forest and Sheffield because of forest management history. The last research objective of this study is to establish baseline data of the upland snake community in the montane longleaf pine habitats of Paulding Forest and Sheffield. This research is the first to document the community structure and diversity of upland snake species within habitats undergoing montane longleaf pine restoration in this region, and it is the first dedicated survey for the two wildlife management areas.

We expect that the restoration of montane longleaf pine habitats within Paulding Forest and Sheffield WMAs would result in high species richness and diversity of the upland snake community. We hypothesize that upland snake community composition will be correlated with forest management history. Sheffield WMA never underwent anthropogenic disturbances in its management history similar to the conversion of habitats for silviculture use in Paulding Forest. Although the suppression of fire in Sheffield has an anthropogenic cause, it was less of a disruption to the ecosystem than massive land conversion. Sheffield is expected to display greater upland snake species diversity than Paulding Forest due to a lack of intense mechanical disturbance. However, since Paulding Forest has also been undergoing longleaf pine management, upland snake species richness and diversity should eventually approach a similar community to Sheffield. A significant difference in the upland snake communities between plots from Paulding forest and plots from Sheffield would suggest that forest management history has an effect on upland snake communities. No significant relationship between forest management history and upland snake community composition could mean that recent forest management is achieving similar upland snake communities in Paulding Forest and Sheffield WMAs.

METHODS

Drift Fence Trap Arrays

Six locations were selected within habitats undergoing longleaf management within Paulding Forest and Sheffield WMAs (Figure 4). Drift fence arrays with funnel box traps were installed at each site on April 29, 2018. The drift fences were 50ft long by 2ft tall hardware cloth and installed 2in below ground and backfilled with soil. Funnel traps were constructed of pressure treated plywood for the bottom, top, and supports (Burgdorf et al., 2005). The sides and funnel were constructed of hardware cloth. The opening to remove trapped animals was through the back of the traps. A wooden door was attached with bungee cords to close off the back of the trap. This allowed for easy removal of the back of the trap to remove trapped animals. Funnel traps were attached to the distal ends of each drift fence, and soil was filled in at the base of the funnel.

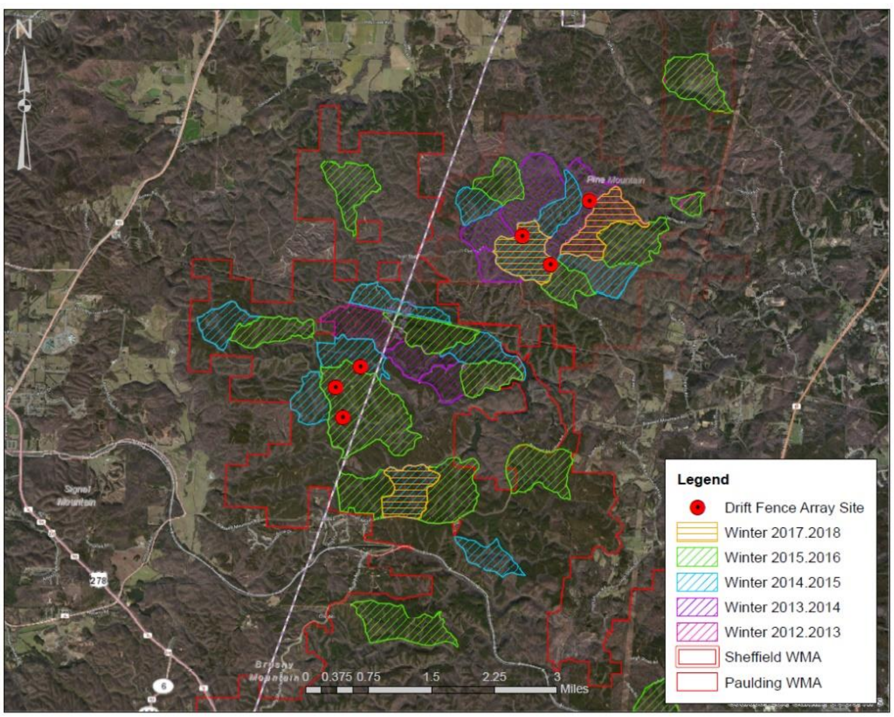

Figure 4. Selected sites within Paulding Forest and Sheffield WMAs to study snake community assemblages within areas undergoing longleaf pine restoration. Bold lines represent state land boundaries. Previous plots where prescribed fire was conducted are shown.

In 2018, 6 arrays were installed in the WMAs, with three in Paulding Forest and three in Sheffield. The sites were chosen based on areas of this most intensive longleaf pine management. Traps were activated, meaning the back of trap was installed and the array was capable of trapping animals, on April 30, 2018. Traps were checked daily from April 30, 2018 until July 1, 2018. On July 1, 2018, the back of the traps were removed and the drift fence array was considered deactivated. This season of trapping will be hereafter referred to as “Early Summer Season”. All drift fence arrays were activated again on August 13, 2018 and again checked daily until October 13, 2018. On October 13, 2018, the traps were deactivated. This season of trapping will be hereafter referred to as “Late Summer Season”.

Drift fences were checked as routinely as possible during the Early Summer Season so that all traps were checked by noon, while during the Late Summer Season drift fences were generally checked in the afternoon due to scheduling needs. Non-target captures (e.g., lizards, amphibians, small mammals, birds, insects) were recorded and then immediately released from traps. Venomous snakes (timber rattlesnakes and copperhead snakes) were recorded and generally released immediately with morphometric data collected only when trained collaborators were present. All non-venomous captures were processed for morphometric and disease sample collection and then released on site away from the drift fence to prevent instant recapture.

An additional method of sampling reptiles was conducted while traps were being checked. The drift fence array sites were relativity far apart and required driving between each site. Therefore, while driving to each array or walking down old logging roads, road cruising and visual encounter surveys were conducted for opportunist captures of snakes and referred to as incidental captures. Since the same roads were driven and walked to reach the drift fences every day during the survey periods, this provided a consistent additional sampling method.

Data Collection

Snakes captured using drift fence trap arrays and found during visual encounter surveys were identified to species and recorded. The morphological data taken for each individual included: snout-to-vent length (cm), tail length (cm), sex, gravidity, and mass (grams). All nonvenomous snakes captured were swabbed to test for Snake Fungal Disease, caused by the fungus *Ophidiomyces ophiodiicola* (Allender et al., 2012; Allender, 2018). Disease test swabs were collected from venomous snakes only when a trained collaborator was present. The results of these samples will not be included in this thesis. Captured snakes were not individually marked for mark and recapture studies. The handling of all reptiles was done under a scientific collecting permit from the GaDNR (Permit #634063259).

Analyses

Total individuals captured and species richness in the early summer, late summer, and pooled data were used to compare regional differences between Paulding Forest and Sheffield. Alternatively, total captures and species richness were used to compare seasonal differences within the same sites. To determine differences in species distribution, detected species richness, individuals captured, and total captures per WMA were calculated. Results are presented graphically by species. To compare the proportion of individuals captured from each snake species, a Chi-square analysis was conducted.

Shannon-Weiner diversity (H´) and equitability (E´) were calculated based on site specific captures and inclusion of incidental captures to determine difference in species diversity and evenness between management treatments. Statistical difference in calculated diversity was determined using a t-test (Hutcheson, 1970). In addition to Shannon-Weiner diversity, Simpson's Diversity Index was calculated. This calculation is different from Shannon-Weiner diversity in that Simpson's takes into account the total number of individuals captured for a species as well as its abundance. It is a dominance index that gives more weight to the dominant species caught. Therefore, the rare species captured will not greatly affect the overall diversity calculation.

Species richness was examined monthly during the entire trapping season by pooling the trapped snakes from drift fence array captures and incidental captures. The species richness was determined for the first and second month of the early summer trapping season- May and June respectively. In order to standardize the species richness of the first and second month of trapping during the late summer trapping season, species richness was calculated within the first month from the start of the trapping seasons on August 13th, and the second month starting on September 14th though the end of this season.

Species accumulation curves were constructed to graphically show the number of species captured as a function of the amount of sampling effort. The first individual on the graph represents the first species captured, while the next individual captured represents the addition of another species or the addition of another individual of the first species. This curve should increase sharply at first as more common species are captured but will then result in a decelerating slope as the probably of capturing a new, possibly rarer, species declines (Gotelli and Colwell, 2011). The theory of a species accumulation curve is that determining how many species characterize a community means sampling until that community is sufficiently sampled. This is accomplished by sampling the community more and more until no new species are found, no matter how much more sampling effort is made. This will result in the species accumulation curve reaching an asymptote, where even as more samples are collected, the species richness will not increase. Conversely, an additional way to plot species accumulation is with a Sample-based species accumulation curve. In this curve, instead of the sampling effort plotted against the species richness, the number of samples (i.e. individuals) is plotted against the species richness.

Environmental data, including the daily maximum and minimum temperatures and precipitation accumulation, were collected from the Georgia Forestry Commission Fire Weather System, a system which archives climate data from weather stations in Georgia. The closest weather station to Paulding Forest and Sheffield WMAs is located in Dallas, GA.

RESULTS

The early Summer session consisted of a total of 372 trap nights and the late summer session consisted of 372 trap nights, making the total effort 744 nights of trapping. During the Early Summer trapping session, a total of 71 individuals representing ten nonvenomous species and two species of venomous snake species were captured. During the Late Summer trapping session, a total of 42 individuals representing six nonvenomous species and two species of venomous snake species were captured (Table 1).

	Early Summer				**Late Summer**			
	Paulding Forest		**Sheffield**		**Paulding Forest**		**Sheffield**	
Nonvenomous species	**Trap**	**Incidental**	**Trap**	**Incidental**	**Trap**	**Incidental**	**Trap**	**Incidental**
Black racer	15	0	6	1	2	1	2	1
Eastern hognose	1	2	4	2	1	0	2	1
Mole kingsnake	0	0	0	0	0	0	0	0
Eastern kingsnake	0	1	2	0	0	0	0	0
Scarlet kingsnake	0	0	0	1	0	0	0	0
Eastern coachwhip	0	0	0	0	0	0	0	0
Rough green snake	0	1	0	0	0	0	0	2
Corn snake	4	0	3	1	2	0	1	1
Gray rat snake	1	1	3	1	1	0	0	1
Northern pine snake	0	1	0	0	0	0	1	0
Eastern garter snake	0	0	1	0	0	0	0	0
Brown snake	0	0	0	1	0	0	0	0
Venomous species								
Copperhead	5	0	2	1	8	1	0	1
Timber rattlesnake	2	0	2	6	3	4	1	5
Pigmy Rattlesnake	0	0	0	0	0	0	0	0
Total	28	6	23	14	17	6	7	12

Table 1. Drift fence array captures and incidental captures of snakes at Paulding Forest and Sheffield WMAs in northwest Georgia during the early summer (May 1 – July 1) and late summer (August 13 – October 13), 2018.

Early Summer Species Presence

During the early summer season, a total of eight species were captured using the drift fence trap arrays with the most common species being the black racer (*C. constrictor*), copperhead (*A. contortrix*), and corn snake (*P. guttatus*). The other five species captured were the timber rattlesnake (*C. horridus*), Eastern hognose (*H. platirhinos*), Eastern kingsnake (*L. getula*), gray rat snake (*P. spiloides*), and Eastern garter snake (*T. sirtalis*). Paulding Forest had a species richness of 6, while Sheffield had a species richness of 8. During the early summer sampling season, an additional four species were discovered as incidental captures using road cruising and visual encounter surveys, including only one of each species for rough green snake (*O. aestivus*), brown snake (*S. dekayi*), scarlet kingsnake (*L. elapsoides*), and the Northern pine snake (*P. m. melanoleucus*). In Paulding Forest, including incidental captures, species richness was 9 while Sheffield was slightly greater at 10.

Early Summer Drift Fence Array Captures

In Paulding WMA, a total of 28 individual snakes from six species were captured using three drift fence trap arrays (Table 1). Black racers made up half of the total captures 53% (n = 15) during the early summer trapping season. Additionally, copperheads accounted for 18% (n = 5), corn snakes accounted for 14% (n = 4), and timber rattlesnakes made up 7% (n = 2) of total captures during the early summer trapping season. The last two species captured in Paulding WMA were hognose snake and gray rat snake, accounting for only 4% (n = 1) each of the total captures (Figure 5). Snake species that were not captured in Paulding WMA in drift fence trap arrays were Eastern kingsnake and Eastern garter snake (Figure 4).

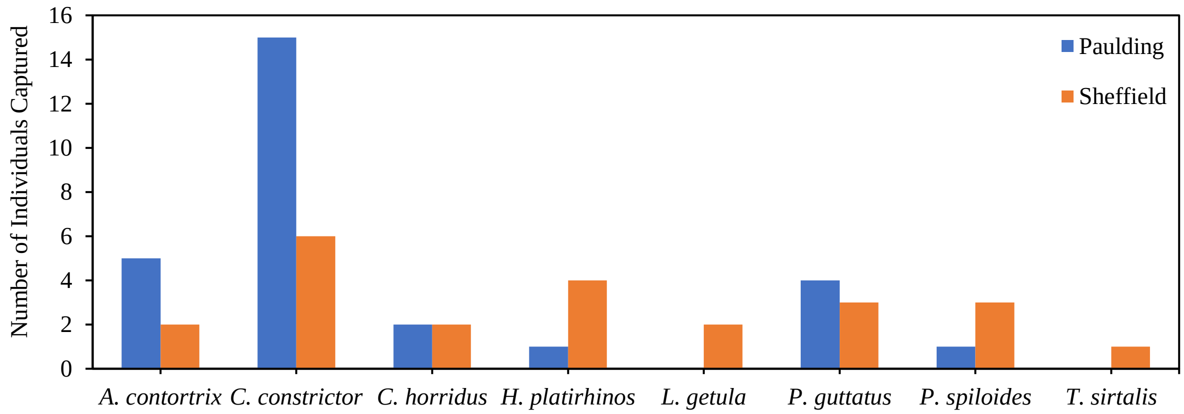

Figure 4. Individual snakes captured using drift fence trap arrays in Paulding Forest and Sheffield WMAs during the early summer season (May 1 – July 1) 2018.

