

Fourchon Maritime Forest Ridge and Marsh Restoration

Vegetative Efforts

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Barataria-Terrebonne National Estuary Program

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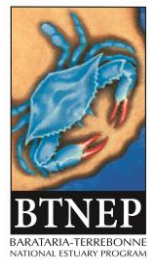


Table of Contents

Table of Figures	iv
Table of Tables	xii
1.0 INTRODUCTION	1
2.0 SITE LOCATION	1
3.0 PROJECT SITE BACKGROUND	4
3.1 Soil Quality	8
3.2 The Far Ridge	9
4.0 METHODS FOR WOODY VEGETATIVE FIELD STUDIES.....	12
4.1 Objectives	12
4.2 Woody Species Selection	13
4.3 Soil Amendment Treatments	16
4.4 Experimental Plot Site Selections.....	16
4.5 Ring Planting.....	17
4.6 Woody Trial Block Plantings.....	20
4.6.1 2010 Block Planting - March 16, 2010	21
4.6.2 2011 Block Planting – March 10, 2011	24
4.6.3 2012 Block Planting – February 23, 2012	26
4.6.4 2013 Block Planting – January 28, 2013	28
4.6.5 2014 Block Planting – March 26, 2014	29
4.7 Linear Ridge Planting – March 28, 2011	31
4.8 Mini Block Planting – March 20, 2012	32

4.9	Herbaceous Field Trial	33
4.10	Data Collection Methods.....	35
4.11	Soil Collection Methods	36
4.12	Weather.....	39
4.13	Non-Experimental Plantings.....	40
4.13.1	2009 to 2015 Ridge Plantings	41
5.0	RESULTS & DISCUSSION	45
5.1	Effects of Cultural Treatments on Species Growth and Survival	46
5.2	Comparison of Year-to-Year Survival for Each Planting Year.....	46
5.3	Single Species Change in Height Comparison Among Planting Years.....	52
5.4	Single Species Survival and Vigor Comparisons Among Planting Years.....	55
5.4.1	Hackberry Survival and Vigor: Comparison Among Planting Years	55
5.4.2	Live Oak Survival and Vigor: Comparison Among Planting Years	57
5.4.3	Sand Live Oak Survival and Vigor: Comparison Among Planting Years	59
5.5	Survival by Orientation.....	60
5.5.1	Survival by Orientation – Far Ridge: Narrow Section	62
5.5.2	Survival by Orientation – Far Ridge: Wide Section	67
5.6	Soil Quality	76
5.7	First Growing Season Survival and Soil Quality.....	82
5.7.1	First Growing Season Survival and Soil Quality: Linear Regression	82
5.7.2	First Growing Season Survival and Soil Quality: Exponential Regression.....	86
5.8	Other Vegetative Trial Plantings	89
5.8.1	Herbaceous: Survival & Spread Comparisons Among Planting Positions	89
5.8.2	Ring Planting	93

5.8.3	Linear Planting	93
5.8.4	Mini Block Planting	93
6.0	RECOMMENDATIONS	94
6.1	Cultural Soil Additives	94
6.2	Woody Seedling Size	95
6.3	Woody Species Selection	95
6.4	Runoff Management and Moisture Retention	96
6.5	Soil Quality & Predictions Based on a Fifty Percent Survival Scenario	100

Appendices:

Appendix 1 Woody Species Seed Collections and Locations

Appendix 2 Assessment and Evaluation of Soil Physical and Chemical Properties of Dredged Material in Constructed Wetland

Appendix 3 Louisiana Drought Maps 2009-2015

Appendix 4 Preliminary Report on Growth and Survival of 10 Vegetative Species Planted at the Fourchon Ridge between 2010-2014: Effect of Additives

Appendix 5 EC and SAR Results Used in the Fourchon Maritime Forest Ridge and Marsh Restoration: Vegetative Efforts Report

Table of Figures

Figure 1 Aerial overview of project site location in SE Louisiana.....	2
Figure 2 As-Built project location plan schematic for Phase Two completed in 2008.	3
Figure 3 Site plan and typical section for base bid, Phase Two, August 27, 2008.	4
Figure 4 Chronological aerial images (a-f) from 1998 to 2015 of Phases 1 and 2 construction of the Fourchon Maritime Forest Ridge and Marsh Creation Project.....	5
Figure 5 Pumping earthen material to Phase Two site in 2006.	7
Figure 6 Excavators digging down fill to marsh elevation and stacking the material to build up the elevation of the ridge. South marsh apron of Far Ridge, May 29, 2008, looking west.	8
Figure 7 Aerial image of all soil sample locations taken at Fourchon Maritime Forest Ridge and Marsh Restoration. The first two letters for each soil sample site correspond to the part of the ridge it collected from: OR – Old Ridge; MR – Middle Ridge; and FR – Far Ridge.	9
Figure 8 Wrack deposition on the south slope of the Far Ridge looking WSW, May 28, 2009.	10
Figure 9 Herbaceous planting along the top edge of Far Ridge, December 13, 2009, looking west.	10
Figure 10 Unvegetated zone between ridge slope to the right and high marsh on the left, December 2, 2015. North marsh apron looking east.....	11
Figure 11 Western end of Far Ridge looking east, December 2, 2015.	12
Figure 12 Acorn weevil on sand live oak acorn, Santa Rosa Island, Escambia County, Florida, October 27, 2013.	14
Figure 13 Live oak seedlings growing out in Deepots™ (D16L) conetainers, April 4, 2011.	14
Figure 14 Woody and herbaceous species growing out in the BTNEP shadehouse on the Nicholls State University Farm in Thibodaux, Louisiana, September 26, 2013.....	15
Figure 15 Aerial view of all vegetative trial planting locations planted on the Middle and Far Ridges from 2009-2014. Imagery date: January 25, 2015.	17
Figure 16 Aerial view of Ring Planting location, planted February 28, 2009 on the Middle and Far Ridges. Middle Ridge replicates are labeled MRC1-3 and Far Ridge replicates labeled FRC1-3. Imagery date: September 4, 2008.....	18
Figure 17 Pre-flagging Ring Planting plot on Middle Ridge prior to planting, February 17, 2009. Looking west.	18

Figure 18 Ring Planting plot on the Far Ridge, February 28, 2009. Looking west.....	19
Figure 19 Schematic of example blocks within experimental block plantings. Species were randomized within each block and treatments were randomized among blocks.	20
Figure 20 Aerial view of the 2010 Block Planting location planted on the Far Ridge March 16, 2010. Plots are labeled A to X. The four yellow rectangles show examples of approximate size and orientation of plots on the ridge. Imagery date: January 25, 2015.	22
Figure 21 Augering holes for 2010 Block Planting, March 16, 2010.	23
Figure 22 Augering holes for 2010 Block Planting, March 16, 2010.	23
Figure 23 Cultural treatments being added to experimental plot at time of planting for 2010 Block Planting, March 16, 2010.	24
Figure 24 Aerial view of the 2011 Block Planting location planted on the Far Ridge March 10, 2011. Plots are labeled A to O. The Imagery date: January 25, 2015.	25
Figure 25 Packing up the gas drills and auger bits, 2011 Block Planting, March 10, 2011. Looking ESE....	25
Figure 26 Aerial view of the 2012 Block Planting location planted on the Far Ridge February 23, 2012. Plots are labeled A to O. Plots K and L from 2011 Block Planting abandoned and added to the east of plot O. The Imagery date: January 25, 2015.....	27
Figure 27 Adding treatments to the plant holes, 2012 Block Planting, February 23, 2012. Looking SW.	27
Figure 28 Aerial view of the 2013 and 2014 Block Plantings' location planted on the Far Ridge January 28, 2013 and March 26, 2014 respectively. Plots from left (west) labeled A to O are 2013 Block Planting. Plots labeled A to I on right (east) side of image are 2014 Block Planting. Plots for the 2013 and 2014 Block Plantings occupy the same plot location as the 2010 Block Planting. Imagery date: January 25, 2015.	28
Figure 29 BTNEP Staff showing volunteers how to add bagasse to plant hole. 2013 Block Planting, January 28, 2013. Looking ENE.	29
Figure 30 Staging plants for 2014 Block Planting, March 26, 2014. Looking north.	30
Figure 31 Aerial view of Linear Planting (March 28, 2011) and Mini Block planting (March 20, 2012) locations on the Far Ridge. Linear Planting plots not labeled, only represented by yellow line. Mini Block Planting plots labeled A, B, and C on right (east) side of image. The Imagery date: January 25, 2015.....	31
Figure 32 Linear Ridge Planting parallel to the southern edge of the Far Ridge, March 22, 2011. Looking east.	32

Figure 33 Honeylocust seedling in Mini Block Planting plot, March 20, 2012.....	33
Figure 34 Aerial view of Herbaceous Field Trial location planted November 11, 2009 on the Far Ridge. Plots are labeled A to F. Each plot had 3 rows (replicates) oriented north to south across the Far Ridge profile. The Imagery date: January 25, 2015.	34
Figure 35 Offloading plants from the boats for the Herbaceous Field Trial, November 11, 2009. On the north marsh apron looking east.....	35
Figure 36 Volunteers taking baseline data measurements, March 10, 2010.	36
Figure 37 January 2015 aerial image of the 15 ridge top soil sample locations from the Far Ridge.	37
Figure 38 Drying soil samples in the greenhouse before bagging and shipping them off for analysis, August 7, 2009.	38
Figure 39 Drought maps at the time of the March 2011 plantings and in June 21, 2011. Green arrow indicates project location.	40
Figure 40 Mean (\pm SE) Survival for each species planted in 2010. Plants were planted in the Spring and survival was calculated for each subsequent Fall. Means with a similar letter within each year are not different. The numbers in the base of each column represent the number of plants used to calculate survival.	49
Figure 41 Mean (\pm SE) Survival for each species planted in 2011. Plants were planted in the Spring and survival was calculated for each subsequent Fall. Initial Survival was very low and did not differ among species for any sample period. The numbers in the base of each column represent the number of plants used to calculate survival.	50
Figure 42 Mean (\pm SE) Survival for each species planted in 2012. Plants were planted in the Spring and survival was calculated for each subsequent Fall. Means with a similar letter within each year are not different. The asterisks indicates that Analysis of Variance detected a difference among treatments, but <i>post hoc</i> analysis could not delineate among the means. The numbers in the base of each column represent the number of plants used to calculate survival.	50
Figure 43 Mean (\pm SE) Survival for each species planted in 2013. Plants were planted in the Spring and survival was calculated for each subsequent Fall. Means with a similar letter within each year are not different. The numbers in the base of each column represent the number of plants used to calculate survival.	51
Figure 44 Mean (\pm SE) Survival for each species planted in 2014. Plants were planted in the Spring and survival was calculated for each subsequent Fall. Means with a similar letter within each year are not different. The numbers in the base of each column represent the number of plants used to calculate survival.	51

Figure 45 Mean (\pm SE) change in height for each sample period for each planting year as compared to the height at planting (baseline height = 0) for Hackberry. The horizontal dashed line represents the mean height at planting for each year. Means within a sample period that have a different letter are not similar. Asterisks mark groups that had a difference among treatments detected by Analysis of Variance, but the difference could not be delineated by <i>post hoc</i> tests.	54
Figure 46 Mean (\pm SE) change in height for each sample period for each planting year as compared to the height at planting (baseline height = 0) for Live Oak. The horizontal dashed line represents the mean height at planting for each year. Means within a sample period that have a different letter are not similar.	54
Figure 47 Mean (\pm SE) change in height for each sample period for each planting year as compared to the height at planting (baseline height = 0) for Sand Live Oak. The horizontal dashed line represents the mean height at planting for each year. Means within each sample period were similar.	55
Figure 48 Mean (\pm SE) Hackberry Survival for each sample period for the 2010, 2011, 2012, and 2013 plantings. Means within a sample period that are marked with a different letter are not similar. Numbers inside of each column represent the number of trees used to calculate the mean value.	56
Figure 49 Mean (\pm SE) Hackberry Vigor for each sample period for the 2010, 2011, 2012, and 2013 plantings. Means within a sample period that are marked with a different letter are not similar. Numbers inside of each column represent the number of trees used to calculate the mean value.	57
Figure 50 Mean (\pm SE) Live Oak Survival for each sample period for the 2011, 2012, 2013, and 2014 plantings. Means within a sample period that are marked with a different letter are not similar. Numbers inside of each column represent the number of trees used to calculate the mean value.	58
Figure 51 Mean (\pm SE) Live Oak Vigor for each sample period for the 2011, 2012, 2013, and 2014 plantings. Means within a sample period that are marked with a different letter are not similar. Numbers inside of each column represent the number of trees used to calculate the mean value.	58
Figure 52 Mean (\pm SE) Sand Live Oak Survival for each sample period for the 2010, 2012, and 2013 plantings. Means within a sample period that are marked with a different letter are not similar. Numbers inside of each column represent the number of trees used to calculate the mean value.	59
Figure 53 Mean (\pm SE) Sand Live Oak Vigor for each sample period for the 2010, 2012, and 2013 plantings. Means within a sample period that are marked with a different letter are not similar. Numbers inside of each column represent the number of trees used to calculate the mean value.	60
Figure 54 Example diagram of planting layout for horizontal blocks on ridge. Horizontal blocks compared plant survival for the two rows (8 plants each row) on the north side of the ridge versus plant survival for the two rows (8 plants each row) on the south side of the ridge.	61

Figure 55 Example diagram of planting layout for vertical blocks on ridge. Vertical blocks compared plant survival for the four rows (4 plants each row) on the north side of the ridge versus plant survival for the four rows (4 plants each row) on the south side of the ridge.	62
Figure 56 Mean (\pm SE) survival for Hackberry planted in 2010 in a horizontal block and sampled 6 months and 1.5 years after planting for each orientation. Means within each sample period are similar but only the South side had survivors by 1.5 years. The number at the base of each column represents the number of individuals used to calculate the mean value.	63
Figure 57 Mean (\pm SE) survival for Sand Live Oak planted in 2010 in a horizontal block and sampled 6 months and 1.5 years after planting for each orientation. No Sand Live Oak planted on the South side survived to 6 months. The number at the base of each column represents the number of individuals used to calculate the mean value.	64
Figure 58 Mean (\pm SE) survival for Hackberry planted in 2013 in a horizontal block and sampled 6 months and 1.5 years after planting for each orientation. The asterisk indicates a difference in survival between the two locations within each time period. The number at the base of each column represents the number of individuals used to calculate the mean value.	65
Figure 59 Mean (\pm SE) survival for Live Oak planted in 2013 in a horizontal block and sampled 6 months and 1.5 years after planting for each orientation. The asterisk indicates a difference in survival between the two locations within each time period. The number at the base of each column represents the number of individuals used to calculate the mean value.	66
Figure 60 Mean (\pm SE) survival for Sand Live Oak planted in 2013 in a horizontal block and sampled 6 months and 1.5 years after planting for each orientation. The asterisk indicates a difference in survival between the two locations within each time period. The number at the base of each column represents the number of individuals used to calculate the mean value.	66
Figure 61 Mean (\pm SE) survival for Hackberry planted in 2010 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. The asterisk indicates a difference in survival between the two locations within each time period. The number at the base of each column represents the number of individuals used to calculate the mean value.	68
Figure 62 Mean (\pm SE) survival for Sand Live Oak planted in 2010 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. The number at the base of each column represents the number of individuals used to calculate the mean value.	68
Figure 63 Mean (\pm SE) survival for Hackberry planted in 2011 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. There were no survivors on the North side after 6 months. The number at the base of each column represents the number of individuals used to calculate the mean value.	69

Figure 64 Mean (\pm SE) survival for Live Oak planted in 2011 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. Means within each sample period are similar. The number at the base of each column represents the number of individuals used to calculate the mean value.....	70
Figure 65 Mean (\pm SE) survival for Hackberry planted in 2012 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. Means within each sample period are similar. The number at the base of each column represents the number of individuals used to calculate the mean value.....	71
Figure 66 Mean (\pm SE) survival for Live Oak planted in 2012 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. The asterisk indicates a difference in survival between the two orientations within each time period. The number at the base of each column represents the number of individuals used to calculate the mean value.....	72
Figure 67 Mean (\pm SE) survival for Sand Live Oak planted in 2012 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. The asterisk indicates a difference in survival between the two locations within each time period. The number at the base of each column represents the number of individuals used to calculate the mean value.....	72
Figure 68 Mean (\pm SE) survival for Hackberry planted in 2013 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. The asterisk indicates a difference in survival between the two locations within each time period. The number at the base of each column represents the number of individuals used to calculate the mean value.....	74
Figure 69 Mean (\pm SE) survival for Live Oak planted in 2013 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. Means within each sample period are similar. The number at the base of each column represents the number of individuals used to calculate the mean value.....	74
Figure 70 Mean (\pm SE) survival for Sand Live Oak planted in 2013 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. The number at the base of each column represents the number of individuals used to calculate the mean value. All means for each sample period were statistically similar.	75
Figure 71 Mean (\pm SE) survival for Live Oak planted in 2014 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. Means within each sample period are similar. The number at the base of each column represents the number of individuals used to calculate the mean value.....	76
Figure 72 Mean (\pm SE) EC on the Far Ridge for each year. Means that share a similar letter are not different.....	77
Figure 73 Relationship between EC (\pm SE) and sample year for the Far Ridge.....	77

Figure 74 Mean (\pm SE) Salts on the Far Ridge for each year. No differences were detected among years.	78
Figure 75 Relationship between Salts (\pm SE) and sample year for the Far Ridge.....	78
Figure 76 Mean (\pm SE) Na on the Far Ridge for each year. No differences were detected among years.	79
Figure 77 Relationship between Na (\pm SE) and sample year for the Far Ridge.	79
Figure 78 Mean (\pm SE) SAR on the Far Ridge for each year. No differences were detected among years.	80
Figure 79 Relationship between SAR (\pm SE) and sample year for the Far Ridge.....	80
Figure 80 Mean (\pm SE) CEC on the Far Ridge for each year. No differences were detected among years.	81
Figure 81 Relationship between CEC (\pm SE) and sample year for the Far Ridge.	81
Figure 82 Linear relationship between mean (\pm SE) first growing season Survival of Hackberry, Live Oak, and Sand Live Oak for each planting year and mean (\pm SE) EC for each planting year.	83
Figure 83 Linear relationship between mean (\pm SE) first growing season Survival of Hackberry, Live Oak, and Sand Live Oak for each planting year and mean (\pm SE) Salts for each planting year.....	84
Figure 84 Linear relationship between mean (\pm SE) first growing season Survival of Hackberry, Live Oak, and Sand Live Oak for each planting year and mean (\pm SE) Na for each planting year.....	84
Figure 85 Linear relationship between mean (\pm SE) first growing season Survival of Hackberry, Live Oak, and Sand Live Oak for each planting year and mean (\pm SE) SAR for each planting year.	85
Figure 86 Linear relationship between mean (\pm SE) first growing season Survival of Hackberry, Live Oak, and Sand Live Oak for each planting year and mean (\pm SE) CEC for each planting year.	85
Figure 87 Exponential relationship between first growing season Survival (\pm SE) and EC (\pm SE) for Hackberry and Live Oak combined. The year indicates the year of planting.	86
Figure 88 Exponential relationship between first growing season Survival (\pm SE) and Salts (\pm SE) for Hackberry and Live Oak. The year indicates the year of planting.	87
Figure 89 Exponential relationship between first growing season Survival (\pm SE) and Na (\pm SE) for Hackberry and Live Oak combined. The year indicates the year of planting.	87
Figure 90 Exponential relationship between first growing season Survival (\pm SE) and SAR (\pm SE) for Hackberry and Live Oak. The year indicates the year of planting.	88

Figure 91 Exponential relationship between first growing season Survival (\pm SE) and CEC (\pm SE) for Hackberry and Live Oak. The year indicates the year of planting.	88
Figure 92 Mean (\pm SE) survival for <i>Panicum</i> planted among three positions on the ridge with or without straw as an additive. Means with different letters are not similar. The numbers inside the base of each column represent the sample size.	90
Figure 93 Mean (\pm SE) spread for <i>Panicum</i> planted among three positions on the ridge with or without straw as an additive. The numbers inside the base of each column represent the sample size.	90
Figure 94 Mean (\pm SE) survival for <i>Paspalum</i> planted among three positions on the ridge with or without straw as an additive. Means with different letters are not similar. The numbers inside the base of each column represent the sample size.	91
Figure 95 Mean (\pm SE) spread for <i>Paspalum</i> planted among three positions on the ridge with or without straw as an additive. The numbers inside the base of each column represent the sample size.	91
Figure 96 Mean (\pm SE) survival for <i>S. patens</i> planted among three positions on the ridge with or without straw as an additive. The numbers inside the base of each column represent the sample size.	92
Figure 97 Mean (\pm SE) spread for <i>S. patens</i> planted among three positions on the ridge with or without straw as an additive. The numbers inside the base of each column represent the sample size.	92
Figure 98 Standing water on top of the far eastern end of Middle Ridge, February 25, 2014.	98
Figure 99 Exposed roots (8+ inches) due to soil erosion of a salt matrimony vine plant on the north slope of the Far Ridge located along the narrower 900 foot long western end, December 2, 2015.	99

Table of Tables

Table 1 Number of individual surviving plants (proportion of individuals of original planting that survived in parenthesis) for each species planted each year. N planted represents the total number of individuals planted that year for that species.	47
Table 2 Pearson Correlation Coefficients for the correlation between height (in) and spread (in) and between height (in) and basal stem diameter (mm). All coefficients are significant at a P value of <0.0001.	52
Table 3 Calculated levels of each soil quality parameter that results in 50% survival based on the exponential relationship between each variable and survival for multiple years of plantings for Hackberry and Live Oak.	100

1.0 INTRODUCTION

While Louisiana has the largest contiguous area of wetlands in the lower United States, it is also losing these wetlands at a breakneck pace. Indeed, the fastest disappearing landmass on earth is occurring within the two estuaries that make up the Barataria-Terrebonne National Estuary. Estuaries are some of the most ecologically productive places on the planet due to their changing salinity regimes and varying landforms.

Coastal Louisiana is losing a football field size area of land every hour. This means we are losing our coastal barrier islands, saline, brackish and fresh marshes, swamps, and chenier ridges that provide habitat for birds, fish and animals. Erosion, salt water intrusion, subsidence, storm events, and anthropogenic activities are the causes of this loss. Chenier ridges and maritime forests act as speed bumps in slowing storm surge during tropical events and provide critically important habitat for many species of Neotropical migratory songbirds. As these landforms are lost, so is the critical habitats over 338 migrating bird species depend upon travelling the Mississippi Flyway each spring and fall.

To combat this loss, new coastal habitats need to be recreated or restored. The Fourchon Maritime Forest Ridge and Marsh Restoration project was the first of its kind utilizing saline sediments to create a maritime ridge for the establishment of trees beneficial to Neotropical migratory songbirds. Use of the readily available surrounding saline sediments is problematic, however, in that they are not initially suitable for the non-halophytic trees selected for this project. Planning and measures then must be undertaken to mitigate for the salinity in the soil. Experimentally designed plantings were conducted utilizing a number of beneficial native woody species and cultural treatments and through statistical analysis of plant response and soil characteristics over time, we try to determine when soil conditions become suitable to support the establishment of the targeted woody species. Armed with this knowledge, future maritime ridge restoration projects created utilizing saline sediments may be able to determine the proper time for woody species establishment through soil sampling alone. Through the construction of maritime forest ridges along Louisiana's coast, the "bones" of our salt marshes providing storm surge protection and habitat for the millions of Neotropical migratory birds as they pass through each year can be rebuilt and restored.

2.0 SITE LOCATION

The Fourchon Maritime Forest Ridge and Marsh Restoration project site (hereinafter referred to as Ridge and Marsh site if referring to the entire project site or just the Ridge if referring to just the ridge top) is approximately 56 acres of created marsh and ridge located immediately

north of Port Fourchon, Louisiana (approximately 0.85 miles north of Flotation Canal), approximately 6.2 miles due south of Leeville, Louisiana, and approximately 11 miles ENE of Grand Isle, Louisiana (Figure 1). A proximal center-point GPS coordinate is 29° 9' 37.00" N by 90° 12' 36.50" W with the ridge linearly oriented in a due east-west direction. The Ridge and Marsh Site was constructed along the sunken ridge of Bayou Cochon in a saltmarsh that had subsided and eroded into open water. Prior to its construction, the open water area directly south of and adjacent to the ridge was restored to saltmarsh again as part of mitigation requirements for the Greater Lafourche Port Commission's port expansion. The Ridge and Marsh site itself is not mitigation, but a public service contribution provided by the Greater Lafourche Port Commission due to excess sediment availability above and beyond the mitigation requirements.

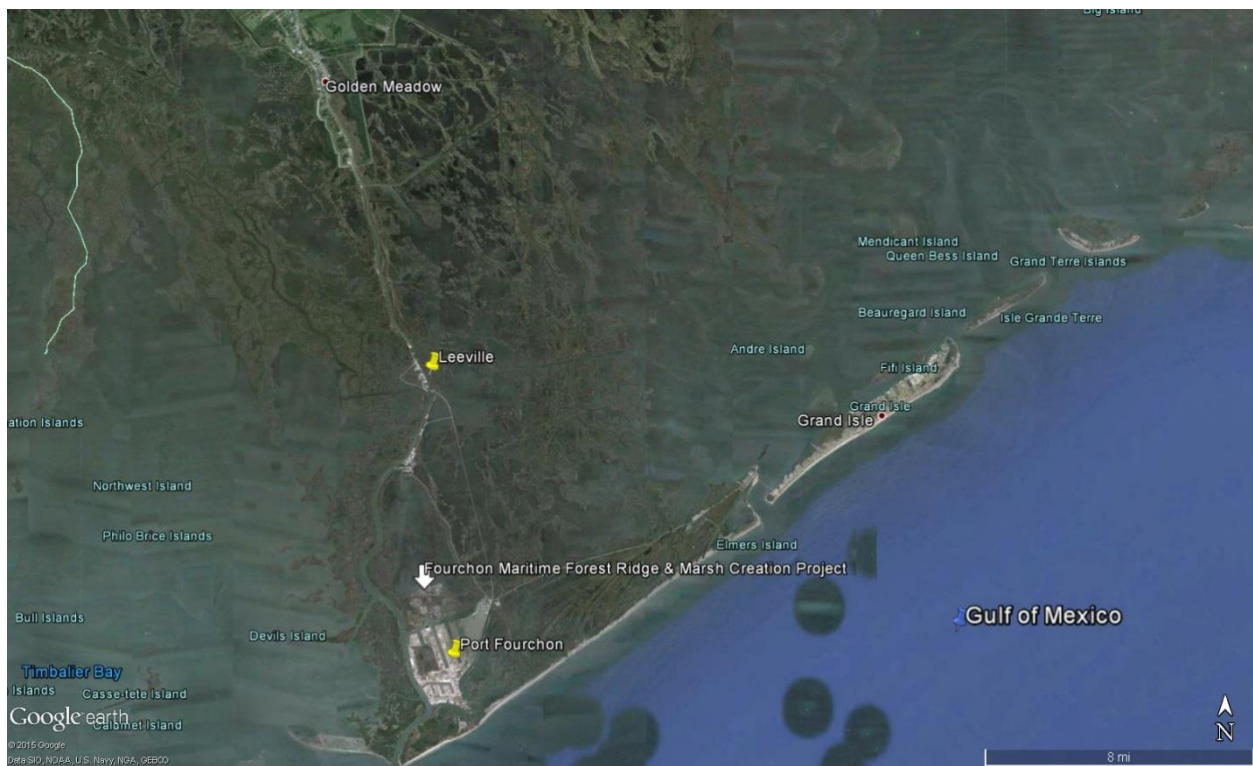


Figure 1 Aerial overview of project site location in SE Louisiana.

The Ridge and Marsh site is approximately 6,050 linear feet and approximately 400 feet wide. The 400 foot wide project footprint was originally created for a 200 foot wide ridge and slope section surrounded on either side by a 100 foot marsh apron section, but this ridge versus marsh dimensions varied considerably as construction realities presented themselves. The Ridge and Marsh site is further broken down into three sections named for the three different times sediment was pumped and shaped over a period of approximately five years to create what constitutes the Ridge and Marsh today. A first, short test section, we call the Old Ridge and Marsh was finished in spring 2003. This Old Ridge and Marsh section today is

approximately 210 feet long by 400 feet wide and 0.82 acres in area (ridge top, 0.15 acres; marsh and ridge slope, 0.67 acres). The first phase of construction, we call the Middle Ridge and Marsh section, was finished in May 2005. The Middle Ridge and Marsh section is approximately 2,000 feet long by 400 feet wide and approximately 18.52 acres in area (ridge top, 5.83 acres; marsh and ridge slope, 12.69 acres). The second phase of construction and latest completed section, we call the Far Ridge and Marsh, was finished in the summer of 2008 (Figure 2). The Far Ridge and Marsh section is approximately 3,850 feet long by 400 feet wide and approximately 36.66 acres in area (ridge top, 7.37 acres; marsh and ridge slope, 29.29 acres). Unlike the previous two sections, because less material was ultimately available than originally thought for this section, the ridge itself only extends approximately 2,900 feet with the last 950 feet or so on the far western end only at marsh elevation (Figure 3). Total ridge top acreage for the entire Fourchon Maritime Ridge (Phases 1 & 2) then is approximately 13.35 acres with a total marsh apron and ridge slope area of approximately 42.65 acres.

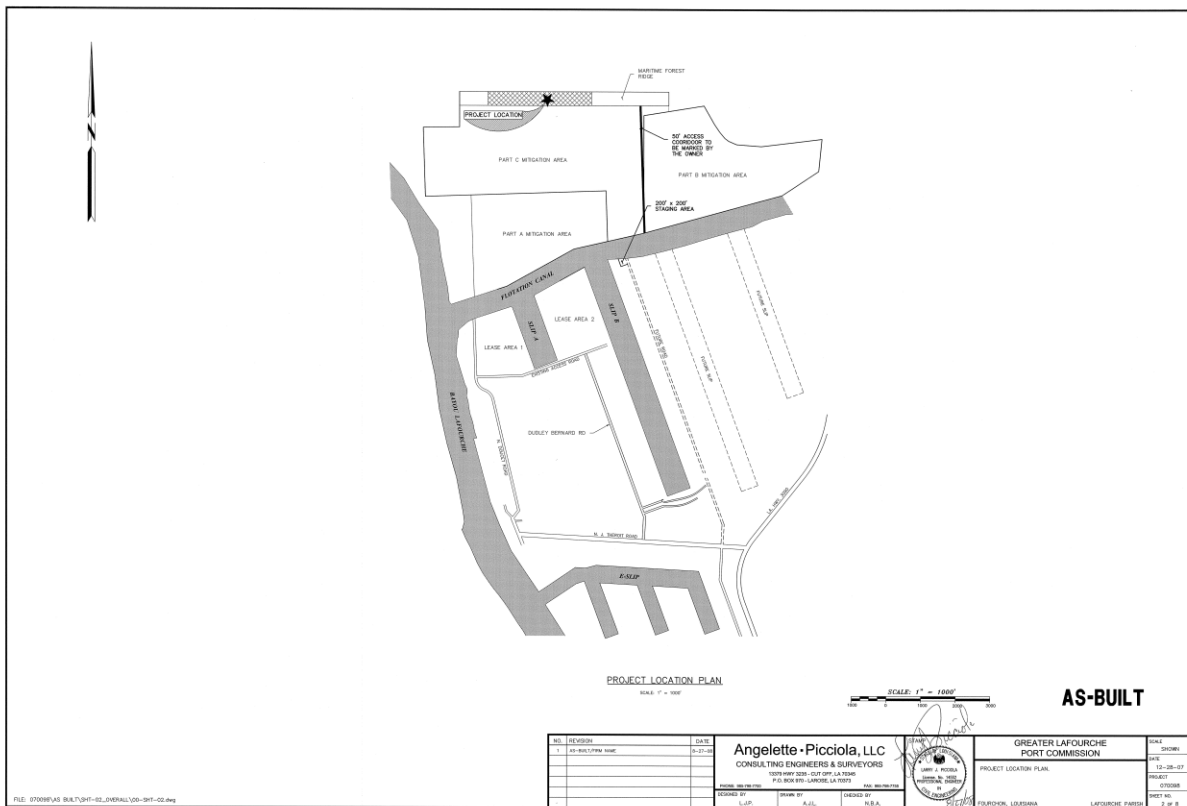


Figure 2 As-Built project location plan schematic for Phase Two completed in 2008.

