HERBIVORY IMPACTS ON GROWTH AND SURVIVAL OF SEEDLINGS IN BOTTOMLAND HARDWOOD FOREST RESTORATION SITES IN THE POST OAK SAVANNAH AND BLACKLAND PRAIRIE ECOREGIONS OF TEXAS, USA

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HERBIVORY IMPACTS ON GROWTH AND SURVIVAL OF SEEDLINGS IN BOTTOMLAND HARDWOOD FOREST RESTORATION SITES IN THE POST OAK SAVANNAH AND BLACKLAND PRAIRIE ECOREGIONS OF TEXAS, USA

By

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Presented to the Faculty of the Graduate School of

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ABSTRACT

Interest in bottomland hardwood forests (BLHW) ecology and restoration has increased over the past 40 years. These communities aid in water quality improvement, streambank stabilization, and urban expansion mitigation. They also provide important habitat for many species of wildlife. Since the majority of remaining BLHW are degraded due to land fragmentation, restoration attempts are becoming commonplace within the Western Gulf Coastal Plain. However, restoration success has been mixed, with managers observing survival rates of <15% for desirable species due to various factors. Over two growing seasons, I investigated multiple factors that have potential to limit BLHW restoration success in East Texas. Specifically, I tested the impacts of herbivory by white-tailed deer (*Odocoileus virginianus*) and feral swine (*Sus scrofa*) on Nuttall oak (*Quercus texana* Buckley), Shumard oak (*Q. shumardii* Buckley), bur oak (*Q. macrocarpa* Michx.), and pecan (*Carya illinoinensis* K. Koch) at BLHW restoration sites at four study areas in east Texas. I also tested the effectiveness of portable electric fences and individual tree shelters in protecting seedlings from herbivory. Herbivory was not the major contributor to seedling mortality, but where it occurred, all protected areas demonstrated higher survival ($\bar{x} = 17\%$) than non-fenced areas ($\bar{x} = 9\%$). Feral swine were the major contributors to herbivory, while white-tailed deer did not cause notable
amounts of seedling mortality. In areas of high white-tailed deer density, prominent browsing was evident, resulting less growth after two years in non-fenced ($x = 2.3$ cm) and electric fenced ($x = 4.3$ cm) plots compared to high fence ($x = 13.0$ cm) and individual tree shelters ($x = 24.2$ cm). In addition to seedling survival and growth, we observed reduced survival rates ($<10\%$) on sites that were inundated more than 40 days during the growing season. Matching species of interest to the site conditions, specifically local hydrologic regimes, should carry a higher priority in planning a restoration project within BLHW in the Western Gulf Coastal Plain.
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TABLE OF CONTENTS

ABSTRACT .................................................................................................................................i

ACKNOWLEDGMENTS ..................................................................................................................iii

TABLE OF CONTENTS ..................................................................................................................iv

LIST OF FIGURES .......................................................................................................................vi

LIST OF TABLES ..........................................................................................................................viii

LIST OF APPENDICES ................................................................................................................x

CHAPTER I. INTRODUCTION TO BOTTOMLAND HARDWOOD RESTORATION RESEARCH WITHIN THE WESTERN GULF COASTAL PLAIN ......................................................1

INTRODUCTION ..............................................................................................................................2

LITERATURE CITED .......................................................................................................................12

CHAPTER II. INFLUENCE OF WHITE-TAILED DEER AND FERAL SWINE HERBIVORY ON BOTTOMLAND HARDWOOD RESTORATION SITES IN DEGRADED RIVER BASINS IN EAST TEXAS ...........................................................18

ABSTRACT ..................................................................................................................................19

INTRODUCTION ..............................................................................................................................21

STUDY AREA ................................................................................................................................27

METHODS

Experimental Design ....................................................................................................................29
LIST OF FIGURES

Figure 2.1. Locations of four study sites used for bottomland hardwood restoration studies in the (A) Blackland Prairie and Post Oak Savannah ecoregions and (B) Sulphur, Sabine, and Trinity River basins of east Texas in 2015 and 2016. ...........................................................................................................................................73

Figure 2.2. Theoretical site layout at one of the four properties. Blocks 1, 2, 4, and 5 contained all mitigation treatment treatments while Blocks 3 and 6 did not have 2.4 m woven wire fences. Replanted 2016 Freestone replaced bur oak with Nuttall oak and Block 4 did not contain an individual tree shelter mitigation treatment.................................................................................................................................74

Figure 2.3. Theoretical layout of one block within one of the canopy cover types depicting individual seedlings at the species level for each mitigation treatment. Red boxes represent inside 20 seedlings that were analyzed for growth..................................................................................................................................................75

Figure 2.4. Richland Creek WMA, Freestone County, Texas. 636 m by 636m grid overlay depicting the effective survey area of the 2015 wildlife density surveys using baited trail camera stations ........................................................................................................................................76

Figure 2.5. Cooper 4D Ranch, Hopkins County, Texas. 636 m by 636m grid overlay depicting the effective survey area of the 2015 wildlife density surveys using baited trail camera stations ........................................................................................................................................77

Figure 2.6. Lyons-McKenney Ranch, Hunt County, Texas. 636 m by 636m grid overlay depicting the effective survey area of the 2015 wildlife density surveys using baited trail camera stations ........................................................................................................................................78

Figure 2.7. Johnson Ranch, Anderson County, Texas. 636 m by 636m grid overlay depicting the effective survey area of the 2015 wildlife density surveys using baited trail camera stations ........................................................................................................................................79

Figure 2.8. Mean percent survival of bur oak, Shumard oak, and pecan seedlings planted in 2015 across 2 canopy cover types and 4 herbivory
mitigation treatments at 4 sites in east Texas (letters denote difference across treatments at $\alpha = 0.10$)

Figure 2.9. Mean percent survival of Nuttall oak, Shumard oak, and pecan seedlings planted in 2016 across 2 canopy covers and 4 herbivory mitigation treatments at the Freestone study location in east Texas (letters denote difference across treatments at $\alpha = 0.10$)

Figure 2.10. Mean percent survival for the 2016 Freestone seedlings at the species level after the first growing season (letters denote significant differences at $\alpha = 0.10$)

Figure 2.11. Replanted 2016 Freestone location: mean total change in height (with standard error) for each species within each mitigation treatment at the different canopy cover types after one growing seasons. In total, 14 Shumard were alive for analysis. Standard Error = 0 due to $n=1$ for that treatment

Figure 2.12. Study location Hunt within the forested area, (A) dense vegetation with increased number of preferred browse species within 2.4m woven wire high fence, (B) non-fenced area consisting of a minor herbaceous layer

Figure 2.13. Simple linear regression for seedling survival at different number of day inundated during the (A) 2015 growing season and (B) after the 2015 and 2016 growing season
LIST OF TABLES

Table 2.1. Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2015 analyzing arcsine square root transformed percent survival of the species with each mitigation treatment two months post planting, after the 2015 growing season, and after the 2016 growing season ..........................................................86

Table 2.2. Days seedlings submerged using estimated USGS surface water gauge height at each study location ...........................................................................................................................................87

Table 2.3. Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2016 at the Freestone study location analyzing arcsine square root transformed percent survival of the species with each mitigation treatment two months post planting and after the 2016 growing season ...........................................................................................................................................87

Table 2.4. Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2015 analyzing seedling height, diameter, volume index, and stand volume index two months post planting ...........................................................................................................................................88

Table 2.5. Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2015 analyzing the change in seedling height, diameter, volume index, and stand volume index over the 2015 growing season ...........................................................................................................................................89

Table 2.6. Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2015 analyzing the change in seedling height, diameter, volume index, and stand volume index over the 2016 growing season ...........................................................................................................................................90

Table 2.7. Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2015 analyzing the total change in seedling height, diameter, volume index, and stand volume index over 2015 and 2016 growing seasons ...........................................................................................................................................91

Table 2.8. Results of deer browse survey within Hunt’s forested area Fall, 2017, including mean tips browsed and tips available for each mitigation
treatment. Recorded occurrences of Shumard oak, bur oak, and pecan are seedlings planted as part of the project. 

Table 2.9. Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2016 at the Freestone study location analyzing seedling height, diameter, volume index, and stand volume index two months post 2016 planting 

Table 2.10. Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2016 at the Freestone study location analyzing seedling change in height, diameter, volume index, and stand volume index after the 2016 growing season 

Table 2.11. Results of 14-day trail camera survey conducted at each study location from late August to early September, 2015
LIST OF APPENDICES

Appendix A. Tukey’s multiple comparisons test on mean seedling survival (%) for seedlings planted in 2015 at the four study locations and in 2016 at the Freestone study location. Letters denote differences among means within the same source of variation per measure period at $\alpha = 0.10$ .........................................................96

Appendix B. Tukey’s multiple comparisons test on initial height, diameter, VI, and SVI two months post planting for seedlings planted in January, 2015. Letters denote differences among means within the same source of variation per measure period at $\alpha = 0.10$ .................................................................................................101

Appendix C. Tukey’s multiple comparisons test on the change in seedling height, diameter, VI, and SVI over the 2015 growing season for seedlings planted in January, 2015. Letters denote differences among means within the same source of variation per measure period at $\alpha = 0.10$ .................................................................................................106

Appendix D. Tukey’s multiple comparisons test on the change in seedling height, diameter, VI, and SVI over the 2016 growing season for seedlings planted in January, 2015. Letters denote differences among means within the same source of variation per measure period at $\alpha = 0.10$ .................................................................................................111

Appendix E. Tukey’s multiple comparisons test on the change in seedling height, diameter, VI, and SVI over the 2015 and 2016 growing season for seedlings planted in January, 2015. Letters denote differences among means within the same source of variation per measure period at $\alpha = 0.10$ .................................................................................................115

Appendix F. Tukey’s multiple comparisons test on initial seedling height, diameter, VI, and SVI two months post planting for seedlings planted in January, 2016. Letters denote differences among means within the same source of variation per measure period at $\alpha = 0.10$ .................................................................................................119

Appendix G. Tukey’s multiple comparisons test on the change in seedling height, diameter, VI, and SVI over the 2016 growing season for seedlings planted in January, 2016. Letters denote differences among means within the same source of variation per measure period at $\alpha = 0.10$ .................................................................................................122

Appendix H. Descriptive statistics for percent survival two months post planting (Time Interval = 0), percent survival from time of plant to the end of
the 2015 growing season (Time Interval= 1), and final percent survival from
time of planting to the end of the 2016 growing seasons (Time Interval = 2) ..........125

Appendix I. Descriptive statistics for percent survival two months post
planting (Time Interval = 0) and percent survival after the first growing
season (Time Interval = 1) for the seedlings planted at Freestone in January,
2016. All seedlings survived initial two months ........................................126

Appendix J. Descriptive statistics for height (cm) two months post planting
(Time Interval = 0), change in height (cm) over the 2015 growing season
(Time Interval= 0-1), change in height (cm) over the 2016 growing season
(Time Interval = 1-2), and total change in height (cm) over the course of the
2015 and 2016 growing seasons (Time Interval = 0-2) .....................................127

Appendix K. Descriptive statistics for diameter (cm) two months post planting
(Time Interval = 0), change in diameter (cm) over the 2015 growing season
(Time Interval= 0-1), change in diameter (cm) over the 2016 growing season
(Time Interval = 1-2), and total change in diameter (cm) over the course of
the 2015 and 2016 growing seasons (Time Interval = 0-2) ..................................129

Appendix L. Descriptive statistics for volume index (cm$^3$) two months post
planting (Time Interval = 0), change in volume index (cm$^3$) over the 2015
growing season (Time Interval= 0-1), change in volume index (cm$^3$) over the
2016 growing season (Time Interval = 1-2), and total change in volume index
(cm$^3$) over the course of the 2015 and 2016 growing seasons (Time Interval =
0-2)......................................................................................................................131

Appendix M. Descriptive statistics for stand volume index (m$^3$/ha) two
months post planting (Time Interval = 0), change in stand volume index
(m$^3$/ha) over the 2015 growing season (Time Interval= 0-1), change in stand
volume index (m$^3$/ha) over the 2016 growing season (Time Interval = 1-2),
and total change in stand volume index (m$^3$/ha) over the course of the 2015
and 2016 growing seasons (Time Interval = 0-2).....................................................133

Appendix N. Descriptive statistics for mean height (cm) two months post
planting (Time Interval = 0) and mean change in height (cm) from two
months post planting to 12 months post planting (Time Interval = 0 to 1) for
the seedlings planted at Freestone in January, 2016 ........................................135
Appendix O. Descriptive statistics for mean diameter (cm) two months post planting (Time Interval = 0) and mean change in diameter (cm) from two months post planting to 12 months post planting (Time Interval = 0 to 1) for the seedlings planted at Freestone in January, 2016 .................................................................136

Appendix P. Descriptive statistics for mean volume index (cm$^3$) two months post planting (Time Interval = 0) and mean change in volume index (cm$^3$) from two months post planting to 12 months post planting (Time Interval = 0 to 1) for the seedlings planted at Freestone in January, 2016 .................................................................137

Appendix Q. Descriptive statistics for mean stand volume index (m$^3$/ha) two months post planting (Time Interval = 0) and mean change in stand volume index (m$^3$/ha) from two months post planting to 12 months post planting (Time Interval = 0 to 1) for the seedlings planted at Freestone in January, 2016 ..................................................................................................................................................................................138
CHAPTER I:
INTRODUCTION TO BOTTOMLAND HARDWOOD RESTORATION RESEARCH WITHIN THE WESTERN GULF COASTAL PLAIN
INTRODUCTION

Bottomland hardwood forests (BLHW) are wetlands that create a riparian corridor adjacent to rivers and streams of various orders in the Gulf and Atlantic coastal plains of the southeast (King and Keeland, 1999). These forested communities are associated with floodplains that have minimal change in topography, creating poorly drained, alluvial floodplains that have characteristic nutrient-rich soils dominated by clay or silty-clay (Taylor et al., 1990; Rudis, 2001). It was not until the 1989 version of the collaborative manual for describing and delineating wetlands created by the Army Corps of Engineers, Environmental Protection Agency, US Fish and Wildlife Service, and Soil Conservation Service that many BLHW were considered and defined as wetlands, increasing their federal protection under the Clean Water Act of 1977 (Kellison and Young, 1997). They were once a prominent ecosystem with 23.5 million hectares distributed across the south central and south eastern United States, but have been reduced by about half (Turner et al., 1981; Brinson and Malvárez, 2002).

Bottomland hardwood forests are diverse ecosystems capable of providing suitable habitat that supports a wide array of wildlife (Rudis, 1995) as well as travel corridors for migratory species (Perkins et al., 2003). These areas are hydrologically diverse, containing many features, such as sloughs, eddies, oxbows, and natural levees (Brinson et al., 1981; Taylor et al., 1990). For reasons such as these, some consider BLHW among the most important habitats to maintain for wildlife (Clark and Benforado,
2012). This diversity supports a variety of game and non-game species of fish and wildlife (Taylor et al., 1990; King and Keeland, 1999). Economically important game species include catfishes (Clariidae), gars (Lepisosteidae), black basses (Micropterus spp.), rabbits (Sylvilagus spp.), wood duck (Aix sponsa) and other waterfowl, wild turkey (Meleagris gallopavo), white-tailed deer (Odocoileus virginianus) and many furbearer species (Taylor and Lay, 1944; Brinson et al., 1981; Allen, 1985; Taylor et al., 1990; Wigley and Roberts, 1994; Allen et al., 2014).

