Factors Affecting the Regrowth of Ilex Glabra in a Routinely Burned Longleaf Forest

Jaybus Price

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FACTORS AFFECTING THE REGROWTH OF ILEX GLABRA IN A ROUTINELY BURNED LONGLEAF PINE FOREST

by

Jaybus Price

A Thesis
Submitted to the Graduate School, the College of Science and Technology and the Department of Biological Sciences at The University of Southern Mississippi in Partial Fulfillment of the Requirements for the Degree of Master of Science

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May 2018
ABSTRACT

This study examines the effects of historical management by use of prescribed fire on *Ilex glabra* stems/m$^2$ and factors affecting the regrowth of *I. glabra* after a prescribed burn to gain beneficial knowledge for management purposes. Environmental factors and morphological parameters of *I. glabra* were sampled before and after a prescribed burn of the Longleaf Trace Nature Preserve in September 2016. The study site is located in Lamar County, Mississippi, just west of Hattiesburg, MS. Stem densities of *I. glabra* were collected once before the prescribed burn and twice after the prescribed burn at 2 month and 9 month intervals. Soil moisture, soil texture, maximum soil surface temperature during the fire, leaf area index at 0m and 1.5m before and after the burn, common woody species presence, and *I. glabra* stem diameter and height were tested for effects on post burn regeneration of *I. glabra*. Frequently burned areas had a significantly higher (F$_{1,67}$= 22.95, p< 9.6e-06, R$^2$= 0.255) *I. glabra* stem density. Maximum soil surface temperature during the fire had a negative correlation (F$_{1,34}$= 10.76, p= 0.002, R$^2$= 0.24) with *I. glabra* stem/m$^2$ at 2 months post burn. Average *I. glabra* stem diameter had a positive correlation (F$_{1,37}$= 4.58, p= 0.039, R$^2$= 0.11) with the average number of sprouts produced per *I. glabra* stem at 2 months post burn. Pre-fire *I. glabra* densities had a positive correlation (F$_{1,37}$= 17.62, p< 0.0002, R$^2$= 0.322) with stem density at 9 months post fire. Early management of *I. glabra* populations is important to keep the plant numbers manageable. Prescribed burning should aim to increase the intensity/residency time of the fire to increase effective damage/shock to *I. glabra* rootstocks.
ACKNOWLEDGMENTS

I would first like to thank Dr. Mike Davis for his support through all my years at USM. He was the person that inspired me to become as invested in plant ecology as I am today. From his impressive knowledge of plants and soils to his always cheery attitude, it has been a pleasure to learn from him.

I would like to thank the members of my committee, Dr. Kevin Kuehn and Dr. Frank Heitmuller, for all their help and suggestions for improving my data processing and revising this thesis. I would also like to thank my honorary committee member, Dr. Carl Qualls, for his help with the statistical analyses of this project.

Courtney Filliben, along with Dr. Davis, deserves a special thanks for establishing the plots used in this study and collecting the initial stem count data used as well. To Brandy Purdy, Matt Lodato, Amy Moseley, Patrick Kirby, Maylisa Smith, and many others, I am much obliged for the helping hands you have extended throughout my graduate career.
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<tr>
<td><em>USM</em></td>
<td>The University of Southern Mississippi</td>
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<td><em>MS</em></td>
<td>Mississippi</td>
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<td><em>LAI</em></td>
<td>Leaf Area Index</td>
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CHAPTER I