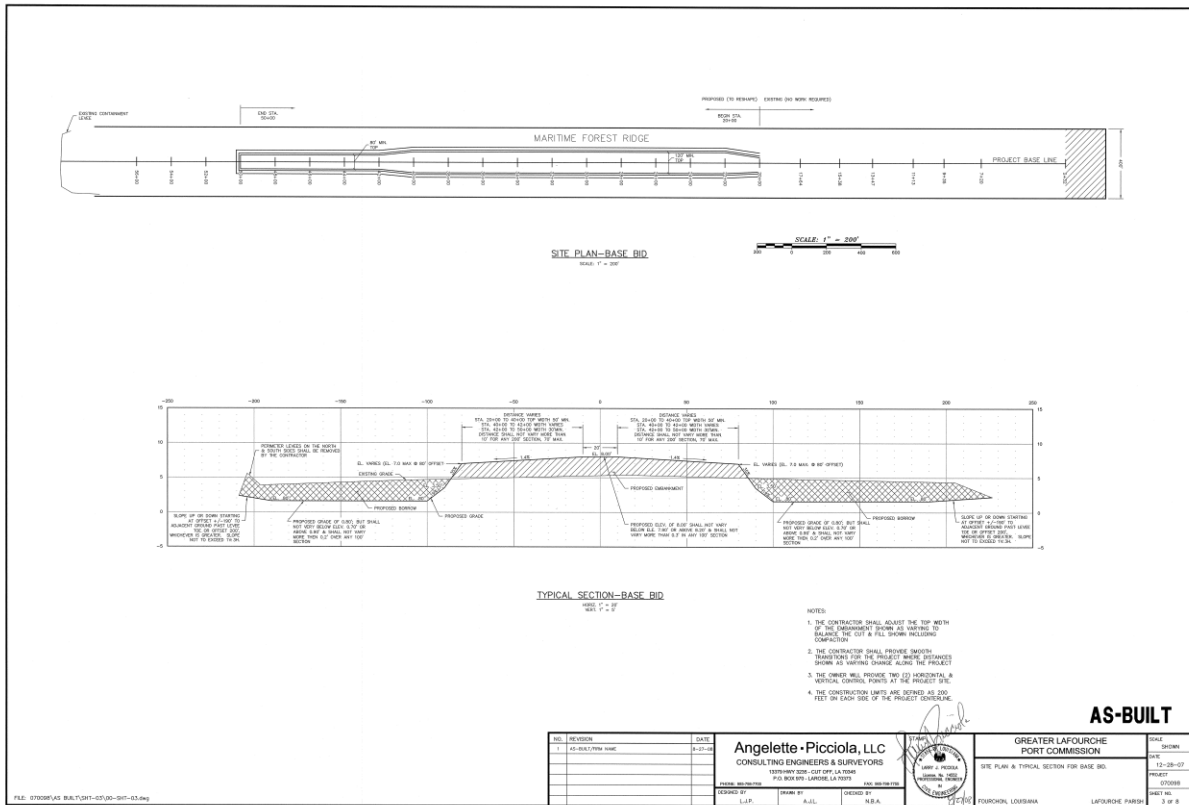


Figure 3 Site plan and typical section for base bid, Phase Two, August 27, 2008.

3.0 PROJECT SITE BACKGROUND

In the late 1990's, the Greater Lafourche Port Commission (GLPC), in an effort to meet increasing demand for boat slip space for companies servicing the oil and gas rigs in the Gulf of Mexico, began construction on a new slip in Port Fourchon. As with all projects that impact wetlands through the dredging of marsh sediment, mitigation of the damages to the marsh is required by law. However, the dredging of the slip and the volume of material that was to be moved exceeded that needed for mitigation. Needing to find something to do with this excess material, the GLPC fostered a partnership with the Barataria-Terrebonne National Estuary Program (BTNEP) to reestablish a chenier ridge and associated coastal marsh habitats along the submerged remnants of a former bayou north of the port and immediately adjacent to the recently created marsh mitigation. Figure 4 shows available imagery from Google Earth of the project area pre-construction (February 1998) through to January 2015.

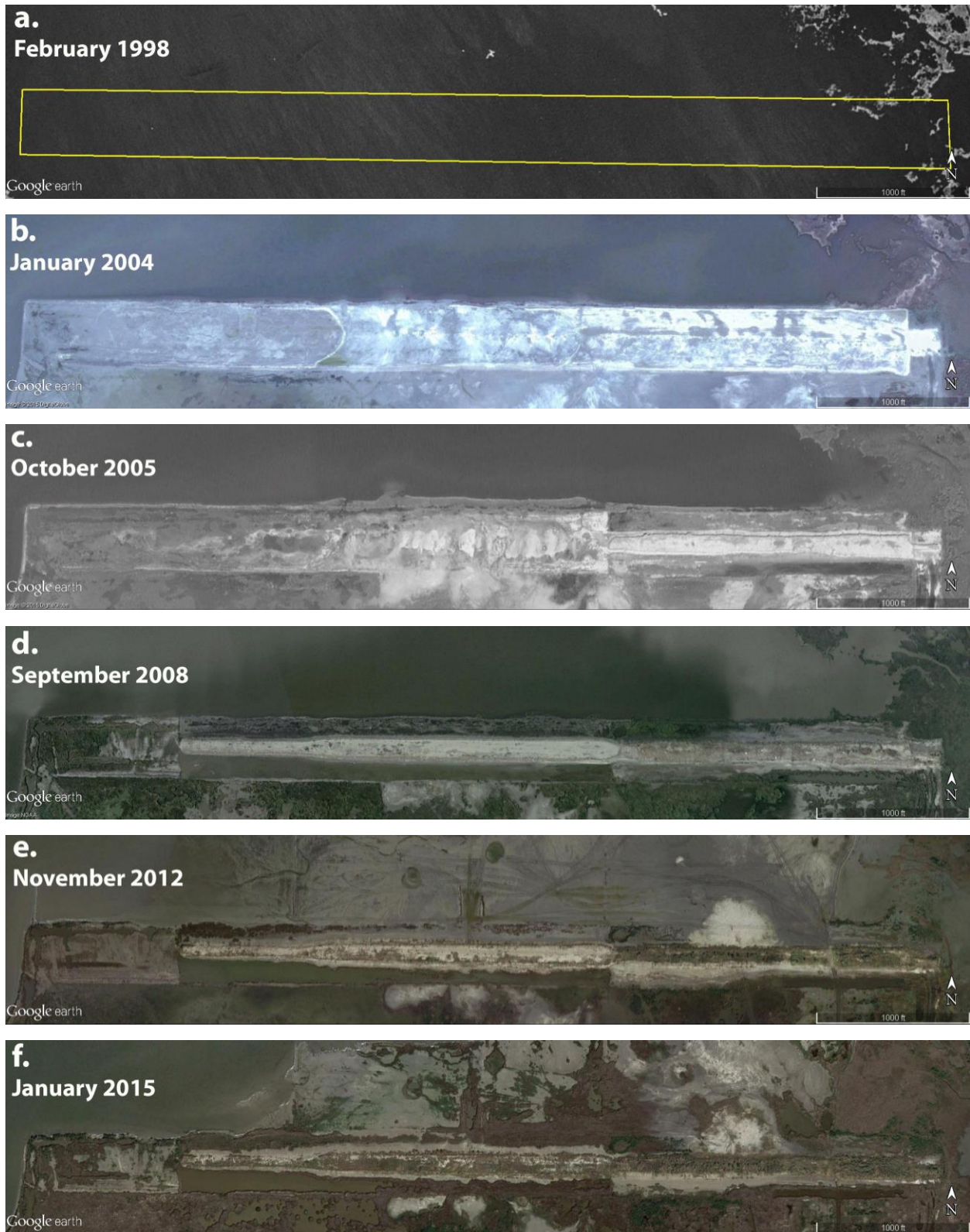


Figure 4 Chronological aerial images (a-f) from 1998 to 2015 of Phases 1 and 2 construction of the Fourchon Maritime Forest Ridge and Marsh Creation Project.

Initially, the maritime forest ridge and marsh restoration project served several purposes. First, it served to protect the recently created mitigation area immediately to the south of the ridge and second, it served as habitat for both fish and wildlife. Also, through the vegetative efforts that BTNEP implemented with hundreds of volunteers, it served to educate people from all over the nation first hand to Louisiana's biggest environmental problem --- coastal land loss.

Using in situ borrow material, an earthen containment dike was dug around the boundaries of a shallow open water site immediately north of the GLPC's mitigation site. The dredged slip material was then pumped via hydraulic dredge through a pipeline as a sediment slurry to the containment area. To get the ridge geometry to a final plus 8 feet in height and 200 foot in width after reworking with a bull dozer and excavator, the 400 foot wide containment area needed to be filled and constructed to an elevation of 4 feet. But because of problems with blowouts in the retention levees due to the pressure exerted on them from the 24 inch slurry pipe and problems with the subsurface in situ material the retention levees were built upon being highly organic and being pushed out by the new, heavier pumped in material, only 3 feet of height of sediment at most was ever obtained in this first area. Therefore, a decision was made to wait and pump a second lift of material, when it became available, to provide the necessary material needed to achieve the landscape desired and permitted for. In the meantime, it was decided to shape a 250 foot long section as an experiment to determine how the material would stack, the time involved in the process, and the equipment and costs needed when it finally became able to fully implement the first phase. This first short section, the Old Ridge and Marsh, was completed in the spring of 2003. BTNEP contracted the Natural Resources Conservation Service (NRCS) Plant Materials Center (PMC) in Golden Meadow to plant herbaceous and woody plants on the top, slopes and flanking edges of the ridge. Herbaceous plants included seashore paspalum, saltgrass, marshhay cordgrass and others. Woody plants included live oak, hackberry and American beautyberry.

As more sediment became available, the second lift of dredge materials was pumped onto the site. After dewatering and drying out, shaping of the first phase of the ridge began in February 2005. Final shaping of this section of the ridge, we call the Middle Ridge, was completed in May of 2005. Dimensions of the ridge and marsh varied across the site with the ridge and slopes 100 to 150 foot wide and the marsh platform flanking either side 125 to 150 foot wide for an overall width of 400 feet north to south and a 2,000 foot length west to east.

In order to try and stabilize the site as quickly as possible, BTNEP contracted with the NRCS PMC to provide plants and technical assistance for vegetative plantings on the ridge and marsh platforms. Multiple plantings were initiated between May 2005 and May 2006. Over 200

volunteers helped during these various plantings. Herbaceous species planted included smooth cordgrass, marshhay cordgrass, saltgrass and seashore paspalum. Woody species planted included salt matrimony vine, red mulberry, hackberry, live oak, American beautyberry, yaupon, wax myrtle and black mangrove. Grass seeding of the ridge was also implemented and included Sordan 79 (Sorghum-Sudangrass hybrid), German R strain millet, “Jose” tall wheatgrass, Alamo switchgrass, chloris, saltgrass and bitter panicum.

After additional pumping of sediment to the project site in late 2006 (Figure 5), Phase Two was shaped in 2008 and completed that summer (Figure 6). Similar to Phase One, with a project width of 400 feet, the overall footprint length was twice the size and the resulting ridge about 50% longer. Originally planned for 4,000 linear feet, less material was available than was originally expected making it necessary to reduce both the length and part of the width of the ridge. While the ridge feature ended up being roughly 2,900 feet long built to an initial 8 feet in elevation, the last 900 feet or so was considerably narrower than the first 2,000 feet. The first 2,000 feet added on to the first phase (Middle Ridge) was approximately 150 to 200 feet wide for the ridge and slopes with the flanking marsh aprons 100 to 125 feet wide each. For the last 900 feet of the ridge (the westernmost end of the ridge), the ridge width was approximately 125 to 150 feet wide with the flanking marsh aprons on either side approximately 125 to 138 feet wide. The last approximately 1,000 feet of the project site (westernmost end) included only the marsh feature and was pumped to an elevation of +1.6 feet.



Figure 5 Pumping earthen material to Phase Two site in 2006.



Figure 6 Excavators digging down fill to marsh elevation and stacking the material to build up the elevation of the ridge. South marsh apron of Far Ridge, May 29, 2008, looking west.

3.1 Soil Quality

The use of in situ saline marsh sediments for the creation of the Ridge caused many problems in getting non-halophytic native woody species to grow at the site. Soils that are too saline don't allow for non-adapted plants to absorb enough water. Plant roots naturally contain salts that help plants take up water from the soil. When the soil salinity gets as high as the roots, however, it becomes harder for water to enter the roots. If soil salinity gets really high, it can actually draw water from the plant roots back into the soil. At excessively high soil salinity concentrations, then, plants begin to wilt and die, no matter the amount of water they receive.

Salts in the soil on the ridge stay high because soil conditions don't allow the salts to leach out. Leaching is inhibited on the ridge because of poor soil structure due to compaction, clays, and high sodium content in the soil keeping the soil particles dispersed. This prevents soil particles from aggregating into larger particles. A larger space between soil aggregates allows for higher air and water permeability. Salts can also build up on the ridge in areas that pool water and don't drain quickly, which allows for a concentration and crusting of salts at the soil surface due to evaporation. Salts can also build up in depressions where water moves through the soil from

higher areas and discharges as a seep into the depression. The soils on the Ridge are saline-sodic soils, which are saline soils containing higher concentrations of sodium salts relative to calcium and magnesium salts.

Because these Ridge soils pose such a dilemma in getting non-halophytic native woody species established on the ridge, a soil sampling regime was established on the Middle Ridge in May 2008 and the Far Ridge in January 2009 in order to begin to get an understanding of the soil characterization over time (Figure 7). Samples included three landforms (marsh, ridge slope, and ridge top) with sampling continued on a nearly biannual basis up until October 2015 with plans for a limited annual sampling beyond the funding of this Coastal Impact Assistance Program (CIAP) grant. Pairing soil sample results and analysis with plant response from experimental plantings, we were able to illustrate the effects these soils have on plant survival and growth parameters that can be useful in planning future woody species plantings on ridge creation projects using in situ saline marsh sediments.



Figure 7 Aerial image of all soil sample locations taken at Fourchon Maritime Forest Ridge and Marsh Restoration. The first two letters for each soil sample site correspond to the part of the ridge it collected from: OR – Old Ridge; MR – Middle Ridge; and FR – Far Ridge.

3.2 The Far Ridge

Following completion of the Far Ridge in the summer of 2008, natural volunteer vegetative establishment was slow in coming. Hurricane Gustav, landing at Cocodrie, Louisiana, September 1, 2008, deposited a thick layer of wrack and debris on the south slope of the ridge (Figure 8). This resulted in very little erosion occurring over the years on the south side. Meanwhile, considerable erosion has occurred on the north side which did not benefit from wrack deposition. Precipitation from surface runoff caused rivulet formation on the ridge top as sediment moved off of the ridge, down the northern ridge slope and onto the northern marsh apron. Gulleys, big enough to stand in, began forming along the northern ridge slope. For years, during rain events a 2 to 3 inch layer of slushy “mud” would form on the surface in areas conducive to rapid erosion (Figure 9). Considerable effort through herbaceous plantings along the north slope and northern top edge of the ridge have slowed the erosion, but some areas along the north side have eroded considerably, especially along the narrower western end.



Figure 8 Wrack deposition on the south slope of the Far Ridge looking WSW, May 28, 2009.



Figure 9 Herbaceous planting along the top edge of Far Ridge, December 13, 2009, looking west.

Although the first 2,000 feet or so of the Far Ridge from the eastern end where it connects to the 2005 phase one Middle Ridge averaged approximately 110 feet of ridge top 4 months post-construction, the last 900 or so feet of the ridge to the western terminus, averaged approximately 64 feet. This narrowing of the ridge on the western end resulted from having less sediment than was anticipated when construction of this phase of the ridge began. This narrower ridge top section has exhibited an increase in erosion over the years and has led to a reduction in the establishment of herbaceous plants that could have reduced this erosion over time.

Seven years post-construction (2015), portions of this narrower western end still have little to any herbaceous vegetation established along the northern slope and northern top edge. The constructed 35% ridge slopes were not stable and have flattened considerably over the years as soil moved from the ridge top out onto the marsh apron. A wide unvegetated zone still remains from the tow of the ridge slope out into the high marsh (Figure 10). Repeated attempts to vegetate this area have failed in gaining vegetative establishment. However, successful smooth



Figure 10 Unvegetated zone between ridge slope to the right and high marsh on the left, December 2, 2015. North marsh apron looking east.

cordgrass (*Spartina alterniflora*) plantings in the lower marsh areas and the natural voluntary establishment of black mangrove (*Avicennia germinans*) from washed in propagules from the surrounding naturally occurring black mangroves have protected the northern slope from wave energy from the northern body of open water. Additionally, subsequent mitigative marsh

creation by the GLPC begun in 2011 and finished in 2012 adjacent and to the north of this marsh apron has further solidified this protection. Even relatively stable areas (not particularly erosive) of the top of the Ridge have been resistant to plant establishment over the years post construction despite repeated herbaceous and woody plantings. It is not known why these areas remain bare, but condition of the soil is the most likely culprit with elevated salinity levels at the top of the list. Similar barren areas remained for years on the Middle Ridge as well, but have now, finally, largely succumbed to encroaching vegetation and repeated plantings.

At the end of 2015, through repeated herbaceous and woody vegetative plantings with the assistance of hundreds of volunteers over the years and through the natural, volunteer establishment of herbaceous plants and shrubs, the plant coverage of the Far Ridge is estimated at 85 to 90 percent (Figure 11).



Figure 11 Western end of Far Ridge looking east, December 2, 2015.

4.0 METHODS FOR WOODY VEGETATIVE FIELD STUDIES

4.1 Objectives

The objectives of the woody vegetative field studies were to: 1) establish a series of woody vegetative trials over time in order to determine plant response to the highly altered soils from a man-made ridge using in situ saline marsh sediments from the Port Fourchon expansion; 2) conduct this series of trials to determine if the addition of cultural treatments increased

survival or plant growth response; 3) determine which woody species survived and grew best in these highly altered saline soils; and 4) determine the change in soil parameters over time that produces conditions suitable for increase in vegetative survival and other plant variables.

4.2 Woody Species Selection

Most of the woody species selected for this study originated from species that had been evaluated under a separate BTNEP/NRCS Plant Materials Center study entitled “An Accelerated Program of Woody Species Selection for Conservation, Restoration, and Neotropical Habitat Enhancement” which had focused on native trees known to grow along the Louisiana coast that were important to Neotropical migratory birds. Additional species selected came out of discussions from BTNEP’s Bird Workgroup populated by various birders from the private and professional sectors and from governmental agencies. Ultimately, over the course of the six years experimental plantings were carried out for this project, ten species were utilized. These species were: live oak (*Quercus virginiana*), sand live oak (*Quercus geminata*), hackberry (*Celtis laevigata*), American beautyberry (*Callicarpa americana*), honeylocust (*Gleditsia triacanthos*), persimmon (*Diospyros virginiana*), roughleaf dogwood (*Cornus drummondii*), yaupon (*Ilex vomitoria*), Hercules’ club (*Zanthoxylum clava-herculis*), and salt matrimony vine (*Lycium carolinianum*). Acorns and seeds for the selected species were collected throughout the year for grow out at BTNEP’s Native Plant Nursery at the Nicholls State University Farm located in Thibodaux, Louisiana. All seeds were collected from coastal Louisiana with the exception of sand live oak, which is native to Louisiana but which no longer is naturally found in any substantial quantity, if at all. Still found in abundance along the Gulf Coast from Mississippi to Florida, BTNEP collected sand live oak acorns along the panhandle of Florida for use in this project. Sand live oak tolerates severe conditions found in maritime areas, even growing in the deep infertile sands found on the coastal dunes of barrier islands. Known for increased tolerance to salt spray and exceptional drought tolerance, it was expected that this species would perform as well or better than most of the species used in this project.

Whenever possible, acorns and seed were selected from coastal areas similar to the project area planted. By collecting seed in areas of maritime influence it is thought that they may be better adapted to the saline soils and harsh conditions found at the Ridge to which they were planted and which lies less than four miles from the Gulf of Mexico. Species collected immediately adjacent to the Gulf were live oak, sand live oak, hackberry, yaupon, and salt matrimony vine. The rest of the species were collected from coastal Louisiana parishes further inland. A seed and dates of collection list has been added as Appendix 1.

Live oak acorns were collected off the ground, while sand live oak acorns were collected off the trees. Both were floated and checked for weevils before potting (Figure 12). The rest of the

woody species seeds were collected from the tree with the exception of persimmon which was collected mostly off the ground. Collected acorns and seeds were immediately brought back to BTNEP's nursery facility, cleaned by hand or macerated with a blender, prepared, and either directly potted, dry stored or cold stratified as necessary. Prior to potting the seed, seeds requiring scarification were scarified.

Acorns and seeds were potted in 2 inch diameter by 7 inch deep Deepots™ (D16L) conetainers (Figure 13). Potting medium used was PRO-MIX® BX MYCORRHIZAE™ which is 75-85%



Figure 12 Acorn weevil on sand live oak acorn, Santa Rosa Island, Escambia County, Florida, October 27, 2013.



Figure 13 Live oak seedlings growing out in Deepots™ (D16L) conetainers, April 4, 2011.

sphagnum moss with the addition of perlite, vermiculite, and limestone. Seedlings were fertilized either with 9 month Osmocote® Smart-Release® Plant Food Plus Outdoor & Indoor 19(N)-6(P)-12(K) or Miracle-Gro® 24(N)-8(P)-16(K) or both for the duration of grow out with no fertilization occurring during the dormant season. Plants were watered with an overhead irrigation system at least once a day (twice in the hot summer months). Potted seedlings were placed in trays and put on tables under a 60% shade cloth (Figure 14). Overwintering of seedlings remained under the shade cloth with seedlings covered and wrapped in plastic sheeting with heat lamps during the occasional freeze. Pesticides used as needed included Spectracide® Malathion Insect Spray Concentrate. Fungicide used as needed was Spectracide® IMMUNOX Multi-Purpose Fungicide Spray Concentrate.

Seedlings, remaining in their containers and trays, were transported to the Ridge by covered trailer to the boat launch, loaded onto boats, and then offloaded by hand at the ridge planting site. An All-Terrain Vehicle (ATV) with a trailer was used to transport plants from the boat offloading site to the planting sites. Cultural treatments were moved to the planting site by way of ATV as well.



Figure 14 Woody and herbaceous species growing out in the BTNEP shadehouse on the Nicholls State University Farm in Thibodaux, Louisiana, September 26, 2013.

4.3 Soil Amendment Treatments

For these woody species trial plantings, a control (no soil amendments) and three soil amendment treatments were used: bagasse, fertilizer, and gypsum.

Bagasse is a by-product of the sugar cane industry. It is the fibrous remains after the process of crushing the cane to extract the sugar. The bagasse used in this study had been sitting in a pile outside for over 20 years and was donated by Organic Processors, Thibodaux, Louisiana. The bagasse served as added organic material that would help retain soil moisture and nutrients in the plant root zone. Organic matter also helps particles in the soil bind together making it more porous to create spaces for air, water, and plant roots. Organic matter also provides nutrients to bacteria and other organisms in the soil which recycle nutrients in to forms readily available to be absorbed by the plants roots.

The fertilizer used for these plantings is a 21 gram 20(N)-10(P)-5(K) slow release orchard tablet from either Forestry Suppliers, Inc., Jackson, Mississippi or Scotts® Agriform, Scotts Miracle-Gro Company, Marysville, Ohio. The 20-10-5 two year release orchard tablets contained: Total Nitrogen (N) 20%, Available Phosphate (P) 10%, Soluble Potash (K) 5%, Chlorine (Cl) 1%, Free Sulfur (S) 2%, Total Iron (Fe) 2.5%, Total Manganese (Mn) 2%, Total Magnesium (Mg) 2.25%, Total Zinc (Zn) 0.18%. The fertilizer tablet provides essential nutrients for plants to flourish. Nitrogen promotes healthy leaf growth through the stimulation of chlorophyll production. Phosphorus promotes the root and stem development. Potassium stimulates early growth, increases protein production and improves water use efficiency.

The gypsum used was Pelletized Gypsum from MK Minerals, Inc., in Wathena, Kansas. The pelletized gypsum contained: Calcium (Ca) 20%, Sulfur (S) 16%, Calcium Sulfate (CaSO_4) 68%, Water Soluble Binder – lignosulfate 2%. Gypsum served to remove sodium in the soil and replace it with calcium. Gypsum also binds clay particles together to make larger particles, creating porous spaces for air, water, and plant roots. Gypsum also adds calcium and sulfur to the soil, important plant nutrients.

4.4 Experimental Plot Site Selections

The eight woody vegetative field trials conducted at the Ridge over the six year period (2009-2014) were planted in five different locations (Figure 15). The first woody trial, called the “Ring Planting”, was the only trial that included replication sites on the Middle Ridge as well as the Far Ridge. This woody trial looked to compare survival and growth between the two ridges. The rest of the woody vegetation trials were located exclusively on the Far Ridge as these studies were done yearly in concurrence with soil sampling to ascertain plant response to soil conditions over time.



Figure 15 Aerial view of all vegetative trial planting locations planted on the Middle and Far Ridges from 2009-2014. Imagery date: January 25, 2015.

4.5 Ring Planting

The first experimental woody species trial planting is the only one that compared survival and growth between the Middle Ridge and the Far Ridge (Figure 16). The Middle Ridge construction was completed in May of 2005, while the Far Ridge was completed in August of 2008. This planting was executed on February 28, 2009 with a total of 114 trade gallon size plants obtained from the Golden Meadow NRCS PMC in Galliano, Louisiana, that were going to be discarded. These plants were considerably pot bound as they had been growing in the trade gallon containers for four years. Typical trade gallon use is for two years. The Middle Ridge was almost four years post-construction and considerably vegetated, mostly with herbaceous species and to a lesser extent some woody species as well (Figure 17). The Far Ridge was still completely barren of any vegetation less than half a year post-construction and yet to begin the 2009 growing season (Figure 18).

Three replications with no soil amendments were planted at each location on the Middle Ridge and Far Ridge. Each replication consisted of 19 trade gallon sized pots of four woody species: red mulberry, sand live oak, yaupon, and American beautyberry. Each replication started with a plant in the center with two rings of plants encircling it at five foot intervals. The inner ring of plants, five feet out from the center, had plants spaced approximately every five feet around the circumference for a total of six plants. The outer ring's plants were also spaced five feet apart around the circumference for another 12 plants. The species were randomly assigned to

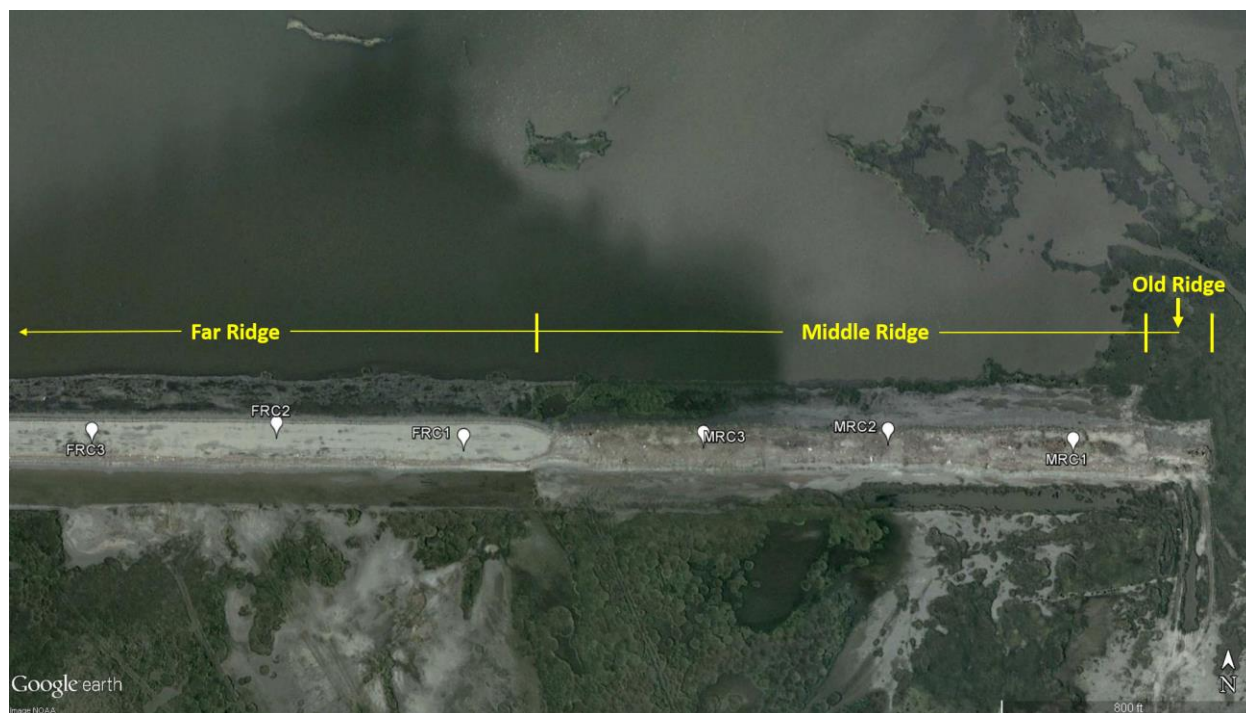


Figure 16 Aerial view of Ring Planting location, planted February 28, 2009 on the Middle and Far Ridges. Middle Ridge replicates are labeled MRC1-3 and Far Ridge replicates labeled FRC1-3. Imagery date: September 4, 2008.



Figure 17 Pre-flagging Ring Planting plot on Middle Ridge prior to planting, February 17, 2009. Looking west.



Figure 18 Ring Planting plot on the Far Ridge, February 28, 2009. Looking west.

one of the 19 positions in the replication plot. Each plant location was delineated with a different color pin flag for future reference.

Planting technique for the Ring Planting included the use of gas drills with 7 inch diameter auger bits. Holes were augered to a depth of 7 inches. Four-year-old root bound woody plants were removed from the trade gallon containers. Roots were cut and pulled so as to stimulate new root growth and encourage roots to spread from root ball. Soil was placed back in the bottom of the hole as needed in order to get the top of the root ball at or just below the surrounding soil level. Additional soil was placed around the sides of the root ball and packed. Two 21 gram slow release orchard tablets containing 20(N)-10(P)-5(K) were placed beside the root ball for fertilizer. Additional soil was added around the sides of the root ball and further packed. Finally, a light covering of soil was added to the entire root ball and firmly packed. Plants were not watered as it was logistically not possible to do so.

Baseline growth data was taken immediately following completion of planting. End of growing season data was collected once at the end of the growing season on September 15, 2009. Vigor was assessed visually on a 9 point scale adopted from the NRCS with 1 having the greatest vigor and 9 being dead. All plants in the Far Ridge plots were recorded as dead. Growth measurements of height, spread, and basal stem diameter were measured from surviving plants in Middle Ridge plots and recorded as described in detail in section 4.10. For consistency of vigor measurements, end of growing season data collection was collected by a single crew of BTNEP staff. Field data measurements were then recorded in Microsoft® Excel Spreadsheets for use in future statistical analysis.

4.6 Woody Trial Block Plantings

Woody trial “block plantings” were planted exclusively on the 2008 Far Ridge ridge top. Replication plots for the woody trial block plantings consisted of 32 plants in 4 rows of 8 plants each (Figure 19). All plants and rows were on 8 foot centers with 12 feet between plots. Plots measured 24 feet by 56 feet. Four foot rebar was pounded into the earth and used to establish the corners. The rebar corners were 4 feet off the first and last lengthwise rows and in line with the plants at the beginning and end of the rows. The locations of the corners were then recorded with GPS. These measures, along with the plants being planted in a grid pattern, insured future finding of plots and plant locations in case of storm damage and as the ridge became increasingly vegetated over the project timeframe. Treatment plots and plants within treatment plots were completely randomized prior to planting. Quantities for soil treatment amendments used per plant (unless otherwise noted: see 2014 Block Planting, page 29) are one quart (32 oz.) of bagasse, one 21 gram orchard tablet fertilizer, and one cup (8 oz.) pelletized gypsum (equivalent to 40 tons per acre based on recommended application from initial soil sample analysis).