Important threatened species and species of concern that use the unique structure of BLHW include Louisiana black bear (Ursus americanus luteolus), Rafinesque’s big-eared bat (Corynorhinus rafinesquii), and southeastern myotis (Myotis austroriparius; Wigley and Roberts, 1997; Gooding et al., 2004; Benson and Chamberlain, 2007; Stuemke et al., 2014). Bottomland hardwood forests also support avian communities made up of approximately 70 species, with the majority being long-distance, Neotropical migrants. Some are considered species of concern due to the decline and degradation of their preferred habitat including prothonotary warbler (Protonotaria citrea), Swainson’s warbler (Limnothlypis swainsonii), Kentucky warbler (Geothlypis formosa), and yellow-billed cuckoo (Coccyzus americanus; Wigley and Roberts, 1994; Wigley and Roberts, 1997; Donovan et al., 2002; LMVJV Forest Resource Conservation Working Group, 2007).
In addition to supporting a diverse wildlife assemblage, these corridors, including their hydrologically diverse features, act as long- and short-term nutrient filters and sinks (Lowrance et al., 1984) that process nutrients such as phosphorus, calcium, magnesium, sodium, and potassium (Taylor et al., 1990) as well as nitrogen from a variety of inputs (Lowrance et al., 1984). Additionally, they aid in filtering and storing contaminants and pollutants from point and non-point sources, thus increasing the overall quality of local water supplies (Lowrance et al., 1984). Watersheds that contain BLHW and other types of wetlands have a substantially increased amount of dissolved organic carbon and particulate organic carbon compared to watersheds and drainage basins of upland areas (Mulholland and Kuenzler, 1979; Brinson et al., 1981). Bottomland hardwood forests and other wetland types are able to store organic carbon and other nutrients during low water output periods and release varying amounts during high water events (Brinson, 1993). These filters and sinks allow for the consistent release of organic carbon material to areas downstream (Mulholland and Kuenzler, 1979; Taylor et al., 1990).

In recent decades, BLHW have been a minor source of timber production in the southern United States with focus shifting to intensively managing pine plantations (Fox et al., 2007). However, prior to recent concerns regarding restoration they were considered economically important and produced $3-$5 billion in hardwood timber annually (Gosselink and Lee, 1989). Even-aged management via clearcutting was one of
the most commonly used harvest and regeneration methods because it would allow for economically important, shade intolerant species such as Shumard oak (*Quercus shumardii* Buckley), Nuttall oak (*Q. nuttallii* Buckley), and cherrybark oak (*Q. pagoda* Raf.) to regenerate within the newly opened areas (Wigley and Roberts, 1994; Meadows and Stanturf, 1997; Twedt and Somershoe, 2013). Land was also frequently converted from BLHW to agricultural fields, areas for urban development, or pine plantations for more economical timber production (McWilliams and Rosson, 1990; Wigley and Roberts, 1994; Wigley and Roberts, 1997). By 1978, the Lower Mississippi Alluvial Plain and East Texas lost major portions of BLHW (Allen *et al.*, 2001)—about 80% (MacDonald *et al.*, 1979) and 60% (Frye, 1987), respectively.

Restoring and preserving BLHW by converting alluvial floodplain areas back into hardwood forests has become a priority in the West Gulf Coastal Plain and Lower Mississippi Alluvial Plain (Sweeney *et al.*, 2002; Twedt and Wilson, 2007). These areas’ local and regional importance to the riverine ecosystems has helped create a push for landowners to attempt conversion of retired agricultural fields back to ecologically functioning BLHW (King and Keeland, 1999). Additionally, there has been a push to enhance the encompassing structure, species composition, and overall size of standing BLHW using silvicultural treatments (Ketzler *et al.*, 2017).

Despite increased interests in restoring degraded BLHW and expanding BLHW by converting abandoned and retired agricultural fields back to BLHW, the attempts to do
so have shown overall mixed results with success being both limited and unpredictable (Stanturf *et al.*, 2001). Factors limiting the majority of restorations have been identified and classified as controllable and uncontrollable factors (Hodges, 1997; Allen *et al.*, 2001). Controllable factors include seed stock quality, species selection to match site characteristics, vegetation competition control, and planting procedures (Allen *et al.*, 2001; Stanturf *et al.*, 2001). Natural factors, such as the annual variation in flooding, drought, and herbivory intensities (Allen *et al.*, 2001), cannot be controlled but can be understood at the site level to determine how they may impact a particular site. Understanding these details at the site level will increase restoration success by providing information to select more appropriate species or mitigation measures on that site (Hodges, 1997).

Within the Western Gulf Coastal Plain, specifically the eastern portion of Texas, there have been restoration attempts to increase the presence of native oaks and hickories that produce large hard mast and, thus, increase the habitat value for wildlife. Since 1996 there have been five large scale research attempts on BLHW restorations at Richland Creek Wildlife Management Area (RCWMA) located in Freestone County, Texas along the Trinity River. The majority have resulted in less than desirable survival (Frentress *et al.*, 1997; Symmank, Unpublished Data). The management area is 14,238 acres and falls within the transition zone between the Post Oak Savanah and Blackland Prairie ecoregions. Green ash (*Fraxinus pennsylvanica* Marshall), sugarberry (*Celtis*
laevigata Willd.), and cedar elm (Ulmus crassifolia Nutt.) are the dominant tree species throughout the bottomland hardwood areas (Oliver et al., 2017; Symmank, Unpublished Data). RCWMA, managed by Texas Parks and Wildlife (TPWD), is considered representative of the hundreds of thousands of acres throughout the Trinity, Red, Sabine, and Sulphur River basins.

In 1996, 81 hectares within a forested area were under-planted with five native species (e.g., bur oak (Q. macrocarpa Michx.), overcup oak (Q. lyrata Walter), Shumard oak, water oak (Q. nigra L.), and pecan (Carya illinoinsis K. Koch)) at 150 seedlings per acre. Low survival of bur oak (11.5%), overcup oak (6.8%), Shumard oak (22.4%), water oak (2.0%), and pecan (2.2%) were observed primarily due to drought conditions experienced throughout the 1996 growing season. Additional mortality was due to herbivory by feral swine, white-tailed deer, and swamp rabbits as well as the rooting behavior of feral swine. The project estimated an overall survival of about 16 seedlings per acre (Frentress et al., 1997).

In 1997, an alternative approach was attempted using more developed containerized saplings planted on 7.7 hectares. Saplings were continuously monitored and watered for 3 years resulting in more than 80% survival. Once watering procedures concluded all of the containerized trees expired, resulting in 100% mortality.

In 2001, 329,000 bare root oak and hickory seedlings were planted on 1,189 acres of open field as part of a project funded by the carbon sequestration investors.
Survival surveys conducted after subsequent growing seasons showed the attempt resulted in 0% survival (Symmank, Unpublished Data).

More recently in 2011, RCWMA staff installed research plots to assess the survival of bur oak, overcup oak, Shumard oak, and pecan on sites that consisted of mowed fields, burned fields, forested ridges consisting of an average 70% canopy cover, and forested swales consisting of an average 87% canopy cover. Staff followed strict planting and seedling storage procedures to reduce mortality. Clipping seedlings’ stem area by 30% to 50% to reduce root to shoot ratio was also tested for each species. Over the course of the first growing season the area received an estimated 19.2 cm of rain, about 40.6 cm less than average. Overall, less than 1% survived in the mowed field, burned field, and forested ridge for all species, after the first growing season. Clipped Shumard oak (37% survival) seedlings did significantly better than unclipped (15% survival) seedlings. Bur oak produced acceptable survival at 46% for clipped and unclipped seedlings. Overcup oak (0% survival) and pecan (1% survival), clipped and unclipped, showed similar results to the seedlings within the mowed field, burned field, and forest ridge (Symmank, Unpublished Data).

In 2014, TPWD and Stephen F. Austin State University initiated a pilot restoration project on three sites at RCWMA using bur oak, Shumard oak, and pecan 1-0 bare root seedlings within forested areas and full unaltered canopy covers. After the first growing season, pecan experienced 100% mortality due to feral swine on two sites within
partially forested and forested areas. Bur oak and Shumard oak experienced about 20% and 15% mortality due to feral swine, respectively. Herbivory by feral swine was lower on the third site with pecan experiencing 15% and bur and Shumard oak experiencing 5% mortality. Overall, the sites experienced a higher rainfall total than past attempts. From March 1, 2014 to September 31, 2014, RCWMA received about 38.1 cm, 22.9 cm less than average. They also observed higher survival rates of pecan (21%), bur oak (40%), and Shumard oak (55%) than previous research and mitigation projects conducted on RCWMA. This research also showed that at the site level, it is possible for feral swine to cause enough damage to preferred species to render a restoration attempt unsuccessful (Oliver et al., 2017).

Richland Creek Wildlife Management Area staff and the Texas Parks and Wildlife Department are determined to make large mast producing oaks and hickories a dominant part of the over-story at RCWMA. They also want to be able to provide guidelines to private land owners in the area that seek to enhance the oak and hickory component of their BLHW. They have attempted to refine methodologies for successful bottomland hardwood forest restoration to be used in areas throughout east Texas. Their work has resulted in 0% survival in multiple attempts using a variety of approaches to about 38% survival after one growing season within forested areas using bur oak, Shumard oak, and pecan. Their recent first year success provided information that drought conditions are not the only major factor that can result in restoration failure.
Herbivory and disturbance by wildlife, such as feral swine, can result in sufficient mortality to decrease the success potential of a restoration site.

To assess how to increase seedling survival during suitable growing season conditions, TPWD partnered with Stephen F. Austin State University to test a variety of wildlife mitigation techniques and to expand their study range by using multiple sites found within three watersheds (i.e., Trinity, Sabine, and Sulphur) and two ecoregions (i.e., Post oak Savanah and Blackland Prairie). I replicated a nested split-split-plot design across four study locations, two along the Trinity River and one along the Sabine and Sulphur Rivers’. I planted 1-0 bare root bur oak, Shumard oak, and pecan seedlings within a non-forested and forested area containing non-fenced, 2.4m woven wire high fence, portable electric fence, and individual tree shelters treatments. I replanted one of the Trinity River sites after the first growing season with Nuttall oak, Shumard oak, and pecan while retaining the respective treatments at the non-forested and forested areas. Initial seedlings were monitored for two years while the replanted seedlings were monitored for one year. Height, diameter, survival, and cause of mortality were recorded two months post planting, after the first growing season for the initial and replanted seedlings, and after the second growing season for the initial seedlings. Supplemental information was collected on white-tailed deer and feral swine densities at each location as well as inundation duration over the two year period. Gaining information on how BLHW restoration attempts respond on multiple study locations will
increase the confidence decision makers have at the state and local level, allowing them to provide detailed guidelines on how to increase diversity of desirable species throughout degraded BLHW and retired agricultural fields or pasturelands.
LITERATURE CITED


composition: proceedings of a symposium held during the Natural Areas Conference.


CHAPTER II:

INFLUENCE OF WHITE-TAILED DEER AND FERAL SWINE HERBIVORY ON BOTTOMLAND HARDWOOD RESTORATION SITES IN EAST TEXAS
ABSTRACT

Bottomland hardwood forests (BLHW) are increasingly subject to active management for water quality improvement, streambank stabilization, to mitigate for urban expansion, and to improve habitat for wildlife. Since the majority of remaining BLHW are degraded, restoration attempts are becoming commonplace within the Western Gulf Coastal Plain. However, restoration success in terms of obtaining high stem densities of desirable species has been mixed, with managers observing survival rates <15% for planted oak and hickory seedlings due to a variety of limitations. Over two growing seasons, I investigated herbivory impacts of white-tailed deer (*Odocoileus virginianus*) and feral swine (*Sus scrofa*) along with the effectiveness of portable electric fences, individual tree shelters, 2.4 m woven wire high fences, and non-fenced areas. Treatments fell within degraded forested areas and abandoned agricultural fields testing four species of interest: Nuttall oak (*Quercus texana* Buckley), Shumard oak (*Q. shumardii* Buckley), bur oak (*Q. macrocarpa* Michx.), and pecan (*Carya illinoinensis* K. Koch). Where herbivory occurred, mitigation techniques produced a higher survival rate (\(\bar{x} = 17.6\%\)) than unprotected areas (\(\bar{x} = 9.1\%\)). In areas of high white-tailed deer density, prominent browsing was evident, resulting in two-growing-season height growth of seedlings being less in non-fenced (\(\bar{x} = 2.33\) cm) and electric (\(\bar{x} = 4.33\) cm) fenced plots.
compared to high fences ($\bar{x} = 13.02$ cm) and individual tree shelters ($\bar{x} = 24.23$ cm).

Additionally, we observed a negative relationship between survival and the number of days inundated during the growing season. Matching species of interest to the site conditions, specifically the local hydrologic regimes, should carry a high priority in planning a restoration project within BLHW in the Western Gulf Coastal Plain.
INTRODUCTION

Bottomland hardwood forests (BLHW) are complex ecosystems that not only are important vegetation types for a diverse range of wildlife, but also provide important ecosystem services such as water quality enhancement, erosion control, water storage, and nutrient cycling (Hodges, 1997; Kellison and Young, 1997; Sweeney et al., 2002). They are defined as forested wetlands that are periodically inundated, usually annually, due to the seasonal overflow of streams, backwater flooding from adjacent rivers, or runoff from large precipitation events during the early- to mid-growing season (Kellison and Young, 1997). They contain minimal topographic relief and are considered poorly drained, alluvial floodplains that have characteristic nutrient-rich clay or silty-clay soils (Taylor et al., 1990; Rudis, 2001).

BLHW were once a prominent ecosystem covering 23.5 million hectares along the rivers and streams in the Atlantic and Gulf Coastal Plains of the south-central and southeastern United States (Fenneman, 1938; Turner et al., 1981). Over the past 100 years, half have been lost due to land conversion for urban development and agricultural row crop use (McWilliams and Rosson, 1990; Kellison and Young, 1997; Brinson and Malvárez, 2002). Additionally, major portions of what is left have been degraded due to unsustainable timber management, such as high grading (Sweeney et al., 2002). By 1978, the Lower Mississippi Alluvial Valley (LMAV) and East Texas had lost
about 80% (MacDonald et al., 1979) and 60% (Frye, 1987), respectively, of their BLHW (Allen et al., 2001).

Tree species that can survive and thereby increase the ecological function of BLHW are flood tolerant or moderately flood tolerant, and are able to withstand variation in soil moisture ranging from inundation to droughty conditions. In particular, tree species like river birch (Betula nigra L.), red maple (Acer rubrum L.; Sweeney et al., 2002), and flood tolerant oaks (Quercus spp.) and hickories (Carya spp.; Battaglia et al., 2008) can aid in river bank stabilization, provide aboveground vertical structure, and in some cases provide seasonal mast for wildlife consumption. Typically, the natural composition of natural southern BLHW will reach a climax successional stage consisting mainly of an elm-ash-sugarberry (Ulmus Americana – Fraxinus pennsylvanica – Celtis laevigata or occidentalis) complex (Hodges, 1997; Allen et al., 2001), while retaining a minor oak-hickory component of 12 to 25 mature, mast producing trees per hectare (Goodrum et al., 1971).

Healthy BLHW support a diversity of wildlife because they provide horizontal and vertical structural complexity, thus creating many available niches (Kellison and Young, 1997; Stanturf et al., 2001; Twedt and Wilson, 2007). For example, within BLHW along the Roanoke River in North Carolina, Sallabanks et al. (2000) recorded 69 species of birds during monitoring censuses in 1992 and 1993. This included Neotropical migrants, short-distance migrants, coastal migrants, and permanent residents. They also observed
high densities of Prothonotary Warblers (Protonotaria citrea) and Acadian Flycatchers (Empidonax virescens), as well as moderate densities of Cerulean Warblers (Dendroica cerulea), Swainson’s Warblers (Limnothlypis swainsonii), and American Redstarts (Setophaga ruticilla).

Voluntary programs, such as the Wetlands Reserve Program (WRP), Conservation Reserve Program (CRP), and Healthy Forest Reserve Program (HFRP) developed by the USDA Natural Resources Conservation Service (NRCS), have provided financial assistance and professional recommendations to landowners that choose to restore degraded wetlands and BLHW that have lost their ecological function and structure. However, community restoration involves uncertainties and is not always successful in restoring all ecological processes (Schoenholtz et al., 2001). For example, species of interest may not be able to travel to and locate a newly restored area, or the newly restored area may not persist (Morris et al., 2006; Moilanen et al., 2009).