In Sheffield WMA, a total of 23 individual snakes from eight species were captured during three drift fence trap arrays (Table 1). Black racers made up the highest percent of captures, accounting for 26% (*n* = 6) during the early summer trapping season. Eastern hognose snakes accounted for 17% (*n* = 4), corn snakes made up 13% (n = 3), and similarly gray rat snakes made up 13% (n = 3) of total captures. Copperheads, timber rattlesnakes, and Eastern king snakes each accounted for 9% (*n* = 2) of captures. Lastly, common garter snakes made up 4% (n=1) of captures (Figure 5). All species that were captured across both WMAs were

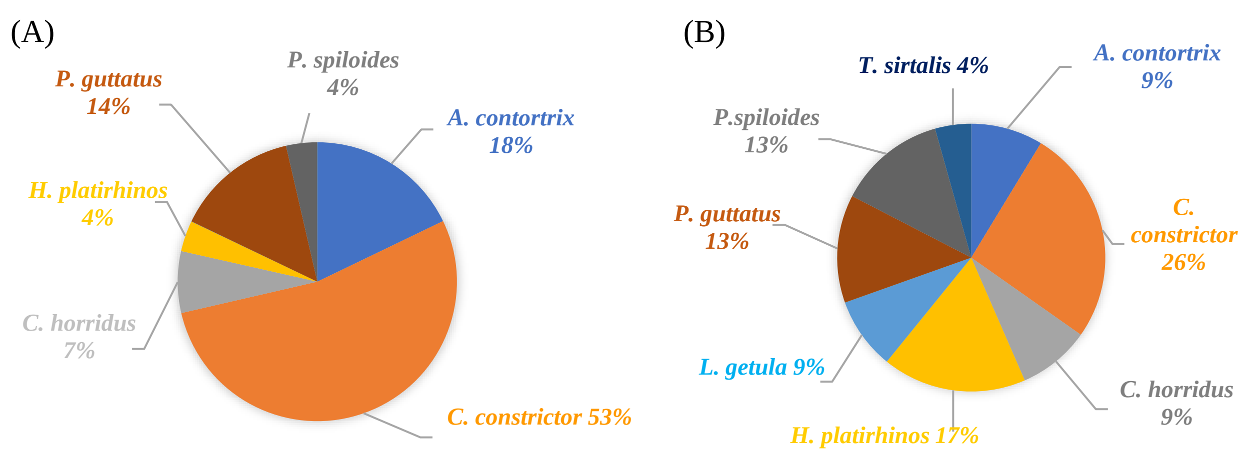

Figure 5. Proportions of individuals from species captured during the early summer trapping season in Paulding Forest (A) and Sheffield (B) WMAs. Incidental captures are not included. P > 0.05.

included in drift fence array captures from Sheffield WMA (Figure 4). The proportion of individuals for each species between each WMA showed no significant difference (*P* =0.999).

Early Summer Incidental Captures

In Paulding Forest, additional individuals were captured as incidental using road cruising and visual encounter surveys. These methods resulted in six individual snakes from five species. One individual (*n* = 1) from the following species were captured: Eastern kingsnake, rough green snake, gray rat snake, and northern pine snake (Figure 7). Lastly, two (*n* = 2) eastern hognose snakes were incidental captures (Figure 6). Snake species not caught as incidental capture in Paulding WMA were copperhead, black racer, timber rattlesnake, corn snake, and eastern garter snake.

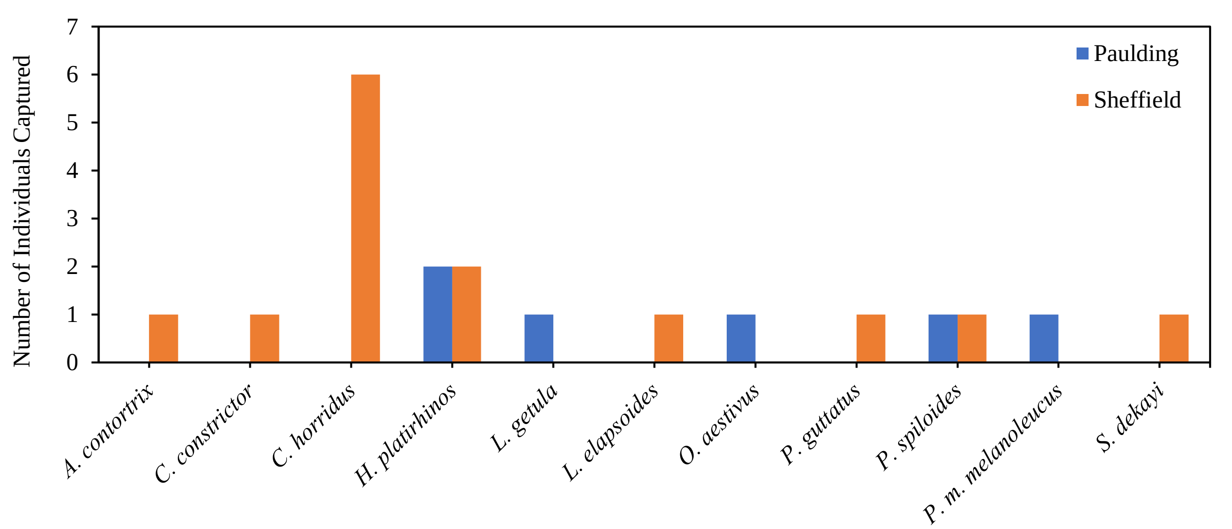

Figure 6. Individual snakes captured as incidental captures in Paulding Forest and Sheffield WMAs during the early summer season (May 1 – July 1) 2018.

Incidental captures from Sheffield WMA added an additional 14 individuals from eight species captured. Timber rattlesnakes made up almost half of the incidental captures at 43% (*n* = 6) from the early summer season (Figure 7). Hognose snakes accounted for the second highest number of captures at 15% (*n* = 2). The other six species captured were copperhead, black racer, corn snake, gray rat snake, brown snake, and scarlet king snake, each accounting for 7% (n = 1) of incidental captures (Figure 6). Snake species not observed as incidental captures were Eastern kingsnake, rough green snake, Northern pine snake, and common garter snake.

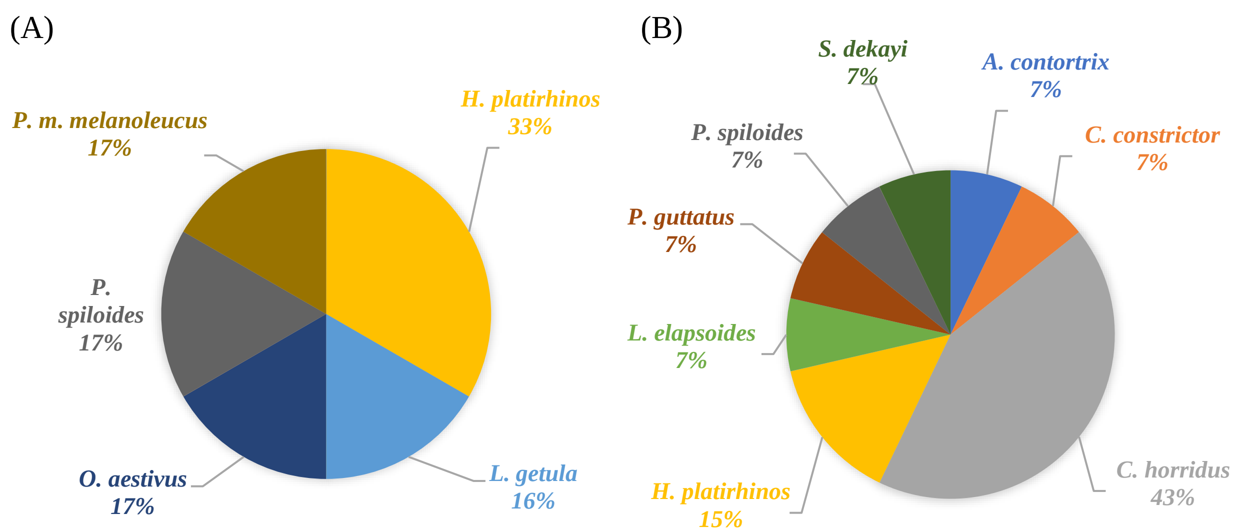

Figure 7. Proportions of individuals from species captured as incidentals during the early summer trapping season in Paulding Forest (A) and Sheffield (B) WMAs.

Late Summer Species Presence

During the late summer sampling season, six species were captured using the drift fence trap arrays (Table 1). The most common species captured were copperheads, timber rattlesnakes, and black racers. The other three species captured during this season were Eastern hognose snake, gray rat snake, corn snake, and Northern pine snake. Paulding Forest had a species richness of 6 while Sheffield had a species richness of 5. Only one species, the rough green snake, was added to the overall species count as an incidental capture. In Paulding Forest, including incidental captures, species richness was 9 while Sheffield was 8.

Late Summer Drift Fence Array Captures

In Paulding WMA, a total of 17 individuals from six species were captured using the three drift fence trap arrays during the late summer trapping season (Table 1). Copperheads accounted for almost half of the total captures 47% (*n* = 8) during this trapping season. The second highest snake species captured was timber rattlesnake, accounting for 17% (*n* = 3). Black racer and corn snake each made up 12% (*n* = 2) of the total captures. The last two species captured, gray rat snake and Eastern hognose snake, each accounted for 6% (*n* = 1) of captures (Figure 9). The only snake species that was not captured in Paulding WMA in drift fence trap arrays was Northern pine snake (Figure 8).

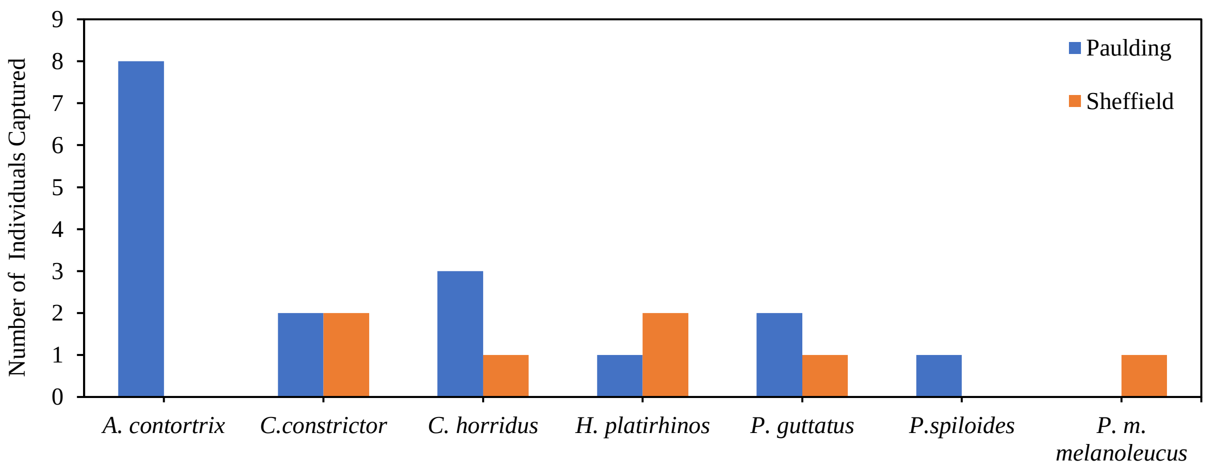

Figure 8. Individual snakes captured using drift fence trap arrays in Paulding and Sheffield WMAs during the late summer season (August 13 – October 13) 2018.

In Sheffield WMA, seven individuals from four species were captured utilizing the three drift fence trap arrays (Table 1). Eastern hognose snakes and black racers each made up 29% (*n* = 2) of total captures. The additional three species captured were timber rattlesnake, corn snake, and Northern pine snake, with each making up 14% (*n* = 1) of total captures (Figure 9). Snake species that were not captured in Sheffield WMA were copperhead and gray rat snake (Figure 8). The proportion of individuals for each species captured between each WMA showed no significant difference (*P* = 0.999).

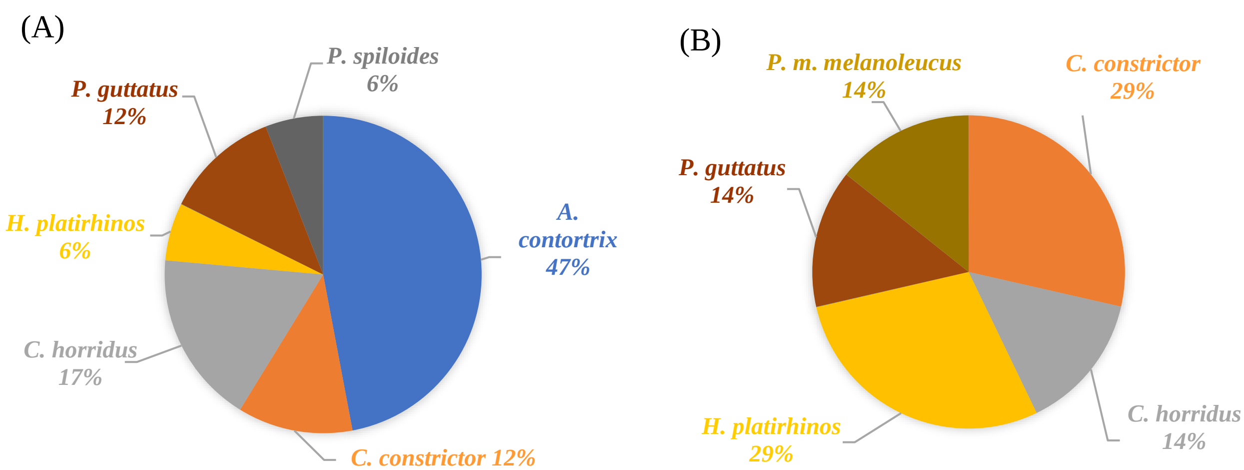

Figure 9. Proportions of individuals from species captured during the late summer trapping season in Paulding Forest (A) and Sheffield (B) WMAs. Incidental captures are not included. P > 0.05.

Late Summer Incidental Captures

In Paulding Forest an additional six individuals from three species were captured as incidental captures during the late summer trapping season. Timber rattlesnakes made up more than half of the incidental captures with 66% (*n* = 4). The two other species captured were a copperhead and a black racer, each accounting for 17% (*n* = 1) (Figure 11). Snake species that were not observed as incidental captures were the Eastern hognose snake, corn snake, gray rat snake, and Northern pine snake (Figure 10).

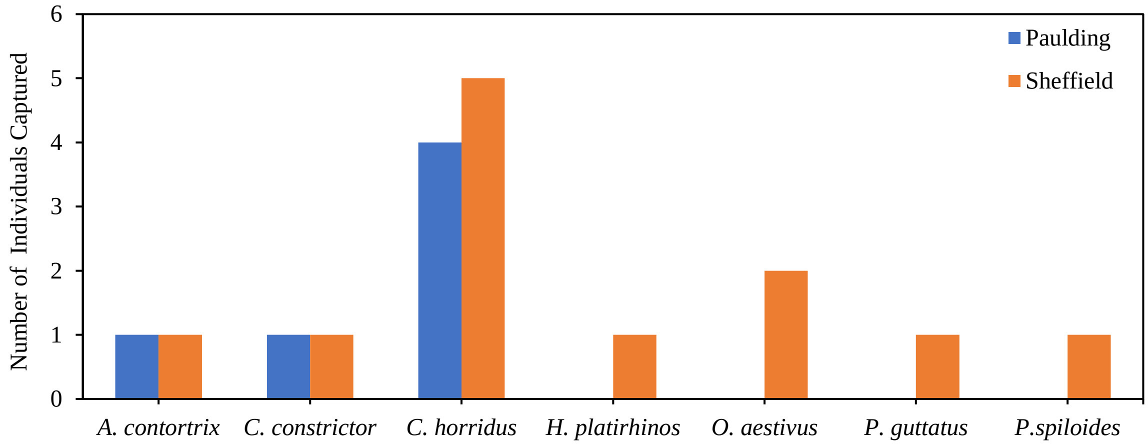

Figure 10. Individual snakes captured as incidental captures in Paulding and Sheffield WMAs during the late summer season (August 13 – October 13) 2018.

During the late summer trapping season in Sheffield WMA, twelve individuals from seven species were captured as incidental captures. Timber rattlesnakes made up a majority of the individuals captured totaling 41% (*n* = 5). Rough green snakes made up 16% (n = 2) of the incidental captures. The remaining species captured were copperhead, black racer, Eastern hognose snake, corn snake, and gray rat snake, each contributing 8% (n = 1) to the total incidental captures (Figure 11). The only snake species not captured during this trapping season using these methods was Eastern kingsnake (Figure 10).

