Update on Plantings and Tree Monitoring in the Vicinity of the Caernarvon Freshwater Diversion: May, 2014 to July, 2016

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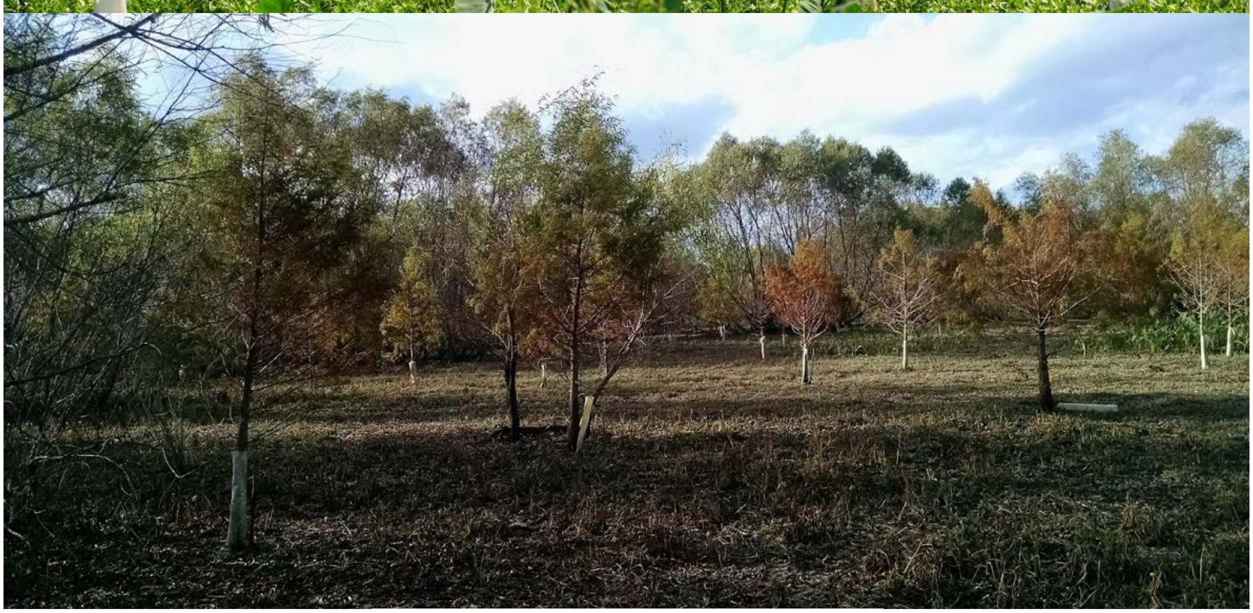
A Project of the Lake Pontchartrain Basin Foundation, Restore the Earth Foundation and the Coalition to Restore Coastal Louisiana

November, 2016



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Acknowledgements

We would like to thank our partners, funders, landowners, land managers and tree grower for all they have contributed to this project!

Partners:
Restore the Earth Foundation
Coalition to Restore Coastal Louisiana

Funders:
Restore the Earth Foundation
Walton Family Fund
Delacroix Corporation
Colonial Pipeline

Landowners:
Delacroix Corporation
Heirs of Peter Moss

Land Managers:
Howard Callahan
Mike Farizo

Nursery Manager/Tree Grower:
Resource Environmental Solutions, LLC
Aaron Pierce

Hundreds of Volunteers!!

Pictures on Front Cover

Top: Planted trees that are 2 years old (in the ground for 1 year).
Bottom: Planted trees that are 4 years old (in the ground for 3 years).

Introduction

Since 2009, the Lake Pontchartrain Basin Foundation (LPBF) has been actively documenting the development of an emerging delta in the receiving basin of the Caernarvon Freshwater Diversion (CFD) outfall canal, Big Mar Pond (Lopez et al. 2014). LPBF has monitored the emerging delta in order to understand the delta building process under the influence of a diversion. In 2010, in partnership with the Coalition to Restore Coastal Louisiana (CRCL) and the Restore the Earth Foundation (REF), LPBF began taking part in tree plantings in the vicinity of the CFD as part of a grant funded reforestation effort. To read the initial report about geomorphic monitoring and freshwater swamp restoration in the vicinity of the Caernarvon Freshwater Diversion visit http://www.saveourlake.org/ and view the report entitled "Geomorphology and Bald Cypress Restoration of the Caernarvon Delta near the Caernarvon Diversion, Southeast Louisiana," (Baker et al. 2011)as well as the updates entitled:

- "Progress Report for Grant *Planting and Monitoring of the Caernarvon Delta in Big Mar*: January through June, 2012" (Baker et al. 2012)
- "Progress Report for the Grant *Planting and Monitoring of the Caernarvon Delta in Big Mar:* July through December, 2012" (Hillmann et al. 2013a)
- "Progress Report for the Grant *Planting and Monitoring of the Caernarvon Delta in Big Mar:* January through June, 2013" (Hillmann et al. 2013b)
- "*Caernarvon Delta and Diversion Study: Status April 2014*" (Hillmann et al. 2014)

This report will serve as a supplement to the aforementioned reports. It summarizes land building, environmental conditions, tree planting and monitoring in the vicinity of the Caernarvon Freshwater Diversion from May 2014 through July 2016. This report highlights two years of volunteer and commercial tree plantings, which includes the deployment of approximately 15,000 wetland trees, consisting of bald cypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica*), red swamp maple (*Acer rubrum* var. *drummondii*) and blackgum tupelo (*Nyssa sylvatica*). This report also discusses the results of tree monitoring for the 2014 and 2015 growing seasons.

Land Building 2014-2016

Since 2011, the delta has expanded at a rate of approximately 50 acres per year through 2016. By the end of the 2016 growing season there was 161 hectares (399 acres) of new land near the outfall canal. A rapidly increasing black willow (*Salix nigra*) forest can be observed on the expanding delta; possibly due to very shallow water bottoms that are able to vegetate during low water. Emergent vegetation leads to land stabilization and subsequently to conditions that allow for willow colonization.

Detecting land building in the pro-delta is difficult because of a mix of floating vegetation, emergent marsh and floating marsh. A conservative estimate of land building through 2016 in the pro-delta is 103 hectares (255 acres). By the end of the 2016 growing season there was approximately 264 hectares (654 acres) of land in Big Mar Pond (delta and pro-delta combined) **(Figure 1**).