Incentive programs focus on protecting endangered species, increasing biodiversity, and enhancing carbon sequestration (Stanturf et al., 2001). Some recommendations and guidelines within the LMAV and Atlantic Coastal Plain (ACP) include desired forest conditions that contain acceptable minimum stocking densities after three growing seasons ranging from 309 seedlings/ha to 494 seedlings/ha to be deemed a successful restoration (Stanturf et al., 2001; LMVJV Forest Resource Conservation Working Group, 2007; Stanturf et al., 2009). These minimum stocking rates are higher than historical
densities and create an unnatural composition, but provide additional food for wildlife and would allow for a commercial pulpwood thinning that would provide opportunities to later shape stand structure with additional management activities (Goodrum et al., 1971; Allen et al., 2001; Stanturf et al., 2001).

Several factors have been identified that influence success of a BLHW restoration project (Stanturf et al., 2001), including tree tolerance to flooding, light requirements, herbivory, seedling quality from nurseries or sowing practices, tree composition impacts on site ecology, and inter- and intra-specific competition (Hodges, 1997; Henderson et al., 2009). Some of these factors are independent of management actions, thus creating unpredictable impacts regardless of silvicultural treatment. For example, flood events impact all seedlings planted at a given elevation. Other factors, including animal behavior and herbivory, can be mitigated by silvicultural or other management activities (Sweeney et al., 2002).

In recent decades there has been increased interest in identifying the primary factors that influence success of forest restoration projects (Sweeney et al., 2002; Heimann and Mettler-Cherry, 2004; Lockhart et al., 2005). Heimann and Mettler-Cherry (2004) determined that elevation, flood duration, and soil texture were the first and most important factors to consider when determining hardwood species composition for restoration in a specific location. However, many agree that vegetative competition
and herbivory are the main controllable factors to increase restoration success (Sweeney et al., 2002; Stanturf et al., 2004; Henderson et al., 2009).

In the south central region of the United States within the Western Gulf Coastal Plain (WGCP) and the LMAV, potential contributors to herbivory on seedlings include: beaver (Castor canadensis; Stanturf et al., 2000), nutria (Myocastor coypus; Stanturf et al., 2000), rabbit (Sylvilagus spp.; Stanturf et al., 2000), white-tailed deer (Odocoileus virginianus; Stanturf et al., 2000; Henderson et al., 2009) and feral swine (Sus scrofa; Mayer et al., 2000; Stanturf et al., 2004). Specifically, white-tailed deer and feral swine have been the major contributors in most cases, causing negative impacts on seedling performance and survival at restoration sites (Alverson et al., 1988; De Steven, 1991; Mayer et al., 2000). Each have wide distributions with varying densities throughout the southern United States (Mayer et al., 2000; Russell et al., 2001).

In particular, feral swine have increased their national distribution from viable populations in 27 states in 2000 (Mayer et al., 2000) to viable populations in at least 37 states in 2014 (Müller et al., 2011, United States Department of Agriculture 2015). Mayer et al. (2000) observed significant predation due to feral swine uprooting and eating rootstocks of seedlings during the first year after planting in a wetland restoration area in west-central South Carolina. Significant herbivory by white-tailed deer also causes increased mortality and stunted growth of hardwood seedlings within naturally and artificially regenerated restoration projects (De Steven, 1991; Russell et
al., 2001; Henderson et al., 2009; Stanturf et al., 2009). These species can limit restoration success at many sites, but the degree of impact varies depending on local population densities, tree species, and other factors. Consequently, understanding ways to predict and mitigate negative impacts of herbivory on BLHW seedlings can help to improve restoration success.

Various techniques are available and have been used to protect seedlings during early establishment, but they vary widely in cost, ease of implementation, and efficacy (Seamans and VerCauteren, 2006). Methods include various arrays of permanent electric fences, permanent and temporary high fence structures, shelters or small fences that protect individual seedlings, and local wildlife density reduction to reduce impacts on seedling survival (Sweeney et al., 2002; VerCauteren et al., 2006). Electric fences constructed with polytape and polyrope (i.e., conductive wires within synthetic ribbons or ropes) have been popular for temporarily protecting wildlife food plots but few investigations have examined their efficacy for reforestation (VerCauteren et al., 2006).

The goal of this project was to identify effective and practical procedures to mitigate impacts on hardwood seedling survival in bottomland hardwood restoration sites. To accomplish this, specific objectives were: (1) quantify the effects white-tailed deer and feral swine had on the survival of four mast-producing hardwood species; (2) compare the effectiveness of portable electric fences for protecting hardwood seedlings compared to more traditional techniques (e.g., woven wire high fences and individual
tree shelters); and (3) quantify seedling growth in relation to non-forested and forested areas and various wildlife mitigation techniques (e.g., 2.4 m woven wire high fence, Tubex USA® individual tree shelters, and Gallagher® 3-wire portable electric fence).

STUDY AREA

I conducted two nested split-split-plot designed BLHW restoration experiments at Cooper 4D Ranch, Hopkins County (Hopkins); Lyons-McKenney Ranch, Hunt County (Hunt); Richland Creek Wildlife Management Area, Freestone County (Freestone 2015); and Johnson Ranch, Anderson County (Anderson) located in east Texas within the WGCP (Figure 2.1). The first experiment continued for two years replicated over the four study locations using Shumard oak (*Quercus shumardii* Buckley), bur oak (*Quercus macrocarpa* Michx.), and pecan (*Carya illinoinensis* K. Koch) 1-0 bare root seedlings, and the second continued for one year at just Richland Creek Wildlife Management Area (Freestone 2016) using Nuttall oak (*Quercus texana* Buckley), Shumard oak, and pecan 1-0 bare root seedlings. The four study locations contain Kaufman clay soils with 0-1% slope that are frequently flooded, range in flood intensity, and range in watershed characteristics that are typical of BLHW in eastern Texas. Each receives about 100-115 cm of precipitation annually. They cover two ecoregions (i.e., Blackland Prairie and Post Oak Savannah; Figure 2.1A) and three drainage basins (i.e., Sulphur, Sabine, and Trinity; Figure 2.1B).
The Hopkins study location is a private hunting club along the Sulphur River that historically used open areas as cattle pastures, but has since developed levees and moist soil management units over portions of the property. This portion of the Sulphur River is not prone to overtopping its banks, but the property retains water in many sloughs and vernal pools containing cedar elm (*Ulmus crassifolia* Nutt.), sweetgum (*Liquidambar styraciflua* L.), and sugarberry (*Celtis laevigata* Willd.).

Hunt study location is another private hunting club that has multiple major tributaries within it that make up the upper reaches of the Sabine River and feed into the Lake Tawakoni Reservoir, approximately 4.5 km east. Pool levels at Lake Tawakoni Reservoir affect the soil moisture at the Hunt study location. The tributaries within the property are small with moderately graded banks, making it the most flood prone study location. Tree composition consisted of honeylocust (*Gleditsia triacanthos* L.), Osage orange (*Maclura pomifera* C.K. Schneid.), and sweetgum.

The Freestone and Anderson study locations are within the Trinity River floodplain. Freestone has been a state maintained wildlife management area since the late 1980’s and Anderson is another private ranch. Each contain large tracts of BLHW and shrink-swell, clayey soils that are affected by the Trinity River. Overstory composition at these sites are primarily cedar elm (*Ulmus crassifolia* Nutt.), willow oak (*Q. phellos* L.), and sugarberry. The Trinity River constitutes the primary drainage basin.
for the Dallas-Fort Worth metroplex, creating a flashy river system during periods of intense precipitation.

METHODS

Experimental Design

The nested split-split-plot design (Figure 2.2) included two areas differing in canopy cover type (i.e., non-forested, [0% canopy cover] and a forested area that had been thinned to approximately 50% canopy cover) nested within each of the locations to examine the differences in herbivory occurrence for reforesting abandoned agricultural fields or pasturelands (non-forested areas) and improving existing stands to contain more large, hard mast producing trees for wildlife (forested area). Whole-plot treatments included a non-fenced area and three wildlife mitigation techniques: 2.4 m woven wire high fences, Tubex USA® 60 cm twin walled polypropylene co-polymer individual tree shelters, and Gallagher® 3-wire portable electric fences. Nuttall oak, Shumard oak, bur oak, and pecan were used for the subplot treatments because they are native to the region, provide good canopy structure, and produce large mast that is heavily used by wildlife. Furthermore, these species are common components of BLHW forest restoration projects (e.g., wetlands reserve program or mitigation projects) in the region.

High fences, ≥2.4 m, are considered a proven technique for mitigation of wildlife damages in a variety of applications with nearly 100% efficacy (Seamans and
VerCauteren, 2006; VerCauteren et al., 2006). Individual tree shelters are commonly used in orchard plantings as well as forest restorations because they are considered low maintenance and promote height growth (VerCauteren et al., 2006). Portable electric fences are mainly used for temporary applications such as seasonal food plots or gardens, but have potential for long term use due to their versatility and durability (Seamans and VerCauteren, 2006; VerCauteren et al., 2006; Reidy et al., 2008). Using these mitigation techniques provides an opportunity to test a relatively new option for habitat restorations, portable electric fences, against more commonly used techniques, high fences and individual tree shelters.

The portable electric fence arrays and individual tree shelters were installed at the time of planting while the woven wire high fence was constructed before planting operations began. High fences contained iron corner posts secured with concrete and t-posts every 7 m for interior support between corners. They spanned 36.5 m by 27.4 m with an interior fence splitting the 36.5 m side to create two 18.3 m by 27.4 m plots side by side. Electric fences contained one outside polytape wire, 45.8 cm off the ground, spanning 18.3 m by 27.4 m and two inside polyrope wires, 24.4 cm and 61.0 cm off the ground, spanning 16.5 m by 25.6 m (Gallagher USA Electric Fencing, Riverside, MO, USA). Individual tree shelters were 60 cm tall, diameter averaged 10.1 cm (packaged in nested sets of five with varying diameters), and held in place by wooden stakes (Tubex USA®, Conservation Services, Waynesboro, VA, USA). Seedlings within fenced
treatments were not left over night without their prescribed fence in full function. To ensure fence function over time and to document wildlife species responsible for any incursions, PRIMOS® Truth Cam 46 Ultra HD motion-activated trail cameras were deployed overlooking each of the fenced treatments (PRIMOS Hunting, Flora, Mississippi).

Three blocks were used within each canopy cover type (Figure 2.2) to account for the minor changes in site characteristics that are not a direct focus of this project (e.g., soil micro-nutrients, elevation, and time of planting). Two blocks at each location consisted of all mitigation treatments and one block consisted of all mitigation treatments excluding a high fence. The Hunt county study location lacked a non-fenced whole-plot within the non-forested area due to residual roots obstructing the area planned to be ripped during site preparations. The subplot level consisted of 21, 1-0 bare root seedlings of each species within each fenced mitigation treatment, and 42, 1-0 bare root seedlings of each species within the non-fenced treatments. Two changes were made for the replanted 2016 Freestone location; (1) Nuttall oak replaced bur oak due to nursery availability, and (2) only two blocks contained individual tree shelters within the forested area. Each canopy cover type at a site contained 882 seedlings (819 seedlings in 2016 Freestone, forested area).
Site Preparation

A variety of silvicultural practices (e.g., ripping and canopy cover reduction) were used to reflect general practices for hardwood reforestation in the region and to homogenize my treatments across sites. Texas Parks and Wildlife Department (TPWD) employees conducted the ripping within each non-forested area with a tractor drawn shank at approximately 35 cm into the soil creating a continuous 35 cm trench or rip across the target area to break up potential compaction (Löf et al., 2012). Each fenced treatment had seven rows 18.3 m long with 3.6 m between each row to fit 21 seedlings of each species while having 1.8 m between seedlings. Each non-fenced subplot had the same number of rows and spacing but each row was only 14.7 m long to fit 42 seedlings of one species.

Each forested area was cruised prior to site preparations to determine what diameter limits were needed to achieve the approximate 50% canopy cover target. Diameter limits at each site were; DBH < 28 cm at Hopkins, < 15 cm at Hunt, < 28 cm at Freestone, and < 38 cm at Anderson. The Texas A&M Forest Service low-thinned each of the forested areas with a skid-steer tree mulching machine following the set diameter limits and removing non-desirable trees (i.e., non-mast producing species) below this limit. Residual basal area at each site was; 6.0 m$^2$/ha at Hopkins, 4.1 m$^2$/ha at Hunt, 3.7 m$^2$/ha at Freestone, 10.6 m$^2$/ha at Anderson.
Bare root (1-0) seedlings were planted during the dormant season (e.g., January to February) using a 30 cm KBC planting bar. Planting procedures and seedlings storage procedures followed those suggested by Allen et al. (2001). I clipped Shumard oak seedlings by removing 30% of the stem at planting to reduce shoot to root ratio and increase survival (M. E. Symmank, Texas Parks and Wildlife Department, unpublished data; Dey et al., 2008). Planting began at the most southern property (Anderson) and ended at the most northern property (Hopkins). Seedlings were planted in a block by block fashion to control for planting conditions, such as temperature and soil moisture at time of planting, that affect survival. Within the non-forested area, seedlings were planted adjacent to rip lines (i.e., ca. 15-30 cm from rip trench).

Herbicide was applied annually in late-April to early May around all seedlings to decrease mortality caused by competing vegetation (Allen et al., 2001; Dey et al., 2008). A foliar-active treatment of Makaze® herbicide with active ingredient glyphosate (41%) was spot applied around each seedling in a 90 cm radius on all plots. Individual seedlings were covered using PVC pipe (15 cm diameter by 90 cm tall) during the application process to protect them from incidental exposure to the herbicide. Grasses and other vegetation tall enough to come into contact with the planted seedlings once the PVC pipe was removed were manually separated from the seedling and pressed down prior to spraying to avoid drift of herbicide from recently sprayed vegetation to the planted seedlings.
Seedling Growth and Survival Measurements

Data were collected on three occasions for the seedlings planted in 2015: 2 months post planting, after the first growing season (12 months post planting), and after the second growing season (24 months post planting). Data were collected on two occasions for the seedlings replanted at Freestone in 2016: 2 months post planting and after the first growing season (12 months post planting).

During each occasion I recorded survival with height (to the nearest cm using a meter stick) and diameter 25 mm above the root collar (to the nearest tenth of a mm using a digital caliper) measurements for living seedlings. If dormant, survival of each seedling was determined by scratching the base of the seedling to determine if the cambium was green. I also recorded cause of mortality if seedlings were dead and/or missing using animal sign and bite mark identifiers when available. Possible causes of mortality included general environmental conditions (e.g., excess of water, periods of dryness, excessive competition, disease, insects, poor planting, or other unidentifiable environmental stressors), uprooted and browsed by feral swine, browsed by white-tailed deer, browsed by other or unknown species of wildlife. Seedlings that were killed by landowner management activities or by other means were removed from the database and not used in further analysis.

All seedlings within a fenced mitigation treatment were used for growth measurements, while in non-fenced whole-plots, only the inside 20 seedlings (Figure
2.3) were used for growth measurements to provide a buffer to control for edge effects. All seedlings within all treatments were used for analyzing survival.

**Growth and Survival Data Analysis**

I combined height and diameter data to derive volume index (VI), and stand volume index (SVI) for each data collection period. Volume index was calculated as basal diameter squared multiplied by height. This index assisted us in understanding seedling development over time (Leite *et al.*, 2016). Stand volume index represents the sum of all seedling volumes within a sub-subplot divided by the area of the plot to get a volume per unit area (m³/ha), and was calculated for the purpose of comparing both survival and growth simultaneously using a single metric. In addition to raw measurements, I determined changes in response variables (i.e., height, diameter, VI, and SVI) by calculating the difference between the current value and that measured in the previous period: (1) two months post planting to end of first growing season, (2) end of first growing season to the end of the second growing season, (3) two months post planting to the end of the second growing season.

I used PROC UNIVARIATE in SAS (v.9.2, SAS Institute, Inc., Cary, NC) to test for normality and homogeneity of the variances within all response variables (height, diameter, VI, SVI, and percent survival). I arcsine square root transformed percent survival to improve normality (Ahrens *et al.*, 1990). I analyzed differences in the response variables using mixed model ANOVAs (PROC MIXED) at α= 0.10. Eleven sources
(four main effects, six 2-way interactions, and one 3-way interaction) of variation were analyzed for the seedlings planted at the original four locations in 2015 and seven sources (three main effects, three 2-way interactions, and one 3-way interaction) for seedlings planted at Freestone in 2016. I used Tukey’s multiple comparison test and Saxton’s pdmix800 macro for SAS to identify differences within significant sources of variation for each response variable (Saxton, 1998).