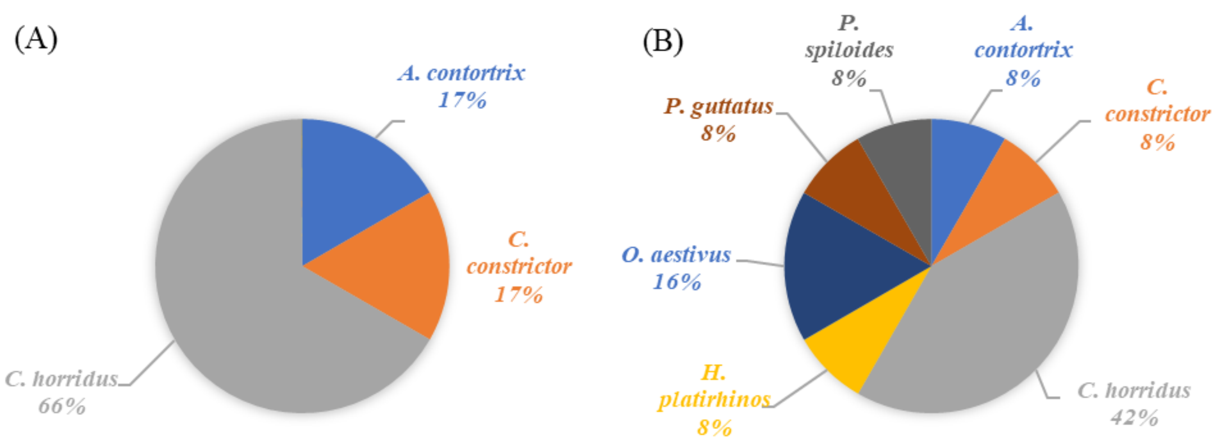

Figure 11. Proportions of individuals from species captured as incidentals during the late summer trapping season in Paulding Forest (A) and Sheffield (B) WMAs.

Pooled Seasons Trapping Results

When the data for both the early summer and the late summer trapping seasons were pooled, eight species were captured using drift fence arrays (Table 2). The most common species captured were copperheads, corn snakes, and black racers. The other species captured during both seasons were Eastern hognose snake, gray rat snake, timber rattlesnake, Eastern kingsnake, common garter snake, and Northern pine snake. Paulding Forest had an overall species richness of 6 while Sheffield had a species richness of 8. The portions of individuals for each species between each WMA showed no significant difference (*P* =0.999) (Figure 12).

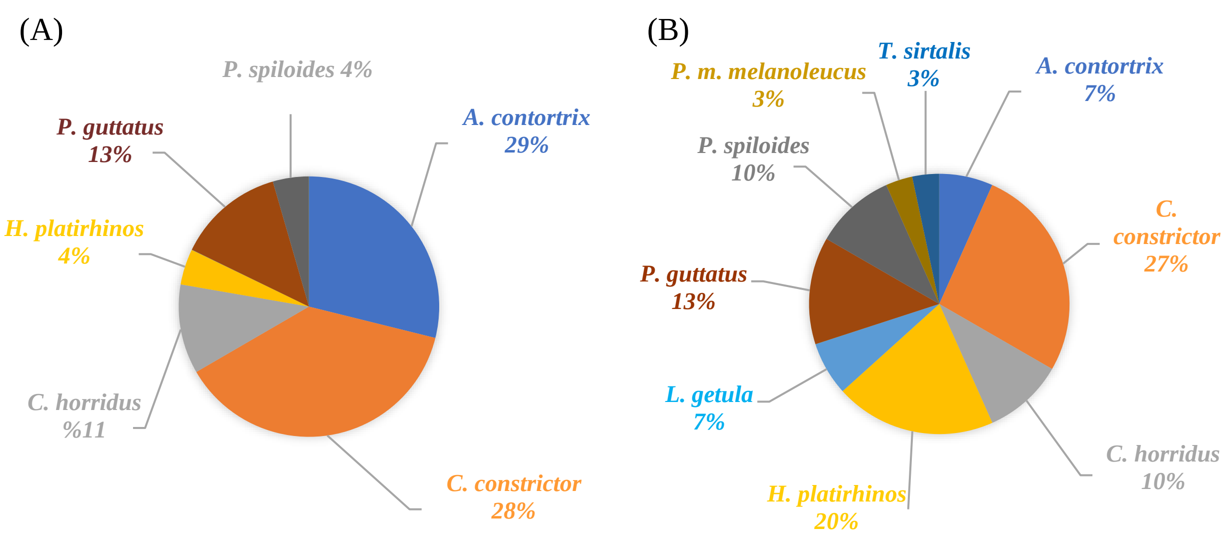

Figure 12. Proportions of individual from species captures pooled from the early summer and late summer trapping seasons in Paulding Forest (A) and Sheffield (B) WMAs. Incidental captures are not included. P > 0.05.

Trapping Seasons Pooled				
	Paulding Forest		**Sheffield**	
Nonvenomous species	**Trapped**	**Incidental**	**Tapped**	**Incidental**
Black racer	17	1	8	2
Eastern hognose	2	2	6	3
Mole kingsnake	0	0	0	0
Eastern kingsnake	0	1	2	0
Scarlet kingsnake	0	0	0	1
Eastern coachwhip	0	0	0	0
Rough green snake	0	1	0	2
Corn snake	6	0	4	2
Gray rat snake	2	1	3	2
Northern pine snake	0	1	1	0
Eastern garter snake	0	0	1	0
Brown snake	0	0	0	1
Venomous species				
Copperhead	13	1	2	2
Timber rattlesnake	5	4	3	11
Pigmy Rattlesnake	0	0	0	0
Total	45	12	30	26

Table 2. Drift fence array captures and incidental captures of snakes at Paulding Forest and Sheffield WMAs in northwest Georgia pooled over both sampling seasons during 2018.

Seasonal Species Presence

Seasonal species captures varied within the same WMA between the early summer and late summer trapping sessions. Total captures decreased in both WMAs (Table 1). In Paulding Forest the most notable change in individuals captured from one species was black racer, which decreased from 15 individuals in the early summer to 2 individuals in the late summer. Overall captures from venomous snakes increased between early summer and late summer (Figure 13). Though the total number of individuals for each species differed between each season, at least one individual from all the same species were found. However, there was not a significant difference in species composition between the early summer and late summer trapping seasons in Paulding Forest (P = 0.999) (Figure 5A and Figure 9A).

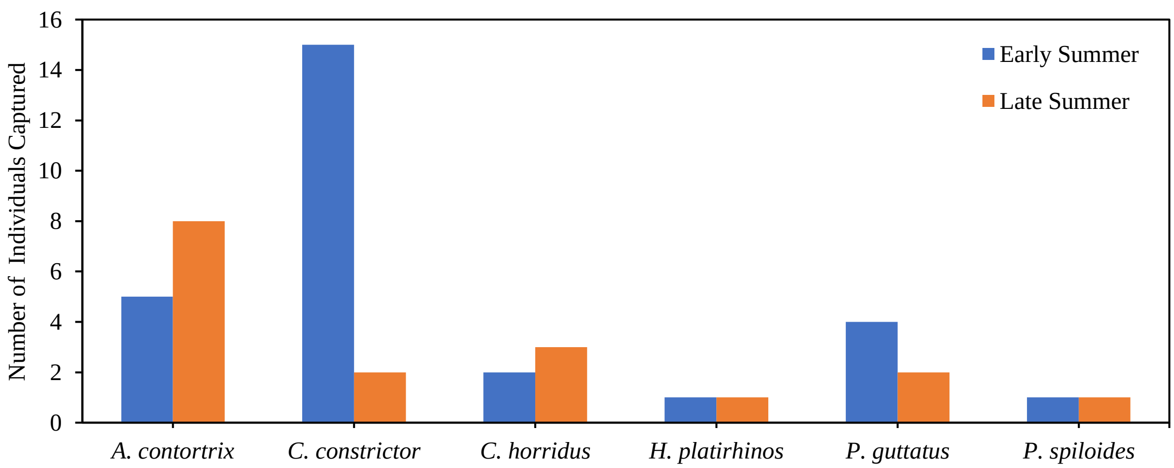

Figure 13. Paulding Forest seasonal comparison between early summer season (May 1 – July 1) and late summer season (August 13 – October 13) individual snakes captured using drift fence arrays.

In Sheffield the total overall captures greatly decreased between the early summer season and late summer season. There were multiple species that were not captured during the late summer season including copperhead, gray rat snake, and Eastern kingsnake, while an additional species, Northern pine snake, was captured during the late summer season that was not captured in the early summer (Figure 14). In Sheffield, there was a significant difference in species composition between the early summer and late summer trapping (*P* = 3.515 x10^{-66}) (Figure 5B and Figure 9B).

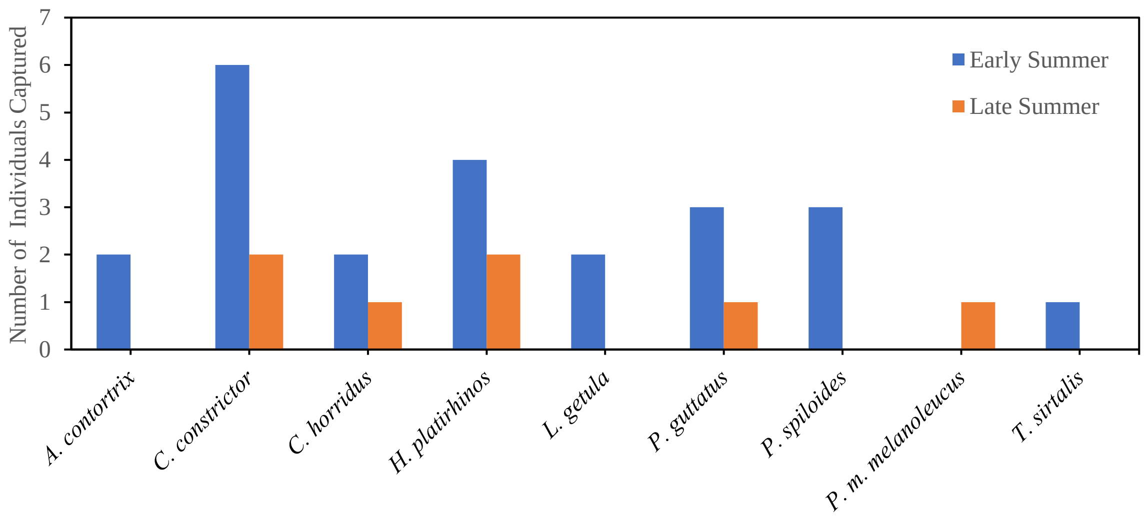

Figure 14. Sheffield seasonal comparison between early summer season (May 1 – July 1) and late summer season (August 13 – October 13) individual snakes captured using drift fence arrays.

Shannon-Weiner Diversity (H) and Evenness (E)

Species diversity was estimated using Shannon-Weiner Diversity (H), and statistical differences were determined using a t-test with a 95% confidence interval (Hutcheson 1970). In the Early Summer, diversity of drift fence array captured species in Sheffield was greater (1.96) than Paulding (1.35), although equitability remained comparable between the two sites (0.75 and 0.79 respectfully) (Table 3).

Shannon-Weiner Diversity (H)					
	Paulding	Paulding w/ Incidental	Sheffield	Sheffield w/ Incidental	Pooled
Early Summer					
Diversity (H)	1.35	1.75	1.96	2.08	1.74
Equitability (E)	0.75	0.94	0.79	0.90	0.84
Late Summer					
Diversity (H)	1.50	1.48	1.55	1.96	1.84
Equitability (E)	0.84	0.83	0.96	0.94	0.90
Season Pooled					
Diversity (H)	1.52	1.79	1.99	2.12	1.83
Equitability (E)	0.85	0.82	0.91	0.85	0.83

Table 3. Shannon-Weiner diversity (H) and equitability (E) indices calculated from individual snake captured with drift fence arrays in Paulding Forest and Sheffield WMAs in northwest Georgia during the early summer and late summer. Season pooled data included the individuals captured from both seasons. Calculations labeled Paulding w/ Incidental and Sheffield w/ Incidental is the combination of drift fence array and incidental captures. Pooled data includes in the pooling of only trapped individual snakes during associated season.

When incidental captures were included in diversity calculations, diversity and equitability was higher at both sites with Sheffield remaining greater than Paulding. Differences in species diversity between Paulding Forest and Sheffield for early summer drift fence captures were statistically significant ($P = 0.006$) (Figure 15).

In the Late Summer, diversity of drift fence trap array captured species of snakes resulted in more similarity between sites (Sheffield =1.55, Paulding Forest 1.50), while equitability remained similar between sites (0.84 and 0.96 respectfully). However, when incidental captures are included in diversity calculations, diversity increases in Sheffield (1.96) while Paulding Forest decreasing slightly (1.48), and equitability remained similar between sites. No difference was found in species diversity between Paulding Forest and Sheffield during the late summer season (*P* = 0.87) (Figure 15).

When the trapping results of each WMA were pooled to combine all drift fence trap array captured snakes, Sheffield maintained greater species diversity (1.99) than Paulding Forest (1.52), with the continuing trend of similar equitability between sites (0.85 and 0.91 respectfully). Diversity of each WMA increased when incidental captures were included over the entire trapping season with Sheffield maintaining greater species diversity (2.12) than Paulding Forest (1.79), though with similar equitability. A statistical difference was found in species diversity between Paulding Forest and Sheffield in pooled season drift fence array captures (*P* = 0.005) (Figure 15).

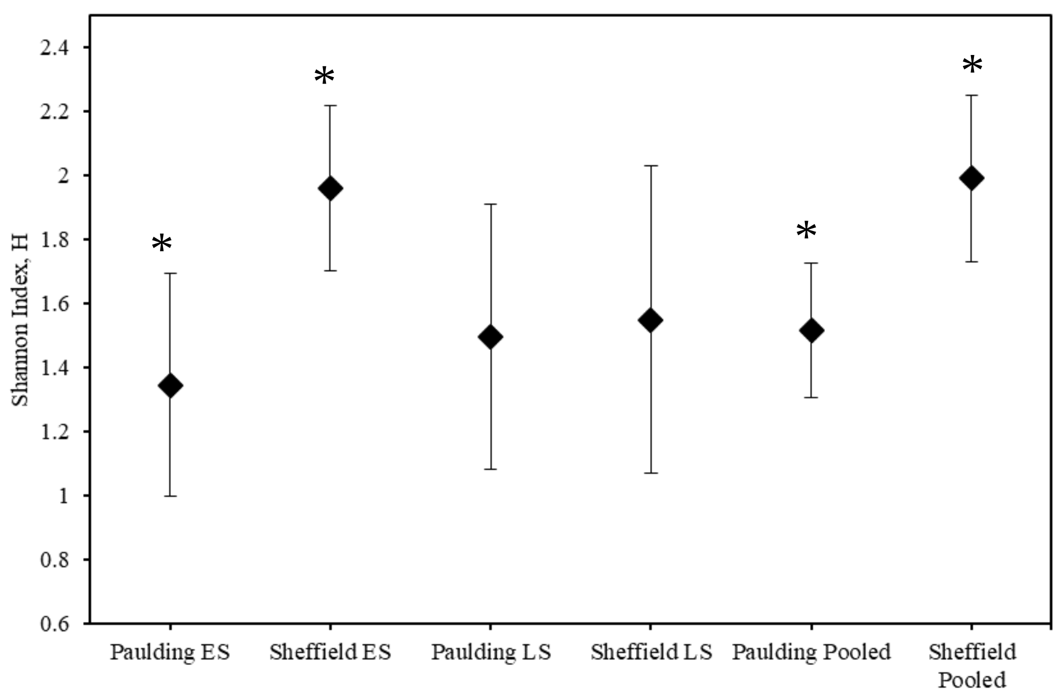

Figure 15. Shannon-Weiner Diversity (H) calculated from snakes captured drift fence arrays traps (±95% CI) in Paulding Forest and Sheffield during the Early Summer (ES) Season, Late Summer (LS) Season and pooled trapping data for both seasons in northwest Georgia from May 1 – October 13, 2018. * Indicates *P* < 0.05.

