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COMPARING MECHANICAL MASTICATION, HERBICIDE APPLICATION, AND PRESCRIBED FIRE WITHIN AN ESTABLISHED LONGLEAF PINE (PINUS PALUSTRIS MILL.) ECOSYSTEM

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COMPARING MECHANICAL MASTICATION, HERBICIDE APPLICATION, AND PRESCRIBED FIRE WITHIN AN ESTABLISHED LONGLEAF PINE (*Pinus palustris* Mill.) ECOSYSTEM

A Dissertation
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy
Forest Resources

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by
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Accepted by:
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ABSTRACT

Longleaf pine (*Pinus palustris* Mill.) forests once dominated the landscape throughout the Southeast and much of its success could be attributed to ecological disturbances such as fire. However, the use of fire as a management tool may be at risk due to a growing human population, negative impacts resulting from smoke production, and the imposition of restrictive federal and state laws, policies, and standards. This study was designed to determine whether alternative silviculture treatments such as herbicide or mechanical mastication can be used as surrogates to prescribed fire. We applied three commonly used silviculture treatments (prescribed burning, mechanical mastication, and herbicide) one time in May 2008 to eighteen approximately equal sized treatment units (0.405 ha) at the Aiken Gopher Tortoise Heritage Preserve, which is located in Aiken County, South Carolina. The firing techniques used during the prescribed fire consisted of a mix of backing, flanking, and head fires. The herbicide used was the granular form of hexazinone [3-cyclohexyl=6-(dimethylamino)-1-methy-1,5-triazine-2,4(1H,3H)-dione] also known as Dupont^{TM} Velpar ULW®, which was broadcast evenly at a rate of 1.26 kg a.i./ha. A Bobcat T-300 with a forestry cutter head and hand tools were used for mechanical mastication; these tools were used to masticate any midstory vegetation (i.e. *Quercus* spp.). Additional treatments were applied in a split-plot design, including rake and non-rake subplots within each of the herbicide and mechanical mastication treatment units. We monitored the response of the understory herbaceous layer (<1.5 m) to each treatment; we assessed the species richness, species diversity, evenness, and the survivorship of naturally regenerated longleaf pine seedlings

(*P. palustris* Mill.). We also measured the litter depth of the forest floor, monitored the foliar cover of *Aristida stricta*, tracked the recruitment of *Aristida stricta* seedlings, and evaluated which treatment provided the maximum usage forage (medium = M, high = H, and very high = VH) for gopher tortoises pre- and post-treatment.

No significant differences were determined between the species richness, species diversity, and evenness following treatments for two consecutive growing seasons. Both prescribed fire and mechanical mastication promoted species richness and diversity values that exceeded pre-treatment levels by the end of the second growing season. Prescribed fire treatments generated the highest relative increases in the evenness values, followed by mechanical mastication, and then herbicide. Mechanical mastication and herbicide treatments generated higher longleaf pine seedling survivorship while prescribed fire negatively affected the longleaf pine seedling survivorship. While the broadcast application of hexazinone caused initial decreases in species richness and diversity, the understory plants gradually began to recover the ensuing year. Prescribed fire positively influenced the *Aristida stricta* foliar cover throughout the study. Initial *Aristida stricta* foliar cover declines were observed following both the herbicide and mechanical mastication treatments; however, it began to recover the following year.

Litter depths were not significantly influenced by any of the study treatments. Prescribed fire generated the greatest initial litter depth reduction (54%) and maintained the slowest litter recovery throughout the study. However, initial (2010) litter depth reductions were also observed each post-treatment year within the herbicide (38%) and mechanical mastication (39%) units.

Aristida stricta seedling counts were not significantly different across the herbicide and mechanical mastication treatment units. However, the rake subplots promoted non-significantly higher *A. stricta* seedling counts following initial treatments versus non-rake subplots. The rake subplots yielded the highest initial increases and maintained the highest difference each post-treatment year.

No significant differences were determined between treatment types for the VH or M ranking gopher tortoise forage values. Significant treatment differences were determined for the H value forage in both post-treatment years. While there were mixed results across each treatment, no significant differences were observed for the prescribed fire treatment units throughout the study. The prescribed fire units yielded positive increases across all preferred gopher tortoise forage initially following treatment and maintained positive gains for the VH and M usage flora species throughout the study. Mechanical mastication produced some gains for the VH and M species initially following treatment; however, these were short-lived and quickly fell below pre-treatment levels by the end of the second post-treatment growing season. The herbicide treatment caused significant decreases for the VH and H gopher tortoise forage species during both post-treatment years.

Based on results from this study, prescribed fire is the preferred silviculture tool that provides the maximum benefit to a xeric sandhills mature longleaf pine community by suppressing woody species, encouraging a diverse herbaceous understory, promoting an overall higher usage forage for gopher tortoises, and reducing litter layer accumulation. However, in areas that the use of fire may be limited or restricted, our study suggests that the use of herbicide and/or mechanical mastication treatments can be used to gain the desired structure and appearance and allow for regeneration of longleaf pine, but these alternative silviculture tools may not promote the desired understory herbaceous layer for target species such as the gopher tortoise. Caution should be made when applying these modern silviculture treatments, since impacts to the ecosystem resilience has not been documented long-term. These modern tools may be the next perturbation that will mimic stochastic events like fire and hurricanes. However, the longleaf pine ecosystem evolved under a fire regime and shifts may result from the new disturbance; consequently, close monitoring should occur following their use.

Keywords: Alternative silviculture practice; Hardwood reduction treatments; Herbicide; Hexazinone; Velpar; Mechanical manipulation; Mastication; Sandhills; *Pinus palustris*; Plant species diversity; Litter depth; Gopher tortoise; *Gopherus polyphemus*; Gopher tortoise forage; South Carolina Department of Natural Resources

DEDICATION

First and foremost I want to praise God for providing me the insight and drive to pursue my dreams and goals. I know it is through His strength (Philippians 4:13) I can accomplish anything, and I will reap a harvest if I do not give up (Galatians 6:9)! Special thanks go to my wife, Kelley, my daughters, Kinley and Leylinn, and my son Mattison. There is no doubt in my mind that without my wife's support and encouragement and my children's daily smiles and laughs I could not have completed this process. Even though it has been a hard road to travel, this life challenge and experience has forever changed me as a scientist, father, husband, and human!!

"The vast possibilities of our great future will become realities only if we make ourselves responsible for that future." –Gifford Pinchot

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CHAPTER ONE

INTRODUCTION

BACKGROUND

Although the longleaf pine (*Pinus palustris* P. Mill) habitat is considered one of the most diverse ecosystems in the world, it is classified as "critically endangered" (Noss *et al.* 1995). Historically, longleaf pine forests dominated the southeastern United States and were maintained with both natural and anthropogenic fires (Glitzenstein *et al.* 1995, Landers *et al.* 1995, Franklin 1997, Jose *et al.* 2006). Prior to European settlement, these forests covered between 24 to 37 million hectares from Virginia to eastern Texas and south through central Florida (Boyer 1990, Simberloff 1993, Frost 1993, Varner *et al.* 2003, Jose *et al.* 2006); however, current reports estimate that less than 1 million hectares remain today (Dennington and Farrar 1983, Engstrom *et al.* 1996, Varner *et al.* 2003, Jose *et al.* 2006). Old-growth longleaf stands only make up approximately 0.01% of the remaining forests (Means 1996, Varner and Kush 2001, Varner *et al.* 2003); moreover, much of the remaining forests are devoid of an understory with a diverse herbaceous layer (Ware *et al.* 1993, Outcalt 2000, Varner *et al.* 2003). The herbaceous layer associated with the longleaf pine community varies depending on the geographic area or habitat type (Jose *et al.* 2006, Sorrie and Weakley 2006). The species richness of the longleaf pine ecosystem is highly diverse for a temperate woodland and has been compared to that of tropical rainforests (Peet and Allard 1993, Means 1996, Brockway *et al.* 2005). Walker (1993) reports that range-wide over 187 rare vascular plant taxa occur within longleaf pine habitats. A variety of vertebrate and invertebrate species depend on the existence of longleaf pine communities (Jones and Franz 1990, Breininger *et al.* 1991, Ashton and Ashton 2008). A number of plant and animal species have been added to the U.S. Fish and Wildlife Service's threatened or endangered species list since the decline of the longleaf pine ecosystem. The gopher tortoise (*Gopherus polyphemus* Daudin), a keystone species, has been documented to provide safe haven to more than 300 vertebrate and invertebrate species within its burrow (Young and Goff 1939, Landers and Speake 1980, Milstrey 1986 , Witz and Palmer 1991, Florida Fish and Wildlife Conservation Commission 2007). The legal status of the gopher tortoise varies depending on the population, being listed as federally threatened wherever found west of Mobile and Tombigbee Rivers in Alabama, Mississippi, and Louisiana to state listed as threatened/endangered in Alabama, Georgia, Florida, and South Carolina (U.S. Fish and Wildlife Service 2013). In 2011, the federal listing for the eastern portion of the gopher tortoise was elevated to a candidate status.

The first documented Eurasian impacts to the longleaf pine community came about in the 1600s when disease was introduced by Spanish explorers. Disease and conflicts eliminated approximately two-thirds of the Native American population, therefore reducing the use of fire as a management tool (Carroll *et al.* 2002). The Spaniards also transported livestock (i.e. cattle and hogs) to supplement their food supply. The livestock was often turned loose for open-range grazing (Croker 1979). Unfortunately, many of the domestic hogs strayed off and laid the foundation for creating a population of free-ranging feral hogs (*Sus scrofa* Linneus; a.k.a. pineywoods rooters). Although wild hogs consume pretty much anything in their path, they developed an affinity for longleaf pine seedling roots. Walker (1999) reports that a single boar can consume up to 800 longleaf pine seedlings in a ten hour period. Seedling consumption by wild hogs negatively impacted the natural regeneration of the longleaf pine (Lipscomb 1989).

During the 1700s and 1800s impacts on longleaf pine forests increased dramatically when timber harvesting became more efficient with the inventions of water-powered sawmills, steam log skidders, and the railroad (Jose *et al.* 2006). However, technological improvements in the 1800s and 1900s prompted Euro-Americans to expand across the southeast further impacting the remaining longleaf pine forests with poor silviculture, intensive agriculture practices, and forest conversions (Croker 1979, Jose *et al.* 2006). Mature longleaf pine was also being exploited by the American Navy to build ships. In fact, according to anecdotal reports, the U.S.S. Constitution, also known as Old Ironsides, was primarily constructed of pine (a.k.a. longleaf pine) and southern live oak (*Quercus virginiana*) in 1794. Today, it is the world's oldest floating commissioned vessel. Further impacts resulted when the United States Congress passed the Indian Removal Act on May 28, 1830. The Act essentially drove the Five Tribes (a.k.a. five Southeastern Native American nations)—Cherokee, Chickasaw, Chostaw, Muscogee, and Seminole—off of land they inhabited and managed with fire.

The history of fire suppression can be traced back to the late 1910s when the United States Department of Agriculture Forest Service created the "10 a.m. Fire Control Policy." This policy was created to suppress all fires in all locations prior to 10 o'clock the following day (Lundgren 1999). In the 1940s, after the attack at Pearl Harbor and bombardment of shells that exploded along the coast of Santa Barbara by a Japanese submarine, the fear that numerous wildfires could be ignited via enemy attack became a reality for United States citizens. With many of the able men fighting in World War II and not available to fight wildfires, this became a matter of national importance. In fact, the United States government worked out a deal with Mr. Walt Disney in 1942 to use Bambi as the first animal to help prevent wildfires. However, Bambi was only on loan for one year. Consequently, in 1944 the first poster of Smokey Bear was released. Bambi and Smokey Bear were part of a national campaign that was designed to educate the general public about suppressing wildfires. Since the public was not educated about the value of fire as a management tool (e.g. wild vs. controlled), this fire campaign created a frenzy of fire suppression. The impacts of this successful campaign still exist today. As a result of reduced anthropogenic fires and increased wildfire suppression, both the understory and overstory of the longleaf pine ecosystem were invaded by scrub species (i.e. *Quercus* spp.) that quickly developed and began to out-compete the natural longleaf pine and the herbaceous understory species.

Today, the quality of silviculture techniques and agricultural practices has improved in regards to environmental protection and forest management. In addition, scientists have identified the economical and environmental value of the longleaf pine ecosystem. Still, the longleaf pine faces another challenge: wildland-urban interface (WUI; Davis 1987). Tracts of land that were once dominated by longleaf pine and isolated in rural areas are now surrounded by neighborhoods, strip malls, and highly travelled roads. According to the United States Census Bureau (2002), the current United

States population is estimated at over 310 million people. This makes the United States the third largest population in the world. The United States Census Bureau (2002) reports that by the year 2048 there will be an estimated population of over 8 billion people living on planet earth. In fact, the population of South Carolina alone increased by 15.1% between 1990 and 2000. According to the United States Census Bureau (2011), the population of Aiken County, South Carolina has increased 46% between 1980 and 2008.

With such significant increases in the population, wildland-urban interface appears to be unavoidable. Consequently, federal, state, and local laws, policies, and standards are becoming increasingly restrictive concerning the use of prescribed fire (a.k.a. controlled burning) as a management tool (Keeling *et al.* 2006). According to the Citizens Against Polluted Air (CAPA) (2009), breathing "…clean air is as fundamental as the right to freedom of speech." They also reported that in 1998 the Iowa Supreme Court ruled that "…government bodies do not have the right to allow burning that results in smoke crossing property lines." The United States Environmental Protection Agency (EPA 2004) under Sections 108 and 109 of the Clean Air Act (CAA) has the authority to establish and revise the National Ambient Air Quality Standards (NAAQS) to provide protection for the nation's public health and the environment. The cost of insurance premiums to cover prescribed burning has skyrocketed over the past decade. According to Darryl Jones with the South Carolina Forestry Commission (per. comm.. May 2, 2011) insurance premiums currently range from $250 (single event) to $19,000 (annual policy); premiums are based on total volume of acres burned annually, average tract size, or the tract size for a single event. Although liability has become a concern while conducting prescribed burns in recent years, it is increasingly difficult to conduct prescribed burns without negatively influencing someone either by an occasional escaped fire, smoke, or increased air pollutants.

As the wildland-urban interface increases, the use of fire as a management tool will become increasingly difficult; consequently, the flora and fauna species that depend on longleaf pine ecosystems (a fire dependent system) are at risk. This is of special interest to the South Carolina Department of Natural Resources (SCDNR) because many of its land managers are challenged with restoring and maintaining longleaf pine ecosystems while trying to retain suitable habitat for many game and non-game species including the red-cockaded woodpecker and the gopher tortoise. While there are some studies that have examined alternative silviculture practices other than fire, few have simultaneously investigated prescribed fire and its alternative treatments side-by-side within an established longleaf pine ecosystem. Consequently, a study was conducted on Aiken Gopher Tortoise Heritage Preserve in Aiken County, SC from 2007 to 2011, in order to determine how alternative silviculture practices compare to prescribed burning in regards to natural longleaf pine seedling and wiregrass recruitment and survivorship, vegetative understory response, and litter depth accumulation.

Cecil Frost (2000) best summarized the existence of the longleaf pine forest in his doctoral dissertation when he stated that for "…the first time in evolution, survival of all native plant communities and species will depend on human management." Unless alternative silvicultural practices are explored to sustain longleaf pine forests, the restrictions placed on prescribed burning as a management tool could potentially extirpate some or all of the remaining 1 million hectares of longleaf pine habitat, the restored areas, and the flora and fauna that depend on them. It is suggested that restoration of these fragmented longleaf pine stands should focus on redefining the stand structure and establishing the ecological trajectory that mimics or duplicates a natural stand in species composition or diversity at multiple spatial and temporal scales versus some arbitrary point in history (Brockway *et al.* 2002).

STUDY SITE

This study was conducted at Aiken Gopher Tortoise Heritage Preserve (AGTHP) in Aiken County, South Carolina (Fig. 1.1). The preserve is located in the western portion of South Carolina (33 ^{o} 29’ 48”N, -81 ^{o} 25’ 17”W) in an area referred to as the sandhills ecoregion. Even though Aiken County, SC crosses five watersheds, the study area falls within the South Fork Edisto watershed as defined by the United States Environmental Protection Agency (EPA 2012; EPA #0305024). The 656 hectare heritage preserve is owned by SCDNR and is currently managed primarily for the gopher tortoise (*Gopherus polyphemus* Daudin). Historical aerial photographs, dating back to 1938, and a title search indicate that the study area falls within the ownership of one residence that clear-cut and converted a majority of the property to cultivated fields (F&ME Consultants 1999). The mean monthly air temperature ranges from 8.3^{o} C in January to 27.1^{o} C in July. The mean monthly precipitation ranges from 6.5 cm in November to 12.8 cm in July (Southeast Regional Climate Center 2011). The soils that dominate this property are a mix of Lakeland, Troup, and Fuquay (USDA 1985). These are deep, marine-deposited, relatively sterile, well-drained sandy soils with an average pH of 4.8 (Appendix 1.1; Clemson 2007). Based on the historical aerial photographs and increment tree bore sampling, the dominant longleaf pine overstory canopy trees are approximately 35 years old with a basal area ranging from 7 to 17 m^2/ha. The midstory is made up of scrub shrubs dominated by oaks (*Quercus* spp.; Appendix 1.2). The understory contains a diverse herbaceous ground layer, including wiregrass (*Aristida stricta* Michx.) and a variety of bluestems (*Andropogon* spp.). The section of the heritage preserve where this study occurred was acquired in 1999 and the manager at that time, Johnny P. Stowe, burned on an as needed basis or at least biennially (pers. comm. May 02, 2011); consequently, the entire midstory and understory is relatively uniform. Prescribed burns were last conducted across this 55 hectare section of the property in March & April 2005, respectively. The location of the study area and treatment units are delineated in Figure 1.2.

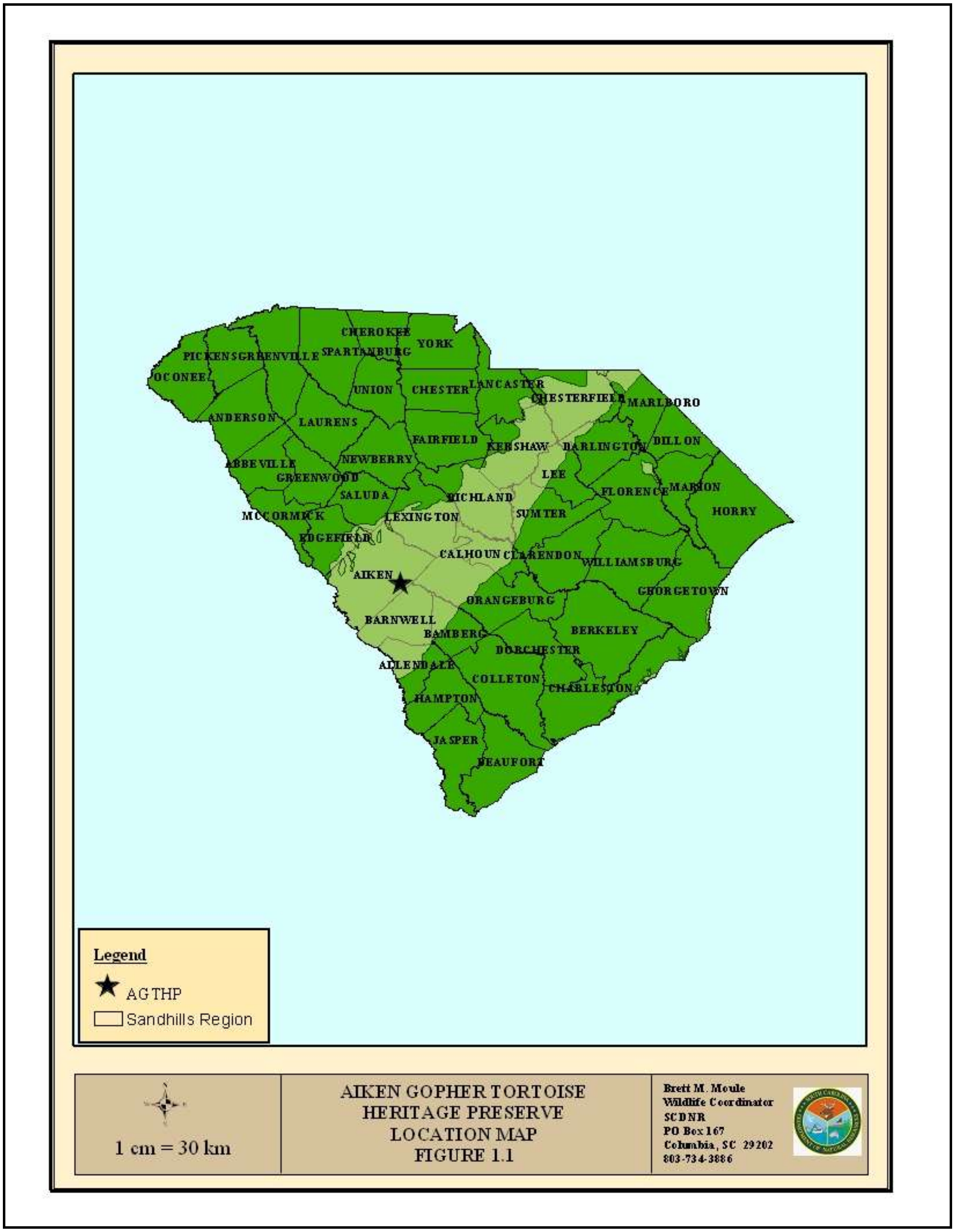

Figure 1.1. General location of Aiken Gopher Tortoise Heritage Preserve in Aiken County, SC.

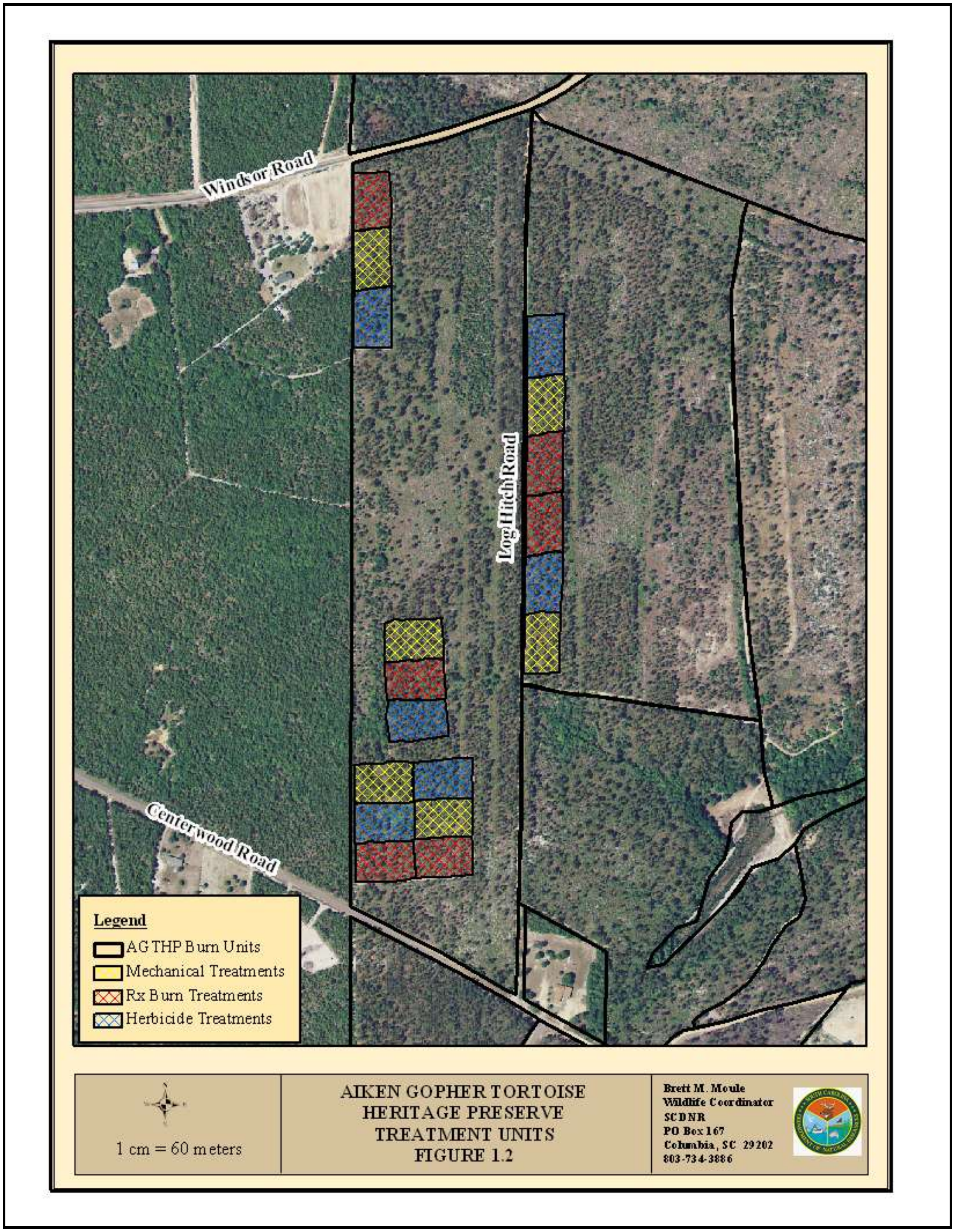

Figure 1.2. Treatment units at Aiken Gopher Tortoise Heritage Preserve, Aiken County, SC.

OBJECTIVES AND DISSERTATION STRUCTURE

The overall goal of my dissertation is to determine how the application of herbicide and mechanical mastication influence the species diversity of the understory vegetation and how each impact litter depth levels, while retaining suitable habitat for gopher tortoises on Aiken Gopher Tortoise Heritage Preserve, Aiken County, SC. More specifically, I want to determine if herbicides or mechanical mastication can be used as surrogates for prescribed burning.

To answer these questions, this research is designed to achieve the following objectives: (1) compare the effects of prescribed burning, mechanical mastication, and herbicide treatment on the understory herbaceous layer and naturally regenerated *P. palustris* seedlings of a mature longleaf pine forest pre- (2007) and post-treatment (2008, 2009, and 2010) for three consecutive years; (2) assess the impacts that each treatment had on the litter depth post-treatment for three consecutive years and determine if the removal or retention of the forest floor litter layer influenced the recruitment of *A. stricta* seedlings; and (3) determine which treatment provided the maximum usage forage for gopher tortoises by comparing the response of the understory herbaceous layer post-treatment two consecutive years to literature. The remainder of the dissertation consists of 5 chapters. Chapter 2 is a literature review of the effort to restore longleaf pine ecosystems, including the restoration of the understory layer using herbicides and mechanical mastication as alternative silviculture practices. Chapter 3 quantifies and compares the selected silviculture treatment effects on the understory herbaceous layer. Chapter 4 quantifies the effects selected silviculture treatments have on litter depths and wiregrass (*A. stricta*) seedling recruitment. Chapter 5 investigates which silviculture treatment provides the optimum forage for the gopher tortoise (*G. polyphemus*). Chapter 6 summarizes major conclusions and recommendations from Chapters 3 to 5. The main emphasis in all chapters is to increase our understanding of the response of the longleaf pine ecosystem to alternative silviculture practices and suggest how they can be applied to help sustain this ecosystem and the gopher tortoise population. I am also hopeful that the ecological knowledge gained from this study can be applied to help perpetuate the continued restoration efforts required to maintain and enhance longleaf pine forests.

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CHAPTER TWO

LITERATURE REVIEW

LONGLEAF PINE

Prior to European settlement in the Southeast, the pyroclimax longleaf pine (*Pinus palustris* Mill.) ecosystem dominated the landscape from Virginia to eastern Texas and south through central Florida (Figure 2.1; Boyer 1990a, Simberloff 1993, Frost 1993, Varner *et al.* 2003, Jose *et al.* 2006, Peet 2006). Since the range of the longleaf pine ecosystem extends across a variety of geographical areas, it has adapted to an array of edaphic conditions (Wells and Shunk 1931, Kirkman *et al.* 2001) and habitat types ranging from xeric sandhills, to wet, poorly-drained flatwoods, to the mountains of northern Alabama and Georgia (Varner *et al.* 2003, Jose *et al.* 2006). Due to the complexity and large spatial range of the longleaf pine, several ecoregion systems have been proposed (Omernik 1987, Bailey 1980, Bailey 1995, Shirazi *et al.* 2003, Peet 2006, Wilken *et al.* 2011, EPA 2011; Figure 2.1). Earlier literature states that longleaf pine could be found in nine states and once dominated between 24 to 38 million hectares (Boyer 1990a, Simberloff 1993, Frost 1993, Varner *et al.* 2003, Brockway *et al.* 2005a & 2005b, Jose *et al.* 2006); however, current reports estimate that less than 1 million hectares remain today (Dennington and Farrar 1983, Engstrom *et al.* 1996, Varner *et al.* 2003, Jose *et al.* 2006). Unfortunately, only 0.01% of the remaining 1 million hectares of longleaf pine forests contain old-growth longleaf pine (Means 1996, Varner and Kush 2001, Varner *et al.* 2003); moreover, much of the remaining forests are devoid of an understory with a diverse herbaceous layer (Ware *et al.* 1993, Outcalt 2000, Varner *et al.*

2003). The degradation of this ecosystem can be attributed to the introduction of free-ranging hogs, timber production, naval store production (turpentine), southern pine plantation conversions (slash pine *P. elliotti* Engelm. and loblolly pine *P. taeda* L.) and fire suppression (Croker 1979, Frost 1993, Landers *et al.* 1995).

Prior to European settlement, both anthropogenic (DeVivo 1991, Denevan 1992, Robbins and Myers 1992, Landers and Boyer 1999, Van Lear *et al.* 2005) and natural fires (Komarek 1974, Carroll *et al.* 2002, Van Lear *et al.* 2005) were responsible for shaping the landscape of the longleaf pine's natural range. Once ignition occurred, fires burned freely across vast areas and played a critical role in the competitive success of the longleaf pine and the diverse herbaceous layer (Kush *et al.* 1999). Frost (1995; 2000; Figure 2.2) reported that pre-European settlement fire frequency ranged between 1-3 years for the flat plains (a.k.a. Atlantic & Southern Coastal Plains—Peet 2006; Figure 2.1) and between 4-6 years in irregular plains and tablelands (a.k.a. Fall-line Sandhills/Southern & Eastern Coastal Plains—Peet 2006; Figure 2.1). Dendrochronological evidence from remnant longleaf pines out of Florida and Louisiana define a fire return interval between 2-3 years post-European settlement (Huffman 2006, Stambaugh *et al.* 2011, Knapp *et al.* 2012). As a result of these chronic fires and other ecological disturbances (i.e. atmospheric and insect infestations), the longleaf pine evolved and developed unique characteristics that enabled this species to tolerate and withstand many environmental stressors.

