The Effects of Forest Treatments on Ground – dwelling Herpetofauna and Macroarthropods in Longleaf Pine Forests of South Alabama

by

Colt Ryan Sanspree

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Approved by

Sharon Hermann, Chair, Assistant Professor of Biological Sciences
Becky Barlow, Associate Professor of Forestry and Wildlife Sciences
Craig Guyer, Professor of Biological Sciences
David Steen, Assistant Research Professor of Biological Sciences

Abstract

The purpose of this thesis was to examine long-term effects of forest treatments on captures of herpetofauna, habitat structure, and relative abundance of macroarthropods. In chapter 1, I described my general research questions and reviewed relevant literature.

In chapter 2, I compared habitat structure measurements and captures for herpetofaunal species that have similar detection probabilities; I also tested for correlations between these two factors. Eastern spadefoot toad captures were significantly higher in Burn treatments compared to HerbBurn and Mechburn. Additionally, habitat structure measurements were not significantly different across treatments. Modeling captures with habitat measurements using information theory suggested that coarse woody debris was the most important habitat variable for explaining Eastern narrow-mouthed toad (*Gastrophryne carolinensis*) captures, and midstory basal area was the most important habitat variable for explaining Eastern spadefoot toad (*Scaphiopus holbrookii*) captures.

In chapter 3, I compared relative abundance across order, family, and feeding guild levels for ground-dwelling macroarthropods. Carabidae was marginally higher in Burn compared to HerbBurn treatments. Gryllidae was significantly higher in MechBurn compared to Burn and HerbBurn treatments. However, feeding guild relative abundance was not statistically different.

In chapter 4, I summarized the main conclusions from this study. Results suggest long-term residual effects on Eastern spadefoot toads and Carabidae from one-time herbicide or mechanical treatments in conjunction with frequent prescribed fire.

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TABLE OF CONTENTS

List of Tables

List of Figures

Chapter 1.

Introduction

Background

Longleaf pine forests are one of the most diverse forest types in the United States. Vertebrate fauna include 36 mammal species, 86 bird species, 34 amphibian, and 38 reptile species dependent upon longleaf pine ecosystems (Engstrom 1993, Guyer and Bailey 1993, Means 2004). Compared to vertebrates, arthropods are less well-known. However, Folkerts et al. (1993) suggested a conservative estimate of 4,000 – 5,000 species characteristic of xeric longleaf pine habitat with perhaps 10% classified as endemics. Plant diversity in longleaf pine forests is also high, with a species richness up to 42 species / 0.25 m^2 reported in the moist wiregrass savannas of North Carolina (Walker and Peet 1983).

Longleaf pine and fire maintained habitat

Human influences have had a significant impact on longleaf pine forests. A well-recognized problem is habitat loss due to conversion of sites for human use. It has been estimated that there were 37 million hectares of longleaf pine forests across the southeastern United States at the start of European colonization (e.g. Frost 1993). Of those 37 million hectares of longleaf pine, less than 3 % remain today (Frost 1993, Noss et al. 1995, Varner et al. 2005).

The reasons for the near extinction of this diverse forest type are numerous, but are mainly attributed to land use changes such as agriculture, logging, and exclusion of fire (Frost 1993). In the Southeastern US, fragmentation of the landscape and other anthropogenic factors have resulted in foresters and ecologists relying on the use of prescribed fire to replace lightning-ignited wildfires.

Frequent fire is necessary for maintaining habitat structure of longleaf pine forests (e.g. Glitzenstein et al. 2012). Habitat structure, specifically open canopy with minimal midstory and a herbaceous ground layer, is thought to be vital for maintaining many vertebrate species characteristic of longleaf pine forests (Engstrom 1993, Guyer and Bailey 1993). Often, prescribed fire cannot be applied to an area due to drought, increased fuel load, legal restrictions such as EPA regulations, issues with social acceptance, or other factors (Riebau and Fox 2001, McIver and Weatherspoon 2010, Winter et al. 2002).

National Fire and Fire Surrogate Study

If prescribed fire cannot be successfully implemented, forest managers must rely on other techniques to manage fuel. Alternatives to prescribed fire have been increasingly researched in the last decade and have appeared more frequently in scientific literature. *Fire surrogate* is defined as an alternative treatment method to prescribed fire that reduces fuel loads and also decreases the probability of extreme fire behavior (McIver et al. 2009). Fire surrogates have been a topic of research because of the uncertain effects of these forest management treatments (McIver et al. 2009). In 1996, the National Fire and Fire Surrogate (FFS) study was envisioned to make comparisons between fire and fire surrogate treatments in numerous forest types nationwide (McIver et al. 2009, McIver and Weatherspoon 2010). The Fire and Fire Surrogate study was designed as a multidisciplinary experiment to evaluate the ecological and economic consequences of prescribed fire and prescribed fire alternatives (Boerner et al. 2008, Hartsough et al. 2008, McIver and Weatherspoon 2010). The FFS study spanned many fields including weather, vegetation, soils, wildlife, fuels, invertebrates, pathology, and economics (McIver and Weatherspoon 2010). Treatments compared in the FFS were prescribed fire, mechanical, mechanical plus prescribed fire, herbicide plus prescribed fire, and control (no treatment) (McIver and Weatherspoon 2010, Steen et al. 2010, McIver et al. 2013).

Effects of Forest Treatments in Longleaf Pine

One of the sites selected for the FFS project was the Solon Dixon Forestry Education Center (SDFEC) in Andalusia, Alabama. This site consisted of historic longleaf pine that had been previously maintained with prescribed fire (Outcalt and Brockway 2010). The initial treatments at this site were prescribed fire only, thin plus prescribed fire, thin only, herbicide plus prescribed fire, and control. Initial effects of the treatments on vegetation structure and composition are described in previous publications (Outcalt 2005, Outcalt and Brockway 2010). Also, some short – term effects of the treatments on herpetofauna and arthropods were described in three publications (Rall 2004, Campbell et al. 2008a, Steen et al. 2010).

Effects of Prescribed Fire

Prescribed fire is frequently used as an efficient and cost effective management tool in longleaf pine to reduce fuel loads and control encroaching hardwood vegetation (e.g. Glitzenstein 2012 and Provencher et al. 2002). Prescribed fire reduces competition from fast growing oaks that can negatively affect young longleaf pines by shading (Chapman 1932). Prescribed fire in longleaf is thought to benefit the flora and fauna dependent upon this forest type for some part of their life (Folkerts et al. 1993, Guyer and Bailey 1993). In addition, prescribed fire is thought to benefit some frog species by providing increased availability of habitat and shelter for emigrating juveniles (Roznik and Johnson 2009). While effects on arthropods is lesser known some authors suggest that prescribed fire has negative short – term effects on arthropod abundance (New and Hanula 1998), while others suggest arthropods are positively affected (Hanula and Wade 2003). A few studies suggest that arthropods may not be affected by prescribed fire, at least at the order level (Campbell et al. 2008a, 2008b).

Effects of Herbicide

Herbicide is frequently used in combination with prescribed fire to enhance restoration efforts in longleaf pine by targeting hardwoods (Brockway and Outcalt 2000, Outcalt and Brockway 2010). Herbicides are applied to vegetation using various methods, however use of backpack sprayers may limit effects on non – target plants by better controlling application. Effects of herbicides have been studied mainly on amphibians in a controlled setting, but suggest both direct lethal and sub-lethal effects can result (Hayes et al. 2002, Relyea 2005). Effects of herbicide on arthropods have been studied extensively in agricultural settings but only a few studies exist in forest settings. Short – term effects of herbicide plus prescribed fire are thought to increase the abundance of some saproxylic beetle species in longleaf pine forests (Campbell et al. 2008a).

Effects of Thinning

Like herbicide treatments, thinning treatments are also used in conjunction with prescribed fire to target hardwood removal in longleaf pine forests (Provencher et al. 2001, Outcalt 2005). Thinning reduces basal area in forests by cutting, logging, and mulching which, in turn, may lead to hotter and drier conditions at the ground level. Subsequently, thinning plus burn treatments have been suggested to increase short – term mortality of longleaf pines (Campbell et al. 2008a). Thinning has been suggested to negatively influence some pond-breeding amphibians, possibly by shortening the hydroperiods of ephemeral pools or drying them up altogether (Sutton et al. 2013). Conversely, thinning plus burn treatments may have increased the abundance of Curculionidae and other saproxylic beetles compared to control treatments, but results were not consistent between years (Campbell et al. 2008a).

Purpose of Current Study

The purpose of the current study was to revisit some of the FFS treatments described in Rall (2004) to evaluate the long-term effects on ground - dwelling herpetofauna and macroarthropods in longleaf pine forests. I was interested in the responses of herpetofauna and macroarthropods to forest treatments, some of which were initiated in 2002 and would provide some much needed long – term response data. Specifically, in 2014 and 2015 I compared the daily captures of herpetofauna across treatments to detect any significant differences. Additionally, captures of herpetofauna were compared against habitat measurements to test for habitat associations that might have influenced daily captures. In 2015, ground – dwelling macroarthropods were compared across treatments using relative abundance of taxonomic ranks and feeding guilds. In addition, I was interested in whether habitat quality revealed residual effects of either of the supplemental treatments (herbicide or mechanical) compared to the use of fire alone. To explore this question I assessed habitat quality using measurements of coarse woody debris, basal area for mid-and overstory, and shrub density.