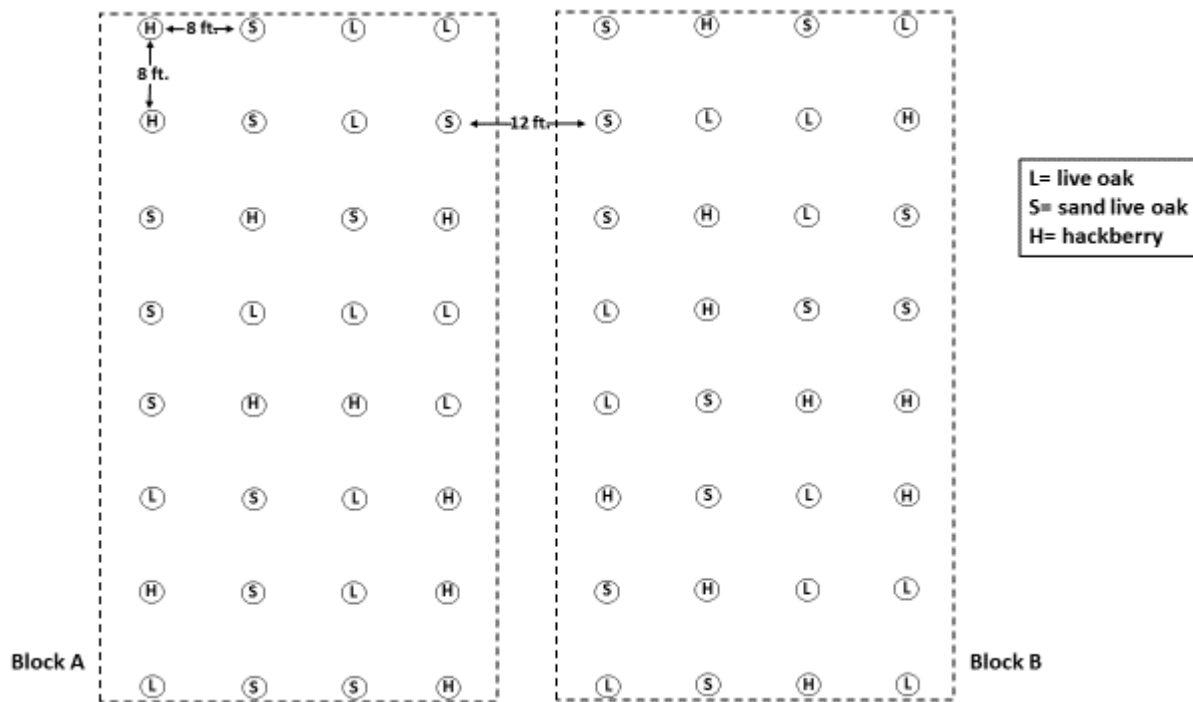


Figure 19 Schematic of example blocks within experimental block plantings. Species were randomized within each block and treatments were randomized among blocks.

Treatments for replicates varied according to experimental design. A control (no additives) and three treatments (bagasse, fertilizer, and gypsum) and various combinations of these three were used for the different block plantings listed below. The following is a description of a replicate of all 3 treatments (bagasse + fertilizer + gypsum); therefore, for a description of a replicate of only bagasse as a treatment, you would remove the description of the addition of the fertilizer and gypsum with everything else remaining the same.

Planting technique for the woody trial block plantings included the use of gas drills with 7 inch diameter auger bits. Holes were augered to a depth of 7 inches. A third of a cup of the bagasse, used as organic matter for moisture retention, was placed at the bottom of the hole. One year old woody seedlings grown out in 2 inch by 7 inch Deepots™ (D16L) conetainers were removed from the Deepots™ and placed in the hole. Soil displaced while augering the holes was placed back in the bottom of the hole as needed in order to get the top of the root ball at or just below the surrounding soil level. Additional soil was placed around the sides of the root ball and packed to midway up the root ball. A 21 gram slow release fertilizer orchard tablet was placed beside the root ball. Additionally, one third of a cup of bagasse and half a cup of gypsum was placed in the hole. Additional soil was added around the sides of the root ball and further packed to almost up to the surrounding soil level. The last third of bagasse and the last half cup of gypsum were added around the root ball in the hole. Finally, a light covering of displaced in situ soil was added over the entire root ball and firmly packed. Plants were not watered as it was logistically not possible to do so.

4.6.1 2010 Block Planting - March 16, 2010

The first woody trial block planted on the Far Ridge, named the “2010 Block Planting”, is the westernmost woody trial planting site. Because the westernmost 900 foot end of the Far Ridge averaged about 64 feet of ridge top and the replication plots measured 24 feet by 56 feet, and because erosion of the ridge was already visibly taking place, the first 7 (A-G) plots were oriented lengthwise west to east (Figure 20). Once the plots got to the 900 or so feet in from the westernmost end of the ridge top, the ridge top began to average about 110 feet wide for the rest of the 2000 or so feet of ridge. Because of the widening of the ridge at this point, the plots were reoriented with the lengthwise side of the plot oriented south to north for the rest of the 17 plots (H-X). The entire 24 plots of this woody trial occupied about 1,100 linear feet of the ridge.



Figure 20 Aerial view of the 2010 Block Planting location planted on the Far Ridge March 16, 2010. Plots are labeled A to X. The four yellow rectangles show examples of approximate size and orientation of plots on the ridge. Imagery date: January 25, 2015.

This woody trial included 3 species (sand live oak, salt matrimony vine, and hackberry) totaling 32 plants per plot and 8 levels of soil amendments (bagasse, fertilizer, gypsum, bagasse x fertilizer, bagasse x gypsum, fertilizer x gypsum, bagasse x fertilizer x gypsum, and control) replicated 3 times for a total of 24 plots and 768 total plants (Figures 21, 22 & 23).

Treatment plots and plants within treatment plots were completely randomized prior to planting. This planting was implemented on March 16, 2010, utilizing volunteer help. Baseline growth data was taken immediately following completion of planting. End of growing season data was collected six times for this trial at the beginning of October in 2010, 2011, 2012, 2013, 2014, and 2015. Vigor was assessed visually on a 9 point scale adopted from the NRCS with 1 having the greatest vigor and 9 being dead. Height, spread, and basal stem diameter were measured and recorded as described in detail in section 4.10. For consistency in vigor measurements, end of growing season data collection was collected by a single crew of BTNEP staff. Field data measurements were then recorded in Microsoft® Excel Spreadsheets for use in future statistical analysis.



Figure 21 Augering holes for 2010 Block Planting, March 16, 2010.



Figure 22 Augering holes for 2010 Block Planting, March 16, 2010.



Figure 23 Cultural treatments being added to experimental plot at time of planting for 2010 Block Planting, March 16, 2010.

4.6.2 2011 Block Planting – March 10, 2011

The second woody trial block planted on the Far Ridge, named the “2011 Block Planting”, was located immediately adjacent and to the east of the first woody trial location. Because it was decided to leave a section of the top of the Far Ridge to grow up initially, naturally and without an experimental woody block planting, this next planting was reduced in size by reducing the number of levels of soil amendments. This reduced the footprint from 24 plots to 15 plots. Since the entirety of this woody trial fell in the wider section of the Far Ridge, all of the plots were oriented south to north lengthwise with the first plot (A) to the west and running east to the last plot (O). Because the staging area for bringing plants and equipment up onto the ridge top had already been established, a break in the plots was put in, resulting in the last 4 plots beginning approximately 90 feet further east from the rest of the 11 plots (Figure 24). These plots were of the same size and dimensions of the 2010 Block Planting, being 24 feet in width and 56 feet in length.

This woody trial included 3 species (live oak, hackberry, and American beautyberry) totaling 32 plants per plot and 5 levels of soil amendments (bagasse, fertilizer, gypsum, bagasse x fertilizer x gypsum, and control) replicated 3 times for a total of 15 plots and 480 total plants. Treatment plots and plants within treatment plots were completely randomized prior to planting. This planting was implemented on March 10, 2011 utilizing volunteer help (Figure 25). Baseline growth data was taken immediately following completion of planting. End of growing season data was collected five times for this trial at the beginning of October in 2011, 2012, 2013,



Figure 24 Aerial view of the 2011 Block Planting location planted on the Far Ridge March 10, 2011. Plots are labeled A to O. The Imagery date: January 25, 2015.



Figure 25 Packing up the gas drills and auger bits, 2011 Block Planting, March 10, 2011. Looking ESE.

2014, and 2015. Vigor was assessed visually on a 9 point scale adopted from the NRCS with 1 having the greatest vigor and 9 being dead. Height, spread, and basal stem diameter were measured and recorded as described in detail in section 4.10. For consistency in vigor measurements, end of growing season data collection was collected by a single crew of BTNEP staff. Field data measurements were then recorded in Microsoft® Excel Spreadsheets for use in future statistical analysis.

4.6.3 2012 Block Planting – February 23, 2012

The third woody trial block planted on the Far Ridge, named the “2012 Block Planting”, is located in the same exact plots as the 2011 Block Planting. Because the 2011 Block Planting had such extreme mortality and there was no more available space to do a large 15 plot planting on the Far Ridge, it was decided to do the planting in the same plots as the year before except instead of planting in the exact same locations (as there were some plants that did survive), for this planting all the plants were shifted over 1 foot to the east. Also, surviving plants from the previous year’s trial planting were reflagged with double pin flags and the current year’s planting was flagged different colors so as not to confuse the two. Additionally, as plans for a tidal creek to be dug through the middle of the ridge at the point where a gap was made in the 2011 Block Planting plots became known prior to this planting (although still not constructed at the time of this writing), the two plots on either side of the gap were abandoned and added onto the east end of the 2011 Block Planting plots (Figure 26). This gap area was widened, because it was feared that the size of the tidal creek and slope created from its creation might erode the previous adjacent plots on either side of the gap.

This woody trial included 3 species (live oak, sand live oak, and hackberry) totaling 32 plants per plot and 5 levels of soil amendments (bagasse, fertilizer, gypsum, bagasse x fertilizer x gypsum, and control) replicated 3 times for a total of 15 plots and 480 total plants (Figure 27).

Treatment plots and plants within treatment plots were completely randomized prior to planting. This planting was implemented on February 23, 2012 utilizing volunteer help. Baseline growth data was taken immediately following completion of planting. End of growing season data was collected four times for this trial at the beginning of October in 2012, 2013, 2014, and 2015. Vigor was assessed visually on a 9 point scale adopted from the NRCS with 1 having the greatest vigor and 9 being dead. Height, spread, and basal stem diameter were measured and recorded as described in detail in section 4.10. For consistency in vigor measurements, end of growing season data collection was collected by a single crew of BTNEP staff. Field data measurements were then recorded in Microsoft® Excel Spreadsheets for use in future statistical analysis.



Figure 26 Aerial view of the 2012 Block Planting location planted on the Far Ridge February 23, 2012. Plots are labeled A to O. Plots K and L from 2011 Block Planting abandoned and added to the east of plot O. The Imagery date: January 25, 2015.



Figure 27 Adding treatments to the plant holes, 2012 Block Planting, February 23, 2012. Looking SW.

4.6.4 2013 Block Planting – January 28, 2013

The fourth woody trial block planted on the Far Ridge, named the “2013 Block Planting”, was located back in the first 15 plots of the 2010 Block Planting’s 24 plots, beginning with the first plot on the west and continuing to the east (Figure 28). As was the case in the 2012 Block Planting, being that there was no more available space to do a large 15 plot planting on the Far Ridge, it was decided to do the planting in the same plots as the first year’s planting, the 2010 Block Planting. Again, instead of planting in the exact same locations (as there were still some plants that did survive from the 2010 Block Planting), for this planting all the plants were shifted over 1 foot to the east. Also, surviving plants from the first year’s trial planting were reflagged with double pin flags and the current year’s planting was flagged different colors so as not to confuse the two.

This woody trial included 3 species (hackberry, live oak, and sand live oak) totaling 32 plants per plot and 5 levels of soil amendments (bagasse, fertilizer, gypsum, bagasse x fertilizer x gypsum, and control) replicated 3 times for a total of 15 plots and 480 total plants (Figure 29).

Treatment plots and plants within treatment plots were completely randomized prior to planting. This planting was implemented on January 28, 2013 utilizing volunteer help. Baseline



Figure 28 Aerial view of the 2013 and 2014 Block Plantings’ location planted on the Far Ridge January 28, 2013 and March 26, 2014 respectively. Plots from left (west) labeled A to O are 2013 Block Planting. Plots labeled A to I on right (east) side of image are 2014 Block Planting. Plots for the 2013 and 2014 Block Plantings occupy the same plot location as the 2010 Block Planting. Imagery date: January 25, 2015.



Figure 29 BTNEP Staff showing volunteers how to add bagasse to plant hole. 2013 Block Planting, January 28, 2013. Looking ENE.

growth data was taken immediately following completion of planting. End of growing season data was collected three times for this trial at the beginning of October in 2013, 2014, and 2015. Vigor was assessed visually on a 9 point scale adopted from the NRCS with 1 having the greatest vigor and 9 being dead. Height, spread, and basal stem diameter were measured and recorded as described in detail in section 4.10. For consistency in vigor measurements, end of growing season data collection was collected by a single crew of BTNEP staff. Field data measurements were then recorded in Microsoft® Excel Spreadsheets for use in future statistical analysis.

4.6.5 2014 Block Planting – March 26, 2014

The fifth woody trial block planted on the Far Ridge, named the “2014 Block Planting”, was located back in the last 9 plots of the 2010 Block Planting’s 24 plots, beginning with the first plot immediately following the last plot of the 2013 Block Planting from the previous year and continuing east to the last block of the first year’s planting (see Figure 28 above). As was the case in the 2012 Block Planting and the 2013 Block Planting, being that there was no more available space to do a 9 plot planting on the Far Ridge, it was decided to do the planting in the same plots as the first year’s planting, the 2010 Block Planting. Again, instead of planting in the exact same locations (as there were still some plants that did survive from the 2010 Block

Planting), for this planting all the plants were shifted over 1 foot to the east. Also, surviving plants from the first year's trial planting were reflagged with double pin flags and the current year's planting was flagged different colors so as not to confuse the two.

This woody trial included 3 species (live oak, yaupon, and roughleaf dogwood) totaling 32 plants per plot and 3 levels of soil amendments (bagasse x fertilizer x gypsum, bagasse doubled x fertilizer doubled x gypsum doubled, and control) replicated 3 times for a total of 9 plots and 288 total plants (Figure 30). Treatment plots and plants within treatment plots were completely randomized prior to planting. Since there appeared to be no added benefits to the previous year's planting with the addition of treatments versus the control (no treatment) at the amounts originally used, it was decided to try doubling treatment amounts to see if this would increase survival and plant response versus the control. Therefore, some alterations to the planting techniques described above were implemented for this planting. First, all of the holes were increased in size to 10 ¾ inches in diameter. For the soil level amendment where the treatments were doubled, this meant that instead of one quart of bagasse, two quarts were used; instead of one 21 gram orchard fertilizer tablet, two were used; and instead of 1 cup of gypsum, two cups were used. This planting was implemented on March 26, 2014, utilizing volunteer help. Baseline growth data was taken immediately following completion of planting. End of growing season data was collected twice for this trial at the beginning of October in 2014 and 2015. Vigor was assessed visually on a 9 point scale adopted from the NRCS with 1 having



Figure 30 Staging plants for 2014 Block Planting, March 26, 2014. Looking north.

the greatest vigor and 9 being dead. Height, spread, and basal stem diameter were measured and recorded as described in detail in section 4.10. For consistency in vigor measurements, end of growing season data collection was collected by a single crew of BTNEP staff. Field data measurements were then recorded in Microsoft® Excel Spreadsheets for use in future statistical analysis.

4.7 Linear Ridge Planting – March 28, 2011

Additionally, after the 2011 Block Planting was implemented on March 10, 2011, a smaller planting was implemented on March 22 and 28, 2011, to add a diversity of species to the woody species planting trials. This planting was called the “Linear Ridge Planting” because it consisted of 6 plots of 30 plants in each plot in single rows running west to east immediately adjacent and south of the 2011 and 2012 Block Plantings’ plots on the top of the ridge (Figure 31). Rebar was again used to delineate the beginning and end of each plot with pin flags used for plant locations on 8 foot centers.



Figure 31 Aerial view of Linear Planting (March 28, 2011) and Mini Block planting (March 20, 2012) locations on the Far Ridge. Linear Planting plots not labeled, only represented by yellow line. Mini Block Planting plots labeled A, B, and C on right (east) side of image. The Imagery date: January 25, 2015.

This woody trial included 3 species (Hercules’ club, honeylocust, and persimmon) totaling 30 plants per plot and 2 levels of treatments (bagasse x fertilizer x gypsum, and control) replicated 3 times for a total of 6 plots and 180 total plants (Figure 32). Treatment plots and plants within treatment plots were completely randomized prior to the planting. The control replicates of this



Figure 32 Linear Ridge Planting parallel to the southern edge of the Far Ridge, March 22, 2011. Looking east.

planting were implemented utilizing volunteer help on March 22, 2011, and treatment replicates were implemented on March 28, 2011 by BTNEP staff. Baseline growth data was taken immediately following completion of planting. End of growing season data was collected twice for this trial at the beginning of October in 2011 and 2012. Data collection was abandoned after the end of growing season collection in 2012 once it was determined there were no remaining surviving plants. Vigor was assessed visually on a 9 point scale adopted from the NRCS with 1 having the greatest vigor and 9 being dead. Height, spread, and basal stem diameter were measured and recorded as described in detail in section 4.10. For consistency in vigor measurements, end of growing season data collection was collected by a single crew of BTNEP staff. Field data measurements were then recorded in Microsoft® Excel Spreadsheets for use in future statistical analysis.

4.8 Mini Block Planting – March 20, 2012

This small woody trial planted on the Far Ridge, named the “Mini Block Planting”, was located immediately adjacent to the 2011 and 2012 Block Planting’s plots and was a small trial instituted to increase the diversity of species being evaluated in the trials and consisted of only one level of soil amendments (fertilizer) and only 3 plots of 32 plants per plot for a total of 96 plants for the planting (see Figure 30 above). Four species were utilized for this planting: live oak, persimmon, American beautyberry, and honeylocust (Figure 33). Treatment plots and plants within treatment plots were completely randomized prior to planting. This planting was implemented on March 20, 2012, less than a month after the 2012 Block Planting utilizing



Figure 33 Honeylocust seedling in Mini Block Planting plot, March 20, 2012.

volunteer help. Baseline growth data was taken immediately following completion of planting. End of growing season data was collected four times for this trial at the beginning of October in 2012, 2013, 2014, and 2015. Vigor was assessed visually on a 9 point scale adopted from the NRCS with 1 having the greatest vigor and 9 being dead. Height, spread, and basal stem diameter were measured and recorded as described in detail in section 4.10. For consistency in vigor measurements, end of growing season data collection was collected by a single crew of BTNEP staff. Field data measurements were then recorded in Microsoft® Excel Spreadsheets for use in future statistical analysis.

4.9 Herbaceous Field Trial

One herbaceous field trial was implemented on the western end of the Far Ridge in November of 2009 to better ascertain what herbaceous species could be established on the ridge (Figure 34). This planting was laid out across the profile of the ridge from the north marsh apron up the north slope, across the ridge top, down the south slope and into the south marsh to see in what



Figure 34 Aerial view of Herbaceous Field Trial location planted November 11, 2009 on the Far Ridge. Plots are labeled A to F. Each plot had 3 rows (replicates) oriented north to south across the Far Ridge profile. The Imagery date: January 25, 2015.

zones the species would do best. Three species of herbaceous grasses were selected for the planting: seashore paspalum (*Paspalum vaginatum*), marshhay cordgrass (*Spartina patens*), and bitter panicum (*Panicum amarum*). One treatment (straw) and a control (no additives) were replicated three times for each species. Each treatment plot had rebar driven into the sand to delineate the beginning and end of each plot. Each treatment plot had 3 rows of 25 plants per row with each row representing one replicate. Plants were placed on 5 foot centers and marked with pin flags making each row 120 feet long. Each row began in the high marsh on the north side of the ridge and ended in the high marsh on the south side of the ridge. This marsh zone of the row was planted with 5 to 6 plants. Above the marsh zone, but below the ridge top, were the north and south ridge slopes. In this zone, 6 to 7 plants were planted. On the ridge top, 13 to 14 plants were planted. Plant numbers in each zone varied for each row as the topography of the ridge changed. Treatment plots and plants within treatment plots were completely randomized prior to planting. This planting was implemented on November 11, 2009, utilizing volunteer help (Figure 35). Baseline growth data was not taken at the time of planting while vigor was assumed a 1 (excellent). End of growing season data was collected only once for this trial at the beginning of October 2010. Vigor was assessed visually on a 9 point scale adopted from the NRCS with 1 having the greatest vigor and 9 being dead. Height, spread, and basal stem diameter were measured and recorded as described in detail in section 4.10. For

consistency in vigor measurements, end of growing season data collection was collected by a single crew of BTNEP staff. Field data measurements were then recorded in Microsoft® Excel Spreadsheets for use in future statistical analysis.



Figure 35 Offloading plants from the boats for the Herbaceous Field Trial, November 11, 2009. On the north marsh apron looking east.

4.10 Data Collection Methods

Baseline data at the time of the plantings, as well as end of growing season data collections, were taken for all of the experimental plantings (Figure 36). Baseline data collected assumed a vigor of 1 (excellent or greatest) at time of planting as plants were selected from a larger quantity at the BTNEP Native Plant Nursery in Thibodaux, Louisiana, and only those exhibiting the greatest vigor were chosen to be included in the experimental plantings. Besides vigor, the other growth parameters measured were height (overall from the ground to the highest living portion of the plant whether it was a stem or leaf; measured in whole and half inch increments with a tape measure), spread (widest single axis of the plant when observed from overhead with the axis passing through the main stem of the plant; measured in whole and half inch increments with a tape measure), and basal stem diameter (measured with a digital caliper approximately 3 inches above the ground on the main stem of the plant and avoiding any branches; measured in millimeters rounding to 2 decimal places). Baseline data was collected with the help of volunteers.

End of growing season data collection was collected at the beginning of October each year for all vegetative field studies. Vigor was assessed visually on a 9 point scale adopted from the



Figure 36 Volunteers taking baseline data measurements, March 10, 2010.

NRCS with 1 having the greatest vigor and 9 being dead. Height, spread, and basal stem diameter were measured and recorded as described above. For consistency in vigor measurements, end of growing season data collection was collected by a single crew of BTNEP staff. Field data measurements were then recorded in Microsoft® Excel Spreadsheets for use in future statistical analysis.

4.11 Soil Collection Methods

Construction on the Far Ridge was completed in the fall of 2008. The first soil collection occurred in January 2009. Soil samples were collected approximately every 6 months with the exception of the spring 2012 and spring 2015 soil sampling periods. A total of 12 soil sample collections were taken: January 2009, August 2009, January 2010, August 2010, February 2011, October 2011, October 2012, May 2013, December 2013, May 2014, October 2014 and October 2015.

Soil samples along the top of the ridge were taken approximately every 200 feet (Figure 37). A crisscross pattern was employed on the ridge top in order to randomly capture the different land and soil features. A clean shovel was used for sampling. A hole was dug down to the top of the blade (approximately 9 inches) and then a uniform sample approximately 1 ½ to 2 inches thick was dug out. A drywall finishing knife was used to square the bottom and cut the side edges off of the sample, leaving a 2 ½ to 3 inch wide by 9 to 10 inch long sample. Soil samples were bagged in Ziploc® Freezer Gallon bags and labeled with a Sharpie®. Stakes were then located with a GPS and these positions were cataloged. These initial soil samples were taken and then marked with a wooden stake painted with an orange tip. Subsequent samples were taken 2 feet out from the wooden stake at compass heading positions, alternating positions for each sampling so as not to sample the same spot twice. These subsequent sample locations were marked with 2 orange pin flags.



Figure 37 January 2015 aerial image of the 15 ridge top soil sample locations from the Far Ridge.

Bagged soil samples were immediately brought from the field to be dried in a covered area at our facility in Thibodaux, Louisiana (Figure 38). Once dried, samples were thoroughly mixed and then 2 cups of material was rebagged and sent off for soil analysis to A&L Analytical Laboratories, Inc., Memphis, Tennessee (samples collected from January 2009 until February 2011) or LSU Agricultural Center's Soil Testing and Wetland Soil Characterization Laboratories, Baton Rouge, Louisiana (samples collected October 2011 to October 2015).

The soil analysis package from the A&L Analytical Laboratories, Inc., included organic matter, cation exchange capacity, pH, soluble salts, and extractable elements i.e. P, K, Ca, Mg, S, Na Zn, Mn, Fe, Cu, boron (B), and nitrate (NO₃⁻). Mehlich III (an acid extractant with the mixture of 0.2N CH₃COOH + 0.25N NH₄NO₃ + 0.013N HNO₃ + 0.015N NH₄F + 0.001M EDTA) was used to determine the concentration of extractable elements. The soil analyses from the LSU Agricultural Center's Soil Testing and Wetland Soil Characterization Laboratories included pH, electrical conductivity (EC), salinity, macro- and micronutrients. Salinity, conductivity, soluble salts, and pH were analyzed using a ratio of 1:2 for dry soil and distilled water. Electrical conductivity measures the ability of soluble salts to conduct electricity in water. The macro and micronutrients including phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg),



Figure 38 Drying soil samples in the greenhouse before bagging and shipping them off for analysis, August 7, 2009.

sulfur(S), sodium (Na), iron (Fe), copper (Cu), and zinc (Zn) were analyzed from the water soluble extract of the 1:2 soil and water ratio, and the element concentration was determined using ICP (Inductively Couple Plasma Spectrophotometer). Cation Exchange Capacity (CEC) and Sodium Adsorption Ratio (SAR) were calculated based on the element analyses. SAR is defined as the ratio of sodium to calcium plus magnesium. The calculations are based on molecular weight of each of the three elements and their respective valence and expressed as milliequivalent (meq) for CEC and an index value for SAR.

A problem was realized in 2011 with the analyses of the soil samples collected and analyzed by A&L Analytical Laboratories, Inc. between 2008 and 2011 as it was determined they were inappropriate for high saline coastal soils. The extractant used by A&L Analytical Laboratories, Inc. for most of the metal analysis, calculation of Sodium Adsorption Ratio, and calculation of Cation Exchange Capacity was Mehlich III (an acid extractant with the mixture of $0.2N \text{ CH}_3\text{COOH} + 0.25N \text{ NH}_4\text{NO}_3 + 0.013N \text{ HNO}_3 + 0.015N \text{ NH}_4\text{F} + 0.001M \text{ EDTA}$). For coastal saline soils, the preferred extractant is distilled water rather than an acidic solution. Distilled water only extracts the dissolved salts in the soil, providing a closer measurement of the actual soil conditions and effects on plants. An acidic extractant, on the other hand, extracts acid-soluble cations from the mineral component of soils, such as calcium in shell and carbonates present in the Fourchon Ridge sediments. Although Mehlich III is commonly used in inland agricultural

soils and is assumed to mimic the cation and nutrient extracting ability of plants, it is an inappropriate extractant for high saline coastal soils.

The objectives of Manoch Kongchum's research were to: 1) assay and interpret the physical and chemical analyses of all soil samples previously completed by A&L Analytical Laboratories, Inc. in 2011; and 2) assist BTNEP project managers in the implementation and analysis of the incomplete 2012, 2013, and 2014 soil sample series.

The major findings of Kongchum's study mainly establishes a baseline for the other work that is presented in the main body of this report that documents trends for all parameters over the course of the vegetative studies and data collected from 2009–2015. In general, across the overall sites sampled that included marsh soils and ridge top soils, the marsh soils can be classified as saline-sodic and the ridge top soils can be classified as high salinity and borderline sodic soils. For both Mehlich III and water extracts, older ridge soils experienced a decrease in sodium with a relative increase in calcium due to rainwater leaching of soluble sodium constituents over time. A&L Labs versus LSU Soils Lab methods were comparable for macro and micro nutrients in addition to EC, CEC and SAR.

The full results from these analyses are found in Appendix 2 in detail in the report entitled "Assessment and Evaluation of Soil Physical and Chemical Properties of Dredged Material in Constructed Wetland" by Manoch Kongchum. However, because of differences laid out in our caveats that precedes Manoch Kongchum's report, we have used results for EC and SAR for soil samples collected between October 2011 and October 2015 from LSU and not Manoch Kongchum for statistical analysis in this report (see Appendix 5).

4.12 Weather

After the condition of the soil, weather played the next most significant role in plant survival on the ridge. With most planting sites for coastal restoration plantings located in hard to reach places, in difficult areas to maneuver, and usually using prohibitively large quantities of plants, it is almost always logistically impossible to mechanically water these types of plantings. Besides the cultural treatments used in the experimental field trials, no care was afforded these plantings in order to better mimic standard planting procedures for most coastal restoration vegetative plantings.

The last few years have been fairly typical for rainfall. In 2011, however, Louisiana experienced a pronounced drought (Figure 39). The 2011 Block Planting and the Linear Ridge Planting, both implemented in March of 2011 were planted during a severe drought that eventually became a declared exceptional drought (the highest level) by mid-June. The drought was gone before the end of the growing season, but the effect of the drought on the plants was the greatest

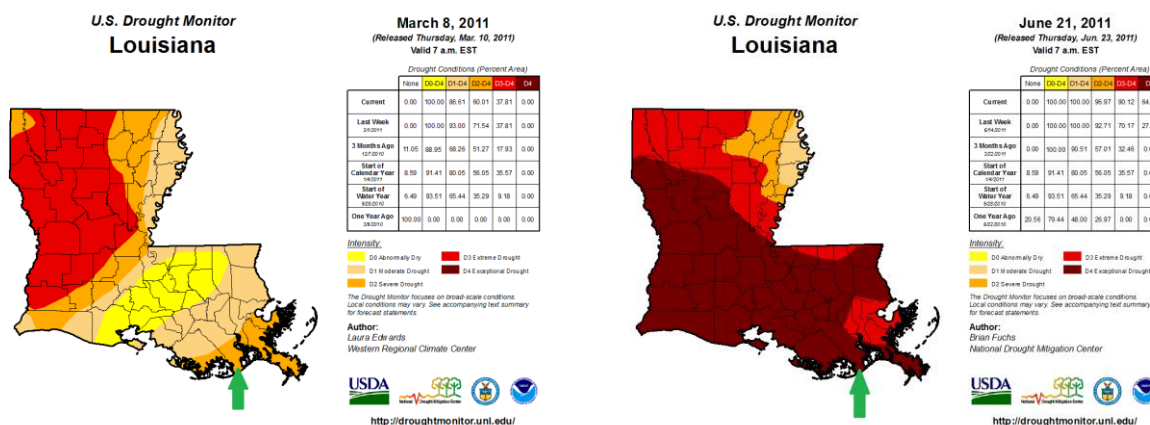


Figure 39 Drought maps at the time of the March 2011 plantings and in June 21, 2011. Green arrow indicates project location.

mortality exhibited in both of these plantings compared to any of the others. Even well-established plants on the Middle Ridge suffered and died during this event. In fact, the entire marsh surrounding the Ridge became a complete brown marsh event with all the smooth cordgrass dying off. Rainfall during this period at the Galliano, Louisiana, weather station 21.5 miles NNE of the Ridge recorded a 1.55 inch rainfall on March 10th, an additional 3 inch rain on March 30th, and then only 1.77 inches of precipitation over the next 92 days. Rainfall during this period at the Grand Isle, Louisiana, weather station 14.5 miles ENE of the Ridge recorded a 1.1 inch rain on March 10th, no rain on March 30th and only 3.3 inches of rain over the next 120 days.

All of the study years ended the growing season with no drought conditions and the only other years to be planted during a drought were 2009 (moderate drought) and 2012 (extreme drought).

Drought maps from all the planting and growth data collection years (2009-2015) are included in Appendix 3.

4.13 Non-Experimental Plantings

Most plantings implemented on the ridge were not part of vegetative trials but executed in order to reduce soil erosion and create habitat while obtaining at least an 80% vegetative coverage on the Ridge. At the time of this writing, December 2015, visual inspection of the vegetative coverage of the Ridge appears to be around 85 to 90%.

From 2009 to the end of 2015, 38 non-experimental plantings were implemented utilizing 753 volunteers with over 62,000 plants being planted on the Middle and Far Ridges. Since the Middle Ridge had already received numerous herbaceous plantings since its completion in 2005

and exhibited exceptional herbaceous coverage by 2009, all plantings on the Middle Ridge from 2009 on were woody species plantings. A total of 8,501 woody seedlings were planted on the Middle Ridge over the 7 year period. Post construction of the Far Ridge in the summer of 2008, establishment of herbaceous vegetation and woody seedlings was undertaken up until April of 2015. On the Far Ridge marsh aprons, 18,700 bare root plugs of smooth cordgrass were planted with the vast majority being planted on the exposed northern marsh apron. An additional 22,560 herbaceous plants were planted along the ridge slopes and up onto the ridge top margins. Finally, 12,305 woody seedlings were planted on the Far Ridge top.

All seeding, grow out, and plantings (experimental and non-experimental) had an educational component for the volunteers assisting BTNEP in the effort. Volunteers learned about the problems impacting coastal Louisiana and efforts being implemented to mitigate their impacts. Volunteers learned about the importance of these native woody species to Neotropical migratory songbirds. BTNEP's volunteers for this project, mostly college students, came from all across the nation and the knowledge we imparted to them about the importance of native woody species to Neotropical migratory songbirds was transferred back to their areas of origin. Educating people from around the nation about the impacts of Louisiana's land loss is important, because the cost and severity of the problem is going to require buy-in from the entire nation.