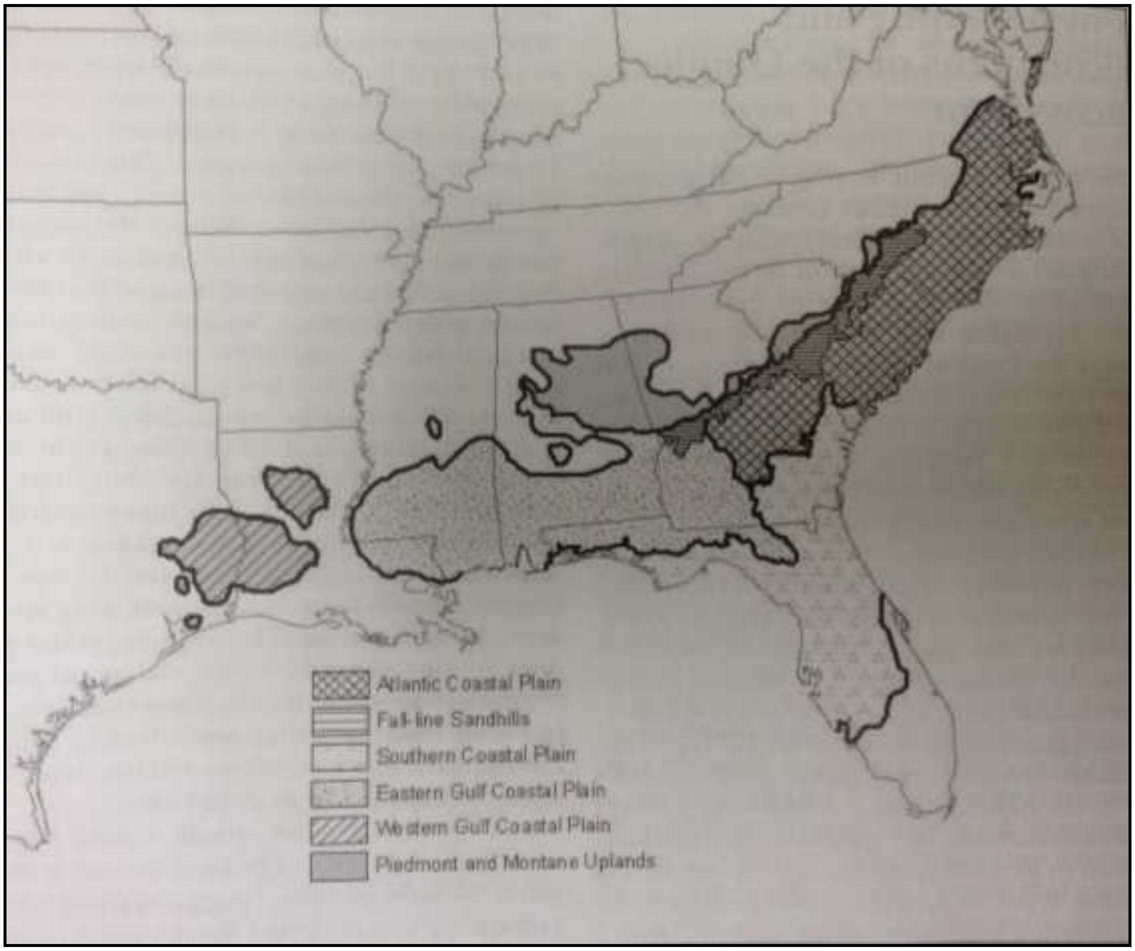

Figure 2.1. Pre-European-settlement range of longleaf pine (*Pinus palustris*; Peet 2006)

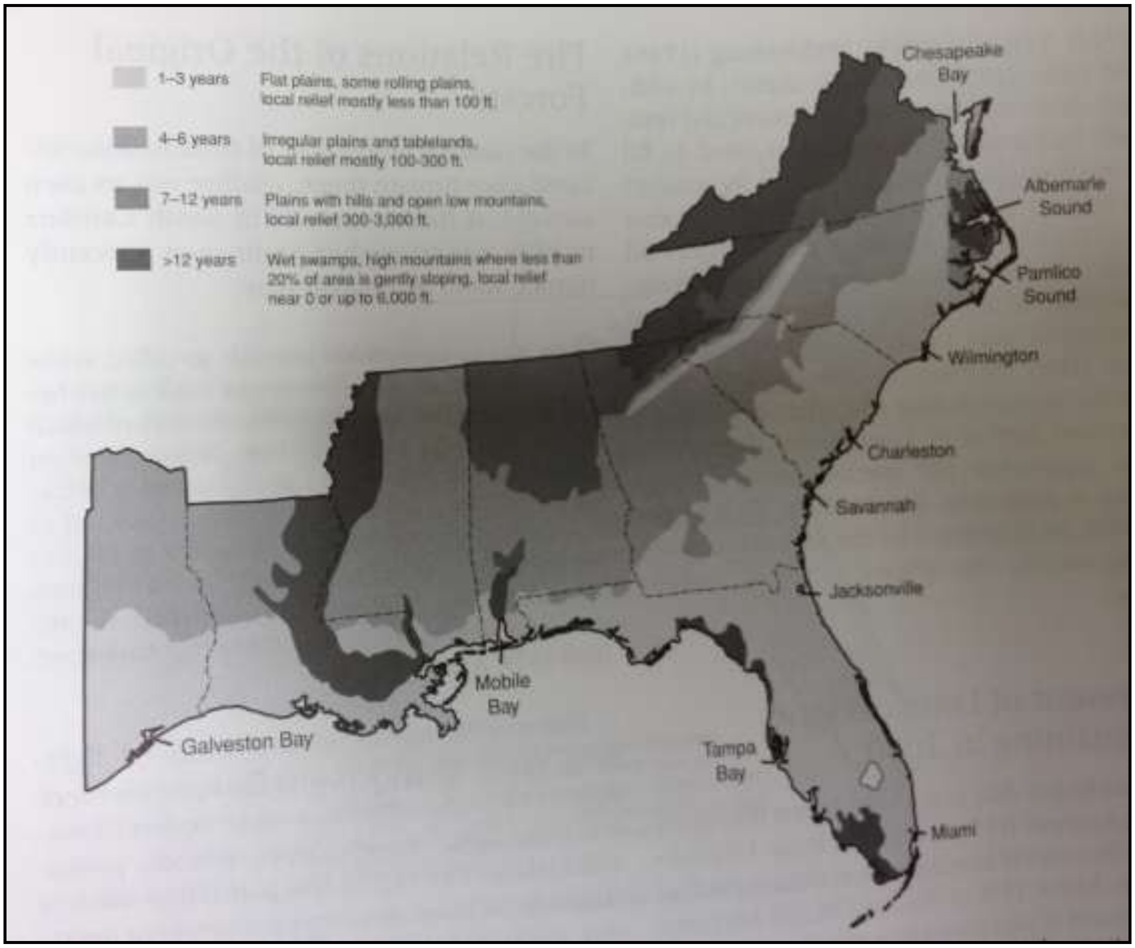

Figure 2.2. Fire frequency throughout the southeastern United States (revised from Frost 1995; 2000)

Longleaf pine are not prolific seeders and the seeds require over three years to develop physiologically (Pederson *et al.* 1999). Thus, a good seed crop may develop once every 4-7 years (Croker and Boyer 1975, Dennington and Farrar 1983, Boyer 1990b). Also, the seeds are relatively heavy and do not disperse great distances. Reports indicate that the longleaf pine seed also requires exposed mineral soil in order to have proper germination (Croker 1975, Dennington and Farrar 1983, Boyer 1990b). Therefore, ecological disturbances have been reported as critical for its survival. For example, after the passing of a fire, the bare mineral soil is often exposed to the longleaf pine seed (Croker 1979). Once the seed germinates and becomes established, it exerts most of its energy developing an extensive tap root and increasing the thickness of its root collar (Wade *et al.* 2000); however, it also forms needles that are densely packed around the terminal bud. These needles provide the terminal bud with a protective, insulated layer (Andrews 1917, Wahlenberg 1946). After the initial grass phase, 3-7 years depending on site conditions (Haywood 2000, Jose *et al.* 2003), the longleaf pine seedling has a rapid growth period referred to as the bolting phase. This adaptation places critical tissues (i.e. apical meristem) above any damage (a.k.a. danger zone) that could be caused by fire (Whelan 1995). Once the longleaf pine passes this initial phase, it transitions into the candle phase. The life span of a longleaf pine can vary from 300 to 500 years depending on site and environmental factors (Platt *et al.* 1988, Henderson 2006). Longleaf pines, compared to other pines found in the *Pinus* genus, not only produce a higher quality product but can also withstand fire, disease, insects, wind stressors, and grow well on poor or low quality sites (Johnson and Gjerstad 2006).

Because of these adaptive traits, longleaf pine could be found in a variety of habitats and physiographic regions (Figure 2.1). Even though longleaf pine forests can be divided into a variety of ecoregions and habitat types, many researchers attribute its historic dominance to frequent surface fires (Noss 1989, Landers *et al.* 1995, Van Lear *et al.* 2005, Mitchell *et al.* 2006).

At first glance, longleaf pine forests appear to be monospecific with a single dominant tree overstory (*P. palustris* Mill) and an understory dominated by bunch grasses (*Andropogon* spp. or *Aristida* spp.). However, after closer examination, it becomes clear that while the overstory is dominated by a single tree, the understory houses a plethora of flora (Walker and Silletti 2006) and fauna species (Moler 1992, Engstrom 1993, Guyer and Bailey 1993, Carroll *et al.* 2002). In fact, the diversity of the longleaf pine ecosystem has been compared to that of the tropical rainforests (Peet and Allard 1993, Means 1996). Peet and Allard (1993) reported that as many as 40 plant species per square meter were observed in longleaf pine savannas and 140 species per 1000 m^2 for mesic longleaf woodlands. Walker (1993) reports that range-wide there have been over 187 rare vascular plant taxa documented within the different longleaf pine habitats. Depending on the physiographic region, the understory is comprised of bluestem grasses (*Andropogon* spp.—western) or wiregrass (*Aristida beyrichiana*—FL to central SC or *A. stricta* central SC to NC; Kesler *et al.* 2003). The fauna associated with the longleaf pine communities are as diverse as the flora. Engstrom (1993) documented that there are 36 mammals and 86 bird species that are characteristic of the longleaf pine forest. Some of the highest densities of herpetofauna in North America have been reported to occur within the range of the remnant longleaf pine (Kiester 1971, Dodd 1995, Means 1996). One-hundred and seventy species (74 amphibians, 96 reptiles) can be found within longleaf pine forests. Dodd (1995) reports that many of these species are sensitive to fragmentation and reductions in habitat quality; consequently, many of these species are listed federally, by states as endangered or threatened, or are candidates for listing. The following are example species that Dodd (1995) cites: the flatwoods salamander (*Ambystoma cingulatum*), stiped newt (*Notophthalmus perstriatus*), Carolina and dusky gopher frogs (*Rana capito capito, R. c . sevosa*), eastern indigo snake (*Drymarchon corais*), gopher tortoise (*Gopherus polyphemus*), eastern diamondback rattlesnake (*Crotalus adamanteus*), and Florida pine snake (*Pituophis melanoleucus mugitus*). Some of these specialists include the federally endangered red-cockaded woodpecker (*Picoides borealis* Vieillot) and the gopher tortoise (*Gopherus polyphemus* Daudin). The gopher tortoise, a keystone species, provides refuge in its burrow to over 300 vertebrate and invertebrate species (Milstrey 1986 , Witz *et al.* 1991, Moler 1992, Florida Fish and Wildlife Conservation Commission 2007). The gopher tortoise was first listed in 1987 as federally threatened in the western portion of its range (west of the Mobile and Tombigbee rivers in Alabama, Mississippi, and Louisiana; 50 CFR § 17.11). Since that time, gopher tortoises found in the eastern portion of its range have been elevated to candidate status for listing as threatened under the Endangered Species Act (50 CFR § 17). Due to the decline of the longleaf pine forests, over 30 plant and animal species have been added to the federally threatened or endangered species list (Van Lear *et al.* 2005). Alabama, Florida, Georgia, and South Carolina have identified the longleaf pine community as a high priority in each of their state Comprehensive Wildlife Conservation Plans (CWCP). Moreover, the longleaf pine habitat is considered one of the most diverse ecosystems in the world and is classified as “critically endangered” (Noss *et al.* 1995).

It has been well documented that in the absence of fire, longleaf pine ecosystems quickly transform from open, park-like savannas into closed canopy forests dominated by hardwood trees and shrubs (Christensen 1981, Streng *et al.* 1993, Kush *et al.* 1999, Glitzenstein *et al.* 2003a, Van Lear *et al.* 2005, Varner *et al.* 2005). Moreover, with an increase in the density of hardwoods in both the overstory and midstory, the understory quickly decreases in species diversity, richness, and cover (Gilliam and Platt 1999, Kush and Meldahl 2000, Varner *et al.* 2000). Studies report that fire is needed to sustain longleaf pine forests (Grelen 1978, Brockway and Lewis 1997, Glitzenstein *et al.* 2003a). Grelen (1978, 1983) suggests that duplicating a natural fire regime, 1-3 years during the growing season, will help the growth and survival of longleaf pine forests. Brockway and Lewis (1997) reported that species diversity and richness can be increased under specific fire regimes. Longleaf pine is a very intolerant pioneer species (Boyer 1990b, Landers *et al.* 1995) and can be out-competed for site resources by many tree species (Brockway and Lewis 1997). Frequent fires give longleaf pine the competitive edge over other flora species. Consequently, understanding the role of natural ecological disturbances (e.g. fire) and whether these disturbances can be duplicated is vital for the success of the longleaf pine and associated species.

Fire is an effective and widely accepted tool in managing longleaf pine communities (Croker and Boyer 1975, Carroll *et al.* 2002, Stanturf *et al.* 2002, Van Lear *et al.* 2005); however, it is becoming increasingly difficult to use. Unfortunately, as urban sprawl continues and the human population increases and expands, the wildland-urban interface (WUI; Davis 1987) is becoming unavoidable. In fact, according to the Citizens Against Polluted Air (CAPA) (2009), breathing "…clean air is as fundamental as the right to freedom of speech." They also reported that in 1998 the Iowa Supreme Court ruled that "…government bodies do not have the right to allow burning that results in smoke crossing property lines." A number of groups such as Mad Mothers of America (2012) and Clean Air Revival (2007) are developing a movement to ban prescribed burning. The Mad Mothers of America website depicts the attitude of the U.S. Forest Service as "cold-blooded" and describes its employees as "Drip Torch Baby Killers." These groups and organizations are using these concerns and legal decisions to influence the general public and federal, state, and local decision makers concerning the use of prescribed fire. Even though the Smokey Bear campaign was initiated more than 65 years ago, it is still influencing society today. Many American adults today can still recite the famous slogan "Only You Can Prevent Forest Fires." While fire has been successfully used as a management tool for thousands of years and reports identify that there are many benefits to its use (Grelen 1978, Brewer 1994, Brockway and Lewis 1997, Brewer 1999a, Brewer 1999b, Kush *et al.* 1999, Kush and Meldahl 2000, Carroll *et al.* 2002, Stanturf *et al.* 2002, Glitzenstein *et al.* 2003a,), negatives can also be encountered when it is employed (McKee 1982, Boyer 1987, Boyer and Miller 1994, DeBano *et al.*

1998, Kush *et al.* 1998, Haywood 2000, Varner *et al.* 2005, McCaffrey 2006, Jack *et al.* 2010).

Even though longleaf pine is a pyrophytic species and has evolved specific adaptive characteristics to survive and be reproductively successful as a direct result of fire, previous studies indicate that the growth of longleaf pine seedlings and overstory trees can be negatively affected after the passing of a fire (Boyer 1987, Boyer and Miller 1994, Kush *et al.* 1998, Boyer 2000, Haywood 2000, Varner *et al.* 2005, Jack *et al.* 2010). For example, Boyer (1993) reported that compared to no-burn treatment, fire was responsible for reducing pine growth by 19% over a 19 year period. It has been documented that fire can be successful at controlling the midstory from the invasion of hardwood species; however, many times this is a short-lived victory depending on the fire regime (Abrahamson 1984, Brown and Smith 2000). Consequently, it is possible that the reserves in the underground root systems quickly regenerate the above-ground biomass and replace the existing midstory with a thicker, more competitive layer (Christensen 1981, Streng and Harcombe 1982).

While there are several factors such as soil texture, slope, vegetation, fire severity, depth of litter and duff, and precipitation that impact how a fire will influence the degree of erosion in a particular area, research has consistently shown that fires can increase soil erosion rates, especially in areas that are prone to erosion by exposing the bare mineral soil (Wright *et al.* 1976, Van Lear and Waldrop 1989, DeBano *et al.* 1998, Stanturf *et al.* 2002, DeBano *et al.* 2005). Fire can alter the soil structure by removing the litter layer that would have otherwise been broken down and added to the humus layer. Often when vegetation and litter layers are removed the infiltration capacity of a soil is altered (Zwolinski 1971, Martin and Moody 2001, Debano *et al.* 2005). Debano *et al.* (2005) reports that surface soil properties can be altered after the passing of a fire because ash and charcoal may clog soil pores resulting in the increase of soil bulk density or a decrease in the porosity which can make soils vulnerable to the kinetic force of rain drops. Water quality (the physical, chemical, and biological characteristics of water) can be negatively affected via sediment that is transported from watershed surfaces to water resources such as ponds, lakes, and streams following a fire (DeBano *et al.* 1998, Neary *et al.* 2005).

Forest fires can temporarily influence air quality by creating a surge of particulates, carbon monoxide, carbon dioxide, hydrocarbons, and nitrogen oxides that can enter the atmosphere, consequently increasing potential human health issues (Liu *et al.* 2005, EPA 1998). According to McCaffrey (2006), smoke can impact approximately 30 percent of households due to health issues. Wade and Lunsford (1989) report that over "… 90 percent of the particulate emissions from prescribed fire are small enough to enter the human respiratory system. These particulates can contain hundreds of chemical compounds, some of which are toxic. Repeated exposure could lead to complicated health issues such as respiratory problems or cancer." Schwartz (2002) reports that as "particle levels go up, people die." It has been reported that smoke produced via wood is 40 times more chemically active than smoke produced from tobacco; consequently, it can harm the body for a longer period of time (Lachocki *et al.* 1989). The United States Environmental Protection Agency (EPA 2012a) reports that fine particle pollution can lead to significant health problems such as decreased lung function, irregular heartbeat, and premature death, especially among the elderly, children and infants. While smoke produced by forest fires can produce potentially negative human health issues, it can also create safety issues around smoke sensitive areas such as highways and secondary roadways. Auburn University (2012) reported that vehicular accidents and fatalities are becoming a serious problem as a result of smoke produced by prescribed burning. They alleged that prescribed fire across several southern states was responsible for 20 accidents and 10 fatalities in a ten year period between 1979-1988 and 19 accidents and 7 fatalities in a six year period between 1989-1994.

Sometimes even a planned event (i.e. prescribed fire) can get out of hand, such as the prescribed burn that occurred on May 4, 2000 in Los Alamos, NM (Holloway 2000, Nelson 2002, Brunson and Evans 2005). National Parks officials quickly lost control when the fire crossed boundary lines and burned 19,222 hectares and consumed 200 homes. A 2003 prescribed burn in Salt Lake City and Provo, Utah that was intended to burn 243 hectares resulted in consuming 3,168 hectares and inundated the Wasatach Front metropolitan area with smoke for a week (Brunson and Evans 2005).

The destructive nature of fire and the displacement of humans have been observed in the United States for more than a century (Cohen 2008). Cohen (2008) reported that across the United States between 1990 and 2007 wildfires destroyed approximately 12,000 homes. Between 2002 and 2003, catastrophic fires on the west coast, including California, Arizona, Colorado, Montana, and Oregon, burned over 4.5 million hectares, took the lives of 51 firefighters and 22 civilians, and cost the state of California alone over $250 million dollars to contain. These events exhausted fire suppression funds during 2002 and 2003; consequently, President George W. Bush initiated the Healthy Forests Initiative (HFI) in 2002 and signed the Healthy Forests Restoration Act into law in 2003 to help alleviate this problem in the future (Bush 2002, Agee and Skinner 2005). The HFI requires a timely response to disease and insect infestations that threaten to devastate forests, and it focuses on reducing undergrowth and brush in priority areas to diminish the chances of catastrophic fire events.

ALTERNATIVE SILVICULTURE PRACTICES

With so many concerns and the potential for negative consequences associated with fire, it is possible that one day the use of it as conservation tool may become restricted or obsolete. Consequently, the remaining old-growth longleaf pine forests, the existing restored forests, and the embedded biotic communities that are dependent upon them are at risk. Therefore, the usefulness and viability (including the positive and negative effects) of alternative silvicultural practices, such as the use of herbicides or mechanical mastication, need to be investigated in order to aid in restoring and maintaining the longleaf pine ecosystem and its biodiversity. Even though the paradigm of conservation has shifted from managing for a single species to a holistic ecosystem basis, scientists are now challenged with the task of managing ecosystems in a way that mimics natural disturbances in order to maintain the structure, ecological processes, and the function of the entire system while being governed by policies, protocols, and practices (Hunter 1993, Christensen *et al.* 1996, Franklin *et al.* 2002). Moreover, modern land managers are even further tasked with the responsibility of filtering through a vast amount of research and anecdotal reports to successfully apply adaptive management strategies to restore, enhance or maintain these and other sensitive ecosystems. Consequently, it is critical that land managers are provided actual outcomes versus desired outcomes while managing these ecosystems for multiple objectives (i.e. timber revenue, Threatened and Endangered species, recreational use, etc.). In fact, under the National Forest Act (1976; Sec. 6—National Forest System Resource Planning), it is required that silvicultural practices maintain the diversity of plant and animal communities on publicly owned forests. It is imperative that today's society begins exploring and evaluating alternative conservation tools that are available, effective, and successful at managing the forests of today and tomorrow. It is not a matter of if but a matter of when these alternative silviculture tools will be needed to help the survival of the longleaf pine communities and other unique ecosystems. The loss of longleaf pine communities "…could very well prove catastrophic for the numerous embedded biotic communities that are ecologically linked to them" (Brockway *et al.* 2005a). Whether it is through the use of prescribed fire, chemical treatment, mechanical mastication, or some combination of these, longleaf pine communities are now and will forever be dependent upon land managers favoring ecological function and defining a desired trajectory.

Herbicide Treatment

It has been observed that many types of organisms such as plants, bacteria, and algae have developed the ability to produce biochemicals that enable them to restrict the growth, survival or reproduction of other organisms (Muller 1966, Jose and Gillespie 1998, Harrington 2006). Humans built on this concept by developing and applying pesticides to control unwanted vegetation around the mid-twentieth century (Shepard *et al.* 2004). The term pesticide is an all-inclusive term that includes any substance or mixture of substances intended for preventing, destroying, repelling, mitigating any pest, or is used as a plant regulator, defoliant, or desiccant (EPA 2012b). In the 1940s, one of the first herbicides developed was 2,4-dichlorophenoxyacetic acid (a.k.a. 2,4-D). It was formulated for use in agricultural fields, aquatic weed control, and turf management to combat problematic broadleaf weeds. It is the most widely used and researched herbicide in the world. Since that time, a variety of specialized (forestry) herbicides have been developed such as hexazinone, imazapyr, and triclopyr. Forestry herbicides can be used in a variety of ways: 1) to combat unwanted vegetation, 2) to release desirable seedlings from competition, and 3) to prepare sites for a new stand of trees (Ford-Robertson 1971, Haywood 1993, Bullock 2011). Despite the fact that these forestry herbicides have been widely accepted and used across the United States and throughout the southeast, there are few reports available that define their impacts on the native ground-layer vegetation, especially in natural forested communities.

Litt *et al.* (2001) performed an extensive literature review regarding herbicide effects on ground-layer vegetation (<1.4 m tall), specifically in forests of the southeastern

United States. Based on the criteria set by their study (e.g. sound experimental design, quantitative data, study conducted in southern pinelands), only 21 of 125 published studies were retained for analysis. Among them, only eight studies evaluated the impacts that herbicides have on the ground-layer vegetation in the sandhills (Boyer 1990c, Wilkins *et al.* 1993a, Wilkins *et al.* 1993b, Berish 1996, Brockway *et al.* 1998, Kush *et al.* 1999, Provencher *et al.* 2001a, Provencher *et al.* unpublished data). Litt *et al.* (2001) also investigated the impacts of herbicides on plant species of special concern (i.e. *Aristida* spp.). Among the six studies reviewed on species of concern, there were several inconsistencies reported (Wilkins *et al.* 1993a, Wilkins *et al.* 1993b, Brockway *et al.* 1998, Clewell and Lasley 1998 (Trials 1 & 3), Provencher *et al.* 2001a). For example, Wilkins *et al.* (1993a) reported an average decrease of 63.4% in foliar cover in *Aristida* spp. by the end of the first growing season with the application of Pronone® (hexazinone) while other studies reported increases by as much as 378.9% (Wilkins *et al.* 1993b) and 33% (Brockway *et al.* 1998) using similar rates of the same herbicide. Although Litt *et al.* (2001) conducted an in-depth literature review concerning the impacts herbicides have on ground-layer vegetation, they reported that the "most notable finding was that the effects of herbicides on native ground-layer vegetation in natural flatwoods and sandhills have rarely been measured." Moreover, they reported that it was difficult to distinguish between desirable and undesirable species because many studies grouped plant species together (i.e. graminoids, forbs, composites) versus individual species. Provencher *et al.* (2001a) also reported that besides fire there is little quantitative information concerning the impacts alternative silviculture practices such as herbicides or mechanical treatments have on groundcover species.

Since the Litt *et al.* (2001) review, a limited number of studies evaluating the impacts herbicides have on the native flora found within an established pine stand have been published (Haywood 2007 & 2009, Freeman and Jose 2009, Jose *et al.* 2010, Iglay *et al.* 2010, Kaeser and Kirkman 2010). According to Shepard *et al.* (2004), there are no systems in place that track the use of forestry herbicides in the United States. Jack *et al.* (2011) reported the "… use of herbicides has been proposed by some as a substitute for prescribed fire in southern pine forests, but very few studies have directly compared the effects of fire and herbicides in the same forest at the same time."

Even though there are a limited number of studies that have been published concerning the effects herbicides have on the herbaceous layer of a longleaf pine ecosystem, the existing research has documented the impacts herbicides may have in a variety of *Pinus* spp. forest types or study areas (Wilkins *et al.* 1993b, Hay-Smith and Tanner 1994a/1994b, Brockway *et al.* 1998, Boyd *et al.* 1995, Kush *et al.* 1999, Provencher *et al.* 2001b, Miller and Chamberlain 2008, Haywood 2009, Freeman and Jose 2009, Kaeser and Kirkman 2010). For example, Wilkins *et al.* (1993b) studied the effects of the herbicide hexazinone applied at 0.42, 0.84, and 1.68 kg/ha active ingredient spot-grid application to a xeric sandhills site that had experienced 40 years of fire suppression. They reported significant changes in the graminoid (increases) and oak (decreases) cover across all treatments. Furthermore, no impacts were observed for the woody non-oak species and the forbs, while wiregrass increased with higher rates of herbicide. Moreover, oak mortality increased as the stem diameter decreased. Hay-Smith and Tanner (1994b) recommend that hexazinone be applied directly to target species at a rate between 0.84 and 1.68 kg/ha. They concluded that the use of hexazinone released longleaf pine seedlings and wiregrass without damaging other ground-layer species while reducing the scrub oak competition. Boyd *et al.* (1995) examined the impacts that broadcast application of forest herbicides would have seven years after treatment in a planted loblolly (*P. taeda*) stand. Herbicides were applied at maximum site-specific recommended rates. No treatment effects were observed on species richness or diversity for either the understory or the overstory. Boyd *et al.* (1995) did not report any statistical differences found among the herbaceous vegetative layer seven years after applying herbicide using a broadcast application method. A study completed by Brockway *et al.* (1998) examined the impacts low-rate (1.1 or 2.2 kg/ha) hexazinone has on plant cover, diversity and biomass within a sandhills site in Florida. They reported a reduction in the mid- and over-story oaks while there was an increase in the wiregrass, graminoids, and forbs. However, there was a decrease in forb cover, species richness and diversity with the broadcast method following treatment the first year. Brockway *et al.* (1998) did not recommend broadcast application of herbicide even though long-term vegetative surveys were not completed or reported in their study. Kaeser and Kirkman (2010) investigated the effects that nine different herbicides had on ten commonly found longleaf pine herbaceous species from the Poaceae (grasses), Fabaceae (legumes), and Asteraceae (composites) families. They reported that native species in these families can be impacted or killed depending on the type or rate of herbicide used. However, they cautioned that their study was conducted on relatively young seedlings (30 day and 60 day) raised in a green house; consequently, the herbicide impacts to these same species at varying ages in a field setting are uncertain. Jose *et al.* (2010) investigated the impacts that imazapyr (0.21 ae kg/ha), hexazinone (0.56 ai kg/ha) and sulfometuron methyl (0.26 ai kg/ha) plus hexazinone (0.56 ai kg/ha) have on longleaf pine seedlings and the ground-layer vegetation within a coastal plain flatwoods longleaf pine site in Florida. The main objective was to increase both pine seedling growth and the herbaceous ground-layer cover. Imazapyr produced the highest seedling growth; however, it did have a negative impact on seedling survival over the control treatment. While the hexazinone and sulfometuron methyl plus hexazinone treatments resulted in greater longleaf pine growth compared to the control treatment, it was not evident that the herbicides were effective against the shrub species until eight months post application. Neither sulfometuron nor sulfometuron plus hexazinone treatments showed any significant impacts on the grass, forb, or shrub cover.

It has also been reported that there are positive growth responses by both the understory longleaf pine seedlings (Loveless *et al.* 1989, Knapp *et al.* 2006, Knapp *et al.* 2008, Jose *et al.* 2010, Freeman and Jose 2009, Hu 2011) and the mature overstory trees when using herbicides (Freeman and Jose 2009). Although the results varied among these and the studies reported by Litt *et al.* (2001), the commonality among them was generally a positive response (except for Kaeser and Kirkman 2010) by the herbaceous ground layer either initially or by the second growing season and a reduction of non-desirable species (i.e. *Quersus* spp.). The variation documented among these studies may have been the result of different types of herbicides being used, the rate of application, method of application, local weather conditions, or site conditions.

Herbicide Regulation, Toxicity, and Fate

According to the United States Environmental Protection Agency (EPA), the first pesticide control law was enacted in 1910. Pesticides (which include herbicides) are regulated by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the Federal Food, Drug and Cosmetic Act (FFDCA), and the Food Quality Protection Act (FQPA) in the United States (EPA 2012c). The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) was passed in 1947. The FIFRA's main function at that time was to define procedures for registering pesticides and to establish labeling provisions. The Act has been amended and rewritten several times since then. In its current form, the FIFRA "…mandates that EPA regulate the use and sale of pesticides to protect human health and preserve the environment." However, it does not preempt state/tribal or local laws. The use of each pesticide can be further regulated by each state/tribe or local government. Under the FIFRA (40 CFR Part 158), EPA defines specific data requirements for the registration of new pesticides that include the product's chemistry (including active and inert ingredients), dietary and non-dietary hazards to humans, hazards to domestic animals and non-target organisms, and environmental fate and residue limits (tolerances). As part of registering a pesticide, the EPA requires an evaluation of the acute and chronic toxicity or hazard of a pesticide on a variety of aquatic and terrestrial organisms (Tatum 2004, EPA 2012b, EPA 2012d). During the pesticide analysis phase, the EPA examines the ecological effects, the exposure characteristics, and their relationship with each other. Typically, worst-case-scenarios or exposures are evaluated. All studies required for registration must adhere to the conditions under the Good Laboratory Practice (GLP) standards (40 CFR Part 160). Maximum residue pesticide levels are determined under the FQPA which are set by the EPA and the Food and Drug Administration (Tu *et al.* 2001). The FQPA established new safety standards and residue limits which account for cumulative exposure or synergistic effects for pesticides used on foods (EPA 2012e). Under the National Water Quality Assessment Program, the United States Geological Survey (USGS) monitors pesticide levels in groundwater and surface water (Shepard *et al.* 2004). Also in 1974, Congress passed the Safe Drinking Water Act (42 U.S.C. § 300f et seq. 1974; EPA 2012f) that requires the EPA to establish minimum standards for drinking water in the United States. The U.S. Environmental Protection Agency also established the Health Advisory Levels (HAL) as guidelines to assist state and local officials in responding to drinking water contamination.

Even though extensive testing of pesticides (herbicides) is required under FIFRA and numerous private, state and federal agencies scrutinize their potential impacts to the environment (Michael 2000), the general public remains concerned about the potential impacts that herbicides potentially have on non-targeted organisms such as humans, wildlife, pets and livestock (Dunlap and Beus 1992, Guynn *et al.* 2004, Shepard *et al.* 2004, Tatum 2004, DeGraff *et al.* 2007). Moreover, critics of the FIFRA claim that the toxicity testing is insufficient to represent how native organisms will respond (Power and

McCarty 1997) or how the entire ecosystem will react to the use of a herbicide (Pratt *et al.* 1997, Taub 1997). While older literature reports that the EPA did not require the testing for the application of multiple herbicides or inert ingredients (including surfactants) from a single tank or container (Colborn and Short 1999, Giesy *et al.* 2000, Tatum 2004), current EPA guidelines outline specific requirements addressing these concerns under the EPA's Harmonized Testing Guidelines and the Code of Federal Regulation 40 CFR 158 and 161. The EPA has become increasingly concerned about impurities or impurities associated with an active ingredient such as inert ingredients, emulsifiers, surfactants, stabilizers, diluents, aerosol propellents, solvents, and wetting agents, so they have required these impurities to be identified under the Product Properties Test Guidelines (EPA 712-C-98-310).

While there is public concern over the use of herbicides, Michael (2000) reports that "approximately 2.1 billion kg active ingredient (a.i.) of pesticides are used in the U.S. annually." Fallis (1993) reports that nearly 226,000 ha of forest lands were treated with herbicide in the Southeast in 1992. It was reported in the National Primary Drinking Water Regulation that an estimated 5262 metric tons of glyphosate herbicide alone was used in 1990 and has increased to around 8482 metric tons in recent years and was applied to between 5.2 to 8.1 million hectares (EPA 2012g). Research shows that since forestry herbicides are only used a few times throughout a timber rotation (i.e. typically during site preparation and mid-rotation; Michael and Neary 1993) the chronic toxicity, reproductive effects and carcinogenicity are less likely than a herbicide that is applied multiple times over a long period (i.e. agriculture & residential application;

Tatum 2004). Since modern forestry herbicides are specifically formulated to disrupt or alter a target biochemical process unique to a plant, the potential for impacts to wildlife or non-targeted organisms is low (Tatum 2004). In fact, Fishel *et al.* (2007) reported that many of the newly formulated herbicides are less harmful than many of the commonly used or consumed products found in the average home in the United States.

The environmental fate of a herbicide is simply what happens to it once it is released into the environment. The fate of a herbicide in the environment is dependent upon a number of factors including the rate at which it was applied, the type of herbicide, site characteristics (i.e. soil type, soil pH, number of microorganisms present, litter depth, vegetation type and uptake), and several environmental factors (i.e. precipitation, oxygen supply, and temperature) (Ogle and Warren 1954, Norris 1981). Since many of the herbicides used today are both water soluble (Tatum 2004) and made of organic compounds (Rao 2000), they are unstable in the environment and begin to be removed almost immediately upon application. Therefore, they are presumed not to bioaccumulate or persist in the environment, especially if the material safety data sheet (MSDS) is followed (O'Brien *et al.* 2010). If a herbicide is not intercepted by a plant's foliage and it reaches the forest floor, the degradation process begins via microorganisms and abiotic chemical and photochemical transformation (Mazur 1968). However, pesticides that escape this fate, due to weather or improper application, are at risk of being transported away from the target area. Herbicides can move vertically (leaching) in the soil profile, through plant uptake, or volatilization; they can also move horizontally (across the soil surface) (Mazur 1968, Michael and Neary 1993). Even though there are risks associated with herbicide moving off-site, extensive research has been conducted to determine potential movement and contamination risks (Neary *et al.* 1986, Michael *et al.* 1999, Michael and Neary 1993, Neary *et al.* 1996, DeGraff *et al.* 2007).