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Chapter 2

Effects of Forest Treatments on Captures of Herpetofauna in Longleaf Pine Forests of South Alabama

Introduction

Structure is arguably the most important forest component in regulating resident communities and population structures and is generally defined as the physical features of a location including abiotic and biotic components such as vegetation, topography, and/or soils (McComb 2008). MacArthur and MacArthur (1961) suggested that forest structure, specifically the heights of herbs, bushes, and trees, was more important for explaining species diversity than the composition of the plant community. Forest structure can influence resident communities by providing habitat components such as food, shelter, or other services (Tews et al. 2004).

Land managers in the southeastern United States often focus on modifying forest structure to favor timber growth and control nuisance vegetation. Prescribed fire is often used to manage the structure of longleaf pine (*Pinus palustris* Mill.) forests (e.g. Glitzenstein et al. 2012). Longleaf pine is dependent upon frequent fire for many reasons including seedling establishment and suppression of oaks and other hardwoods that can outcompete the vertical growth of young longleaf (Chapman 1932). Repeated burns in longleaf pine forests may promote high species richness in many groups of organisms (e.g. Provencher et al. 2003) however, where reptiles and amphibians (herpetofauna) have been considered studies have mixed outcomes. For example, Schurbon and Fauth (2003 and 2004) indicated negative fire effects on herpetofauna while Steen et al. (2010) suggested that overall amphibian species richness did not differ among burn and non-burn plots. One reason that outcomes of fire effects may differ among studies is that, while there are at least 170 species of herpetofauna that occur within the range of longleaf pine, there are 34 amphibian and 38 reptile species that depend on longleaf pine forests during some portion of their life history (Guyer and Bailey 1993, Dodd 1995). Although direct mortality of specialist herpetofaunal species is rarely reported following prescribed burns (e.g. Engstrom 2010), fire effects is thought to be indirectly related to prescribed fire regulating various habitat components (Pilliod et al. 2003). For example, prescribed fire applied to maintain longleaf stands was suggested to increase available shelter for emigrating juvenile frogs, which the frogs selected over fire-suppressed longleaf stands (Roznik and Johnson 2009). Maintenance of longleaf pine forests with prescribed fire is likely to create appropriate habitat for herpetofauna that depend on this forest type (Russell et al. 1999, Means et al. 2004). However, there have been few opportunities to evaluate long-term effects of longleaf pine management on herpetofauna.

In addition to prescribed fire, other techniques used to manage longleaf pine forests include herbicide and mechanical treatments (e.g. Provencher et al. 2001). Although there is some evidence that suggests that short-term effects of these treatments on herpetofauna may not be harmful (e.g. Greenberg and Waldrop 2008, Steen et al. 2010) long-term effects are rarely studied. Herbicides are often used in conjunction with prescribed fire to manage invasive woody vegetation in longleaf pine forests, and the combination has been suggested to be more effective at restoration than prescribed fire alone (Brockway and Outcalt 2000). While the indirect effects of herbicides on amphibian communities have been studied, information on direct effects is currently limited to mostly controlled settings (e.g., Hayes et al. 2002, Relyea 2005). However there are a few examples of field studies that have included herbicide treatments along with mechanical ones (e.g. Litt et al. 2001). Mechanical treatments such as thinning and mastication are used in longleaf forests to reduce overstory competition and to manage midstory and understory plant communities (Outcalt and Brockway 2010, Harrington 2011). Mechanical treatment effects on herpetofauna appear to vary by species, but may have negative effects on ephemeral pond breeding amphibians (Simmons 2007, Sutton et al. 2013).

The purpose of the current study was to assess 1) how forest management treatments influenced captures of herpetofauna in longleaf pine forests, and 2) which habitat variables are correlated with captures. Some treatments were applied beginning in 2002 (Rall 2004) and so offer a longer-term perspective than many studies.

I used a replicated random block design to assess the effects of three treatments on captures of herpetofauna. Treatments included prescribed fire, prescribed fire plus herbicide, and prescribed fire plus mechanical to evaluate the additive effects of herbicide and mechanical treatments on prescribed fire. In addition to common forestry measurements, I used measurements of coarse woody debris to evaluate any potential habitat associations. Coarse woody debris (CWD) is important as it may provide suitable microhabitat for herpetofauna and shelter for various prey items (Harmon et al. 1986, Brown et al. 2003). The treatments being compared were originally part of the national Fire and Fire Surrogate (FFS) study assessing ecological and economic effects of treatments to reduce fuel loads in temperate forests across much of the United States (McIver et al. 2012, 2013). Although there are four published papers related to short-term effects of the FFS project in the Gulf Coastal Plains (Campbell et al. 2008, Sharp et al. 2009, Outcalt and Brockway 2010, Steen et al. 2010), the work reported here is the first effort to assess long-term effects on some of the FFS plots that remain active.

Methods

Study Site

The study site is the Solon Dixon Forestry Education Center (SDFEC) located approximately 35 km southwest of Andalusia, Alabama (31.3085° N, 86.4833° W) on the Gulf Coastal Plain (see Figure 1). The 2,165 ha tract of land is managed by Auburn University to provide natural resource education, support research, and generate income. The majority of land is situated in Covington County, Alabama and the remaining minority is in Escambia County, Alabama to the west. The dominant overstory tree species at this location is longleaf pine (*Pinus palustris*) but also includes intermixed shortleaf pine (*P. echinata* Mill.), slash pine (*P. elliottii* Engelm.), spruce pine (*P. glabra* Walter), loblolly pine (*P. taeda* L.) and oaks (*Quercus* spp.). Understory composition is dominated by gallberry (*Ilex glabra* (L.) A. Gray) and yaupon holly (*Ilex vomitoria* Aiton). Soils on the selected study sites consist of sandy loam or loamy sand paleudults that are from the Bonify, Dothan, Malbis, Orangeburg, and Troup series (Outcalt and Brockway 2010). Karst topography is also abundant at this location with numerous water-filled depressions spread throughout the area.

Study Design

The study consisted of a randomized complete block design with 3 blocks. Three treatments were randomly applied to three experimental units within each block so that each treatment had three total replications. Experimental units were selected based on similar structure and management history and were grouped based on similar soil features (Outcalt and Brockway 2010, Steen et al. 2010). Experimental units each had a 12.25 ha core area surrounded by a 20 m buffer and were infrequently managed by prescribed fire prior to start of the study.

Treatments in the current study were prescribed fire (Burn), herbicide + prescribed fire (HerbBurn), and mechanical + prescribed fire (MechBurn) (see Table 1). This study followed-up a portion of a long-term experiment that initially included two additional treatments in each block, mechanical only and reference, which are described in previous publications (Rall 2004, Outcalt 2005, Campbell et al. 2008, Sharp et al. 2009, Outcalt and Brockway 2010, Steen et al. 2010). In all cases prescribed fire was applied to all treatments by handheld drip torches. Burns were initially completed using growing season fires and subsequently used both growing and dormant season fires. A combination of backing, strip head, flanking, and spot ignition patterns were used to achieve desired results.

All experimental units had prescribed fire applied during the dormant season three to four years prior to start of this study to ensure similar time since last burn. Prescribed fire treatments were initiated in April - May 2002 and were burned every 2 – 4 years thereafter. HerbBurn treatments had a one-time application of the herbicide Garlon 4 in fall 2002. The herbicide was applied to woody vegetation up to 2 m tall using backpack sprayers to limit impact on non-target vegetation. Herbicide was applied at a 4.0 – 4.5 % solution mixed with a surfactant. Prescribed fire was applied to HerbBurn plots starting in April 2003 and burned every 2 – 4 years thereafter. MechBurn plots were initially thinned to basal area of 11.5 – 13.5 m^2 / ha in March - April 2002. Thinning targeted hardwoods and non-longleaf pines and was completed using a rubber tire skidder, feller – buncher, and chain saw. In May – Jun 2005, MechBurn treatments were masticated by a front mounted roller-chopper. Smaller midstory hardwoods and understory vegetation were masticated down to 15 cm above ground level (Outcalt and Brockway 2010). In late March 2009, prescribed fire was applied to the MechBurn treatments and was reapplied every 2 – 3 years thereafter. The MechBurn treatments were originally thin-only treatments and did not include a prescribed fire application because the treatment was meant to be applied as a fire surrogate. After the initial funding was exhausted, the thin-only treatments had prescribed fire applied and became the current MechBurn treatments. This resulted in a four year gap between the last mechanical (mastication) – thinning treatment and beginning of prescribed fire applications.

Herpetofauna Sampling

Herpetofauna were repeatedly sampled June through August 2014 and 2015 using constructed drift fences that were modified from Rall (2004). A single drift fence array was randomly placed within each treatment unit for sampling (see Figure 2). Drift fences consisted of four vertical wings of 15 m flashing in an "x" configuration. Each wing of flashing was buried approximately 5 cm and had a buried 19 L pitfall trap at the middle and terminal end. At the center of the drift fence was a 102 x 102 cm square box funnel trap consisting of hardware cloth sides (0.64 cm diameter holes), 5.08 x 5.08 cm vertical corner supports that were 40.64 cm tall, and top and bottom made from 1.27 cm thick oriented strand board (OSB). A 40.64 x 30.48 cm lid fastened by two hinges was used to access captures. Each wing of flashing joined a side of the box funnel trap leading into a funnel with a 12 cm diameter entrance outside trap and a 6 cm diameter exit inside trap. Each side of the box funnel trap had a funnel that was angled upward inside the trap approximately 20 degrees from horizontal to prevent any captures from escaping.