1.1 INTRODUCTION

The need for forest management as a means of efficient restoration or lumber production is constant and always advancing. New information on management is important to improve the efficacy of various management strategies. This study examines some factors affecting management of a specific shrub species in *Pinus palustris* forests. Historically, *P. palustris*, or longleaf pine, dominated the landscape of the southeastern coastal plain in the United States from east Texas to southern Virginia, possibly covering 92 million acres (Boyer, 1990; Frost, 2006). Currently, longleaf pine forest acreage has been reduced to 5-10 million acres. Most of the remaining acreage is comprised of secondary growth that is in poor condition (Noss, 1988; Noss, 1989). Many efforts are being made to restore longleaf pine forests in its native range because of its value as lumber and many endangered species that are endemic to longleaf pine ecosystems (Guyer and Bailey, 1993; Walker, 1993). Natural longleaf pine restoration proves problematic because of the slow growth rate of seedlings, predation of seeds by animals, and poor seedling production and survival (Croker and Boyer, 1975; Means, 1985; Myers, 1990). Many strategies have been developed to help restore and manage longleaf pine forests. The most common strategy is the three-cut shelterwood silvicultural technique that involves several stages of cutting trees and seed bed preparation before *P. palustris* seedlings are planted (Boyer, 1979; Kitchens, 1989). This shelterwood strategy and later, established longleaf forest management strategies involve the use of prescribed fires. *Pinus palustris* is described as a fire-resistant species adapted to low intensity, high frequency surface fires that occur on a 2-10 year regime (Brown
and Davis, 1973; McCune, 1988; Platt et al., 1991). Longleaf pines utilize a pyrogenic strategy of growth through their fire-resistant adaptations by taking advantage of reductions in competition to out-compete other woody plants and the elimination of leaf litter allows for greater seedling establishment (Landers, 1991; Means, 1985; Platt et al., 1988). Historically, fires would have been caused by lightning strikes, likely by striking a tree (Means, 1985; Platt et al., 1991). The tree struck by lightning would have smoldered for days after the lightning strike, which allowed enough time for the ground fuel to dry out, and an ember would eventually fall to the ground igniting the fuel source (Landers, 1991; Means, 1985, Platt et al., 1988). From this research, it is clearly important for longleaf ecosystems to undergo routine disturbance through low intensity fires, with frequency depending on the ecosystem sub-type. These longleaf ecosystem sub-types have been described in a study by Peet and Allard (1993) in which they separate the longleaf pine ecosystem into as many as 23 distinct communities based on soil moisture and plant associations. The site at which this study takes place is classified, according to Peet and Allard, as a southern-mesic-longleaf-woodland (SMLW.) This classification is due to the plant associations of *Quercus marilandica*, *Q. falcata*, *Q. stellata*, *Schizachyrium scoparium*, *S. tenerium*, *Pteridium aquilinum*, and the focus of this study *Ilex glabra*.