Wildlife Surveys

I conducted infrared triggered trail camera surveys (Jacobson et al., 1997; Demarais et al., 2000; Holtfreter et al., 2008; Williams et al., 2011) to provide baseline data on the population densities of white-tailed deer and feral swine at each of the study locations. Surveys provided valuable information on behaviors and distributions of each within the study locations. Surveys were conducted late August to early September using PRIMOS® infrared triggered trail cameras (PRIMOS Hunting, Flora, Mississippi). I conducted 14-day surveys at each site that spanned 324 ha using 8 cameras around each canopy cover type (non-forested and forested area) at Freestone (Figure 2.4), and spanned 445 ha with 11 cameras encompassing both canopy cover types at each of the three remaining study properties: Hopkins (Figure 2.5), Hunt (Figure 2.6), and Anderson (Figure 2.7). Each survey site consisted of one camera per 41 ha placed on a grid created using the Fishnet application on ArcMap 10.3.1 (ESRI 2015. ArcGIS Desktop. Redlands, CA: Environmental Systems Research Institute). Bait stations were a minimum of 305 m
from any of the planted study areas (Figures 2.5.-2.8) to prevent confounding the experimental design by baiting animals into the study area.

Cameras were placed within 50 m of the predetermined location, 1 m off the ground, facing due north, and set to trigger when movement was detected. To limit multiple pictures of the same individuals, cameras were set to delay five minutes between trigger events. Camera locations were pre-baited using 22.6 kg of shelled corn 4 days prior to the start of surveys to acclimate wildlife to the camera sites. Bait was refreshed when the survey period began as well as every 3-4 days thereafter. Baiting was consistent across all properties at 11.3 kg per camera site while cameras were active. The density estimates determined at each property were used to interpret the damage done by wildlife based on the density of the wildlife populations and the observed impact of herbivory on the seedlings.

White-tailed deer population density estimation followed Jacobson et al. (1997) (revised by Demarais et al. (2000) and McKinley et al. (2006)) using individually identifiable branched antlered bucks and buck to doe ratios. Population density estimation methodology for feral swine was similar to Holtfreter et al. (2008) and Williams et al. (2011). This methodology is driven by uniquely identifying each pig (i.e., young, old, male, and female). In addition to uniquely identifying individuals, feral swine could be patterned to identify specific groups. All of the feral swine photographs were sorted into uniquely identified adult boars, adult sows, and juveniles, as well as a
maximum number of non-uniquely identifiable pigs found in a single photograph. The maximum number of non-uniquely identifiable pigs found in a single photograph was used to correct for the animals that could not be identified (Williams et al., 2011). An abundance estimate was produced by summing all of the uniquely identified animals with the maximum number of non-uniquely identifiable pigs observed in any one image during the survey.

In addition to density estimates, I conducted a deer browse survey (Lay, 1967) in December, 2016 within Hunt’s forested area type to describe the impacts of white-tailed deer in an area less prone to flooding. I established sixteen 1/100 acre circular plots within different treatments: four within the high fences, six within the portable electric fences, and six within the non-fenced area. Within each 1/100 acre plot, the number of branch tips available and the number of branch tips browsed were recorded by species for each mitigation treatment. Species were then categorized by browsing preference: 1st choice, 2nd choice, and 3rd choice. The average number of tips browsed and tips available were reported by mitigation treatment and species (Lay, 1967).

Flood Duration Estimation

Seedling flood tolerance is usually less than mature tree flood tolerance (Broadfoot and Williston, 1973). I estimated the number of days seedlings were inundated at each study location to aid in explaining variation in survival and growth between study locations and the non-forested and forested areas. Flood depth
estimates were recorded three ways: (1) through images captured by PRIMOS® Truth Cam 46 Ultra HD cameras that were deployed to monitor fence function, (2) personal observation when visiting study locations to conduct site maintenance, or (3) through communication with landowners and TPWD employees. I placed marked t-posts in front of at least one trail camera per site as a reference to estimate water depth. I recorded location, date, time, and depth of each observed flood and compared the estimated depths to the nearest United State Geological Survey (USGS) surface water gauge to determine at what depth on the USGS gauge each location’s seedlings would be considered submerged. Once estimated, I summed all days over the course of the project where USGS gauges exceeded the estimated depth for seedling inundation. Archived gauge data were obtained back to January, 2015 via https://waterdata.usgs.gov.

Numbers of days inundated at each site were broken into dormant and growing season inundation periods. I ran a linear regression using the number of days seedlings were inundated at each canopy cover type over the 1st growing season and over the 1st two growing seasons against the percent survival at each canopy cover type for the given growing seasons. Seedling dormancy dates were estimated through personal observation by checking a subset of seedlings during site maintenance and by using wetlands (WETS) climate tables produced by the National Resources Conservation Service (NRCS) for the counties of interest and the surrounding counties. The WETS
tables define climatic characteristics for specific areas using historical data on temperature and precipitation. They provide estimates on the length of growing season based on temperature indices predicting winter freeze damage and probabilities of an average growing season length. I used the 28 degrees Fahrenheit index for moderate winter freeze effect with a 50% probability for each study location.

RESULTS

Survival

Two Month Survival

Within the first two months canopy cover type was the only significant main effect in terms of survival (Table 2.1). Plots within the forested area had a lower survival rate (\( \bar{x} = 94.5\% \)) than plots within the non-forested area (\( \bar{x} = 99.8\% \); Appendix A). Most of the mortality was due to higher feral swine predation on seedlings within forested area treatments (Freestone = 20.6% and Anderson = 6.9% mortality due to feral swine). Within the forested area, pecan had lower survival than Shumard oak and bur oak (Appendix A) due to feral swine predation. Flooding did not become a major factor leading to mortality until May, 2015. Categorical data recorded for cause of mortality on individual seedlings could not be statistically analyzed due to failure of model convergence attributable to the large number of treatment combinations with either zero or very low survival rates.

One Year Survival
Survival varied at the site, canopy cover type, mitigation treatment, and species levels after the first growing season of 2015 (Table 2.1). Overall number of live seedlings dropped from $n = 6,416$ two months post planting to $n = 1,384$ after one year. Environmental conditions, especially flooding, were a major contributor (70.2%) to mortality. Herbivory from feral swine was also a moderate contributor (9.0%) to mortality. Total survival dropped from 96.2% after two months post planting to 20.8% after the first growing season. Freestone and Anderson, both along the Trinity River, produced lower survival rates (5.3% and 7.8%, respectively) than Hopkins (32.6%) and Hunt (47.9%; Appendix A). Anderson, Freestone, and the non-forested area at Hunt were submerged for large portions of the growing season: 81, 89, and 30 days respectively (Table 2.2). Survival differed between Hunt’s non-forested (11.4%) and forested area (74.5%), which likely caused significant site by canopy cover type and site by mitigation treatment interactions (Table 2.1). Overall, canopy cover types differed with non-forested areas ($\bar{x} = 13.7\%$) producing a lower survival rate than the forested area ($\bar{x} = 30.8\%$).

Among mitigation treatments, non-fenced seedlings ($\bar{x} = 14.9\%$) were less likely to survive compared to any of the fenced treatments; high fences ($\bar{x} = 28.3\%$), individual tree shelters ($\bar{x} = 25.5\%$), electric fences ($\bar{x} = 22.5\%$) were similar (Appendix A). Over the course of the first growing season, Hopkins’ forested and non-forested areas experienced 41.8% and 8.7% mortality, respectively, due to feral swine in non-fenced
plots. Additionally, Freestone’s forested area experienced 47.8% mortality due to feral swine within non-fenced plots. At this point, total mean loss of seedlings in non-fenced plots to feral swine predation was 14% but there was a wide range, with <1% at Hunt and 25% at Hopkins.

Two Year Survival

Overall number of live seedlings dropped from \( n = 1,384 \) to \( n = 923 \) after the second growing season. Most of the additional mortality was due to environmental conditions. Minimal occurrences of herbivory were observed in year two. Once again all of the main effects were significant for percent survival (Table 2.1). Overall survival dropped from 20.8% after the first growing season to 13.8% after the second growing season. Anderson, Freestone, and the non-forested area at Hunt were submerged for an additional 44, 46, and 12 days, respectively, during the 2016 growing season (Table 2.2). Percent survival for Hunt’s non-forested and forested areas decreased from 11.4% and 74.5% to 4.6% and 59.7%, respectively (Appendix A). Overall survival was lower in the non-forested area (\( \bar{x} = 7.3\% \)) compared to the forested area (\( \bar{x} = 22.7\%; \text{ Appendix A} \)). For each species, percent survivals were higher within the forested area (Appendix A).

Percent survival also differed by mitigation treatment within each canopy cover type (Figure 2.8). After two growing seasons, seedlings were about twice as likely to survive if protected by a high fence (\( \bar{x} = 20.3\%)\), individual tree shelter (\( \bar{x} = 17.7\%)\), or electric fence (\( \bar{x} = 14.9\%)\) compared to seedlings that were not protected by a physical
barrier (\( \bar{x} = 9.1\% \); Appendix A). In total, 504 of the 6,670 seedlings planted were killed by feral swine. Their preference seemed to vary by species with them killing 295 pecan (58.5\%) seedlings compared to 126 bur oak (25.0\%) seedlings and 83 Shumard oak (16.5\%). After two growing seasons their impact on non-fenced seedlings still ranged from site to site with <1\% at Anderson and 26\% at Hopkins killed by feral swine. Even though feral swine seemed to target pecan over bur oak and Shumard oak, pecan (\( \bar{x} = 20.8\% \)) still had higher overall survival than bur oak (\( \bar{x} = 14.6\% \)) which had a higher percent survival than Shumard oak (\( \bar{x} = 10.4\% \); Appendix A).

Survival – Freestone 2016 Replant

All seedlings planted at the Freestone County study location in January 2016 survived the first two months post planting. After the first growing season all main effects were significant for survival after the first growing season (Table 2.3). Survival was higher in the non-forested area (\( \bar{x} = 36.2\% \)) than in the forested area (\( \bar{x} = 30.7\% \)) after one growing season (Appendix A). Individual tree shelters within the forested area (\( \bar{x} = 22.0\% \)) produced the lowest survival (Figure 2.9). Percent survival also differed across species planted (Appendix A). After the first growing season only 21 Shumard oak seedlings survived (\( \bar{x} = 4.2\% \)), while Nuttall oak and pecan had >60\% survival (Figure 2.10). Herbivory was not a factor in causing additional mortality, as all seedling mortality appeared to be a result of environmental conditions endured over the first growing season.
Growth Parameters

Two Months Post Planting

Initial seedling heights, diameter, and VI two months post planting varied among sites, mitigation treatments, and tree species (Table 2.4). These results represent the initial values for each response variable and the variation could result from several factors (e.g., order in which sites were planted, bias in seedling choice to plant, order in which sites were measured, or variability in measuring crew members). However, because these parameters varied in the initial surveys, I used changes in height, diameter, and VI rather than raw values for further analyses.

Seedlings planted at the Anderson study location were larger than seedlings planted at the other study locations in terms of height ($\bar{x} = 31.38$ cm), diameter ($\bar{x} = 0.521$ cm), and volume index ($\bar{x} = 10.280$ cm$^3$; Appendix B). Seedlings planted at Freestone ($\bar{x} = 28.57$ cm) were shorter than seedlings at Hopkins ($\bar{x} = 29.12$ cm) and Hunt ($\bar{x} = 29.74$ cm) study locations (Appendix B). Initial diameter and volume index had different relationships at the site level than height with seedlings planted at the Freestone ($\bar{x}$ diameter = 0.449 cm, $\bar{x}$ volume = 7.095 cm$^3$) and Hopkins ($\bar{x}$ diameter = 0.460 cm, $\bar{x}$ volume = 7.459 cm$^3$) study locations having smaller diameters and volumes than seedlings at the Hunt ($\bar{x}$ diameter = 0.492 cm, $\bar{x}$ volume = 8.856 cm$^3$) study location (Appendix B).
Seedlings within electric fences ($\bar{x} = 28.06$ cm) and high fences ($\bar{x} = 28.57$ cm) were shorter than non-fenced seedlings ($\bar{x} = 29.99$ cm), while individual tree shelters ($\bar{x} = 34.50$ cm) contained the tallest seedlings (Appendix B). Seedlings within high fences ($\bar{x} = 0.458$ cm) and non-fenced seedlings ($\bar{x} = 0.463$ cm) had smaller diameters than seedlings within electric fences ($\bar{x} = 0.482$ cm) and individual tree shelters ($\bar{x} = 0.506$ cm; Appendix B). In terms of volume index, seedlings within high fences ($\bar{x} = 7.405$ cm$^3$), non-fenced seedlings ($\bar{x} = 7.675$ cm$^3$), and electric fence ($\bar{x} = 8.036$ cm$^3$) were smaller than seedlings within individual tree shelters ($\bar{x} = 10.004$ cm$^3$; Appendix B).

Not surprisingly, seedlings of different species varied in initial size. Pecan seedlings ($\bar{x}$ height = 24.38 cm, $\bar{x}$ diameter = 0.454 cm) were shorter and thinner than Shumard oak seedlings ($\bar{x}$ height = 26.72 cm, $\bar{x}$ diameter = 0.465 cm), which were shorter and thinner than bur oak seedlings ($\bar{x}$ height = 37.95 cm, $\bar{x}$ diameter = 0.521 cm Appendix B).

Significant main effects for SVI included site, mitigation treatment, and tree species (Table 2.4). Unlike other parameters, SVI is based on measurements summed across all seedlings in the plot; therefore, SVI values were affected by seedling mortality in the first two months after planting. At this point, feral swine killed and uprooted 181 (48%) of the non-fenced seedlings in the forested area at the Freestone study location. There, they seemed to prefer pecan (122 seedlings, 67.4%) over bur oak (43 seedlings, 23.8%) and Shumard oak (16 seedlings, 8.8%). During this time period they also killed
and uprooted 63 (33.3%) of the electric fenced seedlings within the forested area at Anderson study location, but did not show any type of preference towards a single species.

**First Growing Season**

All species had similar change in height over the first growing season in 2015 (Table 2.5). Seedlings within individual tree shelters ($\bar{x} = 10.03$ cm) increased more in height compared to seedlings not within a fence ($\bar{x} = 2.44$ cm), electric fence ($\bar{x} = 3.51$ cm), or high fence ($\bar{x} = 2.76$ cm; Appendix C). There were no other significant main effects in 2015. Additionally, there were no significant main effects for changes in seedling diameter or VI after the first growing season (Table 2.5).

All main effects of site, canopy cover type, mitigation treatment, and species were significant for change in SVI (Table 2.5). Mean SVI decreased within all main effects due to varying mortality among study locations: Anderson ($\bar{x} = -0.0139$ m$^3$/ha) < Freestone ($\bar{x} = -0.0094$ m$^3$/ha) < Hopkins ($\bar{x} = -0.0073$ m$^3$/ha) = Hunt ($\bar{x} = -0.0053$ m$^3$/ha; Appendix C).

**Second Growing Season**

Over the course of the second growing season in 2016, changes in height differed among mitigation treatments and species (Table 2.6). Pecan ($\bar{x} = 5.50$ cm) and Shumard oak ($\bar{x} = 7.70$ cm) outgrew bur oak ($\bar{x} = 2.42$ cm), while seedlings within individual tree shelters ($\bar{x} = 8.18$ cm) outgrew seedlings within high fences ($\bar{x} = 6.11$ cm),
electric fences (X̅ = 2.08 cm), and non-fenced plots (X̅ = 1.14 cm; Appendix D). Once again there were no significant main effects for change in diameter or VI (Table 2.6).