4.13.1 2009 to 2015 Ridge Plantings

28 February 2009: Thirty-nine volunteers assisted in planting a total of 4,185 woody seedlings on the Middle and Far Ridge sections. Of this total, 2,725 were conetainers: 1,150 live oak and 1,575 red mulberry. The rest, 1,460, were trade gallons: 400 American beautyberry, 400 red mulberry, 350 sand live oak, 250 yaupon holly, and 60 hackberry.

15 April 2009: A total of 336 live oak seedlings in 4" x 14" containers were planted on the Middle Ridge.

21 April 2009: A total of 200 hackberry bare root seedlings donated from Louisiana Department of Agriculture and Forestry (LDAF) were planted on the Middle Ridge.

11 November 2009: Seventeen volunteers assisted in an herbaceous planting on the Far Ridge top and slopes. A total of 4,450 4" containers were planted. Of this total, 1,850 were marshhay cordgrass, 1,850 seashore paspalum, 300 saltgrass, 150 bitter panicum and 300 coastal dropseed. An herbaceous establishment study was established also at this time across the profile of the ridge and is included in detail earlier in this report.

12 & 13 December 2009: A follow up herbaceous planting on the Far Ridge top and slopes was undertaken over two days in December 2009. Three volunteers came out and assisted on December 12th and another 20 came out on December 13th. A total of 4,000 4" containers were planted. Of this total, 2,000 were marshhay cordgrass and 2,000 were seashore paspalum.

9 March 2010: The southern marsh platform of the ridge was planted with 7,000 plugs of smooth cordgrass by 55 volunteers.

15 March 2010: A woody species planting of 1,045 containers was conducted on the Middle Ridge. Of this total, 603 were salt matrimony vine, 331 hackberry, 111 red mulberry and 48 honeylocust. This planting was assisted by 33 volunteers.

22 & 23 March 2010: Thirty-five volunteers helped plant a total of 2,075 4" woody species containers on the Middle Ridge. Of the 2,075 4" containers, woody species planted included 1,250 red mulberry, 450 hackberry and 375 live oak.

29 & 30 March 2010: Twenty-nine volunteers planted 4,000 plugs of smooth cordgrass on the northern marsh platform of the Far Ridge.

26 October 2010: Seven volunteers came out and helped plant 3,000 smooth cordgrass plugs on the north marsh platform of the Far Ridge.

29 October 2010: Thirteen volunteers helped plant 900 marshhay cordgrass and 500 seashore paspalum 4" containers on the slopes and the top of the Far Ridge.

14 December 2010: Seventeen volunteers helped plant 1,000 containers on the Middle Ridge of the following species: live oak, hackberry, honeylocust, and persimmon.

25 February 2011: Sixteen volunteers helped plant 775 salt matrimony vine containers on the slopes and top of the Far Ridge.

22 March 2011: Forty-two volunteers helped plant 2,000 4" containers of seashore paspalum on the slopes and top of the Far Ridge.

25 August 2011: Three volunteers and a large staff from BTNEP, NRCS and the Terrebonne/Lafourche SWCD came out and helped plant 2,000 marshhay cordgrass, 1,000 seashore paspalum, and 500 bitter panicum 4" containers on the top and north side of the Far Ridge.

6 October 2011: Twenty volunteers helped plant 2,000 smooth cordgrass bare root plugs on the north marsh platform adjacent to the Far Ridge and 1,500 bitter panicum 4" containers on the north slope and top of the Far Ridge.

30 October 2011: Twenty-three volunteers helped plant 2,700 smooth cordgrass bare root plugs on the north marsh platform adjacent to the Far Ridge.

13 March 2012: Twenty-eight volunteers helped plant 800 conetainers of woody plants on the Middle Ridge. The four species planted were live oak, sand live oak, honeylocust and persimmon.

20 March 2012: Thirty-four volunteers helped plant 675 conetainers of live oak, American beautyberry and honeylocust on the Far Ridge just east of the Mini Block Planting that was planted at the same time.

27 March 2012: Twenty-two volunteers helped plant 700 conetainers of salt matrimony vine on the Far Ridge. An additional 100 myrtle oak 4x14" containers were planted as well.

8 January 2013: Twenty-one volunteers helped plant 850 conetainers of woody seedlings on the westernmost end of the Far Ridge. 550 salt matrimony vine conetainers were planted along the top and northern slope of the ridge and 300 live oak conetainers were planted on top of the ridge.

11 March 2013: Fifteen volunteers helped plant 750 conetainers of live oak seedlings on the top of the eastern end of the Far Ridge. A slow release fertilizer was added to each hole.

12 March 2013: Thirty-five volunteers helped plant 500 conetainers of four species of woody seedlings on the top of the eastern end of the Far Ridge. The five species planted were: 200 salt matrimony vine, 100 hackberry, 50 persimmon, 100 live oak, and 50 honeylocust. A slow release fertilizer was added to each hole.

19 March 2013: Fourteen volunteers helped plant 500 conetainers of salt matrimony vine seedlings along the northern slope of the eastern end of the Far Ridge.

16 November 2013: Sixty volunteers helped plant 4,175 herbaceous and woody plants on the top and northern slope of the eastern end of the Far Ridge and the top and northern and southern slopes of the entire Middle Ridge. Woody species planted with fertilizer tablets on the Middle Ridge were: 150 trade gallons (TG) of live oak, 50 TG of American beautyberry, 40 TG of hackberry, 30 TG of honeylocust, and 25 TG of persimmon. Woody species planted with fertilizer tablets on the eastern end of the Far Ridge were: 600 conetainers of salt matrimony vine, 100 conetainers of yaupon, 100 conetainers of live oak, and 50 conetainers of persimmon. Herbaceous species planted were: 100 trade gallon pots of switchgrass, 232 4-inch pots of railroad vine, 100 4-inch pots of beach morning-glory, 598 4-inch pots of seashore paspalum,

1300 conetainers of seashore paspalum, 500 1-inch conetainers of seashore paspalum, and 200 conetainers of Gulf bluestem.

19 November 2013: Eight volunteers helped plant 2,220 herbaceous and woody plants on the top and northern slope of the central and western portions of the Far Ridge. Woody species planted with fertilizer tablets were: 300 salt matrimony vine, 100 conetainers of live oak, and 50 conetainers of persimmon. Herbaceous species planted were: 70 trade gallon pots of switchgrass, 150 4-inch pots of railroad vine, 50 4-inch pots beach morning-glory, 350 4-inch pots of seashore paspalum, 700 conetainers of seashore paspalum, 300 1-inch conetainers of seashore paspalum, and 150 conetainers of Gulf bluestem.

20 November 2013: Six volunteers helped plant 1,560 herbaceous and woody plants on the top and northern slope of the western portions of the Far Ridge. Woody species planted with fertilizer tablets were: 150 conetainers of salt matrimony vine, 150 conetainers of yaupon, 150 conetainers of persimmon, and 200 conetainers of live oak. Herbaceous species planted were: 30 trade gallon pots of switchgrass, 50 4-inch pots of railroad vine, 30 4-inch pots of beach morning-glory, 150 4-inch pots of seashore paspalum, 500 conetainers of seashore paspalum, 100 1-inch conetainers of seashore paspalum, and 50 conetainers of Gulf bluestem.

10 March 2014: Ten volunteers helped plant 650 conetainers of four species (live oak, hackberry, American beautyberry and salt matrimony vine) of woody seedlings on the top of the western end of the Far Ridge. A slow release fertilizer was added to each hole.

12 March 2014: Ten volunteers helped plant 850 conetainers of five species (live oak, hackberry, persimmon, yaupon and salt matrimony vine) of woody seedlings on the top of the eastern end of the Far Ridge. A slow release fertilizer was added to each hole.

25 March 2014: Ten volunteers helped plant 275 trade gallons of nine species (live oak, sand live oak, Hercules-club, hackberry, green ash, red mulberry, American beautyberry, honeylocust and persimmon) of woody seedlings on the easternmost to middle top of the Middle Ridge. A slow release fertilizer was added to each hole.

26 March 2014: Ten volunteers after planting the 2014 Block Planting helped plant an additional 312 conetainers of woody seedlings immediately south of the 2014 Block Planting on the Far Ridge and spreading out east and west of its footprint. The three species planted were yaupon, live oak and roughleaf dogwood. A slow release fertilizer was added to each hole.

12 December 2014: Eighteen volunteers helped plant 700 salt matrimony vine conetainers along the northern slope of the Far Ridge toward the western end. A slow release fertilizer was added to each hole.

17 March 2015: Fourteen volunteers planted 90 trade gallon sized woody plants on the Middle Ridge and 550 conetainers on the east end of the Far Ridge. Of the 90 trade gallon sized woody plants planted on the Middle Ridge 35 were yaupon, 25 live oak, 10 persimmon, 10 roughleaf dogwood, and 10 hackberry. The 550 conetainers planted on the Far Ridge included 300 live oak, 150 American beautyberry, and 100 hackberry.

24 March 2015: Eight volunteers helped plant 70 trade gallon sized live oaks on the Middle Ridge and 350 conetainers (200 live oak and 150 hackberry) on the western end of the Far Ridge.

1 April 2015: Eleven volunteers planted 200 trade gallons (80 live oak, 50 yaupon, 30 persimmon, 30 roughleaf dogwood, and 10 hackberry) on the Middle Ridge.

5.0 RESULTS & DISCUSSION

Statistical analysis for this report was conducted by Dr. Quenton Fontenot, Head and Professor of Biological Sciences, Nicholls State University, Thibodaux, Louisiana. Dr. Fontenot used SAS (Statistical Analysis System) developed by SAS Institute, Cary, North Carolina, for the following analyses for each section in this report. Effects of Cultural Treatments on Species Growth and Survival (5.1): Analysis of Variance (ANOVA) followed by a Tukeys *post hoc* analysis was used to delineate differences among treatments. Comparison of Year-to-Year Survival for Each Planting Year (5.2): Analysis of Variance (ANOVA) followed by a Tukeys *post hoc* analysis was used to delineate differences among treatments. Single Species Change in Height Comparison Among Planting Years (5.3): Correlation analysis to determine the relationship among height, spread, and BSD. Analysis of Variance (ANOVA) followed by a Tukeys *post hoc* analysis was used to delineate differences among treatments. Single Species Survival and Vigor Comparisons Among Planting Years (5.4): Analysis of Variance (ANOVA) followed by a Tukeys *post hoc* analysis was used to delineate differences among treatments. Survival by Orientation (5.5): Analysis of Variance (ANOVA) followed by a Tukeys *post hoc* analysis was used to delineate differences among treatments. Soil Quality (5.6): Analysis of Variance (ANOVA) followed by a Tukeys *post hoc* analysis was used to delineate differences among treatments. First Growing Season Survival and Soil Quality (5.7): Regression analysis to determine the relationship between survival and each soil quality variable. Herbaceous: Survival and Spread Comparisons Among Planting Positions (5.8): Analysis of Variance (ANOVA) followed by a Tukeys *post hoc* analysis was used to delineate differences among treatments.

5.1 Effects of Cultural Treatments on Species Growth and Survival

We analyzed the use of cultural treatments for all of the experimental plantings (2010-2014) conducted on the Far Ridge through their first two growing seasons (see Appendix 4). Woody species looked at collectively in all of the experimental plantings included live oak, sand live oak, salt matrimony vine, hackberry, American beautyberry, persimmon, honeylocust, yaupon, Hercules' club, and roughleaf dogwood. Cultural treatments consisted of a control (no additives), bagasse, fertilizer, gypsum, and various combinations of these additives. The soil treatments were added to the dug holes at the time of the plantings. Each planting was done in treatment blocks with the mean of each block used as a replicate. Survival and growth data (height, spread, basal stem diameter, and vigor) was collected at the time of planting as a baseline and at the end of each growing season (October) through 2015.

Results from statistical analysis demonstrated that there was no statistical benefit in adding treatments for survival and growth to these plantings. The high mortality exhibited in most of these plantings may have contributed to this outcome. However, even live oak planted in 2013 and 2014 that exhibited the highest survival rates (56% and 72% after first growing season respectively) and hackberry planted in 2013 with a survival rate of 59% after the first growing season, did not show any benefits in adding cultural treatments compared to the control. The only exception appears to be for salt matrimony vine in the 2010 planting for the first growing season only, with the addition of fertilizer increasing spread and the addition of bagasse increasing basal stem diameter.

5.2 Comparison of Year-to-Year Survival for Each Planting Year

Comparison of Year-to-Year Survival for Each planting Year comes from the main big block planting for each planting year from 2010-2014. For each planting year, year-to-year survival was compared among species. Table 1 (page 47) shows a side by side comparison of species and planting years with species survival at the end of each growing season up to the final growth/survival data collection in October 2015.

2010: The 2010 planting utilized three species: salt matrimony vine, hackberry, and sand live oak. Comparison of survival of all species for the 2010 planting year varied for every year except 2013 and 2015 (Figure 40). Salt matrimony vine, a salt tolerant, small evergreen shrub found naturally in the vicinity of the project site, had the greatest survival after the first growing season at 99%. Salt matrimony vine only lost one more plant over the next five growing seasons in 2013, being the most persistent species of the three and remaining with a 99% survival after five years. Hackberry survival the first year was significantly less than that of salt matrimony vine at only 20%, but was still significantly greater than that of sand live oak, which had the lowest survival at 2% (or just 3 plants out of 192). The next year, in 2011, the year of the

Fourchon Maritime Forest Ridge and Marsh Restoration

Table 1 Number of individual surviving plants (proportion of individuals of original planting that survived in parenthesis) for each species planted each year. N planted represents the total number of individuals planted that year for that species.

Species	Year Planted	N Planted	Approximate Time Since Planting					
			6 Months	1.5 Years	2.5 Years	3.5 Years	4.5 Years	5.5 Years
Hackberry	2010	335	66 (0.197)	23 (0.069)	19 (0.057)	18 (0.054)	17 (0.051)	14 (0.042)
Sand Oak	2010	192	3 (0.016)	3 (0.016)	2 (0.01)	2 (0.01)	1 (0.005)	1 (0.005)
Matrimony Vine	2010	241	239 (0.992)	239 (0.992)	239 (0.992)	238 (0.987)	238 (0.987)	238 (0.987)
Beautyberry	2011	150	1 (0.007)	1 (0.007)	1 (0.007)	1 (0.007)	1 (0.007)	-
Hackberry	2011	150	2 (0.013)	2 (0.013)	2 (0.013)	1 (0.007)	1 (0.007)	-
Live Oak	2011	180	7 (0.039)	7 (0.039)	7 (0.039)	6 (0.033)	6 (0.033)	-
Hackberry	2012	150	29 (0.193)	24 (0.16)	23 (0.153)	17 (0.113)	-	-
Live Oak	2012	165	33 (0.200)	31 (0.188)	31 (0.188)	31 (0.188)	-	-
Sand Oak	2012	165	17 (0.103)	17 (0.103)	15 (0.091)	12 (0.073)	-	-
Hackberry	2013	165	98 (0.594)	84 (0.509)	43 (0.261)	-	-	-
Live Oak	2013	165	92 (0.558)	88 (0.533)	80 (0.485)	-	-	-
Sand Oak	2013	150	46 (0.307)	44 (0.293)	24 (0.16)	-	-	-
Dogwood	2014	90	3 (0.033)	2 (0.022)	-	-	-	-
Live Oak	2014	99	71 (0.717)	57 (0.576)	-	-	-	-
Yaupon	2014	99	14 (0.141)	8 (0.081)	-	-	-	-

exceptional drought, only 35% of the first year surviving hackberries survived, significantly less than either salt matrimony vine or sand live oak. Survival for hackberry in the remaining years was 80% or higher after each growing season. Final overall survival for the 2010 planting after five growing seasons for hackberry was 4%. For sand live oak, two of the three first year surviving plants were lost over the next five years for a final survival of 1%. The severe saline-sodic soil conditions at the time of planting is the most likely cause for the high mortality of the two non-halophytic species, hackberry and sand live oak. The excessive drought the following year caused additional mortality to the hackberry. Salt matrimony vine, being a halophytic and xeric tolerant plant survived exceptionally well under these same conditions.

2011: The 2011 planting utilized three species: live oak, hackberry, and American beautyberry. Comparison of survival of all species for the 2011 planting year showed no differences in any of the years (Figure 41). All three species experienced extreme mortality by the end of the first growing season. Survival rates the first year for live oak, hackberry, and American beautyberry were 4, 1, and 1 percent respectively. At the end of 2015, live oak survival was down to 3% and the others remained at 1% each. The extreme mortality for all 3 species was most likely due to the exceptional drought experienced during their planting year and the high soil salinity and adverse soil conditions exhibited at that time.

2012: The 2012 planting utilized 3 species: live oak, hackberry, and sand live oak. Comparison of survival of all species for the 2012 planting year showed no variation in survival until 2015, the fourth growing season, when live oak had the greatest survival (Figure 42). All three species experienced heavy mortality by the end of the first growing season. Survival rates for the first year for live oak, hackberry, and sand live oak were 20, 19, and 10 percent respectively. The low survival rates were probably due to poor soil conditions exacerbated by an extreme drought at the time of the planting. Year-end survival of the remaining surviving plants was above 83% for all species for the next two years, but in 2015 hackberry and sand live oak survival dropped to 74 and 73 percent respectively. It is possible the moderate drought that started off the 2015 growing season caused the higher mortality seen in hackberry and sand live oak than was seen in the 2013 and 2014 growing seasons when no drought was recorded. Live oak, however, had significantly higher survival (100%) over the same year, 2015. Final overall survival at the end of 2015 for live oak, hackberry, and American beautyberry was 18, 11, and 7 percent respectively.

2013: The 2013 planting utilized 3 species: live oak, hackberry, and sand live oak. Comparison of survival of all species for the 2013 planting year varied at 6 months and 2.5 years (Figure 43). At 6 months (end of first growing season), sand live oak had the lowest survival. At 2.5 years (end of third growing season), live oak had the greatest survival. Hackberry and live oak survival broke the 50% survival barrier for the first time with hackberry at 59% and live oak at 56% at

the end of the first growing season. Sand live oak had significantly lower survival at 31%. Survival of remaining plants for all three species at the end of the second growing season in 2014 was 85% or higher. The third and final growing season saw a significant drop in survival for both hackberry (51%) and sand live oak (53%) versus live oak (91%), as was similar for the 2012 planting year plants. It is possible the moderate drought that started off the 2015 growing season caused the higher mortality seen in hackberry and sand live oak than was seen in the 2014 growing season when no drought was recorded. Live oak appears to be more drought tolerant than the other two species in this environment. Final overall survival for the 2013 planting for live oak, hackberry, and sand live oak was 48, 25, and 15 percent respectively.

2014: The 2014 planting utilized 3 species: live oak, yaupon, and roughleaf dogwood. Live oak had significantly higher survival (72%) than yaupon (14%) and roughleaf dogwood (3%) at the end of the first growing season (Figure 44). There was no difference in survival for the second growing season (1.5 years) when survival ranged from a high of 80% for live oak to a low of 57% for yaupon. Final overall survival for the 2014 planting for live oak, yaupon, and roughleaf dogwood was 58, 8 and 2 percent respectively. Although soil conditions were improving over the planting years (as evidenced by the highest survival for live oak in a planting year for 2014), the high mortality for the yaupon and roughleaf dogwood species is probably due to a higher sensitivity to saline-sodic soils for these two species.

2010 Block Planting Comparison of Survival

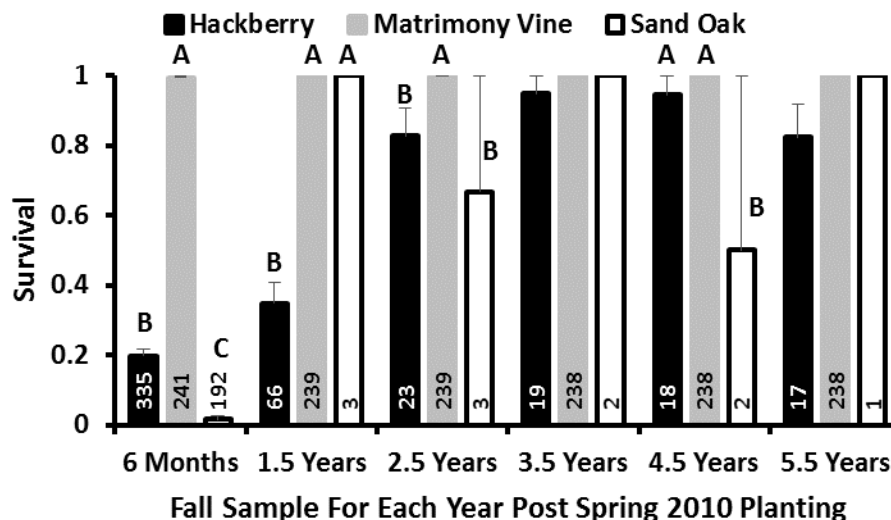


Figure 40 Mean (\pm SE) Survival for each species planted in 2010. Plants were planted in the spring and survival was calculated for each subsequent fall. Means with a similar letter within each year are not different. The numbers in the base of each column represent the number of plants used to calculate survival.

2011 Block Planting Comparison of Survival

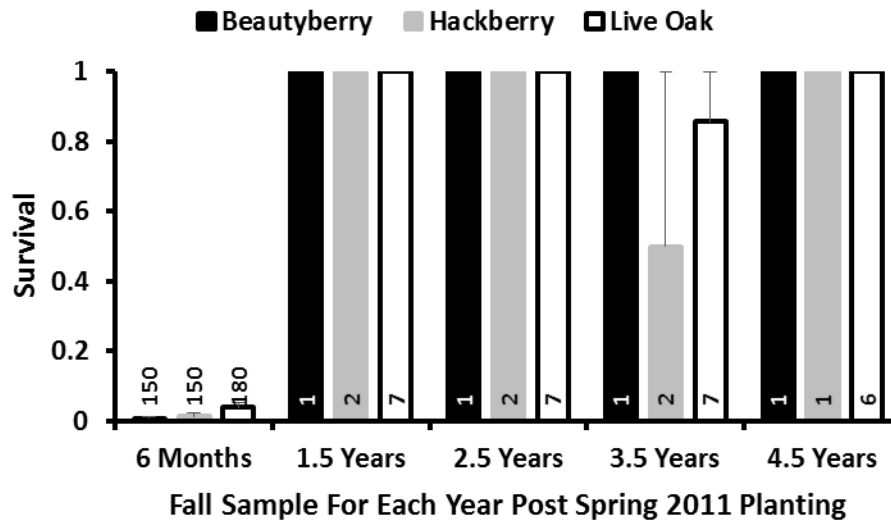


Figure 41 Mean (\pm SE) Survival for each species planted in 2011. Plants were planted in the spring and survival was calculated for each subsequent fall. Initial Survival was very low and did not differ among species for any sample period. The numbers in the base of each column represent the number of plants used to calculate survival.

2012 Block Planting Comparison of Survival

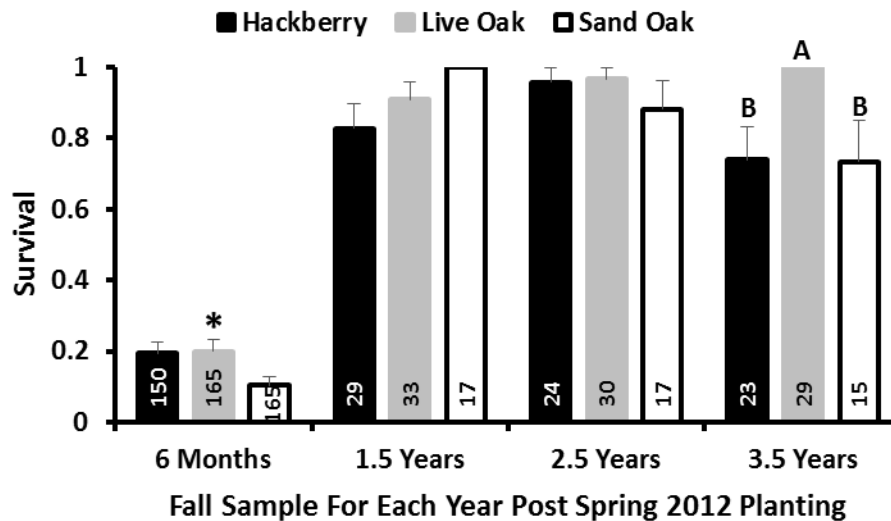


Figure 42 Mean (\pm SE) Survival for each species planted in 2012. Plants were planted in the spring and survival was calculated for each subsequent fall. Means with a similar letter within each year are not different. The asterisks indicates that Analysis of Variance detected a difference among treatments, but *post hoc* analysis could not delineate among the means. The numbers in the base of each column represent the number of plants used to calculate survival.

2013 Block Planting Comparison of Survival

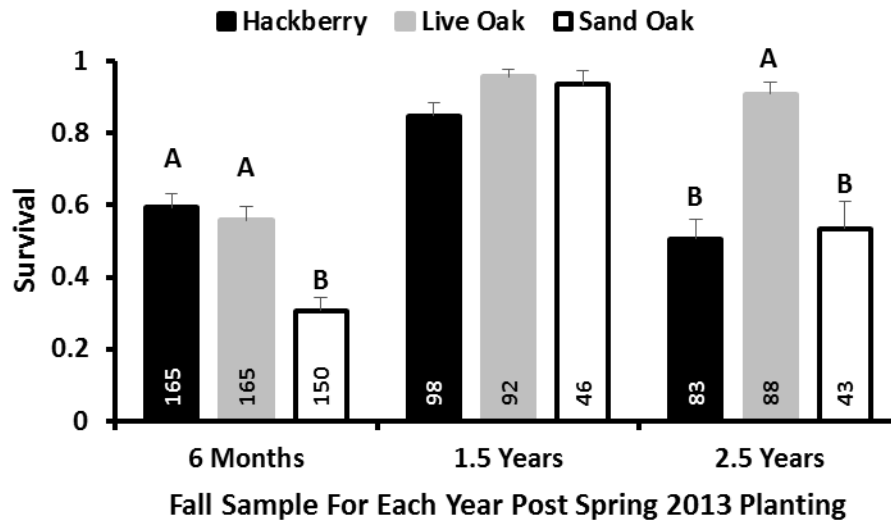


Figure 43 Mean (\pm SE) Survival for each species planted in 2013. Plants were planted in the spring and survival was calculated for each subsequent fall. Means with a similar letter within each year are not different. The numbers in the base of each column represent the number of plants used to calculate survival.

2014 Block Planting Comparison of Survival

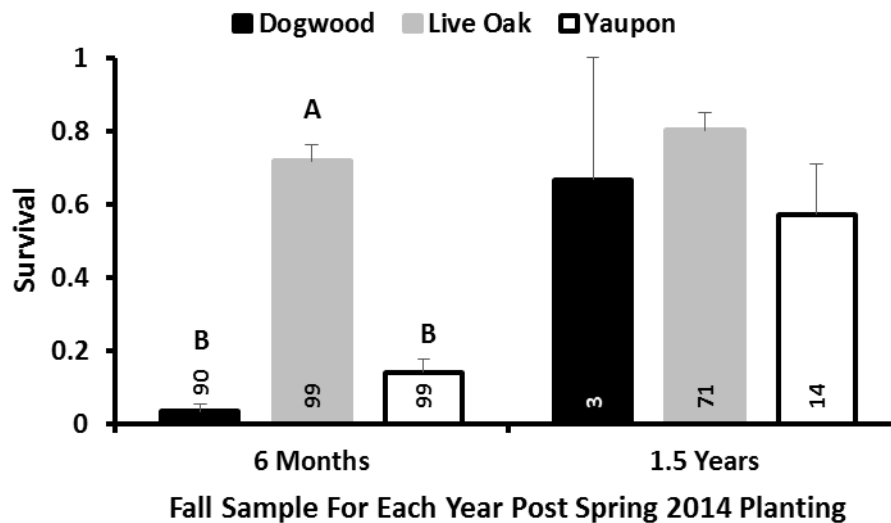


Figure 44 Mean (\pm SE) Survival for each species planted in 2014. Plants were planted in the spring and survival was calculated for each subsequent fall. Means with a similar letter within each year are not different. The numbers in the base of each column represent the number of plants used to calculate survival.

5.3 *Single Species Change in Height Comparison Among Planting Years*

Measurements of woody vegetation growth can include change in height, spread, and basal stem diameter (BSD). As a growing plant will increase in height, spread, and BSD over time it is reasonable to expect a degree of correlation among the three variables. We collected growth measurements of height, spread, and basal stem diameter for all surviving plants at the end of each growing season (2009-2015) for all experimental plantings. We compared the correlation between height and spread and between height and BSD for each species for each planting year. The correlation between height and spread was highly significant (all comparisons had a P Value less than 0.0001). The strength of the correlation (Pearson Correlation Coefficient) ranged from 0.4901 – 0.904 with a mean strength of correlation = 0.7262 (Table 2). All correlations between height and BSD were highly significant with all P Values < 0.0001. The strength of correlation ranged from 0.4453 – 0.9193 and averaged 0.7092. These results indicate that height, spread, and BSD change in proportion to each other. Although there is some variation among species and planting years, any of the three growth measurements will provide similar comparative information regarding growth over time. Therefore, because we found height, spread, and basal stem diameter to be highly correlated, we only used change in height as a measure in growth to reduce the amount of graphs and redundancy of this analysis. We report the stats of the rest of the variables in Table 2. Mean heights for each species were calculated from baseline measurements at the time of planting. The change in height at the end of the first growing season to below the baseline mean is due to dieback of plants from inhospitable soil and/or drought conditions.

Table 2 Pearson Correlation Coefficients for the correlation between height (in) and spread (in) and between height (in) and basal stem diameter (mm). All coefficients are significant at a P value of <0.0001.

Species	Planting Year	Height and Spread	Height and Basal Stem Diameter
Live Oak	2011	0.89047	0.91931
Live Oak	2012	0.86195	0.87709
Live Oak	2013	0.78287	0.73235
Live Oak	2014	0.49006	0.55556
Hackberry	2010	0.85329	0.61059
Hackberry	2011	0.56519	0.62644
Hackberry	2012	0.90464	0.91271
Hackberry	2013	0.58841	0.44525
Sand Oak	2010	0.67642	0.68075
Sand Oak	2012	0.67584	0.75487
Sand Oak	2013	0.69921	0.68586

Hackberry: We found no significant difference in change in mean height for hackberry for all of the plantings (2010-2013) over all of the growing seasons except for the fifth growing season (4.5 years) when the change in mean height increased significantly for planting year 2011 compared to planting year 2010 (Figure 45). However, since planting year 2011 only had one plant, the results are not statistically significant or meaningful. The change in mean height index generally increased over time for all planting years after an initial dieback the first growing season. Initial dieback for the first growing season ranged from 4 inches for planting year 2013 to 7.5 inches for planting year 2010. By the end of the third growing season, all planting years had regained their dieback height and averaged 6 inches taller than at the time of planting. By the end of the fourth growing season, all planting years averaged 19 inches higher than at the time of planting or 13 inches growth in one year.

Live Oak: Change in mean height for live oak was only significant at the end of the first growing season when the 2011 planting year lost more height than the 2014 planting year (Figure 46). This was probably due to the exceptional drought of 2011 causing the seedlings to dieback more than the 2014 planting year's first growing season when no drought was occurring. The change in mean height index generally increased over time for all planting years after an initial dieback the first growing season. By the end of the second growing season, all planting years had regained their dieback height and averaged 0.5 inches taller than at the time of planting. By the end of the third and fourth growing season, all planting years averaged together 11.5 and 34 inches higher, respectively, than at the time of planting.

Sand Live Oak: There was no significant difference in change in mean height for sand live oak for all planting years through all growing seasons (Figure 47). The change in mean height index generally increased over time for all planting years after an initial dieback the first growing season. Average dieback at the end of the first growing season for all planting years was 4.5 inches in height. By the end of the second growing season, all planting years had regained their dieback height and averaged 2.5 inches taller. By the end of the third and fourth growing season, all planting years averaged 11 and 15.5 inches higher, respectively, than at the time of planting.

Initial dieback after the first growing season manifested in one of two ways: dieback of some length of the tops of the main stem or death of the main stem and regrowth through new shoot(s) from the roots.