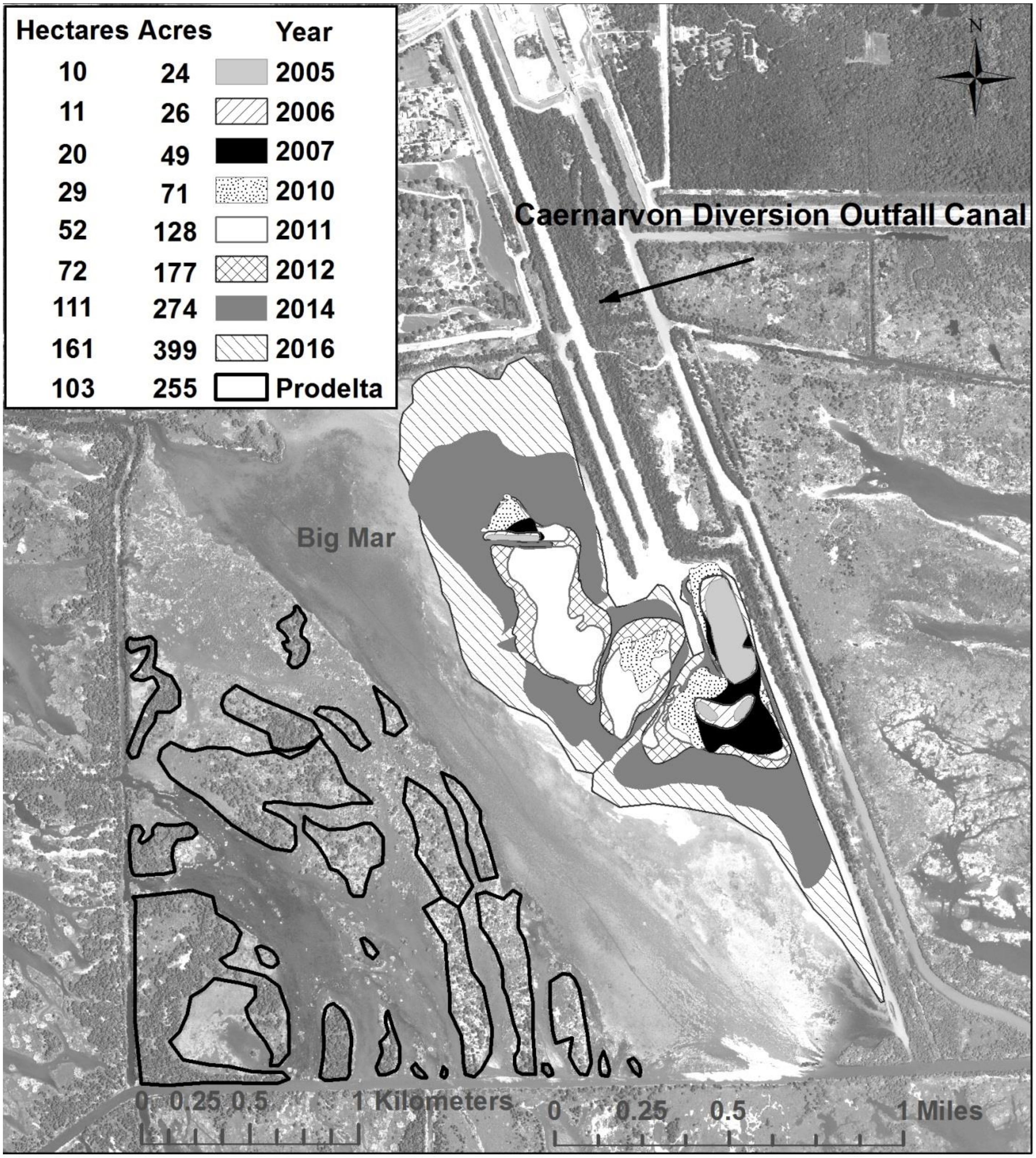
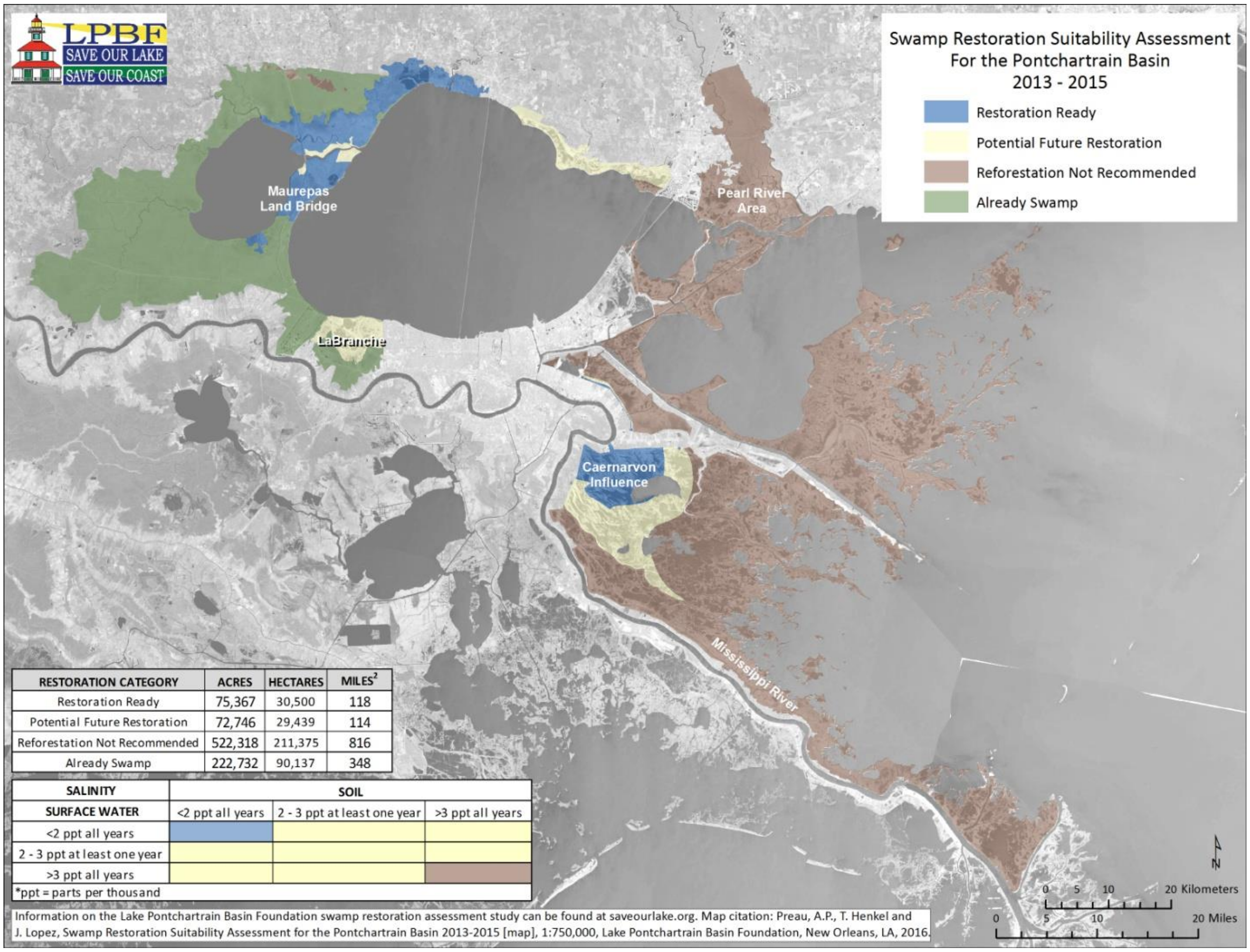


Figure 1: Delta growth overtime from 2005 through the 2016 growing season. From 2014 -2016, the delta complex in Big Mar gained land at approximately 50 acres a year.

Purpose of Swamp Tree Plantings

Natural bald cypress regeneration is widely believed to be precluded in southeast Louisiana due to nutria herbivory, high interstitial soil salinity, altered hydrological regimes and slow germination rates (Conner and Toliver 1990). Therefore, under existing conditions, without human intervention, bald cypress seedling mortality is quite high (Myers et al. 1995, Holm et al. 2011). However, using a combination of soil salinity and surface water salinity data, LPBF has identified over 30,000 hectares of land suitable for swamp restoration throughout the Pontchartrain Basin, primarily situated on the Maurepas Land Bridge and in the vicinity of the Caernarvon Freshwater Diversion (Henkel et al. 2016)(**Figure 2**).