Significant main effects for changes in SVI include canopy cover type and mitigation treatment (Table 2.6). Mean SVI in the non-forested area was X̅ = -0.0003 m³/ha while in the forested area it was a positive X̅ = 0.0003 m³/ha (Appendix D). High fence was the only mitigation treatment to produce a positive SVI (X̅ = 0.0013 m³/ha), which was greater than SVI’s produced by individual tree shelters (X̅ = -0.0001 m³/ha), electric fences (X̅ = -0.0002 m³/ha), and non-fenced (X̅ = -0.0006 m³/ha) mitigation treatments (Appendix D). Change in height over the first growing season had a relatively high covariate parameter estimate of blocking (3.2198), others not reported were ≤0.

**Two Growing Season Growth**

From March, 2015 to December, 2017, total change in height among mitigation treatments was the only significant main effect in terms of change in height, diameter, and VI (Table 2.7). Individual tree shelters put on more height (X̅ = 18.89 cm) than high fences (X̅ = 9.55 cm), electric fences (X̅ = 5.67 cm), and non-fenced plots (X̅ = 3.10 cm; Appendix E). Significant interactions included site by canopy cover type, site by mitigation treatment, canopy cover type by species, and mitigation treatment by species (Table 2.7).

Within Hunt’s forested area there was obvious white-tailed deer browsing pressure in the non-fenced and electric fence mitigation treatments (Table 2.8) creating
a greater range in total change in height at the mitigation treatment level: individual tree shelter ($\bar{x}$ = 24.23 cm) > high fence ($\bar{x}$ = 13.02 cm) > electric fence ($\bar{x}$ = 4.33 cm) = non-fenced ($\bar{x}$ = 2.33 cm). On the other hand, total change in height within the non-forested area was on the low end of the range for all mitigation treatments: individual tree shelters ($\bar{x}$ = 11.43 cm) > high fence ($\bar{x}$ = 6.64 cm) > electric fence ($\bar{x}$ = 1.50 cm).

High fences and individual tree shelters theoretically excluded all white-tailed deer and provided 100% protection to the seedlings, while electric fences varied in efficacy and were breached by white-tailed deer and feral swine during the study period based on evidence provided by deployed trail cameras.

Across all study locations, total change in diameter and volume showed multiple significant interactions in the Mixed Model ANOVA (Table 2.7), but the Tukey’s post hoc analysis did not determine where the differences were within an interaction (Appendix E). It is possible that some of these interactions were due to collinear or correlated factors, or that the sample sizes were too small when the data were broken down into specific groups and sub-groups. However, change in bur oak VI ($9.17 \text{ cm}^3$) at Hopkins was greater than pecan ($5.33 \text{ cm}^3$) and Shumard oak ($3.18 \text{ cm}^3$) seedlings at Hopkins and pecan seedlings ($2.43 \text{ cm}^3$) at Anderson (Appendix E).

The total change in SVI was significant for all main effects, similar to the results after the first growing season (Table 2.7). Overall, SVI was negative due to mortality reducing the number of seedlings. This produced similar results for total change in SVI
(Table 2.7) and survival (Table 2.1) after two growing seasons. Additional differences came from differences in growth at each canopy cover type, mitigation treatment, and species levels (Appendix E). Two year change in height and VI had relatively high covariate parameter estimates of blocking (6.0068 and 3.6171, respectively), others not reported were ≤0.

Growth Parameters – Freestone 2016

Two Months Post Planting

Significant main effects for seedling height two months post planting included canopy cover type, mitigation treatment, and species, while species was the only significant main effect for diameter, VI, and SVI (Table 2.9). Again, variations in initial height could result from several factors (e.g., unequal sample size (Appendix N), bias in seedling choice to plant, order in which canopy cover types were measured, variability in measuring crew members, or a combination of the four). Differences at the species level were expected due to the physical differences of Nuttall oak, Shumard oak, and pecan. Initially pecan seedlings ($\bar{x} = 32.33$ cm) were shorter than Shumard oak ($\bar{x} = 38.53$ cm), while Nuttall oak seedlings were initially taller than both ($\bar{x} = 47.84$ cm; Appendix F). Initial seedling diameter of Shumard oaks ($\bar{x} = 0.486$ cm) was smaller than pecan ($\bar{x} = 0.499$ cm), while Nuttall oak seedlings were again bigger than both ($\bar{x} = 0.561$ cm; Appendix F). These results represent the initial values for each response variable (height, diameter, and VI) and because there was variation I used changes in height,
diameter, and VI for further analyses. Covariance parameter estimates of blocking were near zero, confirming blocking was not significant for these response variables at this scale.

Species was the only significant main effect for SVI, which again is due to the physical characteristics of the species of interest since all seedlings survived up to this point. Similar to the original four study locations, further analyses were conducted on the change of each response variable over the course of the first growing season because of these differences. Initial VI two month post planting had a relatively high covariate parameter estimate of blocking (2.8094), others not reported were ≤0.

First Growing Season

Significant main effects for height include mitigation treatment and species (Table 2.10). Seedlings within individual tree shelters ($\bar{x} = 11.32$ cm) outgrew seedlings within electric fences ($\bar{x} = 2.63$ cm), high fences ($\bar{x} = 2.44$ cm), and non-fenced plots ($\bar{x} = 2.15$ cm; Figure 2.11). At the species level, pecan ($n = 247, \bar{x} = 5.10$ cm) outgrew Nuttall oak ($n = 309, \bar{x} = 3.77$ cm), while Shumard oak sample size ($n = 14, \bar{x} = 0.64$ cm) was small so inferences could not be made (Appendix N). Some Shumard oak plots had no seedlings survive while others were limited to one seedling.

Significant main effects for change in diameter included canopy cover type and species (Table 2.10). The non-forested area ($\bar{x} = 0.013$ cm) produced a positive change driven by Nuttall oak within high and electric fences while the forested area ($\bar{x} = -0.052$ cm)
cm) produced a negative change driven by Shumard oak within electric and non-fenced areas (Appendix G). At the species level all mean changes in diameter were negative but again Shumard oak consisted of a small sample (n = 14) and no inferences could be made (Appendix G). Canopy cover type was the only significant main effect for VI after the first growing season. Again, the non-forested area (x̅ = 2.435 cm³) produced a positive change driven by Nuttall oak within high and electric fences while the forested area (x̅ = -1.230 cm³) produced a negative change driven by Shumard oak within electric and non-fenced areas.

All main effects and interactions were significant for SVI (Table 2.10). Again, this index accounts for mortality within species replications as well as single seedlings dramatically changing size over the first growing season. Patterns of SVI change by mitigation treatment were similar for each species individually (Appendix G).

Wildlife Surveys

I collected and analyzed approximately 24,000 images from the four, 14-day trail camera surveys (Table 2.11). Of these, about 20.4% contained photos of white-tailed deer and 32.8% contained photos of feral swine. All study locations had similar, moderate densities of feral swine while the Hopkins County study location and Freestone County’s forested area had low white-tailed deer densities compared to the moderate white-tailed deer densities at the other study locations (Alverson et al., 1988; Russell et al., 2001). Density estimates for white-tailed deer had higher variation (x̅ =
0.15 individuals/ha, \( \sigma = 0.10 \) individuals/ha) than feral swine across study locations (\( \bar{x} = 0.12 \) individuals/ha, \( \sigma = 0.02 \) individuals/ha; Table 2.11).

The Texas Parks and Wildlife department estimates white-tailed deer densities across Deer Management Units (DMU) across Texas. Freestone and Anderson study locations fell within DMU 19 North while Hopkins and Hunt study locations fell within in DMU 18. Freestone’s forested area white-tailed deer density estimate (0.05 deer/ha) fell within the 95% confidence interval of TPWD’s 3-year average for DMU 19 North (\( \bar{x} = 0.08 \) deer/ha; 95% interval = 0.15 to 0.04 deer/ha) while Freestone’s non-forested area (0.17 deer/ha) and Anderson (0.19 deer/ha) were more dense than the 3-year average. Hopkins’ white-tailed deer density estimate (0.05 deer/ha) equaled the 3-year average for DMU 18 (\( \bar{x} = 0.05 \) deer/ha, 95% interval = 0.08 to 0.03 deer/ha) while Hunt (0.28 deer/ha) was more dense than the 3-year average.

The Hunt County study location contained the highest density of white-tailed deer (Table 2.11), which was about five times denser than the 3-year average for DMU 18, and experienced obvious visual signs of heavy browsing within the forested area (Figure 2.12). The white-tailed deer browse survey determined areas protected by high fences had more available biomass and higher diversity of preferred browse species compared to areas protected by electric fences and non-fenced areas (Table 2.8). These results provide insight as to why survival and height growth for Shumard oak and bur
oak were less in the non-fenced and electric fenced areas than in the high fence area (Appendix A and E).

Flood Duration

On average, seedlings were dormant from 1 December to 31 March of each year. Inundation duration and intensity varied by study location and by canopy cover type within the Hunt County study location (Table 2.2). Overall, mean days of inundation ranged from 103 days/year (Freestone) to about 2 days/year (Hopkins). Peak inundation periods occurred, on average across sites, during the mid-2015 growing season, 2015 growing season to dormant season transition, and mid-2016 growing season.

Freestone and Anderson study locations along the Trinity River showed similar patterns of inundation (Table 2.2) and survival (Appendix A). The Anderson County study location was approximately 33 km south of the study location in Freestone County allowing more time for the accumulated runoff to dissipate and resulting in fewer days inundated. Both experienced flood depths near 3.5 m at times during the study.

Hunt was along the Sabine River and its non-forested area was the flashiest of all locations. Inundation events lasted a maximum of 4 days at depths near 2 m. Canopy cover types differed in elevation by about 2 m, resulting in the non-forested area flooding 10-times more often than the forested area on the same property (Table 2.2). This section of the Sabine River was part of the headwaters for Lake Tawakoni and the study area hydrology was affected by the water levels within the lake. This section also
does not have steep banks like the Trinity and Sulphur Rivers. Hopkins was on a section of the Sulphur River that is less affected by inundation. The hydrology in this portion of the river was driven by the water release rates of the Cooper Lake dam positioned approximately 13 kilometers upstream.

The simple linear regression between survival and growing season inundation duration shows a negative relationship when compared after the first growing season (Figure 2.13A) and in total, after two growing seasons (Figure 2.13B). The longer seedlings are inundated during the growing season the less likely they are to survive. Additional research is needed to investigate whether this is a linear or reverse J-curve relationship between survival and the number of days inundated during the growing season for these species within the WGCP.

DISCUSSION

There are many limitations (e.g. prolonged inundation, droughts, wildlife, and nursery stock variability) to overcome in BLHW restorations to obtain a desired density of preferred tree species. Planting desirable species and decreasing the presence of competing vegetation, though important, may not be sufficient in the WGCP to successfully produce functional BLHW (Allen et al., 2001; Stanturf et al., 2004). My stocking density was 1,495 seedlings/ha across treatments to investigate the impacts white-tailed deer and feral swine had on my species of interest and to see if the mitigation techniques tested would have potential to maintain an acceptable minimum
stocking. A variety of research throughout the LMAV and the ACP has shown that an acceptable minimum density after three years is between 309 seedlings/ha to 494 seedlings/ha to meet the desired forest conditions for diversity and structure (Allen et al., 2001; Stanturf et al., 2001; LMVJV Forest Resource Conservation Working Group, 2007; Stanturf et al., 2009). At that rate I would need 21% to 33% survival in my plots after three years to achieve minimum acceptable stocking density (Allen et al., 2001). The recommended stocking densities for the LMAV and ACP are a good starting point for restoration projects in the WGCP, but may not be suitable for the WGCP region since there are differences in soil characteristics, species composition, and hydrology between BLHW in the WGCP and the LMAV and ACP (Hodges, 1997; Hupp, 2000).

Mortality from herbivory was not observed within the one year, Freestone County 2016 study plots, so survival variability was a result of environmental conditions over the first growing season. Additionally, white-tailed deer herbivory did not cause a notable amount of mortality over the project duration, even with densities ranging from average to high within the project area. Overall, seedlings protected by a mitigation treatment were about twice as likely to survive as non-fenced seedlings after two growing seasons. Over the course of my two year study, two of the four locations experienced excessive amounts of mortality within the forested area due to herbivory by feral swine. Feral swine herbivory occurred within non-forested areas, but not to the extent that was observed within the forested areas. Evidence provided by the Hopkins
and Freestone forested area showed that feral swine have the potential to limit the establishment of hardwood seedlings at some sites.

White-tailed did not cause mortality but their effects were visually present at Hunt’s forested area (Lay, 1967). The unprotected areas and the portable electric fences had noticeably less herbaceous and woody vegetation available after the two growing seasons. Additionally, high fences did not allow any white-tailed deer or feral swine to enter the plots. This, along with images collected from trail cameras monitoring the plots and the lack of animal sign, showed that my high fence at the Hunt County study location were 100% effective at excluding wildlife. Individual tree shelters showed that they can protect the desirable seedlings planted while doubling the rate of height growth compared to high fences and about six-times the rate of height gain in electric fences and non-fenced plots in the Hunt County forested area.

Overall, trail cameras monitoring mitigation treatments captured approximately 20,000 images. I did not observe feral swine or white-tailed deer within my high fences. Individual tree shelters allowed minor occurrences of herbivory, showing a higher efficacy within the non-forested area (0.4% mortality due to herbivory) compared to the forested area (4.0% mortality due to herbivory). Electric fences showed a lower efficacy than individual tree shelters, but still provided some degree of protection compared to the herbivory rates in non-fenced plots. Their function was impacted by inundation and falling limbs which provided avenues for wildlife to breach the fence and access these
areas for limited times. Also, they provided a higher efficacy in the non-forested area (2.8% mortality due to herbivory) compared to the forested area (10.3% mortality due to herbivory) probably due to increased debris in forested sites. Mitigation treatments showed varied greatly by cost: Individual tree shelters cost about $2,250 per 1000 seedling plot, portable electric fence $3,440 per 1000 seedling plot with 1.8 m by 3.6 m spacing, and 2.4m woven wire high fence $6,775 for materials and $4,510 for labor per 1000 seedling plot with 1.8 m by 3.6 m spacing (VerCauteren et al., 2006).

When herbivory by feral swine occurred, preference varied by species. They preferred pecan seedlings over bur oak and bur oak over Shumard oak the majority of the time. On a single occasion two months post planting, feral swine breached one electric fence treatment, killed all but three seedlings within, and showed no species preference. The rooting signs left behind by feral swine suggested that seedling predation may have been an indirect result of rooting around one particular snag potentially targeting insects or other food material (Campbell and Long, 2009; Barrios-Garcia and Ballari, 2012).

Herbivory by feral swine, though important in specific instances, was not the most important mortality factor on my sites. Environmental conditions acting on each study location, more specifically frequent inundation that persisted into the mid to late growing season, were a more important cause of mortality (Broadfoot and Williston, 1973). Environmental conditions caused equal amounts of mortality across non-fenced
and mitigation treatments. In the study initiated in 2015, seedlings within the non-forested area were affected more than seedlings within the forested area. The non-forested area soils receive more direct sunlight compared to the forested area soils, potentially causing different rates of change in soil moisture or more intense drought conditions and stress to seedlings within the non-forested area (Allen et al., 2001). Three of the four non-forested areas were inundated >40 days during the growing season causing >90% mortality, while only two of the four forested area areas were. Thus, the response may be related to duration of inundation particularly at the Hunt site (Broadfoot and Williston, 1973). Establishing a canopy cover first using rapidly growing species such as eastern cottonwood (Populus deltoids Bart. ex Marsh.) can increase survival of under-planted oak and hickory species by reducing stress caused by varying soil moisture conditions (Schoenholtz et al., 2001; Gardiner et al., 2004). This suggests that the forested area could have alleviated some of the stress caused by the environmental conditions my study sites endured.

The combination of seedlings planted within a forested area and protected by either a high fence or individual tree shelters had the best chance of survival (Appendix A). Within this combination, individual tree shelter seedlings grew twice as tall as seedlings within high fences which grew three- to four-times taller compared to electric fences and non-fenced plots after two growing seasons. Electric fences produced
comparable survival rates to non-fenced areas and individual tree shelters but lower survival than the more traditional 2.4 m high fence (Figure 2.8).