Hackberry Change in Height Comparison Among Planting Years

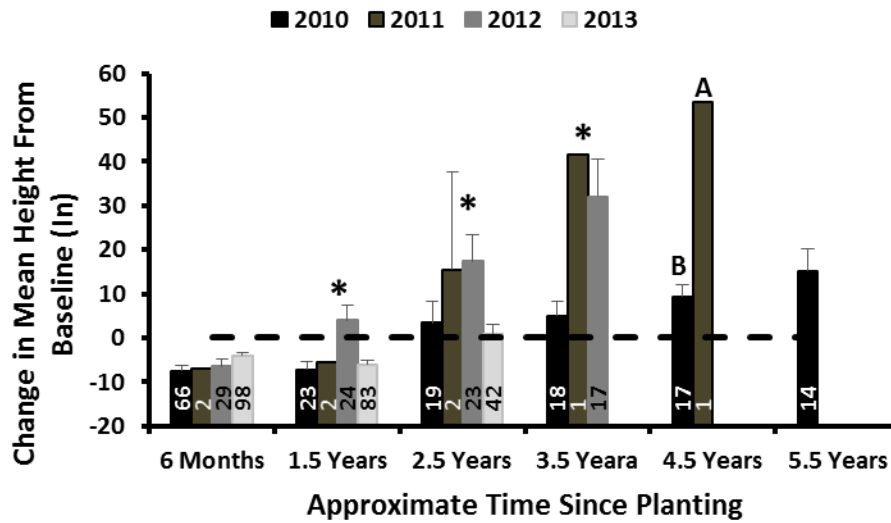


Figure 45 Mean (\pm SE) change in height for each sample period for each planting year as compared to the height at planting (baseline height = 0) for Hackberry. The horizontal dashed line represents the mean height at planting for each year. Means within a sample period that have a different letter are not similar. Asterisks mark groups that had a difference among treatments detected by Analysis of Variance, but the difference could not be delineated by *post hoc* tests.

Live Oak Change in Height Comparison Among Planting Years

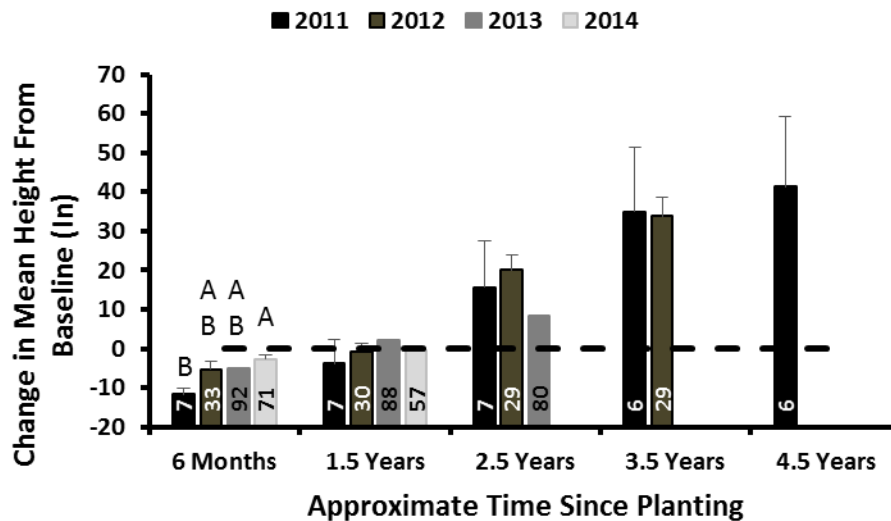


Figure 46 Mean (\pm SE) change in height for each sample period for each planting year as compared to the height at planting (baseline height = 0) for Live Oak. The horizontal dashed line represents the mean height at planting for each year. Means within a sample period that have a different letter are not similar.

Sand Live Oak Change in Height Comparison Among Planting Years

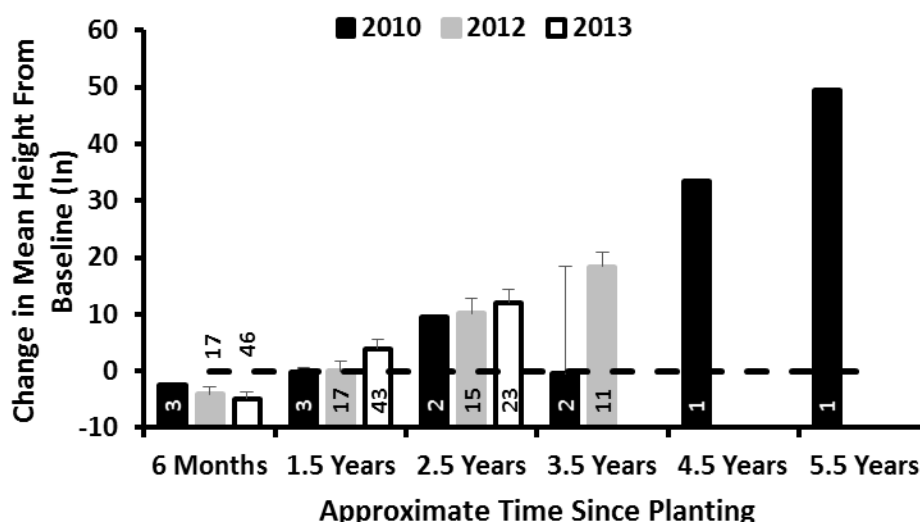


Figure 47 Mean (\pm SE) change in height for each sample period for each planting year as compared to the height at planting (baseline height = 0) for Sand Live Oak. The horizontal dashed line represents the mean height at planting for each year. Means within each sample period were similar.

5.4 Single Species Survival and Vigor Comparisons Among Planting Years

Of the ten woody species that were used over the course of all of the experimental woody trials at the Far Ridge, three species were used in 3 or more plantings in order to compare survival and growth response chronologically as soil conditions changed. Two species were planted 4 years consecutively: 1) hackberry: 2010, 2011, 2012 and 2013; and 2) live oak: 2011, 2012, 2013, 2014. The third species, sand live oak was planted 3 years: 2010, 2012 and 2013.

5.4.1 Hackberry Survival and Vigor: Comparison Among Planting Years

Hackberry survival 6 months post planting was greatest for the 2013 planting at 59% and lowest for the 2011 planting at 1% (Figure 48). The 2013 plantings high survival rate was probably due to improving soil conditions and 2011's poor survival mostly due to the exceptional drought of that year along with poor soil conditions. First year survival rate for 2010 and 2012 was 20 and 19 percent respectively. Although only 2 out of 150 Hackberry survived the 2011 planting at 6 months, both plants survived to the 2.5 year period. Because both plants from the 2011 planting survived, survival was 100% and among the highest survival rates of the four planting years at both 1.5 and 2.5 years. Beyond the 6 month mark, survival was relatively high for all plantings except the 2010 planting at 1.5 years (35%) and the 2013 planting year at 2.5 years (51%). Although not statistically different from 2012 and 2013, second growing season survival rate was lowest for the 2010 growing year (35%) as this was the year of the exceptional drought

(2011). The moderate drought at the beginning of 2015 may have contributed to the 2013 planting having the lowest survival rate (51%) of all the planting years for the third growing season.

Hackberry vigor varied among planting years at only the end of the first growing season (Figure 49). The least robust plants (highest vigor index) were recorded for the 2011 planting year, the year of the exceptional drought. The most robust plants (least vigor index) were recorded for the 2013 planting year. No differences for vigor were detected among the planting years beyond the first growing season, but the vigor index generally decreased over time for all planting years indicating that the maturing trees were improving their robustness.

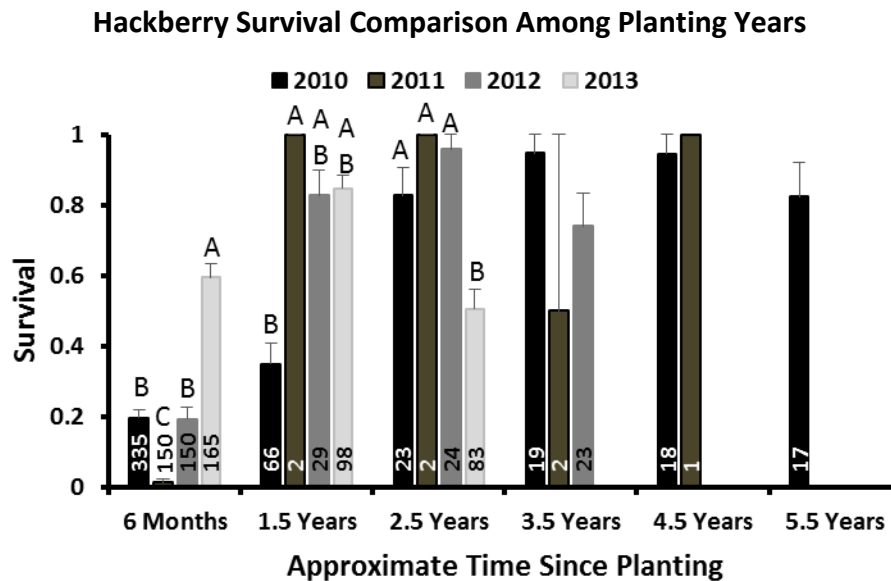


Figure 48 Mean (\pm SE) Hackberry Survival for each sample period for the 2010, 2011, 2012, and 2013 plantings. Means within a sample period that are marked with a different letter are not similar. Numbers inside of each column represent the number of trees used to calculate the mean value.

Hackberry Vigor Comparison Among Planting Years

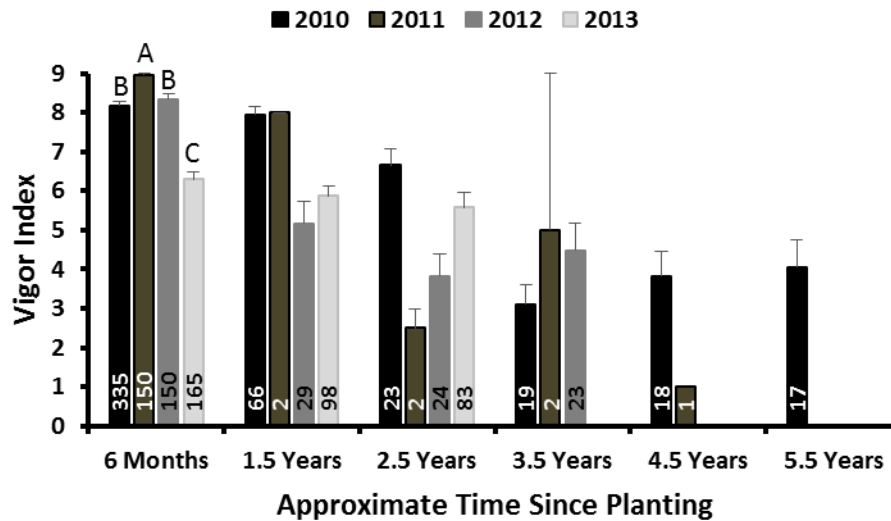


Figure 49 Mean (\pm SE) Hackberry Vigor for each sample period for the 2010, 2011, 2012, and 2013 plantings. Means within a sample period that are marked with a different letter are not similar. Numbers inside of each column represent the number of trees used to calculate the mean value.

5.4.2 Live Oak Survival and Vigor: Comparison Among Planting Years

Live oak survival varied among the planting years only for the first growing season with the lowest survival in planting year 2011 (4%) and with each following year having significantly higher survival than the year before: 2012 (20%), 2013 (56%), and 2014 (72%) (Figure 50). This trend of increasing survival through the planting years is most likely due to improving soil conditions. The extremely low survival in 2011 is probably due to the exceptional drought recorded that year and poor soil conditions. The improving but low survival in 2012 is likely due to the planting being implemented in an extreme drought and continued poor soil conditions. Beyond the first growing season, survival was relatively high for all plantings (80% or greater).

Live oak vigor varied among planting years for the first 3 growing seasons (6 months to 2.5 years after planting) (Figure 51). The most robust plants (lowest vigor index) for the first growing season (6 months) was for the 2014 planting with the least robust plants (greatest vigor index) in 2011, the year of the exceptional drought. The least robust plants (highest vigor index) for the second growing season (1.5 years) was the 2011 planting year that was probably due to the extreme drought that began the 2012 growing season. No differences for vigor were detected among the planting years beyond the third growing season (2.5 years), but the vigor index generally decreased over time for all planting years indicating that the maturing trees' vigor were improving.

Live Oak Survival Comparison Among Planting Years

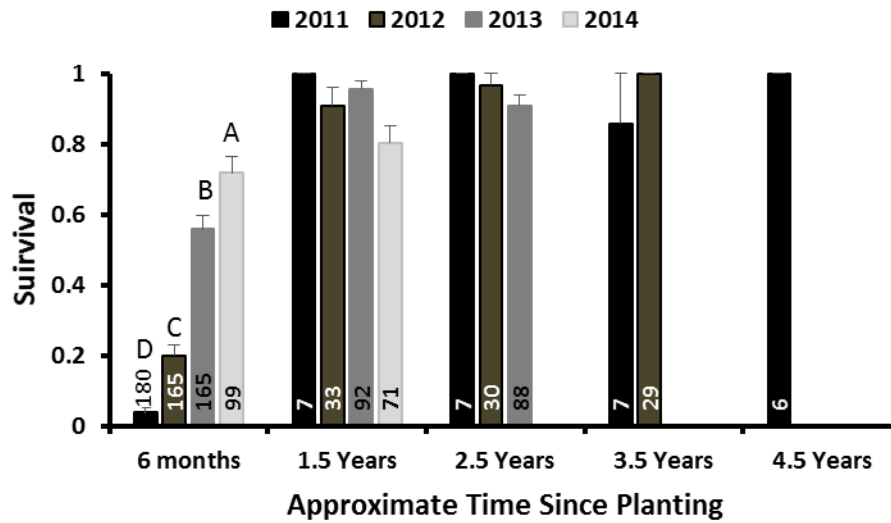


Figure 50 Mean (\pm SE) Live Oak Survival for each sample period for the 2011, 2012, 2013, and 2014 plantings. Means within a sample period that are marked with a different letter are not similar. Numbers inside of each column represent the number of trees used to calculate the mean value.

Live Oak Vigor Comparison Among Planting Years

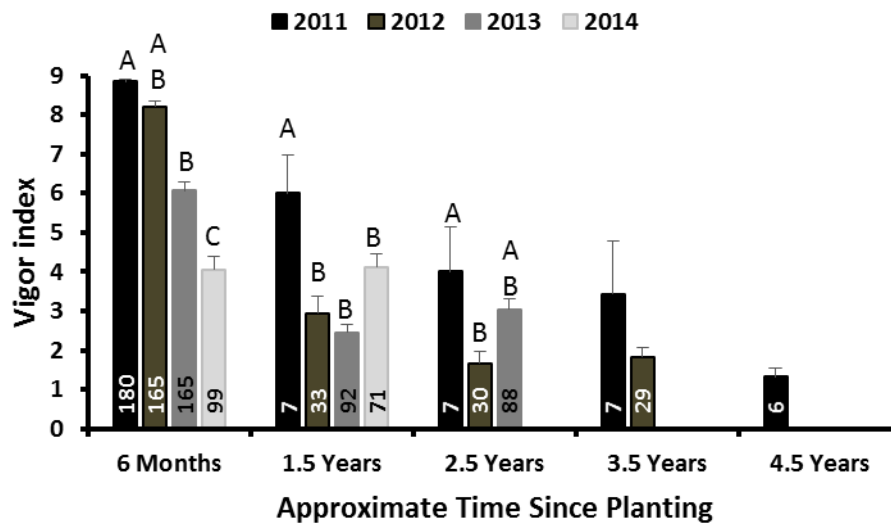


Figure 51 Mean (\pm SE) Live Oak Vigor for each sample period for the 2011, 2012, 2013, and 2014 plantings. Means within a sample period that are marked with a different letter are not similar. Numbers inside of each column represent the number of trees used to calculate the mean value.

5.4.3 Sand Live Oak Survival and Vigor: Comparison Among Planting Years

Sand live oak survival at the end of the first growing season (6 months) was greatest for the 2013 planting (31%) and lowest for the 2010 planting (2%) (Figure 52). This trend of increasing survival through the years is probably due to improving soil conditions. No statistical difference was seen in survival for the second growing season. For the third growing season, survival for 2012 (88%) was greater than the survival for 2013 (53%) which could be due to the moderate drought in 2015 affecting planting year 2013's third growing season survival. For the fourth growing season survival was highest for 2010 (100%), however the 2010 planting year only had two plants remaining. For the fifth growing season survival was highest for 2010 (50%), however the 2010 planting year only had two plants remaining. For the sixth growing season survival was highest for 2010 (100%), however the 2010 planting year only had one plant remaining.

Sand live oak vigor varied among planting years for the first 3 growing seasons (Figure 53). The 2013 planting year had the most robust plants (lowest vigor index) for the first growing season (6 months). The 2010 planting year had the least robust plants (greatest vigor index) for the second growing season (1.5 years). The 2012 planting year had the most robust plants (lowest vigor index) for the third growing season (2.5 years). No differences for vigor were detected among the planting years for the fourth growing season (3.5 years). For the fifth growing season (4.5 years) and sixth growing season (5.5 years), no differences for vigor were detected among the planting years.

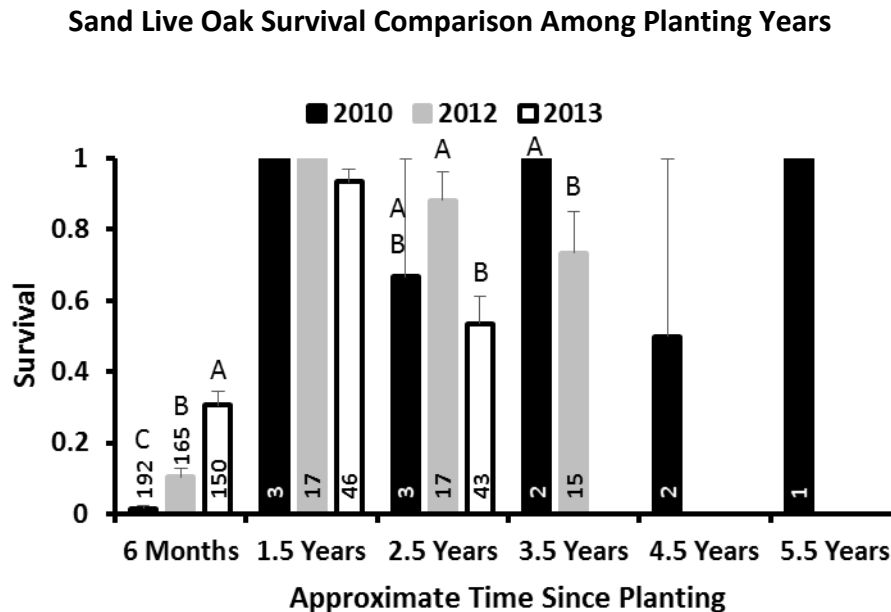


Figure 52 Mean (\pm SE) Sand Live Oak Survival for each sample period for the 2010, 2012, and 2013 plantings. Means within a sample period that are marked with a different letter are not similar. Numbers inside of each column represent the number of trees used to calculate the mean value.

Sand Live Oak Vigor Comparison Among Planting Years

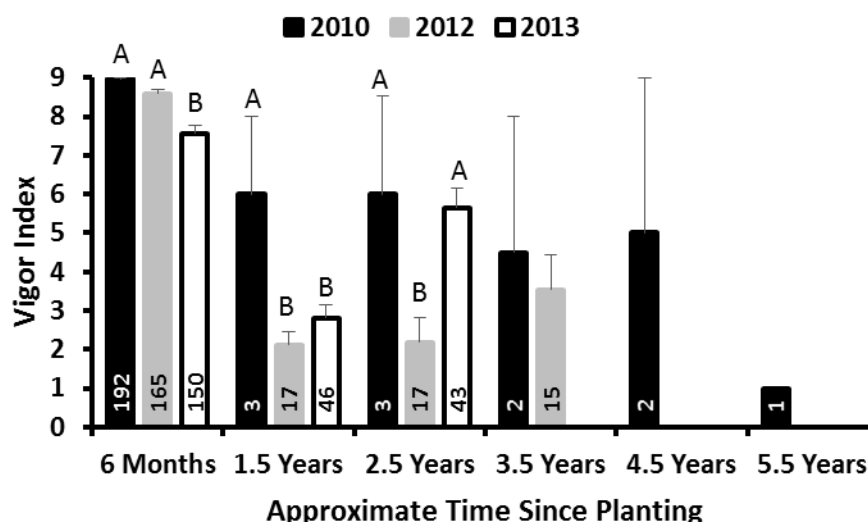


Figure 53 Mean (\pm SE) Sand Live Oak Vigor for each sample period for the 2010, 2012, and 2013 plantings. Means within a sample period that are marked with a different letter are not similar. Numbers inside of each column represent the number of trees used to calculate the mean value.

5.5 Survival by Orientation

Based on field observations that appeared to show better survival for woody seedlings planted on the south side versus the north side of the Far Ridge, we analyzed seedlings by row positions for the 3 species (hackberry, live oak, and sand live oak) planted at least 3 times in the experimentally designed block plantings for differences in survival. Because the 2010 and 2013 planting years planting area spanned across both the narrower western end of the Far Ridge and the wider eastern section of the Far Ridge, with the narrower western section exhibiting higher soil erosion within the planting blocks than in the wider eastern section of the Far Ridge, it was decided to analyze them separately.

Two planting years, 2010 and 2013, had a portion of the planting area located on the narrower western end. This narrower western end section of the Far Ridge visually exhibited more soil erosion than the wider eastern end section of the Far Ridge. Both sections exhibited considerably more soil erosion off the north side of the ridge compared to the south side. Plants planted on the north side of the ridge were compared to plants planted on the south side of the ridge for survival for the first two growing seasons.

For block planting years 2010 and 2013, a portion of the plantings experimental rectangular blocks were oriented with the long side horizontal (west to east) resulting in four rows with 8 plants in each row and another portion was oriented with the long side vertically (south to

north) resulting in 8 rows with 4 plants in each row. These block orientations were necessary because of the topography of the planting site. The 4-rowed horizontal blocks were the result of the narrower ridge on the western end of the Far Ridge that had to be oriented with the longer side west to east in order to fit in this section. The 8-rowed vertical blocks were the result of the wider eastern section of the Ridge being able to accommodate the long side of the rectangle south to north across the top of the ridge. Because of the different topography, 4-row blocks were analyzed separately from 8-row blocks. Block planting years 2011, 2012, and 2014 were only located on the wider eastern section of the Far Ridge, so they were oriented vertically with the long side of the rectangle south to north. These plantings then were only analyzed with 8-row blocks.

Initial construction design of the Far Ridge had a high point in the center of the ridge that sloped off in two directions to the north and to the south. Horizontal and vertical block plots had equal amount of rows on the north side of the ridge and on the south side of the ridge. Therefore, the horizontal blocks had 2 rows on the north side of the ridge and 2 on the south side. The vertical blocks had 4 rows on the north side of the ridge and 4 rows on the south side of the ridge. The north side rows and the south side rows were then compared for survival as shown in the figures below (Figures 54 & 55).

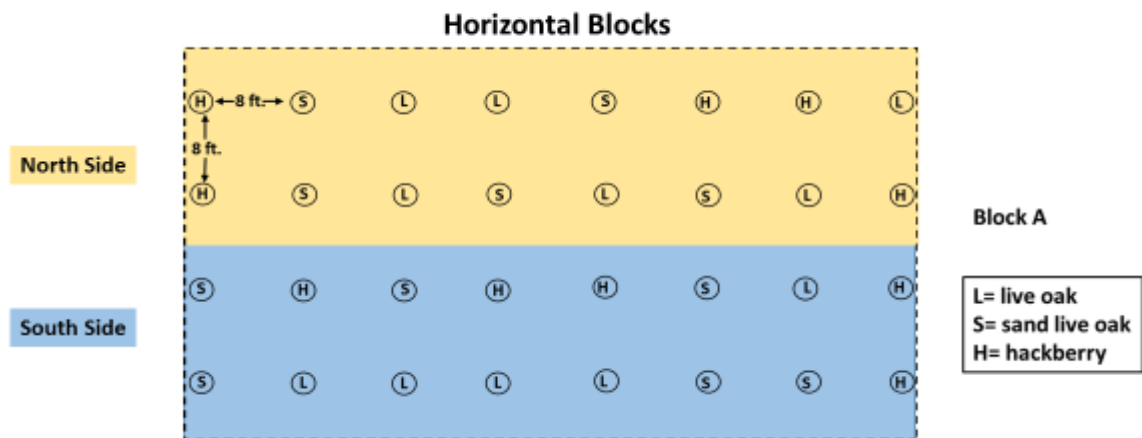


Figure 54 Example diagram of planting layout for horizontal blocks on ridge. Horizontal blocks compared plant survival for the two rows (8 plants each row) on the north side of the ridge versus plant survival for the two rows (8 plants each row) on the south side of the ridge.

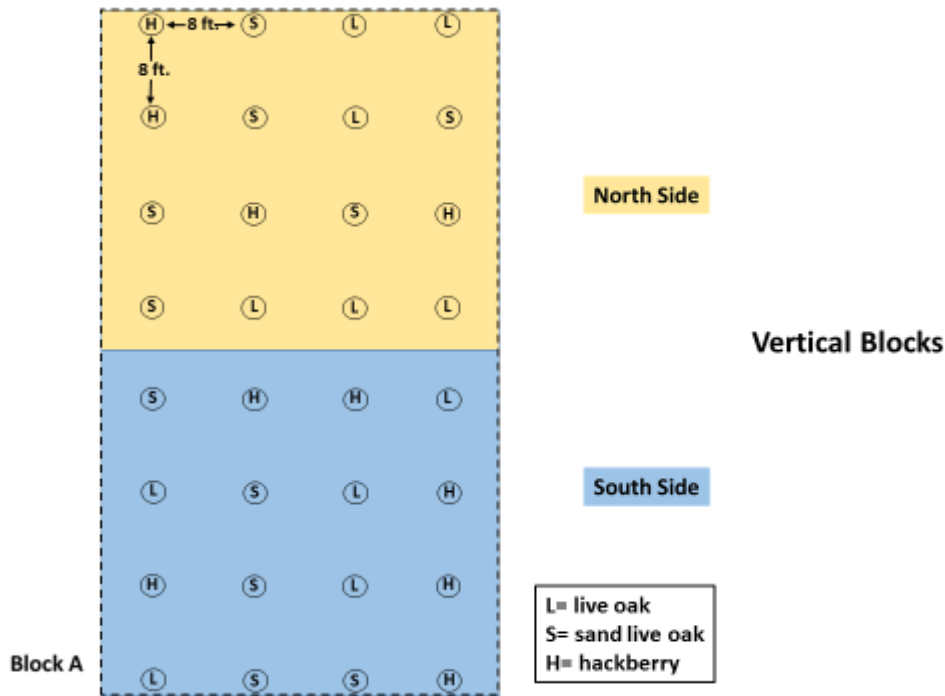


Figure 55 Example diagram of planting layout for vertical blocks on ridge. Vertical blocks compared plant survival for the four rows (4 plants each row) on the north side of the ridge versus plant survival for the four rows (4 plants each row) on the south side of the ridge.

5.5.1 Survival by Orientation – Far Ridge: Narrow Section

This section of the ridge was not of sufficient width on the top or crown to orient the planting blocks with the long side of the rectangle south to north, so these first 7 blocks were oriented with the long side of the rectangle west to east, resulting in 4 rows (west to east) of 8 plants in each row. The plants in the two northernmost rows were compared to the plants in the two southernmost rows for survival over the first two growing seasons.

5.5.1.1 2010 Survival by Orientation – Far Ridge: Narrow Section

The 2010 planting year utilized two species we analyzed for survival by orientation on the narrower section of the Far Ridge: hackberry and sand live oak. There was no significant difference in survival for hackberry seedlings between the south and north orientations for either the first or second growing seasons (Figure 56). Approximately a year and a half post-construction of the ridge, soil conditions were still poor at the time of planting resulting in low survival after the first growing season for plants in both orientations (15% south vs. 16% north). Only the south side orientation had any survivors (14%) by the end of the second growing season.

Sand live oak survival exhibited no significant difference between the north and south orientations for either the first or second growing seasons (Figure 57). All but one sand live oak seedling on the north orientation died by the end of the first growing season. Approximately a year and a half post-construction of the ridge, soil conditions were still poor at the time of planting resulting in low survival after the first growing season for plants in both orientations.

2010 Hackberry Survival by Orientation - Far Ridge: Narrow Section

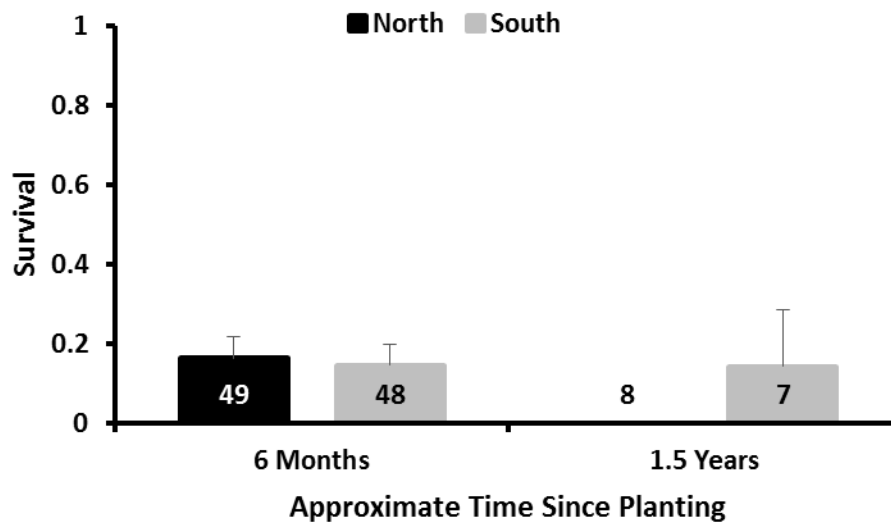


Figure 56 Mean (\pm SE) survival for Hackberry planted in 2010 in a horizontal block and sampled 6 months and 1.5 years after planting for each orientation. Means within each sample period are similar but only the South side had survivors by 1.5 years. The number at the base of each column represents the number of individuals used to calculate the mean value.

2010 Sand Live Oak Survival by Orientation - Far Ridge: Narrow Section

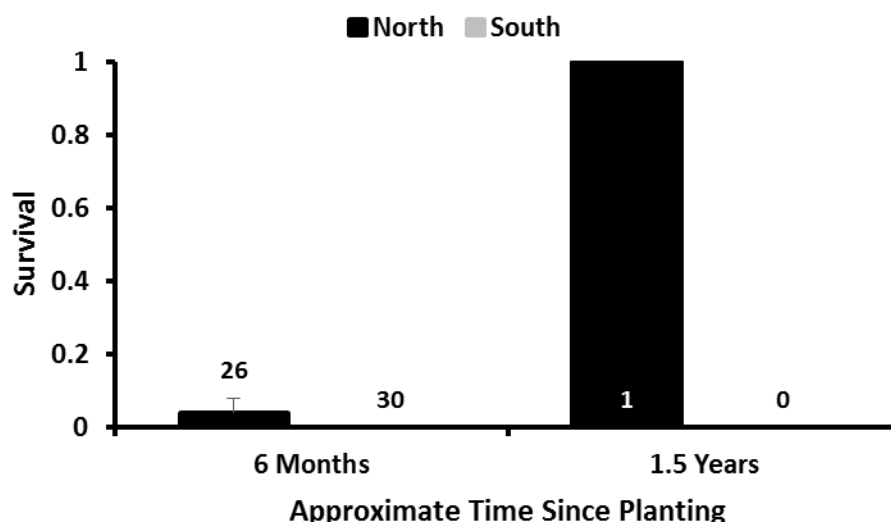


Figure 57 Mean (\pm SE) survival for Sand Live Oak planted in 2010 in a horizontal block and sampled 6 months and 1.5 years after planting for each orientation. No Sand Live Oak planted on the South side survived to 6 months. The number at the base of each column represents the number of individuals used to calculate the mean value.

5.5.1.2 2013 Survival by Orientation – Far Ridge: Narrow Section

The 2013 planting year utilized three species we analyzed for survival by orientation on the narrower section of the Far Ridge: hackberry, live oak, and sand live oak. Hackberry survival in the two rows on the south side of the Far Ridge was significantly greater (59%) than survival of hackberry seedlings planted in the two rows on the north side of the Far Ridge (33%) at the end of the first growing season (Figure 58). No significant difference was seen in survival of hackberry seedlings in the second growing season.

Live oak survival for the south oriented seedlings was significantly greater (66%) than the survival of the live oaks planted on the north side (21%) at the end of the first growing season (Figure 59). There was no difference at the end of the second growing season.

Sand live oak survival for the south oriented seedlings was significantly greater (42%) than the survival of the sand live oaks planted on the north side (14%) at the end of the first growing season (Figure 60). There was no difference at the end of the second growing season.

Survival was significantly greater for all 3 species of plants planted on the south side compared to the north side after the first growing season. The greater survival for the south side orientation is probably mostly due to less soil erosion around the plants and also to greater soil moisture retention in the rooting zone. No significant difference was seen in survival of any of

the 3 species planted at the end of the second growing season as all species at both orientations had survival in excess of 80%. No difference in survival between orientations at the end of the second growing season is probably due to advantages of the plants already being established and rooted in place from the first growing season.