A 739 ml plastic storage container provided water to prevent desiccation of captures in box funnel traps. Each water container had the accompanying lid attached so that smaller captures could use the lid as a ramp to access water. A sponge soaked with water was placed in each 19 L pitfall trap to prevent desiccation of captures and prevent drowning during large rain events. Traps were checked daily and captured herpetofauna were identified to species level, aged, sexed, with mass and SVL measured, and were marked to assess number of recaptures. Traps were checked on a rotation to limit influence on diurnal herpetofauna activity (Rall 2004). Captures (excluding snakes) were toe-clipped, where feasible, by clipping the second inside toe on the right hind foot during 2014 and the left hind foot for 2015. Alternating hind feet allowed researchers to determine year of first capture. Also, clipping only a single toe versus several toes for individual markings limited adverse effects on health and recapture probability (McCarthy and Parris 2004). Non-venomous snakes were marked by clipping only the number two ventral scale during 2014 or number 20 ventral scale during 2015 using marking techniques by Enge (1997). Venomous snakes were identified to species level and released without measuring or marking to decrease risk to researchers.

Habitat Structure Sampling

Habitat structure was measured at each site during December 2015 and January 2016. Each site was divided into four equal sized areas and had a rectangular 20 x 50 meter subplot placed in the center. Each habitat structure measurement was nested within this area, ensuring that at least one 20 x 50 m subplot was within ≈ 50 m of the drift fence array. Overstory basal area (BA; m^2 / 0.1 ha) was measured on the entire subplot, while midstory BA (0.5 m^2 / ha) was measured on half (20 x 25 m) of the subplot (Outcalt and Brockway 2010). Overstory consisted of trees at least 15 cm diameter at breast height (dbh, measured at 1.4 m from ground level) and midstory trees were less than 15 cm dbh. North or south halves of the subplot were randomly chosen for midstory measurement by flipping a coin 3 times. Shrub density (# stems / 0.008 ha) was measured as an understory component by centering a 4 x 20 m belt transect in each subplot and counting the total number of woody stems ≥ 0.5 m tall but < 1.4 m tall, excluding vines such as *Rubus, Smilax,* and *Vitis* that were present at some sites. Any vegetation under 0.5 m tall was considered ground cover and was not sampled due to timing of habitat measurement. Coarse woody debris (m^2 / ha) was measured over the entire 20 x 50 m subplot and consisted of all dead woody debris on the ground that was at least 10 cm at widest point and at least 1 m long (Enrong et al. 2006). Length and width of widest point was recorded and then converted into total area per subplot. Timing of measurements allowed researchers to easily detect CWD compared to sampling during the growing season. To maximize precision of measurements, the same two observers completed all measurements while others recorded measurements and established the subplots.

Statistical Analysis

Because I was interested in treatment level effects on captures, I limited species comparisons to those that had similar detection probabilities. One of the most important factors to incorporate into statistical analysis when evaluating treatment effects on herpetofauna is detection probability. Detection probability has become a popular topic in ecology along with the use of occupancy analysis (MacKenzie et al. 2006). Not incorporating detection probability into statistical comparisons can lead to biased results when detection varies between treatments or sites and is less than one (MacKenzie et al. 2002, Bailey et al. 2004, Means et al. 2004). Following methodology in Sutton et al. (2013), detection probabilities were estimated with the program PRESENCE (v 10.9; Hines 2006) using species with at least 100 unique captures. I treated the data as a single sampling event, combining both years, and used a single-season model. Additionally, occupancy was kept constant across models. Two models were assessed, using information theory and Akaike Information Criteria (AIC), for selected species (≥ 100 captures) and included a null model (constant occupancy with no covariates) and a model that allowed detection to vary by treatment (Akaike 1974, Anderson et al. 2000, Sutton et al. 2013). An estimate of over dispersion ($\hat{c}$) was calculated and used to correct the fit of the models (MacKenzie and Bailey 2004, MacKenzie et al. 2006).

Statistical comparisons of species among treatment levels were completed using generalized linear models in the program R (R Core Team 2014) and the package glmmADMB (Skaug et al. 2011, Bolker et al. 2012). The glmmADMB package allowed us to model over-dispersed capture data with a negative binomial distribution and to account for over inflation of zeros because the selected species were captured within each treatment level but not detected by researchers during several trap days. Failing to account for excess zeros in ecological count data has been suggested to decrease the ability to detect relationships and could lead to different parameter and precision estimates (Martin et al. 2005). I included fixed effects and random effects for sites nested within blocks to account for repeated sampling through time. Results were considered statistically significant at $P \leq 0.05$.

To evaluate responses to forest management treatments, I used generalized linear models and information theory in the program R to model species (with constant detection) captures and habitat structure measurements (R Core Team 2014). I standardized habitat variables due to numerous data measurement scales and did not include treatment as an explanatory variable because researchers were interested in evaluating the structural effects of the treatments on captures. The models included fixed effects, random effects for sites nested within a block, zero-inflation, and negative binomial distribution to account for over dispersion. I generated a global model to perform an all subsets analysis and included parameters in an equal number of models. Models were ranked according to difference in AIC score (ΔAIC) relative to top ranked model (AIC = 0.00). I included Akaike weights (ω_i) of each model to represent the probability that the model is the best model among those models considered (Anderson et al. 2000). Full model averaged parameters were calculated for multimodel inference including betas, unconditional standard error, and individual variable weights. Model averaging calculates weighted averages of the estimates to integrate model uncertainty and is an elegant approach when there are multiple top models within 2 ΔAIC of the best model (Mazerolle 2006). In addition, this permits ranking of habitat structure variables according to relative weight or importance to explaining species captures (Arnold 2010).

Habitat data was also compared using one-way ANOVAs with repeated measures to test for treatment effects. Habitat data was log (x + 1) transformed when necessary to meet the assumptions of normality and homogeneity of variance (Gotelli and Ellison 2013).

Results

Capture Summary

I had 909 total captures during the 486 trap nights including 19 reptile and 15 amphibian species (see Table 2). Amphibians made up 83.3 % of the captures and reptiles made up the remaining 16.7 %. The most captured amphibian and reptile were the Eastern narrow-mouthed toad (*Gastrophryne carolinensis*) and the six-lined racerunner (*Aspidoscelis sexlineatus*) with 286 captures and 42 captures, respectively.

Detection Probabilities

Model comparisons between constant detection probability and varying detection probability by treatment revealed that constant detection probability was the best model for two species, *G. carolinensis* and Eastern spade-foot toad (*Scaphiopus holbrookii*; n = 134). The difference between the two models for *G. carolinensis* was 19.05 ΔQAIC and had a detection probability of 0.41 (± S.E. 0.09). The difference between the two models for *S. holbrookii* was 64.77 ΔQAIC and had a detection probability of 0.10 (± S.E. 0.18). Overall, detection probabilities for the two selected species were low, especially for *S. holbrookii* which also had large standard error.

Species Comparisons

Species that had at least 100 captures and constant detection probability were compared across treatments using daily capture rates. Captures of *G. carolinensis* were not significantly different between any treatment levels ($P \geq 0.334$). Burn treatments had 14.17 (± 4.76 – 42.14; 95 % C. L.) times as many captures of *S. holbrookii* as HerbBurn treatments ($P < 0.0001$). Burn treatments also had 16.10 (± 5.22 – 49.65; 95 % C. L.) times as many *S. holbrookii* captures as MechBurn treatments ($P < 0.0001$). However, HerbBurn and Mechburn treatments were not significantly different ($P = 0.846$).

Habitat comparisons

Habitat structure measurements revealed noticeable levels of heterogeneity within treatment levels (see Table 3). My results indicated that habitat variables were not significantly different between treatments. In general, mean overstory BA was highest in the HerbBurn treatment, mean midstory BA was highest in the Burn treatment, mean shrub density was highest in the MechBurn treatment, and CWD was highest in the Burn treatment.

Habitat Associations

AIC analysis indicated that there were multiple models within 2 ΔAIC of the best model for *G. carolinensis* and *S. holbrookii* (see Table 4). The best model among those considered for explaining *G. carolinensis* captures included a single variable for CWD. Other models ≤ 2 ΔAIC of the best model also included CWD and had one additional parameter each, which were of little additional explanatory value and considered uninformative due to a more parsimonious explanation. Model averaging suggested that all measured habitat structure variables had weak negative effects on *G. carolinensis*. Variable support according to individual variable weights was low for midstory BA, overstory BA, and number of understory wordy stems, with CWD clearly ranked as the most important habitat structure variable among those considered for *G. carolinensis* (ω_i = 0.97). The best model among those considered for *S. holbrookii* included variables for CWD and midstory BA. All other models ≤ 2 ΔAIC of the best model also included the variable midstory BA. One model ≤ 2 ΔAIC of the best model included an additional variable for overstory BA that was of little further explanatory value and also considered uninformative due to a more parsimonious explanation. Model averaging suggested that midstory BA had a large positive effect, CWD and overstory BA had small positive effects, and number of understory woody stems had a small negative effect on *S. holbrookii*. However, variable weights were low for CWD, overstory BA, and number of understory woody stems, with midstory BA obviously ranked as the most important habitat structure variable among those considered for *S. holbrookii* (ω_i = 0.90).

Discussion

The results suggest that long-term responses to longleaf forest management techniques vary by species. Amphibians, specifically toads, had the highest capture rates in the study. Results indicated that detection probabilities for *Gastrophryne carolinensis* and *Scaphiopus holbrookii* were similar across treatments and that resulting differences were not caused by uneven detection. Comparisons of *G. carolinensis* yielded no significant differences, while comparison of *S. holbrookii* yielded significantly more captures in Burn treatments compared to HerbBurn and MechBurn treatments. Habitat modeling results indicated that CWD may be an important habitat component for *G. carolinensis* and midstory BA may be an important habitat component for *S. holbrookii*.