Although pecan seedlings seemed to be preferred by feral swine, they had the highest survival rate overall. Pecan trees are considered more (weakly to moderately) tolerant to inundation compared to bur oak (intolerant to weakly tolerant) and Shumard oak (weakly tolerant; Whitlow and Harris, 1979; Allen et al., 2001; Stanturf et al., 2004). Surprisingly, bur oak had higher survival than Shumard oak even though bur oak is considered less flood tolerant (Whitlow and Harris, 1979; Stanturf et al., 2004). This phenomenon could be a result of my bur oak seedlings being initially larger than Shumard oak at the time of planting (Stanturf et al., 2004).

Individual tree shelters required more maintenance compared to high fences, but less than portable electric fences. Flooding dislodged wooden stakes holding shelters in place and carried off shelters, leaving the seedlings vulnerable. At times, this phenomenon caused physical damage to seedlings and deposited sediment on tree shelters, decreasing the amount of light that was able to penetrate them. Individual tree shelters also alter the internal environment (e.g., increase temperature, relative humidity, and CO₂ concentration) to enhance growing conditions (Burger et al., 1992; Kjelgren and Rupp, 1997). However, they can create extreme conditions, such as heat stress, that increase mortality. The seedlings within individual tree shelters grew twice as tall during each growing season compared to the other treatments tested. Recently,
Tree shelter companies have released improved tree shelters that include vents specifically designed to create an optimum balance between the ambient environment and the shelter’s internal environment (Tubex USA®, Conservation Services, Waynesboro, VA, USA). Floods causing physical damage to seedlings or tree shelters creating extreme environments could be why survival rates for Freestone 2016 were lowest within the individual tree shelter plots after the first growing season.

Within the forested area, electric fences required the most upkeep due to falling limbs, trees, and debris that washed up during flooding. This broke the poly-wires and disrupted the connection between the energizer and the fence, decreasing the overall integrity of the fences, and providing opportunities for feral swine and white-tailed deer to breach the fence. The forested area also decreased the reliability of the solar energizers. During times of dense canopy, battery charges would become too weak to power each fence. Overall, these events decreased the efficacy of the fences over time. In addition, past research has shown that animals, given enough time, can learn how they can breach the fences without receiving a shock or how to penetrate a fence by watching other animals (VerCauteren et al., 2006). This phenomenon could be why portable electric fences did not perform as well as the more common mitigation techniques I tested.

Replanted 2016 Freestone location showed similar trends in terms of change in height by mitigation treatment after one growing season but provided confounding
results in terms of survival by mitigation treatment with individual tree shelters having the lowest percent survival after one growing season. This phenomenon could be related to Nuttall oak being less shade tolerant than bur oak, internal conditions being too extreme, and/or environmental conditions being more favorable outside the shelters for the species planted on my site (Burger et al., 1992; Kjelgren and Rupp, 1997; Allen et al., 2001)

Seedlings need assistance when small and vulnerable to overcome the major (i.e., variety of environmental conditions) and minor (i.e., herbivory due to feral swine) threats to survival. The faster seedlings can reach a free to grow stage (>1.5 m), the more likely they are to reach maturity, produce large mast, and overcome the stresses related to herbivory, browse pressure, and flooding (Allen et al., 2001). The study showed that Individual tree shelters provide assistance for both of these threats. They allow seedlings time to establish themselves and prepare for environmental and wildlife impacts that may be significant over the initial three years of establishment (LMVJV Forest Resource Conservation Working Group, 2007).

CONCLUSION

Matching species of interest to the site conditions, specifically local hydrologic regimes, should carry a high priority in planning a restoration project within BLHW in the WGCP. This study showed that mitigation for herbivory pressures is possible. Feral swine have potential to cause high mortality rates within a site but population density was not
a reliable predictor of mortality from feral swine. White-tailed deer did not cause high rates of mortality but caused reduced height gain over time at least one study location. This has a significant impact on seedling establishment by keeping seedlings vulnerable to other impacts such as inundation, erosion, and drought (Côté et al., 2004). If seedlings cannot overcome continuous browsing by white-tailed deer year after year they will eventually die (Côté et al., 2004).

In the WGCP it is possible to achieve acceptable rates of survival. Once a diverse group of species are selected for a restoration project, it is important to take into consideration the likelihood of extreme weather events impacting a specific restoration site, whether that is noting at what level rivers and streams adjacent to the area overtop their banks or the frequency at which dormant or growing season flooding occurs (Broadfoot and Williston, 1973; Dey et al., 2012). If inundation is a factor, staggering planting over the course of many years will allow for compensation of the total loss of one planting year. These recommendations go hand in hand with increased monitoring of sites. Additional monitoring, multiple times per season, will allow managers to notice herbivory damage by feral swine and white-tailed deer and allow them the opportunity to protect seedlings via tree shelters.
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discounting when calculating offset ratios for impacted habitat. Restoration Ecology 17, 470-478.


Figure 2.1. Locations of four study sites used for bottomland hardwood restoration studies in the (A) Blackland Prairie and Post Oak Savannah ecoregions and (B) Sulphur, Sabine, and Trinity River basins of east Texas in 2015 and 2016.
Figure 2.2. Theoretical site layout at one of the four properties. Blocks 1, 2, 4, and 5 contained all mitigation treatment treatments while Blocks 3 and 6 did not have 2.4 m woven wire fences. Replanted 2016 Freestone replaced bur oak with Nuttall oak and Block 4 did not contain an individual tree shelter mitigation treatment.
Figure 2.3. Theoretical layout of one block within one of the canopy cover types depicting individual seedlings at the species level for each mitigation treatment. Red boxes represent inside 20 seedlings that were analyzed for growth.
Figure 2.4. Richland Creek WMA, Freestone County, Texas. 636 m by 636m grid overlay depicting the effective survey area of the 2015 wildlife density surveys using baited trail camera stations.
Figure 2.5. Cooper 4D Ranch, Hopkins County, Texas. 636 m by 636m grid overlay depicting the effective survey area of the 2015 wildlife density surveys using baited trail camera stations.
Figure 2.6. Lyons-McKenney Ranch, Hunt County, Texas. 636 m by 636 m grid overlay depicting the effective survey area of the 2015 wildlife density surveys using baited trail camera stations.
Figure 2.7. Johnson Ranch, Anderson County, Texas. 636 m by 636m grid overlay depicting the effective survey area of the 2015 wildlife density surveys using baited trail camera stations.
Figure 2.8. Mean percent survival of bur oak, Shumard oak, and pecan seedlings planted in 2015 across 2 canopy covers and 4 herbivory mitigation treatments at 4 sites in east Texas (letters denote difference across treatments at $\alpha = 0.10$).
Figure 2.9. Mean percent survival of Nuttall oak, Shumard oak, and pecan seedlings planted in 2016 across 2 canopy covers and 4 herbivory mitigation treatments at the Freestone study location in east Texas (letters denote difference across treatments at $\alpha = 0.10$).
Figure 2.10. Mean percent survival for the 2016 Freestone seedlings at the species level after the first growing season (letters denote significant differences at $\alpha = 0.10$).
Figure 2.11. Replanted 2016 Freestone location: mean total change in height (with standard error) for each species within each mitigation treatment at the different canopy cover types after one growing seasons. In total, 14 Shumard were alive for analysis. Standard Error = 0 due to \( n=1 \) for that treatment.
Figure 2.12. Study location Hunt within the forested area, (A) dense vegetation with increased number of preferred browse species within 2.4m woven wire high fence, (B) non-fenced area consisting of a minor herbaceous layer
Figure 2.13. Simple linear regression for seedling survival at different number of day inundated during the (A) 2015 growing season and (B) after the 2015 and 2016 growing season.

For the 2015 growing season:
- Regression equation: \( y = -0.0045x + 0.4337 \)
- \( R^2 = 0.6007 \)

For the 2015 and 2016 growing seasons:
- Regression equation: \( y = -0.0021x + 0.2981 \)
- \( R^2 = 0.4618 \)
Table 2.1. Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2015 analyzing arcsine square root transformed percent survival of the species with each mitigation treatment two months post planting, after the 2015 growing season, and after the 2016 growing season.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Two Months Post Planting</th>
<th>After 2015 Growing Season</th>
<th>After 2016 Growing Season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>df</td>
<td>F</td>
<td>p</td>
</tr>
<tr>
<td>Site</td>
<td>3</td>
<td>1.52</td>
<td>0.2106</td>
<td>113.26</td>
</tr>
<tr>
<td>Canopy Type</td>
<td>1</td>
<td>2.78</td>
<td>0.0968</td>
<td>53.29</td>
</tr>
<tr>
<td>Mitigation treatment</td>
<td>3</td>
<td>1.56</td>
<td>0.2602</td>
<td>11.28</td>
</tr>
<tr>
<td>Species</td>
<td>2</td>
<td>1.18</td>
<td>0.3098</td>
<td>18.49</td>
</tr>
<tr>
<td>Site*Canopy Type</td>
<td>3</td>
<td>1.82</td>
<td>0.1449</td>
<td>70.77</td>
</tr>
<tr>
<td>Site*Mitigation treatment</td>
<td>9</td>
<td>3.11</td>
<td>0.0016</td>
<td>5.26</td>
</tr>
<tr>
<td>Site*Species</td>
<td>6</td>
<td>1.61</td>
<td>0.1474</td>
<td>6.47</td>
</tr>
<tr>
<td>Canopy Type * Mitigation treatment</td>
<td>3</td>
<td>0.69</td>
<td>0.5573</td>
<td>0.69</td>
</tr>
<tr>
<td>Canopy Type * Species</td>
<td>2</td>
<td>3.97</td>
<td>0.0205</td>
<td>2.88</td>
</tr>
<tr>
<td>Mitigation treatment * Species</td>
<td>6</td>
<td>1.03</td>
<td>0.4095</td>
<td>0.87</td>
</tr>
<tr>
<td>Canopy Type * Mitigation treatment * Species</td>
<td>6</td>
<td>4.68</td>
<td>0.0002</td>
<td>0.93</td>
</tr>
</tbody>
</table>
Table 2.2. Days seedlings submerged using estimated USGS surface water gauge height at each study location.