*Ilex glabra*, or gallberry, is a perennial shrub in the Aquifoliaceae family. Gallberry is evergreen with alternate, simple, and entire to finely toothed, obovate to elliptical leaves. It typically grows to a maximum size of four meters high in clusters up to three meters wide from tuberous rhizomes (Weakley, 2010; Dirr and Alexander, 1991). *Ilex glabra* is native to the coastal plains of the United States ranging from Texas to
Florida and north as far as Nova Scotia, Canada (Weakley, 2010; Brouillet et al., 2006). Gallberry is dioecious with male flowers occurring in groups of three and female flowers occur singly or in clumps of up to three (Dirr and Alexander, 1991). Berries are produced, as the female flowers, singly or in groups of up to three and are generally found to be bitter and unpalatable (Halls, 1977). Even though gallberry fruits are not a preferred food source for wildlife, it's general abundance and large production of berries make it an important food source for many species (Johnson and Landers, 1978). Whitetail deer incorporate gallberry fruits, twigs, and foliage as an important part of their diet (Halls, 1977; Johnson and Landers, 1978; Ripley et al., 1965). Johnson and Landers' (1978) study found that gallberry fruit is an important source of food for raccoon during the winter in Alabama, and their study as well as research by Halls (1977) found that gallberry was a minor source of food for most wild birds. Gallberry, having tuberous rhizomes, is a clonal plant made up of many genet and ramet groups (Dirr and Alexander, 1991; Godfrey and Wooten, 1981; Halls, 1977; Kush et al., 1999; Lemon, 1943; Radford et al., 1968). The growth form and relative attractiveness of gallberry make this plant desirable as a horticultural species, and several varieties have been produced such as “Shamrock,” “Densa,” and “Compacta.” The clonal nature of gallberry makes it particularly difficult to determine exactly what an individual is without the use of genetic tests or by digging up the plants to trace all root/shoot connections. Therefore, in this study, individual stems will be used to quantify I. glabra for statistical testing. Much of the rhizome of I. glabra is located within the top two inches of the soil. Small fibrous roots occur along the entire length of the rhizome, while long roots occur infrequently along the rhizome and may extend to a shallow water table (Laycock, 1967). In a study
by Miller et al. (1995), *I. glabra* rhizome was quantified between 660 and 1,459 rootstocks per acre in a coastal plains *Pinus taeda* forest. The large rhizome of gallberry helps account for the percent shrub cover (67-75%) commonly found in coastal plain forests (Lemon, 1943). A high amount of vegetative cover by *I. glabra* produces the problem of reduced species diversity in a longleaf pine forest (Brockway and Lewis, 1997). This is important from a management standpoint because the longleaf pine ecosystems contain the greatest diversity of plant species, up to 40 species per square meter, ever found in a temperate zone (Peet and Allard, 1993). In order to manage an established *Pinus palustris* forest for restoration, it is important to incorporate a management strategy that controls the aboveground biomass of gallberry. As mentioned, prescribed burning is a common and necessary way to manage such a forest. There are two main types of controlled burns that affect the intensity of the fire. Use of a head fire in prescribed burning is to produce a fast moving, high intensity fire, but it is difficult to control. A head fire is produced by igniting fuel on the upwind side of an area and allowing the wind to push the fire through the forest. This type of fire would be detrimental in a longleaf ecosystem because of the high risk of damaging or killing the pine trees. A backing fire is the most commonly used method of performing a prescribed burn. A backing fire produces a slow, low intensity fire. Igniting fuel on the downwind side of an area allows the fire to “back” into the wind which controls the speed of the fire and feeds it the oxygen needed to burn most of its fuel source. A backing fire is appropriate for use in a longleaf ecosystem because it consumes most leaf litter as fuel which allows for better *Pinus palustris* seedling establishment, and it kills most fire intolerant plants which allows proper woody and herbaceous species to regrow. *I.*
*Ilex glabra*, being a common native plant in longleaf pine forests, has its own strategy to deal with frequent fires. Gallberry's extensive rhizome helps with plant survival through the fire, and then the rhizome and root crowns allow quick regrowth after the disturbance (Abrahamson, 1984; Burton and Hughes, 1961; Halls et al., 1964; Heyward and Barnette, 1934; Langdon, 1981; Rundel, 1981). While *I. glabra* is an evergreen, it is highly flammable due to volatile chemicals found in the plant tissues (Burgan and Susott, 1991; Komarek, 1974; Komarek, 1983; Rogers et al., 1986; Sackett, 1975). Ether and benzene-ethanol extractives are the major volatile chemicals and can comprise 44.6 percent of dry leaf weight (Rundel, 1981). Though the leaves are very volatile, the stems of gallberry can contribute more to fuel composition because they make up more than 55 percent of the plant's dry weight (McNab et al. 1978). With such highly volatile plant tissues, Hough (1969) reported that gallberry leaves have a heat value as high as 5,000 calories per gram. The high flammability of gallberry foliage works as an advantage and potential disadvantage when prescribed burning. The disadvantage is that large patches of gallberry can ignite very quickly and create an intense “flare” of fire that could ignite/damage/kill trees. Without prescribed fire, these conditions have been shown to worsen with time (Wade et al., 1998). It has been recognized that in these ecosystems prescribed fires are recommended to prevent the accumulation of volatile fuel sources such as gallberry (Sackett and Cooper, 1971). The advantage is that the “flare” caused by gallberry foliage ignition will likely kill the aboveground shoots. In fact, it has been shown that properly administered prescribed burns generally top-killed *I. glabra* (Burton and Hughes, 1961; Halls and Hughes, 1964; Langdon, 1981). This may have an immediate effect on the aboveground gallberry; however, the underground rhizomes are
typically unharmed. Furthermore, within months after the fire, regrowth occurs, often sprouting more stems than were top-killed (Burton and Hughes, 1961; Halls and Hughes, 1964; Halls 1977). This effect seems to be short-lived though. Some new sprouts die off the second year after the fire, and as the stand ages, competition by larger gallberry stems choke out many of the smaller stems (Lemon, 1943). Other studies suggest that, instead of returning to previous densities, periodic burning actually increases the density of gallberry over time (Schmalzer and Hinkle, 1992). The differing results found by previous research may be due to the season in which the forest is burned. A study by Brockway and Lewis (1997) suggests that dormant season prescribed fires decrease the density of gallberry patches in a longleaf/wiregrass ecosystem; leading to increases in plant diversity and lowering litter cover. The study by Schmalzer and Hinkle (1992) took place in an oak-saw palmetto scrub ecosystem. This could mean that the ecosystem type has a significant effect on gallberry regrowth. The height of *I. glabra* stems is also a matter that contains inconsistencies between multiple studies. Some studies report that gallberry stem height is reduced for up to three years after a controlled burn (Burton and Hughes, 1961; Lewis and Hart, 1972). Other research by Paul Lemon (1943) concluded that gallberry can grow up to two feet in height in a growing season following a prescribed burn, compared to 4-6 inches of height in a normal, non-fire growing season.