Comparisons of *G. carolinensis*, the most captured species, indicated that the forest treatments may not have a significant effect on this species. Rall (2004) reported no significant differences in *G. carolinensis* captures during the first two years of treatments at SDFEC and evaluation after a longer time-period produced the same result. Steen et al. (2010) revisited data provided by Rall (2004) and proposed that generalist amphibians were unlikely to be affected by most Fire and Fire Surrogate treatments. Although *G. carolinensis* maintains populations within longleaf pine it has a wide eastern U.S. distribution that occurs in numerous other forest types (Nelson 1972) and so is classified as a generalist (Guyer and Bailey1993). Generalist habitat requirements such as cover and moisture have been described for *G. carolinensis*, with most individuals found under logs or other woody debris (Jensen 2008). The results further support that CWD may be important for *G. carolinensis*, and that forest management treatments that influence CWD are expected to impact *G. carolinensis*. One possible explanation that could help explain the negative effect for CWD on *G. carolinensis* is that one Burn site (Site # 6) did not have recurrent prescribed fire applied during sampling of herpetofauna and habitat structure. Every other site had recurrent prescribed fire applied once during sampling in either 2014 or 2015. The Burn site that did not have recurrent prescribed fire applied during sampling had almost twice the amount of CWD of any other site and also had the lowest total *G. carolinensis* captures (n = 15). This inconsistency, coupled with only having nine total sites, could have influenced the outcome of the habitat association analysis.

On the other hand, response of *S. holbrookii* suggested that this species was affected by forest treatments, even after many years since the one-time application of herbicide or mechanical activity. Specifically, results indicated that *S. holbrookii* may benefit from Burn treatments when compared to HerbBurn and MechBurn treatment alternatives. This suggests that captures of *S. holbrookii* were higher in two of the three Burn sites (n = 118) than all HerbBurn and Mechburn sites combined (n = 15). The one Burn treatment that had low *S. holbrookii* captures also had relatively low amphibian captures (n = 43), most of which were *G. carolinensis* (n = 35). Additionally, the results suggest that midstory BA is an important habitat component and may positively affect *S. holbrookii*. Specifically, 96 % of *S. holbrookii* captures in Burn treatments were juveniles, indicating that midstory BA could be an important habitat component for this life stage.

Previously described habitat variables associated with *S. holbrookii* are sandy soil for burrowing and ephemeral breeding ponds (Mount 1975, Johnson 2003). Although *G. carolinensis* has been known to breed in lakes and waters with extended hydroperiods, ephemeral ponds are also important breeding sites (Mount 1975). Sutton et al. (2013) suggested that canopy removal by thinning could negatively influence some ephemeral pond-breeding amphibians such as *G. carolinensis* in pine – hardwood mixed forests. I found no such pattern for

G. carolinensis when comparing captures across treatments in longleaf pine forests. However, the suggested negative influence of thinning of different forest types on ephemeral pond breeding amphibians could help explain the difference in captures of *S. holbrookii* between Burn and MechBurn treatments as indicated by the lower number of captures in MechBurn treatments. Thinning of canopy could lead to drier conditions at the ground level and decreased hydroperiods of ephemeral pools by allowing more light penetration through the canopy. The difference in *S. holbrookii* captures between Burn and HerbBurn treatments cannot be explained by reduction in basal area as neither received a thinning treatment. Additionally, the HerbBurn treatments retained higher average overstory BA and total basal area (overstory BA + midstory BA). A potential explanation for the difference in *S. holbrookii* captures between Burn and HerbBurn treatments is that there may have been an interaction between *S. holbrookii* captures and habitat variables midstory BA and CWD, all of which had higher average measurements in Burn treatments than HerbBurn. However, I found no justification to account for this potential interaction prior to habitat association modeling.

The MechBurn treatments consisted of a combination of thinning and understory mastication in 2002 and 2005, respectively. It is unknown at this point what long-term additive effect the midstory – understory mastication had on the MechBurn treatment as my experiment was not fully factorial. While this study focused primarily on the structural components influencing captures of herpetofauna, the authors note that most of the midstory BA measurements in Burn treatments were from patches of gap regeneration of longleaf pine (Brockway and Outcalt 1998).

Conclusions

The results suggest that managing longleaf pine with recurrent prescribed fire only may have long – term benefits for juvenile *S. holbrookii* when compared to the additive effects of herbicide and mechanical treatments. The three forest management treatments do not appear to have long – term effects on *G. carolinensis*. Additionally, habitat structure such as midstory BA is suggested to benefit at least the juvenile stage of *S. holbrookii* and prescribed fire may provide higher levels of this habitat component. Therefore, prescribed fire is recommended as a preferred management technique in similar longleaf pine forests where benefits to *S. holbrookii* are preferred. Treatment effects are likely causing the differences seen in *S. holbrookii* due to the large 12.25 ha core treatment areas and small 10 m^2 home range of *S. holbrookii* (Jensen et al. 2008). The results also suggest that midstory basal area in longleaf pine forests may be associated with juvenile *S. holbrookii*, although further study is warranted to explain this potential association.

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Table 1. List of treatments for Burn, HerbBurn, and MechBurn applied at the Solon Dixon Forestry Education Center (SDFEC), Andalusia, Alabama. Treatment data from SDFEC staff and in part from Outcalt and Brockway 2010.

Site	Treatments									
	Herbicide	Thinning	Mastication	1st Burn	2nd Burn	3rd Burn	4th Burn	5th Burn	6th Burn	7th Burn
Burn 1				5/15/2002	4/15/2004	5/18/2006	4/16/2008	4/13/2010	6/18/2012	6/17/2014
Burn 2				4/17/2002	5/6/2004	4/17/2007	4/23/2009	5/8/2013		
Burn 3				5/20/2002	7/6/2004	7/10/2006	6/17/2008	4/13/2011	1/21/2015	
HerbBurn 1	9/23/2002			4/15/2003	6/8/2005	4/24/2007	4/20/2009	12/2/2011	6/19/2014	
HerbBurn 2	9/28/2002			4/15/2003	6/20/2005	5/5/2008	5/28/2010	2/10/2014		
HerbBurn 3	9/30/2002			4/15/2003	6/9/2005	4/23/2007	5/14/2009	1/30/2012	7/15/2014	
MechBurn 1		3/27/2002	5/2005	3/18/2009	4/18/2011	6/25/2014				
MechBurn 2		3/31/2002	6/2005	3/19/2009	3/5/2012	4/9/2014				
MechBurn 3		4/4/2002	5/2005	2/18/2011	2/18/2013	4/22/2014				

Table 2. Total captures of herpetofauna in Burn, HerbBurn, and MechBurn treatments during 2014 – 2015 at the Solon Dixon Forestry Education Center, Andalusia, Alabama.

Species	Treatment		
	Burn	HerbBurn	MechBurn
Amphibians			
Southern chorus frog (*Acris gryllus*)	0	2	0
Mole salamander (*Ambystoma talpoideum*)	0	9	0
Fowler's toad (*Anaxyrus folweri*)	3	0	0
Southern Toad (*Anaxyrus terrestris*)	17	101	64
Chamberlain's dwarf salamander (*Eurycea chamberlaini*)	1	0	0
Southern two-lined salamander (*Eurycea cirrigera*)	2	0	0
Eastern narrow-mouthed toad (*Gastrophryne carolinensis*)	84	111	91
Green treefrog (*Hyla cinerea*)	1	0	0
Pine woods treefrog (*Hyla femoralis*)	0	0	1
Green frog (*Lithobates clamitans*)	2	12	51
Southern leopard frog (*Lithobates sphenocephalus*)	2	5	7
Eastern newt (*Notophthalmus viridescens*)	0	4	0
Slimy salamander (*Plethodon glutinosus*)	0	1	0
Southern chorus frog (*Pseudacris nigrita*)	0	1	0
Eastern spadefoot toad (*Scaphiopus holbrookii*)	119	8	7
Reptiles			
Copperhead (*Agkistrodon contortrix*)	0	4	4
Green anola (*Anolis carolinensis*)	7	1	1
Six-lined racerunner (*Aspidoscelis sexlineatus*)	11	7	24
Scarlet snake (*Cemophora coccinea*)	2	0	0
Black racer (*Coluber constrictor*)	2	8	3
Eastern coachwhip (*Coluber flagellum*)	1	3	4
Eastern diamondback rattlesnake (*Crotalus adamanteus*)	1	0	1
Timber rattlesnake (*Crotalus horridus*)	0	0	1
Gopher tortoise (*Gopherus polyphemus*)	0	2	0
Eastern hognose snake (*Heterodon platirhinos*)	0	1	0
Corn snake (*Pantherophis guttata*)	2	2	2
Gray Rat snake (*Pantherophis spiloides*)	0	0	1
Florida Pine snake (*Pituophis melanoleucus mugitus*)	0	2	2

Table 2. continued

Species	Treatment		
	Burn	HerbBurn	MechBurn
Broadheaded skink (*Plestiodon laticepts*)	5	2	3
Eastern fence lizard (*Sceloporus undulatus*)	6	7	7
Ground skink (*Scincella laterale*)	6	3	2
Pigmy rattlesnake (*Sistrurus miliarius*)	1	0	0
Southeastern crowned snake (*Tantilla coronata*)	7	1	1
Common garter snake (*Thamnophis sirtalis*)	0	1	0

Totals do not include 49 anuran and 3 lizard specimens that could not be identified due to red imported fire ant (*Solenopsis invicta*) predation during sampling.