Neary *et al.* (1986) conducted a study in the north Georgia Piedmont that monitored the water quality of ephemeral streams in four watersheds after the application of 1.68 kg ha^{-1} active ingredient of pelleted hexazinone. Hexazinone concentrations peaked initially after the first storm flow event, declined rapidly, and were no longer detectable within 7 months of treatment. Concentrations never reached lethal levels that produced any phytotoxicity in aquatic macrophytes or algae. In fact, an *in situ* study below the four treated watersheds reported that there were no herbicide-related impacts to species composition or diversity (Mayack *et al.* 1982). Michael *et al.* (1999) reported that granular (Velpar ULW) and liquid (Velpar L) hexazinone aerially applied to a watershed at three times the prescribed rate (6.72 kg ha^{-1}) did not alter or negatively impact the benthic community structure or richness. Michael and Neary (1993) investigated the findings of several studies that examined the environmental fate of multiple herbicides applied in the southern United States. One of their main objectives was to determine how a streamside management zone (SMZ) would influence the movement, dissipation, and fate of herbicides. It appears that SMZs act as filters and drastically reduce contamination. However, it was determined that the degree of contamination is influenced by the technique of application (i.e. aerial > broadcast > stem injection). DeGraff *et al.* (2007) investigated the fate and mobility of the herbicide hexazinone in the Sierra and Stanislaus National Forests (California). They monitored hexazinone in the soil, vadose zone (a.k.a. unsaturated zone), and surface water. They confirmed that hexazinone is mobile and can move from a targeted area; however, their monitoring did not detect concentrations that exceeded the State of California's water quality value of 400 ug/L. Based on the mobility of hexazinone, they did recommend continued water monitoring for one to four years following a reforestation project once hexazinone is detected. These and other reports indicate that contamination of non-targeted terrestrial and aquatic fauna and invertebrate species is unlikely, especially if the MSDS is followed. Moreover, modern forestry herbicides are formulated in a way that enables the applicator to target specific species (i.e. *Quercus* spp. vs. *Pinus* spp.). Herbicides can also be applied to different developmental phases or stages of stand development which will further reduce potential harm to non-targeted organisms.

Mechanical Mastication

Mechanical mastication is a type of mechanical treatment and has been defined as the act of mulching, chewing, shredding, grinding, pulverizing, or kneading of above-ground live and dead woody material, concentrating the generated debris on the forest floor (Glitzenstein *et al.* 2003b, Brockway *et al.* 2009, Kane *et al.* 2010, Rummer *et al.* 1999). With concerns of undesirable effects caused by the use of fire and herbicide, mechanical mastication is becoming a useful alternative tool to manage fuel load levels (Glitzenstein *et al.* 2003b, Agee and Skinner 2005, Kane *et al.* 2006a, Kane *et al.* 2006b) and a presumed way to mimic natural disturbances (Kush *et al.* 1999, Rummer *et al.* 1999, Glitzenstein *et al.* 2003b, Kane *et al.* 2010). Even though prescribed fire has been used as a surrogate to promote or mimic the natural processes created by wildfires (e.g. stand structure, herbaceous ground-cover, and exposing bare-mineral soil), there are times when it may not be an option. For example, in stands where fire has been suppressed for an extended period of time or where public safety or health is of concern (Rummer *et al.* 2002). Despite the fact that there is legislation in place, such as the Healthy Forests Restoration Act of 2003 (U.S. Public Law 108-148) which promotes fuel reduction activities (such as prescribed fire) a majority of it is required to occur within the wildland-urban interface (WUI; Davis 1987, Bush 2002, Schwilk *et al.* 2009). Consequently, the use of fire under this legislation is somewhat negated due to public concerns over aesthetic impacts, reduced air quality, and potential structural damage (Berry and Hesseln 2004, Liu *et al.* 2005, McCaffrey 2006, Schwilk *et al.* 2009). As a result of these concerns and potential liabilities, land managers are turning toward mechanical treatments to satisfy their management objectives.

The use of mechanical mastication as a surrogate for fire to thin a stand sometimes is termed “emulation silviculture” (McRae *et al.* 2001) or “emulating natural disturbances” (Crow and Perea 2004, Schwilk *et al.* 2009). Typically, mastication is accomplished by using a piece of equipment which is outfitted with either a boom mounted rotary head masticator, a rotating horizontal drum masticator, or integrated cutter head (Beckley and Windell 1999, Windell and Bradshaw 2000, Vitorelo *et al.* 2009). However, mechanical mastication can be used to combat and reduce the competing undesirable hardwood midstory, modify stand structure, and reduce heavy fuels with minimal environmental impact (Coulter *et al.* 2002, Hatchett *et al.* 2006, Kane 2007, O'Brien *et al.* 2010).

When fire is suppressed in pyroclimax communities and no other silviculture treatments are applied, the midstory will often become invaded with a dense thicket of undesirable and unmerchantable scrubby trees which ultimately alter and suppress the herbaceous layer, modify the available fuels, affect nutrient cycling, and negatively influence the overall health and sustainability of the ecosystem (Waldrop *et al.* 1989, Brockway and Lewis 1997, Harrod *et al.* 1999, Rummer *et al.* 1999, Brockway *et al.* 2009). This succession promotes fire-resistant litter and influences the fire behavior (Agee 1996), consequently shifting the plant community's trajectory to a stand that is dominated by fire-intolerant species (Christensen 1981, Kush *et al.* 1999, Provencher *et al.* 2001a). Use of mechanical mastication has been proposed as a surrogate for fire to restore and reestablish the community's structure and function. While numerous studies have evaluated fuel reduction treatments (Agee and Skinner 2005, Glitzenstein *et al.* 2006, Hood and Wu 2006, Kane 2007, Hugget *et al.* 2008, O'Brien *et al.* 2010), there are few comparative studies that have been conducted on the ecological impacts mechanical mastication has in southern pine stands (Rummer *et al.* 1999, Glitzenstein *et al.* 2003b, Stanturf *et al.* 2003, Brockway *et al.* 2009, Schwilk *et al.* 2009, Kreye *et al.* In Prep., Kreye and Kobziar 2010).

Brockway *et al.* (2009) investigated the impacts that mastication alone and mastication followed by fire (i.e. winter, spring, and summer) have on stand structure and plant diversity. While the initial results were consistent with what one would expect of a forest with a frequent fire regime (Fule' *et al.* 2001, Outcalt 2003, Agee and Skinner 2005, Stephens and Moghaddas 2005), it was short-lived due to the vigorous sprouting of the midstory in the unburned sites. Consequently, they concluded that while mechanical mastication could be used in the short-term to reduce the severity and intensity of potential wildfires by modifying stand structure and fuel types, prescribed fire would be needed to restore and sustain the pyrophytic community. Rummer *et al.* (1999) compared mechanical midstory reduction treatments on vegetative and herpetofaunal communities in southern pine stands located in Georgia and Louisiana. In general, the midstory reduction treatment had no effect on the amphibians and reptiles; however, as reported by Brockway et al. (2009), the masticated layer quickly sprouted and recovered. Consequently, follow-up treatments such as fire, herbicide, or re-mastication are recommended. Vitorelo *et al.* (2009) reviewed the equipment options, effectiveness, costs, and environmental impacts of modern masticators. They found that masticators are a viable option, especially in environmentally sensitive areas, because of the low compaction due to light ground pressure (1.9-10 psi; Windell and Bradshaw 2000, Halbrook 2006) and minimal soil disturbance (Hatchett *et al.* 2006, Moghaddas and Stephens 2008). Since masticators generate a mulch layer and concentrate it on the forest floor, bare soil exposure and erosion are reduced (Hatchett *et al.* 2006, Moghaddas and Stephens 2008) and biomass is retained (Jain et al. 2007, Kreye and Kobziar 2010, O'Brien *et al.* 2010). While retention of biomass is important for nutrient cycling and erosion and sediment control, the potential for fire will likely be increased due to a redistribution and increase of fine fuels (Kane *et al.* 2006a, Kane *et al.* 2006b, Kane 2007, Jain et al. 2007, Hartsough *et al.* 2008).

While the main focus of the mechanical section thus far has been on the impacts mechanical mastication has on the ecological environment in southern pine stands, it is also necessary to review studies that propose the manipulation of the unmerchantable mid- or understory through alternative vegetation control treatments such as hand-clearing or felling and girdling. Kush *et. al.* (1999) reported that there was similar species diversity among the hardwood control treatments (chemical: 117 plant species; mechanical: 114 plant species) while there was a variation in the burn treatments depending on the season of the ignition (i.e. winter: 114 plant species; spring: 104 plant species, summer: 105 plant species). Provencher *et al.* (2001a) proposes the “habitat modification hypothesis” which states that the species richness and density of the herbaceous life form should increase proportional to the reduction in hardwood. They reported a 93.2% oak density reduction compared to the control plots the first year using felling/girdling treatments while maintaining a 62.8% reduction by the fourth year, respectively. Increases were observed in the number of species in the felling/girdling plots following initial treatment; however, the highest median species richness (50 species/400 m^2) was reported following felling/girdling and fire. Haywood (2000) and Boyer (1990b) both report that longleaf pine seedlings are more successful at developing without competition. Haywood (2000) reported that more than half of the longleaf pine seedlings treated by mulching grew out of the grass phase after three growing seasons compared to the control seedlings. By the fifth growing season 87% were out of the grass phase and on average had better growth than the control seedlings (142 cm average versus 78 cm). It is widely accepted that restoring the ground-layer vegetation in a longleaf pine ecosystem requires increasing light availability and reducing competition from woody plants (Harrington and Edwards 1999, Harrington *et al.* 2003, Pecot *et al*. 2007). As literature indicates, this can be accomplished by removing the mid-story through mechanical means.

SUMMARY

Longleaf pine was once a diverse, dominating ecosystem throughout its range and much of its success could be attributed to ecological disturbances such as anthropogenic and natural fires. It was dominant during a time when fire was able to traverse across large contiguous areas uninterrupted—a time when fire was viewed as an essential part of life. The United States Census Bureau (2002) reported that by the year 2048 the human population inhabiting planet earth will have increased an estimated 8 billion people since the 1800s. With such drastic increases in the population, wildland-urban interface (WUI) appears to be unavoidable. While many of these WUI residents like the idea of being surrounded by forested or natural areas, many of them do not understand what is required to sustain these natural communities. With increased restrictions on using prescribed fire within the WUI, land managers are interested in seeking suitable alternative silvicultural practices to prescribed fire that will enable them to restore, maintain, and sustain desirable longleaf pine communities and the fauna that depend on them.

Literature indicates that the forests that the European immigrants experienced had more than likely been occupied by Native Americans for over 12 thousand years; therefore, much of what was recorded early on was the product of both anthropogenic and natural processes. Unfortunately, much of the earlier data collected was not detailed or reliable enough concerning plant community composition, structure, and processes (Brockway *et al.* 2005a, White and Walker 1997). Regardless, it may be an impossible task to restore the original forests to their pre-European conditions because the natural conditions (e.g. climate) may have changed; however, efforts can be made to restore the natural system's trajectory and recruit characteristic flora and fauna species.

The Society for Ecological Restoration defines ecological restoration as an "intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity, and sustainability" (SER 2004). Brockway et al. (2005a) stated that restoration is a long-term process and any and all gains should be valued. However, "…one pervasive assumption of restoration ecology is that restoring habitat structure will return community composition and function to a less disturbed reference condition" (Provencher *et al.* 2001a). On the contrary, restoration often requires additional efforts and increased disturbances. It is through particular land disturbances that specific species common to an ecosystem will respond (i.e. the production of viable wiregrass seed after a growing season burn; Denslow 1980, Greenberg 1993, Provencher *et al*. 2001a). It is critical to restore both the overstory longleaf pine canopy and the herbaceous understory plant community (Harrington 2006, Walker and Silletti 2006) and fire is becoming more difficult to use as a conservation tool. A closer examination of whether alternative silvicultural treatments can be used to mimic natural disturbance is needed.

While studies do exist that reviewed the impacts alternative treatments have on the ecosystem function and structure, many of them focused on the effects of treatments after a follow-up prescribed fire, were limited to conservation tools of their time (i.e hand-clearing), focused on a single targeted species (i.e. *Pinus* spp.), occurred in a plantation stand or green house, or did not simultaneously compare all three silviculture treatments (fire, herbicide, and mechanical mastication). Using prescribed fire as a follow-up treatment masks the effects of alternative conservation tools alone. Moreover, many of the studies that suggested using fire as a follow-up treatment did not report the potential negative impacts that could result from combining these two treatments such as increased fire residence time and increased soil temperature (Busse *et al.* 2005).

If the ultimate goal is to perpetuate the longleaf pine ecosystem in the future, it is imperative that alternative conservation tools be explored and tested side-by-side under the same testing conditions in the same forest. It has been well documented that in the absence of fire or disturbance, longleaf pine ecosystems quickly transform from open, park-like savannas into closed canopy forests dominated by hardwoods trees and shrubs (Christensen 1981, Streng *et al.* 1993, Kush *et al.* 1999, Glitzenstein *et al.* 2003a, Van Lear *et al.* 2005, Varner et. al. 2005). Understanding the role of natural disturbances and whether these disturbances can be duplicated is vital for the success of this long-lived ecosystem and the biotic communities that inhabit them. Ultimately, the type and condition of the stand and the land manager's objectives should dictate which type or combination of treatments may be required to restore the ecosystem’s function, structure, and trajectory.

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CHAPTER THREE

COMPARING THE EFFECTS OF PRESCRIBED BURNING, MECHANICAL MASTICATION AND HERBICIDE TREATMENTS ON THE ESTABLISHMENT OF THE UNDERSTORY HERBACEOUS LAYER IN A LONGLEAF PINE (*Pinus palustris* Mill.) FOREST IN AIKEN COUNTY, SOUTH CAROLINA

ABSTRACT

This study was designed to determine whether alternative silviculture treatments such as herbicide or mechanical mastication can be used as surrogates to prescribed fire. We compared the effects of prescribed burning, mechanical mastication, and the broadcast application of DuPont^{TM} Velpar® ULW (hexazinone; 1.26 kg a.i./ha) on the understory vegetative layer and the naturally regenerated longleaf pine (*Pinus palustris*) seedlings of a mature longleaf pine forest within the boundaries of Aiken Gopher Tortoise Heritage Preserve, Aiken County, SC. The preserve is owned and managed by the South Carolina Department of Natural Resources (SCDNR). The experiment was set up as a randomized complete block design (RCBD) with six blocks each containing three types of silviculture treatment (prescribed burning, mechanical mastication, or granular hexazinone), totaling 18 treatment units across the approximately 55 hectare study site. Each treatment unit is approximately 0.405 ha in size. Treatments were applied one time in May 2008. Species richness and diversity measures exceeded pre-treatment levels by the second growing season following prescribed fire the and mechanical mastication treatments. While the broadcast application of hexazinone caused initial decreases in species richness and diversity, the understory plants gradually began to recover the ensuing year. Prescribed fire treatments generated the highest relative increases in the evenness values, followed by mechanical mastication, and then herbicide. Both the herbicide and mechanical mastication treatments resulted in greater longleaf pine seedling survival compared to prescribed fire; however, they caused initial declines in the foliar cover of the keystone species wiregrass (*Aristida stricta*). Results from this study show that it may be possible to use herbicide and/or mechanical mastication treatments as surrogates for prescribed fire to sustain the diversity of the understory and allow for the regeneration of longleaf pine.

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Keywords: *Pinus palustris* Mill; Herbicide; Mechanical manipulation; Hardwood reduction treatments; Plant species diversity; Sandhills

INTRODUCTION

Longleaf pine (*Pinus palustris* Mill.) forests historically dominated the southeast United States stretching from Virginia to eastern Texas and south through central Florida prior to European settlement (Boyer 1990a, Frost 1993, Landers *et al.* 1995). Reports estimate that less than 0.01% of old-growth longleaf pine forests remain today (Means 1996, Varner and Kush 2001, Varner *et al.* 2003). Research has shown that species diversity, richness, composition, and the overall structure of the longleaf pine ecosystem are influenced by ecological disturbances (i.e. fire, tornadoes, hurricanes, and beetle infestations; Christensen 1981, Boyer 1990b, Landers *et al.* 1995, Brockway and Lewis 1997, Maliakal and Menges 2000, Jose *et al.* 2006). Prior to European settlement, both anthropogenic (Robbins and Myers 1992, Landers and Boyer 1999, Van Lear *et al.* 2005) and natural fires (Komarek 1974, Carroll *et al.* 2002, Van Lear *et al.* 2005) were responsible for shaping and sustaining the longleaf pine ecosystem. Literature reports that prior to European settlement fire frequency within the longleaf pine ecosystems ranged between 1-6 years (Frost 1995 & 2000, Peet 2006). Dendrochronological evidence from remnant longleaf pines estimate a fire return interval between 2-3 years post-European settlement (Huffman 2006, Stambaugh *et al.* 2011). The degradation of this ecosystem can be attributed to the introduction of free-ranging hogs, production of naval stores (turpentine and pitch), timber harvesting, southern pine plantation conversions (slash pine *P. elliotti* Engelm. and loblolly pine *P. taeda* L.) and fire suppression (Croker 1979, Frost 1993, Landers *et al.* 1995).

Longleaf pine forests are considered some of the most diverse ecosystems in the world, but they are classified as “critically endangered’ (Noss *et al.* 1995). It is estimated that longleaf pine forests provide suitable habitat for as many as 300 different herbaceous plant species, 60 percent of the amphibian and reptile species found in the southeast, and it includes the habitat for at least 122 endangered or threatened plant and animal species (Fritscher 2011). Over 30 plant and animal species associated with longleaf pine forests are found on the federally threatened or endangered species list (Van Lear *et al.* 2005). Reports indicate that as many as 40 plant species per square meter were observed in longleaf pine savannas and 140 species per 1000 m^2 for mesic longleaf woodlands (Peet and Allard 1993). There are as many as 36 mammals and 86 bird species represented in longleaf pine forests (Engstrom 1993). Longleaf pine forests provide refuge and safe haven to more than one-hundred and seventy amphibians and reptiles (Dodd 1995), many of which are federally or state protected. Some examples include the flatwoods salamander (*Ambystoma cingulatum*), striped newt (*Notophthalmus perstriatus*), Carolina and dusky gopher frogs (*Rana capito capito, R. c . sevosa*), eastern indigo snake (*Drymarchon corais*), gopher tortoise (*Gopherus polyphemus*), and the red-cockaded woodpecker (*Picoides borealis*).

Despite the clear desirability and positive benefits of using prescribed fire as a conservation management tool, there are times when fire application must be restricted. This is particularly true around the wildland-urban interface (WUI; Davis 1987). Tracts of land that were once dominated by longleaf pine in rural areas are now surrounded by neighborhoods, strip malls, and highly travelled roads. With the increase in human population and urban sprawl, the use of prescribed fire in land management is becoming more problematic. However, government agencies, private land owners, and universities are increasingly interested in reestablishing, restoring, preserving, or enhancing longleaf pine forests and the embedded biota throughout its natural range. Consequently, it is becoming critical to assess whether alternative silviculture practices such as herbicides and mechanical mastication treatments can be used as surrogates for fire in managing longleaf pine ecosystems. Finding a viable alternative to prescribed fire is of special interest to the South Carolina Department of Natural Resources (SCDNR) because many of its land managers are challenged with restoring and maintaining longleaf pine ecosystems in order to provide suitable habitat for many game and non-game species including protected flora and fauna.

In this study, we experimentally compared the effects of three commonly available hardwood reduction techniques on both the understory herbaceous layer and the naturally regenerated *P. palustris* seedlings in a mature longleaf pine forest. Treatments consisted of growing season prescribed fires, broadcast application of the granular form of the herbicide hexazinone, and midstory mechanical mastication. In this study, mechanical mastication is defined as the act of mulching, shredding, grinding, or pulverizing the above-ground live and dead woody material, concentrating the generated debris on the forest floor (Glitzenstein *et al.* 2003, Brockway *et al.* 2009, Kane *et al.* 2010, Rummer *et al.* 2002).

MATERIALS AND METHODS

Study Site

The study site is located within the boundaries of Aiken Gopher Tortoise Heritage Preserve (AGTHP) in Aiken County, South Carolina (Figure 3.1; Latitude 33.505, Longitude -81.413). This heritage preserve is located in the western part of South Carolina within the xeric sandhills of the state. The sandhills region—a landform that was created by the oceans depositing sandy soils inland at the Fall Line millions of years ago—separates the Coastal Plain and the Piedmont (Nelson 1986). The 656 hectare property is owned by the South Carolina Department of Natural Resources (SCDNR) and is currently managed primarily for the gopher tortoise (*Gopherus polyphemus* Daudin). The soils that dominate this property are a mix of Lakeland, Troup, and Fuquay soils (USDA 1985). These are deep, marine-deposited, relatively sterile, well-drained sandy soils with an average pH of 4.8 (Appendix 1.1). The preserve drains into the South Fork of the Edisto River, which joins with the North Fork of the Edisto River to form an integral part of the Ashepoo-Combahee-Edisto (ACE) Rivers Basin.

According to the United States Department of Agriculture (2012), AGTHP occurs within plant hardiness zone 8a. The mean monthly air temperature ranges from 8.3° C in January to 27.1° C in July. The mean monthly precipitation ranges from 6.5 cm in November to 12.8 cm in July (Southeast Regional Climate Center 2011). Historical aerial photographs, dating back to 1938, and a title search indicate that the study site, a 55 hectare section of the property, falls within the ownership of one residence that clear-cut and converted a majority of the property to cultivated fields (F&ME Consultants 1999).

Based on the historical aerial photographs and tree core sampling, the dominant longleaf pine overstory trees are approximately 35 years old. At the start of the study, the diameter at breast height (DBH) of the overstory longleaf pine trees ranged from 18 to 27 cm and the average basal area was 12 m^2/ha.

Even though the fire frequency, seasonality, and intensity of prescribed fires has historically varied across the study site at Aiken Gopher Tortoise Heritage Preserve, the last prescribed fires conducted were low intensity backing fires ignited in March and April 2005. Because prescribed fire was the preferred management tool across this heritage preserve prior to 2005, the midstory is made up of scrub shrubs dominated by oaks (*Quercus* spp.). The understory contains a diverse native herbaceous ground layer including wiregrass (*Aristida stricta* Michx.) and a variety of bluestems (*Andropogon* spp.). Although a variety of graminoids were present on the study site, the most abundant were *Aristida* spp. and *Andropogon* spp. The forb/herb functional groups were represented by a diverse number of species; however, the species varied in their percentage of cover depending on the type of plant and its growth habit. For example, the cover class for *Tephrosia virginiana* ranged from 8.40% to 20.67% within the burn units, whereas *Cnidoscolus stimulosus* ranged from 1.4% to 2.0%. A complete species list is available in Appendix 3.2.

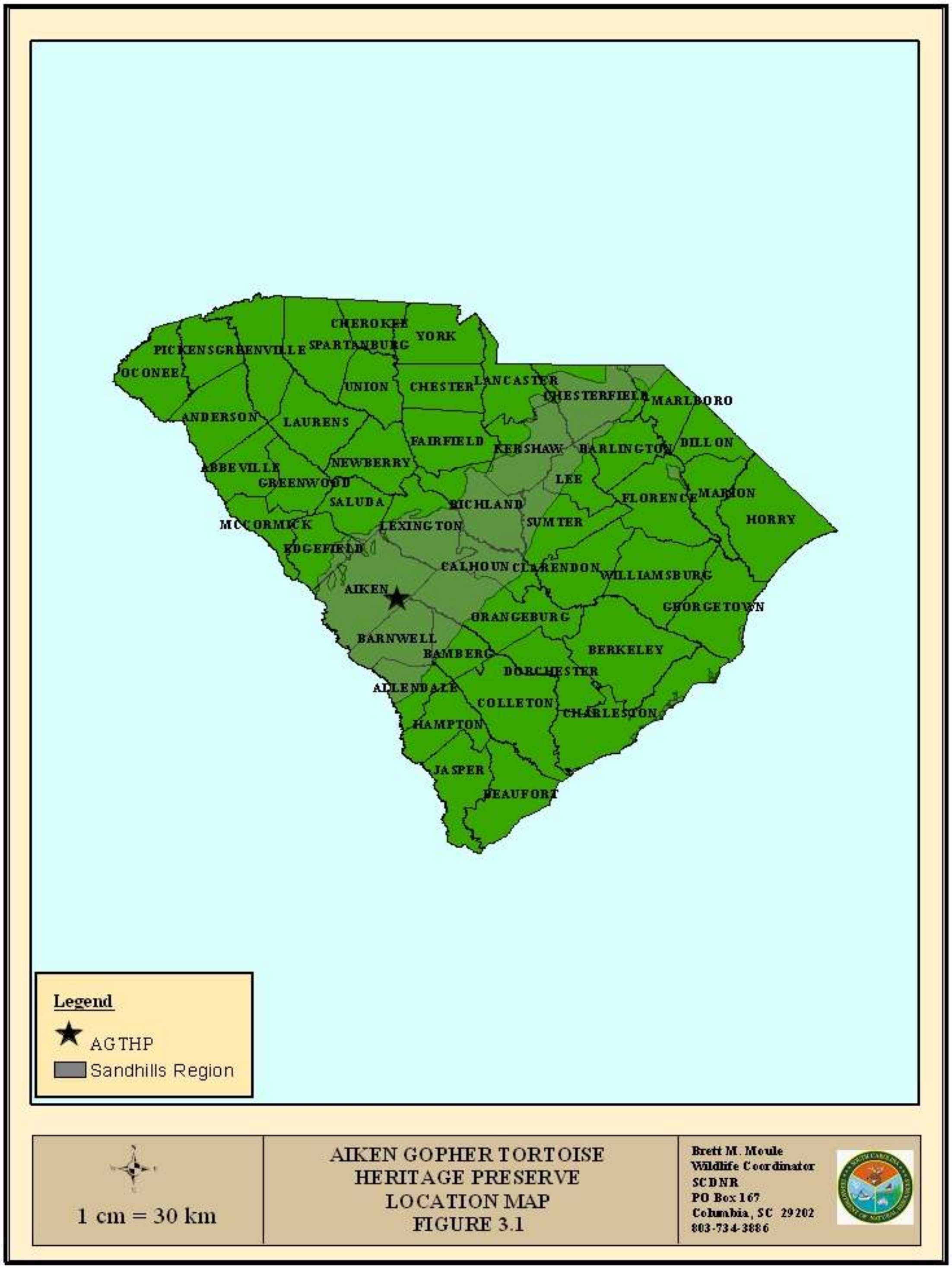

Figure 3.1. General location of Aiken Gopher Tortoise Heritage Preserve, Aiken County, SC.

Experimental Design

The experiment was set up as a randomized complete block design (RCBD). The study site contained six blocks with three treatments per block (prescribed fire, mechanical mastication, and broadcast application of granular hexazinone), totaling eighteen approximately equal-sized treatment units (±0.405 hectare; Figure 3.2). Within each treatment unit there is a rectangular 20 x 50 meter sample plot (±0.1 hectare) containing ten permanent 10 x 10 meter modules (0.01 hectare), modeled after the Carolina Vegetation Survey protocol (CVS; Figure 3.3; Lee *et al.* 2006). While there are two proposed modules identified within each 20 x 50 meter sample plot for the CVS method, intensive and residual, vegetative presence data was collected from a 20 x 50 meter sample area defined by all four intensive modules (2, 3, 8, and 9; Figure 3.3). Longleaf pine seedling counts were conducted within each intensive nested 1 m^2 corner (depth 3). To reduce edge effect, each treatment unit was surrounded by an approximately 3 meter firebreak while each 20 x 50 meter sample plot was surrounded by an approximately 15 to 20 meter vegetative buffer. Treatments occurred one time in May 2008.

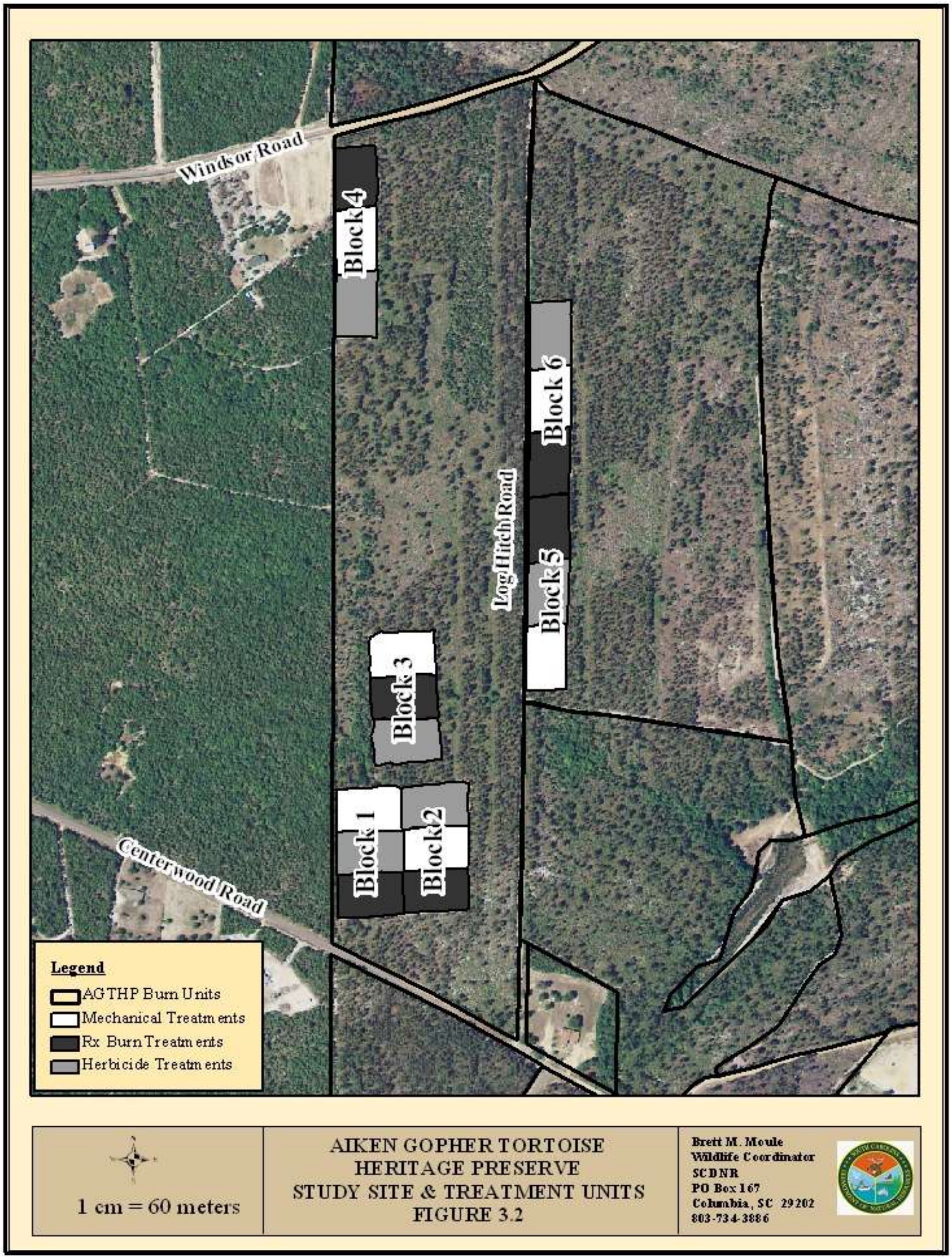

Figure 3.2. Study site & treatment units at Aiken Gopher Tortoise Heritage Preserve, Aiken County, SC.

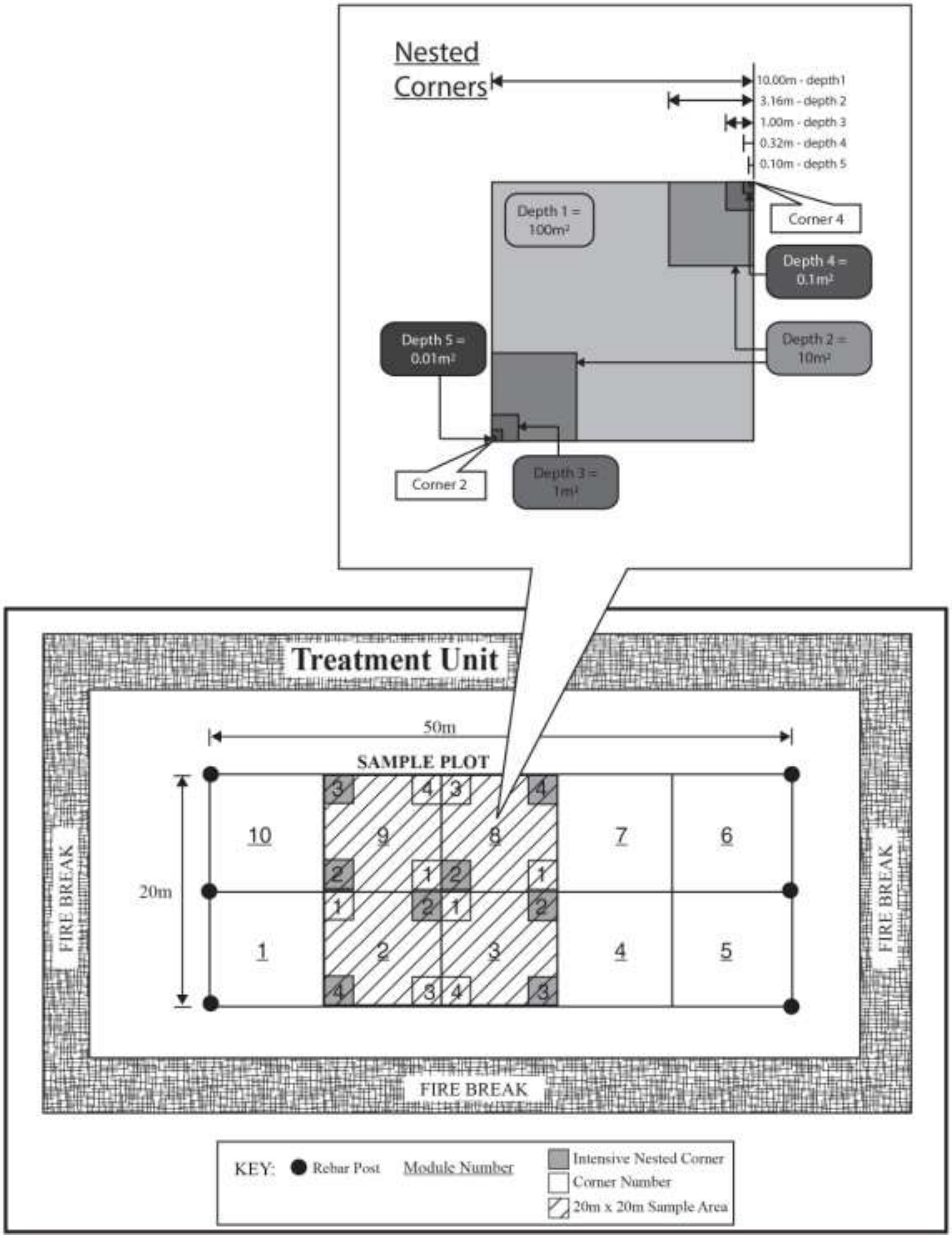

Figure 3.3. Example of a treatment unit with an embedded 20 x 50 meter sample plot with established 10 x 10 meter modules (Lee *et al.* 2006).