The calculated Shannon-Weiner Diversity (H) for each WMA for each trapping season, can be used to determine if diversity changed in the same WMA between the trapping seasons. Comparing the diversity of Sheffield during the early summer season and the late summer season, there was no significant difference in the calculated diversity (P =0.579). Paulding Forest also did not differ significantly between the trapping seasons (P= 0.161).

Simpson's Index of Diversity (D)

Species diversity was also examined using Simpson's Index of Diversity (D). Snakes captured from drift fence arrays during the early summer season in Paulding Forest WMA resulted a lower diversity (D = 0.68) than Sheffield WMA (D =088). When diversity is calculated including incidental captures, Sheffield still maintained greater species diversity (D = 0.89) than Paulding Forest (D = 078). A similar trend occurs during the late summer season where Sheffield, again, had greater diversity (D = 0.90) than Paulding Forest (D = 0.76). When incidental captures are included in diversity calculations, the diversity of both WMAs does not change. When drift fence array captures are pooled over both seasons for each WMA, the same trends are observed. Sheffield WMA maintains greater diversity (D = 0.86) than Paulding Forest (D = 0.76). Lastly, when captures from both drift fence arrays and incidental captures are pooled over both seasons for both WMAs, the trend continues with Sheffield having greater diversity (D = 0.87) than Paulding Forest (D = 0.81) (Table 4).

Simpsons Index of Diversity (D)				
	Paulding	Paulding w/ Incidental	Sheffield	Sheffield w/ Incidental
Early Summer				
Diversity (D)	0.68	0.78	0.88	0.89
Late Summer				
Diversity (D)	0.76	0.76	0.90	0.90
Seasonal Pooled				
Diversity (D)	0.76	0.81	0.86	0.87

Table 4. Simpsons Index diversity (D) calculated from individual snake captured with drift fence arrays in Paulding Forest and Sheffield WMAs in northwest Georgia during the early summer and late summer. Season pooled data included the individuals captured from both seasons. Calculations labeled Paulding w/ Incidental and Sheffield w/ Incidental is the combination of drift fence array and

Species Richness

Total species richness detected varied between seasons and between Paulding Forest and Sheffield. Figures 9, 10 and 11 show species detections each month of trapping, since the Late summer trapping began on August 13 and ended on October 13 the data is represented from August 13 to September 13 and September 14 to October 13 to prevent misrepresentation of monthly species richness since half of two months were surveyed. Species richness for captured individuals using drift fence array traps peaked in June in Sheffield at 7 species then began dropping during August into October (Figure 16). Paulding Forest maintained consistent species richness throughout the trapping season, dropping slightly during the month of June (Figure 16).

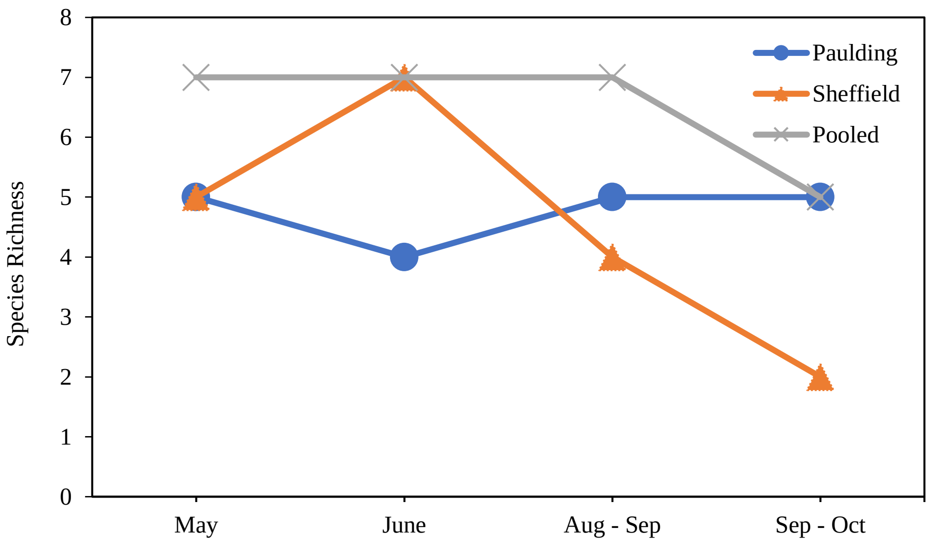

Figure 16. Seasonal snake species richness detected with drift fence trap arrays at Paulding Forest Wildlife Management Area and Sheffield Wildlife Management Area in Northwest Georgia during May – October, 2018. The late summer season was standardized into two months. Data from all arrays are pooled.

Species richness detected by incidental captures showed a decrease in richness during June to August and then a slight increase during late September and October in both Paulding Forest and Sheffield (Figure 17). Seasonal species richness when both drift fence arrays and

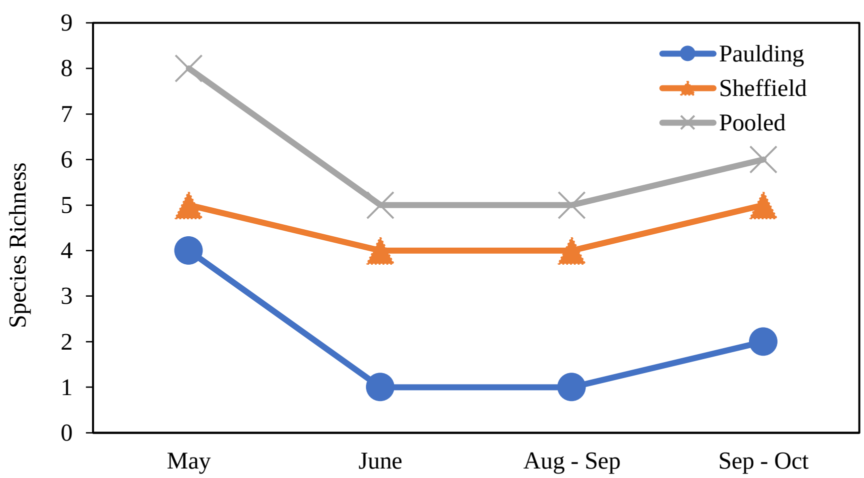

Figure 17. Seasonal snake species richness detected by incidental catpures at Paudling Forest and Sheffield during May – October, 2018. The late summer season was standardized into two months. Data from all incidental captures are pooled.

incidental captures again shows the trend that Paulding Forest maintained a somewhat consistent species richness, while Sheffield showed an increase in species richness between May and June with a similar increase from August to October (Figure 18).

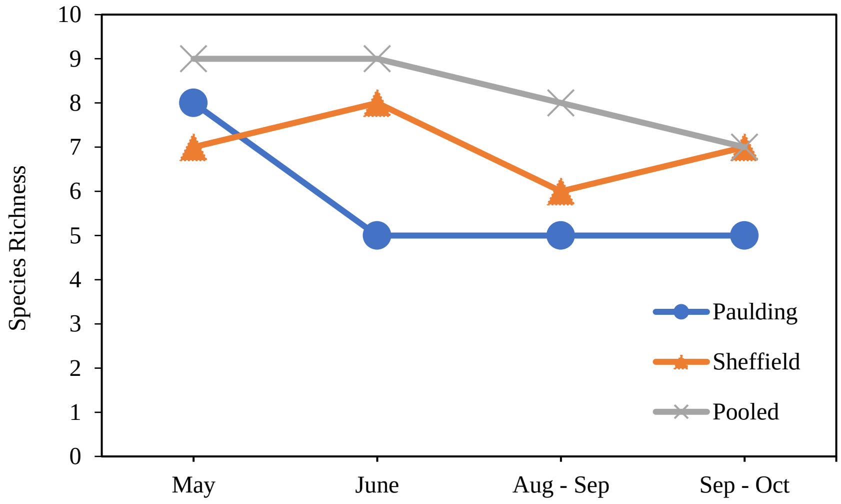

Figure 18. Seasonal snake species richness detected by a combination of drift fence trap arrays and incidental catpures at Paudling Forest and Sheffield during May – October, 2018. The late summer season was standardized into two months. Data from all incidental captures are pooled.

Species Accumulation

In order to discover how many species occur in the community, it was sampled continuously until no new species were found and a species accumulation curve reached an asymptote. Species richness accumulation curves were produced for Paulding Forest and Sheffield to show the accumulation of species within the snake community over the sampling seasons. In early summer, Paulding Forest reached an asymptote sooner than Sheffield. Additionally, Sheffield reached a higher species richness and the asymptote later than Paulding. During the late summer, Paulding Forest reaches a peak species richness of five species, all of which are considered a part of the upland snake community (Figure 19). Sheffield reached a peak species richness of eight, seven of which are part of the upland snake community (Figure 20).

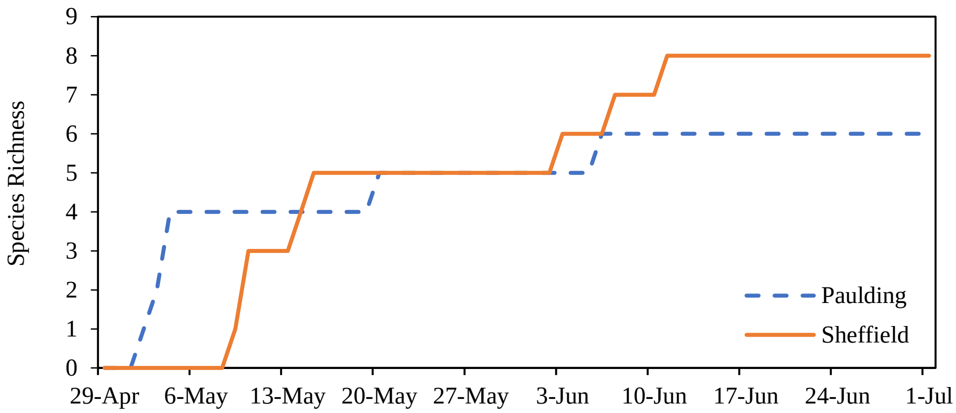

Figure 19. Species accumulation curves based in when a new species was detected over the early summer trapping season. These accumulation curves do not include incidental captures in species richness calculations.

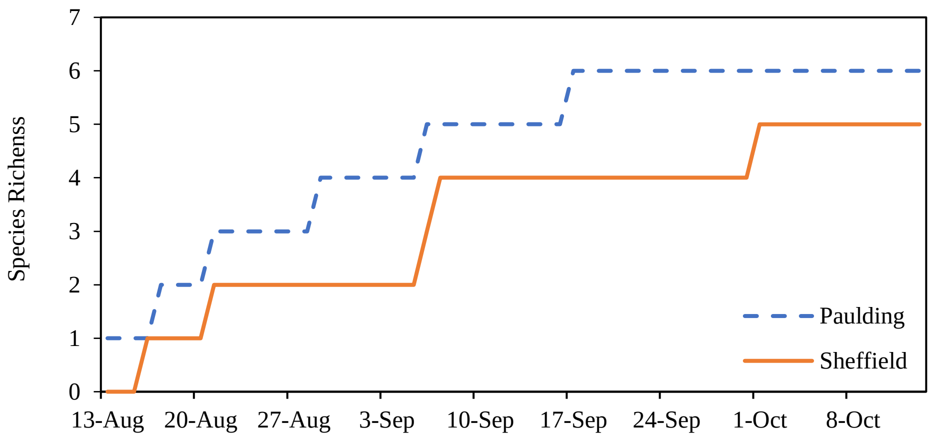

Figure 20. Species accumulation curves based in when a new species was detected over the late summer trapping season. These accumulation curves do not include incidental captures in species richness calculations.

The ninth species, common garter snake, is not a part of the upland snake community. By pooling species richness over the complete sampling effort, Paulding Forest reaches an asymptote during the early summer season with no more species detected by the late summer season. Conversely, Sheffield species richness accumulation slows after eight species are found in the early summer, then during the late summer an additional species was captured reaching a final species richness of nine (Figure 21). Incidental captures were not included in the species accumulation curves.

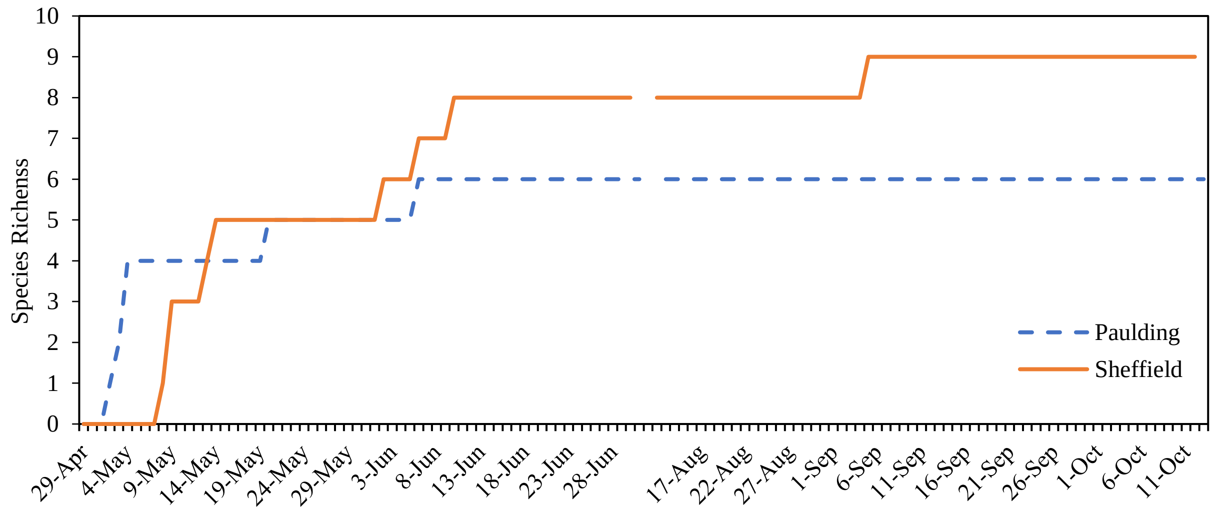

Figure 21. Species accumulation curves based on pooled accumulation of new species detected over both trapping seasons, early summer and late summer. These accumulation curves do not include incidental captures in species richness calculations.