2013 Hackberry Survival by Orientation - Far Ridge: Narrow Section

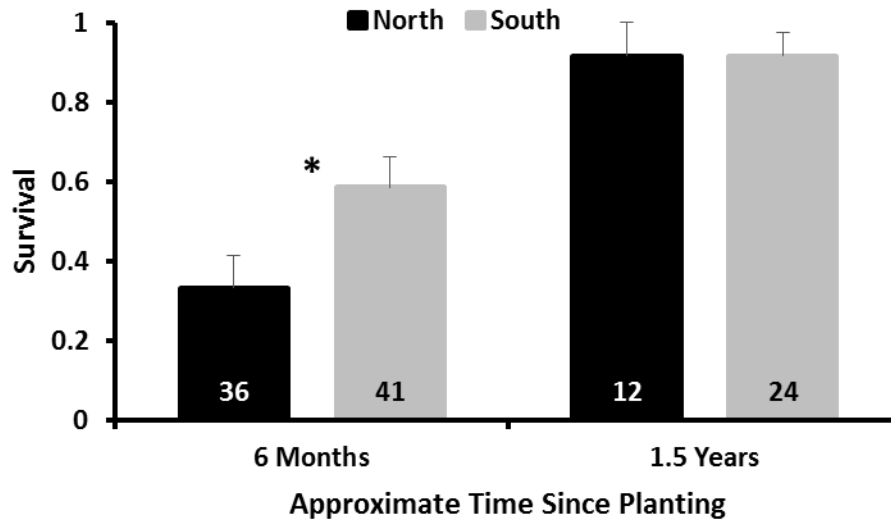


Figure 58 Mean (\pm SE) survival for Hackberry planted in 2013 in a horizontal block and sampled 6 months and 1.5 years after planting for each orientation. The asterisk indicates a difference in survival between the two locations within each time period. The number at the base of each column represents the number of individuals used to calculate the mean value.

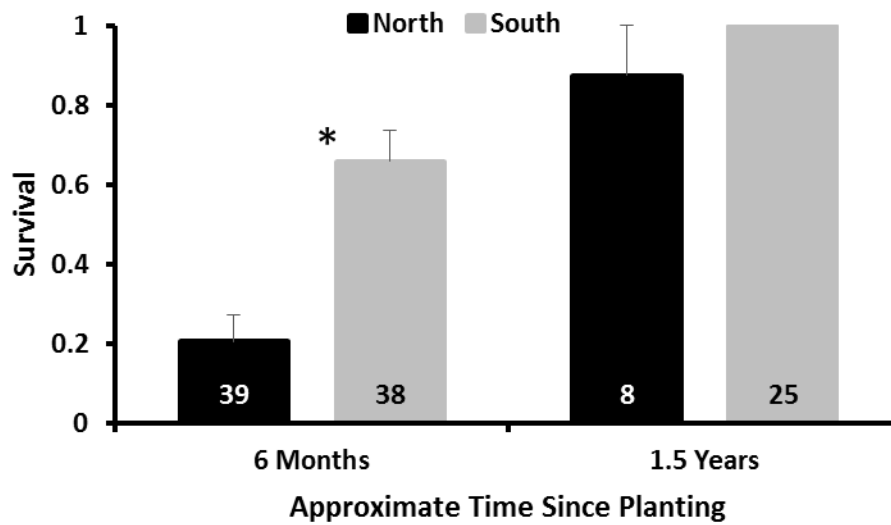
2013 Live Oak Survival by Orientation - Far Ridge: Narrow Section

Figure 59 Mean (\pm SE) survival for Live Oak planted in 2013 in a horizontal block and sampled 6 months and 1.5 years after planting for each orientation. The asterisk indicates a difference in survival between the two locations within each time period. The number at the base of each column represents the number of individuals used to calculate the mean value.

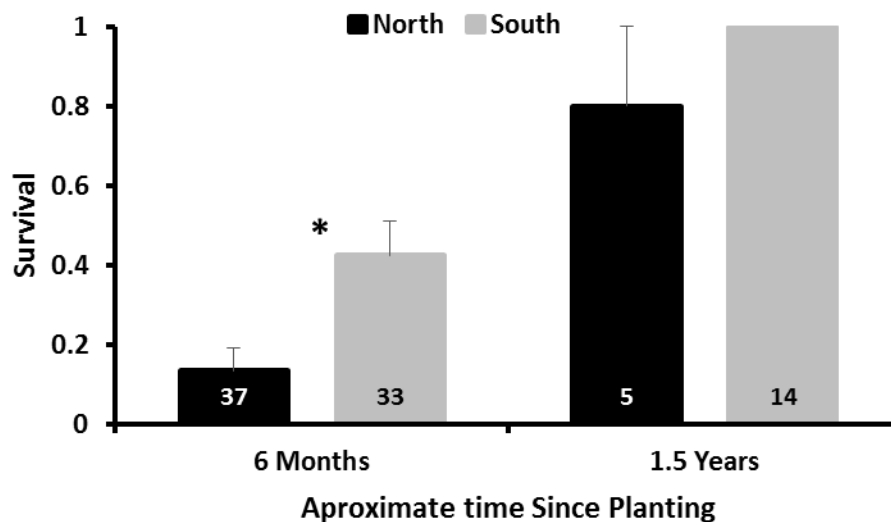
2013 Sand Live Oak Survival by Orientation - Far Ridge: Narrow Section

Figure 60 Mean (\pm SE) survival for Sand Live Oak planted in 2013 in a horizontal block and sampled 6 months and 1.5 years after planting for each orientation. The asterisk indicates a difference in survival between the two locations within each time period. The number at the base of each column represents the number of individuals used to calculate the mean value.

5.5.2 Survival by Orientation – Far Ridge: Wide Section

This section of the ridge was of sufficient width on the top or crown to orient the planting blocks with the long side of the rectangle south to north, resulting in 8 rows (west to east) of 4 plants in each row. The plants from the four northernmost rows were compared to the plants of the four southernmost rows for survival over the first two growing seasons.

5.5.2.1 2010 Survival by Orientation – Far Ridge: Wide Section

The 2010 planting year utilized two species we analyzed for survival by orientation on the wider section of the Far Ridge: hackberry and sand live oak. There was no significant difference in survival for hackberry seedlings between the north and south orientations for the first growing season. Hackberry survival at the end of the first growing season was 26% for the south orientation and 17% for the north orientation (Figure 61). However, survival for hackberry seedlings planted on the south side was significantly greater (55%) than hackberry seedlings planted on the north side (25%) by the end of the second growing season. Poor soil conditions were likely the cause for low survivorship after the first growing season at both orientations. The greater survivorship of hackberry seedlings at the south orientation versus the north orientation was probably due to reduced soil erosion and better soil moisture retention in the planting area of the south orientation.

Sand live oak survival exhibited no significant difference between the north and south orientations for either the first or second growing seasons (Figure 62). Only one sand live oak seedling at each orientation survived till the end of the first growing season making survival for each 1%. Both seedlings remained at the north and south side orientations by the end of the second growing season. Approximately a year and a half post-construction of the ridge, soil conditions were still poor at the time of planting and likely the cause of the mortality of both species.

2010 Hackberry Survival by Orientation - Far Ridge: Wide Section

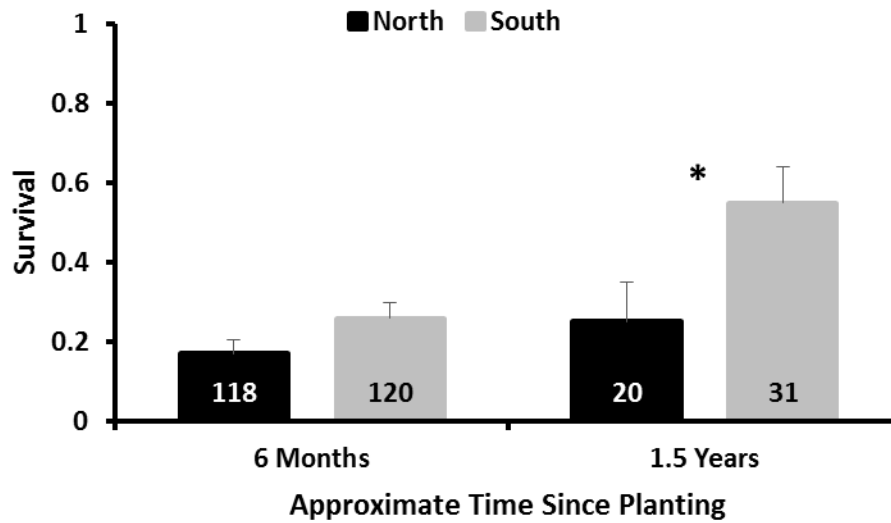


Figure 61 Mean (\pm SE) survival for Hackberry planted in 2010 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. The asterisk indicates a difference in survival between the two locations within each time period. The number at the base of each column represents the number of individuals used to calculate the mean value.

2010 Sand Live Oak Survival by Orientation - Far Ridge: Wide Section

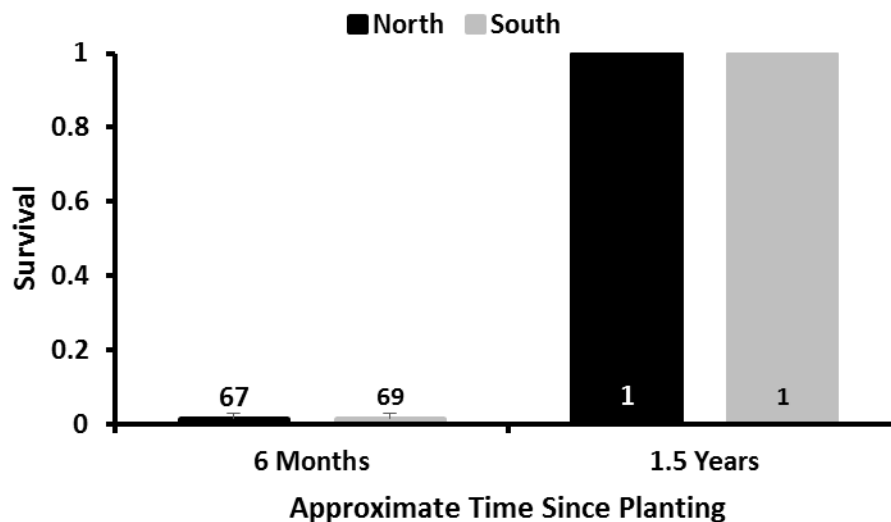


Figure 62 Mean (\pm SE) survival for Sand Live Oak planted in 2010 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. The number at the base of each column represents the number of individuals used to calculate the mean value.

5.5.2.2 2011 Survival by Orientation – Far Ridge: Wide Section

The 2011 planting year utilized two species analyzed for survival by orientation on the wider section of the Far Ridge: hackberry and live oak. There was no significant difference in survival after the first growing season for either hackberry or live oak as almost all of the seedlings at both orientations died (hackberry: south 3% vs, north 0%; live oak: 6% south vs. 2% north) (Figures 63 & 64). The extreme mortality for this planting year for both species is likely due to continued poor soil conditions and to the exceptional drought during the growing season. The few surviving plants from both species all survived to the end of the second growing season, however.

2011 Hackberry Survival by Orientation - Far Ridge: Wide Section

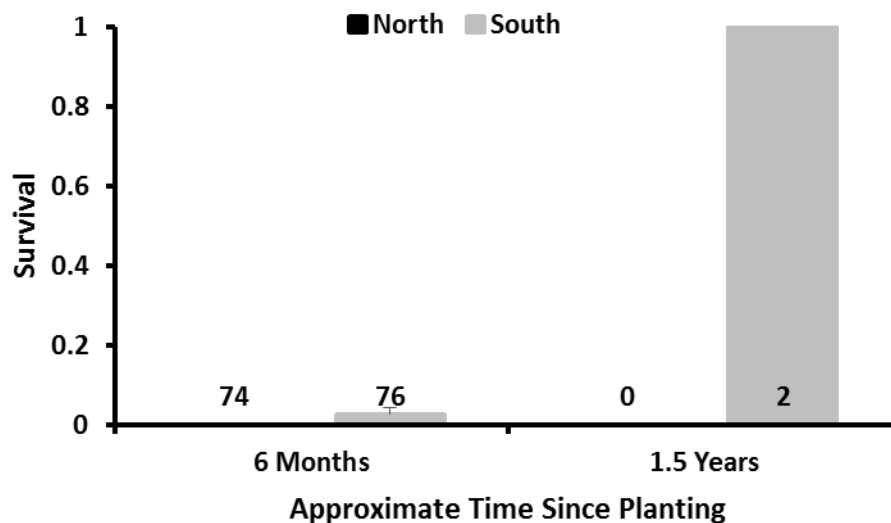


Figure 63 Mean (\pm SE) survival for Hackberry planted in 2011 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. There were no survivors on the North side after 6 months. The number at the base of each column represents the number of individuals used to calculate the mean value.

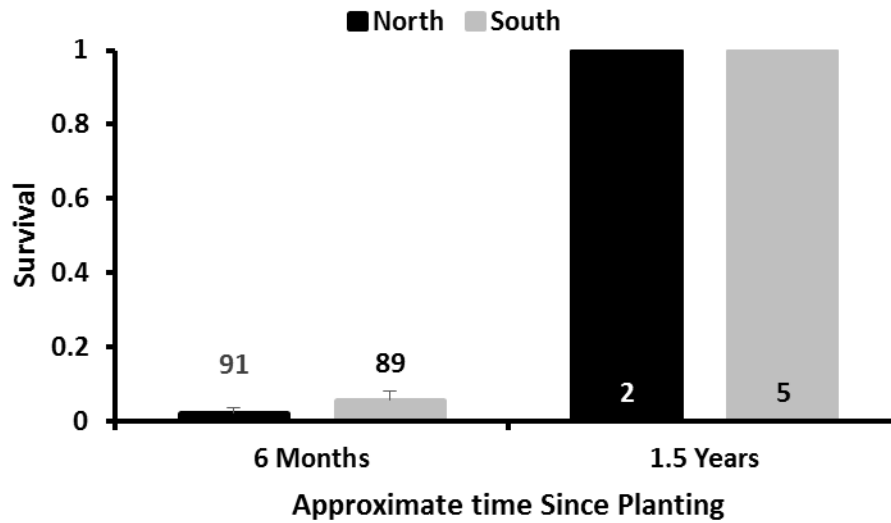
2011 Live Oak Survival by Orientation - Far Ridge: Wide Section

Figure 64 Mean (\pm SE) survival for Live Oak planted in 2011 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. Means within each sample period are similar. The number at the base of each column represents the number of individuals used to calculate the mean value.

5.5.2.3 2012 Survival by Orientation – Far Ridge: Wide Section

The 2012 planting year utilized three species analyzed for survival by orientation on the wider section of the Far Ridge: hackberry, live oak, and sand live oak. Hackberry survival exhibited no significant difference between the north and south orientations for the first or second growing seasons (Figure 65). First growing season survival was 25% for the south orientation and 13% for the north orientation. Survival at the end of the second season was greater than two thirds for both orientations.

Survival of live oak seedlings planted on the south side (32%) of the Far Ridge was significantly greater after the first growing season than live oak seedlings planted on the north side (8%) (Figure 66). There was no significant difference in survival between the north and south orientations after the second growing season with both greater than 85%.

Sand live oak survival of seedlings planted on the south side (18%) of the Far Ridge was significantly greater after the first growing season than sand live oak seedlings planted on the north side (3%) (Figure 67). There was no significant difference in survival between the north and south orientations after the second growing season as they were both 100%.

Although there was no difference in survival between orientations for hackberry, the greater survivorship of live oak and sand live oak seedlings at the south orientation versus the north orientation was probably due to reduced soil erosion and better soil moisture retention in the planting area of the south orientation. And although soil conditions were improving with each passing year, the general poor first season survival of all species was probably due to an extreme drought at the time of the planting and continued poor soil conditions. Rain did follow a couple of weeks after planting, but only enough to reduce it to a moderate drought which then persisted until late July. Established plants fared better for the second growing season with all 3 species survival better than two out of three.

2012 Hackberry Survival by Orientation - Far Ridge: Wide Section

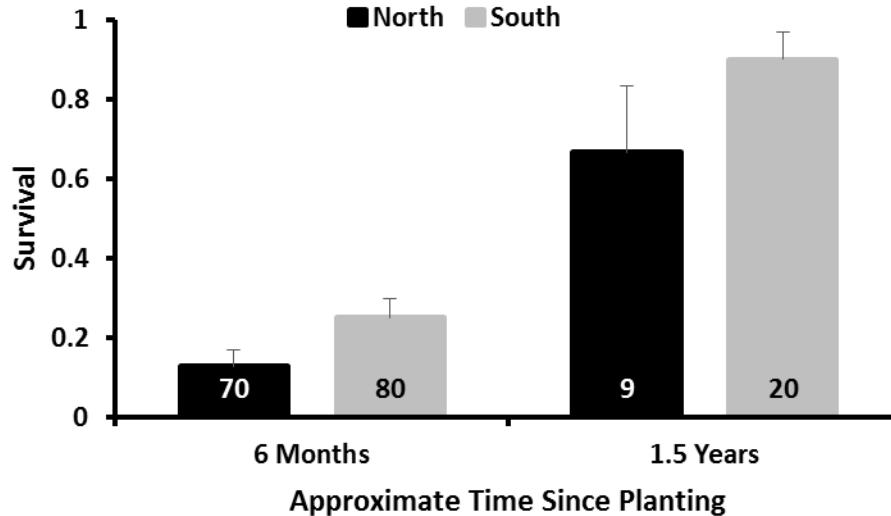


Figure 65 Mean (\pm SE) survival for Hackberry planted in 2012 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. Means within each sample period are similar. The number at the base of each column represents the number of individuals used to calculate the mean value.

2012 Live Oak Survival by Orientation - Far Ridge: Wide Section

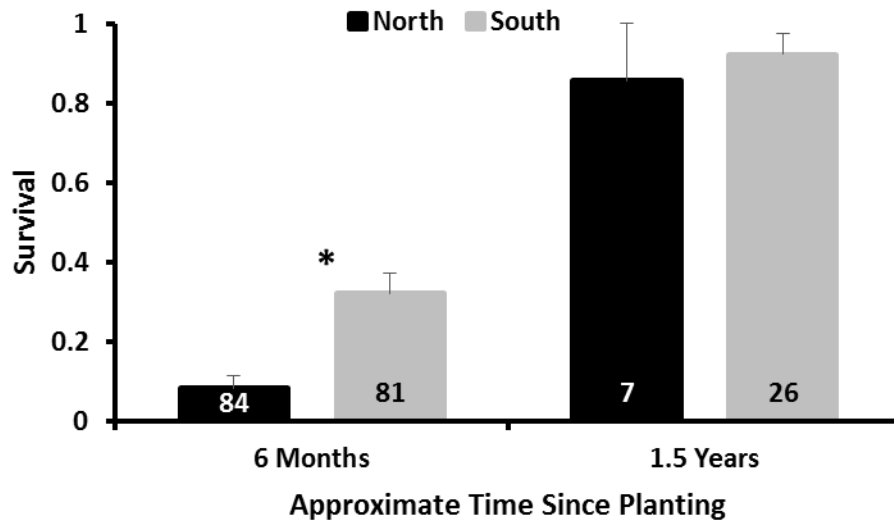


Figure 66 Mean (\pm SE) survival for Live Oak planted in 2012 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. The asterisk indicates a difference in survival between the two orientations within each time period. The number at the base of each column represents the number of individuals used to calculate the mean value.

2012 Sand Live Oak Survival by Orientation - Far Ridge: Wide Section

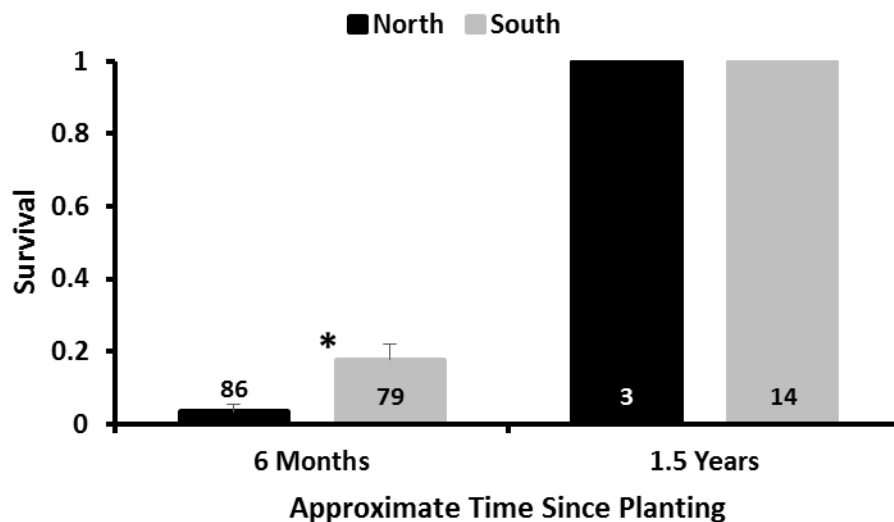


Figure 67 Mean (\pm SE) survival for Sand Live Oak planted in 2012 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. The asterisk indicates a difference in survival between the two locations within each time period. The number at the base of each column represents the number of individuals used to calculate the mean value.

5.5.2.4 2013 Survival by Orientation – Far Ridge: Wide Section

The 2013 planting year utilized three species analyzed for survival by orientation on the wider section of the Far Ridge: hackberry, live oak, and sand live oak. Hackberry survival exhibited no significant difference between the north and south orientations for the first growing season (72% south vs. 69% north) (Figure 68). However, survival of hackberry seedlings on the north side (93%) was significantly greater than the seedlings located on the south side (70%) after the second growing season. This instance of the north orientation's survival being significantly greater after the second growing season than the south side's orientation is the only instance through all the planting years for either growing season.

There was no significant difference in live oak survival between orientations for the first (63% south vs. 71% north) or second growing seasons (96% south vs. 94% north) (Figure 69).

There was also no significant difference in sand live oak survival between orientations for the first (28% south vs. 39% north) or second growing seasons (91% south vs. 94% north) (Figure 70).

First year survival for all 3 species improved significantly from previous year's plantings. Survival for hackberry and live oak both exceeded 50% for the first time and at both orientations. Sand live oak survival, although improved, did not exceed 50% at either orientation. The absence of a difference in survival at orientations for the first growing season across all species could be due to a reduction of soil erosion off the north side as the slope begins to level off, the absence of a drought and improved soil quality.

2013 Hackberry Survival by Orientation - Far Ridge: Wide Section

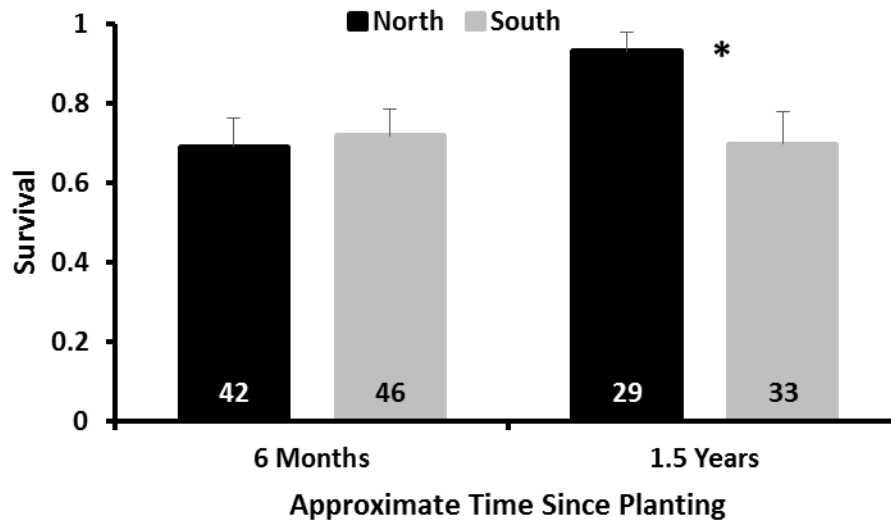


Figure 68 Mean (\pm SE) survival for Hackberry planted in 2013 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. The asterisk indicates a difference in survival between the two locations within each time period. The number at the base of each column represents the number of individuals used to calculate the mean value.

2013 Live Oak Survival by Orientation - Far Ridge: Wide Section

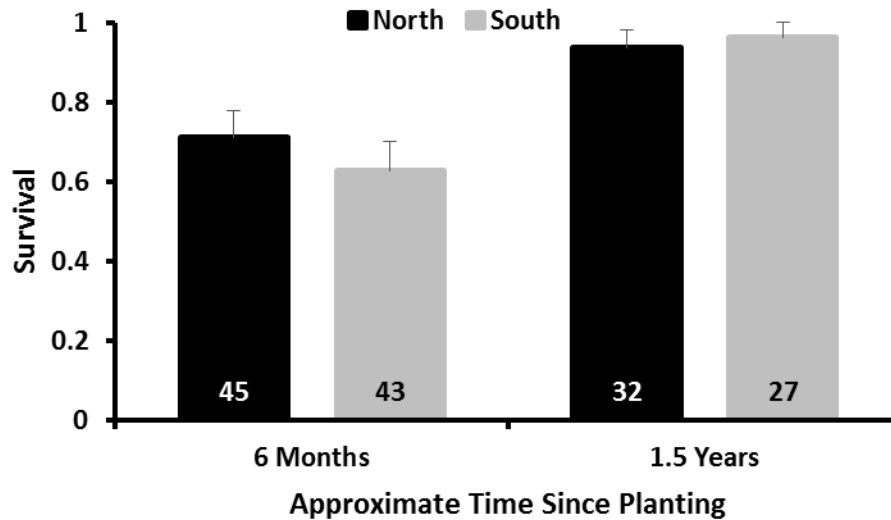


Figure 69 Mean (\pm SE) survival for Live Oak planted in 2013 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. Means within each sample period are similar. The number at the base of each column represents the number of individuals used to calculate the mean value.

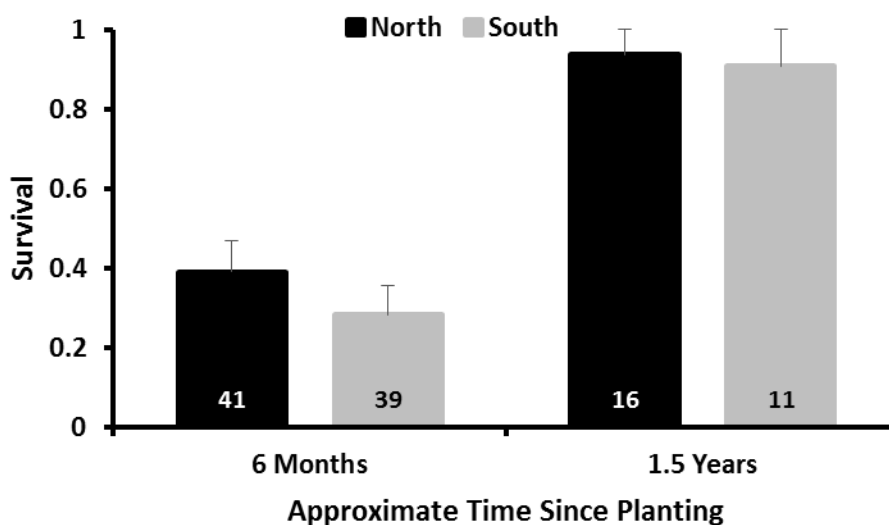
2013 Sand Live Oak Survival by Orientation - Far Ridge: Wide Section

Figure 70 Mean (\pm SE) survival for Sand Live Oak planted in 2013 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. The number at the base of each column represents the number of individuals used to calculate the mean value. All means for each sample period were statistically similar.

5.5.2.5 2014 Survival by Orientation – Far Ridge: Wide Section

The 2014 planting year analyzed only live oak seedlings for survival by orientation on the wider section of the Far Ridge. Live oak survival was significantly greater in the south orientation (80%) versus the north orientation (63%) for the first growing season (Figure 71). There was no significant difference between orientations for the second growing season (80% for both). The 2014 planting year was the highest overall survival for live oak and the highest survival for orientation (south) of all the planting years with live oak. Increase in plant survival was directly related to a decrease in sodium in the soil rooting zone, improved soil conditions, adequate fresh water, and absence of drought.

2014 Live Oak Survival by Orientation - Far Ridge: Wide Section

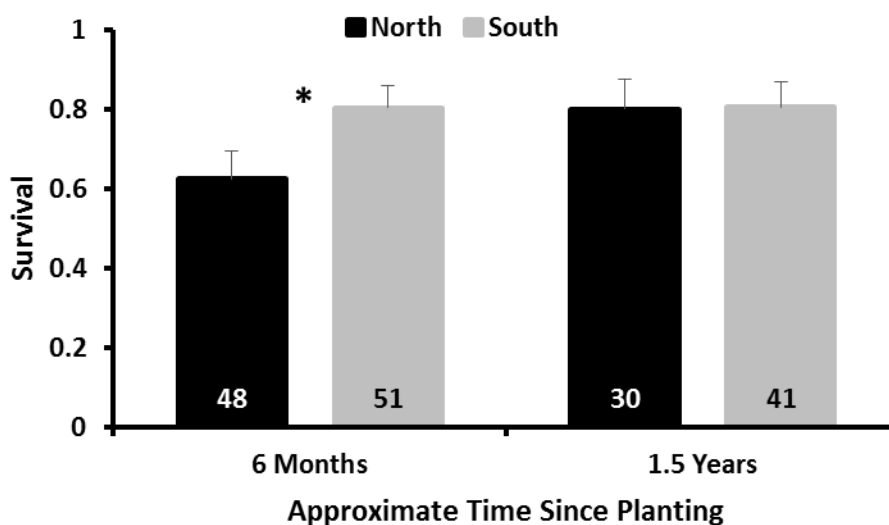


Figure 71 Mean (\pm SE) survival for Live Oak planted in 2014 in a vertical block and sampled 6 months and 1.5 years after planting for each orientation. Means within each sample period are similar. The number at the base of each column represents the number of individuals used to calculate the mean value.

5.6 Soil Quality

We compared Electrical Conductivity (EC), Soluble Salts (Salts), Sodium (Na), Sodium Adsorption Ratio (SAR), and Cation Exchange Capacity (CEC) on the Far Ridge among sample years with ANOVA and Regression (Figures 72-81) using a mean of all 15 soil samples collected from the top of the Far Ridge. Using the mean gave a better representation of the soil across the ridge overall as a single value, similar to a composite sample, however, there was considerable variation in the results among the 15 sample locations across the top of the Far Ridge. For comparison of the individual sampling locations see Appendix 2.

None of the variables showed a significant difference among years, but all 5 variables had a significant decreasing trend over time based on regression analysis. This decreasing trend indicates that the sodium in the rooting zone of the ridge is being leached and transported out of the rooting zone, leading to improved qualities in chemical and physical properties of the soil for plants. As a result, soil quality on the Far Ridge is improving over time.

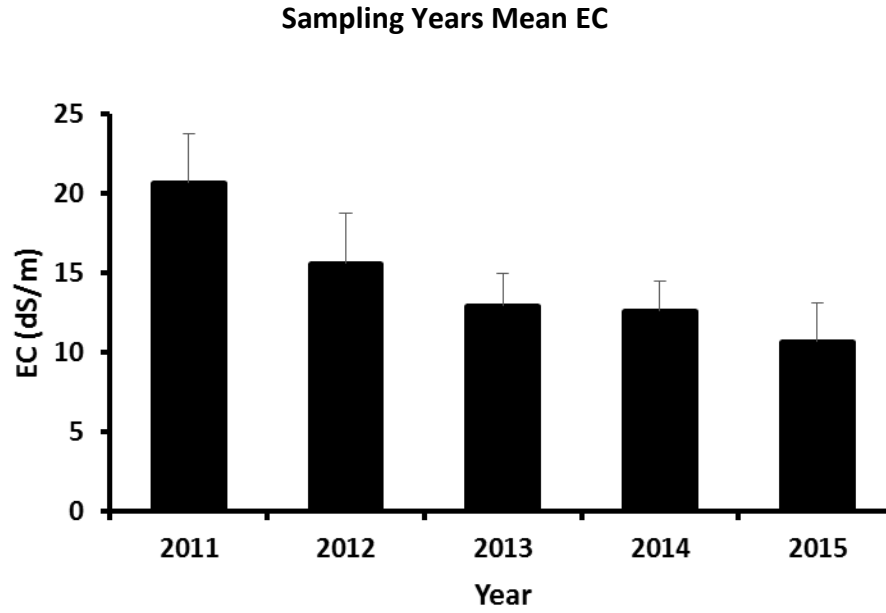


Figure 72 Mean (\pm SE) EC on the Far Ridge for each year. Means that share a similar letter are not different.