Each block (n = 6) received three types of silviculture treatment (F = fire, H = herbicide and M = mechanical mastication) that were randomly assigned and applied one time in May 2008. The firing techniques used were a mix of backing, flanking, and head fires. The South Carolina Forestry Commission predicted a maximum temperature of 27^{o} C for the day of the prescribed burns and light and variable winds in the morning and winds out of the south at 5 miles per hour during the afternoon. Average relative humidity recorded during the burns was 39.52%. The herbicide used was the granular form of hexazinone [3-cyclohexyl=6-(dimethylamino)-1-methy-1,5-triazine-2,4(1H,3H)-dione] also known as Dupont^{TM} Velpar ULW® that was broadcast evenly at a rate of 1.26 kg a.i./ha. The herbicide treatment was applied during stable weather conditions using a Stihl® SR 420 Backpack Blower. Since the herbicide was to be applied within the same month as the other treatments, the timing of the application did not coincide with any rainfall events. However, several anecdotal reports indicated an estimated 10 cm of rainfall for Aiken County, South Carolina during the month of May 2008. Mechanical mastication consisted of a Bobcat T-300 with a forestry cutter head and hand tools; these tools were used to masticate any above-ground live or dead woody material from the midstory vegetative layer (i.e. *Quercus* spp.) and concentrate it on the forest floor.

Measurements

In 2007, stands were selected based on "a spatially continuous unit of vegetation with uniform composition, structure, and environmental conditions" (Figure 3.2; Jennings *et al.* 2004). We randomly assigned treatments to each treatment unit within each block of the study and permanently established treatment units with a north-south or east-west orientation depending on the vegetative restrictions of the stand (Figure 3.2). Each embedded 20 x 50 meter sample plot was marked using rebar and each module was marked using pin flags. All treatment units were created so that surveys could be conducted in an unbiased manner, sampled repeatedly throughout the study, and inventoried by different researchers while producing similar results (Lee *et al*. 2006). A single soil pH value was generated per treatment unit by averaging the pH values generated from ten soil samples that were collected for each treatment unit (1 per module; Figure 3.3; Appendix 1.1).

Pre-treatment vegetative surveys were conducted in September 2007 (understory; <1.5 meters) and January 2008 (overstory) to establish base-line data on the existing vegetation including individual counts of all naturally recruited longleaf pine seedlings established within each intensive nested 1 m^2 corner. These surveys were duplicated for two consecutive years following treatments. The age of the longleaf pine seedlings could not be determined since annual rings are not produced during this growth phase (Pessin 1934). However, based on survivorship data collected from the fire units post-treatment (2008), it was estimated that the longleaf pine seedlings sampled in the 1 m^2 nested corners across the study site were established on an unknown date in Fall 2005 after the two prescribed fires were conducted prior to this study. Total foliar cover of the *Aristida stricta* was measured by line-intercept method along two 50 meter transects that were established along the existing 20 x 50 meter sample plots within each treatment unit. All measurements generated by the line-intercept method were summed and divided by 100 (two 50 meter transects) to produce a total percent foliar cover value for the *Aristida stricta* per treatment unit. Care was taken not to enter any of the intensive nested corners or trample any of the herbaceous vegetation during sampling periods. Repeated post-treatment measurements were completed at the end of each consecutive growing season (typically completed in September each year) to determine any shifts in the herbaceous community.

Plant species were recorded and tallied for each treatment unit. Identification and nomenclature for each observed plant species were consistent with the Integrated Taxonomic Information System (ITIS; 2012) and taxonomic authorities (Radford *et al.* 1968, USDA Plants Database 2012). When plant species were unidentifiable in the field, specimens were either collected outside of the 20 x 50 meter sample plot or photographed and efforts were made to work with personnel at SCDNR or the herbariums located at Clemson University and the University of South Carolina to identify. In cases when the specimen could not be identified to a particular epithet, it was assigned to a designated genus (i.e *Lactuca* spp). A complete list of species collected, identified, and used in analyses is presented in Appendix 3.2.

Hemispherical photography along with HemiView version 2.1 Canopy Software (Delta-T Devices, Ltd.) was used to quantify and calculate visible sky and sky obstruction at the treatment unit level. A Nikon Coolpix 4500 digital camera equipped with a 180° fisheye lens on a self-leveling mount at a height of 1.4 m was used to sample each point. Two photographs were taken per treatment unit and the values averaged. Photographs were collected during dawn hours and on a uniformly cloudy day which improved photo quality and reduced glare generated by the sun or foliage.

We evaluated effects of silviculture treatments based on the presence of herbaceous species found at the 20 m^2 scale collected from the intensive modules, percent cover of *A. stricta* along two 50 meter transect lines established within each treatment unit, and the naturally regenerated longleaf pine seedlings found within the intensive nested 1 m^2 corners in 2007, 2008, and 2009. Statistical analysis of the treatment effect, time effect, and treatment and time interaction for species richness data, percent cover of *A. stricta*, and naturally generated longleaf pine seedling counts were completed using the mixed-model analysis of variance (PROC GLIMMIX) with a random residual statement to account for repeated measures throughout the study in SAS statistical software (2010; version 9.2; SAS Institute, Inc., Cary, NC). Unless otherwise specified, all levels of significance are based on $\alpha = 0.05$.

Presence data was then used to compute Simpson (*D*; SIDI; Simpson 1949) and Shannon (*H'*; SHDI; Shannon 1948) diversity indices and evenness (E_H) among species (Ludwig and Reynolds 1988). To overcome the counterintuitive nature of the Simpson diversity index, the index value (*D*) was subtracted from 1; thus, species diversity will increase with value. Species richness (N_0) is typically defined as the number of species per sample or the number of species present in a particular area, whereas evenness is the relative abundance of species distributed among a sample (DeJong 1975, Brockway and Outcalt 2000). Species richness was determined based on tallying every species observed at the 20 m^2 scale within each treatment unit.

RESULTS

Effect of Treatments on Understory Plants

In total, there were 86 species observed and recorded during the 2007 pre-treatment vegetative survey across all intensive modules, with 62 species in the prescribed burn units, 75 species in the herbicide treatment units, and 67 species in the mechanical mastication treatment units. There was no significant treatment difference observed for the species richness during the pre-treatment or post-treatment survey periods. That is, the species richness did not differ pre-treatment across the treatment units in 2007 ($p = 0.0528$), nor were there any significant differences reported post-treatment in either 2008 ($p = 0.3052$) or 2009 ($p = 0.2306$). Even though there were no statistical differences observed between the treatments, changes over time were observed for each treatment (Table 3.1). Prescribed fire positively influenced the species richness each post-treatment year. The herbicide treatment had significant initial impacts on the species richness ($p = 0.011$); however, these impacts appear to be short-lived because the plant species richness begins to increase by the end of the 2009 growing season (Table 3.1). Species richness significantly increased the first growing season following mechanical mastication treatment ($p = 0.044$), but it began to return to pre-treatment levels by the end of the 2009 growing season. By the end of the 2009 growing season, the overall species richness had increased to an overall count of 88 species, with 64 species in the prescribed burn treatment units, 68 species in the herbicide treatment units, and 69 species in the mechanical mastication treatment units. While the 2009 species richness tallies were similar to the 2007 values, when comparing pre-treatment and 2009 post-treatment values (Table 3.1) prescribed fire and mechanical mastication caused approximately 6% increases each and the herbicide treatment caused a 9% decrease.

Table 3.1. Species richness (N_0) at the 20 m^2 scale by treatment and pre- and post-treatment years. Means are followed by standard error in parenthesis. The same upper-case letters indicate no significant differences within columns and the same lower-case letters indicate no significant difference within rows at $\alpha = 0.05$.

Treatment	2007*	2008	2009
Prescribed Fire	$^{A}30.00^{a}$ (3.62)	$^{A}31.33^{a}$ (4.45)	$^{A}31.67^{a}$ (3.43)
Herbicide	$^{A}40.50^{a}$ (3.62)	$^{A}35.33^{b}$ (4.45)	$^{A}36.67^{b}$ (3.43)
Mechanical	$^{A}36.00^{a}$ (3.62)	$^{A}40.00^{b}$ (4.45)	$^{A}38.00^{ab}$ (3.43)

*Pre-treatment year

Wiregrass (*Aristida stricta*) Foliar Cover Changes

No significant differences were observed when investigating either the pre-treatment units in 2008 (p = 0.6940) or either post-treatment year (2009: p = 0.0778; 2010: p = 0.3559). However, there were significant gains reported for the prescribed fire treatment units (p = 0.0389; Table 3.2). That is, the average total *A. stricta* foliar cover increased initially by 49% on the prescribed fire treatment units (Figure 3.4). Following the application of herbicide, the foliar cover of *A. stricta* declined by 42%; however, no significant differences were determined (p = 0.1277). Evidence of recovery was suggested by the end of the 2010 growing season when the percent foliar cover values approached pre-treatment levels in the herbicide units. While there were no significant differences reported for the mechanical mastication units (p = 0.7863), this treatment was responsible for a 24% foliar cover decrease the initial post-treatment year. However, *A. stricta* percent foliar cover levels progressively recovered and increased to approximately pre-treatment levels by the end of the 2010 growing season.

Table 3.2. Mean averages based on *Aristida stricta* foliar cover measurements collected along two established 50 meter transects per treatment at the end of the 2008, 2009, and 2010 growing seasons. Means are followed by standard error in parenthesis. The same upper-case letters indicate no significant differences within columns and the same lower-case letters indicate no significant difference within rows at α = 0.05.

Treatment	2008*	2009	2010
Prescribe Fire	$^{A}0.052^{a}$ (0.020)	$^{A}0.074^{ab}$ (0.019)	$^{A}0.078^{b}$ (0.025)
Herbicide	$^{A}0.052^{a}$ (0.020)	$^{A}0.030^{a}$ (0.019)	$^{A}0.050^{a}$ (0.025)
Mechanical	$^{A}0.034^{a}$ (0.020)	$^{A}0.026^{a}$ (0.019)	$^{A}0.031^{a}$ (0.025)

*Pre-treatment year

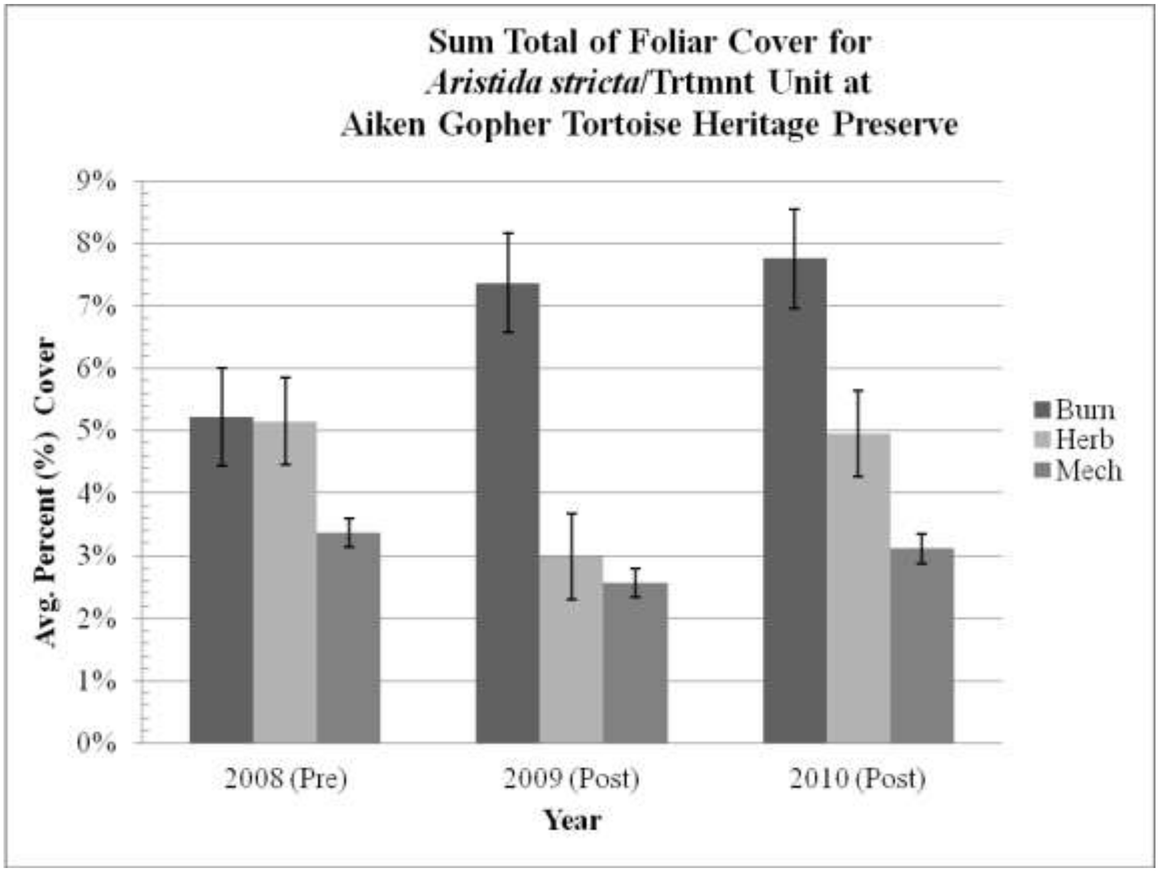

Figure 3.4. Foliar cover sum totals for *Aristida stricta* per treatment unit at Aiken Gopher Tortoise Heritage Preserve, Aiken County, SC.

Longleaf Pine Seedling Survival

Prior to conducting longleaf pine seedling counts, basal areas (BA) and visible sky cover (percent openness) were determined to evaluate if any significant overstory canopy differences existed based on stand and treatment unit selection (Figure 3.5 and Table 3.3). While the basal area ranged from 9 to 15 m^2/ha there was no significant difference discovered between the treatment units ($p = 0.2856$). The percent openness values ranged from 41% to 50% with no significant differences determined ($p = 0.4901$). There was no correlation between the number of natural longleaf pine seedlings that germinated following the 2005 prescribed fires and the basal area or percent openness per treatment unit. Block 3 had one of the lowest percentages of canopy openness (42%) and a relatively high basal area value (56) yet yielded the highest number (135) of surviving longleaf pine seedlings at the 1 m^2 scale post 2005 prescribed burns. On the other hand, block 1 was the next highest producer, yielding 46 longleaf pine seedlings, but it had a lower basal area and a higher percent of openness.

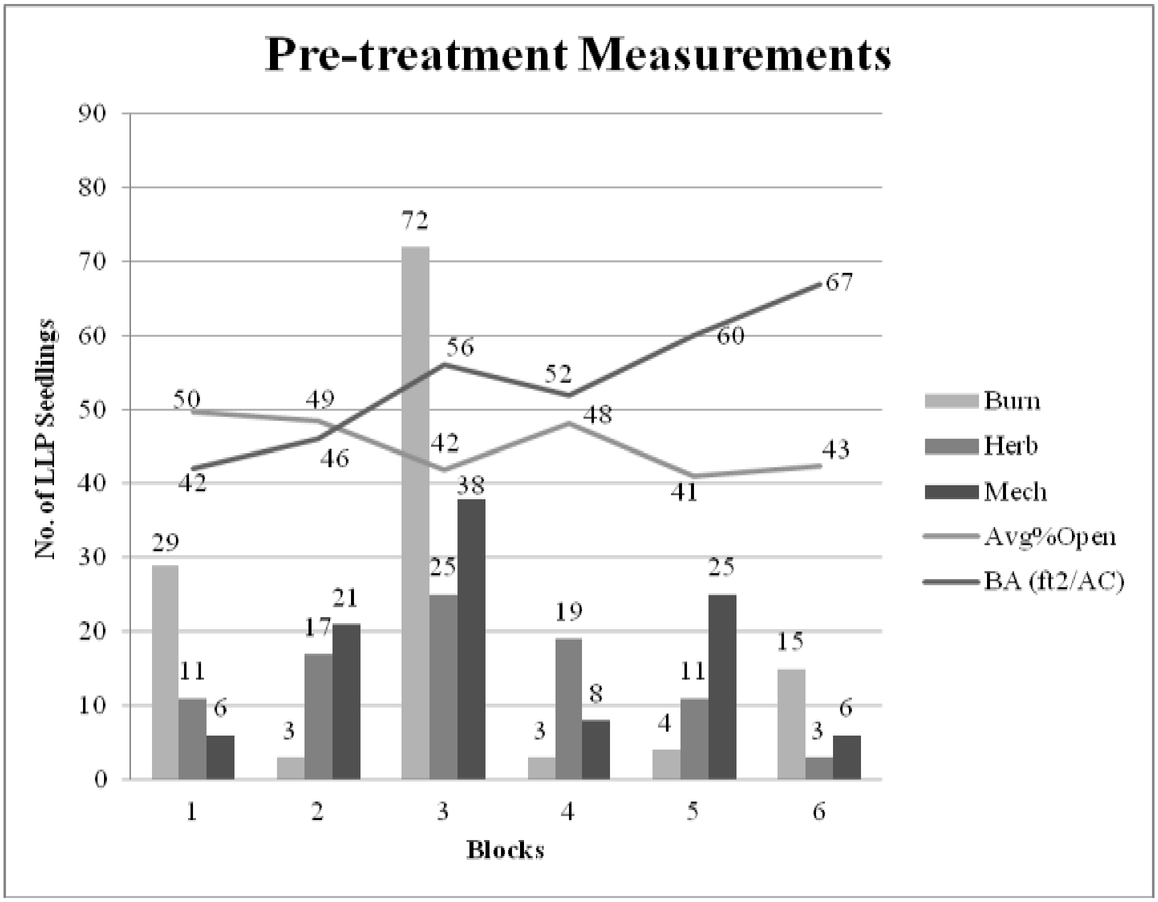

Figure 3.5. Comparison between longleaf pine seedling counts, basal area and percent (%) of overstory canopy openness at Aiken Gopher Tortoise Heritage Preserve, Aiken County, SC.

Table 3.3. Pre-treatment (2007) longleaf pine seedling counts by block and treatment type at 1 m^2 scale.

Block	Burn	Herbicide	Mechanical	Total	BA 2008	%Openness*
1	29	11	6	46	42	50
2	3	17	21	41	46	49
3	72	25	38	135	56	42
4	3	19	8	30	52	48
5	4	11	25	40	60	41
6	15	3	6	24	67	43

* %Openness is generated based on averaged visible sky values using HemiView version 2.1 Canopy Software (Delta-T Devices, Ltd.).

No pre-treatment (2007) differences were detected for the longleaf pine seedlings when comparing treatment units ($p = 0.8463$; Table 3.4). However, significant differences were observed between the treatments each post-treatment year (2008: $p = 0.0002$; 2009: $p = 0.0004$). When comparing the effects of the herbicide treatment throughout the study, no significant differences were reported ($p = 0.0746$). However, the prescribed burn and mechanical treatments yielded significant within treatment differences (F: $p < 0.0001$; H: $p < 0.0001$). The herbicide and mechanical treatment units resulted in the higher survivorship of longleaf pine seedlings consistently across all survey years compared to prescribed fire treatment. Prescribed fire and mechanical mastication treatments yielded lower survival rates (2.38%; 42.31%) compared to the herbicide treatment (81.40%) by the end of the 2008 growing season (Figure 3.6).

Table 3.4. Longleaf pine seedling counts by treatment year and treatment at 1 m^2 scale at the end of the 2007, 2008, and 2009 growing seasons. Means are followed by standard error in parenthesis. The same upper-case letters indicate no significant differences within columns and the same lower-case letters indicate no significant difference within rows at $\alpha = 0.05$.

Treatment	2007*	2008	2009
Prescribe Fire	$^{A}11.89^{a}$ (4.55)	$^{A}0.28^{b}$ (0.19)	$^{A}0.38^{b}$ (0.23)
Herbicide	$^{A}11.89^{a}$ (4.47)	$^{B}9.68^{a}$ (3.68)	$^{B}8.02^{a}$ (3.08)
Mechanical	$^{A}14.88^{a}$ (5.55)	$^{B}6.30^{b}$ (2.46)	$^{B}4.86^{b}$ (1.94)

*Pre-treatment year

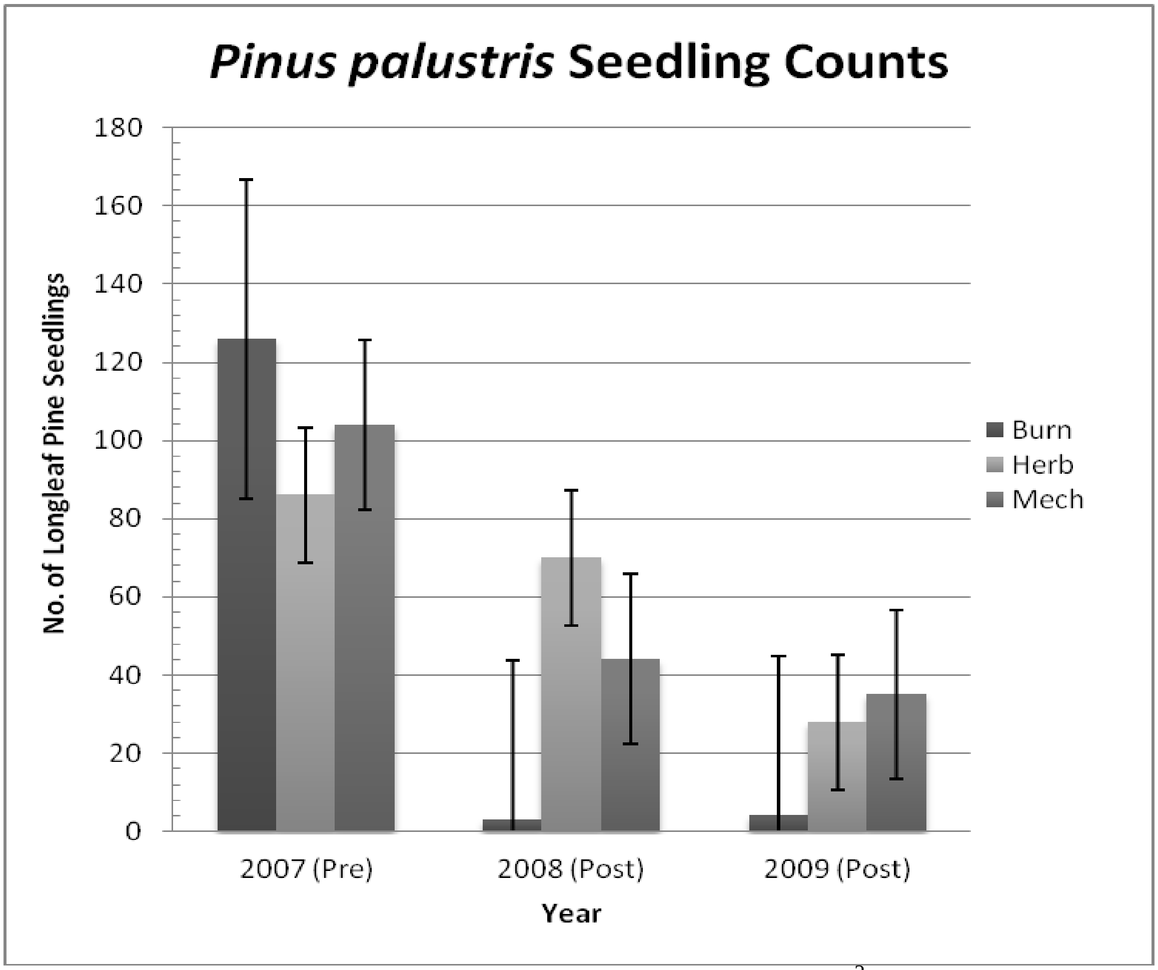

Figure 3.6. Longleaf pine seedling counts by treatment year at 1 m^2 scale at the end of the 2007, 2008, and 2009 growing seasons.

Herbaceous Understory Plant Diversity

Even though there was an initial decline observed in species richness following the herbicide application, there was no significant treatment by year interaction found between any of the treatments using the Simpson index (SIDI; 20 m^2: $p = 0.4637$); however, there were differences detected with the Shannon index of diversity (SHDI; 20 m^2: $p = 0.0274$). When the treatment effects were examined for the SHDI following each post-treatment year no significant within year differences were observed (2008: $p = 0.3089$; 2009: $p = 0.2934$). By the end of the 2009 growing season, the diversity values exceeded all pre-treatment levels for the prescribed fire and mechanical mastication treatment units (Table 3.5). Pre-treatment levels were not achieved on the herbicide treatment units by the end of the 2009 growing season. However, diversity values indicated a return to pre-treatment levels and when comparing 2007 and 2009 data no statistically significant differences were determined for either indices (Table 3.5). Increases in plant species diversity were observed each post-treatment year following mechanical treatment. Although the 2009 diversity value on mechanical treatment units exceed pre-treatment levels, slight declines were observed from 2008 to 2009.

There were no significant differences observed between the treatments for the plant species evenness value ($p = 0.2458$). The plant species evenness improved in all treatments by the end of the 2009 growing season (Table 3.6). Evenness increased in the prescribed fire and mechanical treatment units each consecutive year following treatment. In fact, the prescribed fire treatment had a significant increase in evenness by the end of 2009 growing season ($p = 0.0008$; Table 3.6). While the hexazinone treatment units indicated no change the first post-treatment year, non-significant increases were observed between the 2008 and 2009 growing seasons. In fact, by the end of the 2009 growing season, the evenness levels were slightly higher than pre-treatment levels, indicating an increase in species equitability. While all treatments increased evenness, prescribed fire promoted the highest relative gains (3.8%), followed by mechanical mastication (2.6%), and then herbicide (2.6%).

Table 3.5. Diversity indices values at the 20 m^2 scale to prescribed fire, hexazinone treatment, and mechanical mastication. Means are followed by standard error in parenthesis. The same upper-case letters indicate no significant differences within columns and the same lower-case letters indicate no significant difference within rows at $\alpha = 0.05$.

	2007*	2008	2009
***Simpson Diversity Index* (1-*D*)**			
Prescribe Fire	$^{A}0.9583^{a}$ (0.005)	$^{A}0.9600^{a}$ (0.006)	$^{A}0.9617^{a}$ (0.005)
Herbicide	$^{A}0.9700^{a}$ (0.005)	$^{A}0.9650^{a}$ (0.006)	$^{A}0.9683^{a}$ (0.005)
Mechanical	$^{A}0.9667^{a}$ (0.005)	$^{A}0.9717^{a}$ (0.006)	$^{A}0.9700^{a}$ (0.005)
Shannon Diversity Index			
Prescribe Fire	$^{A}3.1401^{a}$ (0.126)	$^{A}3.1787^{a}$ (0.142)	$^{A}3.2214^{a}$ (0.146)
Herbicide	$^{A}3.4813^{a}$ (0.126)	$^{A}3.3257^{b}$ (0.142)	$^{A}3.3858^{ab}$ (0.146)
Mechanical	$^{A}3.3471^{a}$ (0.126)	$^{A}3.4438^{a}$ (0.142)	$^{A}3.3988^{a}$ (0.146)

*Pre-treatment year

Table 3.6. Evenness responses at the 20 m^2 scale to prescribed fire, hexazinone treatment, and mechanical mastication. Means are followed by standard error in parenthesis. The same upper-case letters indicate no significant differences within columns and the same lower-case letters indicate no significant difference within rows at $\alpha = 0.05$.

Treatment	2007*	2008	2009
Prescribe Fire	$^{A}0.6917^{a}$ (0.014)	$^{A}0.6950^{a}$ (0.015)	$^{A}0.7183^{b}$ (0.012)
Herbicide	$^{A}0.7200^{a}$ (0.014)	$^{A}0.7200^{a}$ (0.015)	$^{A}0.7283^{a}$ (0.012)
Mechanical	$^{A}0.7083^{a}$ (0.014)	$^{A}0.7233^{ab}$ (0.015)	$^{A}0.7267^{b}$ (0.012)

*Pre-treatment year

DISCUSSION

While humans have been using fire as a vital conservation tool to manage longleaf pine ecosystems directly and indirectly for thousands of years in the southeastern United States (Walker and Peet 1983, Glitzenstein *et al.* 1995, Landers *et al*. 1995, Jose *et al.* 2006), its use may be restricted or halted by regulatory agencies concerned about the public outcry over health and safety issues regarding particulate and smoke production. This has triggered a need to explore alternative silviculture tools such as herbicides and mechanical mastication to maintain and perpetuate existing and future longleaf pine ecosystems. Although there are existing studies that have reviewed the impacts alternative treatments have on the longleaf pine ecosystem function and structure, many of them focused on the effects of treatments after a follow-up prescribed fire, were limited to conservation tools of their time (i.e hand-clearing), focused on a single targeted species (i.e. *Pinus* spp.), occurred in a plantation stand or green house, or did not compare all three cultural treatments (prescribed fire, herbicide, and mechanical manipulation) within the same forest at the same time. This paper was designed to compare the ecological effects of prescribed fire, herbicide and mechanical mastication treatments simultaneously within the same forest under the same conditions.

Herbaceous Response to Treatments

The species richness of the understory was not significantly affected by any of the treatments; however, there were within-treatment group effects over time observed. Species richness values steadily increased throughout the entire study for the prescribed fire treatment units. The reduction in non-pyrophytic vegetation such as oaks was generated by applying prescribed fire and is consistent with other studies (Rebertus *et al.*1989, b; Glitzenstein *et al.* 1995); however, in the event that fire is delayed or only applied once, the effects are typically ephemeral in nature and the woody plants sprout rapidly often exceeding pre-treatment levels in subsequent years (Waldrop *et al.* 1992, Abrahamson and Abrahamson 1996a & b, Liu *et al*. 1997). The broadcast application of hexazinone on this xeric sandhills site initially reduced species richness. While this study did not assess the cover classes of vegetative groups and did not tally the above ground biomass, the initial reduction in richness may have partially been driven by decreases in the overall non-desirable woody species such as *Quercus* spp. as reported in literature (Long and Flinchum 1992, Wilkins *et al.* 1993a). This decrease in woody foliar cover may have also created an opportunity for on-site suppressed seeds to be stimulated and liberated the following growing season, consequently causing a steady increase by the end of the 2009 survey period (Wilkins *et al.* 1993b, Brockway *et al.* 1998). Mechanical mastication treatment positively influenced the species richness by the end of the 2008 growing season; however, species richness began to decline by the end of the 2009 growing season. The downward trend of species richness at the end of the 2009 growing season may be the result of the sprouting of competing midstory vegetation that was temporarily suppressed in 2008 due to the treatment. By the end of the 2009 growing season, pre-treatment species richness values were exceeded on both the prescribed fire and mechanical mastication treatment units. Our study found that while there is a temporary reduction in the species richness of the herbaceous layer following broadcast application of hexazinone or mechanical mastication, the benefits can possibly outweigh the short-term negatives by reducing competition and stimulating the understory herbaceous layer and seed bank.

Wiregrass (*Aristida stricta*) Foliar Cover Changes

Our study found that silviculture treatments did not significantly affect the cover of wiregrass (*A. stricta*) throughout the study. Contrary to literature, our study did not show any decreases in wiregrass cover following the application of prescribed fire (Garren, 1943, Moore *et al.* 1982, Landers *et al.* 1990, Outcalt 1994a, Brockway and Outcalt, 2000). In fact, our findings indicate that wiregrass cover expanded each consecutive year. Wiregrass cover declined initially with the hexazinone and mechanical mastication treatments, however, recovery was observed by the end of the second growing season. These findings did not agree with Brockway *et al.* (1998), who reported that the broadcast application of granular hexazinone did not impair the growth of wiregrass. Parrott (1967) reported that wiregrass responds favorably with increasing available site resources. Our results generally concur with Parrott’s (1967) findings and earlier studies showing the beneficial effects of herbicide application on graminoid species (Bush *et al.* 1990; Outcalt 1992, 1993, 1994b, 1995). Literature suggests that minimal soil disturbance following drum-chopping did not decrease the cover of wiregrass on xeric sandhill sites in South Carolina (Walker and van Eerden 1998). Our data suggested an initial decrease in wiregrass cover following the application of the mechanical mastication treatment. However, the wiregrass cover levels began to gradually increase in the ensuing growing season and returned to pre-treatment levels. By the end of the 2009 growing season, the prescribed fire treatment units yielded the highest gains and maintained the overall greatest percent of wiregrass cover, followed by herbicide treatment units, then the mechanical mastication units.