Sample-Based Species Accumulation

Similar to the species accumulation curve is the Sample-based species accumulation curve, where instead of the number of samples taken compared to the number of species collected, the total number of individuals captured is compared to the number of species collected. In the early summer season, Paulding Forest had a total of 28 individuals captured, resulting in a species richness of six at the capture of the 21st individual. In Sheffield, a total of

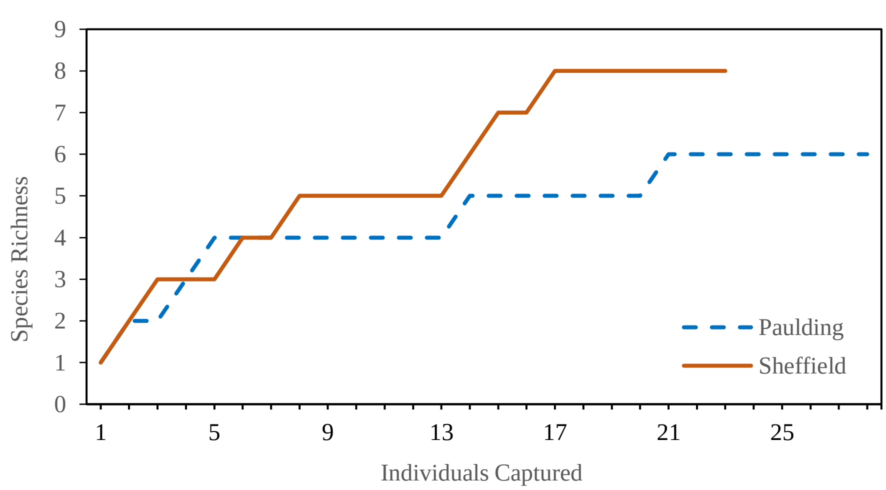

Figure 22. Sample Based species accumulation curves based in the early summer season when a new species was detected as additional individuals were captured. These accumulation curves do not include incidental captures in species richness calculations.

23 individuals were captured, resulting in a species richness of eight with the capture of the 17th individual (Figure 22).

During the late summer season, Paulding Forest had 17 captured individuals from six species. The sixth species was captured as the 13th individual. In Sheffield during this season, seven individuals were captured from five species. The fifth species was detected with the seventh individual captured (Figure 23). Individual pooled from both seasons for each WMA

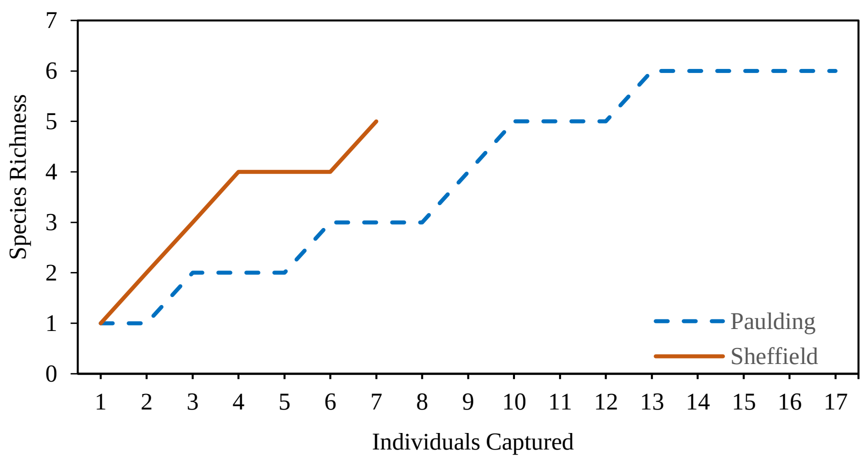

Figure 23. Sample Based species accumulation curves based in the late summer season when a new species was detected as additional individuals were captured. These accumulation curves do not include incidental captures in species richness calculations.

shows that a total of 45 individuals were captured from six species in Paulding Forest. The sixth species was captured as the 21st individual, and no new species were captured between individuals 21 and 45. Sheffield had 30 individuals from nine species from pooled captures. The ninth species captured in Sheffield was the 25th individual (Figure 24).

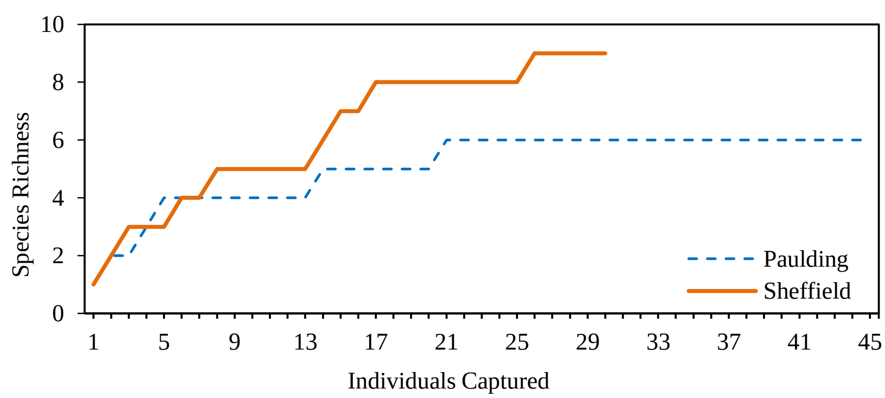

Figure 24. Sample based species accumulation curves based on pooled accumulation of new species detected as new individuals were captured during early and late summer season. These accumulation curves do not include incidental captures in species richness calculations.

Environmental Data

Environmental data was collected from the Georgia Forestry Commission, Fire Weather System (Georgia Forestry Commission). Using this resource, the daily maximum and minimum temperatures for every day and the daily precipitation accumulation in 2018 was collected. The daily maximum and minimum temperatures from January 1 to December 13, 2018 is graphically represented (Figure 25A). A subset of that data to represent the maximum and minimum temperatures during the early and late summer sampling seasons (Figure 25B).

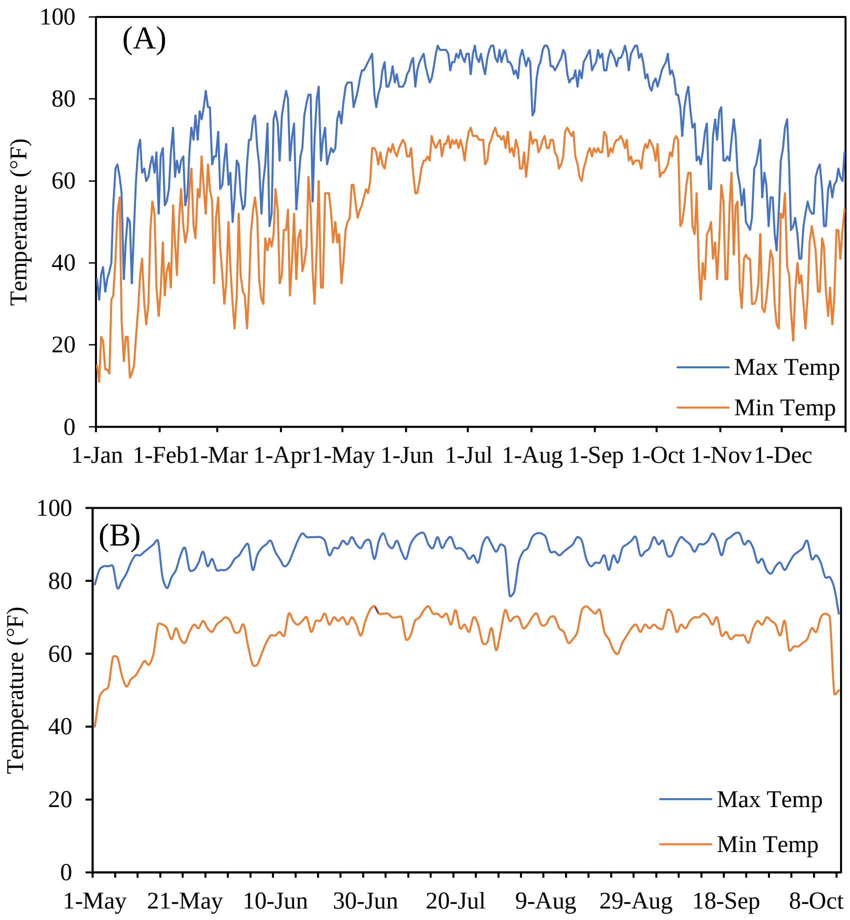

Figure 25. Daily Maximum and Minimum Temperatures from January 1, 2018 – December 31, 2018 (A) and daily maximum and minimum temperature during trapping season from May 1 – October 13, 2108 (B). Data collected from the Georgia Forestry Commission data base at the Dallas, Ga weather station.

During May 2018, the average maximum and minimum temperature were 84 °F and 60 °F respectfully, during June 89°F and 66°F, August was 87°F and 67°F, September was 89°F and 67°F, lastly October was 76°F and 53°F. The daily precipitation from January 1 to December 2018 was collected (Figure 26A). A subset of that data represents that daily precipitation during the sampling seasons from May 1 to October 13, 2018 (Figure 26B). During the months of May, June, August, September, and October, the average precipitation was as follows (0.15 in, 0.12in, 0.15in, 0.13in, and 0.22in respectively).

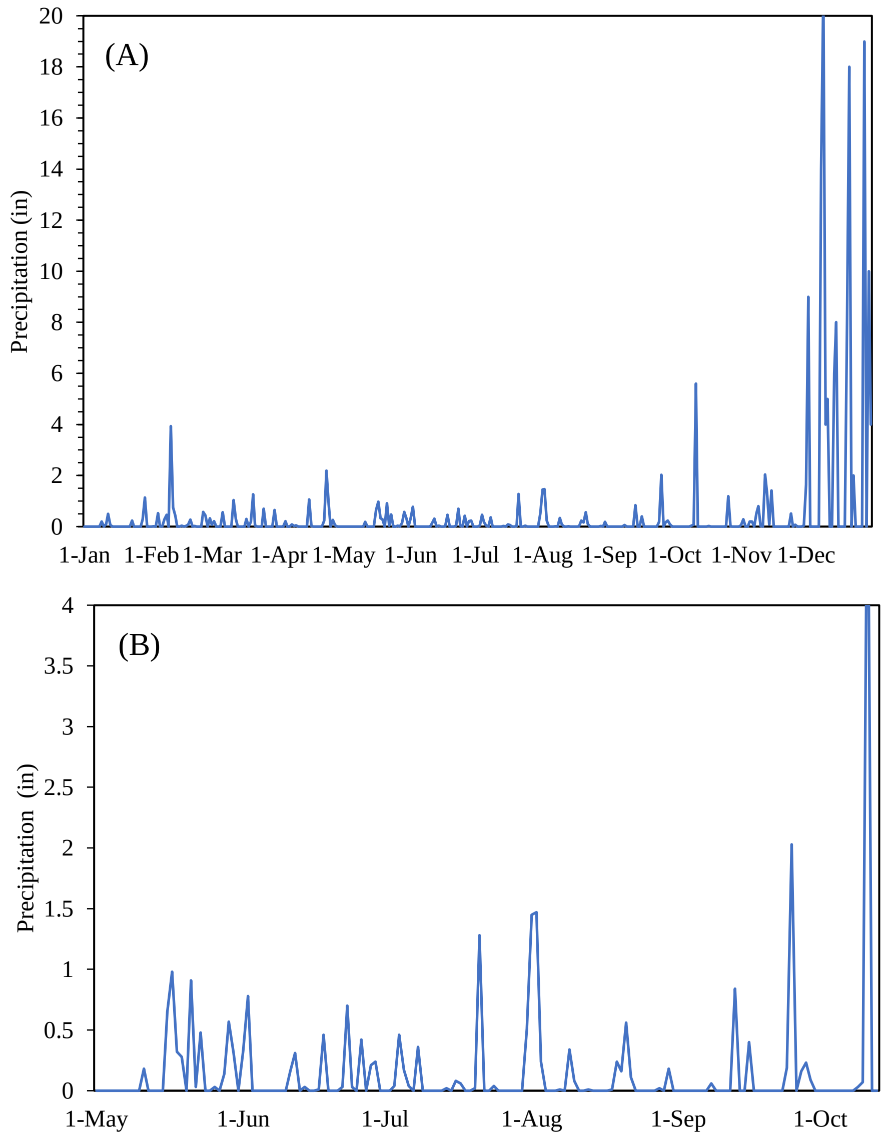

Figure 26. Daily Precipitation from January 1, 2018 – December 31, 2018(A) and Precipitation during trapping season from May 1 – October 13, 2018 (B) Data collected from the Georgia Forestry Commission data base at the Dallas, Ga weather station.

Other Vertebrate Captures

In addition to the snakes captured in drift fence array traps, other vertebrate species were captured as well. Non-target vertebrate captures were documented and recorded for Paulding Forest and Sheffield WMA. During the early summer season, 94 non-target individuals from vertebrate species were captured in trap arrays. In Paulding Forest, 44 non-target vertebrates were captured including five individuals from three reptile (non-snake) species, nine individuals from four amphibian species, 30 individuals from seven mammalian species, and no avian species. In Sheffield, 50 non-target vertebrates were captured including 13 individuals from three reptile (non-snake) species, 13 individuals from four amphibian species, 21 individuals from six mammalian species, and three individuals from two avian species. A total of 55 non-target vertebrate individuals were captured in drift fence arrays during the late summer season. In Paulding Forest, 29 non-target vertebrates were captured including seven individuals from two reptile (non-snake) species, one individual from one amphibian species, 20 individuals from four mammalian species, and one individual from an avian species. In Sheffield, 26 non-target vertebrates were captured including one individual from one reptile (non-snake) species, nine individuals from three amphibian species, 16 individuals from six mammalian species, and no avian species (Table 5).

		Early Summer		Late Summer	
		Paulding Forest	Sheffield	Paulding Forest	Sheffield
Scientific Name	**Reptile Species**	**Trapped**	**Trapped**	**Trapped**	**Trapped**
Anolis carolinensis	Green anole	0	0	2	0
Aspidoscelis sexlineata	Six-lined racerunner	1	0	0	0
Plestiodon fasciatus	Common five-lined skink	0	2	0	0
Plestiodon laticeps	Broadhead skink	1	2	0	1
Sceloporus undulatus	Eastern fence lizard	3	9	5	0
	Amphibian Species				
Anaxyrus americanus	American toad	5	8	0	7
Anaxyrus fowleri	Fowler's toad	2	4	0	0
Lithobates clamitans	Green frog	1	1	1	1
Lithobates sphenocephalus	Southern leopard frog	1	0	0	1
	Mammalian Species				
Sylvilagus floridanus	Eastern cottontail rabbit	0	0	0	1
Tamias striatus	Eastern chipmunk	4	1	1	0
Microtus pennsylvanicus	Meadow vole	3	5	0	2
Ochrotomys nuttalli	Golden mouse	1	7	0	2
Peromyscucs sp.	Deer mouse	7	1	4	4
Sigmodon hispidus	Hispid cotton rat	9	1	10	5
Neotoma magister	Allegheny wood rat	4	0	5	2
Blarina sp.	Short-tailed shrew	2	6	0	0
	Avian Species				
Toxostoma rufum	Brown thrasher	0	2	0	0
Thryothorus ludovicianus	Carolina wren	0	1	1	0
	Total	44	50	29	26

Table 5. Drift fence array captures of non-target vertebrates at Paulding Forest and Sheffield WMAs in northwest Georgia during the early summer (May 1 – July 1) and the late summer (August 13 – October 13), 2018.

DISCUSSION

Previous to this study, knowledge of upland snake communities in montane longleaf pine habitats was limited. Total species richness and relative abundances differed significantly between Sheffield and Paulding Forest, while the proportion of individuals for each species within the upland snake community did not differ significantly. Overall, the use of rotational prescribed fire and overstory thinning methods used for longleaf pine restoration in Northwest Georgia are supporting diverse upland snake species communities. The results of this study indicate that snake species are frequently occupying habitats undergoing intensive longleaf pine restoration management. 11 snake species were considered a part of the upland snake community that could be present in Paulding Forest and Sheffield WMAs. Nine snake species were captured in drift fence arrays in Sheffield, while only six snake species were captured in Paulding Forest. Incidental captures of snakes resulted in nine snake species captured in Sheffield and eight snake species captured in Paulding Forest. When considering only the 11 upland snake species, both WMAs detected eight of these species using either method.