Table 3. Mean ± SE of habitat structure measurements for Burn, HerbBurn, and MechBurn treatments measured December 2015 and January 2016 at the Solon Dixon Forestry Education Center, Andalusia, Alabama. CWD = coarse woody debris, MBA = midstory basal area, OBA = overstory basal area, SHR = shrub density.

	Treatment			P - value
Habitat variable	Burn	HerbBurn	MechBurn	
OBA (m^2 / 0.1 ha)	1.61 ± 0.21	1.81 ± 0.15	1.39 ± 0.19	0.371
MBA (m^2 / 0.05 ha)	0.07 ± 0.03	0.04 ± 0.02	0.02 ± 0.01	0.179
SHR (# / 0.008 ha)	226.58 ± 56.32	171.25 ± 31.84	264.75 ± 77.87	0.960
CWD (m^2 / 0.1 ha)	8.90 ± 2.32	6.25 ± 1.35	7.03 ± 1.55	0.658

Table 4. Top models (< 2 ΔAIC) and model averages of habitat structure variables on captures of Gastrophryne carolinensis and Scaphiopus holbrookii at the Solon Dixon Forestry Education Center, Andalusia, AL. CWD = coarse woody debris, MBA = midstory basal area, OBA = overstory basal area, SHR = shrub density.

Top Models						Model Averages			
Species	Models	Number variables (K)	AIC	Delta AIC (Δ_i)	Akaike weights (ω_i)	Habitat variables	Estimates (β)	Unconditional SE	Individual variable weights (ω_i)
Gastrophryne carolinensis	CWD	5	983.2	0.00	0.35	CWD	-0.34	0.12	0.97
	CWD + MBA	6	984.6	1.46	0.17	MBA	-0.03	0.07	0.33
	CWD + OBA	6	985.1	1.95	0.13	SHR	-0.01	0.06	0.28
	CWD + SHR	6	985.2	1.99	0.13	OBA	-0.01	0.05	0.27
Scaphiopus holbrookii	CWD + MBA	6	371.6	0.00	0.30	MBA	1.00	0.43	0.90
	CWD + MBA + OBA	7	373.1	1.50	0.14	CWD	0.34	0.38	0.60
	MBA + OBA	6	373.2	1.55	0.14	OBA	0.15	0.30	0.39
	MBA	5	373.5	1.94	0.11	SHR	-0.21	0.56	0.26

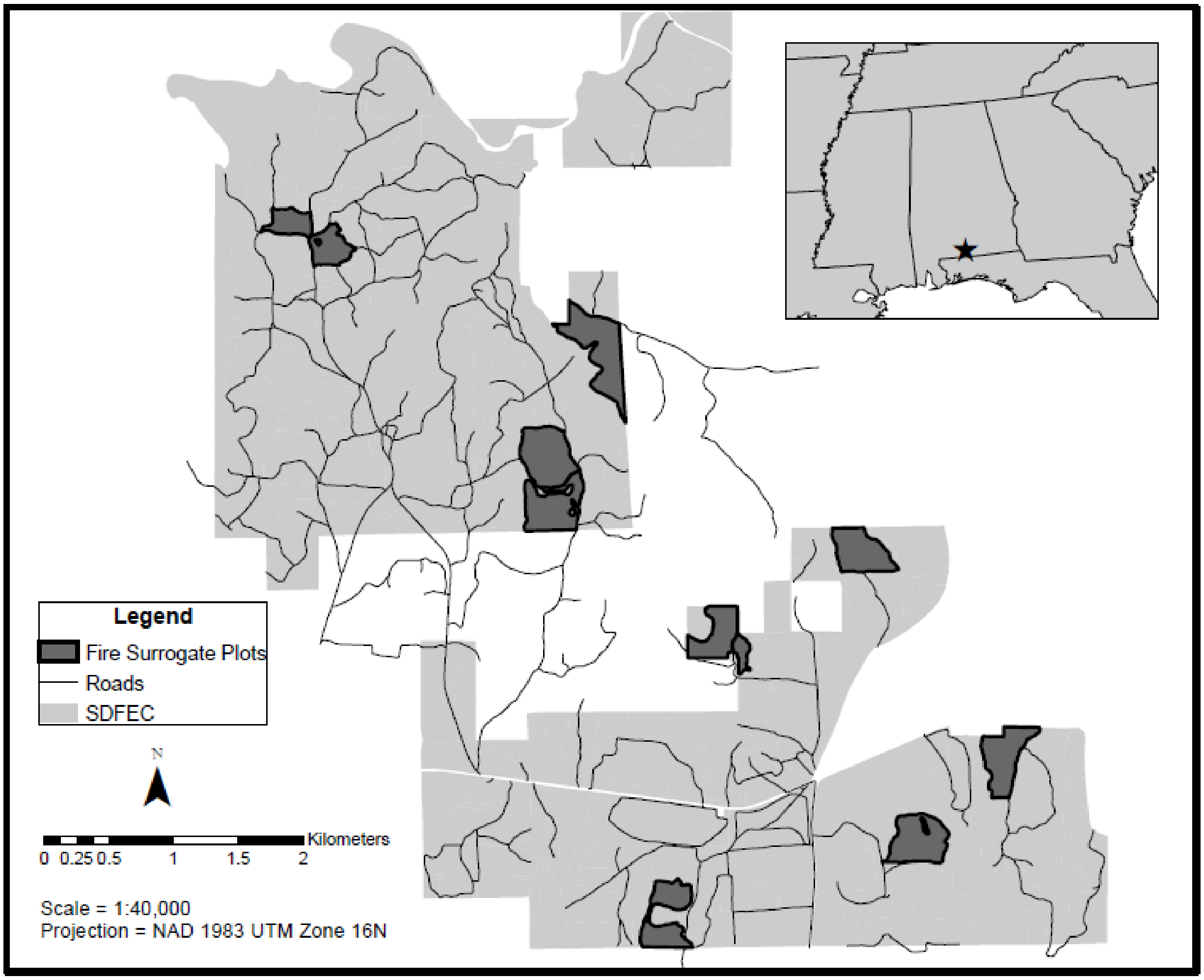

Figure 1. Study site at the Solon Dixon Forestry Education Center (SDFEC), Andalusia, Alabama**.**

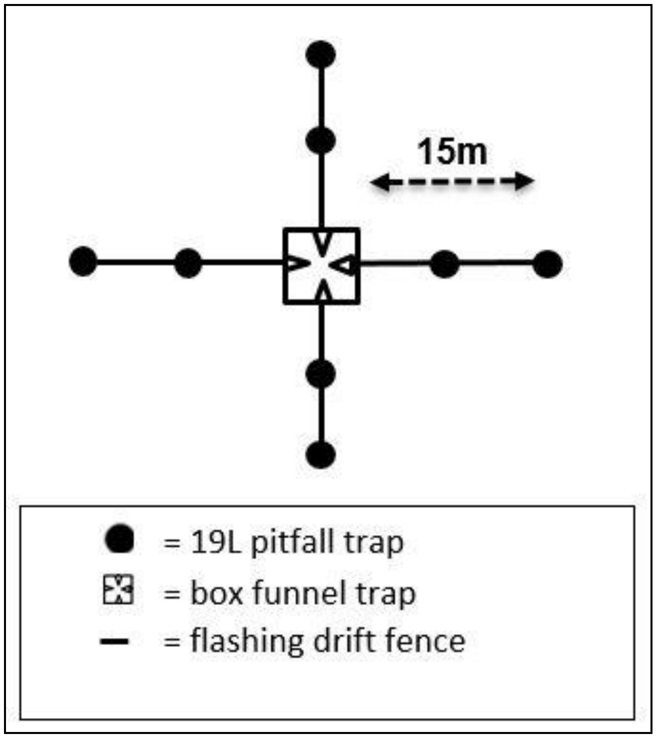

Figure 2. Drift fence design for sampling herpetofauna during 2014 – 2015 at the Solon Dixon Forestry Education Center, Andalusia, Alabama. The design was modified from Rall (2004).

Chapter 3

Effects of Forest Treatments on Ground-dwelling Macroarthropods in South Alabama Longleaf Pine Forests

Introduction

Arthropods are one of the most important components of forest communities. Arthropods have an important direct influence on soils by altering both chemical and physical properties and are often considered ecosystem engineers due to their ability to regulate the availability of resources to other organisms (Jones et al. 1994, Lavelle et al. 1997, Jouquet et al. 2006). Above the soil layer, arthropods facilitate the breakdown of leaves and needles by shredding and ultimately providing a refined food source that bacteria and fungi can readily breakdown (Hopkin and Read 1992, Moldenke et al. 2000). Xylophagous arthropods and the microbial inocula that they introduce influence the breakdown of coarse woody debris and subsequently impact valuable microhabitat for other arthropods (Schowalter et al. 1988, Horn and Hanula 2008, Hanula et al. 2009). In addition to influencing soil properties and decomposition of organic matter, arthropods also influence forest plant communities. For example, arthropods are responsible for fertilizing almost 75 % of flowering plants in longleaf pine (*Pinus palustris* Mill) ecosystems (Folkerts et al. 1993). Also, herbivorous arthropods can regulate the structure and composition of plant communities. Arthropods can synchronize their phenology with that of their host plants, and some seed predators such as Carabidae have been suggested to regulate seed banks on a national scale (Van Asch and Visser 2007, Bohan et al. 2011). Thus, ground – dwelling arthropods have a substantial effect on many components of forest communities.