<table>
<thead>
<tr>
<th>River Basin</th>
<th>Submergence at estimated USGS Gauge Height (m)</th>
<th>USGS Gage ID Number</th>
<th>Research County</th>
<th>Dormant Season Days</th>
<th>Growing Season Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trinity</td>
<td>9.45</td>
<td>08065000</td>
<td>Anderson</td>
<td>70</td>
<td>125</td>
</tr>
<tr>
<td>Trinity</td>
<td>9.75</td>
<td>08062700</td>
<td>Freestone</td>
<td>71</td>
<td>135</td>
</tr>
<tr>
<td>Trinity</td>
<td>9.75</td>
<td>08062700</td>
<td>Freestone (replanted 2016)</td>
<td>39</td>
<td>46</td>
</tr>
<tr>
<td>Sabine</td>
<td>3.65</td>
<td>08017300</td>
<td>Hunt (non-forested)</td>
<td>18</td>
<td>42</td>
</tr>
<tr>
<td>Sabine</td>
<td>5.18</td>
<td>08017300</td>
<td>Hunt (forested area)</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Sulphur</td>
<td>5.18</td>
<td>07342500</td>
<td>Hopkins</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2.3. Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2016 at the Freestone study location analyzing arcsine square root transformed percent survival of the species with each mitigation treatment two months post planting, after the 2016 growing season.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>F</th>
<th>p</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two Months Post Planting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canopy Type</td>
<td>1</td>
<td>0.18</td>
<td>0.6776</td>
<td>5.26</td>
<td>0.0301</td>
</tr>
<tr>
<td>Mitigation treatment</td>
<td>3</td>
<td>105.92</td>
<td>&lt;0.0001</td>
<td>4.93</td>
<td>0.0271</td>
</tr>
<tr>
<td>Species</td>
<td>2</td>
<td>16.09</td>
<td>&lt;0.0001</td>
<td>263.04</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>After 2016 Growing Season</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canopy Type*Mitigation treatment</td>
<td>3</td>
<td>1.75</td>
<td>0.1811</td>
<td>6.88</td>
<td>0.0015</td>
</tr>
<tr>
<td>Canopy Type*Species</td>
<td>2</td>
<td>0.16</td>
<td>0.8561</td>
<td>4.62</td>
<td>0.0192</td>
</tr>
<tr>
<td>Mitigation treatment*Species</td>
<td>6</td>
<td>0.92</td>
<td>0.4971</td>
<td>2.90</td>
<td>0.0268</td>
</tr>
<tr>
<td>Canopy Type<em>Mitigation treatment</em>Species</td>
<td>6</td>
<td>1.04</td>
<td>0.4231</td>
<td>1.56</td>
<td>0.1987</td>
</tr>
</tbody>
</table>
Table 2.4. Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2015 analyzing seedling height, diameter, volume index, and stand volume index two months post planting.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Height (cm) F</th>
<th>p</th>
<th>Diameter (cm) F</th>
<th>p</th>
<th>Volume Index (cm³) F</th>
<th>p</th>
<th>Stand Volume Index (m³/ha) F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>3</td>
<td>26.68 &lt;0.0001</td>
<td></td>
<td>60.74 &lt;0.0001</td>
<td></td>
<td>46.07 &lt;0.0001</td>
<td></td>
<td>12.05 &lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Canopy Type</td>
<td>1</td>
<td>1.22 0.2692</td>
<td>0.2692</td>
<td>1.29 0.2565</td>
<td>0.314</td>
<td>1.01 0.314</td>
<td>0.15</td>
<td>0.6958</td>
<td></td>
</tr>
<tr>
<td>Mitigation treatment</td>
<td>3</td>
<td>44.36 &lt;0.0001</td>
<td></td>
<td>8.56 0.0041</td>
<td></td>
<td>18.46 0.0002</td>
<td></td>
<td>13.48 0.0008</td>
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</tr>
<tr>
<td>Species</td>
<td>2</td>
<td>1278.13 &lt;0.0001</td>
<td></td>
<td>114.53 &lt;0.0001</td>
<td></td>
<td>395.78 &lt;0.0001</td>
<td></td>
<td>92.94 &lt;0.0001</td>
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</tr>
<tr>
<td>Site*Canopy Type</td>
<td>3</td>
<td>19.92 &lt;0.0001</td>
<td></td>
<td>61.37 &lt;0.0001</td>
<td></td>
<td>33.95 &lt;0.0001</td>
<td></td>
<td>7.86 &lt;0.0001</td>
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<tr>
<td>Site*Mitigation treatment</td>
<td>9</td>
<td>12.05 &lt;0.0001</td>
<td></td>
<td>18.79 &lt;0.0001</td>
<td></td>
<td>21.45 &lt;0.0001</td>
<td></td>
<td>6.31 &lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Site*Species</td>
<td>6</td>
<td>24.42 &lt;0.0001</td>
<td></td>
<td>1.99 0.0636</td>
<td></td>
<td>3.08 0.0052</td>
<td></td>
<td>0.52 0.7942</td>
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</tr>
<tr>
<td>Canopy Type * Mitigation treatment</td>
<td>3</td>
<td>4.79 0.0025</td>
<td></td>
<td>0.34 0.7981</td>
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<td>0.22 0.8858</td>
<td></td>
<td>0.56 0.6413</td>
<td></td>
</tr>
<tr>
<td>Canopy Type * Species</td>
<td>2</td>
<td>2.07 0.1268</td>
<td></td>
<td>1.69 0.1841</td>
<td></td>
<td>2.79 0.0616</td>
<td></td>
<td>0.52 0.5932</td>
<td></td>
</tr>
<tr>
<td>Mitigation treatment * Species</td>
<td>6</td>
<td>14.92 &lt;0.0001</td>
<td></td>
<td>6.41 &lt;0.0001</td>
<td></td>
<td>10.93 &lt;0.0001</td>
<td></td>
<td>3.02 0.0076</td>
<td></td>
</tr>
<tr>
<td>Canopy Type * Mitigation treatment * Species</td>
<td>6</td>
<td>18.21 &lt;0.0001</td>
<td></td>
<td>2.31 0.0313</td>
<td></td>
<td>2.62 0.0153</td>
<td></td>
<td>0.69 0.6619</td>
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</tr>
</tbody>
</table>
Table 2.5. Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2015 analyzing the change in seedling height, diameter, volume index, and stand volume index over the 2015 growing season.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>F</th>
<th>p</th>
<th>F</th>
<th>p</th>
<th>F</th>
<th>p</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in Height (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Site</td>
<td>3</td>
<td>1.48</td>
<td>0.21</td>
<td>0.09</td>
<td>0.96</td>
<td>1.01</td>
<td>0.38</td>
<td>22.99</td>
<td>&lt;0.00</td>
</tr>
<tr>
<td>Canopy Type</td>
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<td>0.04</td>
<td>0.84</td>
<td>0.03</td>
<td>0.85</td>
<td>0.68</td>
<td>0.41</td>
<td>5.67</td>
<td>0.018</td>
</tr>
<tr>
<td>Mitigation treatment</td>
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<td>6.28</td>
<td>0.01</td>
<td>1.92</td>
<td>0.19</td>
<td>2.41</td>
<td>0.12</td>
<td>3.59</td>
<td>0.054</td>
</tr>
<tr>
<td>Species</td>
<td>2</td>
<td>0.05</td>
<td>0.95</td>
<td>1.16</td>
<td>0.31</td>
<td>0.65</td>
<td>0.52</td>
<td>45.47</td>
<td>&lt;0.00</td>
</tr>
<tr>
<td>Site*Canopy Type</td>
<td>3</td>
<td>6.99</td>
<td>0.00</td>
<td>16.62</td>
<td>&lt;0.00</td>
<td>8.89</td>
<td>&lt;0.00</td>
<td>3.91</td>
<td>0.009</td>
</tr>
<tr>
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<td>7.11</td>
<td>&lt;0.00</td>
<td>3.02</td>
<td>0.00</td>
<td>4.42</td>
<td>&lt;0.00</td>
<td>6.82</td>
<td>&lt;0.00</td>
</tr>
<tr>
<td>Site*Species</td>
<td>6</td>
<td>4.34</td>
<td>0.00</td>
<td>0.88</td>
<td>0.51</td>
<td>2.13</td>
<td>0.04</td>
<td>1.8</td>
<td>0.101</td>
</tr>
<tr>
<td>Canopy Type * Mitigation treatment</td>
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<td>0.02</td>
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<td>0.89</td>
<td>0.98</td>
<td>0.40</td>
<td>0.44</td>
<td>0.723</td>
</tr>
<tr>
<td>Canopy Type * Species</td>
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<td>0.05</td>
<td>4.32</td>
<td>0.01</td>
<td>4.06</td>
<td>0.01</td>
<td>0.26</td>
<td>0.768</td>
</tr>
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<td>Mitigation treatment * Species</td>
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<td>3.06</td>
<td>0.00</td>
<td>2.91</td>
<td>0.00</td>
<td>4.00</td>
<td>0.00</td>
<td>2.63</td>
<td>0.018</td>
</tr>
<tr>
<td>Canopy Type * Mitigation treatment * Species</td>
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<td>3.55</td>
<td>0.00</td>
<td>2.16</td>
<td>0.04</td>
<td>1.51</td>
<td>0.17</td>
<td>0.53</td>
<td>0.762</td>
</tr>
</tbody>
</table>
Table 2.6 Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2015 analyzing the change in seedling height, diameter, volume index, and stand volume index over the 2016 growing season.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Change in Height (cm)</th>
<th></th>
<th>Change in Diameter (cm)</th>
<th></th>
<th>Change in Volume Index (cm(^3))</th>
<th></th>
<th>Change in Stand Volume Index (m(^3)/ha)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>3</td>
<td>1.18</td>
<td>0.3165</td>
<td>1.31</td>
<td>0.2684</td>
<td>0.14</td>
<td>0.9344</td>
<td>0.76</td>
<td>0.515</td>
</tr>
<tr>
<td>Canopy Type</td>
<td>1</td>
<td>0.04</td>
<td>0.8379</td>
<td>0.05</td>
<td>0.8296</td>
<td>0.00</td>
<td>0.9867</td>
<td>14.86</td>
<td>0.0002</td>
</tr>
<tr>
<td>Mitigation treatment</td>
<td>3</td>
<td>5.83</td>
<td>0.0144</td>
<td>0.57</td>
<td>0.6489</td>
<td>2.24</td>
<td>0.1463</td>
<td>9.46</td>
<td>0.0029</td>
</tr>
<tr>
<td>Species</td>
<td>2</td>
<td>3.05</td>
<td>0.0482</td>
<td>0.12</td>
<td>0.8852</td>
<td>0.63</td>
<td>0.5349</td>
<td>0.41</td>
<td>0.6653</td>
</tr>
<tr>
<td>Site*Canopy Type</td>
<td>3</td>
<td>0.78</td>
<td>0.5066</td>
<td>5.76</td>
<td>0.0007</td>
<td>4.63</td>
<td>0.0032</td>
<td>3.21</td>
<td>0.024</td>
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<td>0.0012</td>
<td>2.53</td>
<td>0.0073</td>
<td>2.52</td>
<td>0.0076</td>
<td>6.27</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Site*Species</td>
<td>4</td>
<td>0.43</td>
<td>0.787</td>
<td>3.27</td>
<td>0.0114</td>
<td>3.66</td>
<td>0.0058</td>
<td>2.1</td>
<td>0.055</td>
</tr>
<tr>
<td>Canopy Type * Mitigation treatment</td>
<td>3</td>
<td>1.14</td>
<td>0.3313</td>
<td>2.22</td>
<td>0.0848</td>
<td>2.87</td>
<td>0.0359</td>
<td>8.21</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Canopy Type * Species</td>
<td>2</td>
<td>2.29</td>
<td>0.1016</td>
<td>1.01</td>
<td>0.365</td>
<td>0.34</td>
<td>0.7103</td>
<td>1.07</td>
<td>0.3446</td>
</tr>
<tr>
<td>Mitigation treatment * Species</td>
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<td>1.48</td>
<td>0.1827</td>
<td>2.37</td>
<td>0.0284</td>
<td>1.47</td>
<td>0.1869</td>
<td>2.54</td>
<td>0.0218</td>
</tr>
<tr>
<td>Canopy Type * Mitigation treatment * Species</td>
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<td>1.71</td>
<td>0.1168</td>
<td>1.25</td>
<td>0.2774</td>
<td>0.91</td>
<td>0.4853</td>
<td>1.50</td>
<td>0.1768</td>
</tr>
</tbody>
</table>
Table 2.7. Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2015 analyzing the total change in seedling height, diameter, volume index, and stand volume index over 2015 and 2016 growing seasons.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Total Change in Height (cm)</th>
<th>Total Change in Diameter (cm)</th>
<th>Total Change in Volume Index (cm$^3$)</th>
<th>Total Change in Stand Volume Index (m$^3$/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>F</td>
<td>p</td>
<td>F</td>
<td>p</td>
</tr>
<tr>
<td>Site</td>
<td>3</td>
<td>0.68</td>
<td>0.5617</td>
<td>1.31</td>
<td>0.2712</td>
</tr>
<tr>
<td>Canopy Type</td>
<td>1</td>
<td>0.15</td>
<td>0.6992</td>
<td>0.08</td>
<td>0.7727</td>
</tr>
<tr>
<td>Mitigation treatment</td>
<td>3</td>
<td>9.86</td>
<td>0.0025</td>
<td>0.20</td>
<td>0.8926</td>
</tr>
<tr>
<td>Species</td>
<td>2</td>
<td>1.73</td>
<td>0.1774</td>
<td>0.96</td>
<td>0.3846</td>
</tr>
<tr>
<td>Site*Canopy Type</td>
<td>3</td>
<td>4.46</td>
<td>0.0041</td>
<td>15.93</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Site*Mitigation treatment</td>
<td>9</td>
<td>5.51</td>
<td>&lt;0.0001</td>
<td>1.39</td>
<td>0.1901</td>
</tr>
<tr>
<td>Site*Species</td>
<td>4</td>
<td>1.48</td>
<td>0.2063</td>
<td>2.26</td>
<td>0.0613</td>
</tr>
<tr>
<td>Canopy Type * Mitigation treatment</td>
<td>3</td>
<td>1.75</td>
<td>0.1552</td>
<td>0.97</td>
<td>0.4082</td>
</tr>
<tr>
<td>Canopy Type * Species</td>
<td>2</td>
<td>4.49</td>
<td>0.0115</td>
<td>0.11</td>
<td>0.893</td>
</tr>
<tr>
<td>Mitigation treatment * Species</td>
<td>6</td>
<td>3.74</td>
<td>0.0011</td>
<td>1.36</td>
<td>0.2303</td>
</tr>
<tr>
<td>Canopy Type * Mitigation treatment * Species</td>
<td>6</td>
<td>1.62</td>
<td>0.1376</td>
<td>5.54</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>
Table 2.8. Results of deer browse survey within Hunt’s forested area Fall, 2017, including mean tips browsed and tips available for each mitigation treatment. Recorded occurrences of Shumard oak, bur oak, and pecan are seedlings planted as part of the project.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Preference</th>
<th>Mean Tips Browsed</th>
<th>Mean Tips Available</th>
<th>Mean Tips Browsed</th>
<th>Mean Tips Available</th>
<th>Mean Tips Browsed</th>
<th>Mean Tips Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Briar</td>
<td>Smilax sp.</td>
<td>1</td>
<td>0</td>
<td>9.0</td>
<td>1.3</td>
<td>2.2</td>
<td>1.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Poison Ivy/Oak</td>
<td>Toxicodendron sp.</td>
<td>1</td>
<td>0</td>
<td>6.0</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Rubis</td>
<td>Rubus sp.</td>
<td>1</td>
<td>0</td>
<td>6.5</td>
<td>0.2</td>
<td>1.8</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Honey locust</td>
<td>Gleditsia sp.</td>
<td>1</td>
<td>0</td>
<td>5.0</td>
<td>2.2</td>
<td>2.8</td>
<td>0.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Shumard Oak</td>
<td>Quercus Shumardii</td>
<td>2</td>
<td>0</td>
<td>3.0</td>
<td>2.3</td>
<td>2.5</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Bur Oak</td>
<td>Quercus macrocarpa</td>
<td>2</td>
<td>0</td>
<td>3.5</td>
<td>1.7</td>
<td>1.7</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Water Oak</td>
<td>Quercus nigra</td>
<td>2</td>
<td>0</td>
<td>10.5</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Red Oak</td>
<td>Quercus rubra</td>
<td>2</td>
<td>0</td>
<td>0.3</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Vitis sp.</td>
<td>Vitis sp.</td>
<td>2</td>
<td>0</td>
<td>0.3</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Red Mulberry</td>
<td>Morus rubra</td>
<td>2</td>
<td>0</td>
<td>0.3</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Virginia Creeper</td>
<td>Parthenocissus quinquefolia</td>
<td>2</td>
<td>0</td>
<td>0.5</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Sumac</td>
<td>Rhus sp.</td>
<td>2</td>
<td>.</td>
<td>.</td>
<td>2.7</td>
<td>4.8</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Hawthorn</td>
<td>Crataegus sp.</td>
<td>2</td>
<td>.</td>
<td>.</td>
<td>1.5</td>
<td>1.7</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Ash</td>
<td>Fraxinus sp.</td>
<td>3</td>
<td>0</td>
<td>0.3</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Sugarberry</td>
<td>Celtis laevigata</td>
<td>3</td>
<td>0</td>
<td>48.8</td>
<td>10.5</td>
<td>10.7</td>
<td>4.8</td>
<td>5.8</td>
</tr>
<tr>
<td>Persimmon</td>
<td>Diospyros texana</td>
<td>3</td>
<td>0</td>
<td>0.3</td>
<td>0.0</td>
<td>2.8</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Hercules Club</td>
<td>Zanthoxylum clava-herculis</td>
<td>3</td>
<td>0</td>
<td>0.8</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Pecan</td>
<td>Carya illinoinensis</td>
<td>3</td>
<td>0</td>
<td>2.0</td>
<td>3.3</td>
<td>3.3</td>
<td>.</td>
<td>.</td>
</tr>
</tbody>
</table>
Table 2.9. Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2016 at the Freestone study location analyzing seedling height, diameter, volume index, and stand volume index two months post 2016 planting.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Height (cm)</th>
<th>F</th>
<th>p</th>
<th>Diameter (cm)</th>
<th>F</th>
<th>p</th>
<th>Volume Index (cm³)</th>
<th>F</th>
<th>p</th>
<th>Stand Volume Index (m³/ha)</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canopy Type</td>
<td>1</td>
<td>37.38</td>
<td>&lt;0.001</td>
<td></td>
<td>1.72</td>
<td>0.1896</td>
<td></td>
<td>0.41</td>
<td>0.5228</td>
<td></td>
<td>0.60</td>
<td>0.4457</td>
<td></td>
</tr>
<tr>
<td>Mitigation treatment</td>
<td>3</td>
<td>8.99</td>
<td>0.0045</td>
<td></td>
<td>0.63</td>
<td>0.6113</td>
<td></td>
<td>0.69</td>
<td>0.5831</td>
<td></td>
<td>0.83</td>
<td>0.509</td>
<td></td>
</tr>
<tr>
<td>Species</td>
<td>2</td>
<td>308.30</td>
<td>&lt;0.0001</td>
<td></td>
<td>45.99</td>
<td>&lt;0.001</td>
<td></td>
<td>117.73</td>
<td>&lt;0.0001</td>
<td></td>
<td>52.22</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Canopy Type*Mitigation treatment</td>
<td>3</td>
<td>6.71</td>
<td>0.0002</td>
<td></td>
<td>0.42</td>
<td>0.7408</td>
<td></td>
<td>0.89</td>
<td>0.4481</td>
<td></td>
<td>0.38</td>
<td>0.7663</td>
<td></td>
</tr>
<tr>
<td>Canopy Type*Species</td>
<td>2</td>
<td>12.56</td>
<td>&lt;0.0001</td>
<td></td>
<td>4.78</td>
<td>0.0085</td>
<td></td>
<td>10.30</td>
<td>&lt;0.0001</td>
<td></td>
<td>4.36</td>
<td>0.0233</td>
<td></td>
</tr>
<tr>
<td>Mitigation treatment*Species</td>
<td>6</td>
<td>3.95</td>
<td>0.0006</td>
<td></td>
<td>2.34</td>
<td>0.0301</td>
<td></td>
<td>1.64</td>
<td>0.1318</td>
<td></td>
<td>0.56</td>
<td>0.7594</td>
<td></td>
</tr>
<tr>
<td>Canopy Type<em>Mitigation treatment</em>Species</td>
<td>6</td>
<td>4.05</td>
<td>0.0005</td>
<td></td>
<td>0.59</td>
<td>0.7383</td>
<td></td>
<td>1.06</td>
<td>0.3879</td>
<td></td>
<td>1.13</td>
<td>0.3734</td>
<td></td>
</tr>
</tbody>
</table>
Table 2.10. Mixed model ANOVA results (degrees of freedom [df], F-statistic [F], and p-value [p]) for seedlings planted in January, 2016 at the Freestone study location analyzing seedling change in height, diameter, volume index, and stand volume index after the 2016 growing season.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Change in Height (cm)</th>
<th>F</th>
<th>p</th>
<th>Change in Diameter (cm)</th>
<th>F</th>
<th>p</th>
<th>Change in Volume Index (cm³)</th>
<th>F</th>
<th>p</th>
<th>Change in Stand Volume Index (m³/ha)</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canopy Type</td>
<td>1</td>
<td>0.00</td>
<td>0.9448</td>
<td>0.448</td>
<td>15.21</td>
<td>0.0001</td>
<td></td>
<td>4.72</td>
<td>0.0302</td>
<td>10.67</td>
<td>0.0031</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mitigation treatment</td>
<td>3</td>
<td>12.18</td>
<td>0.0016</td>
<td>0.7356</td>
<td>0.43</td>
<td>0.7356</td>
<td></td>
<td>1.82</td>
<td>0.2144</td>
<td>3.78</td>
<td>0.0527</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Species</td>
<td>2</td>
<td>7.21</td>
<td>0.0008</td>
<td></td>
<td>9.38</td>
<td>&lt;0.0001</td>
<td></td>
<td>2.23</td>
<td>0.1088</td>
<td>69.65</td>
<td>&lt;0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canopy Type*Mitigation treatment</td>
<td>3</td>
<td>0.90</td>
<td>0.4403</td>
<td></td>
<td>0.37</td>
<td>0.7774</td>
<td></td>
<td>0.63</td>
<td>0.5987</td>
<td>6.95</td>
<td>0.0014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canopy Type*Species</td>
<td>2</td>
<td>5.80</td>
<td>0.0032</td>
<td></td>
<td>3.27</td>
<td>0.0387</td>
<td></td>
<td>9.17</td>
<td>0.0001</td>
<td>33.85</td>
<td>&lt;0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mitigation treatment*Species</td>
<td>6</td>
<td>1.76</td>
<td>0.1054</td>
<td></td>
<td>1.41</td>
<td>0.2069</td>
<td></td>
<td>0.42</td>
<td>0.8677</td>
<td>2.29</td>
<td>0.0655</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canopy Type<em>Mitigation treatment</em>Species</td>
<td>5</td>
<td>3.06</td>
<td>0.0097</td>
<td></td>
<td>2.58</td>
<td>0.0254</td>
<td></td>
<td>0.43</td>
<td>0.8286</td>
<td>2.29</td>
<td>0.0655</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2.11. Results of 14-day trail camera survey using one camera per 41 ha conducted at each study location from late August to early September, 2015.