Soil type or moisture may also play a role in the resurgence of *I. glabra* after a prescribed fire. A study by Grelen and Lewis (1981) postulates that gallberry thrives on fire, especially if growing in areas with moist soil.

The location being utilized in this study is a 160 acre tract of longleaf pine forest/savanna. The property is located in Forrest and Lamar counties Mississippi, near
Hattiesburg, and is currently owned by the University of Southern Mississippi. The property can be categorized by areas that are managed by prescribed burning and areas that have been left undisturbed since the 1980's. The burned areas of the property are administered prescribed burning at a two year interval. Sites were chosen within both areas to compare gallberry in frequently burned areas versus unburned areas. The frequently burned areas of the site are expected to have a higher \( I. \text{ glabra} \) stems/m\(^2\) density. This study began before a controlled burn and was monitored during and after the prescribed fire. Frequently burned plots were used to examine effects of environmental and morphological characteristics on gallberry stems/m\(^2\) before and after a prescribed fire. Gallberry stems/m\(^2\) was predicted to be higher in post burn collections than pre-burn collections. Gallberry stem densities were also predicted to increase with time after the prescribed burn. Common woody plant diversity was sampled at burned sites before and after the fire. Common woody plant diversity was expected to have an inverse relationship with \( I. \text{ glabra} \) stems/m\(^2\). Leaf area index (LAI) was collected at burned sites before and after the prescribed fire at multiple height levels. The LAI measured above gallberry height was predicted to have no change after the controlled burn. The LAI measured at ground level was predicted to be higher after the prescribed fire. LAI was measured not only to examine any interaction with \( I. \text{ glabra} \) growth/regrowth, but because shrub cover is not necessarily dependent on the number of gallberry stems (Lewis and Hart, 1972). Soil samples were collected from burned and unburned sites for texture evaluation. The top 30 cm of soil was sampled for texture analysis since the majority of the \( I. \text{ glabra} \) rhizome exists in the top 5 cm of the soil (Laycock, 1967). This size of soil sample will better represent the variations in soil
texture across the study site. The study site has four major soil associations as follows in decreasing acreage: Freestone-McLaurin-Susquehanna (FMC), Freestone-Susquehanna and Prentiss (FsD), Prentiss fine sandy loam (PnB), and Falkner silt loam (FaB).

*Figure 1.1 Site Soil Map*

Freestone series soils are from loamy/clayey alluvium deposits and are composed of sandy loam to loam in the top 30 cm of the soil profile. Susquehanna series soils are from clayey marine deposits and are composed of silt loam to clay in the top 30 cm of the soil profile. McLaurin series soils are from loamy fluviomarine deposits and are composed of sandy loam in the top 30 cm of the soil profile. Prentiss series soils are from loamy alluvium deposits and are composed of fine sandy loam to loam in the top 30 cm of the soil profile. Falkner series soils are from silty loess over silty clay marine deposits and are composed of silt loam to silty clay loam in the top 30 cm of the soil profile (Soil Survey Staff, NRCS, USDA). Freestone, Susquehanna, McLaurin, Prentiss, and Falkner series soils make up about 68, 35.75, 35, 11, and 5.75 acres of the study site. 

*Figure 1.1: FMC: 129.3 acres, FsD: 16.1 acres, PnB: 8.2 acres, FaB: 6.4 acres. Adapted from Web Soil Survey (Soil Survey Staff, NRCS, USDA).*
respectively. The remaining 4.5 acres of the study site were allocated to 3.5 acres of hydric soils, Trebloc and Bibb, and 1 acre of minor non-hydric soils, Stough, Quitman, Savannah, Malbic, and Saucier (Soil Survey Staff, NRCS, USDA).