RESTORATION CATEGORY	ACRES	HECTARES	MILES^2
Restoration Ready	75,367	30,500	118
Potential Future Restoration	72,746	29,439	114
Reforestation Not Recommended	522,318	211,375	816
Already Swamp	222,732	90,137	348

SALINITY	SOIL		
SURFACE WATER	<2 ppt all years	2 - 3 ppt at least one year	>3 ppt all years
<2 ppt all years			
2 - 3 ppt at least one year			
>3 ppt all years			
*ppt = parts per thousand			

Figure 2: Swamp restoration suitability map for the Pontchartrain Basin. Over 30,000 hectares of land is restoration ready throughout the basin.

The *Multiple Lines of Defense Strategy* (MLODS) features healthy swamps as an integral part of southeast Louisiana's defenses against hurricane storm surges (Lopez 2009) (**Figure 3**). It is the goal of LPBF to plant wetland trees and implement an important feature of MLODS. LPBF actively monitors the growth of planted trees and uses that data and lessons learned to increase the success of future swamp restoration plantings. The work being done in the vicinity of the CFD is a unique opportunity to test the effectiveness of proposed Louisiana State Master Plan restoration initiatives (CPRA 2012), which include proposed river diversions.

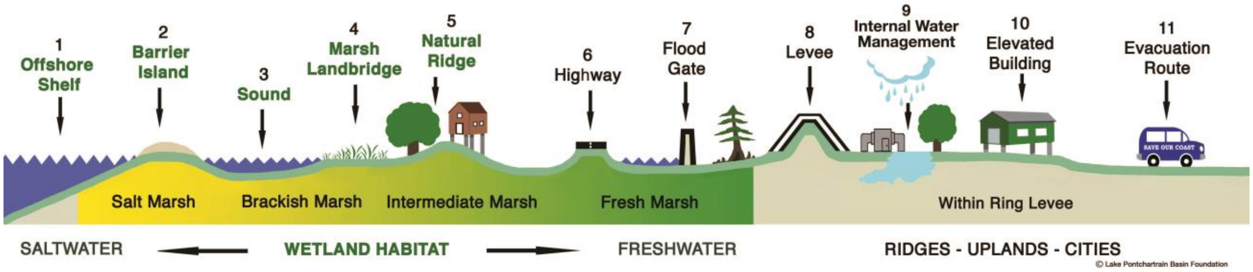


Figure 3: The *Multiple Lines of Defense Strategy* showing how healthy swamps reinforce flood protection levees by absorbing storm surge energy.

To date, ten wetland tree plantings have taken place in the vicinity of the diversion (**Figures 4 and 5**). Most planted trees are 1-year old saplings grown by Ecological Restoration Services, LLC, using the EKOgrown® method, which promotes root growth and prevents girdling of roots within the container. The most recent plantings took place during the winter of 2014/2015 and the winter of 2015/2016.

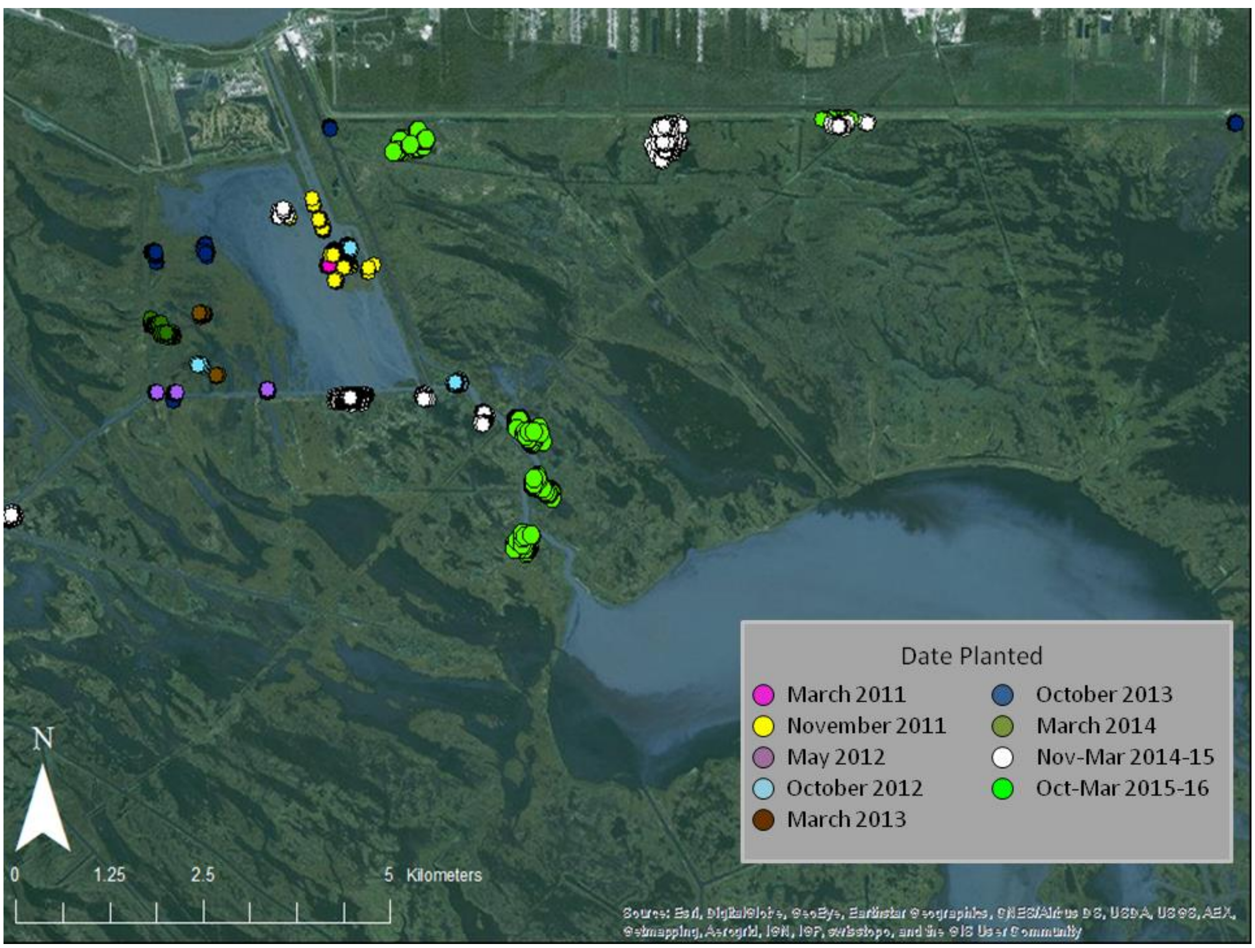


Figure 4: The distribution and location of all plantings and sites (excluding October 2010) in the vicinity of the Caernarvon Freshwater Diversion. The first planting is not shown due to 100% mortality.