General Site Trends

Detected community composition varied somewhat between Paulding Forest and Sheffield and varied during between trapping seasons. Greater species richness of trapped snake species was observed in Sheffield than in Paulding Forest during the early summer season of trapping. The Shannon-Weiner Diversity calculated for snake species captured during this season was significantly greater in Sheffield than Paulding Forest. Simpsons diversity also supported this finding as this diversity index was greater in Sheffield than Paulding forest. Proportion of individuals captured for each species were not significantly different. The regional differences decreased during the late summer trapping seasons. Upland snake species richness becomes more similar between Paulding forest and Sheffield during this season. The Shannon-Weiner diversity becomes more similar, and though Sheffield maintains a greater diversity, the difference is not significant. Calculation of Simpsons diversity showed that more individuals from few species were found in Paulding Forest, while Sheffield had a greater diversity of species captured.

Pooled data from both seasons of trapping supports the constant trend that Sheffield WMA maintained greater species diversity than Paulding WMA, even considering that fewer individuals were captured in Sheffield than in Paulding. The pooled drift fence array capture data used to calculate Shannon-Weiner diversity in Sheffield was found to be significantly higher than diversity detected in Paulding Forest. The differences observed may be a result of forest management history. The habitats with more recent silviculture history in Paulding Forest showed less species richness and upland snake species diversity, while Sheffield has mature longleaf pine habitats that have not been disturbed by logging in the previous half-century. Management to restore montane longleaf pine habitats has been implemented in both WMAs, but the history of land use may be influencing upland snake communities.

Trapping seasons were conducted during what is expected to be the peak activity periods for most snake species. The spring is peak activity for mating activities, and more individuals are likely to be captured while searching for mates. In the late summer, juveniles are hatching, and adults are moving to their over-wintering sites (Jensen et al., 2008). Shannon-Wiener diversity calculations showed that both WMAs did not significantly differ in the diversity of snake species captured between the early summer and late summer trapping sessions. Proportion of total individuals captured for each different species did not differ significantly for Paulding Forest between the early and late summer trapping sessions. However, the same comparison for

Sheffield resulted in a significant difference in the proportion of individuals for each species captured. This was most likely due to the low number of captured individuals in trap arrays for Sheffield WMA.

In both WMAs, venomous snake species were captured by both methods consistently in both sampling seasons. These species did not show a seasonal shift in activity observed with other species, as evidenced by the similar captures rates. This likely due to the fact that both copperheads and timber rattlesnakes will reproduce in both spring and the fall while most other snake species captured in this study reproduce in the spring only (Jensen et al., 2008).

Detected community composition varied between Paulding and Sheffield; however, most species that were captured occurred in both WMAs. The proportion of individual species in the communities did differ between WMAs. During the early summer seasons, black racers made a disproportionally large proportion of total captures. Although traps in Paulding WMA had a greater number of overall captures, they were disproportionally composed of black racers. During this season, more Eastern hognose snakes were captured in Sheffield WMA. An common garter snake was captured exclusively in Sheffield WMA. Considering this species is mostly associated with moist habitats, this was a juvenile individual that most likely was exploring new habitats. Additionally, Northern pine snakes were exclusively captured by drift fence in Sheffield WMA. However, with the additional method of visual encounter surveys, Northern pine snake was also found in Paulding Forest. This observation supports the idea that multiple methods should be employed when conducting studies of snake species presence and diversity.

Multiple Method Utilization

This study utilized a modified drift fence and funnel trap design that targeted larger bodies snakes. That likely caused a bias against capturing smaller, litter-dwelling species; even when they would enter a trap, the hardware cloth would most likely allow smaller individuals to leave. Most species captured using the drift fences and funnel traps were heavier-bodied snakes and often appeared to have a larger maximum body girth than the diameter of the funnel. This study's methodologies did slightly differ from other community sampling studies in that only a single fence was used at each side with a funnel trap at the distal ends of the fence. A trap was not installed at the center of the fence like other studies. The funnel traps bisected the fence to prevent an individual from passing around the fence without entering the funnel. The funnel was also kept backfilled with soil to prevent any deterrence if they encountered a foreign object. Although these modifications to traditional drift fence and funnel trap designs overcame some traditional biases against larger-bodied snakes, it did not overcome others.

Including the additional survey methods of road cruising and visual encounter surveys resulted in an overall increase of species detection and more accurately reflects relative species richness. For every species that was captured in a drift fence and funnel trap array, additional individuals were captured incidentally as well, although some snake species captured as incidentals were not captured using drift fence arrays. If only captures from drift fence arrays were considered, it would lead to inaccurate conclusions of presence for multiple species captured during this study. An example of this is the detection of Northern pine snakes in this study. Only one individual was captured in a drift fence in Sheffield while another was found as an incidental capture in Paulding Forest. Considering this species is likely in low densities and difficult to detect, the addition of the incidental capture led to a better survey of species presence in both Paulding Forest and Sheffield. The additional method was able to detect species that the traps were biased against, such as the captures of rough green snake and scarlet kingsnake. Of course, utilizing multiple methodologies does not automatically result in 100% detection. These results do not account for variable detection probabilities. For example, these methods were only conducted in upland habitats where aquatic snake species are unlikely to be detected. These methods can confirm the presence of a species at a site; however, non-detection does not indicate that a species does not occur in that area (Mackenzie et al., 2002). Total captures in this survey were relatively low compared to many of similar studies, likely due to fewer sample locations. Even with a low number of sampling locations, these methods were able to detect a highly secretive species, the Northern pine snake.

Undetected species

Prior to this survey effort to document snakes in Paulding Forest and Sheffield WMA, no other dedicated survey effort had taken place. The 2007 Bio Blitz which resulted in 22 new county records for multiple reptile and amphibian species did not result in any captures or county records of larger bodied snakes. These data support the suggestion that this region of Georgia and, specifically, these two WMAs have remained understudied and under-surveyed for the upland snake community. This community is expected to be made up of 11 species of snakes: black racer, Eastern hognose, mole kingsnake, Eastern kingsnake, coachwhip, corn snake, gray rat snake, Northern pine snake, copperhead, timber rattlesnake, and pigmy rattlesnake. Only eight of these species were detected within the WMAs with one or both of the survey methods used in this study. The species that were not detected in this study were the coachwhip, mole kingsnake, and pigmy rattlesnake. This study took place at the Northern extent of the coachwhip range, and observations of this species have been recorded in half of the neighboring counties.

Anecdotally, local private property owners and hunters have mentioned seeing coachwhips in the area, but they were not detected during this survey. The mole kingsnake, a species that lives most of its life underground, was not detected using either method during this survey, though records indicate their presence within Paulding and Polk counties. Finally, the pigmy rattlesnake was not detected during this study, which took place on the northern extent of this species range. Anecdotally, the species has been found in Paulding WMA from locals and GaDNR Staff accounts, but this species was not detected in this study. Like most rattlesnakes, this species is an ambush predator, and in addition to its small size is unlikely to encounter the drift fence and enter the funnel trap.

Conclusions

The limited data addressing snake communities in managed forests of the Southeast in combination with the documented declines in many reptile species indicate the need for continued research and monitoring. The montane longleaf pine habitats in Paulding Forest and Sheffield appear to support a rich and diverse upland snake community. Wildlife management areas become increasingly important as reserves for wildlife as many habitats are lost or converted for anthropogenic use. To maintain upland habitats, however, wildlife and forests managers rely on anthropogenic intervention. Though Sheffield and Paulding differ greatly in their forest management history, current forest management practices are similar. Management in both areas have the same end goal of sustainable upland montane longleaf pine habitats. Accordingly, this management is expected to benefit species that require open upland habitats. Based on the findings in this study, the upland snake communities appear to be diverse in both Paulding Forest and Sheffield. Diversity and equitability estimates calculated for Sheffield WMA are reaching levels predicted by latitudinal gradients of richness and diversity of the

Southeast (Vitt, 1987; Dalrymple et al., 1991). While Paulding Forest WMA estimates of diversity are currently below the levels predicted by the latitudinal gradients, equitability is approaching predicted values.

In order to continue understanding the snake communities in these managed habitats, this study should be expanded to include additional survey sites in subsequent years. This will also potentially allow for sufficient sampling effort that will discover the upland snakes that were not detected in this study. Additionally, conducting similar surveys in the hardwood forest drainages that are a characteristic of the montane longleaf pine ecosystem will target the snake community that favors aquatic habitats.

MANAGEMENT IMPLICATION

Paulding Forest and Sheffield Wildlife Management Areas both support a rich and diverse upland snake community. This conclusion is supported by the data from this study even with the caveat that trapping biases were present and species richness and diversity estimates are only from a single trapping season. Implementation of forest management practices by the Georgia Department of Natural Resources and The Nature Conservancy is playing a critical role in the maintenance of existing upland longleaf pine habitats and the restoration of altered habitats. These forest management practices will not harm the upland snake communities in these areas and could potentially benefit them. In Sheffield, the return of fire through prescribed burns is a critical tool to revert and maintain the mature longleaf pines already present within its boundaries. These sites are more characteristics of montane longleaf pine habitats and provide other restoration efforts a reference habitat. In Paulding, prescribed fire in combination with removing loblolly pines and replanting longleaf pines will be critical for long term survival of fire-tolerant species. In both WMAs, reintroduction of fire maintains open-canopy, savannah-like vegetation structure where fire-evolved reptiles and amphibians inhabit (Means and Campbell, 1981; Means et al., 2004). This study suggests that forest management practice taking place at Paulding Forest and Sheffield Wildlife Management Areas, such as prescribed fire and hardwood removal, has likely not had negative impacts on the upland snake community. The restoration efforts may even be benefiting upland snake communities in both WMAs, but more research is needed to establish this trend.

One of the important findings of this study is that a population of Northern pine snakes exists within the boundaries of these state-owned lands. This species had not been observed within the WMAs for many years, and it was doubted this species of concern was present in the WMAs (J. Jenson, personal communication, 2017). Individuals of this species were even found directly next to habitats that in just the previous year experienced a clear cut to plant longleaf pines. The second individual of this species was detected in a habitat that experienced a prescribed fire during winter 2016-2017, suggesting that the forest management practice is providing suitable habitats for this specialist snake species. Both of these occurrences support that forest management for maintaining the montane longleaf pine community is not harming and may be benefiting this at-risk species.

Continuing research at these sites to document species presence will be necessary to determine the presence of undocumented upland snake species not found during the study. Adding more sites to survey will also begin to determine seasonal activity patterns of upland snake species. This study on the upland snake communities has since expanded to include an additional 18 sites under the direction of one of the collaborators of this project (Project Pine

Snake). Other taxonomic groups, such as plants, avian, or mammalian communities, should also be studied within these habitats in order to understand a more complete picture of how restoration management is influencing communities. Bat species studies in the same habitats also indicated there was not a negative response to restoration practices (Hunt and McElroy, 2017). Currently, studies on the plant communities have begun in these areas. This study was able to provide baseline community data and snake species occupying these managed habitats in Northwest Georgia. Continuing community research in these montane longleaf pine habitats is necessary to meet conservation objectives, including protecting the ecological integrity of the snake communities.

NATURAL HISTORY NOTES and NOTABLE FINDINGS

INTRODUCTION

During the planning, exploratory field excursions, and subsequent execution of surveys for upland snakes, other notable observations and discoveries took place. It is inevitable that while conducting field surveys, regardless of the target organisms, other interesting findings will be discovered if biologists remain observant. The best way to describe these occurrences is serendipitous discoveries. These are discoveries that happen by chance because someone was in the right place at the right time to observe a behavior, a new species, or rediscover a species long thought to be gone. This section serves to document these serendipitous findings that occurred while the main focus of conducting surveys and checking drift fence arrays for upland snake species communities took place.

SPOTTED SALAMANDER (*Ambystoma maculatum*)

The spotted salamander (*Ambystoma maculatum*) is a native Georgia species that mainly occurs in habitats above the fall line in Georgia, though some population are known in the coastal plain. This is one of the largest species within the genus *Ambystoma* in Georgia. Its distinctive coloration includes two rows of round yellow spots that extend from the head to the end of the tail. Although suitable habitat for this species is bottomland hardwood forests around floodplains, occasionally they will also be found in upland hardwood habitats when suitable breeding sites are present. Adults spend a majority of the year underground, only emerging to migrate to breeding sites in January and reaching their peak breeding in February.

Preliminary surveys to determine target locations to install drift fences and funnel traps were conducted, and surveyors were opportunistically searching for reptiles and amphibians. The target habitats were upland longleaf pine habitats under forest management that includes hardwood thinning, prescribed fire, and herbicidal treatments. On November 14, 2017, during one of the preliminary surveys, an upland longleaf pine habitat in Sheffield WMA was being surveyed. A large fallen pine tree log was flipped for any hiding reptiles or amphibians. Under this log, a large female spotted salamander was found above ground using this log for cover. This female had a snout-to-vent length of 105 mm and 200 mm total length. The habitat surrounding this observation included an open canopy dominated by longleaf pines, a midstory of loblolly pine, and an understory of bluestem grasses and blackberry.

This observation deserved a special mentioned because October is long before the usual breeding season begins, so this observation was outside the observed behavior for this species. Montane longleaf habitats are a unique ecosystem because of the integration of species native to mountains habitats and a those native to drier longleaf pine habitats. In this ecosystem, species utilizing the available habitats are not well understood. As mentioned in Chapter 1, reptiles and amphibians in montane longleaf pine habitats are understudied. This observation demonstrates that *Ambystoma* salamanders are utilizing dry montane longleaf pine habitats, at least on occasion.

SLENDER GLASS LIZARD (*Ophisaurus attenuatus*)

Glass lizards are a unique group that lack limbs in convergence with snakes but retain many characteristics of “true lizards”. They retain external ears and moveable eyelids. Many species can reach 100 cm or more in total length; however, unlike snakes a majority of this length is attributed to the tail. These tails are fragile and often break off, similar to other lizards, to distract potential predators and allow for escape. A distinctive morphological trait that sets glass lizards apart from snakes and other lizards is a lateral fold of skin along each side of the body. Species in this family often inhabit open, grassy areas and coastal sand dunes. Glass lizards are seldom found, often spending much of the time underground or under cover. Georgia has four native species of glass lizards, though only two species occur in the Piedmont and mountain ecoregions of Georgia, the slender glass lizard (*Ophisaurus attenuatus*) and eastern glass lizard (*Ophisaurus ventralis*) (Jensen et al., 2008).

As described in previously, while checking drift fence arrays surveyors were watching for snakes basking or crossing on roads. On June 18, 2018, while walking to a trap array on an old dirt logging road within Paulding Forest WMA, a glass lizard was spotted basking on the road at approximately 10:15am. Paulding Forest WMA crosses the county line between Paulding County and Polk County, and this finding occurred within Polk County. Habitat in the surrounding area where the glass lizard was discovered had in the previous year had been clear cut and planted with immature longleaf pine seedlings. This habitat developed into an open grassland dominated by bluestem grasses (*Andropogon sp.*), immature longleaf pines, and blackberry shrubs (*Rubus sp.*). The other adjacent habitat was mixed hardwood-pine forest. The National Audubon Society Field Guide to Reptiles and Amphibians (Behler and King, 1979), Amphibians and Reptiles of Georgia (Jensen et al. 2008), and Peterson Field Guide to Reptiles and Amphibians: Eastern and Central North American (Collins et al., 1998) were used to confirm the glass lizard's identification as a Slender Glass lizard (*O. attenuatus).* This identification was further confirmed by Georgia Department of Natural Resources Senior Wildlife Biologist, John Jensen (J. Jensen, personal communication, 2018). This individual had a snout-to-vent length of

24 cm, a tail length of 72 cm, total length of 96 cm and weighed 83 g. This individual represented the first county record for *O. attenuatus* within Polk County, Georgia. A photo of this individual was provided to the Georgia Museum of Natural History and received a photo voucher number (GMNH 51893). This county record was published by the Society for the Study of Amphibians and Reptiles in their peer-reviewed quarterly journal Herpetological Review within the section Geographic Distributions in the December 2018 edition (Gulsby and McElroy, 2018).