Immediately before the prescribed fire, soil moisture was measured. Soil moisture was predicted to have a positive correlation with gallberry stem densities after the prescribed burn. During the fire, soil surface temperature was monitored. Soil surface temperature was expected to have a negative relationship with gallberry stem densities after the fire. Within two months after the burn, the number of new sprouts per remaining gallberry stem were counted and diameter and heights of each remaining stem were recorded. Paul Lemon’s (1943) study found that two to four new sprouts generally emerge from the base of an old stem or nearby along the rhizome soon after the disturbance. Stem diameter was predicted to be positively correlated with the number of new sprouts produced after a fire. Larger stem diameters were also predicted to have a positive effect on the number of gallberry stems/m² post burn.
1.2 METHODS

1.2.1 Site Selection/Preparation

A 160 acre tract of longleaf pine forest/savanna was chosen as the study site. Roughly 90 acres of the property have been managed with prescribed burns since 2009 at a 2 year interval. Plots were placed randomly within gallberry patches in burned and unburned areas. Forty plots were established in burned areas and thirty plots in unburned areas. Each plot was marked using a metal stake in the center with a numbered metal tag attached and a GPS was used to mark each center stake location. Burned plots were labeled GBRY 01-40 and unburned plots were labeled GBRY 41-70. Afterward, four metal stakes were used to mark out a 2 by 2 meter square area around each center stake. All sampling occurred within the established area for each plot.

1.2.2 Pre-Fire Sampling

Preliminary samples were collected before the prescribed burn was administered. Stem counts were used to quantify the number of *Ilex glabra*, *Ilex vomitoria*, *Diospyros virginiana*, *Vaccinium spp.*, *Gaylussacia spp.*, and *Rhus copallinum* within each plot. The stem counts included any of these woody species, regardless of height, that were less than 5 cm diameter at breast height (no individual plants came close to this size in any plots). While stem counts were collected, the maximum height of *I. glabra* in each plot was also recorded. A measure of pre-fire common woody species diversity was derived from the stem count data. Soil cores were collected at all plots using a 12 inch by 1 inch soil core sampler from AMS, Inc. (Art's Manufacturing and Supply Inc. American Falls, Idaho USA). Soil samples were labeled with the corresponding plot number and stored
in a freezer until processing began. Leaf area index (LAI) readings were recorded at each burned site using a LiCor Biosciences LAI-2200C Plant Canopy Analyzer with a 90 degree shade attached (LiCor Biosciences Lincoln, Nebraska USA). LAI was collected at the center of each plot by taking a reading at ground level and one at 150 cm high. Soil surface temperature during the fire was collected. In order to do that, the data loggers needed protection from the fire. Large PVC pipe housings were made to store the data logger for each plot. The housings were partially buried at each burned plot and temperature probe wire was installed in each to read the soil surface temperature at 1 cm depth. Two days before the prescribed burn, the EasyLog EL-USB-TC temperature loggers were labeled, attached to each probe, and placed into the protective housing to begin logging temperature (Lascar Electronics Inc., Erie, PA USA). The data loggers were set to record the temperature in Celsius once per minute. Data loggers were allowed to record throughout the prescribed burning period and were reclaimed after the burn was complete. Immediately before the prescribed fire, soil moisture data was collected at each burned plot. A Field Scout TDR 300 soil moisture probe was used to measure moisture levels at 4 locations within each plot at 10 cm depth and those numbers were used to determine an average soil moisture for each plot.

1.2.3 Post Fire Sampling

After the prescribed burn, an initial regrowth period of 2 months was allowed before post-fire sampling began. The number of new gallberry sprouts per remaining gallberry stem were counted and an average number of new sprouts per stem was calculated. Each remaining stem's diameter was measured in millimeters with calipers at 10 cm height, and each stem's height was measured in centimeters using a meter stick.
Approximately 9 months after the prescribed burn, another round of data was collected. Stem counts were preformed again using the same methods as pre-fire stem counts. The maximum height of *I. glabra* was also recorded again. LAI measurements were also recollected at the center of each plot at ground level and 150 cm high.