Longleaf Pine Seedling Survival

While the survival of this cohort of longleaf pine seedlings may have been influenced by other abiotic (e.g. light, soil moisture, nutrients) and biotic (e.g. predation, competition) variables, significant treatment effects were observed for all three treatments by the end of the 2009 growing season. The highest seedling mortalities were observed following the prescribed fire in May 2008 which only had 2.38% of the longleaf pine seedlings survive. The percent mortality of the longleaf pine seedlings was consistent with values reported in the literature following prescribed fire treatment (Boyer 1985 and 1990b, Grace and Platt 1995, Provencher *et al.* 2001). Boyer (1974, 1990a, 1993) reported that longleaf pine seedlings are vulnerable to fire in earlier stages of development and that the size of the root collar diameter (RCD) is a good indicator of when to conduct an initial dormant season prescribed fire (>0.762 cm). Gagnon and Jack (2004) found that longleaf pine seedlings treated with herbicide had a 96% survival rate and developed quicker in height and growth compared to fire. The longleaf pine seedling survival rate (81.4%) for our herbicide treatment units is consistent with literature. No seedlings were observed emerging from the grass phase for any of the treatments during this study. In fact, survival rates continued to decrease throughout the study for all treatments. This may have been a direct effect of above- and below-ground competition from the herbaceous layer and overstory canopy (Boyer 1993, Palik *et al.* 1997) or predation (Croker 1989). No correlations were determined between initial seedling development and overstory tree basal area or percent canopy openness as reported by others during this study. By the end of the first growing season post-treatments, the longleaf pine seedlings survival rate for the herbicide units was 81.4%, followed by 42.31% for the mechanical mastication units, then 2.38% for the prescribed fire units.

Influence on Herbaceous Layer Diversity

No significant decreases in species richness were observed for all three treatments. Prescribed fire treatment positively influenced the species richness throughout the study. The broadcast application of Velpar® ULW caused initial significant within-treatment decreases in plant species richness. This initial decline has been reported by others due to the herbicide being in close proximity to nearly all plants (Blake *et al.* 1987, Brockway *et. al.* 1998, Brockway and Outcalt 2000). Even though foliar cover class data is not being reported at this time, decreases in the midstory oaks and other hardwoods were observed using a low-rate (1.26 kg a.i./ha) application of hexazinone. This observation is consistent with literature (Brockway *et al.* 1998, Long and Flinchum 1992). Brockway *et al.* (1998) reported that the turkey oak mortality ranged from 83 to 93%. This reduction in above- and below-ground competition potentially liberated abiotic site resources and created an opportunity for existing plants to grow and expand (Metlen and Fiedler 2006, Collins *et al.* 2007). By the end of the 2009 growing season, the species richness began to recover and return to pre-treatment levels within the hexazinone treatment units. This finding is consistent with literature which suggests that plant diversity will remain relatively stable or even increase by subsequent growing seasons (Blake *et al.* 1987, Brockway and Outcalt 2000).

Both the SIDI and SHDI produced similar diversity trends for each treatment. That is, prescribed fire caused increases for both indices throughout the study. Mechanical mastication treatments yielded the highest diversity values for all treatments across each post-treatment year. The non-significant decline by the end of the 2009 growing season may be related to the sprouting and recovery of the midstory plants (Brockway and Outcalt 2000). However, significant declines were observed for the SHDI values following the initial herbicide treatment, but signs of recovery began by the end of the 2009 growing season. The initial decrease in diversity followed by a recovery period after the broadcast application of herbicide is consistent with literature (Neary 1991).

The trend toward greater species equitability was achieved on all treatment units by the end of the 2009 growing season. The broadcast application of granular hexazinone across the treatment units did not positively influence the plant evenness initially; this may suggest that less herbicide resistant plant species can be negatively impacted with herbicide. However, literature reports that many perennial plants and the seeds from the seed bank are responding to the reduction in competition and local site resources (Kane *et al.* 2010); consequently, the herbaceous layer recovers in ensuing years. All three treatments positively influenced the flora species evenness.

MANAGEMENT IMPLICATIONS

It has been proposed that alternative silviculture practices such as herbicides and mechanical mastication be used as surrogates for fire to perpetuate the ecological structure, integrity, and function of the once dominate pyroclimax longleaf pine ecosystem. While this xeric sandhills site can be characterized by extreme water deficiencies, acidic soils, and low soil fertility, there were approximately 121 plant species identified throughout the study, which is typical of a longleaf pine ecosystem (Appendix 3.2; Peet and Allard 1993). The success and survivorship of longleaf pine forests may one day become dependent on non-traditional silviculture practices to maintain the highly diverse herbaceous-dominated ground layer and support the dependent fauna. The results from this study suggest the possibility that the broadcast application of granular hexazinone at a relatively low rate and above ground mechanical mastication treatments and vegetative hand-manipulation may be used to sustain the diversity of the herbaceous understory vegetation, promote natural longleaf pine seedling regeneration, and remove competing hardwoods from the mid-story. The study confirmed that small longleaf pine seedlings, less than 3 years old in our case, are highly susceptible to mortality following prescribed fire; however, they benefit from reduced competition and increased site resources generated by herbicide and mechanical manipulation treatments. Wiregrass, on the other hand, is positively influenced by prescribed fire and is initially reduced by the alternative silviculture treatments. While follow-up treatments would be expected for these alternative silviculture treatments, prescribed fire may need to be applied on a regular basis depending on the sprouting vigor of woody species. All three of these hardwood control treatments have benefits and limitations and should be used with consideration of site conditions and management objectives. Our study was a relatively short study that only lasted three years, which may not have been long enough to assess the full impacts of each silviculture treatment to the native understory vegetative community, its function or structure; consequently, our findings should be regarded as tentative.

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CHAPTER FOUR

INFLUENCE OF SILVICULTURE TREATMENTS ON FOREST FLOOR LITTER ACCUMULATION AND THE ASSESSMENT OF WIREGRASS (*Aristida stricta)* SEEDLING ESTABLISHMENT WITHIN RAKE AND NON-RAKE SUBPLOTS LOCATED IN A MATURE LONGLEAF PINE (*Pinus palustris* Mill.) ECOSYSTEM AT AIKEN GOPHER TORTOISE HERITAGE PRESERVE, AIKEN COUNTY, SOUTH CAROLINA

ABSTRACT

It has been well documented that in the absence of fire, longleaf pine ecosystems (*Pinus palustris* Mill.) quickly transform from open, park-like savannas into closed canopy forests dominated by hardwood trees and shrubs, reduced understory vegetative diversity and increased litter depths. This reduction in the understory vegetative diversity may be a direct result of the midstory attenuating light resources. Conversely, it may be because of litter accumulation on the forest floor. Our study examined how treating the woody midstory of a longleaf pine forest with three commonly used cultural practices (prescribed fire, herbicide and mechanical mastication) would affect the litter depth and how the removal or retention of the forest floor litter layer would influence the recruitment of the keystone understory species, wiregrass (*Aristida stricta*). We installed a randomized complete block design (RCBD) to test the effects of prescribed burning, the broadcast application of granular hexazinone (1.26 kg a.i./ha), and mechanical mastication on the litter depth within each 0.405 ha treatment unit. We also installed a RCBD split plot design with eight randomly assigned rake and non-rake (control) treatment subplots within each herbicide and mechanical mastication treatment units to test what effect, if any, removing the forest floor litter layer would have on the recruitment of wiregrass seedlings. While prescribed fire generated the greatest initial litter depth reduction (54%) and maintained the slowest litter recovery throughout the study, decreases were observed initially and for each post-treatment year within the herbicide (38% initially) and mechanical mastication (39% initially) units. These latter results were influenced by natural and anthropogenic factors. *Aristida stricta* seedling counts were not significantly different across the rake and non-rake treatment units. However, the rake subplots seemed to promote higher *A. stricta* seedling counts and relative differences following initial treatment versus non-rake subplots. Mechanical plus rake yielded the highest initial increases and maintained the highest relative differences compared to the other treatments throughout the study. While mechanical mastication of the woody midstory can lead to a short-term increase in wiregrass, the removal of the litter layer in our study was also needed to maximize its response. However, removing the litter layer may not always be practical. Results from this study suggest that prescribed fire could be used to mimic the results of the herbicide and mechanical mastication plus rake units by reducing both the woody midstory and litter layer. However, in areas that prescribed fire is restricted, our study shows that both herbicide and mechanical mastication treatments along with removing the forest floor litter layer can provide some benefits to the understory herbaceous layer, specifically *A. stricta*.

Keywords: *Pinus palustris*; Herbicide; Mechanical mastication; Hardwood reduction treatments; Plant species diversity; Sandhills; Litter depth; South Carolina Department of Natural Resources

INTRODUCTION

Historically, fire has been a key component that has perpetuated both the *Pinus* spp. and its associated pyrophytic understory communities (Noss 1989, Glitzenstein *et al.* 1995, Landers *et al.* 1995, Franklin 1997, Van Lear *et al.* 2005). The longleaf pine (*Pinus palustris* Mill) forests that once dominated approximately 36 million hectares in the Southeast are prime examples of one such fire dependent ecosystem. Literature reports a relatively short fire frequency for the natural longleaf pine ranging between 1 to 10 years prior to European settlement (Christensen 1981, Glitzenstein *et al.* 1995, Frost 2006). Until current times, these low-intensity frequent fires were responsible for maintaining the structure and understory herbaceous species diversity of the longleaf pine ecosystem (Frost 1993, Streng *et al.* 1993, Gliztenstein *et al.* 1995, Brockway and Lewis 1997, Platt 1999, Sorrie and Weakley 2006). The herbaceous understory of longleaf pine forests is considered one of the most diverse in North America (Sorrie and Weakley 2001, Peet 2006). Today, longleaf pine ecosystems have been reduced to less than 3% of their original historic extent (Noss *et al.* 1995, Jose *et al.* 2006). The degradation of this ecosystem can be attributed to a variety of direct and indirect anthropogenic influences such as the introduction of free-ranging hogs, timber production, agriculture and urbanization, southern pine plantation conversions (slash pine *P. elliotti* Engelm. and loblolly pine *P. taeda* L.) and fire suppression polices (Frost 1993, Landers *et al.* 1995, Henderson 2006).

In the absence of ecological disturbances such as fire, longleaf pine ecosystems quickly transform from open, park-like savannas into closed canopy forests dominated by hardwood trees and shrubs (Christensen 1981, Streng *et al.* 1993, Kush *et al.* 1999, Glitzenstein *et al.* 2003a, Van Lear *et al.* 2005, Varner *et. al.* 2005). Research has shown that the diversity of the understory vegetative layer declines as a direct result of an increase in the midstory. Many believe that this is the direct result of the midstory attenuating light resources (Pessin 1938, Platt *et al.* 1988a, b, Platt and Rathburn 1993, Brewer and Platt 1994, Brewer 1995, Gilliam and Platt 1999, Harrington and Edwards 1999, Provencher *et al.* 2001), while others think it is because of litter accumulation on the forest floor (Chapman 1936, Sydes and Grimes 1981, Facelli and Pickett 1991, Streng *et al.* 1993, Hiers *et al.* 2007). Provencher *et al.* (2001) proposed the "habitat modification hypothesis" which states that the density and species richness of the understory herbaceous layer are directly related to the extent of the midstory. That is as the midstory density decreases, the herbaceous layer should increase or vice versa. Alternatively, Hiers *et al.* (2007) suggested that frequent fires are needed to remove the litter layer prior to it accumulating and negatively influencing the environment of the forest floor, consequently impeding the herbaceous vegetative layer. Literature also suggests that tree litter can influence understory herbaceous communities by sequestering or releasing nutrients or physically impacting the ground flora (Sydes and Grime 1981, Facelli and Pickett 1991, Hiers *et al.* 2007).

Whether it is the removal of the midstory or the disturbance of the forest floor, fire has proven to be a key component that has maintained the structure and function of the longleaf pine ecosystem for thousands of years; however, its use as a conservation tool may become limited or unavailable as a direct result of increasingly restrictive federal, state, and local laws and policies. Moreover, as society advances and becomes more urbanized, humans are losing their personal connection to the land. This disconnect potentially makes it difficult to convey the value and importance of conservation tools such as prescribed fire. Emulating natural disturbance regimes while adhering to policies, protocols, and practices within today's society is becoming a near impossible task (Hunter 1993, Christensen *et al.* 1996, Franklin *et al.* 2002). Therefore, the ability to perpetuate the longleaf pine ecosystem could be lost unless it is determined that alternative cultural practices such as herbicides and mechanical mastication can be used as surrogates for fire.

The goal of this study is to understand the influence that prescribed fire, herbicide and mechanical mastication have on the litter depth and assess whether the removal of the forest floor litter layer will influence the recruitment of the keystone understory species, wiregrass (*Aristida stricta*), within an established (~35 year old) longleaf pine ecosystem. Treatments consisted of growing season prescribed burns, broadcast application of the granular form of the herbicide hexazinone (Velpar® ULW), and midstory mechanical mastication. Mechanical mastication has been defined as the act of mulching, shredding, grinding, or pulverizing of above-ground live and dead woody material, concentrating the generated debris on the forest floor (Glitzenstein *et al.* 2003b, Brockway *et al.* 2009, Kane *et al.* 2010, Rummer *et al.* 2002). All three treatments are described in detail in Chapter 3—*Experimental Design*. Additional silviculture treatments were applied to subplots within the herbicide and mechanical mastication units. These subplots included 2 m^2 rake versus non-rake treatments to determine the response of *A. stricta* seedlings to the removal of the forest floor litter layer. While herbicides and mechanical mastication are commonly used in the southeast U.S.A., studies that evaluated their effects often included follow-up prescribed fire (Provencher *et al.* 2001), were limited to conservation tools of their time (i.e hand-clearing; Boyer and Miller 1994), dealt with fuel loading (Kane *et al.* 2006 a & b), focused on a single targeted species (i.e. *Pinus* spp.; Boyer and Miller 1994, Brockway *et al.* 1998), occurred in a plantation stand or greenhouse (Kaeser and Kirkman 2010), or did not compare all three silviculture treatments (fire, herbicide, and mechanical mastication) simultaneously within the same forest at the same time. Evaluating the effects of these alternative silviculture practices is paramount to the survival, expansion, and recovery of the longleaf pine ecosystem throughout its extent. Here we study these alternative silviculture practices as stand-alone conservation tools and compare them to prescribed fire in order to advance our understanding of how the structure and function of a pyrophytic adapted ecosystem is influenced by their use. We predict that the litter depth will be greatest for the mechanical mastication units, followed by the herbicide units, and then the prescribed burn units. Moreover, *A. stricta* seedling counts will increase with increasing hardwood control efficacy and reduction in forest floor litter depth.

MATERIALS AND METHODS

Study Site, Plot Layout and Measurement

This study was conducted at Aiken Gopher Tortoise Heritage Preserve, Aiken County, South Carolina and included the eighteen approximately equal-sized treatment units and the three silviculture treatments as described in Chapter 3. As reported in Chapter 3, no significant differences were found among the basal area or the light availability for each treatment unit. Two separate measurements were collected to answer the proposed hypothesis: 1) litter depths were measured at eight sampling points around each 20 x 50 meter sample plot then averaged per treatment unit (Figure 4.1), and 2) seedling counts of *Aristida stricta* were made within eight separate 2 m^2 subplots permanently established within the herbicide and mechanical treatment units (Figure 4.2). Simple vertical litter depth measurements of the Oi horizon were taken to the nearest centimeter (cm). The Oi horizon, sometimes referred to as the litter layer, consist of leaves, pine needles and twigs with little to no decomposition (Appendix 4.1 & 4.2). As a result of frequent prescribed burns ignited by South Carolina Department of Natural Resources (SCDNR) prior to the start of this study, very little organic matter or large fuels (>3 inches diameter; a.k.a. 100- or 1000-hour fuels; Appendix 4.2) had accumulated across the site. Pre-treatment and post-treatment measurements were conducted between 2008 and 2011. Resources were limited during 2009, so litter depth measurements were not completed that year. Litter depth measurements were averaged to generate one value per treatment unit. Due to frequent prescribed fire that occurred on the preserve prior to this study, individual fuels were not measured and grouped into classes as described in

Deeming *et al.* (1977). Because literature suggests that the depth of the forest floor mediates the vigor of the herbaceous layer (Hiers *et al.* 2007), *A. stricta* seedling counts were conducted within raked and non-raked (control) 2 m^2 subplots that were located outside of each 20 x 50 meter sample plot positioned within the herbicide and mechanical mastication treatment units (Figure 4.2). While it has been documented that environmental factors such as light availability and soil moisture influence the success of seed and seedling germination and establishment (Kirkman *et al.* 2001, Mulligan 2000, Mulligan and Kirkman 2002, Harrington *et al.* 2003, Pecot *et al.* 2007), our study focused on whether the presence or absence of litter influenced the establishment of *A. stricta* seedlings. *Aristida stricta* seeds were sowed across each 2 m^2 subplot in November 2008 and initial *Aristida stricta* counts were conducted simultaneously. Initial wiregrass counts were conducted to determine the presence of wiregrass in each one of the subplots prior to applying the rake treatment. Wiregrass seeds were collected from within the boundaries of the heritage preserve following a growing season prescribed burn the same year. Seeds were hand collected in October 2008 and separated, so they could either be dispersed across each subplot or sent to personnel at Clemson University for greenhouse germination tests which were run in March and May 2009. Based on germination tests conducted in March and May 2009, the number of seedlings expected to germinate would be 14.3% for March and 17% for May if germination rates were constant for the field. The germination tests were also run to determine the viability of the seed.

Litter depth measurements were compared using a randomized complete block design (RCBD) with six blocks and three treatment units within each block (Figure 3.2;

Figure 4.1). Statistical analysis of the treatment effect, time effect and treatment and time interaction for the litter depth was completed using the mixed-model analysis of variance (PROC GLIMMIX) with a random residual statement to account for repeated measures throughout the study in SAS statistical software (2010; version 9.2; SAS Institute, Inc., Cary, NC). Unless otherwise specified, all levels of significance are based on α = 0.05.

The *A. stricta* seedling counts were compared using a randomized complete block design (RCBD) with five blocks to account for the treatment effects, while subplots were randomly assigned to evaluate rake versus non-rake treatment effects (Figure 4.2). Statistical analysis of the rake/non-rake effect, rake/non-rake and treatment interaction, treatment effect, time effect, and treatment and time interaction for the seedling counts were completed using the mixed-model analysis of variance (PROC GLIMMIX) with a random residual statement to account for repeated measures throughout the study in SAS statistical software (2010; version 9.2; SAS Institute, Inc., Cary, NC). Unless otherwise specified, all levels of significance are based on α = 0.05. Additional information describing site selection, treatments, and treatment application is available in Chapter 3—*Experimental design*.

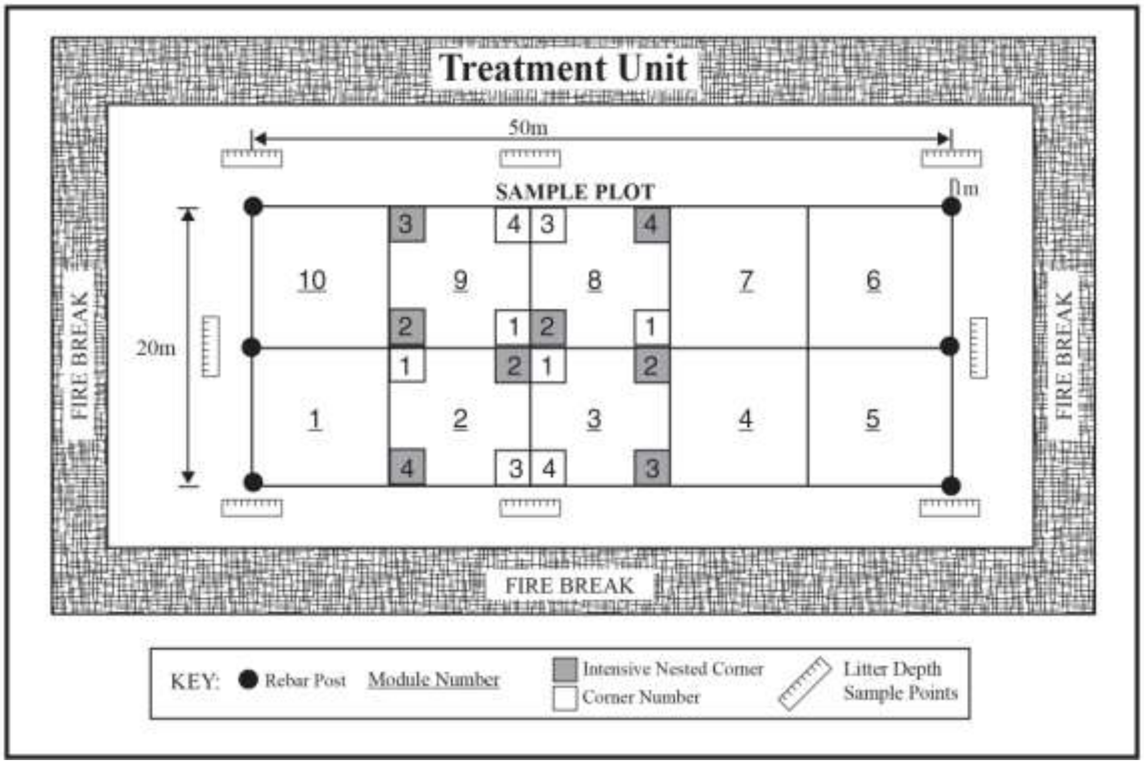

Figure 4.1. Litter depth measurement points at Aiken Gopher Tortoise Heritage Preserve, Aiken County, SC.

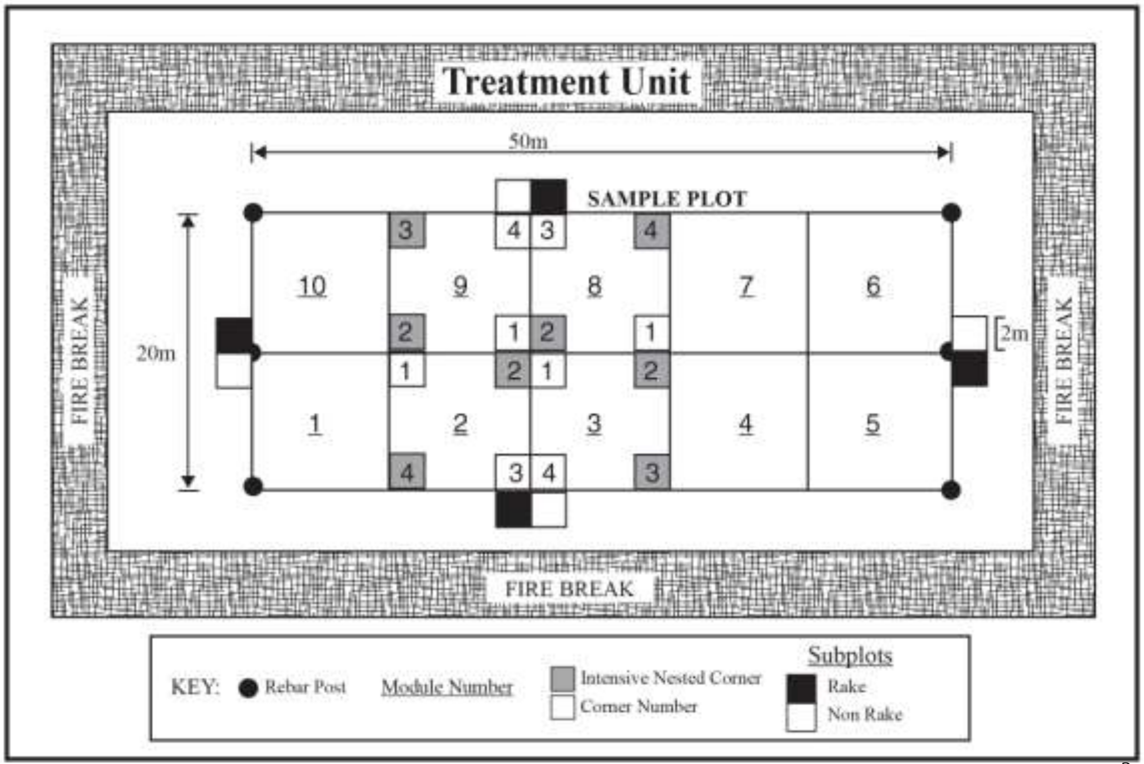

Figure 4.2. *Aristida stricta* seedling counts within eight separate rake and non-rake 2 m^2 subplots permanently established within the herbicide and mechanical mastication treatment units at Aiken Gopher Tortoise Heritage Preserve, Aiken County, SC.

RESULTS

Effect of Treatments on Litter Depth

While there were no significant differences determined pre-treatment (2008: $p = 0.7741$) or either post-treatment year (2010: $p = 0.3005$; 2011: $p = 0.0642$), significant within treatment differences were observed (Table 4.1). By 2010, the average litter depth measurements had decreased for prescribed fire units by 53.9% ($p < 0.0001$), 39.2% ($p < 0.0001$) for the mechanical mastication units, and 38.4% ($p < 0.0001$) for the herbicide units (Table 4.1 and Figure 4.3). The prescribed fire units had the slowest litter accumulation over-time compared to the herbicide and mechanical mastication units. In fact, both the herbicide and mechanical mastication units returned to pre-treatment levels within three years of treatment.

Table 4.1. Litter depth measurements were taken to the nearest centimeter (cm) within each treatment unit and during the pre-treatment and post-treatment years. Means are followed by standard error in parenthesis. The same upper-case letters indicate no significant differences within columns and the same lower-case letters indicate no significant difference within rows at $\alpha = 0.05$.

Treatment	2008*	2010**	2011**
Prescribe Fire	$^{A}5.01^{a}$ (0.34)	$^{A}2.31^{b}$ (0.34)	$^{A}3.59^{c}$ (0.34)
Herbicide	$^{A}4.94^{a}$ (0.34)	$^{A}3.04^{b}$ (0.34)	$^{A}4.76^{a}$ (0.34)
Mechanical	$^{A}4.68^{a}$ (0.34)	$^{A}2.84^{b}$ (0.34)	$^{A}4.35^{a}$ (0.34)

*Pre-treatment year **Post-treatment years ***Measurements were not collected in 2009

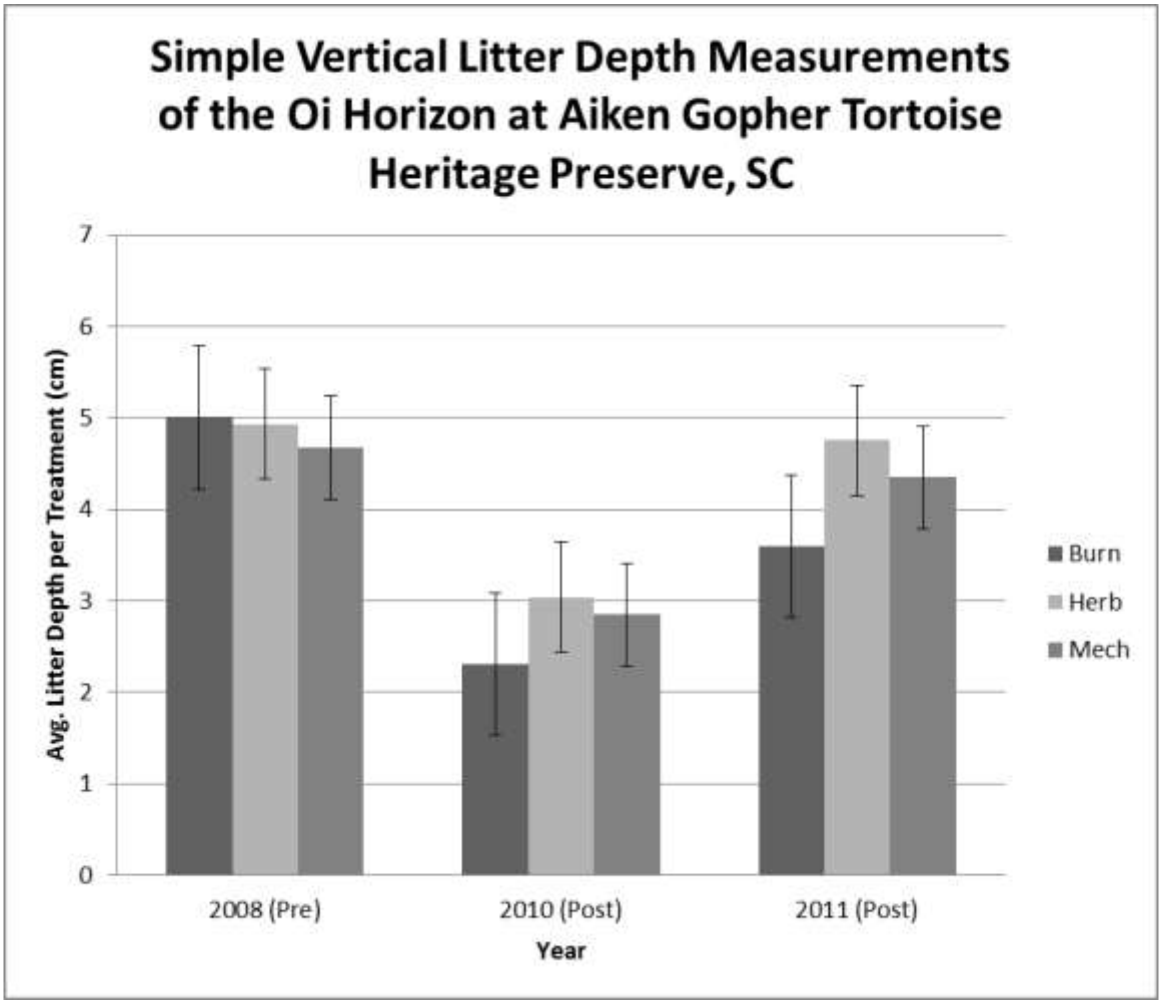

Figure 4.3. Litter depth measurements were taken to the nearest centimeter (cm) within each treatment unit and during the pre-treatment and post-treatment years at Aiken Gopher Tortoise Heritage Preserve, Aiken County, SC. Measurements were not collected in 2009.

Response of Wiregrass (*Aristida stricta*) Seedlings to Treatment

The recruitment of *Aristida stricta* seedlings was not significantly influenced by the rake versus non-rake subplot treatments (p = 0.2365). Even though there were no significant differences found among the subplot treatments, the rake subplots appeared to promote higher *A. stricta* seedling counts and relative differences following initial treatments versus non-rake subplots (Figures 4.4 and 4.5). The mechanical rake treatment seemed to positively influence the recruitment of wiregrass seedlings (Figure 4.5). Even though counts decreased within the mechanical mastication rake plots by the following year, counts were relatively higher than any other treatment. Non-rake units displayed mixed results for the herbicide and mechanical subplots. That is, there was no recruitment of seedlings initially following the herbicide non-rake treatment; however, the mechanical non-rake treatment seemed to encourage some seedling recruitment.

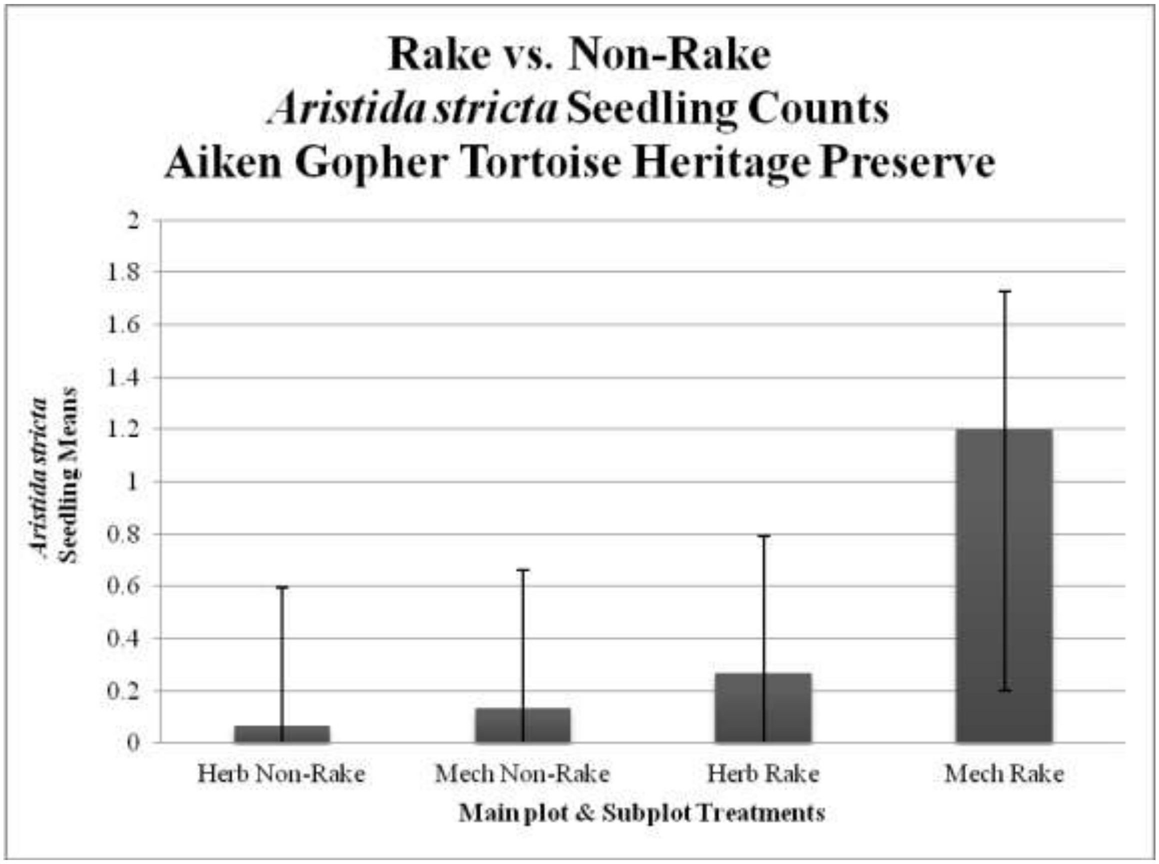

Figure 4.4. Count averages of *Aristida stricta* seedlings for rake and non-rake treatments within the Velpar® ULW and mechanical mastication treatment units at Aiken Gopher Tortoise Heritage Preserve, Aiken County, SC.