NORTHERN PINE SNAKE (*Pituophis melanoleucus melanoleucus*)

In Georgia, pine snakes occur in northern portions of the state and the southern portions, avoiding the Piedmont ecoregion. The coastal plain populations are known to be the Florida pine snake subspecies (*P. m. mugitus*), and though they are an uncommon species to encounter, their preferred habitats are known (Jenson et al., 2008). These populations prefer xeric habitats with sandy soils, often associated with either gopher tortoise (*Gopherus polyphemus*) burrows or small mammal burrows being used as shelter. Pine snakes outside of the coastal plain are rarely encountered, and what is known about their habitat preferences is limited. Morphologically, pine snakes have an enlarged rostral scale indicative of life below ground, for moving soil and debris. It has been observed that pine snakes will occasionally excavate their own burrows and nest chambers (Moore, 1893; Zappalorti et al., 1983), but these burrows are often well hidden or overlooked. Many of the records of this behavior come from studies done on Northern pine snake is the New Jersey Pine Barrens (Burger and Zappalorti, 1986; Burger and Zappalorti, 1991; Burger and Zappalorti, 1992). In other portions of the Northern pine snake range, nesting behavior and documentation is limited to three record from the Sandhills region of North Carolina (Beane and Pusser, 2007; Beane and Pusser, 2012).

On 24 June 2018, while checking on a drift fence array located in Paulding Forest WMA, a newly excavated burrow was found at 10:00 AM in the side of an embankment of soil at the edge of an old logging deck site. Its location was adjacent to the trail created that led to the nearest trap array. This spot was passed daily since installing and activating the drift fence arrays; therefore, this burrow was known to have been created within 24 hours of the day it was observed. A small dirt apron was observed at the entrance of the burrow, similar in shape to ones created by gopher tortoises at the entrance of their burrow. This burrow was inspected and was found to be occupied by an animal. Though, only the tail of this animal was visible, its identity could not be determined to be either mammalian or reptilian. Thought it is recorded that pine snakes will dig their own burrows (Jenson et al., 2008; Moore, 1893; Zappalorti et al., 1983), the likelihood this burrow being created by a pine snake seemed unlikely. The following morning (25 June 2018) while checking traps surveyors approached the burrow slowly at 10:30 am in the event the animal that created the burrow was nearby. A Northern pine snake was observed in the burrow with its head sticking out of the entrance. In collaboration with Project Pine Snake, the burrow this snake created was excavated, and it was discovered that this was a young female Northern pine snake and a nest chamber containing six adherent eggs.

The female found with her six eggs represents one of two occurrences of Northern pine snakes found during this study. The second Northern pine snake was captured in a drift fence array on 6 September 2018 in Sheffield Wildlife Management Area. Due to unfortunate circumstances, this individual escaped the trap through the funnel before any morphometric data could be collected. Before escaping, this individual was observed displaying the typical pine snake behavior of inflating their body and hissing loudly. This individual appeared healthy and showed no external symptoms of diseases.

TRAP AVOIDANCE DEMONSTRATED WITH A CORN SNAKE (*Pantherophis guttatus*)

On 8 October 2018, a juvenile corn snake (*Pantherophis guttatus*) was captured using the drift fences array traps. This individual was used to document the process of a snake encountering the drift fence and its subsequent attempts to pass it. The snake was placed in front of the funnel adjacent to the drift fence. The individual moved down the fence, and when it reached the entrance of the funnel it hesitated and turned away from the funnel to move around the trap. The individual was captured before escaping into the grass and was placed again adjacent to the fence. The snake again hesitated and turned away from the funnel. On one attempt, the snake reached the funnel and found that it could go into the funnel but around the fence to come out on the other side of the fence. Another attempt, the snake entered the funnel far enough to reach the end of the funnel then hesitated and turned around to exit the funnel. This was repeated multiple times and each time the snake avoided entering the funnel of the trap. The snake was moved to the opposite end of the fence and placed in front of the second funnel trap. The snake was placed adjacent to the fence again, facing the direction of the funnel traps. The snake moved along the fence and entered the funnel trap with no hesitations. Underlying visual or olfactory cues many be alerting the snake to a previous experience in a trap, leading to an increased avoidance.

INTEGRATION OF THESIS RESEARCH

This study integrated a variety of biological disciplines and used a wide variety of techniques. The fundamental ecological question that this study intended to answer was if land management practices are affecting or changing reptile communities. To begin answering this question, active survey techniques were used to sample the upland snake community in areas undergoing ecological restoration. This required an understanding of preferred habitats for this community of reptiles to increase the likelihood of detecting this generally reclusive community and an ability to properly and accurately record species identification and morphometric data. Ecological field techniques were used to collect the data needed for the study. Data collection required knowledge of proper construction of snake traps, locating and setting up snake traps, map reading, knowledge of GPS, snake species identification, snake morphology and behavior, proper snake handling, measurement techniques, field data collection and recording protocols (field notebook), interaction with local people and forest managers, and a knowledge of how to collect and preserve samples for DNA analysis (an extension of this project that is currently underway). This project also required integration of ecological data with real-world management goals. The project necessitated knowledge of the longleaf pine ecosystem, its history, and how local forest management agencies are currently managing sites to restore longleaf pine habitat. Overall, techniques from ecology, animal biology, morphology, behavior, genetics, and biostatistics were integral to the completion of this research.

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APPENDIX

Scientific Name	**Common Name**	**Preferred Habitat**
Agkistrodon contortrix	**Copperhead**	**Occupy most upland forested habitats, preferring rocky and wooded hillsides**
Carphophis amoenus	Eastern Worm Snake	Piedmont and mountains in hardwood forests; found often under rocks, logs, and debris
Cemophora coccinea	Scarlet Snake	Pine, hardwood, and mixed pine-hardwood woodlands with sandy or loamy soils; often found under rocks and logs
Coluber constrictor	**Black Racer**	**Found in a variety of habitats; often in open areas such as pine and hardwood forests with thin undergrowth and around edges of wetlands**
Crotalus horridus	**Timber Rattlesnake**	**Found in upland areas surrounding swamps and river floodplains, hardwood and pine forests, and mountainous areas**
Diadophis punctatus	Ringneck Snake	Occupy a variety of habitats; often under rocks, logs, and other ground cover
Farancia abaucura	Mud Snake	Aquatic habitats with slow-moving, acidic and swamps and similar wetland habitats
Heterodon platirhinos	**Eastern Hognose**	**Prefer upland woodlands including sandhills, mixed oak-pine forests, avoiding densely wooded habitats and wet areas**
Lampropeltis calligaster	**Mole Kingsnake**	**Upland forests, often associated with longleaf pine savannas**
Lampropeltis getula	**Eastern Kingsnake**	**Strongly terrestrial, occupying hardwood and pine forests near aquatic habitats**
Lampropeltis elapsoides	Scarlet Kingsnake	Pine flatwoods often in sandy soils of the coastal plain or clay-based soils of the Piedmont
Masticophis flagellum	**Coachwhip**	**Often occurring in dry habitats; using rotting pine stumps, root holes and burrows of other animals' refuge**
Nerodia erythrogaster	Plain-bellied Watersnake	Almost always associated with aquatic habitats
Nerodia sipedon	Northern Watersnake	Often found basking on rock and logs over water and hunting in aquatic habitats
Opheodrys aestivus	Rough Green snake	Occupies arboreal habitats covered in the branches of vegetation; often near the water's edge
Pantherophis guttatus	**Corn Snake**	**Found in a variety of habitats such as sandhills, pine forests, mixed pine-hardwood forests; habitats with pine dominated habitats**
Pantherophis spiloides	**Gray Rat Snake**	**Wooded habitats containing large trees including hardwoods, pine, mixed forests, and wetlands**
Pituophis	**Northern Pine Snake**	**Outside of the coastal plain, habitats include hardwood and mixed oak-pine**

melanoleucus melanoleucus		**forests**
Regina septemvittata	Queen Snake	Rarely found far from water and often are found in open, sunny areas under flat rocks and undercut banks
Sistrurus miliarius	**Pigmy Rattlesnake**	**Dry sandhills and longleaf pine forests to seasonally flooded pine flatwoods**
Storeria dekayi	Brown Snake	Found in both hardwood and pine forests; in dry areas, near freshwater, hiding under decaying leaf litter
Storeria occipitomaculata	Red-Bellied Snake	Preferring shaded hardwood and pine forests, often hiding under below ground or under debris and avoiding open-field habitats
Tantilla coronate	Southeastern Crowed Snake	Common in many habitats including sandy areas and forested habitats, highly fossorial often found under litter and woody debris
Thamnophis sauritus	Eastern Ribbon Snake	Found around many aquatic habitats, rarely moving away from these habitats
Thamnophis sirtalis	Common Garter Snake	Most often found in moist habitats, edges around wetlands, few individuals move away from water
Virginia valeriae	Smooth Earth Snake	Inhabit pine and hardwood forests, often hiding under leaf litter, rock, and logs

The snake species with predicted ranges that overlap with Paulding Forest and Sheffield WMAs, in Paulding County, Georgia. Included is a description of preferred general habitats characteristics for each species and microhabitats selections. The 11 species that are included in the description of upland snake species community are in bold.

LITERATURE CITED

Alavalapati, J.R.R., G.A Stainback, and D.R. Carter. 2002. Restoration of the Longleaf Pine Ecosystem on Private Lands in the US South: An Ecological Economic Analysis. Ecological Economics 40(3): 411-419.

Allender, M. 2018. " Swab Collection Protocol for Snakes with SFD" University of Illinois.

Allender, M.C., D. Bunick, E. Dzhaman, L. Burrus, and C. Maddox. 2015. Development and Use of a Real-time Polymerase Chain Reaction Assay for the Detection of *Ophidiomyces ophiodiicola* in Snakes. Journal of Veterinary Diagnostic Investigation 27(2): 217–220.

"Atlanta Herpetology Club BioBlitz." *Atlanta Herpetology Club*, 2007, www2.gsu.edu/~wwwahc/bioblitzspr2007.html#County_Records.

Barrett, K., and C. Guyer. 2008. Differential Responses of Amphibians and Reptiles in Riparian and Stream Habitats to Land Use Disturbances in Western Georgia, USA. Biological Conservation 141(9). 2290-2300.

Beane, J.C., and L.T. Pusser. 2007. *Pituophis melanoleucus melanoleucus* (Northern Pine Snake): reproduction. Herpetological Review 38(4):469.

Beane, J.C., and L.T. Pusser. 2012. Observation on Northern Pine Snake (*Pituophis M. Melanolucus*) Nesting and Behavior in the North Carolina Sandhills. Journal of the North Carolina Academy of Science 128 (3/4): 92-94.

Behler, J.L., F.W. King. 1979. National Audubon Society Field Guide to Reptiles and Amphibians: North America. Knopf, 1.

Brockway, D.G., K.W. Outcalt, D.J. Tomczak, and E.E. Johnson. 2005. Restoration of Longleaf Pine Ecosystems. General Technical Report SRS-83. United States Department of Agriculture, Forest Service, Southern Research Station 83: 34.

Brunjes, K.J., K.V. Miller, M.W Ford, T.B. Harrington, and M.B. Edwards. 2003. Effects of Thinning and Herbicide Application on Vertebrate Communities in Longleaf Pine Plantations. In: Proceedings of the Annual Conference Southeast Association Fish and Wildland Agencies 57: 252-267.

Burgdorf, S.J., D.C. Rudolph, R.N. Conner, D. Saenz and R.R. Schaefer. 2005. A Successful Trap Design for Capturing Large Terrestrial Snakes. Herpetological Review 36(4): 421-424.

Burger, J., and R.T. Zappalorti. 1986. Nest Site Selection by Pine Snake, *Pituophis melanoleucus*, in the New Jersey Pine Barrens. Copeia 1986(1): 116-121.

Burger, J., and R.T. Zappalorti. 1991. Nesting Behavior of Pine Snakes (*Pituophis m. melanoleucus*) in the New Jersey Pine Barrens. Journal of Herpetology 25(2): 152-160.

Burger, J., and R.T. Zappalorti. 1992. Philopatry and Nesting Phenology of Pine Snakes (Pituophis melanoleucus) in the New Jersey Pine Barrens. Behavior Ecology and Sociobiology 30: 331-336.

Burger, J., and R.T. Zappalorti. 2011. The Northern Pine Snake (*Pituophis melanoleucus*): Its Life History, Behavior and Conservation. Nova Science Publishers, Inc.

Cardinale, B.J., J.E. Duffy, A. Gonzalez, D.U. Hooper, C. Perrings, P. Venail, A. Narwani, G.M. Mace, D. Tilman, D.A. Wardle, A.P. Kinzig, G.C. Daily, M. Loreau, J.B. Grace, A. Larigauderie, D.S. Srivastava, and S. Naeem. 2012. Biodiversity Loss and Its Impact on Humanity. Nature 486: 59-67.

Cavitt, J.F. 2000. Fire and a Tallgrass Prairie Reptile Community: Effects on Relative Abundance and Seasonal Activity. Journal of Herpetology 34(1): 12-20.

Cipollini, M. L., J. Culberson, C. Strippelhoff, T. Baldvins, and K. Miller. 2012. Herbaceous Plants and Grasses in a Mountain Longleaf Pine Forest Undergoing Restoration: A Survey and Comparative Study. Southeastern Naturalist 11(4): 637-668.

Collins, J.T., R. Conant, R.T. Peterson, I.H. Conant, and T.R. Johnson. 1998. Peterson Field Guide to Reptiles and Amphibians: Eastern and Central North America. Houghton Mifflin Harcourt, 3.

Cross, C.L., and C.E. Petersen. 2001. Modeling Snake Microhabitat From Radiotelemetry Studies Using Polytomous Logistic Regression. Journal of Herpetology 35(4): 590-597.

Dalrymple, G.H., F.S. Bernardino, T.M. Steiner, and R.J. Nodell. 1991. Patterns of Species Diversity of Snake Community Assemblages, with Data on Two Everglades Snake Assemblages. Copeia 1991(2): 517-521.

Degraaf, R. M., and M. Yamasaki. 2017. A Nondestructive Technique to Monitor the Relative Abundance of Terrestrial Salamanders. Wildlife Society Bulletin 20(3): 260-264.

Dodd, C.K. 1987. Status, Conservation, and Management. Pp. 478-513 in R.A. Seigel, J.T. Collins, and S.S. Novak, eds., Snakes: Ecology and Evolutionary Biology. McGraw Hill Inc., New York. 478-513

Dodd, C.K. 1993. Strategies for Snake Conservation. Pp. 363-393 in R.A. Seigel and J.T. Collins, eds., Snakes: Ecology and Behavior. McGraw Hill, Inc., New York.