### 1.2.4 Processing

Any test utilizing post-fire data will exclude plot GBRY 32 because the plot failed to burn during the prescribed fire. Soil samples were processed by removing soil from core tubes and placing the soil into labeled aluminum trays for drying. Soil samples were dried in an oven for at least two days to remove moisture. Samples were removed from the oven and weighed. Samples were then ground using a mortar and pestle. The soil was then sieved multiple times using several stages of sieve screen width down to 0.05 mm. This allowed silt and clay particles to be separated from any sand, gravel, or large organic matter. The sieved portions of silt/clay and sand were then weighed again and stored in labeled bags. The percent silt/clay and sand by weight was calculated for each respectively. LAI data was downloaded from the data logger and scattering corrections were applied to each using the FV 2200 software from LiCor Biosciences (LiCor Biosciences Lincoln, Nebraska USA). LAI was determined for each plot at each height level for comparison. Plots GBRY 37 and 38 were excluded from any testing because of user error (missing data). Temperature logger data was retrieved using the EasyLog USB software from Lascar electronics (Lascar Electronics Inc., Erie, PA USA). Using this software, the maximum soil temperature during the burn was determined for each plot. Some plots were excluded because of malfunctions with the data loggers (GBRY 8 and 10) or the temperature probe being exposed directly to the fire (GBRY 39). Litter
samples collected from nearby sites were used to compare litter between burned and unburned areas.

1.2.5 Analysis

All statistical analyses were performed using R statistical software (version 3.4.4). All analyses utilized an alpha level of 0.05. All count data collected were converted to a standardized area of count per square meter. All count data were then transformed using a $\sqrt{x+0.5}$ transformation. All data was checked for normality using Shapiro-Wilk tests. Logarithmic transformations were attempted on any data not normally distributed. Soil percent silt/clay by weight, average soil moisture, and soil surface max temperature were all log$_{10}$ transformed. Preburn and Postburn woody species richness, I. glabra stem diameter, and number of new sprouts were non-normal after transformation attempts and were tested using non-parametric analyses. Litter sample data was converted to a standardized measure of dry weight (g) per square meter.

A Bartlett's test was used to confirm equal variances for unburned gallberry stems/m$^2$ and frequently burned gallberry stems/m$^2$. A one-way analysis of variance test was used to compare I. glabra stems/m$^2$ in unburned and frequently burned areas. Leaf litter weights for these areas were significantly different from normal after attempted transformation. A Mann-Whitney U-test was used to compare dry leaf litter weight for unburned and frequently burned areas.

A Bartlett's test was used to check for equal variances between pre-burn, 2 months post burn, and 9 months post burn gallberry stems/m$^2$. Variances between these groups were significantly different. A Friedman's test for repeated measures was used to compare gallberry stems/m$^2$ for pre-burn, 2 months post burn, and 9 months post burn
sample times. Linear regressions were used to examine any correlation of pre-burn
gallberry stems/m², pre-burn maximum height of gallberry, average stem diameter of
gallberry, pre-burn LAI, soil percent silt/clay by weight, average soil moisture, and
maximum soil surface temperature with gallberry stems/m² at 2 months and 9 months
post burn. A linear regression was also used to check for correlation between post burn
LAI and gallberry stems/m² at 9 months post burn. Common woody species present pre
and post burn were significantly different from normal, even after transformations.
Kruskal-Wallis tests were used to examine possible relationships of pre-burn and post
burn common woody species present with *I. glabra* stems/m² at 2 months and 9 months
post burn. Linear regressions were used to check for correlations of average gallberry
stem diameter and stem height with the average number of new sprouts produced per
stem.

Leaf area index was tested for any change by comparing LAI scores before and
after the prescribed burn. A Bartlett's test was used to confirm equal variance between
groups. A repeated measures analysis of variance was used to test for a significant
change in LAI after the fire. Study plots were used as a block, while measurement height
(0 or 1.5m) and measurement time (pre/post fire) were used as grouping factors.
1.3 RESULTS

The one-way ANOVA test comparing *I. glabra* stems/m$^2$ in unburned and frequently burned plots showed a significantly higher gallberry stem density in frequently burned plots (Figure 2.1). Leaf litter weight was not significantly different (W = 260, p = 0.58) between frequently burned and unburned plots according to a Mann-Whitney U-test.