<table>
<thead>
<tr>
<th>Study Location</th>
<th>Hectares Surveyed</th>
<th>Images Analyzed</th>
<th>% Images with Deer</th>
<th>Estimated Abundance</th>
<th>Estimated Density (per ha)</th>
<th>% Images with Swine</th>
<th>Estimated Abundance</th>
<th>Estimated Density (per ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hopkins</td>
<td>445</td>
<td>7,378</td>
<td>6.3</td>
<td>22</td>
<td>0.049</td>
<td>24.5</td>
<td>54</td>
<td>0.121</td>
</tr>
<tr>
<td>Hunt</td>
<td>445</td>
<td>3,467</td>
<td>42.6</td>
<td>123</td>
<td>0.276</td>
<td>24.0</td>
<td>55</td>
<td>0.124</td>
</tr>
<tr>
<td>Freestone (forested area)</td>
<td>324</td>
<td>3,587</td>
<td>1.5</td>
<td>16</td>
<td>0.049</td>
<td>67.7</td>
<td>30</td>
<td>0.093</td>
</tr>
<tr>
<td>Freestone (non-forested)</td>
<td>324</td>
<td>3,910</td>
<td>26.4</td>
<td>55</td>
<td>0.170</td>
<td>37.8</td>
<td>37</td>
<td>0.114</td>
</tr>
<tr>
<td>Anderson</td>
<td>445</td>
<td>5,547</td>
<td>33.1</td>
<td>83</td>
<td>0.187</td>
<td>23.2</td>
<td>71</td>
<td>0.16</td>
</tr>
</tbody>
</table>
Appendix A. Tukey’s multiple comparisons test on mean seedling survival (%) for seedlings planted in 2015 at the four study locations and in 2016 at the Freestone study location. Letters denote differences among means within the same source of variation per measure period at $\alpha = 0.10$.

<table>
<thead>
<tr>
<th>Survival</th>
<th>2015 Sites</th>
<th>2016 Freestone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Two months post planting</td>
<td>1st Growing Season</td>
</tr>
<tr>
<td>Hopkins</td>
<td>99.8% .</td>
<td>32.6% A</td>
</tr>
<tr>
<td>Anderson</td>
<td>95.5% .</td>
<td>7.8% B</td>
</tr>
<tr>
<td>Hunt</td>
<td>100 % .</td>
<td>47.9% A</td>
</tr>
<tr>
<td>Freestone</td>
<td>93.3% .</td>
<td>5.3% B</td>
</tr>
<tr>
<td>non-forested</td>
<td>99.8% A</td>
<td>13.7% B</td>
</tr>
<tr>
<td>forested area</td>
<td>94.5% B</td>
<td>30.8% A</td>
</tr>
<tr>
<td>Non-Fenced</td>
<td>92.6% .</td>
<td>14.9% B</td>
</tr>
<tr>
<td>Electric Fence</td>
<td>96.0% .</td>
<td>22.5% A</td>
</tr>
<tr>
<td>High Fence</td>
<td>99.9% .</td>
<td>28.3% A</td>
</tr>
<tr>
<td>Ind. Shelters</td>
<td>100% .</td>
<td>25.5% A</td>
</tr>
<tr>
<td>Bur/Nuttall</td>
<td>97.5% .</td>
<td>21.4% B</td>
</tr>
<tr>
<td>Pecan</td>
<td>95.4% .</td>
<td>28.1% A</td>
</tr>
<tr>
<td>Shumard</td>
<td>98.2% .</td>
<td>18.1% C</td>
</tr>
<tr>
<td>Hopkins</td>
<td>99.7% .</td>
<td>29.1% B</td>
</tr>
<tr>
<td>Anderson</td>
<td>99.9% .</td>
<td>36.1% B</td>
</tr>
<tr>
<td>Hunt</td>
<td>99.6% .</td>
<td>6.6% C</td>
</tr>
<tr>
<td>Freestones</td>
<td>99.9% .</td>
<td>74.5% A</td>
</tr>
<tr>
<td>non-forested</td>
<td>99.8% .</td>
<td>7.0% C</td>
</tr>
<tr>
<td>forested area</td>
<td>86.9% .</td>
<td>3.7% C</td>
</tr>
</tbody>
</table>
(Continued) Appendix A. Tukey's multiple comparisons test on mean seedling survival.

<table>
<thead>
<tr>
<th>Survival</th>
<th>2015 Sites</th>
<th>Freestones 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Two months post planting</td>
<td>1st Growing Season</td>
</tr>
<tr>
<td>source 1</td>
<td>source 2</td>
<td>source 3</td>
</tr>
<tr>
<td>Hopkins</td>
<td>Non-Fenced</td>
<td>99.2%</td>
</tr>
<tr>
<td></td>
<td>Electric Fence</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td>High Fence</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td>Ind. Shelters</td>
<td>100.0%</td>
</tr>
<tr>
<td>Anderson</td>
<td>Non-Fenced</td>
<td>99.2%</td>
</tr>
<tr>
<td></td>
<td>Electric Fence</td>
<td>84.1%</td>
</tr>
<tr>
<td></td>
<td>High Fence</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td>Ind. Shelters</td>
<td>100.0%</td>
</tr>
<tr>
<td>Hunt</td>
<td>Non-Fenced</td>
<td>99.7%</td>
</tr>
<tr>
<td></td>
<td>Electric Fence</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td>High Fence</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td>Ind. Shelters</td>
<td>100.0%</td>
</tr>
<tr>
<td>Freestones</td>
<td>Non-Fenced</td>
<td>75.8%</td>
</tr>
<tr>
<td></td>
<td>Electric Fence</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td>High Fence</td>
<td>99.6%</td>
</tr>
<tr>
<td></td>
<td>Ind. Shelters</td>
<td>100.0%</td>
</tr>
<tr>
<td>Hopkins</td>
<td>Bur</td>
<td>99.9%</td>
</tr>
<tr>
<td></td>
<td>Pecan</td>
<td>99.8%</td>
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(Continued) Appendix A. Tukey’s multiple comparisons test on mean seedling survival.

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Appendix B. Tukey’s multiple comparisons test on initial height, diameter, VI, and SVI two months post planting for seedlings planted in January, 2015. Letters denote differences among means within the same source of variation per measure period at $\alpha = 0.10$.

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(Continued) Appendix B. Tukey’s multiple comparisons test on initial height, diameter, VI, and SVI two months post planting for seedlings planted in January, 2015.

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(Continued) Appendix B. Tukey’s multiple comparisons test on initial height, diameter, VI, and SVI two months post planting for seedlings planted in January, 2015.

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(Continued) Appendix B. Tukey’s multiple comparisons test on initial height, diameter, VI, and SVI two months post planting for seedlings planted in January, 2015.

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<th>SV (m³/ha)</th>
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Appendix C. Tukey’s multiple comparisons test on the change in seedling height, diameter, VI, and SVI over the 2015 growing season for seedlings planted in January, 2015. Letters denote differences among means within the same source of variation per measure period at $\alpha = 0.10$.

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(Continued) Appendix C. Tukey’s multiple comparisons test on the change in seedling height, diameter, VI, and SVI over the 2015 growing season for seedlings planted in January, 2015.

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Appendix D. Tukey’s multiple comparisons test on the change in seedling height, diameter, VI, and SVI over the 2016 growing season for seedlings planted in January, 2015. Letters denote differences among means within the same source of variation per measure period at $\alpha = 0.10$.

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Appendix D. Tukey’s multiple comparisons test on the change in seedling height, diameter, VI, and SVI over the 2016 growing season for seedlings planted in January, 2015.

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Appendix E. Tukey’s multiple comparisons test on the change in seedling height, diameter, VI, and SVI over the 2015 and 2016 growing season for seedlings planted in January, 2015. Letters denote differences among means within the same source of variation per measure period at $\alpha = 0.10$.

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Appendix E. Tukey’s multiple comparisons test on the change in seedling height, diameter, VI, and SVI over the 2015 and 2016 growing season for seedlings planted in January, 2015.

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Appendix E. Tukey’s multiple comparisons test on the change in seedling height, diameter, VI, and SVI over the 2015 and 2016 growing season for seedlings planted in January, 2015.

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(Continued) Appendix E. Tukey’s multiple comparisons test on the change in seedling height, diameter, VI, and SVI over the 2015 and 2016 growing season for seedlings planted in January, 2015.

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Appendix F. Tukey’s multiple comparisons test on initial seedling height, diameter, VI, and SVI two months post planting for seedlings planted in January, 2016. Letters denote differences among means within the same source of variation per measure period at $\alpha = 0.10$.

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Appendix G. Tukey’s multiple comparisons test on the change in seedling height, diameter, VI, and SVI over the 2016 growing season for seedlings planted in January, 2016.

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<td>Δ VI (cm³)</td>
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Appendix H. Percent survival two months post planting, to the end of the 2015 growing season, and to the end of the 2016 growing seasons.

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Appendix I. Descriptive statistics for percent survival two months post planting (Time Interval = 0) and percent survival after the first growing season (Time Interval = 1) for the seedlings planted at Freestone in January, 2016. All seedlings survived initial two months.

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Appendix J. Descriptive statistics for height (cm) two months post planting (Time Interval = 0), change in height (cm) over the 2015 growing season (Time Interval= 0-1), change in height (cm) over the 2016 growing season (Time Interval = 1-2), and total change in height (cm) over the course of the 2015 and 2016 growing seasons (Time Interval = 0-2).

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Appendix J. Descriptive statistics for height (cm) two months post planting (Time Interval = 0), change in height (cm) over the 2015 growing season (Time Interval = 0-1), change in height (cm) over the 2016 growing season (Time Interval = 1-2), and total change in height (cm) over the course of the 2015 and 2016 growing seasons (Time Interval = 0-2).

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Appendix K. Descriptive statistics for diameter (cm) two months post planting (Time Interval = 0), change in diameter (cm) over the 2015 growing season (Time Interval= 0-1), change in diameter (cm) over the 2016 growing season (Time Interval = 1-2), and total change in diameter (cm) over the course of the 2015 and 2016 growing seasons (Time Interval = 0-2).

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Appendix K. Descriptive statistics for diameter (cm) two months post planting (Time Interval = 0), change in diameter (cm) over the 2015 growing season (Time Interval= 0-1), change in diameter (cm) over the 2016 growing season (Time Interval = 1-2), and total change in diameter (cm) over the course of the 2015 and 2016 growing seasons (Time Interval = 0-2).

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Appendix L. Descriptive statistics for volume index (cm$^3$) two months post planting (Time Interval = 0), change in volume index (cm$^3$) over the 2015 growing season (Time Interval = 0-1), change in volume index (cm$^3$) over the 2016 growing season (Time Interval = 1-2), and total change in volume index (cm$^3$) over the course of the 2015 and 2016 growing seasons (Time Interval = 0-2).

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Appendix L. Descriptive statistics for volume index (cm$^3$) two months post planting (Time Interval = 0), change in volume index (cm$^3$) over the 2015 growing season (Time Interval= 0-1), change in volume index (cm$^3$) over the 2016 growing season (Time Interval = 1-2), and total change in volume index (cm$^3$) over the course of the 2015 and 2016 growing seasons (Time Interval = 0-2).

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Appendix M. Descriptive statistics for stand volume index (m$^3$/ha) two months post planting (Time Interval = 0), change in stand volume index (m$^3$/ha) over the 2015 growing season (Time Interval= 0-1), change in stand volume index (m$^3$/ha) over the 2016 growing season (Time Interval = 1-2), and total change in stand volume index (m$^3$/ha) over the course of the 2015 and 2016 growing seasons (Time Interval = 0-2).

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(Continued) Appendix M. Descriptive statistics for stand volume index (m$^3$/ha) two months post planting (Time Interval = 0), change in stand volume index (m$^3$/ha) over the 2015 growing season (Time Interval= 0-1), change in stand volume index (m$^3$/ha) over the 2016 growing season (Time Interval = 1-2), and total change in stand volume index (m$^3$/ha) over the course of the 2015 and 2016 growing seasons (Time Interval = 0-2).

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Appendix N. Descriptive statistics for mean height (cm) two months post planting (Time Interval = 0) and mean change in height (cm) from two months post planting to 12 months post planting (Time Interval = 0 to 1) for the seedlings planted at Freestone in January, 2016.

<table>
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<th>source</th>
<th>Time Interval</th>
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<th>Std Dev</th>
<th>Minimum</th>
<th>Maximum</th>
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<td>61</td>
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<td>12.29</td>
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<td>65</td>
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<td>10.74</td>
<td>9</td>
<td>61</td>
</tr>
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<td>11.27</td>
<td>12</td>
<td>63</td>
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<td>10.78</td>
<td>18</td>
<td>61</td>
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Appendix O. Descriptive statistics for mean diameter (cm) two months post planting (Time Interval = 0) and mean change in diameter (cm) from two months post planting to 12 months post planting (Time Interval = 0 to 1) for the seedlings planted at Freestone in January, 2016.

<table>
<thead>
<tr>
<th>source</th>
<th>Time Interval</th>
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<th>Std Dev</th>
<th>Minimum</th>
<th>Maximum</th>
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Appendix P. Descriptive statistics for mean volume index (cm$^3$) two months post planting (Time Interval = 0) and mean change in volume index (cm$^3$) from two months post planting to 12 months post planting (Time Interval = 0 to 1) for the seedlings planted at Freestone in January, 2016.

<table>
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<th>Maximum</th>
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Appendix Q. Descriptive statistics for mean stand volume index (m$^3$/ha) two months post planting (Time Interval = 0) and mean change in stand volume index (m$^3$/ha) from two months post planting to 12 months post planting (Time Interval = 0 to 1) for the seedlings planted at Freestone in January, 2016.

<table>
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<th>Minimum</th>
<th>Maximum</th>
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</tbody>
</table>
VITA

After receiving his high school diploma at Gladstone Area High, Gladstone, Michigan, in 2010, Ryan Jacques attended the University of Wisconsin-Whitewater to pursue a degree in Biology which emphasized in Marine Biology and Freshwater Ecology. Active in the undergraduate research program, Ryan worked on two projects focusing on wildlife behavior in the Midwest (April 2012 to May 2013). Also to gain experience in the Marine Biology emphasis he studied abroad at Deakin University, Warrnambool, VIC, Australia from July, 2013 to June 2014. Ryan received his Bachelor of Science degree from UW-Whitewater in August 2014. In January 2015, he entered graduate school at Stephen F. Austin State University, and received a Master’s of Science degree.

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Forest Ecology and Management

This thesis was typed by Ryan J. Jacques