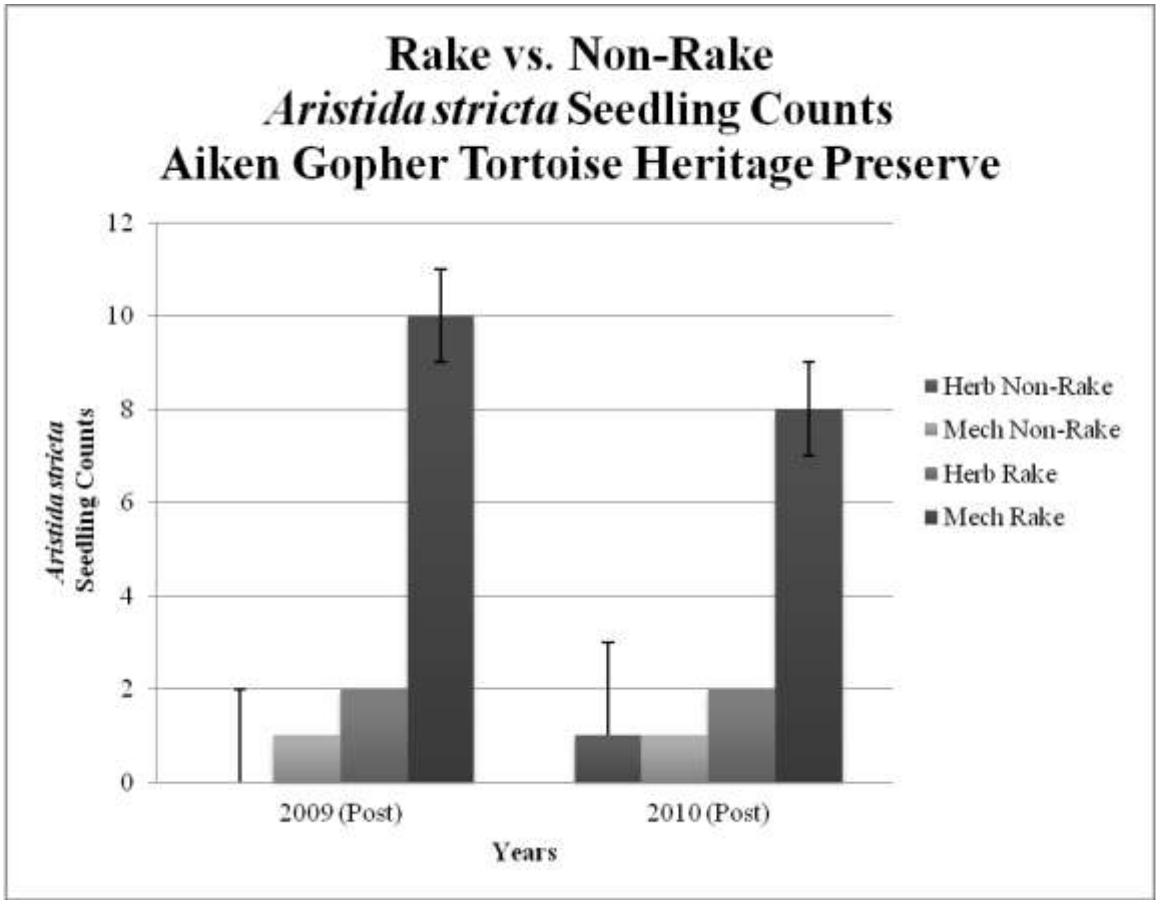

Figure 4.5. *Aristida stricta* seedling counts by Velpar® ULW and mechanical mastication main plot treatments and rake and non-rake subplot treatments at Aiken Gopher Tortoise Heritage Preserve, Aiken County, SC.

DISCUSSION

Even though the ecological and economical benefits of the longleaf pine ecosystem were realized several decades ago, the knowledge, technology and silviculture practices did not exist to restore them. With a strong and growing interest in managing and restoring longleaf pine ecosystems throughout their natural extent (Walker and Peet 1983, Noss 1989, Landers *et al.* 1995, Van Lear et al. 2005, Walker and Silletti 2006), efforts are being made to determine how to maintain the integrity, structure, function and natural processes. One area of influence that is often overlooked is the forest floor. The function of forest litter varies from site-to-site and by litter type, but generally forest floor litter sequesters nutrient availability, stabilizes the soil from extreme fluctuations in temperature and moisture, and provides a protective layer from rain penetration and erosion (Dames *et al.* 1998). While there is extensive literature that discusses litter accumulation and decomposition in temperate forests or grasslands, little research has been conducted in longleaf pine ecosystems (Hendricks *et al.* 2002). Moreover, there is little information concerning the influence alternative cultural practices such as herbicide and mechanical mastication have on the litter depth in an established xeric sandhills longleaf pine ecosystem. Scientists agree that longleaf pine ecosystems, including the embedded flora and fauna, are positively influenced via fire; however, the mechanism which drives this process is still unclear. This paper was designed to compare the influence that fire, herbicide and mechanical mastication have on the litter depth within an established (~35 year old) longleaf pine forest and evaluate whether litter accumulation mediates understory plant community vigor; more specifically, to determine how rake versus non-rake treatments impact the response of *A. stricta* seedlings within this xeric sandhills community.

Effect of Treatments on Litter Depth

While litter production is variable due to species composition, site, climate, and faunal and microbial activity (Bale 2009), literature generally suggests that it is continual throughout the year and increases with stand age (Dames *et al.* 1998, Minogue *et al.* 2007). Hendricks *et al.* (2002) reports that litter layers decompose at varying rates in less fertile sites, such as longleaf pine forests, depending on whether the litter accumulates on the soil surface or is elevated above the ground (i.e. draping from above ground vegetation). We found that litter depths decreased initially following all treatment types. Prescribed fire treatment had the greatest relative percent reduction (54%) by the end of 2010 season followed by mechanical mastication (39%) and then herbicide treatment (38%). Prescribed fire maintained the highest relative difference (28%) between the pre-treatment (2008) and 2011 post-treatment litter depth measurements, followed by mechanical mastication (7%), and then herbicide treatment (4%). Despite the fact that litter accumulation may vary from site-to-site, the rate of litter accumulation on the forest floor following the prescribed fire treatment within our study was generally consistent with literature (Bale 2009). The litter following the herbicide treatment accumulated faster than any other treatment by the end of the second post-treatment year. This could be the result of above ground biomass deteriorating and falling to the forest floor. Our findings were surprising because, in general, forest fuels build up in fire suppressed habitats (Bale 2009, Stamaugh *et al*. 2006); moreover, they decompose and mineralize at a lower rate (Brockway and Lewis 1997, Hendricks *et al.* 2002).

While decomposition rates vary across ecosystem types, they can vary from yearly environmental factors within a given system (Olson 1963, Facelli and Pickett 1991). The unexpected decreases observed following the mechanical mastication and herbicide treatments may have been influenced by either natural or anthropogenic factors or a combination. The decrease in litter depth within the mechanical mastication treatment units may be attributed to the compaction from the mastication equipment. Even though this equipment is ideal to employ within sensitive environmental areas, the operating weight is approximately 4300 kg with a ground pressure range of 1.9 to 10 psi (Windell and Bradshaw 2000, Halbrook 2006). Further impacts could have resulted from a significant snow event that occurred across the midlands of South Carolina prior to 2010 sampling period. Even though on-site measurements were not recorded, anecdotal reports estimated an average of 18 cm of snow accumulated across the county in which the study area is located. It has been reported that snow packing compresses the litter and places it in direct contact with the soil surface (Dix 1960, Knapp & Seastedt 1986), consequently increasing the rate of decay (Dix 1960, Hendricks *et al.* 2002).

It has been reported that forest floor decay is influenced by temperature and moisture conditions and by the chemical and physical properties of the litter (Prescott *et al.* 2004); moreover, soil organisms benefit from increased moisture and temperature which result from mulch being directly deposited on the forest floor (Henricks *et al.* 2002, Joint Fire Science Program 2011). By removing the midstory with herbicide or mechanical treatments, additional light was released to the forest floor which may have increased the microenvironment immediately surrounding the litter. Also, soil moisture may have temporarily increased within the herbicide and mechanical mastication treatment units due to a reduction in evapotranspiration from the midstory. Moreover, the physical properties and structure of the forest materials within the mechanical mastication treatment units were altered through the mastication process; consequently, the surface area-to-volume ratios increased (Kane 2007, Rothermel 1972, 1983) and forest material was placed on the forest floor. The midstory and soil moisture levels were not measured during this study, so I do not know if a comparison of these values would produce a different interpretation of the potential cause of influence on the litter depth.

Response of Wiregrass (*Aristida stricta*) Seedlings to Rake and Non-rake Treatments

Our study found that there were no significant differences found between the rake and non-rake treatments; however, the physical removal of the litter layer seemed to positively influence the recruitment of the wiregrass seedlings (*A. stricta*). Even though there was no significance found between rake and non-rake treatments, some interesting trends were observed. The wiregrass seedlings responded favorably within our study to removal of the midstory and the litter layer within the mechanical mastication treatment units. Unfortunately, these gains appear to be short-lived because by the end of the following year the wiregrass seedling numbers began to decline for both the rake treatments. Our study shows that competition for above-ground resources plays a critical role in the success of the *A. stricta* seed or seedling as suggested in literature (Wood

1958, Wenk 2009). This reduction in above- and below-ground competition freed abiotic site resources and created an opportunity for existing plants to grow and expand (Metlen and Fiedler 2006, Collins *et al.* 2007, Wenk 2009). On the other hand, wiregrass seedlings, documented in our study, seemed to be favored by the removal of the litter layer following the herbicide treatment. That is, the herbicide non-rake subplots indicated zero recruitment following initial treatment, however a single seedling was recorded by the end of the 2010 growing season. The midstory was not measured during this study, so I do not know if a comparison among the herbicide treatment units would show a significant above- or below-ground reduction in the woody species (i.e. *Quercus* spp.) to produce a different interpretation of the cause of impacts. By the end of the 2010 growing season, the mechanical rake treatment units yielded the highest gains and maintained the overall highest relative gains of individual wiregrass seedling counts, followed by herbicide rake treatment units, then the non-rake treatments.

MANAGEMENT IMPLICATIONS

One thing that we have learned from the past is that humans have always manipulated and altered the environments they inhabit. The demise of the natural old-growth longleaf pines that once dominated and covered more than 36 million hectares across the southeastern United States is historic proof. The alternative cultural treatments, herbicide and mechanical mastication, used in our study may provide useful conservation tools that can help land managers who wish to rapidly restore or maintain the understory of a longleaf pine forest within a well-drained xeric site in the southeastern United States, at least for the short-term.

The results from our study support our prediction that the *A. stricta* seedling counts would increase with increasing hardwood control efficacy and reduction in forest floor litter depth. However, the gains were short-lived in the mechanical mastication units and reductions began to occur by the end of the second post-treatment year. Our litter depth predictions were not supported by our data. While it was expected that the litter depths would be greatest for the mechanical mastication units, followed by the herbicide units, and then the prescribed burn units, all treatments had a reduction. Based on our study, prescribed fire produced the highest overall litter depth reduction among all three treatments; moreover, our mechanical mastication treatment along with forest floor litter removal was the best silvicultural practice that encouraged the recruitment and survival of wiregrass seedlings, at least initially. That is, wiregrass seedlings seemed to benefit from the removal of the woody midstory and the litter layer in our study. This of course can be accomplished by the use of prescribed fire; however, if there are any limitations or restrictions with its use mechanical mastication may be a viable option. However, the control of the midstory is short-lived. Based on field observations, the midstory sprouted and recovered at similar rates within the mechanical mastication and the prescribed fire units. Consequently, the use of herbicide may be the preferred option because it may provide longer control of the midstory which has been proven to benefit the herbaceous layer. Based on our study, however, the litter needs to be removed to maximize the ground layer productivity, at least for the wiregrass. The use of these alternative conservation tools is supported by numerous studies that have established the positive effects associated with their use, especially in conjunction with fire (Brockway *et al.* 1998, Provencher *et al.* 2001, Glitzenstein *et al.* 2003a, Gagnon and Jack 2004, Glitzenstein *et al.* 2006, Brockway *et al.* 2009, Freeman and Jose 2009, Schwilk *et al.* 2009, Brockway and Outcalt 2000).

One of the weaknesses of our study, and many other studies, is that it was short-term. Consequently, the repeated application of these treatments could exacerbate negative effects not accounted for in the short-term. Also, unintentionally direct or indirect cascading effects could impact ecosystem processes. Moreover, one type of treatment may not meet the needs of all species. Caution should be made when applying these modern treatments, since the impacts to the ecosystem resilience has not been documented long-term. These modern tools may be the next perturbation that will mimic stochastic events like fire and hurricanes. However, the longleaf pine ecosystem evolved under a fire regime and shifts may result from the new disturbance; consequently, close monitoring should occur following their use. While there were no non-native plants observed pre-treatment or post-treatment during the course of this study, monitoring should occur following their application. We note that our findings and recommendations are based on a short period of time and may not be the best for maintaining or restoring a longleaf pine ecosystem. A future study based on long-term measurements of litter depth and fuel types and response of the herbaceous layer might provide better understanding of the changes encountered within this and other studies.

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CHAPTER FIVE

DETERMINING WHICH SILVICULTURE METHOD PROVIDES THE OPTIMUM FORAGE FOR THE GOPHER TORTOISE (*Gopherus polyphemus* Daudin) IN AN ESTABLISHED LONGLEAF PINE (*Pinus palustris* Mill.) ECOSYSTEM AT AIKEN GOPHER TORTOISE HERITAGE PRESERVE, AIKEN COUNTY, SOUTH CAROLINA

ABSTRACT

The gopher tortoise (*Gopherus polyphemus* Daudin) is either federally or state protected throughout its natural range. Habitat loss and poor habitat management are the predominant threats to the gopher tortoise and associated species. With an increase in wildland-urban interface and amplified difficulties using prescribed fire, we assessed the effectiveness of alternative treatments, such as herbicide and mechanical mastication, for maximizing the productivity of suitable habitat as well as desirable flora forage for species of concern, like the gopher tortoise. We reviewed the available literature on gopher tortoise forage plants with medium (M), high (H), and very high (VH) forage values. We compared this literature to silviculture treatments applied at the Aiken Gopher Tortoise Heritage Preserve, Aiken County, South Carolina. The study site includes eighteen approximately equal-sized treatment units (0.405 ha) and three commonly used silviculture treatments (prescribed fire, herbicide, and mechanical mastication). Our study examined how treating the woody midstory of a longleaf pine forest with each of these treatments would affect the response of preferred (M = medium, H = high, and VH = very high) gopher tortoise understory flora species found in a mature longleaf pine forest. We installed a randomized complete block design (RCBD) to test

the effects of prescribed burning, the broadcast application of granular hexazinone (1.26 kg a.i./ha), and mechanical mastication on the understory herbaceous layer within each 0.405 ha treatment unit. No significant differences were determined between treatment types for the VH ($p = 0.0581$) or M ($p = 0.3486$) ranking forage values. Treatment differences were determined for the H value forage in both post-treatment years (2008: $p = 0.0457$; 2009: $p = 0.0020$). While there were mixed results across each treatment, no significant differences were observed for the prescribed fire treatment units throughout the study. The prescribed fire units yielded positive increases across all preferred gopher tortoise forage initially following treatment and maintained positive gains for the VH and M usage flora species throughout the study. The herbicide treatment caused significant decreases for the VH and H gopher tortoise forage species during both post-treatment years. By the end of the 2009 growing season, the VH and H valued flora species in the herbicide treatment units decreased at a rate of 25.9% and 30.4% respectively compared to pre-treatment levels. Mechanical mastication treatment produced some gains for the VH and M species initially following treatment; however, these were short-lived and quickly fell below pre-treatment levels by the end of the 2009 growing season. Results from this study suggest that prescribed fire treatment produces the highest percent of preferred gopher tortoise flora species compared to herbicide and mechanical mastication treatments. Prescribed fire was the only silviculture practice that produced positive gains by the end of the study. However, in areas that prescribed fire is restricted, our study shows that mechanical mastication may be the most viable alternative silviculture tool available to promote desirable gopher tortoise forage, at least in the short-term.

Keywords: Gopher tortoise; *Gopherus polyphemus*; *Pinus palustris*; Herbicide; Mechanical manipulation; Hardwood reduction treatments; Alternative silviculture practice; Gopher tortoise forage; Plant species diversity

INTRODUCTION

Gopherus polyphemus

The gopher tortoise (*Gopherus polyphemus* Daudin) is one of four tortoises found in North America (Auffenberg and Franz 1982, Diemer 1986, Ashton and Ashton 2008). The range of the gopher tortoise extends from the southwestern region of South Carolina, south through Florida, west across the southern piedmont of Georgia, Alabama, and Mississippi, and finally outspreads into the southeastern portion of Louisiana (Figure 5.1; Diemer 1986, Ashton and Ashton 2008, Conant and Collins 1991). Gopher tortoises are fairly large, terrestrial, herbivorous scavenger turtles (Garner and Landers 1981, Jose *et al.* 2006). Adults (>15 years old) have carapace lengths that range from 18 cm to 39 cm and can attain a maximum weight of around 12 kg (Appendix 5.1; Diemer 1986, Tuberville 1998, Ashton and Ashton 2008). The carapace lengths for neonates and hatchlings (age 0 to 1), yearlings (age 1 to 2), juveniles (age 2 to 4), and subadults (age 4 to maturity) range between 3 cm to 18 cm with weights varying (Appendix 5.1; Ashton and Ashton 2008, Tuberville *et al.* 2009). Gopher tortoises are relatively long-lived turtles (50-60 years) with a deferred sexual maturity and low fecundity (Landers 1980, Diemer 1986, Ernest *et al.* 1994). Sexual maturity is generally reached between 10-21 years (Landers *et al.* 1982, Iverson 1980, Diemer 1986, Tuberville 1998); however, several intrinsic and extrinsic factors can influence this development. Mating generally occurs in spring and nest construction generally takes 15 to 30 days; however, this differs geographically and depends on habitat quality (Ashton and Ashton 2004, 2008). Incubation length varies latitudinally ranging from 80 days (northern Florida) to 110 days

(South Carolina; Diemer 1986). The number of eggs laid varies from 3.8 (Wright 1982) to 8.9 (Burke 1987) across the gopher tortoises' range with the lowest numbers being documented in the northern region (Ashton and Ashton 2008). Survivorship is often very low due to nest depredation. Landers *et al.* (1980) reported that nest depredation occurs within a few weeks of eggs being deposited; they estimated that 87% were depredated and that there would be only one successful clutch once every 10 years. Tuberville *et al.* (2009) estimated a 96% annual mortality rate for hatchlings between the ages of 0 to 1. During Wright's (1982) two year study, he estimated that 74% of eggs were destroyed by predators. While certain species may have greater impacts than others, eggs and hatchlings can fall prey to a variety of mammalian, avian and ophidian predators. More recently in South Carolina, canids (i.e. domestic-yard-dogs and coyotes) have begun to negatively impact the adult age class of the tortoise (per. observation).

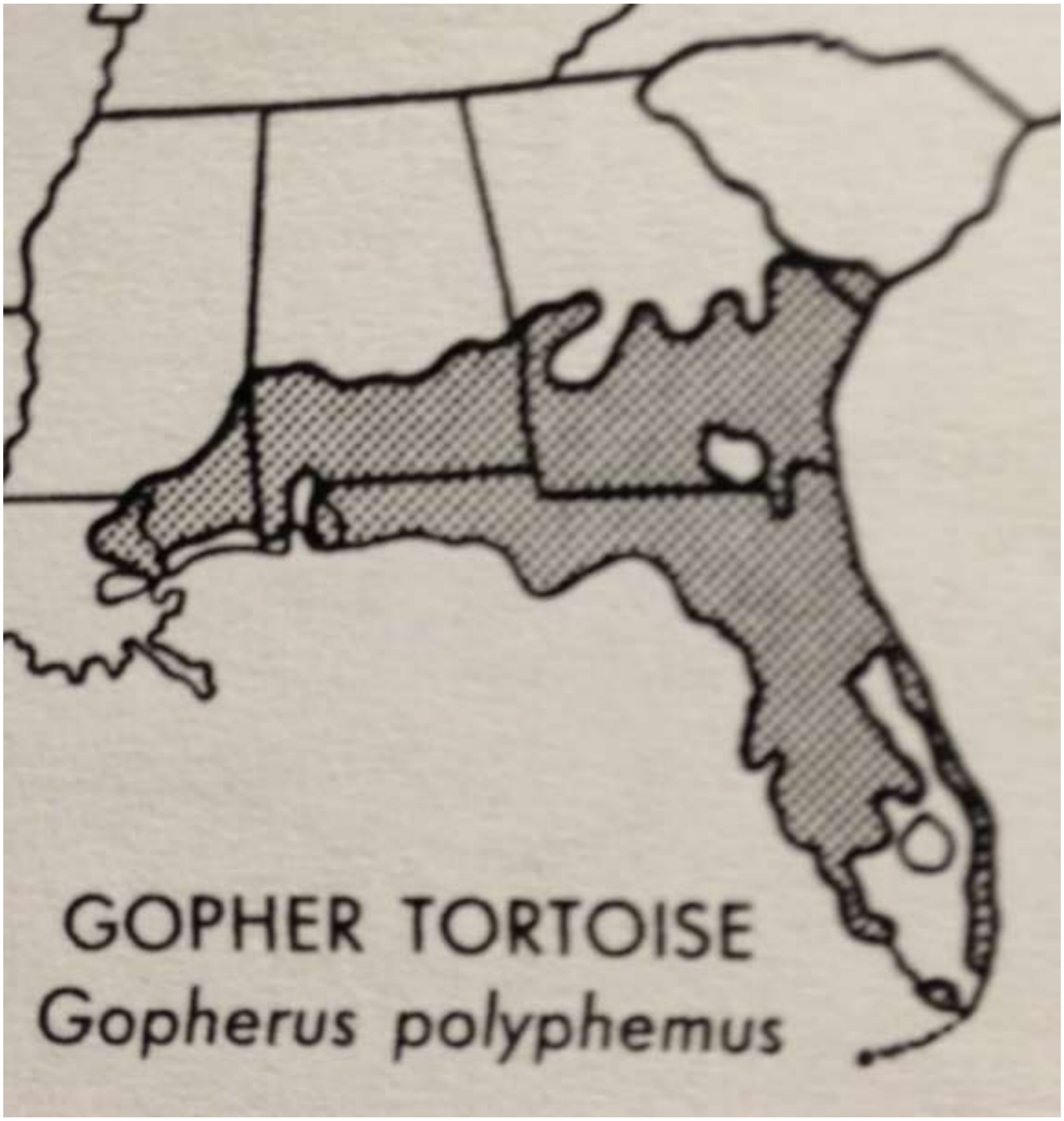

Figure 5.1. *Gopherus polyphemus* range map (Conant and Collins 1991).

Gopher tortoises are generally associated with upland habitats with deep, well-drained sandy soils with a diverse vegetative understory (Diemer 1986; Mushinsky *et al.* 2006). The home range of the gopher tortoise tends to vary based on age class, season, and social interactions (McRae *et al.* 1981, Ashton & Ashton 2008). Smith (1992) and Gourley (1969) report that the gopher tortoises' home range can vary from 0.002 to 3.14 hectares. Diemer (1992) reports a mean home range of 0.88 hectares; however, ranges varied between adult males (0.31 ha) and females (0.05 ha). Even though terrain and habitat types can influence the home range of the gopher tortoise, Auffenberg and Iverson (1979) report that there is a direct correlation between the size of the home range and the quality of the habitat. MacDonald and Mushinsky (1988) found that the diet of gopher tortoises in a sandhills community in west-central Florida consisted of the dominant herbaceous plant species found within the ground layer; with the most common genus identified was *Aristida*, and the most common family was Poaceae. However, the species selection was age dependent. Juveniles typically consume fewer species with defense mechanisms such as *Rubus* spp. or *Cnidoscolus* spp. Garner and Landers (1981) cited that the available forage positively correlated with gopher tortoise density in an area and influenced the carrying capacity. On the contrary, Campbell and Christman (1982) suggest that gopher tortoises are not dependent on a single vegetative plant community, but rather to the physical characteristics of the habitat, such as low growing vegetation, water table levels, loose soil for burrow construction, and adequate sunlight for basking and nesting (Hallinan 1923, Landers 1980, Diemer 1986). While physical characteristics and vegetative availability seem to influence habitat use by the gopher tortoise, both seasonal and annual climatic variation may also affect utilization (Diemer 1986).

The burrow is where the gopher tortoise spends much of its time (Tuberville 1998), especially during estivation or brumation. The gopher tortoise is diurnal and is seldom seen outside the safety of its burrow at night (Tuberville 1998). However, Diemer (1986) reports that tortoises in Florida have been documented utilizing shallow depressions due to barriers created by shallow limestone bedrock and the mild temperatures of the region. Burrows can extend up to 14.5 m (48 ft) long and 3 m (9.8 ft) deep (Jose *et al.* 2006) and end with a well-defined chamber (Ashton and Ashton 2008). It has been reported that the longest burrow recorded occurred within an improved pasture in Marion County, Florida and measured 20.5 m (67 ft.) long and 5.7 m (21 ft) deep (Ashton and Ashton 2008). The compass orientation of the burrow is considered to be random (McCoy *et al.* 1993). Ashton and Ashton (2008) report that no one has defined the criteria that tortoises use to dig their burrows other than the resistance of the underlying material and the influence of the water table (Hallinan 1923, Young and Goff 1939, Diemer 1986). The burrow provides protection from extreme environmental elements and predators. The number of burrows excavated and utilized varies by gopher tortoise, gender and age, geography, season, and habitat quality and availability (Breininger *et al.* 1991, Diemer 1992, Tuberville 1998, Styrsky *et al.* 2010). Generally, burrows are occupied by an individual gopher tortoise; however, a burrow can be utilized by more than one tortoise (Tuberville 1998). Abandoned burrows may become re-occupied. Because gopher tortoises and their burrows, active and inactive, can persist for decades and provide a refuge or microenvironments for many organisms, they are classified as a keystone species (Guyer and Bailey 1993, Means 2006). It has been cited that more than 60 vertebrate and more than 300 invertebrate species seek refuge in gopher tortoise burrows (Young and Goff 1939, Witz and Palmer 1991, Guyer and Bailey 1993, Means 2006, Florida Fish and Wildlife Conservation Commission 2007, Ashton and Ashton 2008). The following are some examples of such species: eastern indigo snake (*Drymarchon couperi*), gopher frog (*Rana capito*), five-lined skink (*Eumeces inexpectatus*), Mole skink (*Eumeces egregius*), hognose snakes (*Heterodon simus* and H. *platirhinos*), southern black racer (*Coluber constrictor*), southern toad (*Bufo terrestris*), burrowing owl (*Athene cunicularia*), and Florida mouse (*Podomys floridanus*). Moreover, there are a variety of invertebrates such as beetles, crickets, and mites that are co-inhabitants within the burrows and depend on the gopher tortoise for food (i.e. consumption of the tortoises feces). Many of these species are either state or federally protected (Guyer and Bailey 1993, Innes 2009). Both anecdotal reports and literature suggest that a decline in the gopher tortoise population could adversely impact many of the organisms that depend on them.

The gopher tortoise is federally threatened wherever found west of the Mobile and Tombigbee rivers in Alabama, Mississippi, and Louisiana; it is state listed as threatened/endangered in Alabama, Georgia, Florida, and South Carolina (U.S. Fish and Wildlife Service 2013). In 2011, the federal listing for the eastern portion of the gopher tortoise was elevated to candidate status (Federal Register 2009; 50 CFR § 17). It has been estimated that the gopher tortoise population has been reduced by 80% since the late

1800s (Diemer 1986, Ashton and Ashton 2008). While the gopher tortoise has been a species of concern and has prompted research and conservation programs in several states, the population is at risk because of an expanding human population and habitat fragmentation and reduction.

Study Purpose

While much of the gopher tortoises habitat was historically maintained by frequent natural and anthropogenic fires (Komarek 1974, DeVivo 1991, Denevan 1992, Robbins and Myers 1992, Landers and Boyer 1999, Carroll *et al.* 2002, Van Lear *et al.* 2005), today there are times when using fire as a management tool is difficult. This is particularly true around wildland-urban interfaces (WUI; Davis 1987). Despite the clear desirability and positive benefits of using prescribed fire as a conservation management tool, land mangers today are challenged with the task of duplicating the natural processes and structure of an ecosystem while at the same time avoiding impacts to adjacent landowners and communities. When fire is suppressed in pyroclimax communities and no other silviculture treatments are applied, the midstory often becomes invaded with a dense thicket of undesirable and often unmerchantable scrubby trees; these trees ultimately alter and suppress the herbaceous layer, modify available fuels, affect nutrient cycling, and negatively influence the overall health and sustainability of the ecosystem (Waldrop *et al.* 1989, Brockway and Lewis 1997, Harrod *et al.* 1999, Rummer *et al.* 1999, Brockway *et al.* 2009).

While some literature identifying the preferred forage of gopher tortoises exists, it typically does not identify specific individual species, nor does it rank the forage value for gopher tortoises (Hallinan 1923, Garner and Landers 1981, MacDonald and Mushinsky 1988). For example, Hallinan (1923) identified grasses as the preferred food source for the gopher tortoise after a single stomach and burrow examination. Garner and Landers (1981) suggest that legumes are the most important forage for gopher tortoises. MacDonald and Mushinsky (1988) report that specific genera within certain families have higher forage value based on scat analysis, foraging observation, and habitat. For example, species found in the family Poaceae make up 98.4% of the scat found during their study; however, specific species were not identified. Innes (2009) states that between 70-80% of the tortoises' diet contains grasses; however, a single tortoise may consume up to 400 plant species. Moreover, Innes (2009) identifies that there are >1,100 plant species that can serve as forage for the gopher tortoise across its range. According to Ashton and Ashton (2008), the ranking or desirability of a species varies within each designated genera. Consequently, the vegetative data of this study was compared to Ashton and Ashton (2008) "Genera and Species Used by Gopher Tortoises as Forage" list. Their list ranks the level of usage for flora species consumed by gopher tortoises. Their designation of each species was based on literature and direct observation. Usage levels were assigned as L = low, M = medium, H = high, and VH = very high. However, Ashton and Ashton (2008) suggest that these levels are not applicable in all habitats or in all situations. Other species such as wetland species could become more important during times of drought. Also, rare species may not occur in high enough numbers to have a significant impact on the forage availability of the gopher tortoise. They also suggest that their list is not all inclusive because nomenclature and scientific names can change. For these reasons some of the species identified during this study could not be ranked against the Ashton and Ashton (2008) list. However, these individual flora species were listed for future reference and assigned a no rank (NR) designation on the tables found in Appendix 5.2, 5.3, and 5.4.

Prescribed fire promotes vegetative diversity, favorable habitat, and can ultimately influence the carrying capacity and potentially define the home range of the gopher tortoise. With recent concerns over losing prescribed fire as a conservation management tool, we were prompted to investigate the effectiveness and usefulness of alternative silviculture practices such as herbicide and mechanical mastication to mimic ecological disturbances of these preferred ecosystems. While literature clearly identifies which types of forage are favored by tortoises throughout the year and across its life span, they do not provide information concerning which type of silviculture practice can be used to maximize the above-ground biomass of flora species favored by gopher tortoises.

Study Goals

Our study examined how treating the woody midstory of an established (~35 year old) longleaf pine forest with prescribed fire, herbicide, and mechanical mastication would affect the response of preferred (M = medium, H = high, and VH = Very High) gopher tortoise understory flora species compared to literature. We predict that the understory herbaceous layer will be positively stimulated with an increasing hardwood control efficacy, consequently providing improved quantities and quality of desirable gopher tortoise forage species. In other words, fire and mechanical mastication treatments may initially provide higher quantities of preferred flora species, but these levels are expected to be short-lived because of the quick recovery of the midstory and increased competition. Consequently, we anticipate that the understory herbaceous species found within the herbicide treatment units will be higher in quantity and promote a higher number of desirable flora species preferred by the gopher tortoise by the end of the study.