*Figure 1.2 Frequently Burned vs. Unburned Density Comparison*

A significant difference (Chi$^2$ = 52.04, df = 2, p < 5.1e-12) in gallberry stems/m$^2$ before the prescribed burn, 2 months post burn, and 9 months post burn was detected by the Friedman's test (Figure 3.1). A Conover-Friedman post-hoc test was used to determine which of the three groups were different. *I. glabra* stems/m$^2$ were significantly different ($p^1 < 2e-16$, $p^2 < 2e-16$, $p^3 < 2e-16$) between all three sampling times.
Pre-burn gallberry stems/m² had no significant correlation (F₁,₃⁷= 0.924, p= 0.342, R²= 0.024) with gallberry stem density at 2 months post burn, but did have a significant positive correlation with stem densities at 9 months post burn (Figure 4.1). Pre-burn maximum height of gallberry stems showed no significant correlation with gallberry stems/m² at either post burn sampling time (2 month F₁,₃⁷= 0.006, p= 0.937, R²= 0.0001; 9 month F₁,₃⁷= 0.734, p= 0.397, R²= 0.019). Pre-burn average gallberry stem diameter had a significant negative correlation with gallberry stems/m² at 2 months post burn (Figure 5.1), but not 9 months post burn (F₁,₃⁷= 1.397, p= 0.244, R²= 0.036). Average gallberry stem diameter had a significant positive correlation with the average number of new sprouts produced per stem at 2 months post burn (Figure 5.1), but average gallberry
stem height did not have a significant correlation ($F_{1,37} = 3.405$, $p = 0.073$, $R^2 = 0.084$) with the average number of new sprouts produced per stem at 2 months post burn.

*Figure 1.4 Initial *I. glabra* Density Correlation

![Initial Gallberry Density Correlation](image)

Figure 1.4: Linear regression ($F_{1,37} = 17.62$, $p < 0.0002$, $R^2 = 0.322$) showing the effect of pre-burn *I. glabra* stems/m² ($x = 59.59 \pm 17.05$ stems) on the number of *I. glabra* stems/m² 9 months post burn ($x = 169.28 \pm 77.18$ stems)

*Figure 1.5 Average Gallberry Stem Diameter Correlations*

![Average Stem Diameter Correlation](image)

Figure 1.5: Left: Linear regression ($F_{1,37} = 4.741$, $p = 0.0359$, $R^2 = 0.113$) showing the effect of pre-burn average *I. glabra* stem diameter ($x = 4.84 \pm 0.92$ mm) on the number of *I. glabra* stems/m² 2 months post burn ($x = 108.72 \pm 67.6$ stems). Right: Linear regression ($F_{1,37} = 4.58$, $p = 0.039$, $R^2 = 0.11$) showing the effect of pre-burn average *I. glabra* stem diameter on the average number of new sprouts produced per stem post burn ($x = 2.69 \pm 0.95$ sprouts)
No correlation between pre-burn leaf area index and gallberry densities at 2 months ($F_{3,35}= 0.931, p= 0.435, R^2= 0.073$) or 9 months ($F_{3,35}= 3.236, p= 0.033, R^2= 0.217$) post burn were discovered using linear regression testing. The significant p-value for 9 months post burn was due to low, yet insignificant p-values for pre-burn LAI at 1.5m and the interaction term of the full factorial formula used. Post burn leaf area index had no significant correlation ($F_{3,35}= 1.37, p= 0.269, R^2= 0.11$) with gallberry densities at 9 months post burn. Leaf area index was found to have a significant interaction term ($F_{1,36}= 6.640, p= 0.0113$) when using a repeated measures ANOVA with sample time and sample height as grouping factors and plot as a block. Figure 6.1 illustrates the interaction found by the ANOVA.

Figure 1.6 Leaf Area Index Interaction

![Figure 1.6](image)

Soil percent silt/clay by weight had no significant correlation with gallberry stems/m² at 2 months ($F_{1,37}= 1.001, p= 0.323, R^2= 0.026$) or 9 months ($F_{1,37}= 0.41, p= 0.53$).
0.525, R² = 0.01) post burn. Average soil moisture was found to have no significant correlation to gallberry stems/m² at 2 months (F₁,₃₇ = 1.866, p = 0.18, R² = 0.048) of 9 months (F₁,₃₇ = 3.33, p = 0.075, R² = 0.082) post burn. Maximum soil surface temperature during the fire did have a significant, negative correlation with gallberry stem densities at 2 months post burn (Figure 7.1), but not at 9 months (F₁,₃₄ = 1.058, p = 0.311, R² = 0.03) post burn.