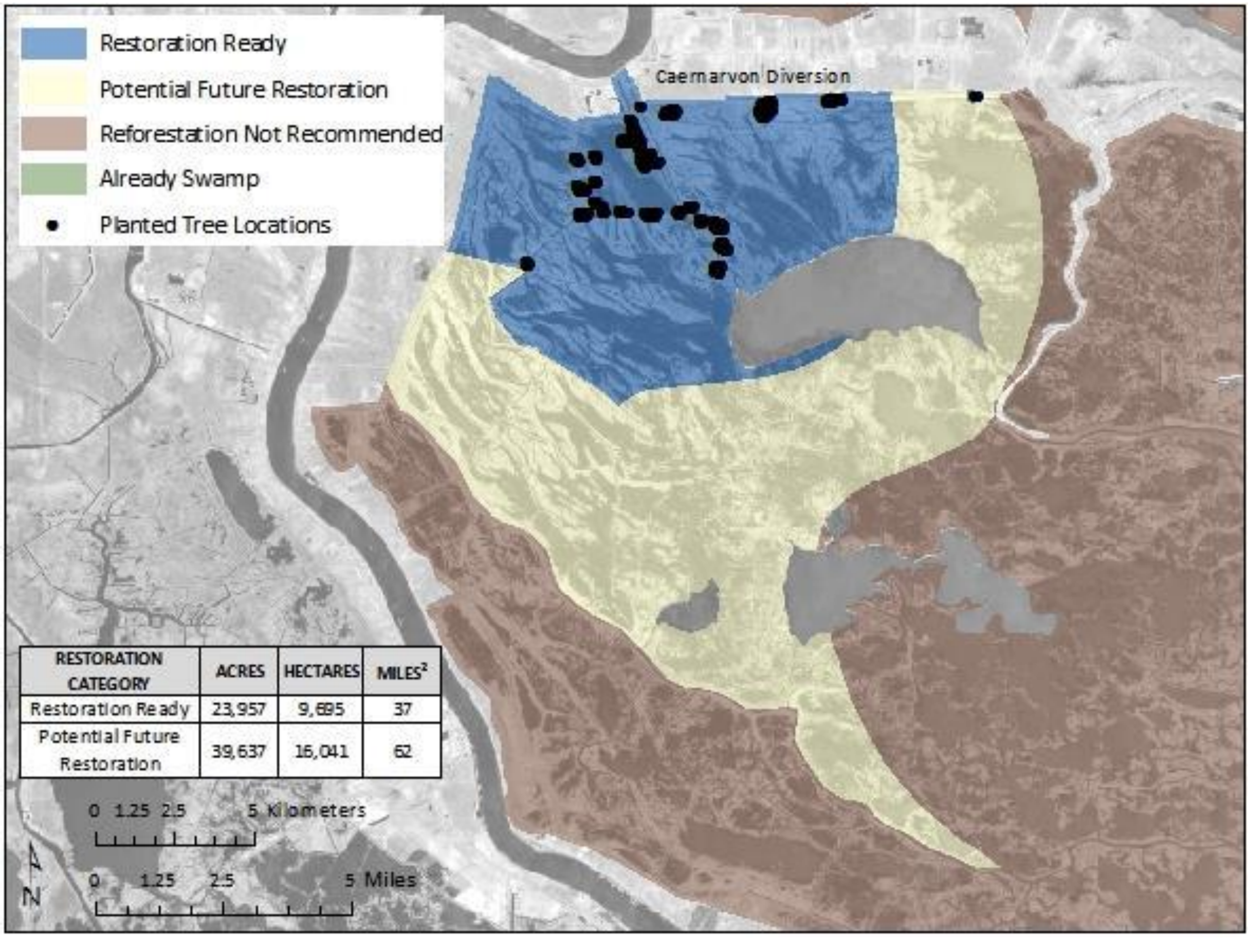


Figure 5: Planted trees in the vicinity of the Caernarvon Freshwater Diversion in an area of the basin which is restoration ready.

Interstitial Soil Salinity

Planting projects are part of many restoration plans in southeast Louisiana and success depends largely on the suitability of the planting locations (soil salinity and hydrological conditions) to the vegetation being planted (Day and Hunter 2013). LPBF has been monitoring soil salinity around the CFD for the past 4 years and has also integrated publicly available soil salinity data from Coastwide Reference Monitoring Stations (CRMS) (CPRA 2016). Monitoring soil salinity enables us to detect the effects of freshwater flow through and management of the diversion on the salinity gradient of the Breton Sound hydrological basin, a sub-basin of the Pontchartrain Basin (Conner et al. 2016). The data was then used to scout suitable planting locations (**Figure 6**). Planting sites that test the maximum salinity tolerance of wetland trees can also be chosen. In general, maximum sustained soil salinity tolerated by swamp tree species in southern Louisiana is 2.5 ppt (higher salinity pulses can be tolerated by bald cypress) (Allen and Burkett 1997, Connor et al. 2007). Therefore, large plantings are generally not conducted in areas with soil salinity greater than 2.5 ppt, but test plantings may occur in soils beyond this threshold. Twenty-five trees are planted at test sites, while 500-5,000 trees, distributed among several locations, are now planted at approved sites.

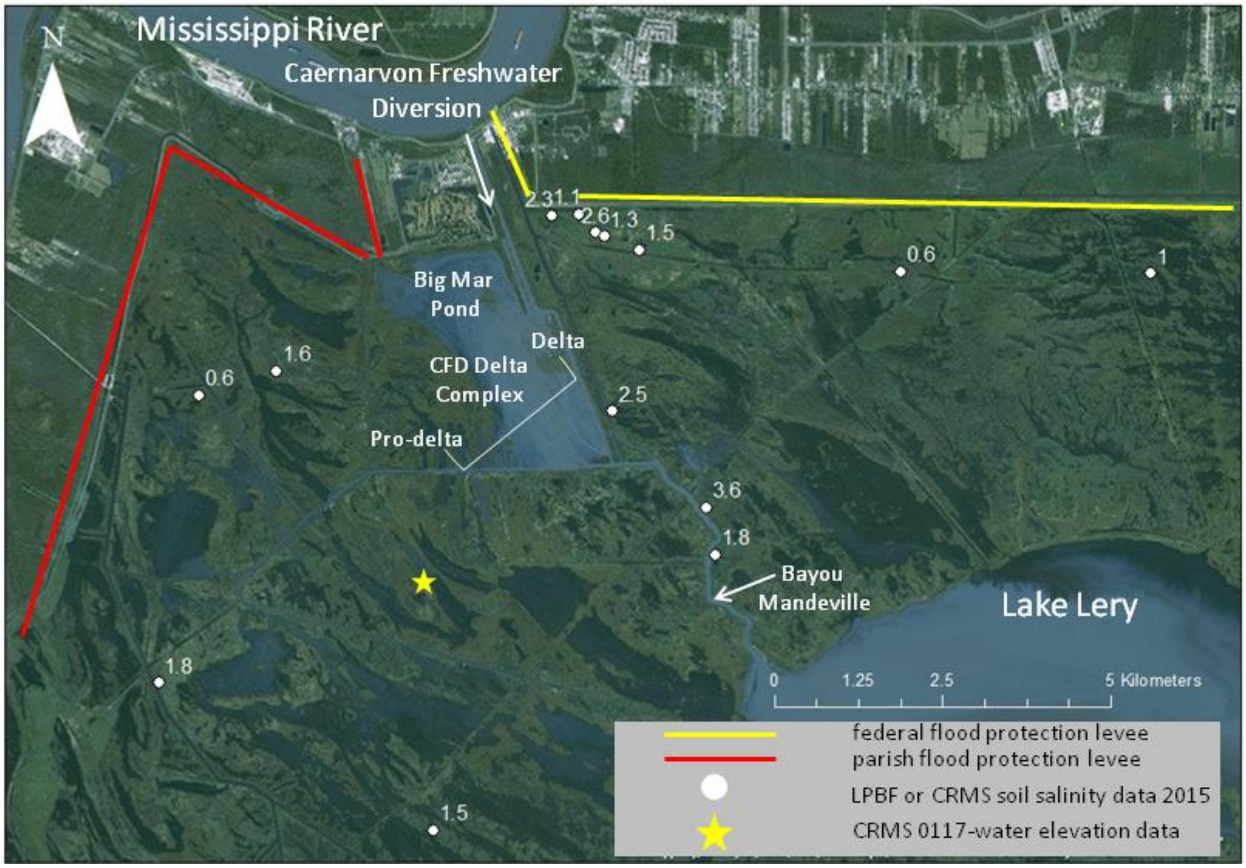


Figure 6: Soil salinity (ppt) in the vicinity of the Caernarvon Freshwater Diversion. All measurements shown were obtained since January 2015. Also shown is the nearest CRMS site (0117).