MATERIALS AND METHODS

Study Site

This study was conducted at Aiken Gopher Tortoise Heritage Preserve (AGTHP), Aiken County, South Carolina (Chapter 3--Figure 3.1 and Figure 5.2). The South Carolina Department of Natural Resources began purchasing tracts of land in this area of Aiken County in the late 1990s and embarked on managing this heritage preserve primarily for the gopher tortoise (*Gopherus polyphemus* Daudin). The preserve consists of approximately 656 hectare dominated by upland xeric longleaf pine-turkey oak habitat (Figure 5.2). The soils found across the property are a mix of Lakeland, Troup, and Fuquay (USDA 1985). The South Carolina Department of Natural Resources used prescribed fire as the primary management tool to promote a desirable herbaceous layer across the entire heritage preserve since the late 1990s. Prescribed burns have been conducted at AGTHP on a biennial or as-needed basis in order to suppress oak species and promote a diverse pyrophytic herbaceous ground layer specifically for gopher tortoises. The last prescribed burns were conducted across the treatment units in March & April 2005.

Treatment Units

This study contains eighteen approximately equal-sized treatment units and three silviculture treatments as described in Chapter 3. No significant differences were found among the basal area or the visible light for each treatment unit as reported in Chapter 3. The three silviculture treatments consist of growing season burns, broadcast application of DuPont™ Velpar® ULW [3-cyclohexyl=6-(dimethylamino)-1-methy-1,5-triazine-2,4(1H,3H)-dione] at a rate of 1.26 kg a.i./ha, and midstory mechanical mastication as described in Chapter 3—*Experimental Design.* The treatment units contain the same 20 x 50 meter sample plots as described in Chapter 3—*Experimental Design*.

The overstory of the treatment units is dominated by approximately 35 year old longleaf pine with a diameter at breast height (dbh) that ranges from 18.03 to 27.43 cm and an average basal area of 12 m^2/ha. The understory contains a diverse native herbaceous ground layer including wiregrass (*Aristida stricta* Michx.) and a variety of bluestems (*Andropogon* spp.). The midstory is made up of scrub shrubs dominated by oaks (*Quercus* spp.).

Individual flora species counts were not conducted; however, tallies were made based on the occurrence of each species identified within each nested corner and/or each 10 m^2 area located in each intensive module per treatment unit. Each time a species was encountered within a nested 3.16 m^2 corner (depth 2) or 10 m^2 intensive module (depth 1) it was assigned a single point (i.e. 1). The maximum number of points that a single species could receive per treatment unit was eight (8) for a sum total of forty-eight (48) for each silviculture treatment (2 nested corners/intensive module x 4 intensive modules/treatment unit x 6 treatment units = 48; Figure 3.3). These values were then summed for each level of usage by the gopher tortoise (Ashton and Ashton 2008). Since the highest quality of habitat is desired for the gopher tortoise at Aiken Gopher Tortoise Heritage Preserve and for management purposes, we only analyzed flora species that ranked medium (M), high (H), or very high (VH) values.

Statistical analysis of the treatment effect, time effect and treatment and time interaction for the flora usage sum totals were completed using the mixed-model analysis of variance (PROC GLIMMIX) with a random residual statement to account for repeated measures throughout the study in SAS statistical software (2010; version 9.2; SAS Institute, Inc., Cary, NC). Unless otherwise specified, all levels of significance are based on $\alpha = 0.05$.

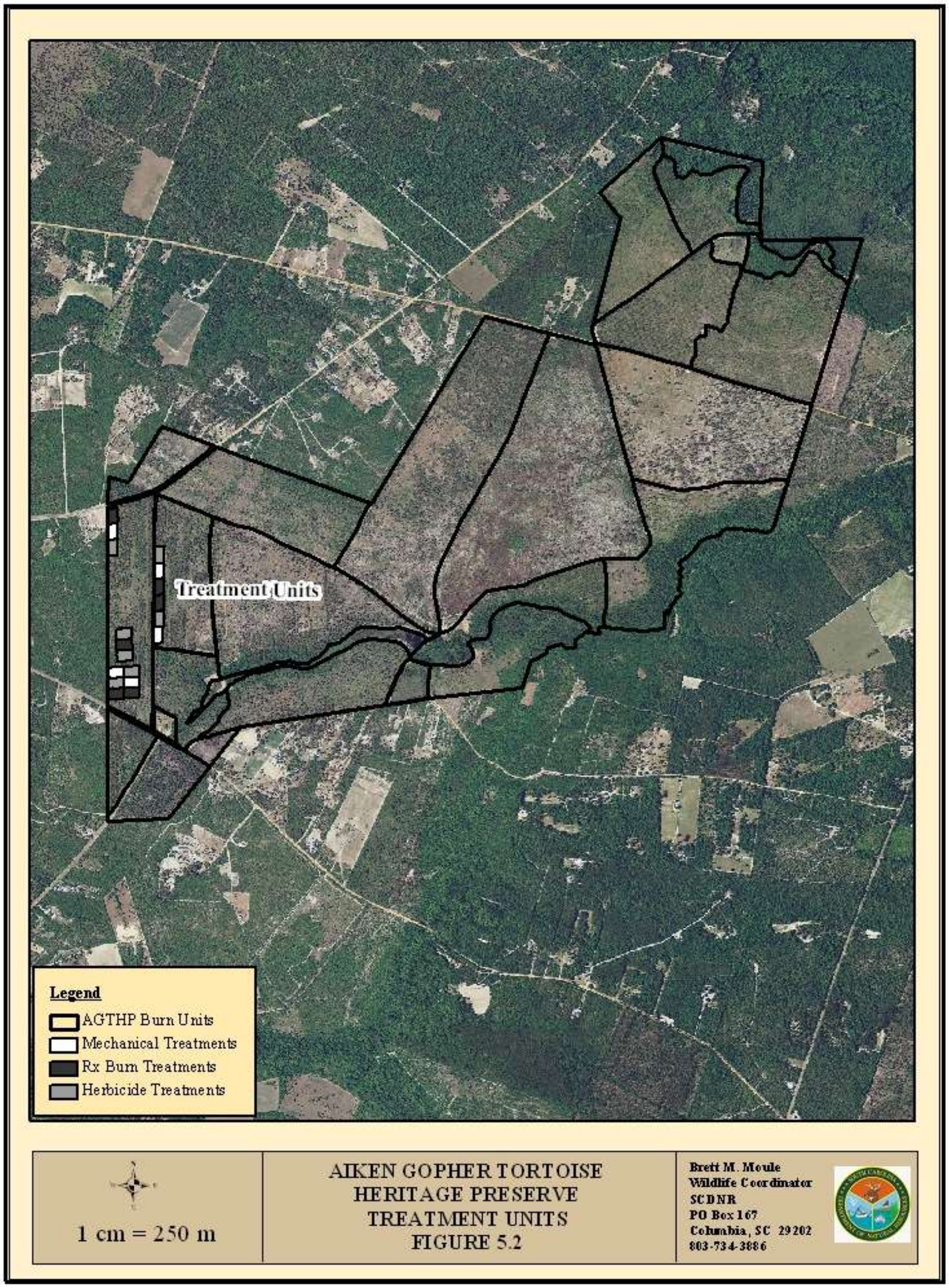

Figure 5.2. Treatment units at Aiken Gopher Tortoise Heritage Preserve, Aiken County, SC.

RESULTS

Understory Herbaceous Response to Silviculture Treatments

Prescribed fire treatment generated a net gain of 5 species when all three forage values were combined, mechanical mastication treatment had a net loss of 32 species, and herbicide treatment had a net loss of 103 (Table 5.1).

While there were no significant treatment differences determined for the assigned flora usage ranking levels VH (2008: $p = 0.0893$; 2009: $p = 0.3251$) or M (2008: $p = 0.7183$; 2009: $p = 0.6329$) for either post-treatment year, significant differences were recorded for the H rank level forage (2008: 0.0457; 2009: $p = 0.0020$).

The prescribed fire treatment units had initial increases for all forage values and did not indicate any significant differences over time; however, non-significant decreases ($p = 0.0677$) were observed by the end of the second growing season (Tables 5.1 and 5.2; Figures 5.3, 5.4, and 5.5).

Initial decreases were noted for all forage levels within the herbicide treatment units (Tables 5.1 and 5.2; Figures 5.3, 5.4, and 5.5). Moreover, there were significant initial decreases for the VH (2008: $p = 0.0420$) and the H (2008: $p = 0.0003$) forage usage levels following treatment (Table 5.2). While there was a reduction in species documented for the M usage level initially across the herbicide treatment units, no significant differences were documented (2008: $p = 0.1447$).

Very high and M usage forage species increased following mechanical mastication treatment by the end of the 2008 growing season; however, all usage values dropped below pre-treatment levels by the end of the 2009 growing season (Tables 5.1

and 5.2; Figures 5.3, 5.4, and 5.5). The H usage forage species steadily decreased over time, consequently causing a significant difference between the pre-treatment and 2009 post-treatment year ($p = 0.0344$). While the number of NRs varied from year-to-year, they made up a relatively low percentage of the herbaceous layer ranging from 11.7% to 18.9%.

Table 5.1. Sum total of species per treatment type, level of usage by gopher tortoises (Ashton and Ashton 2008), and pre-treatment and post-treatment years.

Treatment type Forage usage rank	2007*	2008**	2009**
Prescribed Fire			
Very high	92	107	93
High	126	135	119
Medium	181	203	192
Herbicide			
Very high	112	92	83
High	138	94	96
Medium	259	231	227
Mechanical			
Very high	117	134	113
High	114	105	89
Medium	229	243	226

*Pre-treatment year **Post-treatment year.

Table 5.2. Forage values by treatment and pre-treatment and post-treatment years. Means are followed by standard error in parenthesis. The same lower-case letters indicate no significant difference within rows at $\alpha = 0.05$.

Forage usage rank Treatment type	2007*	2008**	2009**
Very high			
Prescribed Fire	15.33^{a} (2.00)	17.83^{a} (2.22)	15.50^{a} (2.38)
Herbicide	18.67^{a} (2.00)	15.33^{b} (2.22)	13.83^{b} (2.38)
Mechanical	19.50^{ab} (2.00)	22.33^{a} (2.22)	18.83^{b} (2.38)
High			
Prescribed Fire	21.00^{a} (2.61)	22.50^{a} (2.39)	19.83^{a} (1.74)
Herbicide	23.00^{a} (2.61)	15.67^{b} (2.39)	16.00^{b} (1.74)
Mechanical	19.00^{a} (2.61)	17.50^{ab} (2.39)	14.67^{b}(1.74)
Medium			
Prescribed Fire	30.17^{a} (4.75)	33.83^{a} (5.88)	32.17^{a} (4.66)
Herbicide	43.17^{a} (4.75)	38.33^{a} (5.88)	37.67^{a} (4.66)
Mechanical	38.17^{a} (4.75)	40.50^{a} (5.88)	37.67^{a} (4.66)

*Pre-treatment year **Post-treatment year. Forage rank based on level of usage (Ashton and Ashton 2008).

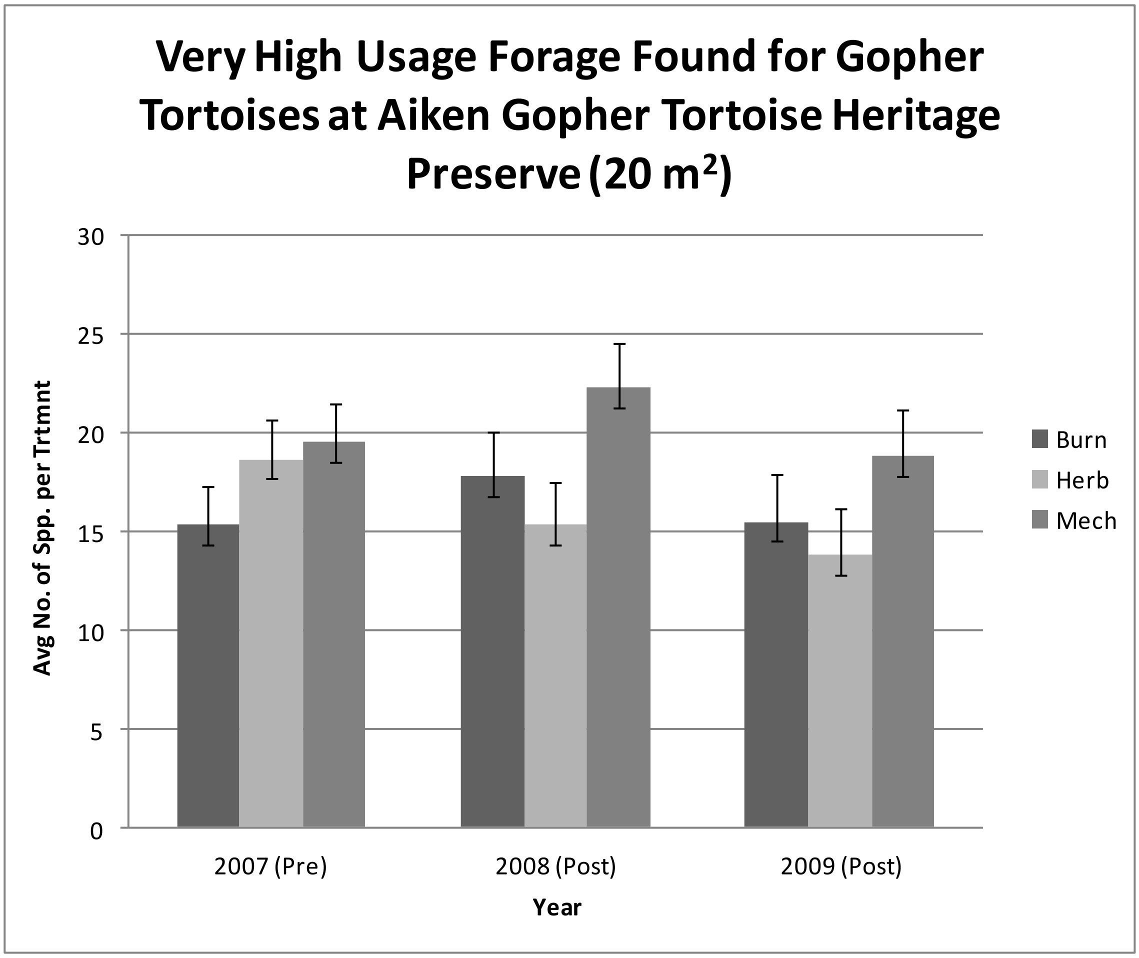

Figure 5.3. Sum totals of very high (VH) ranked gopher tortoise forage found at Aiken Gopher Tortoise Heritage Preserve. Ranking is based on level of usage (Ashton and Ashton 2008).

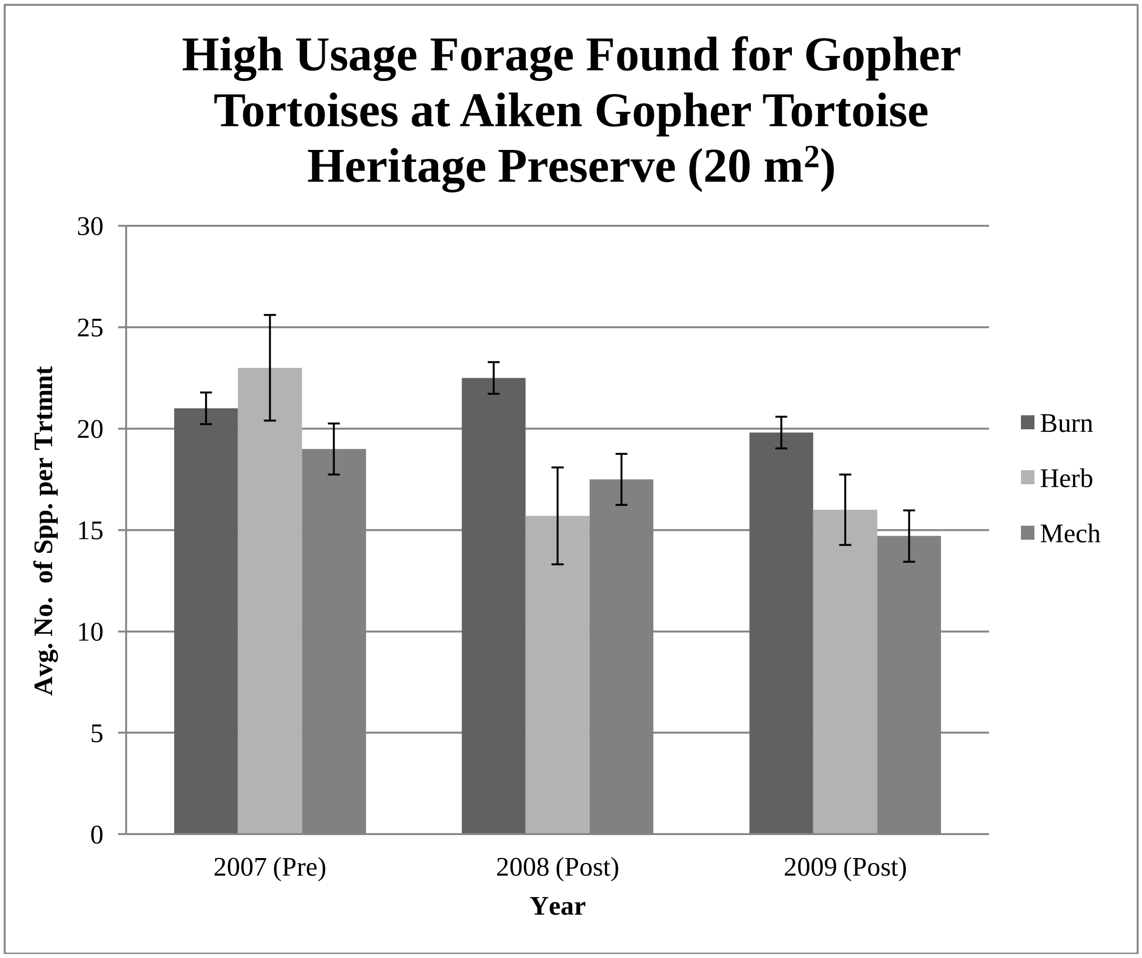

Figure 5.4. Sum totals of high (H) ranked gopher tortoise forage found at Aiken Gopher Tortoise Heritage Preserve. Ranking is based on level of usage (Ashton and Ashton 2008).

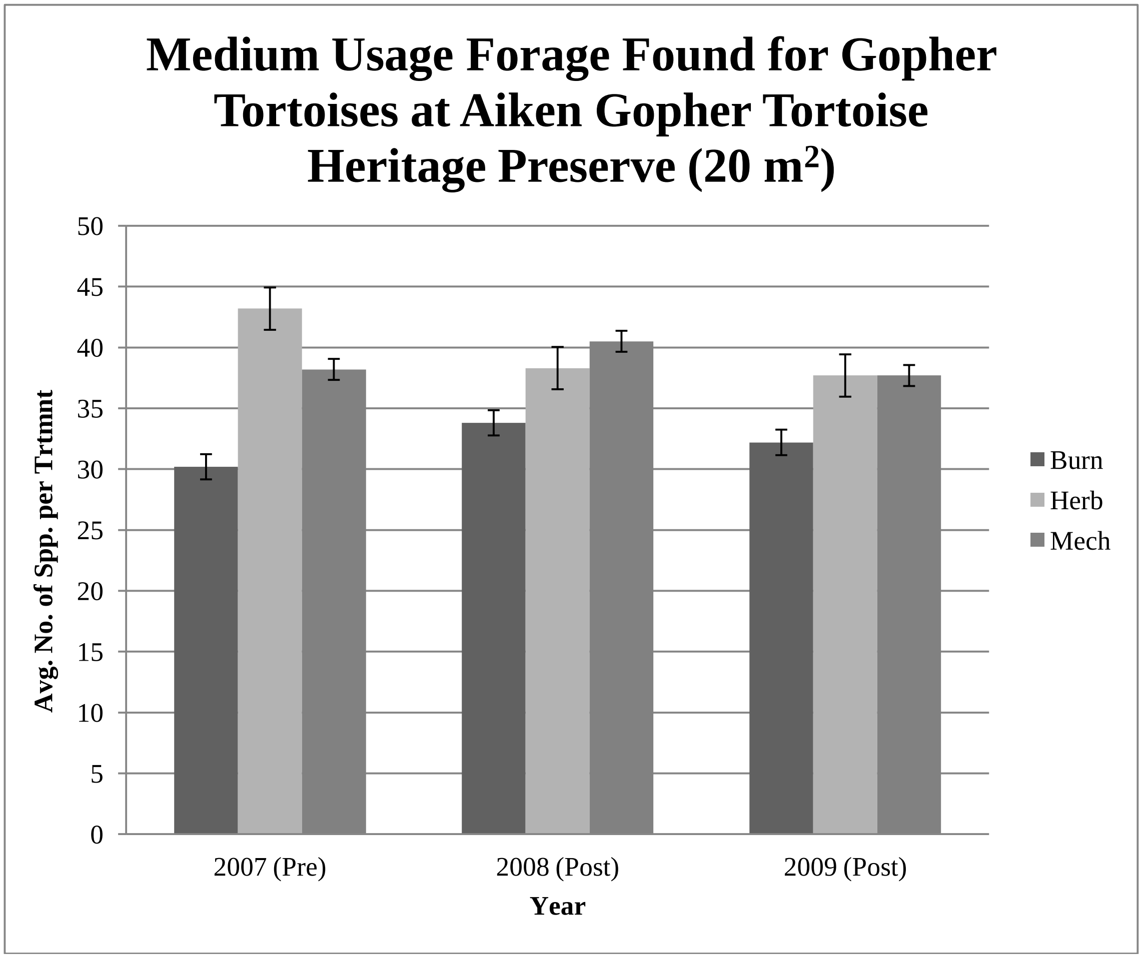

Figure 5.5. Sum totals of medium (M) ranked gopher tortoise forage found at Aiken Gopher Tortoise Heritage Preserve. Ranking is based on level of usage (Ashton and Ashton 2008).

DISCUSSION

Literature suggests that there is a varying degree of influence that the physical features and vegetative community of an ecosystem can have on its use by gopher tortoises. It is apparent that gopher tortoises will not survive and neither will the organisms that depend on them or their burrows unless the appropriate habitat is provided and perpetuated. Even though the type of flora species consumed by the gopher tortoise varies across its life span, it is clear that the level of usage will vary (Ashton and Ashton 2008). Historically it has been demonstrated that ecological disturbances (i.e. fire) positively influence the understory species diversity, especially in longleaf pine forests (Kush *et al.* 1999). As the human population continues to expand and the wildland-urban interface (WUI) increases, many ecosystems and their embedded flora and fauna species are at risk of being severely impacted or extirpated (Brockway *et al.* 2005). This could occur through ecological disturbance restrictions (i.e. prescribed fire), fragmentation, or land conversion (forest or urbanization). Consequently, it is essential to explore alternative silviculture tools that can enable land managers to maximize ecosystem potential within a limited amount of space without negatively influencing adjacent lands or neighbors. Whether it is through the use of prescribed fire, herbicide treatment, mechanical mastication, or some combination of these, many ecosystems are now and will forever be dependent upon land managers favoring ecological function and defining desired trajectories. This study was designed to compare the influence that fire, herbicide and mechanical mastication treatments have on the response of the understory herbaceous layer of an established (~35 year old) longleaf pine forest. More specifically, this study assessed which treatment promotes the greatest number of usage flora species for the gopher tortoise within a xeric sandhills community.

Vegetative Flora Forage Quality

Our study found that there were no significant differences between the treatment types for the VH and M gopher tortoise forage values; however, there were significant differences observed for the H valued flora species. Each treatment had a differing degree of impact on each level (M, H, VH) of preferred gopher tortoise forage.

Prescribed fire positively influenced the VH (+1.1%) and the M (+6%) species causing an increase compared to pre-treatment levels by the end of the 2009 growing season. However, prescribed fire treatment also caused a 6% decrease in the H valued forage species the same year.

By the end of this study, all three gopher tortoise forage values were below pre-treatment levels for both the herbicide and mechanical mastication treatments. However, mechanical mastication caused the least amount of reductions across all identified flora usage levels compared to the herbicide treatment.

The herbicide treatment caused an alarming 25.9% decrease in the VH species and a 30.4% decrease in the H species recorded by the end of the 2009 growing season. This was surprising because as discussed in Chapter 3, the species richness, diversity indices, and the evenness of the herbaceous layer began to recover by the end of the 2009 sampling period for the herbicide treatment units. The positive responses observed may have been the result of a greater number of lower quality flora species responding to this ecological disturbance type. There is no recovery indicated for any of the forage levels identified in this study for the herbicide treatment units.

By the end of this study, mechanical mastication units favored the highest number of VH species (113), followed by prescribed fire units (93), and then herbicide treatment units (83). However, prescribed fire treatment units favored the highest number of H species (119), followed by herbicide treatment units (96), and then mechanical mastication treatment units (89). The herbicide treatment favored the highest number of M usage species (227), followed by mechanical mastication (226), and then prescribed fire (192). Results from this study suggest that prescribed fire treatment produces the highest percent of preferred gopher tortoise flora species compared to herbicide and mechanical mastication treatments. And the prescribed fire treatment was the only silviculture practice that produced positive gains by the end of the study. However, in areas that prescribed fire is restricted, our study shows that mechanical mastication may be the most viable alternative silviculture tool used to promote desirable gopher tortoise forage.

The NR species only made up a relatively small percent of the total sampled species; if ranked and assigned a gopher tortoise usage value, they could influence the overall trend and interpretation of this study. Even though within treatment trends surfaced concerning how each treatment influenced the forage quality, extreme weather patterns could have influenced the response of many of these flora species. During the time of this study (2007-2010), South Carolina experienced several severe drought years which undoubtedly had negative impacts on the understory herbaceous layer. Slight declines observed during this study do not necessarily indicate long-term loss of flora species or a reduction in diversity.

MANAGEMENT IMPLICATIONS

Human expansion is unavoidable, as is the wildland-urban interface. Researchers have documented the negative impacts humans can have on ecosystems and the embedded flora and fauna species within, both directly and indirectly. In the past, endemic species found within the gopher tortoises' preferred habitat relied upon ecological disturbances to perpetuate their competitive success and survival. However, there are times when historically accepted and beneficial silviculture conservation practices, such as fire, are not feasible. While natural disturbances (i.e. wild fires) can occur today, they are typically suppressed quickly and restricted from reaching their full "historic" potential. Therefore, their benefits are never realized. The alternative cultural treatments, herbicide and mechanical mastication, used in our study may provide useful surrogate conservation tools to help land managers rapidly restore or maintain the understory herbaceous layer of a once fire-dependent ecosystem, at least for the short-term.

The data gathered during our study did not support our prediction that higher valued flora (VH, H; Appendices 5.2-5.4) species would be promoted by an increased hardwood control efficacy. In fact, just the opposite occurred. Prescribed fire treatment generated the only positive gains when all three forage values were combined, while herbicide and mechanical mastication treatments caused decreases. While herbicide may provide long-term control of the midstory compared to prescribed fire and mechanical mastication treatments, it is uncertain at what cost. Even though the mechanical mastication treatment produced higher preferred species than the herbicide and prescribed fire treatments, this site has a history of frequent prescribed fires and the species numbers recorded for this treatment could decrease in time as the litter depth increases across the study area.

Since this study was a short-term study, the long-term positives and negatives have not been identified with the use of the proposed alternative conservation treatments. Caution should be made when applying modern treatments since impacts to the ecosystem's resilience have not been documented long-term. Consequently, the repeated application of these treatments could exacerbate negative effects not accounted for in the short-term. Moreover, since many of the habitats that the gopher tortoise occupies were shaped by fire, shifts may result from the new disturbances. Consequently, long-term monitoring programs should be established concurrently with the use of any of the modern conservation tools. We note that our findings and recommendations are based on a short period of time and may not be the best for maintaining the understory herbaceous layer for the maximum preferred forage for gopher tortoises. A future study based on long-term measurements of the herbaceous layer and its response to unnatural alternative disturbances such as herbicide and mechanical mastication may provide a better understanding of the changes encountered within this and other studies.

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CHAPTER SIX

GENERAL CONCLUSIONS AND RECOMMENDATIONS

It is clear that longleaf pine ecosystems evolved and benefit from land disturbances, especially fire. Moreover, the embedded flora and fauna species of longleaf pine ecosystems are also dependent upon these disturbances. With an increasing interest in restoring longleaf pine ecosystems throughout their natural extent and an increasing and expanding human population and development, the wildland-urban interface is unavoidable. Consequently, it is essential that alternative silviculture tools such as herbicide and mechanical mastication are evaluated to determine whether they can be used as surrogates for fire. Our study attempted to assess the effects that silviculture treatments such as Velpar® ULW (hexazinone [3-cyclohexyl=6-(dimethylamino)-1-methy-1,,5-triazine-2,4(1H,3H)-dione) and mechanical mastication have within an established upland xeric sandhills longleaf pine community. The following conclusions and recommendations are based on data gathered from the understory herbaceous layer (<1.5 m) from a forest dominated by approximately 35-year-old longleaf pine located within the property boundaries of Aiken Gopher Tortoise Heritage Preserve, Aiken County, South Carolina during a five year period (2007-2011). The overstory basal area ranged between 7 to 17 m^2/ha and the soils were a mix of deep, marine-deposited, relatively sterile, well-drained Lakeland, Troup, and Fuquay sandy soils with an average pH of 4.8.

CONCLUSIONS

1) Results from this study show that prescribed fire promoted the greatest positive gains for this ecosystem type. However, the use of fire as a treatment negatively impacted the survivorship of longleaf pine seedlings, estimated to be approximately three years old, established prior to applying treatments.
2) Mechanical mastication may be used to sustain the understory herbaceous layer and allow for the regeneration of longleaf pines. However, the positive benefits gained from temporarily removing the midstory are undermined by the quick recovery of the midstory vegetation.
3) Velpar® ULW may possibly be used to sustain the understory herbaceous layer and allow for the regeneration of longleaf pines. However, initial vegetative declines and impacts were observed during this study.
4) The percent of wiregrass (*Aristida stricta*) foliar cover was positively influenced by the use of prescribed fire in our study. Velpar® ULW and mechanical mastication caused initial declines; however, a gradual recovery was observed the second post-treatment year.
5) While there were no significant differences in wiregrass (*Aristida stricta*) seedling counts between rake and non-rake treatments, the removal of the litter layer appeared to improve its survivorship.
6) If managing for fauna species within the longleaf pine ecosystem, such as gopher tortoise (*Gopherus polyphemus* Daudin), land managers need to consider which understory vegetative species are being promoted. In our study, prescribed fire

was the only treatment that yielded positive gains initially across the medium (M), high (H), and very high (VH) preferred gopher tortoise forage. Mechanical mastication promoted initial gains for the M and VH species; however, their numbers fell below pre-treatment counts by the end of the second post-treatment year. Velpar® ULW showed significant declines each post-treatment year for all three gopher tortoise forage levels.

RECOMMENDATIONS

1) The preferred conservation management tool is prescribed fire. Prescribed fire provides the greatest benefit to both the embedded flora and fauna species. Also, this anthropogenic disturbance mimics that of a wildfire disturbance which is what originally shaped and perpetuated this ecosystem type. However, if an objective is to promote natural longleaf pine seeding and self perpetuation, prescribed burns should only be considered initially during the dormant season and when the root collar diameter (RCD) of the longleaf pine seedling is greater than 0.762 cm in size (Boyer 1974, 1990, 1993).
2) If land managers are restricted and prescribed fire is not an option, either alternative silviculture treatment, Velpar® ULW or mechanical mastication, can be used to promote the desired structure and allow for the regeneration of longleaf pine, but they may not encourage the desired understory herbaceous layer for target species such as the gopher tortoise. For our study, each alternative treatment had positive and negative effects. While the use of Velpar® ULW

caused initial declines in the vegetative layer in our study, it could provide maximum midstory control and long-term benefits by reducing competition and freeing site resources to the seed bank and/or existing herbaceous layer. While not tested in our study, literature (Brockway *et al.*1998) suggests herbicide can be spot applied to avoid or minimize the direct contact that it may have on non-targeted flora species. Mechanical mastication, much like prescribed fire, immediately removed midstory competition and freed local site resources. However, with such a quick recovery of the midstory following treatment, this alternative conservation tool would need to be employed on a regular basis (at least biennially).

3) The study site where this study was conducted was historically managed using a frequent prescribed burn regime; consequently, the treatment differences observed during this study may have been altered from that of a site that has not had the long-term application of prescribed fire.
4) Since this was a short-term study, the long-term positives and negatives have not been identified with the use of either Velpar® ULW or mechanical mastication. Repeated applications of either alternative silviculuture treatment could exacerbate negative effects or have cascading effects not accounted for in the short-term. These new disturbance regimes could cause ecosystem shifts; consequently, pre- and post-treatment monitoring should occur concurrently with their use.

5) Regardless of the alternative treatment selected, the property’s objective(s) should define which treatment is employed.