While arthropods are considered one of the most influential groups of organisms within a forest, little is known about the long – term effects of forest management techniques on them. In the southeastern U.S., frequent low intensity fire historically occurred throughout longleaf pine forests (Glitzenstein et al. 2003). However, only about 3% of longleaf pine remains due to logging, fire suppression, and other anthropogenic influences (Van Lear et al. 2005). Prescribed fire is frequently used to both restore and manage existing longleaf pine forests (Provencher et al. 2001a, Carter and Foster 2004). With the frequent use of prescribed fire as a forest management tool, its effects on the ground – dwelling arthropod community is not well understood. New and Hanula (1998) suggested that prescribed fire can have some negative effects on arthropod abundance. Another study found that the short-term effects of prescribed fire altered the arthropod community composition by reducing the number of predators and increasing the number of detritivores (Hanula and Wade 2003). Additionally, some beetle species have been suggested to be attracted to recently burned longleaf stands and can vary depending upon burn intensity (Harris and Whitcomb 1974, Sullivan et al. 2003).

In addition to prescribed fire, herbicide and thinning treatments are commonly used in conjunction with frequent low intensity burning to accelerate restoration efforts of longleaf pine forests that have been degraded by fire suppression (Sharp et al. 2009). Herbicides are used to enhance the effects of prescribed fire on longleaf pines by reducing competing woody vegetation (Brockway and Outcalt 2000). The effects of herbicides on the arthropod community have been studied in agricultural settings, but to a lesser extent in forest communities. Iglay et al. (2012)

suggested that a one - time application of herbicide reduced relative abundance of some Carabidae species, possible by altering vegetation structure and diversity of loblolly pine forests in Mississippi. Campbell et al. (2008a) evaluated the effects of a prescribed fire with herbicide treatment in longleaf pine forests of South Alabama and suggested that some saproxylic beetle species are positively affected and may have short – term increases in abundance. However, abundance of combined beetle species (Coleoptera) was not different between treatments (Campbell et al. 2008a). Some authors suggest that these short-term increases in abundance were due to the attraction of beetles to increased severity of fire (Hanula et al. 2002). Besides herbicide, published studies on the combined effects of prescribed fire and thinning on arthropods are also scarce. Thinning treatments such as logging, roller chopping, and chainsawing are often used as prescribed fire pretreatments to remove encroaching hardwood vegetation and reduce fuel loads in fire – suppressed longleaf pine (Provencher et al. 2001b, Provencher et al. 2002, Menges and Gordon 2010). Thin plus burn treatments have been suggested to increase the abundance of Curculionidae compared to control plots (Campbell et al. 2008a). Also, thinning treatments have been shown to interact with land use history to influence herbivory and plant growth suppression in longleaf pine forests (Hahn and Orrock 2015).

Although there are studies on the benefits of prescribed fire, herbicide, and thinning treatments to the health of longleaf pine forests, more research is needed to understand how these treatments effect abundance and composition of arthropod communities. The purpose of my study was to evaluate the response of ground – dwelling macroarthropods to prescribed fire, herbicide, and thinning treatments in longleaf pine forests of south Alabama. I assessed the effects of these three treatments on relative abundance of orders, families, and feeding guilds of ground – dwelling macroarthropod communities. The treatments were originally part of the national Fire and Fire Surrogate (FFS) project evaluating the ecological and economic effects of fuel reduction treatments in seasonally dry forests (McIver and Fettig 2010, McIver et al. 2013). Currently, there is only one publication evaluating the effects of these treatments on arthropods in south Alabama, which focuses on short – term effects (Campbell et al. 2008a). The current study is the first to document the potential long – term effects.

Methods

Study Site

The study site is the Solon Dixon Forestry Education Center (SDFEC) located approximately 35 km southwest of Andalusia, Alabama (31.3085° N, 86.4833° W) on the Gulf Coastal Plain (see Chapter 1 Figure 1). The 2,165 ha tract of land is managed by Auburn University to provide natural resource education, support research, and generate income. The majority of land is situated in Covington County, Alabama and the remaining minority is in Escambia County, Alabama to the west. The dominant overstory tree species at this location is *P. palustris* but also includes intermixed shortleaf pine (*P. echinata* Mill.), slash pine (*P. elliottii* Engelm.), spruce pine (*P. glabra* Walter), loblolly pine (*P. taeda* L.) and oaks (*Quercus* spp.). Understory composition is dominated by gallberry (*Ilex glabra* (L.) A. Gray), yaupon holly (*Ilex vomitoria* Aiton), and blueberry (*Vaccinium* spp. L.) (Outcalt 2005). Soils on the selected study sites consist of sandy loam or loamy sand paleudults that are from the Bonify, Dothan, Malbis, Orangeburg, and Troup series (Outcalt and Brockway 2010). Karst topography is also abundant at this location with numerous water-filled depressions spread throughout the area.

Study Design

The study consisted of a randomized complete block design with 3 blocks. Three treatments were randomly applied to three experimental units within each block so that each treatment had three total replications. Experimental units were selected based on similar structure and management history and were grouped based on similar soil features (Outcalt and Brockway 2010, Steen et al. 2010). Experimental units each had a 12.25 ha core area surrounded by a 20 m buffer and infrequently managed by prescribed fire prior to start of the study.

Treatments in the current study were prescribed fire (Burn), herbicide + prescribed fire (HerbBurn), and mechanical + prescribed fire (MechBurn) (see Chapter 1 Table 1). This study followed-up a portion of a long-term experiment that initially included two additional treatments in each block, mechanical only and reference, which are described in previous publications (Rall 2004, Outcalt 2005, Campbell et al. 2008a, Sharp et al. 2009, Outcalt and Brockway 2010, Steen et al. 2010). In all cases prescribed fire was applied to all treatments by handheld drip torches. Burns were initially completed using growing season fires and subsequently used both growing and dormant season fires. A combination of backing, strip head, flanking, and spot ignition patterns were used to achieve desired results.

All experimental units had prescribed fire applied during the dormant season three to four years prior to start of this study to ensure similar time since last burn. Prescribed fire treatments were initiated in April - May 2002 and were burned every 2 – 4 years thereafter. HerbBurn treatments had a one-time application of the herbicide Garlon 4 in fall 2002. The herbicide was applied to woody vegetation up to 2 m tall using backpack sprayers to limit impact on non-target vegetation. Herbicide was applied at a 4.0 – 4.5 % solution mixed with a surfactant. Prescribed fire was applied to HerbBurn plots starting in April 2003 and burned every 2 – 4 years thereafter. MechBurn plots were initially thinned to basal area of 11.5 – 13.5 m2 / ha in March - April 2002.

Thinning targeted hardwoods and non-longleaf pines and was completed using rubber tire skidder, feller – buncher, and chain saw. In May – Jun 2005, MechBurn treatments received a mastication treatment by a front mounted roller-chopper. Smaller midstory hardwoods and understory vegetation were masticated down to 15 cm above ground level (Outcalt and Brockway 2010). In late March 2009, prescribed fire was applied to the MechBurn treatments and was reapplied every 2 – 3 years thereafter. The MechBurn treatments were originally thin-only treatments and did not include a prescribed fire application as the treatment was meant to be applied as a fire surrogate. After the initial funding was exhausted, the thin-only treatments had prescribed fire applied and became the current MechBurn treatments. This resulted in a four year gap between the last mechanical (mastication) – thinning treatment and beginning of prescribed fire applications.

Arthropod Sampling

Arthropod sampling for the current study took place June – August 2015 and was completed simultaneously with another study examining similar treatment effects on reptiles and amphibians. An existing trap design was used to target ground-dwelling macroarthropods and consisted of a cross shaped drift fence array with pitfall traps and a center box funnel trap (see Chapter 1 Figure 2). A single 19 L pitfall trap was placed at the middle and at the terminal end of each 15m section of vertical aluminum flashing. The flashing was buried approximately 5 cm and originated from the center box funnel trap. The center box funnel trap was 102 x 102 cm square consisting of hardware cloth sides (0.64 cm diameter holes), 5.08 x 5.08 cm vertical corner supports that were 40.64 cm long, and top and bottom made from 1.27 cm thick oriented strand board (OSB). A 40.64 x 30.48 cm lid fastened by two hinges was used to access captures. Each wing of flashing joined a side of the box funnel trap leading into a funnel with a 12 cm diameter entrance outside trap and 6 cm diameter exit inside trap. Each side of the box funnel trap had a funnel that was angled upward inside the trap approximately 20 degrees from horizontal to prevent any captures from escaping.

The 19 L pitfall traps did not have a killing agent, used by some traditional and contemporary entomological studies, to prevent escapees due to potential adverse effects on herpetofauna captures (Skvarla et al. 2014). Although the trap design is efficient in capturing ground-dwelling macroarthropods, not using a killing agent could have influenced the composition of captured species (Weeks and McIntrye 1997). Also, it is possible that some macroarthropod captures could have been consumed by herpetofauna and other wildlife prior to collection. Therefore, arthropods were collected daily when traps were opened to reduce escapees and limit predation by herpetofauna. Captures were placed into 50 ml plastic centrifuge tubes with 80 % ethanol and taken back to lab for identification. Specimens were identified to the family level using morphological characters, with some beetles and katydids being identified to subfamily levels. Because differences in habitat composition, arthropod activity and population density can affect pitfall captures, I considered my arthropod captures to be an index of “activity density” (Thiele 1977, Spence and Niemela 1994, Greenberg et al. 2010).