Mississippi River Discharge through the Caernarvon Diversion

The decline of south Louisiana wetlands and wetland tree species has partly been attributed to altered hydrological regimes. The building of levees along the Mississippi River, which disconnected the river from surrounding wetlands, limited an important source of fresh water, sediment and nutrients. Planting in the vicinity of the CFD enables us to observe the response of planted trees to re-introduced river water into the surrounding wetlands. During the timeframe covered by this report (May 2014-July 2016), the Mississippi River discharge into the Caernarvon Delta Complex through the CFD structure was minimal (< 500cfs), for most time periods, except for February to April, 2015 and August to November, 2015 (USGS 2016)(**Figure 7**). The area experienced maximum discharge of ≈2,000 cfs (mean daily/provisional data) in late January and early February 2015. Minimum discharge occurred during most of the remaining time periods (approved data and provisional data) (USGS 2016).

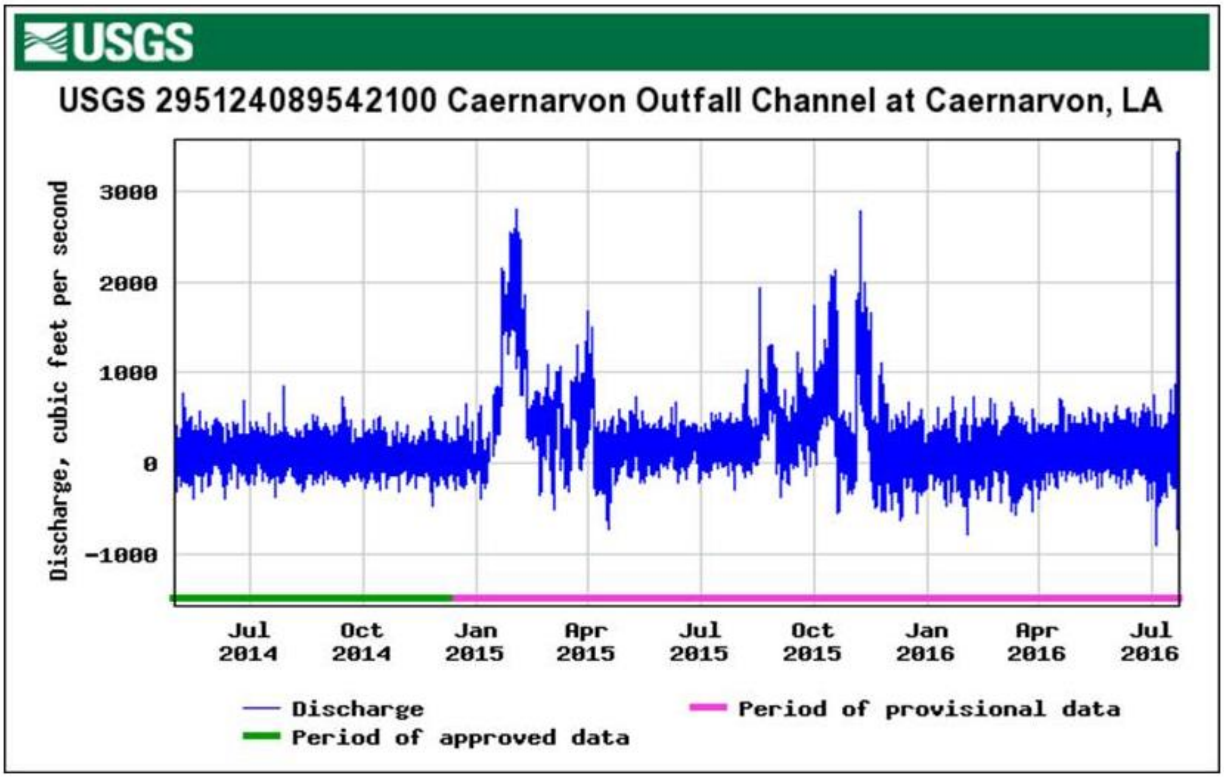


Figure 7: USGS provisional graph of discharge in cubic feet per second (cfs) at the Caernarvon Outfall Channel from May 2014 through July 2016.

Observed high water in the wetlands surrounding the diversion outfall area (**Figure 8**) is influenced primarily by sustained south/southeast winds, as well as precipitation and flow through the diversion greater than 4,000 cfs. Between October 2014 and October 2015 (most recent data available), water elevation topped marsh elevation infrequently and for short durations throughout the year (CRMS 2016). The most extended periods of high water occurred in May through June, 2015, which did not coincide with high flow through the diversion (USGS 2016) but did coincide with sustained south/southeast winds. High water in February 2015 and August to October 2015 did coincide with increased flow through the diversion (≈2,000 cfs), but not enough to induce an increase in water level relative to marsh elevation. During those same time periods, wind direction predominantly came from the south/southeast and southwest, which likely explains the increase in water levels. Overall mean water elevation was 0.5 ft. below the surrounding marsh elevation between October, 2014 and October, 2015 (CPRA 2016).

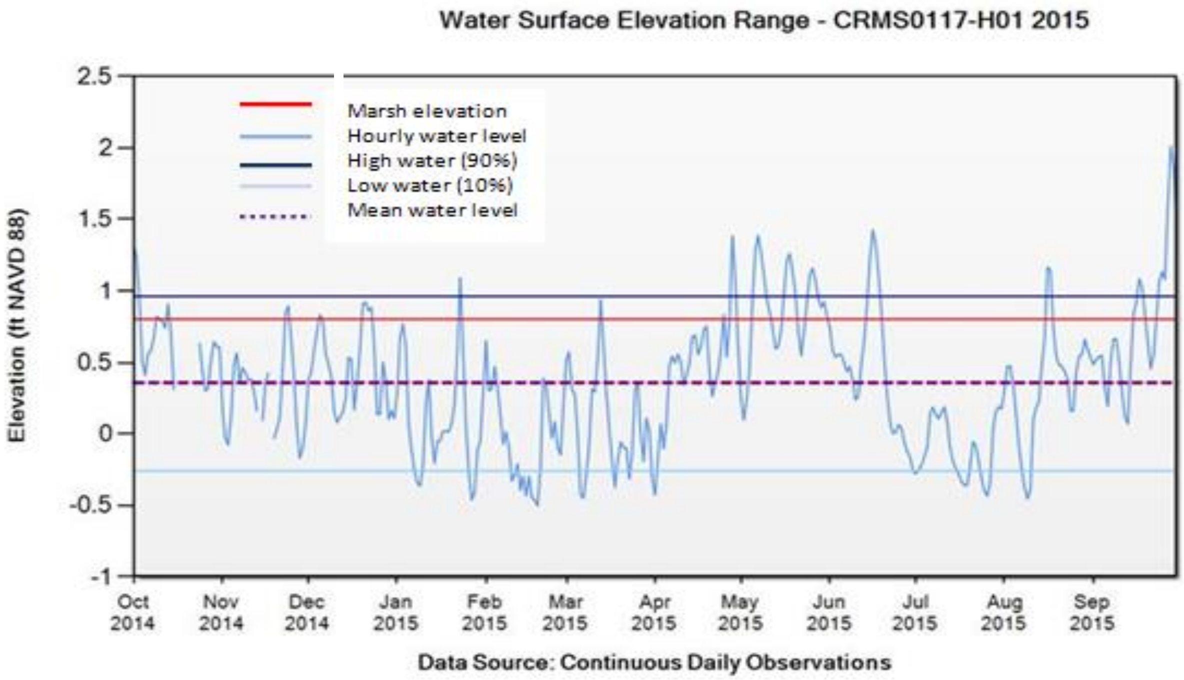


Figure 8: Hydrological data from CRMS 0117 indicating mean water elevation was 0.5 ft. below the surrounding marsh elevation on average. Hourly water elevation data shows that the marsh surface was overtopped infrequently throughout the year.