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APPENDICES

Appendix 1.1

Aiken Gopher Tortoise Heritage Preserve study unit soil profile (pre-treatment 2007)

Unit		Ca	Mg	P	K	Zn	Mn	Cu	B	Na	SoilpH
1	Burn	112.4	20.3	12.9	24	0.99	6.4	0.54	0.1	12.3	4.97
2	Herb	121.5	21.7	17	21	0.79	6.2	0.51	0.08	11	5
3	Mech	101.5	19	7.7	23.7	0.74	10.4	0.46	0.08	11.5	4.96
4	Burn	71.2	16.4	13.1	18.4	0.78	3.3	0.51	0.02	8.4	4.8
5	Mech	82.5	18	8.8	20.9	0.68	3.4	0.43	0.05	9.5	4.8
6	Herb	107.8	20.8	10.1	24.1	0.75	6.3	0.5	0.06	10.3	4.92
7	Herb	85.6	17.1	6.6	23.8	0.6	20.2	0.5	0.1	7.5	4.93
8	Burn	97.1	19.4	6.5	28.2	0.65	11.5	0.46	0.1	9	4.9
9	Mech	87.1	19.4	18.1	23.8	0.68	4.2	0.5	0.09	9.2	4.78
10	Herb	129.4	21.4	7.5	23	0.91	12.2	0.51	0.09	7.2	4.93
11	Mech	73.7	16	9.2	17.8	0.67	3.4	0.47	0	6.7	4.76
12	Burn	68.6	14.8	7.5	18.2	0.74	3	0.47	0.02	7	4.7
13	Mech	76.7	17.2	11.8	16.8	0.77	4.4	0.45	0.06	8	4.68
14	Herb	92.1	19.1	16.6	21.7	0.75	5.7	0.48	0.08	8.3	4.76
15	Burn	96.5	20.9	12.7	19.5	0.7	6.2	0.48	0.09	9.8	4.68
16	Burn	72.75	16.69	7.67	18.85	0.61	6.42	0.448	0.029	7.88	4.688
17	Mech	86.4	19.7	8.7	22.2	0.68	8.2	0.5	0.04	8.6	4.73
18	Herb	77.5	18.1	7	18.1	0.65	4.6	0.47	0.01	9.3	4.69

*The values reported above are based on averages per treatment unit.

**The quantity of each nutrient element extracted from the soil is reported in pounds per acre. This unit of measure is based on the assumption that the surface 6-inch layer of soil over an area of one ace weighs 2 million pounds (Clemson 2007).

Appendix 1.2

Aiken Gopher Tortoise Heritage Preserve example site photographs


Unit 1 (Burn)


Unit 1 (Burn)


Unit 2 (Herbicide)


Unit 2 (Herbicide)


Unit 3 (Mechanical)


Unit 3 (Mechanical)

Appendix 3.2

Species list from Aiken Gopher Tortoise Heritage Preserve (2007-2009)

Scientific name	Common name	Family	Functional group
Andropogon spp.	blue stem	Poaceae	graminoid
Aristida condensate	Piedmont threeawn	Poaceae	graminoid
Aristida purpurascens	arrowfeather threeawn	Poaceae	graminoid
Aristida stricta	pineland threeawn	Poaceae	graminoid
Aristida tuberculosa	seaside threeawn	Poaceae	graminoid
Aristolochia serpentaria	Virginia snakeroot	Aristolochiaceae	forb/herb
Asclepias amplexicaulis	clasping milkweed	Asclepidaceae	forb/herb
Astragalus michauxii	sandhills milkvetch	Fabaceae	forb/herb
Aureolaria pectinata	combleaf yellow false foxglove	Scrophulariaceae	forb/herb
Baptisia perfoliata	catbells	Fabaceae	forb/herb
Baptisia tinctoria	horseflyweed	Fabaceae	forb/herb
Berlandiera pumila	soft greeneyes	Asteraceae	subshrub/forb/herb
Brickellia eupatorioides	false boneset	Asteraceae	forb/herb
Bulbostylis ciliatifolia var. *coarctata*	capillary hairsedge	Cyperaceae	graminoid
Callicarpa americana	American beautyberry	Verbenaceae	forb/herb
Callisia graminea	grassleaf roseling	Commenlinaceae	forb/herb
Callisia rosea	Piedmont roseling	Commenlinaceae	forb/herb
Carphephorus bellidifolious	sandywoods chaffhead	Asteraceae	forb/herb
Chamaecrista fasciculate	partridge pea	Fabaceae	forb/herb
Chrysopsis gossypina	cottony goldenaster	Asteraceae	forb/herb
Cirsium repandum	sandhill thistle	Asteraceae	forb/herb
Cnidoscolus stimulosus	finger rot	Euphobiaceae	forb/herb

Appendix 3.2 (continued)

Species list from Aiken Gopher Tortoise Heritage Preserve (2007-2009)

Scientific name	Common name	Family	Functional group
Commelina diffusa	climbing dayflower	Commelinaceae	forb/herb
Commelina erecta	whitemouth dayflower	Commelinaceae	forb/herb
Conyza canadensis	Canadian horseweed	Asteraceae	forb/herb
Coreopsis delphiniifolia	larkspurleaf	Asteraceae	forb/herb
Coreopsis major	greater tickseed	Asteraceae	forb/herb
Crataegus spp.	hawthorn	Rosaceae	woody/woody
Cyperus filicinus	fern flatsedge	Cyperaceae	graminoid
Cyperus plukenetii	Plukenet’s flatsedge	Cyperaceae	graminoid
Dalea pinnata	summer farewell	Fabaceae	forb/herb
Desmodium strictum	pine barrn ticktrefoil	Fabaceae	forb/herb
Dichanthelium oligosanthes	Heller’s rosette grass	Poaceae	graminoid
Dichanthelium ovale	eggleaf rosette grass	Poaceae	graminoid
Dichanthelium villosissimum	whitehair rosette grass	Poaceae	graminoid
Diospyros virginiana	common persimmon	Ebenaceae	woody/woody
Eragrostis spectabilis	purple lovegrass	Poaceae	graminoid
Eriogonum tomentosum	dogtongue buckwheat	Polygalaceae	forb/herb
Eupatorium compositifolium	yankeeweed	Asteraceae	forb/herb
Eupatorium hyssopifolium	hyssopleaf thoroughwort	Asteraceae	forb/herb
Eupatorium glaucescens	waxy thoroughwort	Asteraceae	forb/herb
Euphorbia curtisii	Curtis’ spurge	Euphorbiaceae	shrub
Euphorbia ipecacuanhae	American ipecac	Euphorbiaceae	forb/herb
Euthamia graminifolia	flat-top goldentop	Asteraceae	forb/herb
Galactia erecta	erect milkpea	Fabaceae	forb/herb/vine
Gelsemium sempervirens	Carolina Jessamine	Loganiaceae	vine/shrub

Appendix 3.2 (continued)

Species list from Aiken Gopher Tortoise Heritage Preserve (2007-2009)

Scientific name	Common name	Family	Functional group
Gymnopogon ambiguus	bearded skeletongrass	Poaceae	graminoid
Galactia regularis	eastern milkpea	Fabaceae	forb/herb
Gaylussacia dumos	dwarf huckleberry	Ericaceae	subshrub/shrub
Hieracium gronovii	queenevil	Asteraceae	forb/herb
Hypericum gentianoides	orangegrass	Clusiaceae	forb/herb
Hypericum hypericoides	St. Andrew’s cross	Clusiaceae	subshrub/shrub
Hypericum microsepalum	flatswoods St. Johnswort	Clusiaceae	subshrub/shrub
Indigofera caroliniana	Carolina indigo	Fabaceae	forb/herb
Ionactis linariifolius	flaxleaf whitetop aster	Asteraceae	forb/herb
Lactuca spp.	common lettuce	Asteraceae	forb/herb
Lechea tenuifolia	narrowleaf pinweed	Cistaceae	forb/herb
Lespedeza capitata	roundhead lespedeza	Fabaceae	forb/herb
Lespedeza hirta	hairy lespedeza	Fabaceae	forb/herb
Lespedeza repens	creeping lespedeza	Fabaceae	forb/herb
Liatris pauciflora	fewflower blazing star	Asteraceae	forb/herb
Liatris tenuifolia	shortleaf blazing star	Asteraceae	forb/herb
Lupinus diffusus	oak ridge lupine	Fabaceae	subshrub/forb/herb
Mimosa microphylla	littleleaf sensitive-briar	Fabaceae	forb/herb
Minuartia caroliniana	pine barren stitchwort	Caryophyllaceae	forb/herb
Nolina georgiana	Georgia beargrass	Asparagaceae	subshrub/shrub
Opuntia humifusa	devil’s-tongue	Cactaceae	shrub
Paspalum setaceum	thin paspalum	Poaceae	graminoid
Passiflora incarnata	purple passionflower	Passifloraceae	forb/herb

Appendix 3.2 (continued)

Species list from Aiken Gopher Tortoise Heritage Preserve (2007-2009)

Scientific name	Common name	Family	Functional group
Physalis lanceolata	sword groundcherry	Solanaceae	forb/herb
Pinus palustris	longleaf pine	Pinaceae	woody/woody
Pityopsis aspera	pineland silkgrass	Asteraceae	forb/herb
Pityopsis graminifolia	narrowleaf silkgrass	Asteraceae	forb/herb
Pityopsis pinifolia	Taylor County goldaster	Asteraceae	forb/herb
Prunus angustifolia	Chickasaw plum	Rosaceae	woody/woody
Prunus serotina	black cherry	Rosaceae	woody/woody
Pseudognaphalium obtusifolium	rabbit-tobacco	Asteraceae	forb/herb
Pteridium aquilinum	western brackenfern	Dennstaedtiaceae	fern/herb
Quercus hemisphaerica	Darlington oak	Fagaceae	woody/woody
Quercus incana	bluejack oak	Fagaceae	woody/woody
Quercus laevis	turkey oak	Fagaceae	woody/woody
Quercus margarettae	sand post oak	Fagaceae	woody/woody
Quercus nigra	water oak	Fagaceae	woody/woody
Rhus copallinum	winged sumac	Anacardiaceae	woody/woody
Rhynchosia reniformis	dollarleaf	Fabaceae	forb/herb
Rhynchospora grayi	Gray’s beaksedge	Cyperaceae	graminoid
Rubus spp.	blackberry	Rosaceae	woody/woody
Sabatia quadrangula	fourangle rose gentian	Gentianaceae	forb/herb
Sassafras albidum	sassafras	Lauraceae	woody/woody
Schizachyrium scoparium var. *stoloniferum*	creeping bluestem	Poaceae	graminoid
Scleria ciliata	fringed nutrush	Cyperaceae	graminoid

Appendix 3.2 (continued)

Species list from Aiken Gopher Tortoise Heritage Preserve (2007-2009)

Scientific name	Common name	Family	Functional group
Sericocarpus tortifolius	Dixie whitetop aster	Asteraceae	forb/herb
Silphium compositum	kidneyleaf rosinweed	Asteraceae	forb/herb
Smilax spp.	common greenbrier	Smilacaceae	woody vine/woody
Solidago odora	anisescented goldenrod	Smilacaceae	forb/herb
Sorghastrum nutans	Indiangrass	Poaceae	graminoid
Sorghastrum secundum	lopsided Indiangrass	Poaceae	graminoid
Sporobolus junceus	pineywoods dropseed	Poaceae	graminoid
Stipulicida setacea	pineland scalypink	Caryophyllaceae	forb/herb
Stylisma patens	coastal plain dawnflower	Convolvulaceae	forb/herb
Tephrosia florida	Florida hoarypea	Fabaceae	forb/herb
Tephrosia spicata	spiked hoarypea	Fabaceae	forb/herb
Tephrosia virginiana	Virginia tephrosia	Fabaceae	forb/herb
Toxicodendron radicans	eastern poison ivy	Anacardiaceae	woody vine/woody
Tragia urens	wavyleaf noseburn	Euphorbiaceae	forb/herb
Tragia urticifolia	nettleleaf noseburn	Euphorbiaceae	forb/herb
Triplasis americana	perennial sandgrass	Poaceae	graminoid
Vaccinium arboreum	sparkleberry	Ericaceae	woody/woody
Vaccinium stamineum	deerberry	Ericaceae	woody/woody
Vernonia angustifolia	tall ironweed	Asteraceae	forb/herb
Viola pedata	birdfoot violet	Violaceae	forb/herb
Vitis spp.	grape	Vitaceae	woody vine/woody

Appendix 4.1

Simple vertical litter depth measurements of the Oi horizon to the nearest centimeter (cm) at Aiken Gopher Tortoise Heritage Preserve, Aiken County, South Carolina

Appendix 4.2

2008 post-mechanical mastication photographs

Appendix 5.1

Gopher tortoise photographs

Neonate/hatchling (age 0 to 1)

Adult (>15 years)

Appendix 5.2

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve pre-treatment (2007)

Family	Forage Species	Common name	Usage[a]	Prescribed Burn	Herbicide	Mechanical
1. Anacardiaceae	*Rhus copallium*	winged sumac	M	*	*	*
	Toxicodendron radicans	eastern poison ivy	M	*	*	*
2. Asteraceae	*Berlandiera pumila*	soft greeneyes	H		*	*
	Carphephorus bellidifolious	sandywoods chaffhead	NR[b]	*	*	*
	Cirsium repandum	sandhill thistle	NR		*	*
	Coreopsis major	greater tickseed	H	*	*	*
	Eupatorium compositifolium	yankeeweed	L		*	*
	Eupatorium linearifolium	waxy thoughwort	NR	*	*	*
	Hieracium gronvii	queenevil	M	*	*	*
	Lactuca spp.	common lettuce	L	*		*
	Liatris pauciflora	fewflower blazing star	L	*	*	*
	Liatris tenuifolia	shortleaf blazing star	M	*	*	*
	Pityopsis aspera	pineland silkgrass	H	*		
	Pityopsis graminifolia	narrowleaf silkgrass	H	*	*	*
	Pityopsis pinifolia	Taylor County goldaster	H	*		

[a] Forage usage value for gopher tortoises (Ashton and Ashton 2008): L=low, M=medium, H=high, and VH=very high; [b] NR = not ranked.

Appendix 5.2 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve pre-treatment (2007)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
2. Asteraceae (cont.)	*Pseudognaphalium obtusifolium*	rabbit tobacco	M	*	*	
	Sericocarpus tortifolius	Dixie whitetop aster	NR		*	
	Silphium compositum	kidneyleaf rosinweed	L	*	*	*
	Solidago odora	anisescented goldenrod	M	*	*	*
	Vernonia angustifolia	tall ironweed	M	*		*
3. Castaceae	*Opuntia humifusa*	devil’s-tongue	VH	*		*
4. Caryophyllaceae	*Stipulicida setacea*	pineland scalypink	L	*	*	*
5. Cistaceae	*Lechea tenuifolia*	narrowleaf pinweed	NR	*	*	*
6. Clusiaceae	*Hypericum gentianoides*	orangegrass	L	*	*	*
	Hypericum hypericoides	St. Andrew’s cross	L	*	*	*
7. Commelinaceae	*Callisia graminea*	grassleaf roseling	M			*
	Commelina diffusa	climbing dayflower	H		*	
8. Convolvulaceae	*Stylisma patens*	coastal plain dawnflower	M	*	*	*

Appendix 5.2 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve pre-treatment (2007)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
9. Cyperaceae	*Bulbostylis ciliatifolia* var. *coarctata*	capillary hairsedge	H	*	*	*
	Cyperus filiculmis	fern flatsedge	H	*	*	*
	Cyperus plukenetii	Plukenet’s flatsedge	VH			*
	Rhynchospora grayi	Gray’s beaksedge	NR	*	*	*
	Scleria ciliata	fringed nutrush	H	*	*	*
10. Dennstaedtiaceae	*Pteridium aquilinum*	western brackenfern	M		*	*
11. Ebenaceae	*Diospyros virginiana*	common persimmon	L	*	*	*
12. Ericaceae	*Gaylussacia dumosa*	dwarf huckleberry	H	*	*	*
	Vaccinium arboretum	Sparkleberry	L	*	*	*
	Vaccinium stamineum	deerberry	H	*	*	*
13. Euphorbiaceae	*Cnidoscolus stimulosus*	finger rot	H	*	*	*
	Euphorbia curtisii	Curtis’ spurge	H		*	
	Euphorbia ipecacuanhae	American ipecac	NR	*	*	*
	Tragia urens	wavyleaf noseburn	M	*	*	*
	Tragia urticifolia	nettleleaf noseburn	M		*	

Appendix 5.2 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve pre-treatment (2007)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
14. Fabaceae	*Astragalus michauxii*	sandhills milkvetch	M		*	
	Baptisia perfoliata	catbells	L	*	*	*
	Baptisia tinctoria	horseflyweed	L	*	*	*
	Desmodium strictum	pinebarren ticktrefoil	M	*	*	*
	Galactia regularis	eastern milkpea	VH	*	*	*
	Lespedeza hirta	hairy lespedeza	H	*	*	*
	Lespedeza repens	creeping lespedeza	H	*	*	*
	Lupinus diffuses	oak ridge lupine	M			*
	Mimosa microphylla	littleleaf sensitive briar	M	*	*	*
	Rhynchosia reniformis	dollarleaf	VH		*	*
	Tephrosia virginiana	Virginia tephrosia	VH	*	*	*
15. Fagaceae	*Quercus incana*	bluejack oak	M	*	*	*
	Quercus laevis	turkey oak	M	*	*	*
	Quercus margarettae	sand post oak	M	*	*	*
	Quercus nigra	water oak	L		*	
	Quercus hemisphaerica	Darlington oak	M	*	*	*
16. Gentianaceae	*Sabatia quadrangular*	fourangle rose gentian	M		*	
17. Lauraceae	*Sassafras albidum*	sassafras	NR	*	*	*
18. Liliaceae	*Nolina Georgiana*	Georgia beargrass	NR		*	

Appendix 5.2 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve pre-treatment (2007)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
19. Passifloraceae	*Passiflora incarnata*	purple passionflower	L	*	*	
20. Pinaceae	*Pinus palustris*	longleaf pine	L	*	*	*
21. Poaceae	*Andropogon* spp.	blue stem	VH	*	*	*
	Aristida purpurascens	arrowfeather threeawn	M	*		*
	Aristida stricta	pineland threeawn	M	*	*	*
	Aristida tuberculosa	seaside threeawn	M	*	*	*
	Dichanthelium oligosanthes	Heller’s rosette grass	VH		*	
	Dichanthelium ovale	eggleaf rosette grass	VH	*	*	*
	Eragrostis spectabilis	purple lovegrass	VH	*		*
	Gymnopogon ambiguus	bearded skeletongrass	VH		*	*
	Paspalum setaceum	thin paspalum	VH		*	*
	Sorghastrum secundum	lopsided Indiangrass	H		*	
22. Polygalaceae	*Eriogonum tomentosum*	dogtongue buckwheat	M	*	*	*

Appendix 5.2 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve pre-treatment (2007)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
23. Rosaceae	*Crataegus* spp.	hawthorn	L		*	*
	Prunus serotina	black cherry	L	*	*	*
	Rubus spp.	blackberry	VH	*		*
24. Scrophulariaceae	*Aureolaria pectinata*	Combleaf yellow false foxglove	NR	*	*	*
25. Smilacaceae	*Smilax* spp.	common greenbriar	M	*	*	*
26. Solanaceae	*Physalis lanceolata*	sword groundcherry	NR		*	
27. Verbenaceae	*Callicarpa americana*	American beautyberry	L	*		
28. Violaceae	*Viola pedata*	birdfoot violet	NR		*	*
29. Vitaceae	*Vistis* spp.	grape	VH	*	*	

Appendix 5.3

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve one year post-treatment (2008)

Family	Forage Species	Common name	Usage[a]	Prescribed Burn	Herbicide	Mechanical
1. Anacardiaceae	*Rhus copallium*	winged sumac	M	*	*	*
	Toxicodendron radicans	eastern poison ivy	M	*	*	*
2. Asclepidaceae	*Ascelepias amplexicaulis*	clasping milkweed	L	*		
3. Asteraceae	*Berlandiera pumila*	soft greeneyes	H		*	*
	Brickellia eupatoriodes	false boneset	NR[b]		*	
	Carphephorus bellidifolious	sandywoods chaffhead	NR	*		
	Cirsium repandum	sandhill thistle	NR		*	*
	Coreopsis delphinifolia	larkspurleaf	NR	*	*	*
	Coreopsis major	greater tickseed	H	*	*	*
	Eupatorium compositifolium	yankeeweed	L	*	*	*
	Eupatorium linearifolium	waxy thoughwort	NR	*	*	*
	Hieracium gronvii	queenevil	M	*	*	*
	Ionactis linariifolius	flaxleaf whitetop aster	NR		*	
	Lactuca spp.	common lettuce	L	*		*
	Liatris pauciflora	fewflower blazing star	L	*	*	*
	Liatris tenuifolia	shortleaf blazing star	M	*	*	*
	Pityopsis aspera	pineland silkgrass	H	*	*	*

[a] Forage usage value for gopher tortoises (Ashton and Ashton 2008): L=low, M=medium, H=high, and VH=very high; [b] NR = not ranked.

Appendix 5.3 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve one year post-treatment (2008)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
3. Asteraceae (cont.)	*Pseudognaphalium obtusifolium*	rabbit tobacco	M		*	
	Silphium compositum	kidneyleaf rosinweed	L	*	*	*
	Solidago odora	anisescented	M	*	*	*
		goldenrod	M	*	*	*
	Vernonia angustifolia	tall ironweed	M	*	*	*
4. Castaceae	*Opuntia humifusa*	devil's-tongue	VH	*	*	*
5. Caryophyllaceae	*Minuartia caroliniana*	pinebarren stitchwort	M		*	
	Stipulicida setacea	pineland scalypink	L	*	*	*
6. Cistaceae	*Lechea tenuifolia*	narrowleaf pinweed	NR	*	*	*
7. Clusiaceae	*Hypericum gentianoides*	orangegrass	L			*
	Hypericum hypericoides	St. Andrew's cross	L	*	*	*
	Hypericum microsepalum	flatswoods St. Johnswort	NR	*		

Appendix 5.3 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve one year post-treatment (2008)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
8. Commelinaceae	*Callisia graminea*	grassleaf roseling	M			*
	Callisia rosea	Piedmont roseling	NR			*
	Commelina diffusa	climbing dayflower	H	*		
	Commelina erecta	whitemouth dayflower	H	*	*	
9. Convolvulaceae	*Stylisma patens*	coastal plain dawnflower	M	*	*	*
10. Cyperaceae	*Bulbostylis ciliatifolia* var. *coarctata*	capillary hairsedge	H	*	*	*
	Cyperus filiculmis	fern flatsedge	H	*	*	*
	Cyperus plukenetii	Plukenet's flatsedge	VH	*	*	*
	Rhynchospora grayi	Gray's beaksedge	NR	*		*
	Scleria ciliata	fringed nutrush	H	*	*	
11. Dennstaedtiaceae	*Pteridium aquilinum*	western brackenfern	M		*	*
12. Ebenaceae	*Diospyros virginiana*	common persimmon	L	*	*	*
13. Ericaceae	*Gaylussacia dumosa*	dwarf huckleberry	H	*	*	*
	Vaccinium arboretum	Sparkleberry	L	*	*	*
	Vaccinium stamineum	deerberry	H	*	*	*
14. Euphorbiaceae	*Cnidoscolus stimulosus*	finger rot	H	*	*	*
	Euphorbia curtisii	Curtis' spurge	H		*	
	Euphorbia ipecacuanhae	American ipecac	NR	*	*	*

Appendix 5.3 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve one year post-treatment (2008)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
14. Euphorbiaceae (cont.)	*Tragia urens*	wavyleaf noseburn	M		*	*
15. Fabaceae	*Astragalus michauxii*	sandhills milkvetch	M			*
	Baptisia perfoliata	catbells	L	*	*	*
	Chamaecrista fasciculata	partridge pea	M			*
	Desmodium strictum	pinebarren ticktrefoil	M	*	*	
	Galactia erecta	erect milkpea	VH		*	*
	Galactia regularis	eastern milkpea	VH	*	*	*
	Indigofera caroliniana	Carolina indigo	H		*	*
	Lespedeza capitata	roundhead lespedeza	M	*		
	Lespedeza hirta	hairy lespedeza	H		*	*
	Lespedeza repens	creeping lespedeza	H	*	*	*
	Lupinus diffuses	oak ridge lupine	M			*
	Mimosa microphylla	littleleaf sensitive briar	M		*	*
	Rhynchosia reniformis	dollarleaf	VH		*	*
	Tephrosia florida	Florida hoarypea	VH		*	
	Tephrosia virginiana	Virginia tephrosia	VH	*	*	*

Appendix 5.3 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve one year post-treatment (2008)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
16. Fagaceae	*Quercus incana*	bluejack oak	M	*	*	*
	Quercus laevis	turkey oak	M	*	*	*
	Quercus margarettae	sand post oak	M	*	*	*
	Quercus nigra	water oak	L	*	*	*
17. Lauraceae	*Sassafras albidum*	sassafras	NR	*	*	*
18. Liliaceae	*Nolina Georgiana*	Georgia beargrass	NR		*	
19. Passifloraceae	*Passiflora incarnata*	purple passionflower	L	*		
20. Pinaceae	*Pinus palustris*	longleaf pine	L	*	*	*
21. Poaceae	*Andropogon* spp.	blue stem	VH	*	*	*
	Aristida condensata	Piedmont threeawn	M	*	*	*
	Aristida purpurascens	arrowfeather threeawn	M	*	*	*
	Aristida stricta	pineland threeawn	M	*	*	*
	Aristida tuberculosa	seaside threeawn	M	*	*	*
	Dichanthelium oligosanthes	Heller’s rosette grass	VH		*	
	Dichanthelium ovale	eggleaf rosette grass	VH	*	*	*
	Dichanthelium villosissimum	whitehair rosette grass	VH	*	*	*

Appendix 5.3 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve one year post-treatment (2008)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
21. Poaceae (cont.)	*Eragrostis spectabilis*	purple lovegrass	VH	*	*	*
	Gymnopogon ambiguus	bearded skeletongrass	VH		*	*
	Paspalum setaceum	thin paspalum	VH	*	*	*
	Schizachyrium scoparium var. *stoloniferum*	creeping bluestem	VH	*	*	*
	Sorghastrum secundum	lopsided Indiangrass	H		*	
	Triplasis americana	perennial sandgrass	H			*
22. Polygalaceae	*Eriogonum tomentosum*	dogtongue buckwheat	M	*	*	*
23. Rosaceae	*Prunus angustifolia*	Chickasaw plum	L			*
	Prunus serotina	black cherry	L	*		*
	Rubus spp.	blackberry	VH	*		*
24. Scrophulariaceae	*Aureolaria pectinata*	Combleaf yellow false foxglove	NR			*
25. Smilacaceae	*Smilax* spp.	common greenbriar	M	*	*	*
26. Verbenaceae	*Callicarpa americana*	American beautyberry	L	*		
27. Violaceae	*Viola pedata*	birdfoot violet	NR			*
28. Vitaceae	*Vistis* spp.	grape	VH	*	*	

Appendix 5.4

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve two years post-treatment (2009)

Family	Forage Species	Common name	Usage[a]	Prescribed Burn	Herbicide	Mechanical
1. Anacardiaceae	*Rhus copallium*	winged sumac	M	*	*	*
	Toxicodendron radicans	eastern poison ivy	M	*	*	*
2. Aristolochiaceae	*Aristolochia serpentaria*	Virginia snakeroot	NR[b]		*	
3. Asclepidaceae	*Ascelepias amplexicaulis*	clasping milkweed	L		*	
4. Asteraceae	*Berlandiera pumila*	soft greeneyes	H		*	*
	Brickellia eupatoriodes	false boneset	NR		*	
	Carphephorus bellidifolious	sandywoods chaffhead	NR	*	*	*
	Cirsium repandum	sandhill thistle	NR		*	*
	Conyza Canadensis	Canadian horseweed	H			*
	Coreopsis delphinifolia	larkspurleaf	NR	*	*	*
	Coreopsis major	greater tickseed	H	*	*	
	Eupatorium compositifolium	yankeeweed	L	*	*	*
	Eupatorium hyssopifolium	waxy thoughwort	L	*	*	
	Hieracium gronvii	queenevil	M	*	*	*
	Ionactis linariifolius	flaxleaf whitetop aster	NR		*	

[a] Forage usage value for gopher tortoises (Ashton and Ashton 2008): L=low, M=medium, H=high, and VH=very high; [b] NR = not ranked.

Appendix 5.4 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve two years post-treatment (2009)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
4. Asteraceae (cont.)	*Lactuca* spp.	common lettuce	L			*
	Liatris secunda	fewflower blazing star	L	*	*	*
	Liatris tenuifolia	shortleaf blazing star	M	*	*	*
	Pityopsis aspera	pineland silkgrass	H	*	*	*
	Pseudognaphalium obtusifolium	rabbit tobacco	M		*	*
	Sericocarpus tortifolius	Dixie whitetop aster	NR		*	*
	Silphium compositum	kidneyleaf rosinweed	L		*	*
	Solidago odora	anisescented goldenrod	M	*	*	*
	Vernonia angustifolia	tall ironweed	M	*	*	*
5. Castaceae	*Opuntia humifusa*	devil's-tongue	VH	*		*
6. Caryophyllaceae	*Stipulicida setacea*	pineland scalypink	L	*	*	*
7. Cistaceae	*Lechea tenuifolia*	narrowleaf pinweed	NR	*	*	*
8. Clusiaceae	*Hypericum gentianoides*	orangegrass	L	*	*	*
	Hypericum hypericoides	St. Andrew's cross	L	*	*	*

Appendix 5.4 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve two years post-treatment (2009)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
9. Convolvulaceae	*Stylisma patens*	coastal plain dawnflower	M	*	*	*
10. Cyperaceae	*Bulbostylis ciliatifolia* var. *coarctata*	capillary hairsedge	H	*	*	*
	Cyperus filiculmis	fern flatsedge	H	*	*	
	Cyperus plukenetii	Plukenet's flatsedge	VH	*	*	*
	Rhynchospora grayi	Gray's beaksedge	NR	*	*	*
	Scleria ciliata	fringed nutrush	H	*		
11. Dennstaedtiaceae	*Pteridium aquilinum*	western brackenfern	M		*	*
12. Ebenaceae	*Diospyros virginiana*	common persimmon	L	*	*	*
13. Ericaceae	*Gaylussacia dumosa*	dwarf huckleberry	H	*	*	*
	Vaccinium arboretum	Sparkleberry	L	*	*	*
	Vaccinium stamineum	deerberry	H	*	*	*
14. Euphorbiaceae	*Cnidoscolus stimulosus*	finger rot	H	*	*	*
	Euphorbia ipecacuanhae	American ipecac	NR	*	*	*

Appendix 5.4 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve two years post-treatment (2009)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
14. Euphorbiaceae (cont.)	*Tragia urens*	wavyleaf noseburn	M	*	*	*
15. Fabaceae	*Baptisia perfoliata*	catbells	L	*	*	*
	Baptisia tinctoria	horseflyweed	NR	*		*
	Chamaecrista fasciculata	partridge pea	M			*
	Dalea pinnata	summer farewell	M			*
	Desmodium strictum	pinebarren ticktrefoil	M	*	*	
	Galactia regularis	eastern milkpea	VH	*	*	*
	Lespedeza capitata	roundhead lespedeza	M	*		
	Lespedeza hirta	hairy lespedeza	H	*		*
	Lespedeza repens	creeping lespedeza	H	*	*	*
	Lupinus diffusus	oak ridge lupine	M	*		*
	Mimosa microphylla	littleleaf sensitive briar	M	*	*	*
	Rhynchosia reniformis	dollarleaf	VH			*
	Tephrosia virginiana	Virginia tephrosia	VH	*	*	*

Appendix 5.4 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve two years post-treatment (2009)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
16. Fagaceae	*Quercus incana*	bluejack oak	M	*	*	*
	Quercus laevis	turkey oak	M	*	*	*
	Quercus margarettae	sand post oak	M	*	*	*
17. Lauraceae	*Sassafras albidum*	sassafras	NR	*	*	*
18. Liliaceae	*Nolina Georgiana*	Georgia beargrass	NR		*	
19. Passifloraceae	*Passiflora incarnata*	purple passionflower	L	*		
20. Pinaceae	*Pinus palustris*	longleaf pine	L	*	*	*
21. Poaceae	*Andropogon spp.*	blue stem	VH	*	*	*
	Aristida condensata	Piedmont threeawn	M	*	*	
	Aristida purpurascens	arrowfeather threeawn	M	*	*	*
	Aristida stricta	pineland threeawn	M	*	*	*
	Aristida tuberculosa	seaside threeawn	M	*	*	*
	Dichanthelium ovale	Heller's rosette grass	VH	*	*	*
	Dichanthelium villosissimum	whitehair rosette grass	VH	*		

Appendix 5.4 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve two years post-treatment (2009)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
21. Poaceae (cont.)	*Eragrostis refacta*	coastal lovegrass	VH			*
	Eragrostis spectabilis	purple lovegrass	VH	*	*	*
	Paspalum bifidum	pitchfork crown grass	VH		*	
	Paspalum setaceum	thin paspalum	VH		*	*
	Schizachyrium stoloniferum	creeping bluestem	VH	*	*	*
	Sorghastrum secunda	lopsided Indiangrass	H		*	
	Triplasis americana	perennial sandgrass	H			*
22. Polygalaceae	*Eriogonum tomentosum*	dogtongue buckwheat	M	*	*	*
23. Rosaceae	*Crataegus* spp.	hawthorn	L			*
	Prunus serotina	black cherry	L	*	*	*
	Rubus spp.	blackberry	VH	*		
24. Scrophulariaceae	*Aureolaria pectinata*	Combleaf yellow false foxglove	NR	*	*	*
25. Smilacaceae	*Smilax* spp.	common greenbriar	M	*	*	*
26. Verbenaceae	*Callicarpa americana*	American beautyberry	L	*		

Appendix 5.4 (continue)

Available forage for gopher tortoises at Aiken Gopher Tortoise Heritage Preserve two years post-treatment (2009)

Family	Forage Species	Common name	Usage	Prescribed Burn	Herbicide	Mechanical
27. Violaceae	*Viola pedata*	birdfoot violet	NR			*
28. Vitaceae	*Vistis* spp.	grape	VH	*	*	