Statistical Analysis

Relative abundance and total relative abundance of macroarthropod specimens were compared between treatments using one – way ANOVAs with repeated measures. Relative abundance is an important metric when comparing community composition (MacArthur 1960, May 1988). I modeled the data in “R” using packages car and nlme (Fox and Weisberg 2011, Pinheiro et al. 2014, R Core Team 2014). Comparisons of relative abundance at the order and family levels were limited to those taxa with ≥ 30 specimens, while total relative abundance included all captures (Greenberg et al. 2010). Larvae were not included in relative abundance comparisons due to low number of specimens ($n < 30$). I also tested for treatment effects on relative abundance of macroarthropod feeding guilds using one – way ANOVAs in “R”. Specimens were assigned to feeding guilds based on primary feeding habits at the family level (Gibson et al. 1997, Arnett and Thomas 2000, Arnett et al. 2002, Capinera et al. 2004, Triplehorn and Johnson 2004, Ubick et al. 2005, Bell et al. 2007). The families Carabidae, Scarabaeidae, and Tettigoniidae were divided into feeding guilds based on different feeding strategies at the subfamily level (Kromp 1999, Ciegler 2000, Capinera et al. 2004, Triplehorn and Johnson 2004, Lundgren 2005, Carvalho et al. 2010). Feeding guilds consisted of herbivore, mixed, predator, saprophage and xylophage. Feeding guilds were used in a broad sense, such as parasitoids being included in the predator category and the mixed category containing taxa that belong to more than one feeding guild (Grimbacher and Stork 2007). Carabids have been traditionally placed in the predator feeding guild, but I placed most subfamilies in the mixed category due to supporting evidence of omnivorous feeding habits (Kromp 1999, Lundgren 2005). Five Coleoptera specimens could not be identified to family level due to predation and were excluded from feeding guild comparisons. Data for comparisons of relative abundance for taxa and feeding guilds were arcsine – square root transformed when necessary to meet the assumptions of normality and homogeneity of variance (Gotelli and Ellison 2013).

Ants (family Formicidae) were excluded from the analysis due to the prevalence of red imported fire ants (*Solenopsis invicta*) at several sites. *S. invicta* was found to cause mortality to amphibian and reptile captures during the previous year’s study. To reduce negative impacts, commercial ant block Amdro (hydramethylnon 0.88 %) granules were applied around traps and spot treated at each site June - August 2014 and 2015. The authors acknowledge that this treatment could have influenced arthropod captures, but suggest that effects to other species were minimal due to the persistence of *S. invicta* during the entire study. Also, adult female spiders of the family Lycosidae are known to carry their young, after hatching, on their abdomen on specialized knobbed hairs (Ubick et al. 2005). Because these juvenile Lycosidae captures were dependent on the capture of the adult female and can often fall off in mass numbers in pitfalls (n = 72), they were excluded from the analysis (Apigian et al. 2006). Other juvenile Lycosids that were not associated with adult females were included in the counts and analysis.

Results

Arthropod relative abundance

During June – August 2015, I captured 2,837 individual macroarthropods consisting of 21 orders and 87 families (see Table 1). Orthoptera and Araneae were the two orders with the most specimens with 975 and 783 individuals respectively. Lycosidae was the family with the most specimens followed by Gryllidae and Rhaphidophoridae with 604, 419, and 409 individuals respectively. Burn treatments had the most unique families with 14, followed by HerbBurn with 10, and MechBurn with 9. Larvae from any order were rarely captured (n = 20) with most belonging to Lepidoptera (n = 14). Comparison of macroarthropod total relative abundance between treatments was not significantly different (see Table 1). Also, comparisons of relative abundance of macroarthropod orders were not significantly different. Comparisons at the family level suggested that Burn treatments had marginally higher relative abundance of Carabidae than HerbBurn treatments (P = 0.062). MechBurn treatments had significantly higher relative of abundance of Gryllidae than Burn and HerbBurn treatments (P = 0.001).

Specimens were assigned to one of five feeding guilds based on family or subfamily feeding habits (see Table 2). The two most numerous feeding guilds for the three treatments accounted for 79 % of captured specimens and were herbivores and predators with 1,151 and 1,081 individuals respectively (see Figure 1). The mixed category was the third most numerous feeding guild with 472 individuals followed by saprophages and xylophages with 97 and 31 individuals respectively. The results suggest that relative abundance of the feeding guilds were not significantly different between treatments (see Table 3).

Discussion

The results suggest that there are no long-term differences in the relative abundance of macroarthropods between Burn, HerbBurn, and MechBurn treatments at the order level. The results support earlier short – term findings by Campbell et al. (2008a, 2008b) that Coleoptera were not significantly different among treatments. At the family level, Carabid beetles may benefit from Burn treatments compared to HerbBurn treatments. Carabid beetles are an important predator of seeds and smaller arthropods and are thought to have strong regulatory effects on both (Ekschmitt et al. 1997, Bohan et al. 2011). Additionally, Carabidae are thought to be good bioindicators of ecosystem disturbance due to their abundance, established taxonomy, and ease of identification (Pearce and Venier 2006). The response of Carabidae to herbicides have been primarily studied in agricultural systems, but effects seem to vary by species (Kromp 1999, Iglay 2012). There is a possibility that the one time application of herbicide could have indirectly affected Carabidae by altering the understory plant community. The herbicide used in this study (Garlon4) is indicated for woody vegetation and broadleaf plant control (Dow AgroSciences 2016). Furthermore, approximately 91 % of the captured carabids in this study were considered omnivorous, with broadleaf plant seeds suggested to be a major portion of their diet (Kromp 1999, Lundgren 2005). A similar study assessing the effects of a one – time application of broadleaf herbicide in conjunction with repeat prescribed fire in loblolly forests also suggested that Carabidae abundance can be negatively affected when compared to prescribed fire treatments alone (Iglay 2012). A more parsimonious explanation for the differences in Carabidae between Burn and HerbBurn treatments can be supported with known habitat associations. Pearce et al. (2003) suggested that Carabidae are associated with amount of CWD as it can provide important microhabitat for shelter and oviposition. Although not statistically different, burn treatments had the highest average CWD measurements and HerbBurn had the lowest average CWD measurements (see Chapter 2 Table 3). Contrasting with my results, other short – term studies found that similar Burn treatments in a Sierra Nevada mixed conifer forest and Appalachian upland hardwood forest had a negative effect and no effect, respectively, on Carabidae (Apigian et al. 2006, Greenberg et al. 2010). However, the Sierra Nevada study used a propylene glycol killing agent that has been suggested to influence the composition of captured species and also the abundance of captured Coleoptera (Weeks and McIntyre 1997, Apigian et al. 2006). These contradictory results further suggest that Carabidae have a varied response to Burn, HerbBurn, and MechBurn treatments that may be dependent on forest type and location.

The results suggested that over the long-term Gryllidae may benefit from MechBurn treatments when compared to Burn and HerbBurn treatments. Many Gryllidae species have been suggested to be associated with open areas such as meadows and fields indicating preference for a reduced overstory component (Howard and Harrison 1984, Harrison and Bogdanowicz 1995). The thinning treatments had on average 23 % and 14 % less overstory BA than HerbBurn and

Burn treatments respectively. However, a study with similar thinning treatments and macroarthropod sampling methods found no significant differences of Gryllidae between treatments (Greenberg et al. 2010).

The results also indicated that relative abundance of feeding guilds were not different between treatments over the long-term. Using feeding guild comparisons allowed us to compare ground – dwelling macroarthropod communities independent of taxonomic rank (Root 1967). Partitioning macroarthropods into feeding guilds using families and subfamilies may have produced some inaccuracies, as some authors suggest feeding habits are not easily predicted above the generic level (Walter and Ikonen 1989). Using generic and species classifications for feeding guild assignments may have suggested that relative abundance of feeding guilds were significantly different across treatments.

Comparing ground – dwelling macroarthropod communities using pitfall traps is a common method used by entomologists and ecologists. However, a familiar problem with pitfall trapping is that macroarthropod captures are a result of both density and activity, and one of these may change while the other remains stable (Spence and Niemela 1994). Nonetheless, using "activity – density" to measure changes in macroarthropod communities has been suggested to be as important as using absolute abundance (Apigian et al. 2006). The pitfall trap sampling methods were designed to capture macroarthropods active at the ground layer and were potentially biased against flying insects and other arthropods that could escape the pitfalls traps. These macroarthropods were most likely underrepresented in my study. Also, because I limited the comparisons to orders and families, there may have been undetected responses at lower taxonomic levels.

Conclusion

The study suggests that Burn, HerbBurn, and MechBurn treatments have similar long-term effects on macroarthropod orders and most families based on relative abundance comparisons. In addition, these treatments appear to have similar macroarthropod feeding guild compositions. Because the study did not include a control treatment, I can only compare experimental treatments to other experimental treatments in the absence of reference data.

The differences in Carabidae between Burn and HerbBurn indicate long-term residual effects of the one-time supplemental herbicide treatment. MechBurn was the only treatment that did not have any suggested negative effects on the macroarthropod community relative to the Burn and MechBurn treatments.

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Table 1. Total and average ± SE macroarthropod specimens per trap day for Burn, HerbBurn, and MechBurn treatments at the Solon Dixon Forestry Education Center (SDFEC), Andalusia, Alabama.