Winter 2014-15 Planting

Previous plantings generally consisted of ≈250 trees per planting and were strictly volunteer events. Due to the success of previous plantings (tree survival, growth), REF, CRCL and LPBF decided to scale up the number of trees planted during the planting seasons. It was decided to plant 10,000 trees in the vicinity of the diversion during the winter 2014/2015 planting season, with half of the trees planted by volunteers and the other half planted commercially. REF provided trees and financed the commercial planting, CRCL coordinated volunteers for the volunteer plantings and LPBF scouted planting locations for both the commercial and volunteer plantings and obtained baseline data (described below) on 800 newly tagged trees, to be incorporated into the tree monitoring program (**Figure 9**).

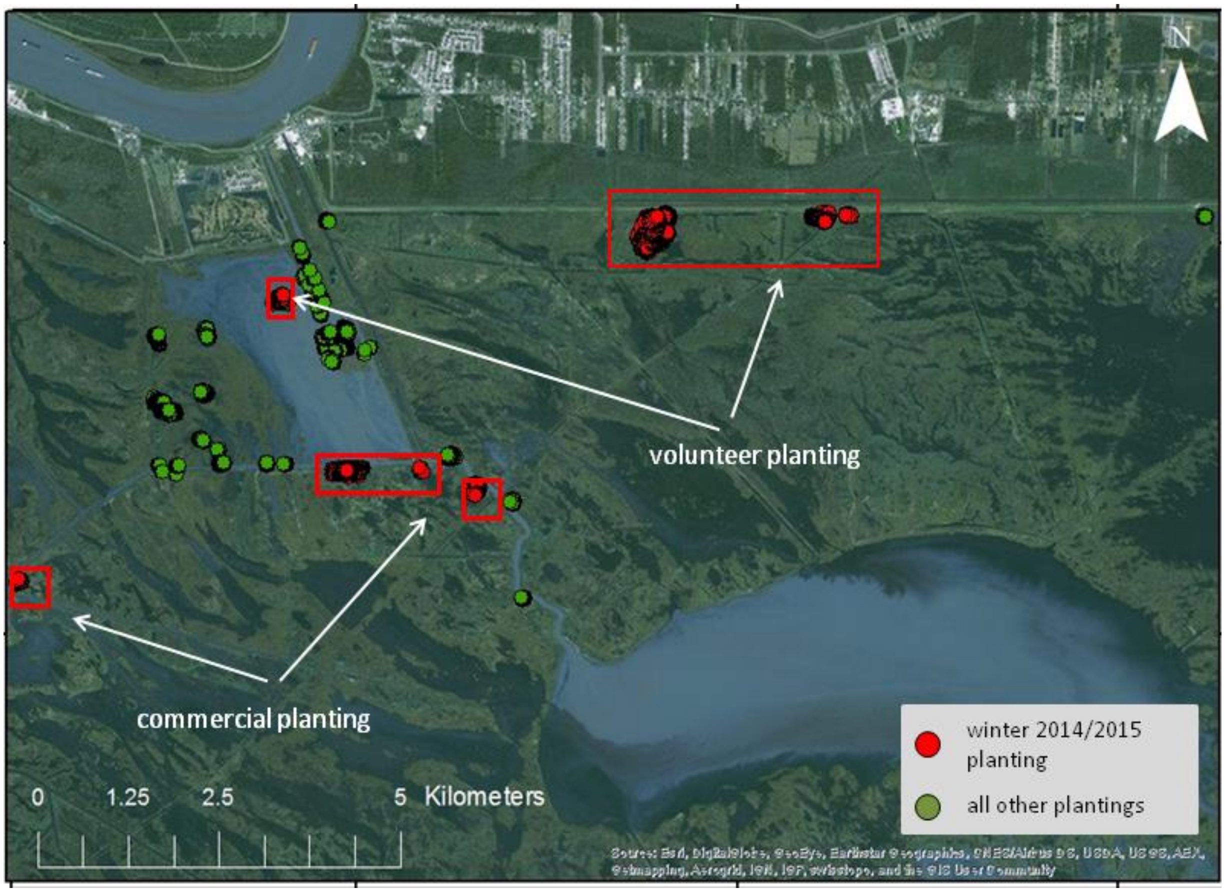


Figure 9: The distribution of sites and trees from the winter 2014-2015 planting, which for the first time included commercially planted trees.

Volunteer Planting

Volunteers planted 5,000 trees during the winter 2014/2015. Trees were planted between October and March over multiple planting events, mostly in front of the newly constructed flood protection levee in St. Bernard Parish, located about 5 km due east of the diversion structure. In general, 250 to 1,000 trees were planted at a time by 20 to 50 volunteers and 4-6 LPBF and CRCL staff members. Before the planting, trees were flagged and 400 randomly selected trees were tagged and measured for baseline data. All trees were then moved on site (**Figure 10A**). The day of each planting volunteers worked in teams of 2 and planted trees approximately 5 meters apart (**Figure 10B**). Each planted tree was wrapped with a nutria excluder (**Figure 10C**). Tagged tree locations were recorded using a Garmin GPSmap 60CSx.

Figure 10: Trees were moved on site either by truck (along the flood protection levee) or by boat (A). Trees were approximately planted 5 meters a part(B) and outfitted with nutria excluders (C).

Commercial Planting

Five thousand trees were planted commercially by ERS, LLC the week of March 9th, 2015. Trees were delivered to the staging area at the Delacroix Corporation boat launch on Monday, March 9th. Four hundred randomly selected trees were flagged, tagged and measured for baseline data. At a later date, LPBF staff went on site and obtained gps locations on all tagged trees that could be found.

Species & Monitoring

Overall, 10,000 trees were planted during this, the 9th planting event. Planting a combination of different species of wetland trees is preferable to planting mono-specific stands of trees in terms of increasing habitat quality. This planting included 7,500 baldcypress (all 5,000 trees in the commercial planting were baldcypress), 1,000 water tupelo, 750 red swamp maple and 750 blackgum tupelo

A total of 767 trees were added to the tree monitoring program (776 out of 800 trees were recovered in the field), which raised the total number of trees in the CFD tree monitoring program to 1,245 (**Table 1**). Data in the species, height, diameter at breast height (d.b.h.), of tagged trees were collected. These parameters are re-measured annually at the end of each growing season (EOS) in late fall and winter. These data show survival and annual growth rates of planted trees under the influence of a diversion.

Table 1: The number of trees planted at each planting, the number of trees per cohort that were placed in the monitoring program, and a breakdown by species are shown by planting season. F= fall, Sp= spring, W= winter.