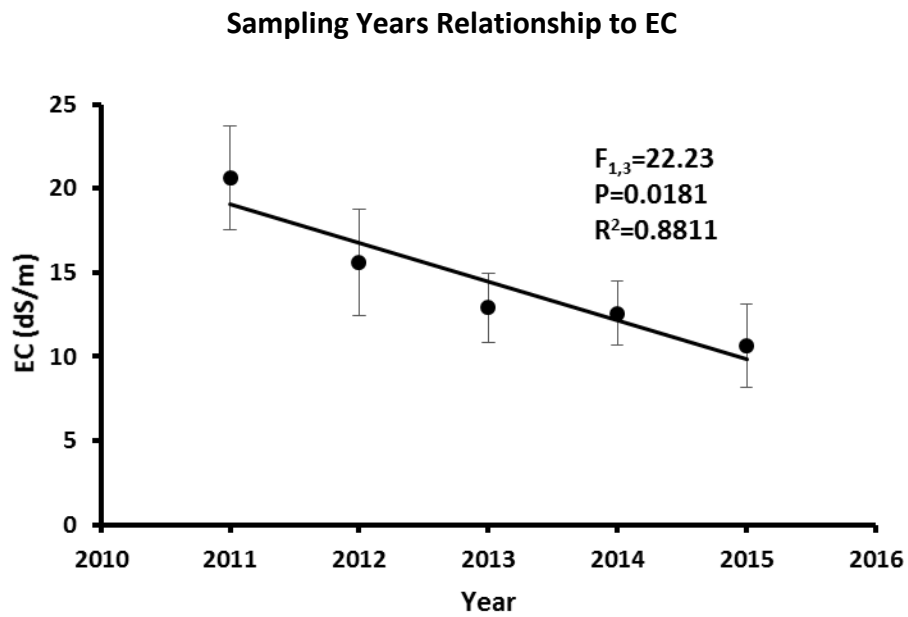


Figure 73 Relationship between EC (\pm SE) and sample year for the Far Ridge.

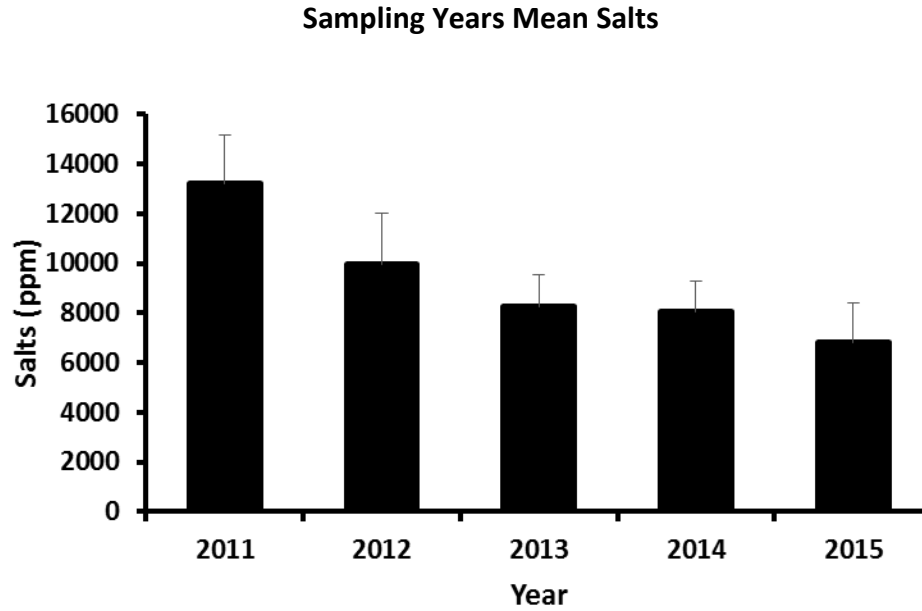


Figure 74 Mean (\pm SE) Salts on the Far Ridge for each year. No differences were detected among years.

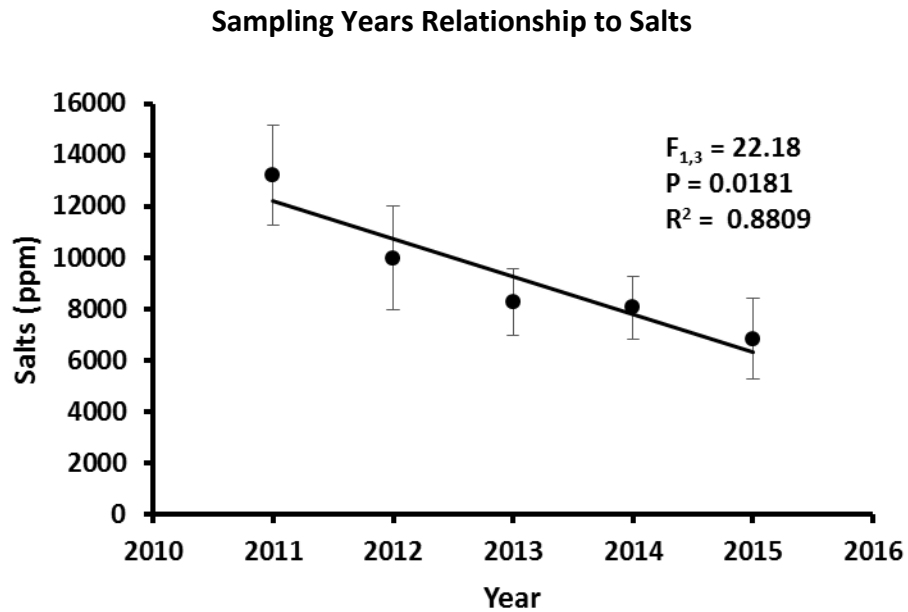


Figure 75 Relationship between Salts (\pm SE) and sample year for the Far Ridge.

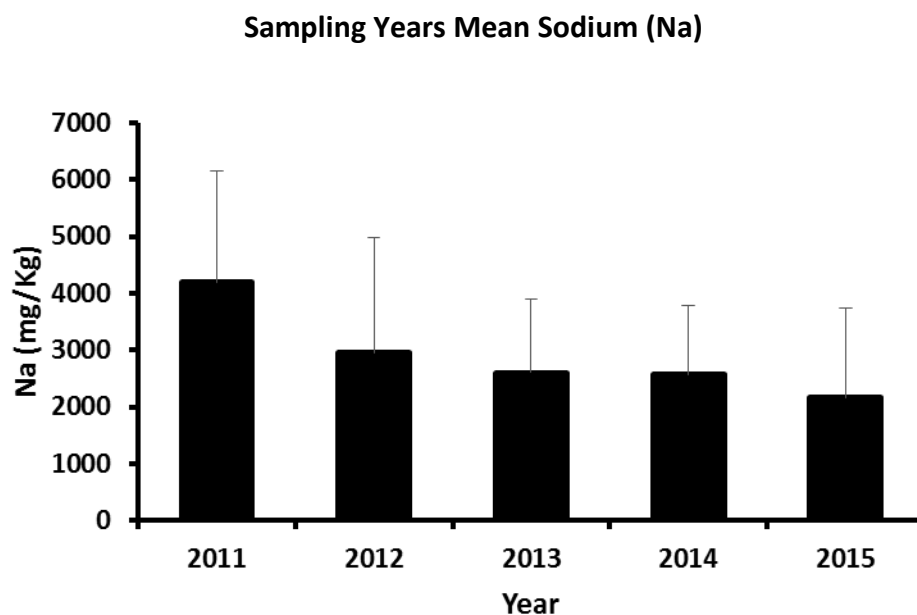


Figure 76 Mean (\pm SE) Na on the Far Ridge for each year. No differences were detected among years.

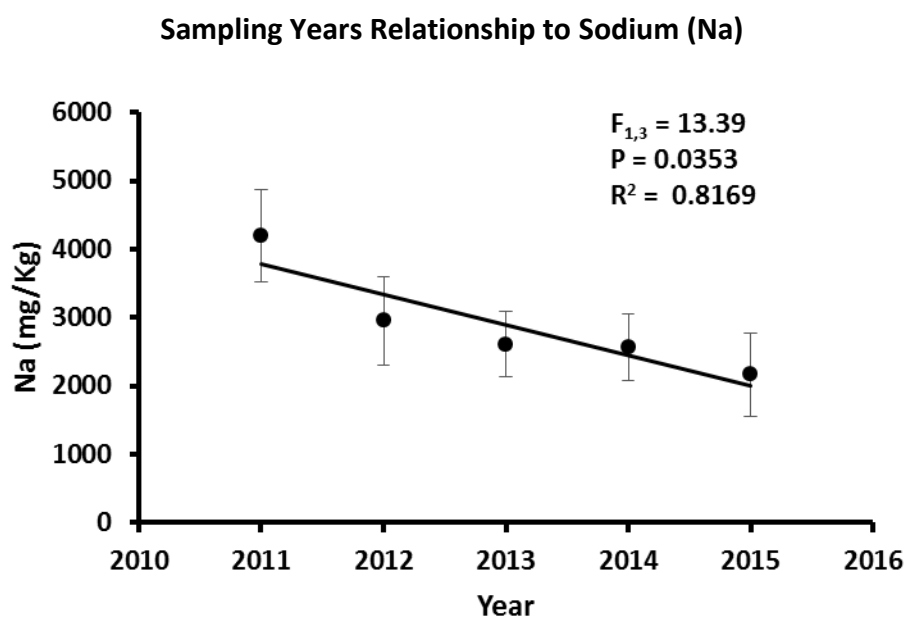


Figure 77 Relationship between Na (\pm SE) and sample year for the Far Ridge.

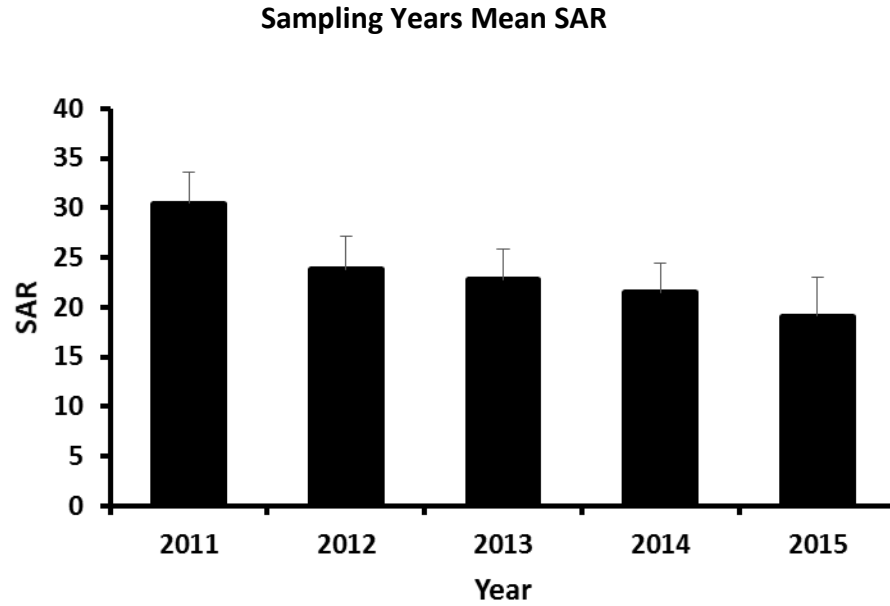


Figure 78 Mean (\pm SE) SAR on the Far Ridge for each year. No differences were detected among years.

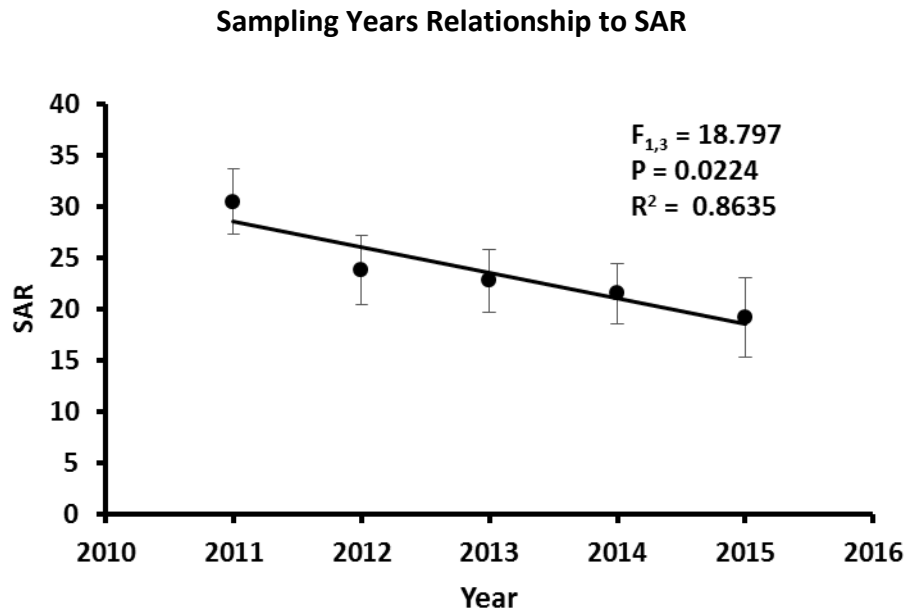


Figure 79 Relationship between SAR (\pm SE) and sample year for the Far Ridge.

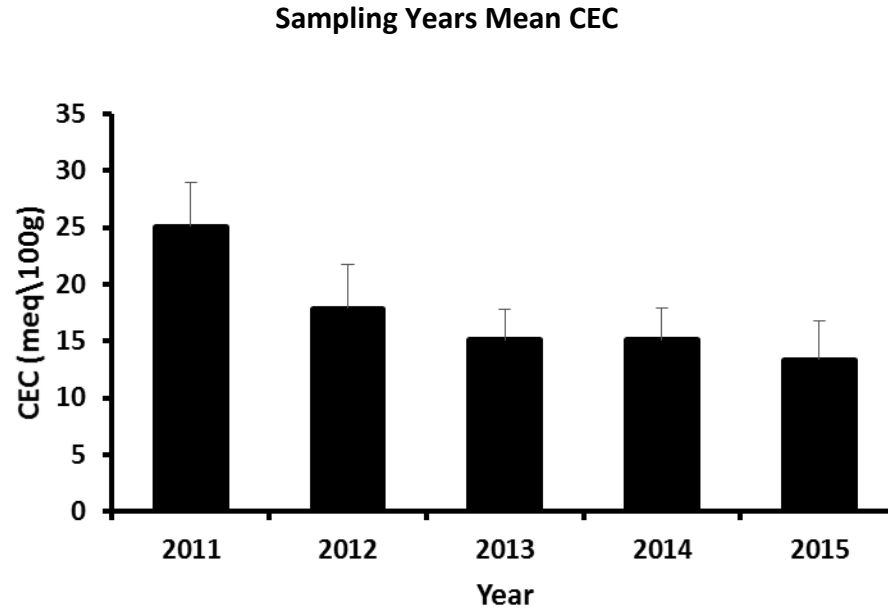


Figure 80 Mean (\pm SE) CEC on the Far Ridge for each year. No differences were detected among years.

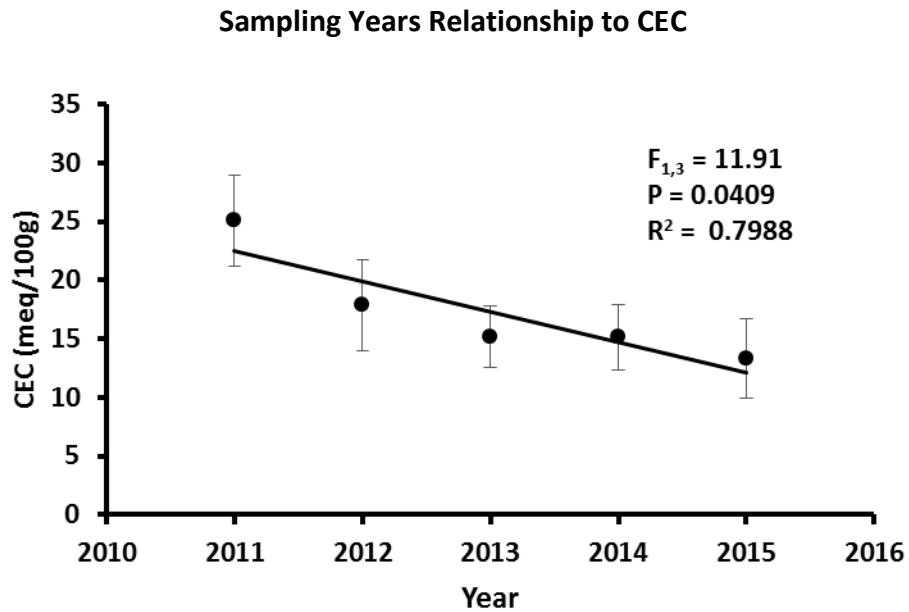


Figure 81 Relationship between CEC (\pm SE) and sample year for the Far Ridge.

5.7 First Growing Season Survival and Soil Quality

The most evident characteristic describing successful establishment of woody vegetation on a newly created ridge appears to be survival during the first growing season. Live oak, sand live oak, and hackberry were the only species planted multiple years and therefore allow an assessment of first growing season survival compared to soil quality over time. Although survival during the first growing season varied among the three species for some planting years, it appears that soil quality had a similar effect on survival for all three species (Figures 82-86). All five soil quality variables (EC, Salts, Na, SAR, and CEC) were highly variable within each year, but demonstrated a decreasing trend in values over time. The decreasing level of all five soil quality variables was significantly related to the increase in first growing season survival over time for hackberry, live oak, and sand live oak. In addition, all three species' survival tended to group close to each other for each year, indicating that soil quality had a similar effect on survival across all species.

We used an exponential regression curve to provide a best fit for a comparison of hackberry and live oak species to the five soil parameters. With the exponential regression curve, each of the five parameters had very high R-square values indicating that each one explained almost all of the variability in survival. The exponential relationship then can be used to predict survival for these species at known soil quality parameter values.

Therefore, it appears that first growing season survival is directly related to soil quality and the soil quality should be assessed prior to planting on future created ridges to ensure a hospitable environment for newly planted woody species. Although all 5 soil quality variables had a significant relationship to survival, EC and Salts have the highest correlations to survival and, as a result, are the best predictors of vegetative survival.

Results from the linear regression and the exponential regression for first growing season survival and soil quality are discussed in the following sections (5.7.1 & 5.7.2).

5.7.1 First Growing Season Survival and Soil Quality: Linear Regression

Regression analysis was used to assess the relationship between first growing season survival for hackberry, live oak, and sand live oak to each of the five soil quality parameters (EC, Salts, Na, SAR, and CEC). LSU Agricultural Center's Soil Testing and Wetland Soil Characterization Laboratories data from October 2011 to October 2015 was used for the five soil quality parameters analysis. The survival of all three species for each year were pooled as a single data base for each regression analysis to assess the survival of woody species in general compared to soil quality.

Each regression analysis indicated an inverse relationship between survival and each soil quality variable (Figures 82-86). Although all three species tended to group by year, sand live oak generally had a lower survival than hackberry and live oak. Out of five soil quality variables, EC and Salts had the highest R^2 values (both at 0.6943) indicating that EC and Salts had the highest influence on survival. (EC and Salts are interchangeable in that Salts are 640 times the EC value and that EC is 640 times less than the Salts value.) SAR had the lowest R^2 (0.5588) indicating the least level of influence on survival.

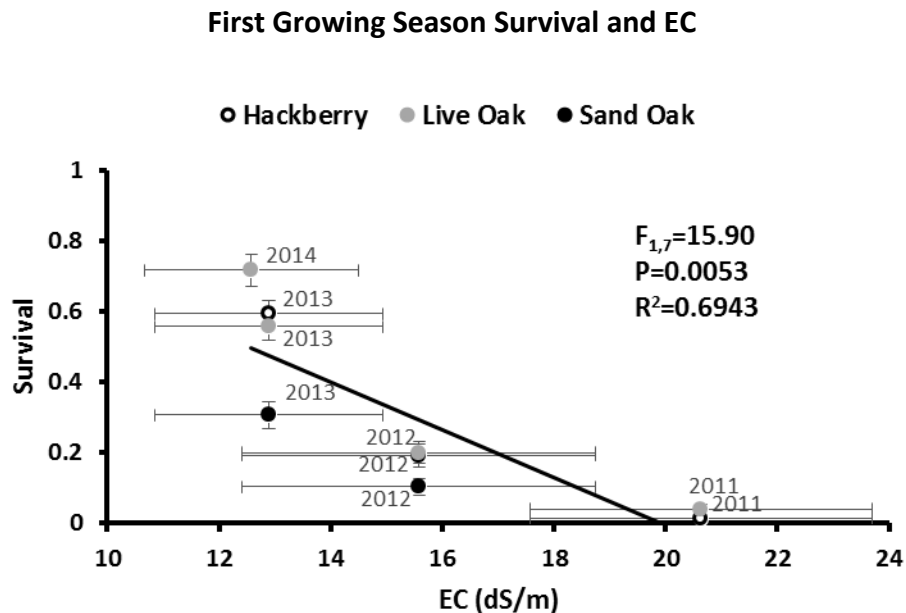


Figure 82 Linear relationship between mean (\pm SE) first growing season Survival of Hackberry, Live Oak, and Sand Live Oak for each planting year and mean (\pm SE) EC for each planting year.

First Growing Season Survival and Salts

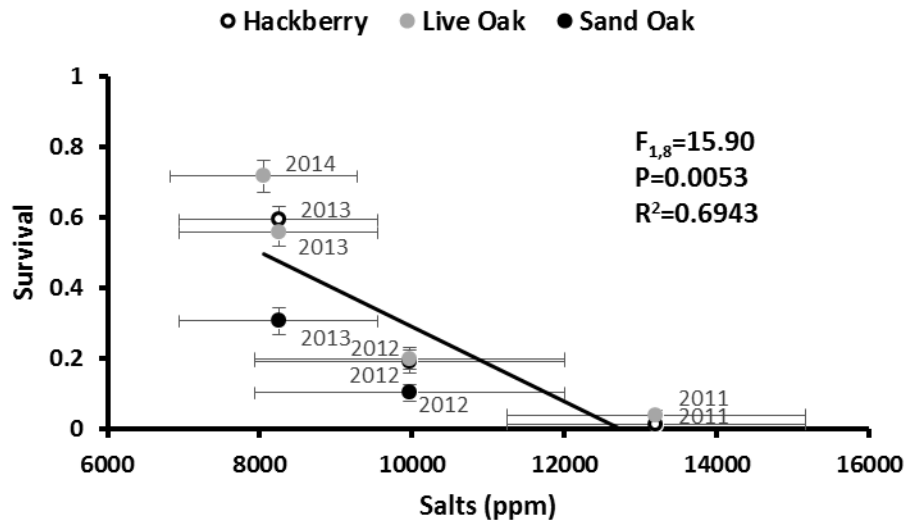


Figure 83 Linear relationship between mean (\pm SE) first growing season Survival of Hackberry, Live Oak, and Sand Live Oak for each planting year and mean (\pm SE) Salts for each planting year.

First Growing Season Survival and Sodium (Na)

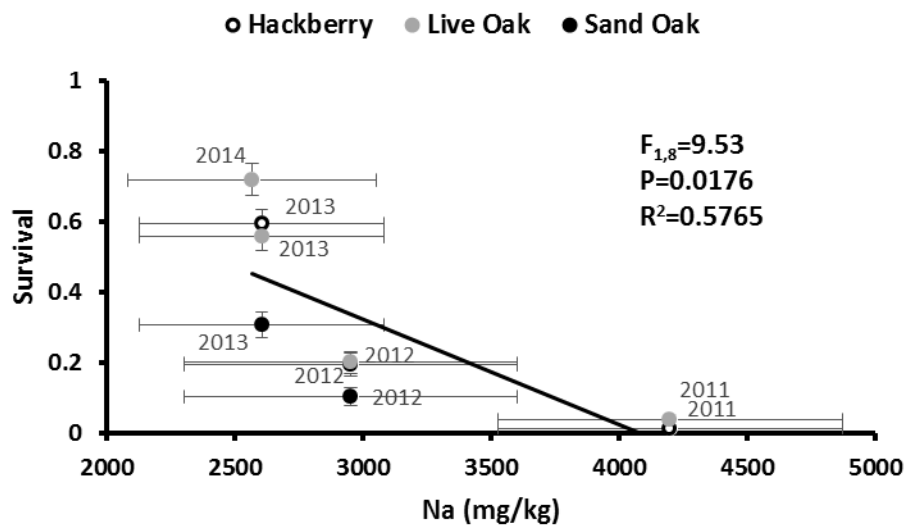


Figure 84 Linear relationship between mean (\pm SE) first growing season Survival of Hackberry, Live Oak, and Sand Live Oak for each planting year and mean (\pm SE) Na for each planting year.

First Growing Season Survival and SAR

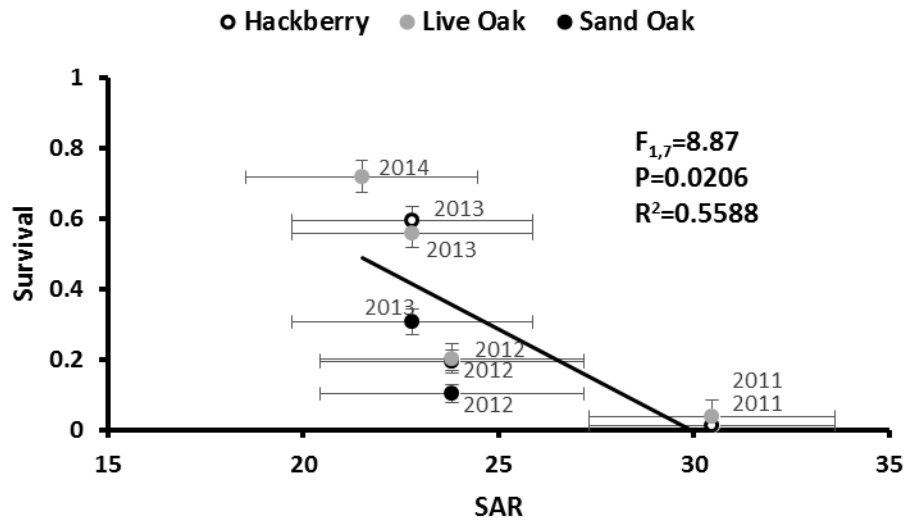


Figure 85 Linear relationship between mean (\pm SE) first growing season Survival of Hackberry, Live Oak, and Sand Live Oak for each planting year and mean (\pm SE) SAR for each planting year.

First Growing Season Survival and CEC

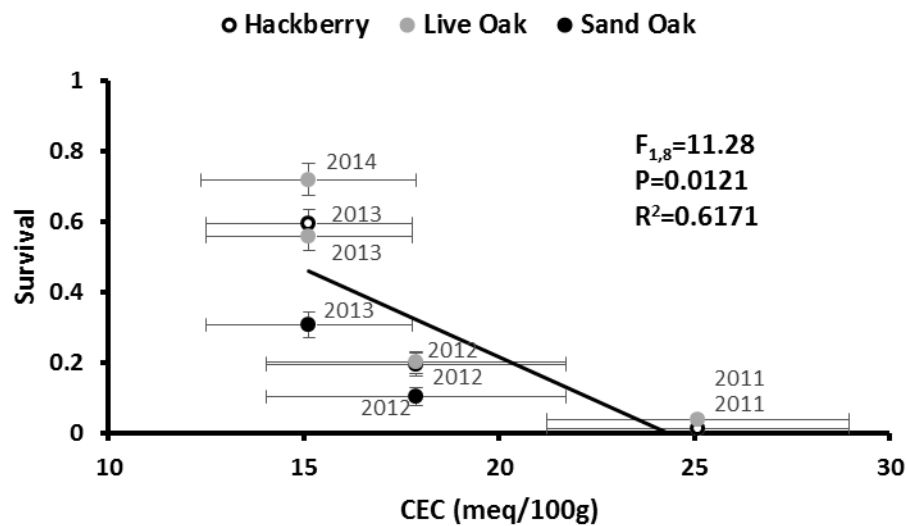


Figure 86 Linear relationship between mean (\pm SE) first growing season Survival of Hackberry, Live Oak, and Sand Live Oak for each planting year and mean (\pm SE) CEC for each planting year.

5.7.2 First Growing Season Survival and Soil Quality: Exponential Regression

To determine the relationship between each soil quality parameter and end of first growing season survival, we used both a simple linear regression and exponential regression models to determine best fit of the survival estimates of Live Oak and Hackberry of each year planted. (Sand live oak was dropped from this regression model as it is expected this species is not likely to be used in future restoration projects similar to this one.) Although the linear regression model revealed a significant relationship between survival and each soil quality parameter, the exponential regression model produced a much higher R-square value than the linear models did (Figures 87-91). Therefore, we used the exponential regression model to estimate the level of each soil quality parameter that would be expected to have 50% survival for Live Oak and Hackberry. All five soil quality variables had very high R^2 values indicating that each of the soil quality variables explained almost all the variability in vegetative survival. Survival for these species, then, can be predicted very well using any of the soil quality variables for these types of restoration sites that use soil from saline sources.

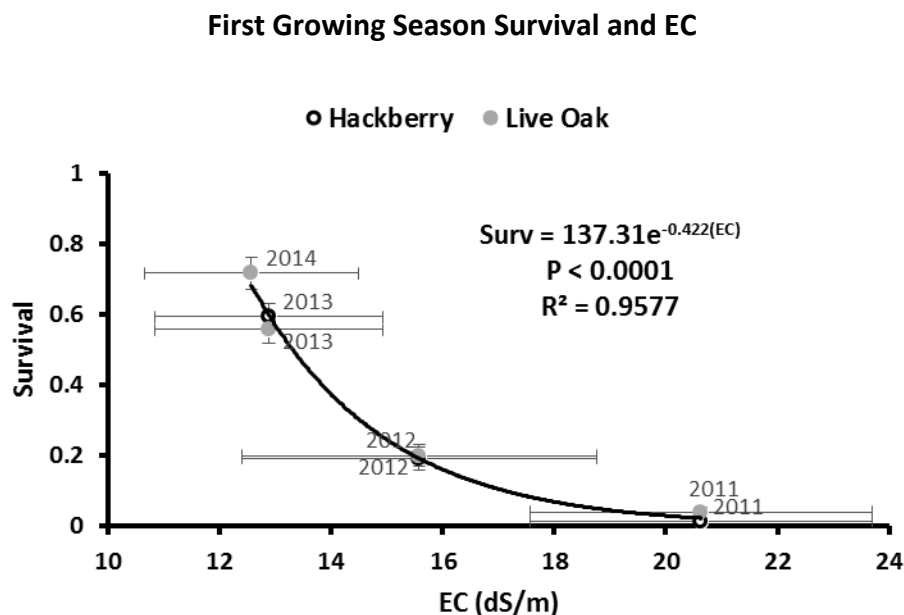


Figure 87 Exponential relationship between first growing season Survival (\pm SE) and EC (\pm SE) for Hackberry and Live Oak combined. The year indicates the year of planting.

First Growing Season Survival and Salts

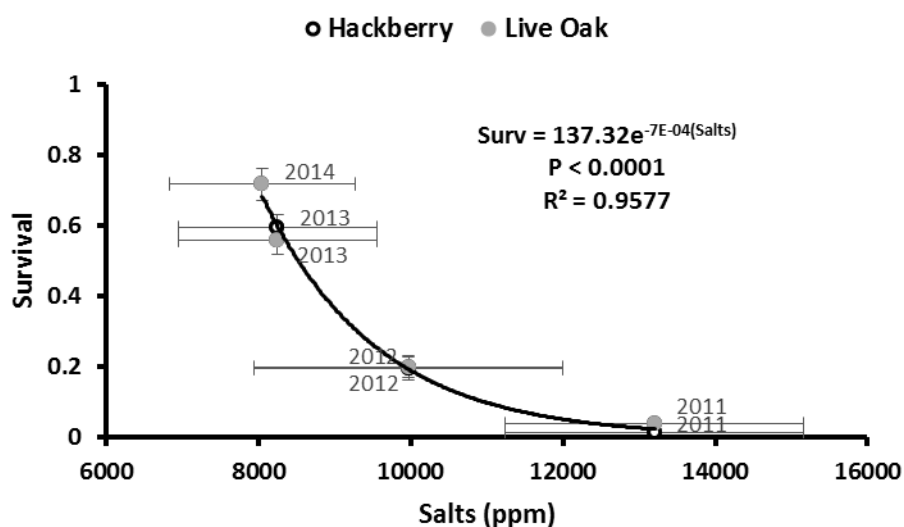


Figure 88 Exponential relationship between first growing season Survival (\pm SE) and Salts (\pm SE) for Hackberry and Live Oak. The year indicates the year of planting.