		Treatment			P - value
Order and Family	Total	Burn	HerbBurn	MechBurn	
Araneae	783	4.57 ± 0.38	5.22 ± 0.41	4.70 ± 0.43	0.606
Lycosidae	604	3.52 ± 0.31	4.02 ± 0.39	3.65 ± 0.37	0.895
Archaeognatha	114	1.15 ± 0.41	0.76 ± 0.22	0.33 ± 0.06	0.668
Meinertellidae	114	1.15 ± 0.41	0.76 ± 0.22	0.33 ± 0.06	0.648
Blattodea	189	1.20 ± 0.22	0.87 ± 0.14	1.43 ± 0.28	0.879
Blattellidae	189	1.20 ± 0.22	0.87 ± 0.14	1.43 ± 0.28	0.919
Coleoptera	375	2.69 ± 0.36	1.83 ± 0.23	2.39 ± 0.30	0.266
Carabidae	135	0.98 ± 0.14[a]	0.43 ± 0.10[b]	1.04 ± 0.18[ab]	0.062
Scarabaeidae	93	0.74 ± 0.30	0.43 ± 0.08	0.55 ± 0.12	0.993
Tenebrionidae	32	0.09 ± 0.04	0.26 ± 0.10	0.25 ± 0.09	0.410
Hemiptera	80	0.30 ± 0.07	0.41 ± 0.10	0.78 ± 0.15	0.172
Hymenoptera	153	1.20 ± 0.24	0.87 ± 0.15	0.76 ± 0.14	0.792
Mutillidae	127	0.96 ± 0.21	0.72 ± 0.13	0.63 ± 0.13	0.781
Orthoptera	975	4.75 ± 0.49	6.39 ± 0.56	6.98 ± 0.55	0.482
Acrididae	110	0.59 ± 0.15	0.91 ± 0.20	0.57 ± 0.15	0.519
Gryllidae	419	1.81 ± 0.35[a]	1.85 ± 0.26[a]	4.15 ± 0.43[b]	0.001
Rhaphidophoridae	409	2.09 ± 0.36	3.26 ± 0.41	2.20 ± 0.35	0.746
Phasmida	58	0.35 ± 0.11	0.39 ± 0.14	0.33 ± 0.10	0.985
Pseudophasmatidae	58	0.35 ± 0.11	0.39 ± 0.14	0.33 ± 0.10	0.989
Total	2837	16.87 ± 1.42	17.48 ± 1.04	18.13 ± 1.16	0.963

Differences between treatments are indicated by different letters within the same row. Comparisons made for taxa that had ≥ 30 specimens (Greenberg et al. 2010).

Table 2. Feeding guild assignments of macroarthropod families and selected subfamilies at the Solon Dixon Forestry Education Center (SDFEC), Andalusia, Alabama.

Herbivore	Saturniidae	Cosmetidae	Scoliidae
Acanaloniidae	Scutelleridae	Crabronidae	Scolopendridae
Acrididae	Tetrigidae	Cryptopidae	Staphylinidae
Alydidae	Cetoniinae	Ctenidae	Tabanidae
Apidae	Conocephalinae	Ctenizidae	Tachinidae
Chrysomelidae	Dynastinae	Culicidae	Theridiidae
Cicadellidae	Melolonthinae	Dictynidae	Theridiosomatidae
Cicadidae	Phaneropterinae	Gnaphosidae	Thomiscidae
Coreidae	Pseudophyllinae	Hahniidae	Tiphiidae
Curculionidae	Mixed	Histeridae	Uloboridae
Cydnidae	Blattellidae	Linyphiidae	Vespidae
Dictyopharidae	Elateridae	Lithobiidae	Cicindelinae
Erebidae	Lepismatidae	Lycosidae	Scaritinae
Geometridae	Meinertellidae	Mantidae	Tettigoniinae
Gryllidae	Tenebrionidae	Miturgidae	Saprophage
Hesperiidae	Harpalinae	Mutillidae	Geotrupidae
Largidae	Predator	Myrmeleontidae	Julida
Lycidae	Agelenidae	Nabidae	Oniscidae
Megalopygidae	Amaurobiidae	Nephilidae	Polydesmida
Noctuidae	Amphinectidae	Oxyopidae	Spirobolida
Notodontidae	Araneidae	Phalangiidae	Trogidae
Pentatomidae	Ascalaphidae	Pisauridae	Aphodiinae
Pseudophasmatidae	Cleridae	Pompilidae	Scarabaeinae
Rhaphidophoridae	Clubionidae	Pyrgotidae	Xylophage
Rhyparochromidae	Coenagrionidae	Reduviidae	Cerambycidae
Romaleidae	Corinnidae	Salticidae	Passalidae

Table 3. Mean ± SE of macroarthropod feeding guilds per trap day for Burn, HerbBurn, and MechBurn treatments at Solon Dixon Forestry Education Center (SDFEC), Andalusia, Alabama.

	Treatment			P - value
Feeding guild	Burn	HerbBurn	MechBurn	
Herbivore	5.46 ± 0.54	7.57 ± 0.65	8.2 ± 0.62	0.409
Mixed	3.48 ± 0.55	2.33 ± 0.32	2.93 ± 0.40	0.843
Predator	6.87 ± 0.64	6.87 ± 0.52	6.17 ± 0.50	0.277
Saprophage	0.91 ± 0.30	0.37 ± 0.12	0.52 ± 0.11	0.317
Xylophage	0.09 ± 0.04	0.24 ± 0.08	0.22 ± 0.06	0.135

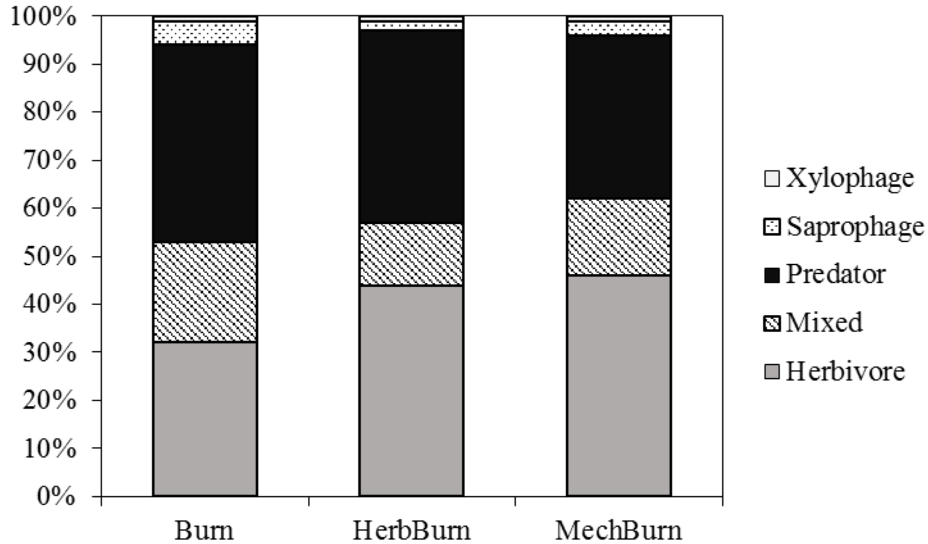

Figure 1. Relative abundance of feeding guilds for macroarthropod specimens in Burn, HerbBurn, and MechBurn treatments at Solon Dixon Forestry Education Center (SDFEC), Andalusia, Alabama.

Chapter 4

Summary

This study suggested that the responses of ground – dwelling herpetofauna and macro – arthropods varies and may depend on specific natural history characteristics. Results indicated treatments may not have an effect on *Gastrophryne carolinensis*, but may affect *Scaphiopus holbrookii*. Captures of *S. holbrookii* were higher in treatments with prescribed fire only relative to other treatments, suggesting that this treatment may be the best among those in the experiment.

Additionally, *S. holbrookii* juveniles may be associated with and benefit from increased midstory BA. However, supporting studies for this habitat association are lacking. There appears to be a very weak negative relationship of *G. carolinensis* with coarse woody debris. This relationship may be coincidental as coarse woody debris is suggested to be beneficial in creating favorable microhabitat.

Results suggest that treatments do not affect ground – dwelling macroarthropods at the order and feeding guild levels. Carabid beetles may benefit from prescribed fire only treatment relative to prescribed fire plus herbicide treatment. Also, the mechanical plus burn treatment may benefit Gryllidae relative to other tested treatments.

Differences in habitat measurements between treatment levels were not statistically significant. Means of some habitat measurements were much higher / lower than others, but high SE of measurements due to appreciable levels of heterogeneity within treatments likely influenced these results. Increasing the number habitat measurement plots within each site could reduce the SE and provide better estimates.

A potential confounding factor for this study was the heavy presence of red imported fire ants (*Solenopsis invicta*) at some of the sites. Mechanical plus burn sites had substantial mortality of herpetofauna due to fire ant predation and accounted for 75.4% of herpetofauna predation by fire ants for the entire study. Many predated captures in this treatment were consumed down to skull and bones within the 24-hour period between checking traps. These predated captures were most likely *G. carolinensis* given their size and skull shape. However, these captures were not included in my analysis due to identity uncertainty and could have influenced the results on herpetofaunal capture comparisons. Additionally, the application of Amdro to all sites during the two years may have indirectly influenced *G. carolinensis* captures as over 90 % of their diet consists of ants. The Amdro application could have influenced the arthropod community composition and abundance, especially the ant community.

Future research at this site should focus on including multiple years and seasons (e.g. fall, winter, spring) to account for variation between years and potential effects on species that are usually only active during colder periods.