Figure 1.7 Max. Soil Surface Temp. Correlation

Pre-burn common woody species presence had no significant relationship to *I. glabra* stems/m² at 2 months (Χ² = 1.964, p = 0.742) or 9 months (Χ² = 7.904, p = 0.095) post burn. Post burn common woody species presence did have a significant negative correlation with gallberry stem densities at 9 months post burn (Figure 8.1).
Figure 1.8: Whisker plot showing the relationship between post burn common woody species (x= 3.07 +/- 0.92 species) and gallberry stem density at 9 months post burn (x=169.28 +/- 77.18 stems)
1.4 DISCUSSION

The number of gallberry stems/m² was found to be higher in frequently burned areas compared to areas that have remained undisturbed for years. From this data, it can be inferred that a regular fire regime has increased the density of gallberry stems/m² over time. Furthermore, gallberry density was observed increasing in numbers at 2 months and at 9 months after the prescribed fire. Indicating again that prescribed fire seems to have an overall positive effect on gallberry stems/m². Gallberry regrowth shortly after the prescribed fire was correlated with the size of pre-fire gallberry (Figure 04), whereas regrowth at 9 months after the fire was correlated with the relative establishment of gallberry in the plots before the fire (Figure 03). Average gallberry stem diameter before the fire was correlated negatively with gallberry stems/m² at 2 months post fire, but was positively correlated with the average number of spouts produced per stem at 2 months post fire (Figure 04). The negative correlation between stem diameter and gallberry density is most likely because plots containing higher numbers of gallberry stems with larger stem diameters had lower gallberry stems/m² initially. The positive correlation between stem diameter and the average number of new sprouts produced per stem is because larger stem diameters are associated with larger rhizomes. Larger rhizomes have more stored energy for new sprout production after a disturbance.

Leaf area index (LAI) had no correlation overall with gallberry densities returning after the fire. The comparison of LAI before and after the burn gave some insight into shading changes caused by the fire. The significant interaction detected by an ANOVA (Figure 05) was caused by an increase in LAI at ground level and a decrease at 1.5m height after the fire. This means that the LAI at 1.5m high likely changed as a result of
the prescribed burn killing other native woody shrub/tree species that grow over 1.5 meters tall. This reduces the overall vegetative cover over 1.5m aboveground. This could be associated with the negative relationship seen between gallberry stems/m² and the number of common woody species present in each plot post burn.

Soil texture and soil moisture are generally correlated because increasing silt and clay percentages in soil usually increases the water holding capacity of the soil. Linear regressions for the relationship of gallberry densities with soil percent silt/clay by weight and soil moisture resulted in no significant correlations. This may be due to a largely similar soil texture across the study site, especially the areas where plots were located. Expanding this study to other sites with varying habitats/soil types could shed more light on any correlation that may be associated with edaphic features of the soil. Maximum soil surface temperature did have a significant correlation with gallberry densities at 2 months post fire (Figure 06). The higher temperatures the soil surface reached during the fire significantly reduced the number of resprouting gallberry at 2 months post burn.

From this study, management of *Ilex glabra* can be advanced by several findings. Early gallberry management is important since returning densities are highly correlated with pre-burn densities. Prescribed burning should be managed in order to increase the intensity and/or residency time of the fire in order to heat the soil surface enough to potentially damage gallberry rootstocks. Further research is required to discover a more definitive relationship between any of the examined factors and the number of *I. glabra* stems/m². Other studies looked at the growth of gallberry over a longer period of time (Brockway and Lewis, 1997; Burton and Hughes, 1961; Lemon, 1943; Schmalzer and Hinkle, 1992). Extending monitoring/sampling time would provide better data for the
ecology overall. As the Brockway and Lewis (1997) study suggests, the seasonality of the prescribed fire may have the most significant effect on its regrowth. Future research should investigate the effects of the seasonality of the prescribed fire so better comparisons can be made to the aforementioned studies. Collecting ground leaf litter samples from each plot would help achieve a more accurate measure of fuel loading. Even further, collection of fuel caught in the standing gallberry vegetation would also account for above ground leaf litter fuels. Slope degree, using a clinometer, would also be valuable data that could add to topographical factors affecting gallberry growth. Most importantly, expanding the study to other *Pinus palustris* forest types would allow for a range of gallberry/longleaf pine habitats to be compared.
REFERENCES