Dodd, C.K., Jr., 1995. Reptiles and Amphibians in the Endangered Longleaf Pine Ecosystem. Pp 129-131 in E.T. LaRoe, G.S. Farris, C.E. Puckett, P.D. Doran, and M.J. Mac, eds., Our Living Resources: A Report to the Nation on Distribution, Abundance, and Health of U.S. Plants, Animals, and Ecosystems. National Biological Service, Washington, D.C.

Dodd, C.K., Jr., W.L. Barichivich, S.A. Johnson, and J.S. Staiger. 2007. Changes in a Northwestern Florida Gulf Coast Herpetofaunal Community Over a 28-y Period. American Midland Naturalist 158(1): 29-48.

Dodd, C. K., Jr., and R. Franz. 1995. Seasonal Abundance and Habitat use of Selected Snakes Trapped in Xeric and Mesic Communities of North-central Florida. Bulletin of the Florida Museum of Natural History 38 Part I(2): 43–67.

Dziadzio, M.C., and L. L. Smith. 2016. Vertebrate Use of Gopher Tortoise Burrows and Aprons. Southeastern Naturalist 15(4): 586–594.

Earley, L.S. 2004. Looking for Longleaf: the Fall and Rise of an American Forest. Chapel Hill, University of North Carolina Press.

Enge, K.M. 2001. The Pitfalls of Pitfall Traps. Journal of Herpetology 35(3): 467-478.

Enge, K.M., and K.N. Wood. 2002. A Pedestrian Road Survey of an Upland Snake Community in Florida. Southeastern Naturalist 1(4): 365-380.

Farjon, A., 2013. Pinus palustris. The IUCN Red List of Threatened Species. Version 2014.3

Fenolio, D.B., T.A. Gorman, K.C. Jones, M. Mandica, L. Phillips, L. Melde, H. Mitchell, and C.A. Haas. 2014. Rearing the Federally Endangered Reticulated Flatwoods Salamander, *Ambystoma Bishopi*, from Eggs through Metamorphosis. Herpetological Review 45(1): 62–65.

Fouts, K. L., C.T. Moore, K.D. Johnson, and J.C. Maerz. 2017. Lizard Activity and Abundance Greater in Burned Habitat of a Xeric Montane Forest. Journal of Fish and Wildlife Management 8(1): 181-192.

Franz, R. 1995. Habitat Use, Movements, and Home Range in Two Species of Rat Snakes (genus Elaphe) in a North Florida Sandhill. Florida Fish and Wildlife Conservation Commission. Nongame Wildlife Program Project Report 61.

Frost, C.C. 1993. Four Centuries of Changing Landscape Patterns in the Longleaf Ecosystem, In: S.H. Hermann, editor. Proceedings of the 18th Tall Timbers Fire Ecology Conference, The Longleaf Pine Ecosystem: ecology, restoration and management, Tall Timbers Research Station Tallahassee, FL. 18: 17-43.

Gibbons, J.W., D.E. Scott, T.J. Ryan, K.A. Buhlmann, T.D. Tuberville, B.S. Metts, J.L. Greene, T. Mills, Y. Leiden, S. Poppy, and C.T. Winne. 2000. The Global Decline of Reptiles, Déjà Vu Amphibians. BioScience 50(8): 653-666.

Gibbons, J.W., and R.D. Semlitsch. 1982. Terrestrial Drift Fences with Pitfall Traps: An Effective Technique for Quantitative Sampling of Animal Populations. Brimleyana 1: 1-16.

Georgia Forestry Commission. Fire Weather System. http://weather.gfc.state.ga.us/

Gotelli, N.J. and R.K. Colwaell. 2011.Estimating Species Richness, Pp. 39-54 in A.E. Magurran and B.J. McGill, eds., Biological Diversity Frontiers in Measuring Biodiversity. New York Oxford University Press.

Graham, S.P., D.A. Steen, M. Bailey, J.C. Godwin, J. Stiles, S. Stiles, T. Langkilde, and C. Guyer. 2015. The Amphibians and Reptiles of Conecuh National Forest, Escambia and Covington Counties, Alabama. Bulletin of the Alabama Museum of Natural History 32: 1-112.

Grant, B.W., A.D. Tucker, J.E. Lovich, A.M. Mills, P.M. Dixon, and J.W. Gibbons. 1991. The Use of Coverboards in Estimating Patterns of Reptile and Amphibian Biodiversity. Wildlife 2001: Populations 379–403.

Gray, J.S. 1989. Effects of Environmental Stress of Species Rich Assemblages. Biological Journal of the Linnean Society 37(1-2): 19-32.

Greenberg, C.H., D.G. Neary, and L.D. Harris. 1994a. Effect of High-Intensity Wildfire and Silvicultural Treatments on Reptile Communities in Sand-Pine Scrub. Conservation Biology 8(4): 1047-1057.

Greenberg, C.H., D.G. Neary, and L.D. Harris. 1994b. A Comparison of Herpetofaunal Sampling Effectiveness of Pitfall, Single-ended, and Double-ended Funnel Traps Used with Drift Fences. Journal of Herpetology 28(3): 319-324.

Griffith, G.E., J.M. Omernik, J.A. Comstock, S. Lawrence, G. Martin, A. Goddard, V.J. Hulcher, and T. Foster. 2001. Ecoregions of Alabama and Georgia, (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey.

Gulsby, M.L., and T. McElroy. 2018. New County Record for *Ophisaurus attenuatus* (Slender Glass Lizard). Herpetological Review 49(4): 715-716.

Guyer, C., and Bailey, M.A. 1993. Amphibians and reptiles on longleaf pine communities. In: S.H. Hermann, editor. Proceedings of the 18th Tall Timbers Fire Ecology Conference, The Longleaf Pine Ecosystem: ecology, restoration and management, Tall Timbers Research Station Tallahassee, FL. 18: 139-158.

Howze, J.M., K.J. Sash, J.P. Carroll, and L.L. Smith. 2019. A Regional Scale Assessment of Habitat Selection and Home Range of the Eastern Rat Snake in Pine-Dominated Forests. Forest Ecology and Management 432: 225-230.

Howze, J.M., K.M. Stohlgren, E.M. Schlimm, and L.L Smith. 2012. Dispersal of Neonate Timber Rattlesnake (*Crotalus horridus*) in the Southeastern Coastal Plain. Journal of Herpetology 46(3): 417-422.

Hunt, M., and T. McElroy. 2017. Profiling Bat Activity and Species Presence in Managed Longleaf Pine Landscapes. Master of Science in Integrative Biology Thesis 21.

Hutcheson, K. 1970. A Test for Comparing Diversities Based on the Shannon Formula. Journal of Theoretical Biology 29: 151-154.

Jensen, J.B., C.D. Camp, J.W. Gibbons, and M.J. Elliot. 2008. Amphibians and Reptiles of Georgia. University of Georgia Press.

Jose, S., E.J. Jokela, and D.L. Miller. 2006. The Longleaf Pine Ecosystem: Ecology, Silviculture, and Restoration. Springer.

Kiester, A.R. 1971. Species Density of North American Amphibians and Reptiles. Systematic Zoology 20(2): 127-137.

Kjoss, V.A., and J.A. Litvaitis. 2001. Comparison of 2 Methods to Sample Snake Communities in Early Successional Habitats. Wildlife Society Bulletin 29(1): 153-157.

Lander, J.L., D.H. Van Lear, and W.D. Boyer. 1995. The Longleaf Pine Forest of the Southeast: Requiem or Renaissance?. Journal of Forestry 93(11): 39–43.

LeQuire, E. 2010. Reptiles and Amphibians in an Upland Longleaf Pine Forest. Joint Fire Science Program Brief 104: 1–6.

Mackenzie, D.I. 2005. Was it there? Dealing with Imperfect Detection for Species Presence/Absence Data. Australian and New Zealand Journal of Statistics 47(1): 65-74.

McLeod, R.F., and J.E. Gates. 1998. Response of Herpetofaunal Communities to Forest Cutting and Burning at Chesapeake Farms, Maryland. The American Midland Naturalist 139(1): 164-177.

Means, D.B. 2006. Vertebrate Faunal Diversity of Longleaf Pine Ecosystems. Pp. 157-213 in S. Jose, E.J. Jokela, and D.L. Miller, eds., The Longleaf Pine Ecosystem: Ecology, Silviculture, and Restoration. Springer, New York.

Means D.B., and H.W. Campbell. 1981. Effects of Prescribed Burning on Amphibians and Reptiles. Pp. 89-97 in G.W. Wood, editor. Prescribed Fire and Wildlife in Southern Forests. The Belle W. Baruch Forest Science Institute of Clemson University, Georgetown, South Carolina.

Means, D. B., C.K. Dodd, S.A. Johnson, and J.G. Palis. 2004. Amphibians and Fire in Longleaf Pine Ecosystem: Response to Schurbon and Fauth. Conservation Biology 18(4): 1149-1153.

Miller, G.J., L.L. Smith, S.A. Johnson, and R. Franz. 2012. Home Range Size and Habitat Selection in the Florida Pine Snake (*Pituophis melanoleucus mugitus*). Copeia 4: 706-713.

Mitchell, R. J., J.K. Hiers, J.J. O’Brien, S.B. Jack, and R.T. Engstrom. 2006. Silviculture That Sustains: The Nexus between Silviculture, Frequent Prescribed Fire, and Conservation of Biodiversity in Longleaf Pine Forests of the Southeastern United States. Canadian Journal of Forest Research 36(11): 2724-2736.

Moore, J.M. 1893. The Eggs of *Pituophis melanoleucus*. American Naturalist 27: 878-885.

Moseley K.R., S.B. Castleberry, and S.H. Schweitzer. 2003. Effects of Prescribed Fire on Herpetofauna in Bottomland Hardwood Forests. Southeastern Naturalist 2(4): 475–486.

Mullin, S.J., and R.J. Cooper. 2000. The Foraging Ecology of the Gray Rat Snake (*Elaphe obsolete spiloides*). II. Influence of Habitat Structural Complexity when Searching for Arboreal Avian Prey. Amphibia-Reptilia 12: 211-222.

Noss, R.F., E.T. LaRoe, and J.M. Scott. 1995. Endangered Ecosystems of the United States: A Preliminary Assessment of Loss and Degradation. U.S. Department of the Interior National Biological Service 28.

Noss, R.F., W.J. Platt, B.A. Sorrie, A.S. Weakley, D.B. Means, J. Costanza, and R.K. Peet. 2015. How Global Biodiversity Hotspots May Go Unrecognized: Lessons from the North American Coastal Plain. Diversity and Distributions 21: 236–244.

Outcalt, K.W. 2000. The Longleaf Pine: Ecosystem of the South. Native Plants Journal Indiana University Press 1(1): 42-53.

Parker, W. S., and M. V. Plummer. 1987. Population Ecology. Pp. 253-301 in R.A. Seigel, J.T. Collins, and S.S. Novak, eds., Snakes: Ecology and Evolutionary Biology. McGraw Hill, Inc., New York.

Peet, R. K. 2006. Ecological Classification of Longleaf Pine Woodlands. Pp. 51-93 in S. Jose, E.J. Jokela, and D.L. Miller, eds., The Longleaf Pine Ecosystem: Ecology, Silviculture, and Restoration. Springer, New York.

Plummer, M.V., and J.D. Congdon. 1994. Radiotelemetric Study of Activity and Movement of Racers (*Coluber constrictor*) Associated with a Carolina Bay in South Carolina. Copeia 1:20-26.

Plummer, M.V., and N.E. Mills. 2000. Spatial Ecology and Survivorship of Resident and Translocated Hognose Snakes (*Heterodon platirhinos*). Journal of Herpetology 34(4): 565-575.

Reinert, H.K. 1993. Habitat Selection in Snakes. Pp. 201-240 in R.A. Seigel, and J.T. Collins, eds., Snakes: Ecology and Behavior. McGraw Hill, Inc., New York.

Russell, K.R., H.G. Hanlin, T.B. Wigley, and D.C. Guynn, Jr. 2002. Responses of Isolated Wetland Herpetofauna to Upland Forest Management. Journal of Wildlife Management 66(3): 603-617.

Sala, O.E., F.S. Chapin, J.J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sanwald, L.F. Huenneke, R.B. Jackson, A. Kinzig, R. Leemans, D.M. Lodge, H.A. Mooney, M. Oesterheld, N.L. Poff, M.T. Sykes, B.H. Walker, M. Walker, and D.H. Wall. 2000. Global Biodiversity Scenarios for the Year 2100. Science 287(5459): 1770-774.

Segura, C., M. Feriche, J.M. Pleguezuelos, and X. Santos. 2007. Specialist and Generalist Species in Habitat Use: Implications for Conservation Assessment in Snake. Journal of Natural History 41(41-44): 2765-2774.

Semlitsch, R. D., S.C. Walls, W.J. Barichivich, and K.M. O'Donnell. 2017. Extinction Debt as a Driver of Amphibian Declines: An Example with Imperiled Flatwoods Salamanders. Journal of Herpetology 51(1): 12–18.

Setser, K., and J.F. Cavitt. 2003. Effects of Burning on Snakes in Kansas, USA, Tallgrass Prairie. Natural Areas Journal 23(4): 315-319.

Smith, A.L., C.M. Bull, and D.A. Driscoll. 2013. Successional Specialization in a Reptile Community Cautions against Widespread Planned Burning and Complete Fire Suppression. Journal of Applied Ecology 50: 1178-1186.

Steen, D.A., L.L. Smith, L.M. Conner, J.C. Brock, and S.K. Hoss. 2007. Habitat Use of Sympatric Rattlesnake Species within the Gulf Coastal Plain. The Journal of Wildlife Management 71(3): 759-764.

Steen, D.A., L.L. Smith, L.M. Conner, A.R. Litt, L. Provencher, J.K. Hiers, S. Pokswinski, and C. Guyer. 2013. Reptile Assemblage Response to Restoration of Fire-Suppressed Longleaf Pine Sandhills. Ecological Applications 23(1): 148–158.

Tuberville, T.D., J.R. Bodie, J.B. Jensen, L. LaClaire, and J.W. Gibbons. 2000. Apparent Decline of the Southern Hog-nose Snake, *Heterodon simus*. The Journal of the Elisha Mitchell Scientific Society 116(1): 19-40.

United States Department of Agriculture- Forest Service. 2000. Resources Planning Act (RPA) Assessment, Final Statistics. Washington, DC: United States Department of Agriculture-Forest Service, Forest Inventory and Analysis.

Varner, J.M., III, J.S. Kush, and R.S. Meldahl. 2003. Structural Characteristics of Frequently Burned Old-Growth Longleaf Pine Stands in the Mountains of Alabama. Castanea 68(3): 211-221.

Vitt, L.J. 1987. Communities. Pp. 335-365 in R.A Seigel, J.T. Collins, and S.S. Novak, eds., Snakes: Ecology and Evolutionary Biology. McGraw Hill, Inc., New York.

Ware, S., C. Frost, and P. D. Doerr. 1993. Southern mixed hardwood forest: the former longleaf pine forest. Pp. 447-493 in W. H. Martin, S. G. Boyce, and A. C. Echternacht, eds., Biodiversity of the southeastern United States. John Wiley & Sons, New York.

Zappalorti, R.T., E.W. Johnson, and Z. Leszcynski. 1983. The Ecology of the Northern Pine Snake, *Pituophis melanoleucus* (Daudion) (Reptilia, Serpentes, Colubridae), in Southern New Jersey, with special notes on habitat and nesting behavior. Chicago Herpetological Society 18: 57-72.