Planting Season	# trees planted	# trees tagged	% trees tagged	Baldcypress #planted	Baldcypress #tag	Water Tupelo #planted	Water Tupelo #tag	Blackgum #planted	Blackgum #tag	Swamp Maple #planted	Swamp Maple #tag	Green Ash #planted	Green Ash #tag
F 2010	200	0	0.0%	200	0	0	0	0	0	0	0	0	0
Sp 2011	175	32	18.3%	175	32	0	0	0	0	0	0	0	0
F 2011	678	139	20.5%	678	139	0	0	0	0	0	0	0	0
Sp 2012	251	50	19.9%	251	50	0	0	0	0	0	0	0	0
F 2012	318	62	19.5%	159	32	100	20	0	0	0	0	56	10
Sp 2013	176	51	29.0%	176	51	0	0	0	0	0	0	0	0
F 2013	296	73	24.7%	166	41	130	32	0	0	0	0	0	0
Sp 2014	250	62	24.8%	181	43	69	19	0	0	0	0	0	0
W 14-15	10,000	776	7.8%	7,500	592	1,000	68	750	59	750	57	0	0
W 15-16	5,000	444	8.5%	3,307	279	788	69	368	32	787	64	0	0
Total	17,594	1,689	9.6%	12,793	1,259	2,090	208	1,118	91	1,537	121	56	10

Baseline Height

Mean baseline height for trees planted during the 9th planting season was similar to previous baseline trees heights recorded for trees planted in the area (Hillmann et al. 2013). Tree baseline height ranged between a maximum of 2.20 m and a minimum of 0.70 m. The average tree height of tagged trees was 1.26 m (SD ±0.18). Mean baseline height was; bald cypress 1.23 m (SD ±0.14), water tupelo 1.26 m (SD ±0.22), black gum tupelo 1.46 m (SD ±0.26) and red swamp maple 1.41 (SD ±0.18).

Baseline D.B.H.

Diameter at breast height (d.b.h.) is a measurement used to monitor tree growth rates and is typically measured at 1.4 meters above ground level unless the tree base is buttressed or otherwise deformed. Mean baseline d.b.h. of tagged trees planted during the 9th planting season was 0.51 cm (SD ±0.14), and ranged from a maximum of 0.93 cm to a minimum of 0.30 cm. Mean baseline d.b.h. for specific species was; bald cypress 0.45 cm (SD ±0.18), water tupelo 0.58 cm (SD ±0.11), black gum tupelo 0.50 cm (SD ±0.15) and red swamp maple 0.49 cm (SD ±0.08). Many of the trees were not tall enough to measure a baseline d.b.h. at planting time.

Winter 2015-2016 Planting

Due to the success of planting 10,000 trees the previous year, it was decided to plant 5,000 trees in the vicinity of the diversion during the winter 2015/2016 planting season. The winter 2015/2016 planting season consisted of strictly volunteer planting events. As in the previous year, REF provided trees, CRCL coordinated volunteers and LPBF scouted planting locations and obtained baseline data (described below) on 450 newly tagged trees to be incorporated into the tree monitoring program (**Figure 11**).

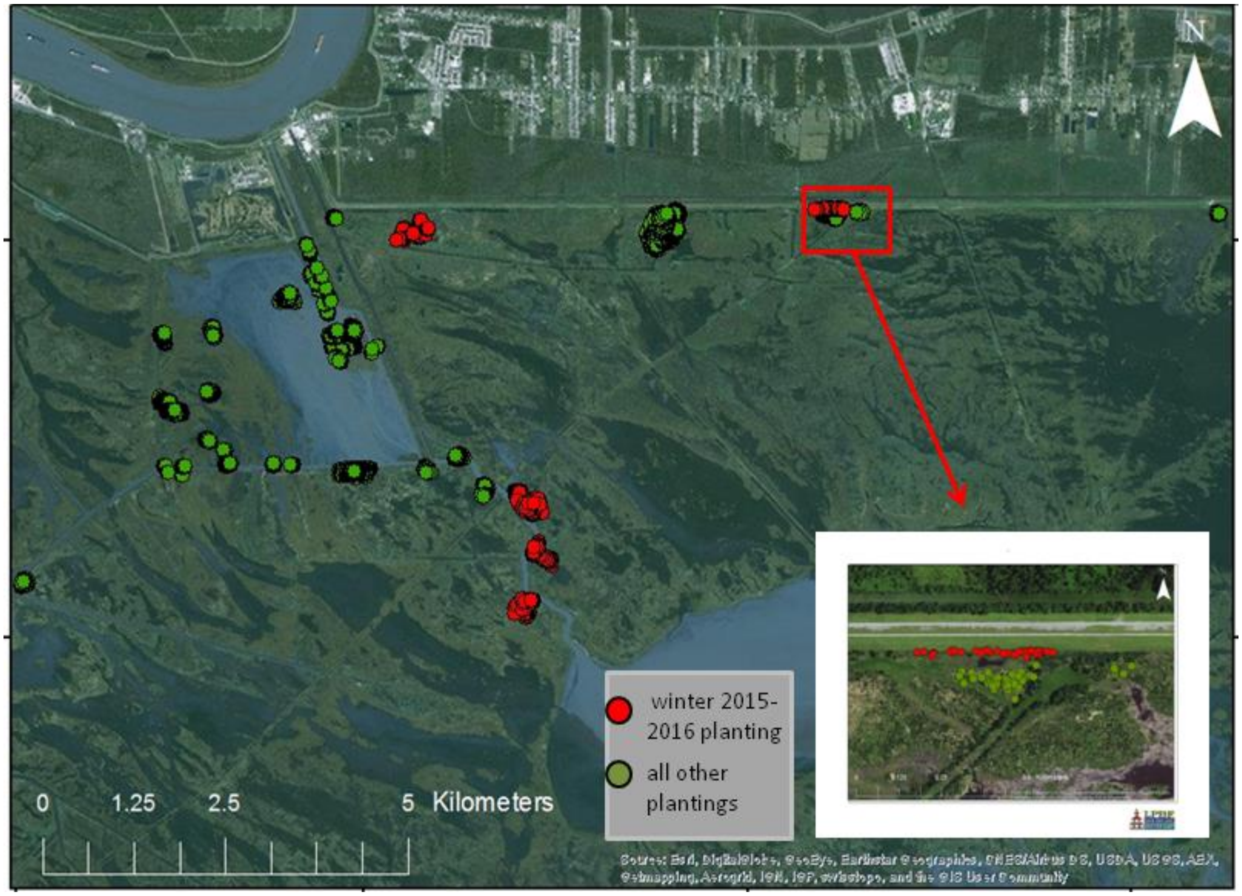


Figure 11: The location and distribution of trees planted during the winter 2015/2016. The inset shows the location of 250 planted 2-year old saplings, donated by the St. Bernard Wetland Foundation. All other trees were 1-year old saplings.

Species & Monitoring

Volunteers planted 5,250 in a series of planting events throughout the winter of 2015 to 2016, which included 3,307 baldcypress, 788 water tupelo, 787 red swamp maple and 368 black gum tupelo. Five thousand trees planted were 1-year old saplings grown by ERS, LLC and were planted along and just off of Bayou Mandeville (**Figure 11**). Two-hundred and fifty trees planted were 2-year old saplings grown by St. Bernard Wetland Foundation and planted along the newly constructed flood protection levee in St. Bernard Parish (**Figure 11 & 12**). This was the 10th planting overall and raised the total number of planted trees in the Caernarvon Vicinity to 17,594.

Figure 12: On April 22, 2016, 2-year old saplings were picked up from the grower (A), and planted by volunteers (B), in front of the newly constructed flood protection levee in St. Bernard parish (C).