First Growing Season Survival and Sodium (Na)

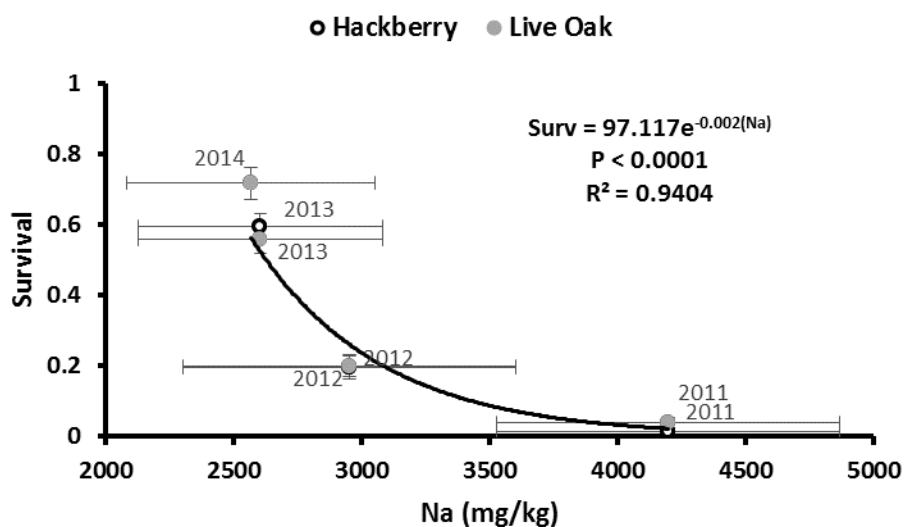


Figure 89 Exponential relationship between first growing season Survival (\pm SE) and Na (\pm SE) for Hackberry and Live Oak combined. The year indicates the year of planting.

First Growing Season Survival and SAR

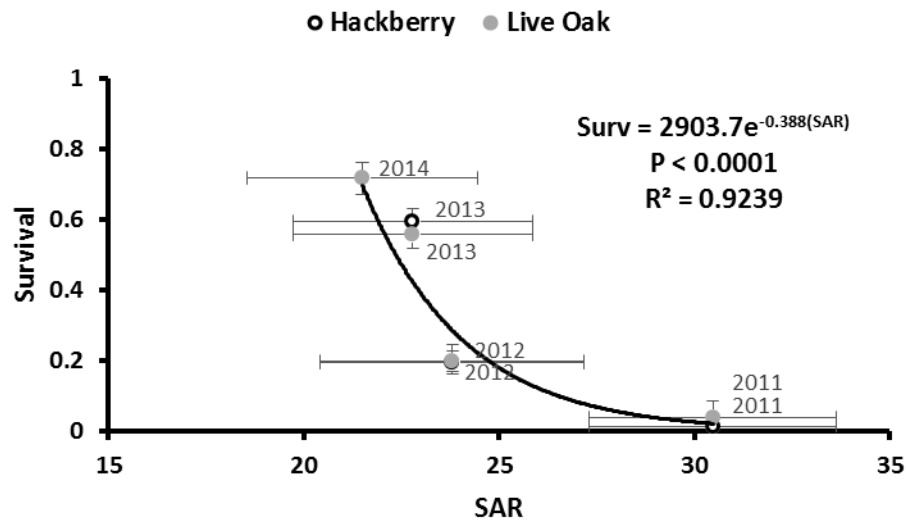


Figure 90 Exponential relationship between first growing season Survival (\pm SE) and SAR (\pm SE) for Hackberry and Live Oak. The year indicates the year of planting.

First Growing Season Survival and CEC

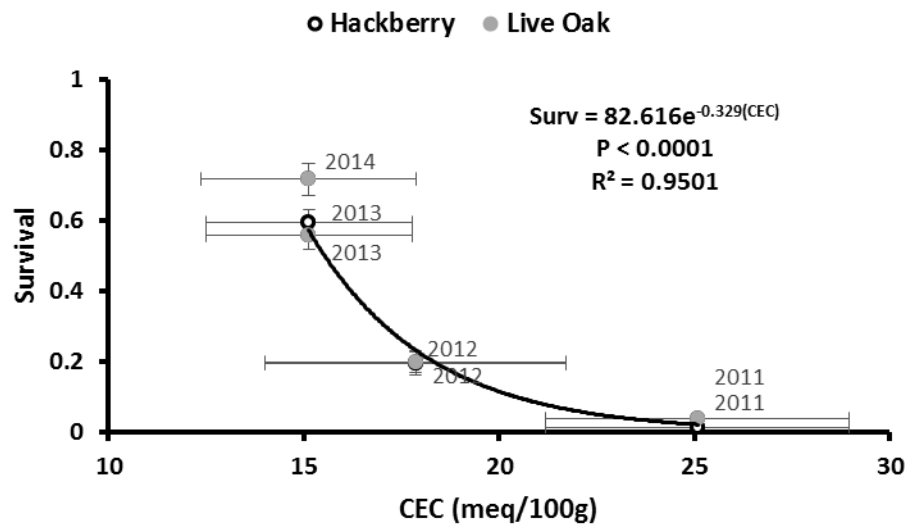


Figure 91 Exponential relationship between first growing season Survival (\pm SE) and CEC (\pm SE) for Hackberry and Live Oak. The year indicates the year of planting.

5.8 Other Vegetative Trial Plantings

5.8.1 Herbaceous: Survival & Spread Comparisons Among Planting Positions

The herbaceous vegetative trial planted November 11, 2009, compared three species: *Panicum amarum* (bitter panicum), *Paspalum vaginatum* (seashore paspalum), and *Spartina patens* (marshhay cordgrass) survival and spread on three positions (marsh, ridge slope, and ridge top) of the Far Ridge with the treatment of organic matter (straw) versus no treatment (control) over one growing season.

There was no difference in survival of *Panicum* between the control and straw for the marsh and ridge slope positions (Figure 92). This was due to no survival of any plants at the marsh position and low survival for both the control (6%) and straw (21%) on the ridge slope position. However, survival of *Panicum* was significantly greater on the ridge top for the straw treatment (41%) than for the control (20%). No difference was seen for spread at any position on the ridge (Figure 93).

There was no difference in survival of *Paspalum* between the control and straw for the marsh (17% and 20% respectively) and ridge slope positions (33% and 39% respectively) (Figure 94). However, survival of *Paspalum* was significantly greater on the ridge top for the straw treatment (95%) versus the control (67%). No difference was seen for spread at any position on the ridge (Figure 95).

There was no difference in survival or spread of *S. patens* between the control and straw for any position on the ridge (Figures 96 and 97). Survival at the marsh, slope and ridge top position for the control was 17%, 22%, and 44% respectively. Survival at the marsh, slope, and ridge top positions for the straw treatment was 20%, 35%, and 65% respectively.

The low survival for all species in this trial at the marsh position may be due to sediment deposition due to the extensive erosion of the ridge in the area of study. This high marsh zone also is an area that still has not vegetated with either planted or volunteer vegetation 7 years post construction. These bare areas probably result from complicated soil conditions related to the saline-sodic nature of these soils. The ridge slope had low survival for all 3 species and may be due to the heavy erosion of the slope during the study period. All 3 species benefited from the addition of organic matter (straw) versus no additive (control). The addition of organic matter increased survival through the absorption of available precipitation and then releasing it slowly back to the plant roots over time as needed.

***Panicum* Treatment Survival Comparison Among Planting Positions**

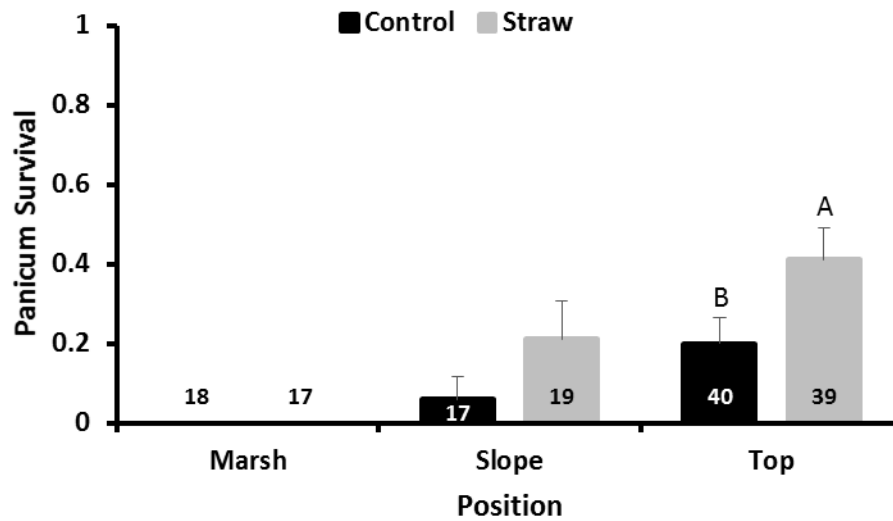


Figure 92 Mean (\pm SE) survival for *Panicum* planted among three positions on the ridge with or without straw as an additive. Means with different letters are not similar. The numbers inside the base of each column represent the sample size.

***Panicum* Treatment Spread Comparison Among Planting Positions**

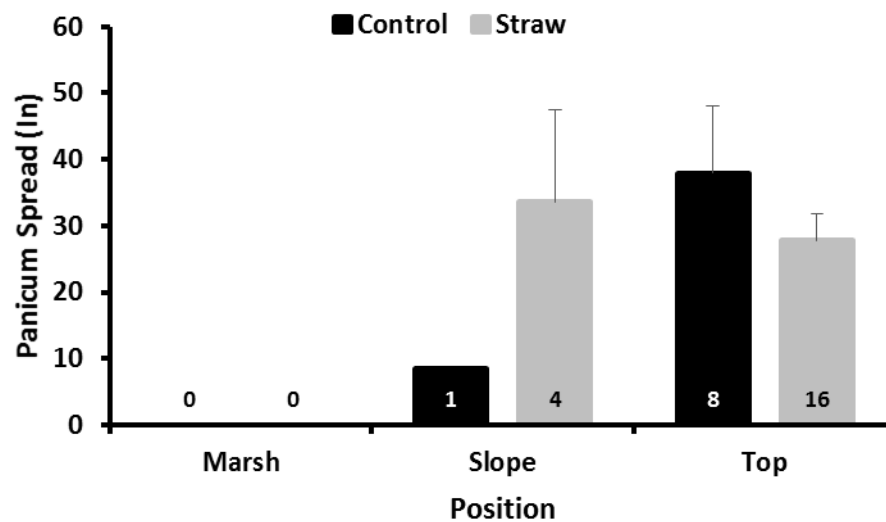


Figure 93 Mean (\pm SE) spread for *Panicum* planted among three positions on the ridge with or without straw as an additive. The numbers inside the base of each column represent the sample size.

***Paspalum* Treatment Survival Comparison Among Planting Positions**

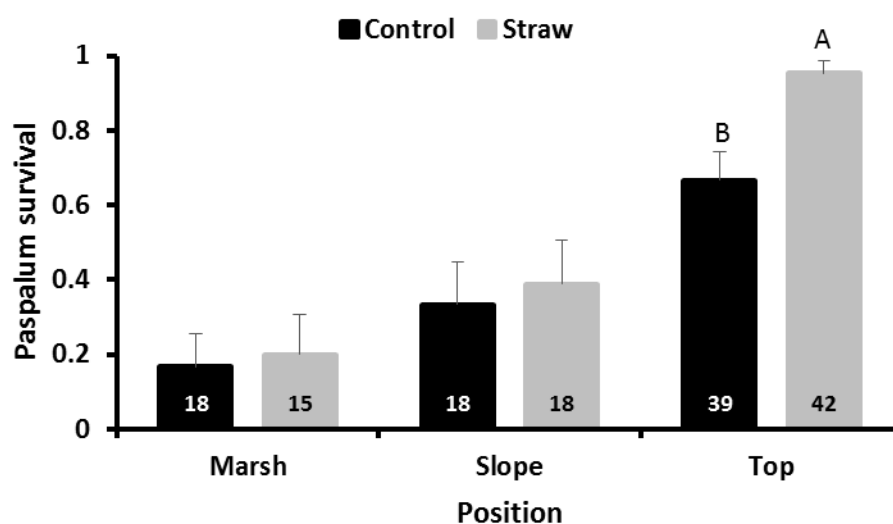


Figure 94 Mean (±SE) survival for *Paspalum* planted among three positions on the ridge with or without straw as an additive. Means with different letters are not similar. The numbers inside the base of each column represent the sample size.

***Paspalum* Treatment Spread Comparison Among Planting Positions**

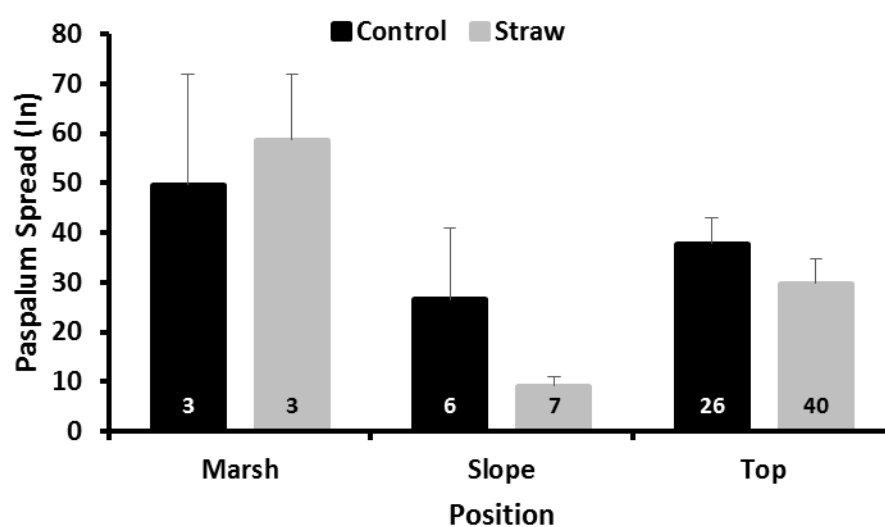


Figure 95 Mean (±SE) spread for *Paspalum* planted among three positions on the ridge with or without straw as an additive. The numbers inside the base of each column represent the sample size.

***S. patens* Treatment Survival Comparison Among Planting Positions**

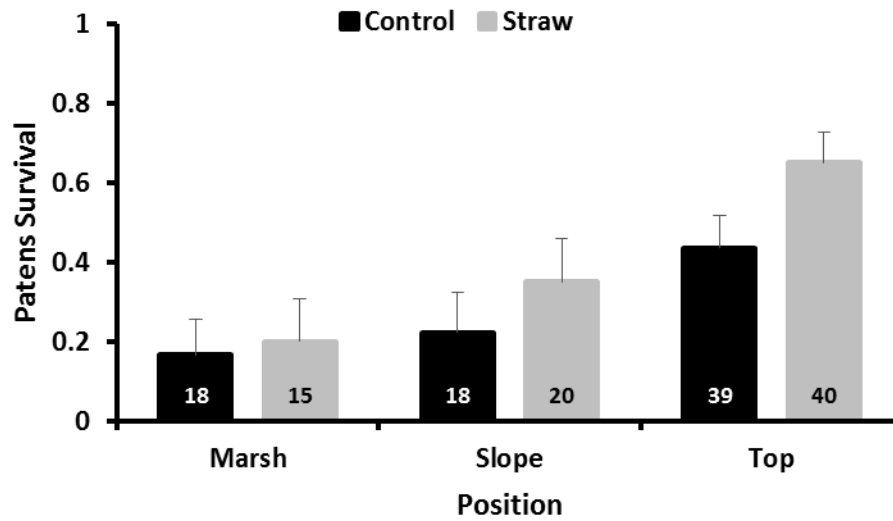


Figure 96 Mean (\pm SE) survival for *S. patens* planted among three positions on the ridge with or without straw as an additive. The numbers inside the base of each column represent the sample size.

***S. patens* Treatment Spread Comparison Among Planting Positions**

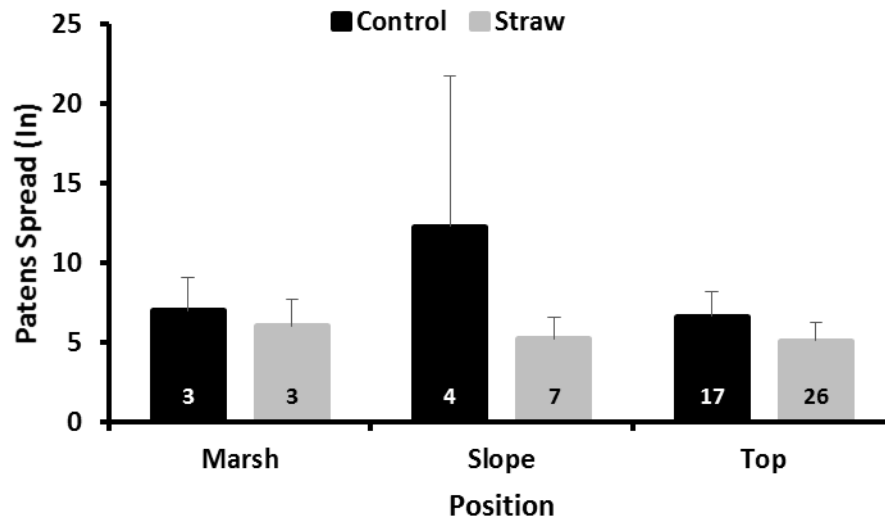


Figure 97 Mean (\pm SE) spread for *S. patens* planted among three positions on the ridge with or without straw as an additive. The numbers inside the base of each column represent the sample size.

5.8.2 Ring Planting

The Ring planting implemented on March 10, 2009, used trade gallon containers of 4 woody species (American beautyberry, red mulberry, yaupon, and sand live oak) with 3 replicates each on the Middle Ridge and on the Far Ridge. Survival for all 4 species on the Far Ridge was 0% as the plants all died by the time of data collection at the end of the first growing season, September 15, 2009. Mortality for plants on the Far Ridge was probably due to a number of factors. First, the soil conditions were at their highest salinity as this was only about 7 months post construction. Also, the trade gallon plants were 4 year old plants with many ranging from 3 to 5 feet tall and were very top heavy. The root balls were only 5 inches deep and planted in a soil that the top 2 to 3 inches would turn to a sloppy “mud” in rain events. Because of these factors, the top heavy trade gallon plants blew over in rain events exposing part of their root balls and contributing to their mortality.

Overall survival for the Middle Ridge 4 species was 31% at the end of the first growing season. Individual species survival was: American beautyberry, 16%; red mulberry, 47%; yaupon, 24%; and sand live oak, 33%. The better survival of the 4 species on the Middle Ridge was probably due to better soil conditions as this part of the ridge was almost 4 years post construction at the time of planting and had better soil moisture retention due to good herbaceous cover and organic matter deposition. The soil did not become as soft after precipitation like the soil on the Far Ridge and as a consequence of this and better protection from the wind from the surrounding vegetation none of these plants blew over.

5.8.3 Linear Planting

The Linear Block Planting implemented March 28, 2011, using 3 species (honeylocust, persimmon, and Hercules’ club) from containers had an overall survival of 1% at the end of the first growing season, October 28, 2011. Only 2 plants out of 180 survived. These 2 plants were both honeylocust, 1 from the control and 1 from the bagasse x fertilizer x gypsum treatment. Individual species survival at the end of the first growing season was honeylocust, 3%; persimmon, 0%; and Hercules’ club, 0%. The high mortality rate is probably due to poor soil conditions and the exceptional drought experienced during this planting year. Both honeylocust plants were dead at the end of the second growing season in October 2013 for an overall survival of 0%.

5.8.4 Mini Block Planting

The Mini Block Planting was a 3 replicate planting of a single treatment (fertilizer) and no control implemented March 20, 2012. Four species were utilized for this planting: American beautyberry, persimmon, live oak, and honeylocust. At the end of the first growing season, October 2012, only 3 plants survived out of 96 for an overall planting survival of 3%. Two of the

surviving plants were honeylocust (2%) and one was live oak (1%). American beautyberry and persimmon had 0% survival. The extreme mortality was likely due to poor soil conditions and the extreme drought ongoing at the time of the planting. The 2 honeylocust seedlings and the 1 live oak seedling are still alive with excellent vigor as of the end of the 2015 growing season. Average height, spread and basal stem diameter for the two honeylocusts is 38.75 inches, 42 inches, and 16 mm respectively. The lone live oak height, spread, and basal stem diameter is 59 inches, 51 inches, and 24 mm.

6.0 RECOMMENDATIONS

6.1 *Cultural Soil Additives*

After analyzing the use of cultural additives (bagasse, fertilizer, and gypsum) for all of the experimental plantings (2010-2014) conducted on the Far Ridge through their first two growing seasons and not finding a difference between their use and that of a control, there is no recommendation to adding these cultural additives to future ridge plantings constructed with saline sediments, at least at the levels used in these woody vegetative trials. Further study is needed to determine if increasing the amount or varying the method of application might increase the benefits of any one of these cultural additives. Increasing application amounts will directly increase plant installation costs. It should be noted, however, that plant installations without the addition of these cultural additives will result in considerable cost savings.

Of course, there are caveats that come with the data for cultural treatments conducted as part of this project. We did not test the effects on the soil or on the plants of using broadcast application of gypsum on the soil surface. In other research using broadcast application of gypsum on saline/sodic soils, this technique was found to be a method for accelerating the leaching process of sodium out of the rooting zone. Due to the initial imperviousness of these soils, however, attention should be paid to gypsum retention in the application area with the expectation that the broadcast gypsum on the soil surface can quickly be lost due to surface runoff after rainfall.

The addition of organic matter (straw) to herbaceous plants, however, led to significantly greater survival versus the control (no treatment) for plants planted upon the ridge top. While there was no significant difference between the addition of an organic matter and without for either the slope or marsh section in this experiment, it is likely that the extensive erosion during this first year after construction led to the high mortality making these comparative results not very meaningful. Their collective high mortality is meaningful in that it shows that adjustments

need to be looked at in future ridge slope design to reduce heavy erosion during the early stages of implementing herbaceous plant establishment.

6.2 *Woody Seedling Size*

Woody seedling size, in addition to herbaceous cover, should be taken into account when planning woody species plantings in dredged saline soils used to construct ridges. Herbaceous plants should be established prior to the planting of woody seedlings for a number of reasons. First, herbaceous plant establishment will create a porous root zone that will help in speeding up the leaching of salts in the highly dispersed soil. Second, litterfall of dead plant material from the herbaceous plants over time will help in the reduction of soil erosion and the increase of soil moisture retention. Detritus on the soil surface slows surface runoff. Detritus covering the soil surface reduces soil moisture loss to wind and solar energy and protects soil aggregates from clay and silt particles that can fill pores when raindrops disturb barren soil. Finally, the roots of the herbaceous plants help bind the soil and will create a matrix for the woody seedling roots to anchor in, reducing erosion and decreasing the chance the woody seedlings will blow down in storm events. Our experience in planting one year old tree seedlings in containers (2" x 7") found this to be a sufficient root to crown ratio and we never saw any of these seedlings blown down. Two year (or older) woody seedlings grown out in trade gallons should be staked as the unstaked 4 year old trade gallon woody plants in the Ring planting implemented on March 10, 2009, (approximately 7 months post construction) were too top heavy and blew down in a storm event. Rainstorms caused the soil to become saturated and "muddy" and the winds from the storm were able to push the plant over. This blow down, as well as the poor soil conditions, resulted in complete mortality of the trade gallon plants.

6.3 *Woody Species Selection*

Woody species composition for use in ridge creation projects utilizing saline sediments should be tailored to the project site's soil conditions. We found that the shrub salt matrimony vine could be used immediately after project completion in saline sediments as this halophytic species is particularly suited (99% survival in 2010 planting and at end of data collection in October 2015) to these early saline-sodic soil conditions. The other species tested required improved soil conditions in order to obtain better plant survival. After salt matrimony vine, live oak had the highest survival of any of the species planted during the woody vegetative trials with the greatest first year survival (72%) in the last planting year in 2014, six years post Ridge construction. Hackberry had the second to highest first year survival (59%) in the 2013 planting year, besting even (but not significantly higher than) live oak (56%). Because there was no statistical difference in survival between the two at the end of the first year's growing season for the 2013 planting, hackberry and live oak are equally suited to be planted for the same low

salinity soil conditions. However, as evidenced by this same 2013 planting, hackberry doesn't seem to persist in the environment as well over time as does live oak (overall plant survival at end of 2015 growing season: hackberry, 25%; live oak, 48%) and may benefit in a delay in planting. That being said, from a planting logistics perspective, it probably makes more sense to delay all woody species establishment until conditions are more conducive for all species being utilized. Sand live oak had the poorest survival of the three species (hackberry, live oak, and sand live oak) that were utilized in three or more of the experimental block plantings. In the 2013 planting year, when all three species were assessed and hackberry and live oak had over 50% survival at the end of the first growing season, sand live oak's survival was significantly lower at 31%. It too, like hackberry, doesn't persist over time as well as live oak does and only ended up with an overall survival of 15% at the end of the 2015 growing season. Because it generally occupies the same function as live oak, is considerably harder to collect (out of state), and had less than a third the overall survival of live oak at the end of the growing season in 2015 for the 2013 planting, sand live oak is not recommended for use in woody species composition makeup for maritime forest ridge projects in Louisiana utilizing in situ saline marsh sediments. However, because it grows well in the sand dunes along the panhandle of Florida where the seed was collected, further study is warranted for its inclusion in sandy dune sediments along Louisiana's barrier islands and headlands.

As to further woody species recommendations, because of the vagaries of early soil conditions and the drought of 2011, only the latest planting year in 2014 provides results to base conclusions upon. Due to the poor survival at the end of the first growing season and at the end of data collection in 2015, yaupon and roughleaf dogwood should not be included as candidates for early inclusion for woody plant establishment on ridge projects utilizing in situ saline sediments. Yaupon and roughleaf dogwood survival at the end of the growing season of 2015 at 8 and 2 percent respectively were considerably lower than was live oak's at 58%. Other species utilized in the experimental trials that are inconclusive due to planting during the 2011 drought were American beautyberry, honeylocust, persimmon, and Hercules' club. Additionally, the Mini Block Planting in March of 2012, utilizing live oak, persimmon, American beautyberry, and honeylocust almost all died probably due to soil conditions and a severe drought at the time of planting.

6.4 Runoff Management and Moisture Retention

Runoff management should be designed into every ridge creation and operation and maintenance. Herbaceous vegetation should be planted or seeded with the goal of covering the ridge surface as soon as possible after construction. By covering the ridge surface with vegetation, detrimental effects due to erosion from rain and wind will be reduced. The ability of

rainfall to leach out salts will increase, as will organic matter deposition, leading to greater soil moisture retention.

Because of the relatively long time inherent in establishing woody species beneficial to Neotropical migratory birds on the highly altered soils from a man-made created ridge using in situ saline marsh sediments, halophytic herbaceous vegetative plantings should precede the woody species plantings, especially if future projects are targeting 80% vegetative coverage within 3 years. Even if woody species can be established reasonably early, their growth rate is not rapid enough to fill in the ridge top area in that short amount of time.

In order to keep the site as uniform as possible and to better be able to find the experimental woody seedlings planted, it was decided not to vegetate inside the woody vegetative field trial blocks with anything except the woody seedlings used in the experimental trials. Of course, these areas began naturally vegetating with *Salicornia* and other pioneer species almost immediately following construction, eventually progressing to all manner of forbs, grasses and shrubs to the point where finding the stunted trees from the vegetative trials within the volunteer vegetation became difficult. For future (non-experimental) plantings, however, when creating ridges with dredged in situ saline marsh soils and trying to establish woody seedlings, herbaceous plantings should be implemented over the entirety of the ridge as soon as possible post construction in order to accelerate soil conditions acceptable for the establishment of non-halophytic woody species.

Designing swales or depression areas into the top of the ridge that can retain precipitation for longer periods of time can also be beneficial in hastening the establishment of herbaceous and woody vegetation (Figure 98). They can also provide longer periods of available fresh water for birds and animals following rainfall. Care must be given to placement of the swales on the ridge top so that it doesn't "blowout" and lead to a quick erosive feature. Monitoring of rill formation and placement of hay bales and/or silt-fences to catch or slow sediment runoff can help stabilize these areas. Concentration of herbaceous vegetation in areas prone or shown to be forming rills can help in sediment runoff reduction as well.

Although our analysis showed no benefit to the addition of bagasse (organic matter) to the seedling holes, it is probably due to the quantities added being too small. The addition of bagasse to this project was limited to only the 7 inch diameter hole the seedlings were planted in. Precipitation would be captured in the immediate area surrounding the plant, but once this soil moisture was taken up by the plant, it had no other surrounding moisture to draw upon. If in situ organic matter can be incorporated into the entire surface area or even worked into the top foot or more of the project site, precipitation would be captured in vastly greater quantities and allow for the plants to capture much more of the surrounding moisture in the soil. The



Figure 98 Standing water on top of the far eastern end of Middle Ridge, February 25, 2014.

addition of organic matter to the entire surface of the project site would also help reduce soil erosion as more of the precipitation would be absorbed into the soil reducing erosion due to surface runoff. Through herbaceous plant establishment, as well as the creation of swales, promotion of water infiltration through the soil horizon will speed up leaching of salts from the soil and lead to a healthier soil better suited to establishing non-halophytic woody species.

According to the as-built schematics provided by the contractor of the ridge, the slopes of the ridge were graded to 35% for both phases of the ridge. Although efforts were made to immediately try to stabilize the ridge slopes through the planting of a variety of halophytic herbaceous species, extensive and heavy erosion occurred post construction. In fact, even to this day, there are extensive stretches of the north side of the Far Ridge where plant establishment has still not occurred. Mostly this has occurred on the narrower 900 foot long western end of the Far Ridge. Repeated attempts to plant these areas have not been very successful due to what appears to be continued rapid erosion. Even plants once established, if not in sufficient quantities to benefit one another through collectively reducing erosion, can

eventually succumb to erosion of soil surrounding their roots (Figure 99). Rapid erosion of the soil in this area may also lead to deeper soils being exposed that have not had the benefit of leaching from precipitation and therefore may have higher salinities for the plants to deal with. Follow up plantings, too, won't benefit from the leaching out of the salts over time, but will be planted in these newly exposed higher saline soils. As mentioned in an earlier section of this report, one area that did not experience heavy erosion post construction is the south slope of the Far Ridge (Phase Two), because of a heavy deposition of wrack from Hurricane Gustav mere weeks post construction. The wrack was deposited along the slope and up to the top edge of the ridge. The wrack deposition helped in reducing erosion from rain runoff and provided organic matter for soil moisture retention which assisted in plant survival and establishment. The wrack deposition also acted as a wind break and collected windborne seed of plants that then established themselves in these areas.



Figure 99 Exposed roots (8+ inches) due to soil erosion of a salt matrimony vine plant on the north slope of the Far Ridge located along the narrower 900 foot long western end, December 2, 2015.

6.5 Soil Quality & Predictions Based on a Fifty Percent Survival Scenario

Soil quality is directly related to woody species establishment. Saline-sodic soils are not conducive to establishment and survival of non-halophytic woody species. Decreasing saline-sodic levels across soil parameters is significantly related to the increase in first growing season survival for these species. Survival through the first growing season has the greatest effect on the successful establishment of non-halophytic woody species on ridges created with saline-sodic soils. Once established through this first critical year, surviving plants tend to persist over time with ever decreasing mortality. Therefore, soil quality should be assessed through sampling prior to planting to ensure soil conditions are hospitable to the survival of the seedlings.

Based on the exponential relationship between each soil parameter and survival for the multiple planting years for hackberry and live oak we are able to make estimates (see Table 3) for soil parameter levels to achieve 50% survival at the end of the first growing season. These predictions are based on our findings for hackberry and live oak combined. For all 5 soil parameters, decreased levels resulted in increased survival. Fifty percent survival was chosen as point for vegetative survival because above this point there is an exponential increase in survival and appears to mark a dramatic inflection point in the data for survival of these species. As soon as the soil conditions reach this critical threshold, plant survival dramatically increases over a narrow window of time. EC and/or Salts (interchangeable) had the highest correlation to survival and are then the best use as an indicator for prediction of a successful planting on ridges created with saline-sodic soils. The results from this report support planting when EC levels decrease to 13.3 dS/m or lower for 50% survival or greater.

Table 3 Calculated levels of each soil quality parameter that results in 50% survival based on the exponential relationship between each variable and survival for multiple years of plantings for Hackberry and Live Oak.

Soil Parameter	Exponential Regression Equation	Estimated 50% Survival Level
EC (dS/m)	$\text{Surv} = 137.31e^{-0.422(\text{EC})}$	13.3
Salts (ppm)	$\text{Surv} = 137.32e^{-0.0007(\text{Salts})}$	8,022.1
Na (mg/kg)	$\text{Surv} = 97.117e^{-0.002(\text{Na})}$	2634.5
SAR	$\text{Surv} = 2903.7e^{-0.388(\text{SAR})}$	22.3
CEC (meq/100g)	$\text{Surv} = 82.616e^{-0.329(\text{CEC})}$	15.5