Initially, 450 trees were tagged and measured for baseline data and 444 tagged trees were subsequently recovered in the field and added to the broader Caernarvon tree monitoring program, which increased the number of tagged trees to 1,689. Of the recovered tagged trees, 279 were baldcypress, 69 were water tupelo, 64 were red swamp maple and 32 were black gum tupelo (**Table 1**).

Baseline Height

Mean baseline height for trees planted during the 10th planting season was similar to previous baseline trees heights recorded for trees planted in the area (Hillmann et al. 2013). Tree height ranged between a maximum of 3.30 m and a minimum of 0.80 m. The mean tree height of tagged trees was 1.55 m (SD ±0.45). Mean baseline height for specific tree species was; baldcypress 1.31 m (SD ±0.25), water tupelo 2.18 m (SD ±0.38), blackgum tupelo 1.74 m (SD ±0.30) and red swamp maple 1.85 (SD ±0.43).

Baseline D.B.H.

Mean baseline d.b.h. of tagged trees planted during the winter 2015/2016 was 0.78 cm (SD ±0.24), which ranged from a maximum of 1.60 cm to a minimum of 0.10 cm. Mean baseline d.b.h. for specific species was; baldcypress 0.61 cm (SD ±0.20), water tupelo 0.88 cm (SD ±0.16), blackgum tupelo 0.63 cm SD (±0.28) and red swamp maple 0.88 cm (SD ±0.23).

Tree Monitoring through 2015

Survival

Overall tree survival of tagged trees was 88% (all surviving tagged trees divided by all tagged trees). Average survival across all plantings was 63% (average of survival of each of nine plantings which have been monitored at least once). The lower survival across all plantings was directly impacted by the first two plantings, which had survival rates of 0% and 18%, due to not using nutria protectors and planting trees on mudflats, which were not stable. Average survival is 78% when these first two plantings are not considered and represents survival beginning when nutria protectors were placed on every tree planted. The overall survival is higher because more trees were planted at later plantings, which had higher survival rates due to applied lessons learned (consistent use of nutria protectors, longer stakes for stabilization, well planned site selection), as well as no large storm event like Hurricane Isaac (August 29, 2012), which impacted earlier plantings. The lowest survival rate was 0% in the first planting, fall 2010 (**Figure 13**). The highest survival rate was 95% for trees planted in fall of 2012 and 2013 (**Figure 13**). The plantings exposed to Hurricane Isaac, especially trees planted in the spring of 2012 (some sites at the convergence of multiple canals) did show a decrease in survival during subsequent monitoring, but considering storm surge up to 18’, a decrease in tree survival would be anticipated. For all plantings, incident increases in survival corresponds to locating previously lost trees.

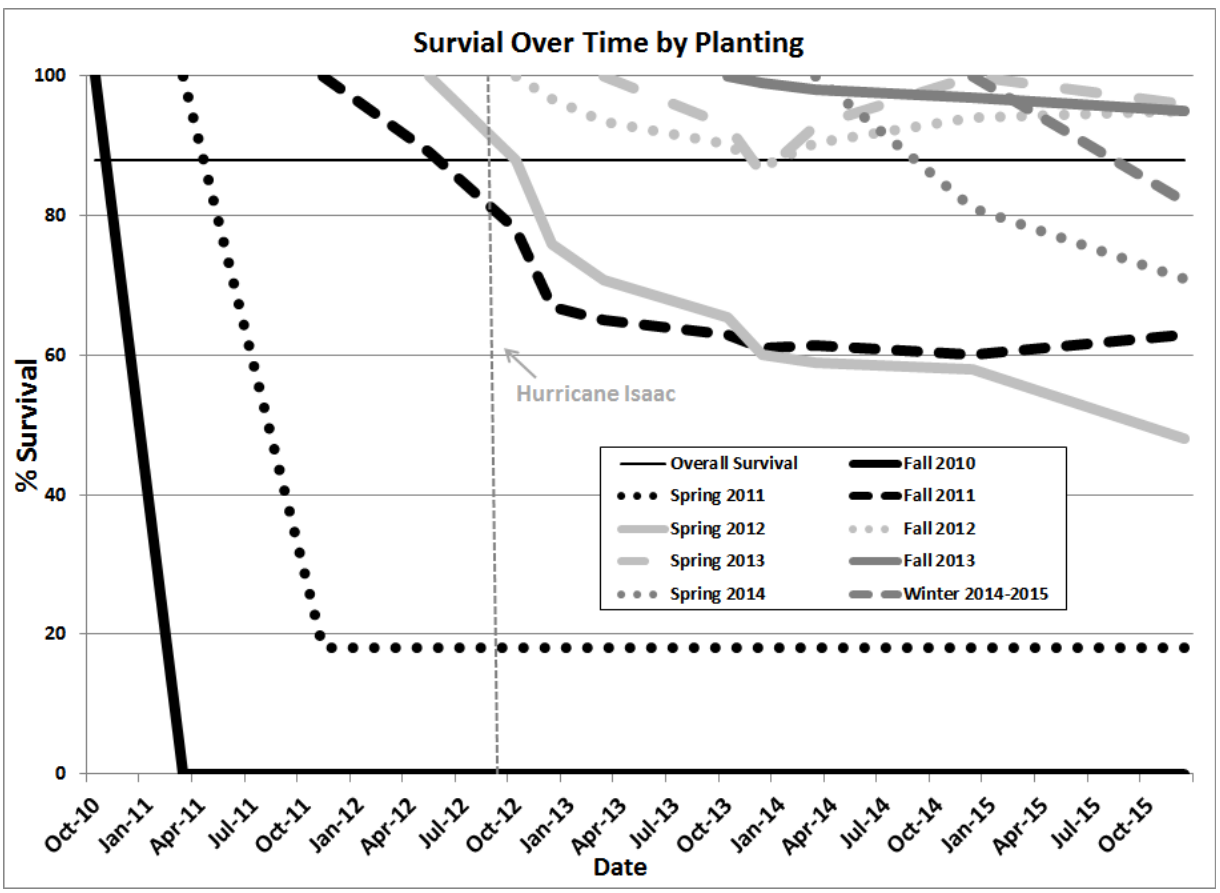


Figure 13: Tree survival over time by tree plantings in the vicinity of the Caernarvon Freshwater Diversion. Overall survival of all tagged trees is 88%.

Survival by Species

The species with the highest survival rate was green ash at 100% but this was also the species with the lowest sample size (n=10) and was only planted at one planting. The species with the next best overall survival was water tupelo at 90% (n=137) which was planted at four of the nine plantings. Swamp red maple had the next best overall survival at 80% (n=59) but was only planted at the winter of 2014/2015. Baldcypress had an overall survival of 78% (n=980) and was planted at every planting. Baldcypress was also the only species to be planted when Hurricane Isaac affected the region. Blackgum survival was low with only 49% survival (n=57) which also was only planted in the most recent planting season, the winter of 2014/2015.

Height Growth

Mean tree height at EOS 2015 across all plantings was 2.43m (SD ±1.13). Tallest trees were found in the spring 2011 planting. Mean tree height from that planting was 5.42 m (SD ±0.99), with a maximum of 7.5 m and a minimum of 3.5 meters. Shortest trees at EOS 2015 were from the most recent planting prior to tree monitoring, winter 2014/2015. Mean tree height from this planting was 1.79 m (SD ±0.37), with a maximum of 4.88 m and a minimum of 0.76 meters (**Figure 14**).

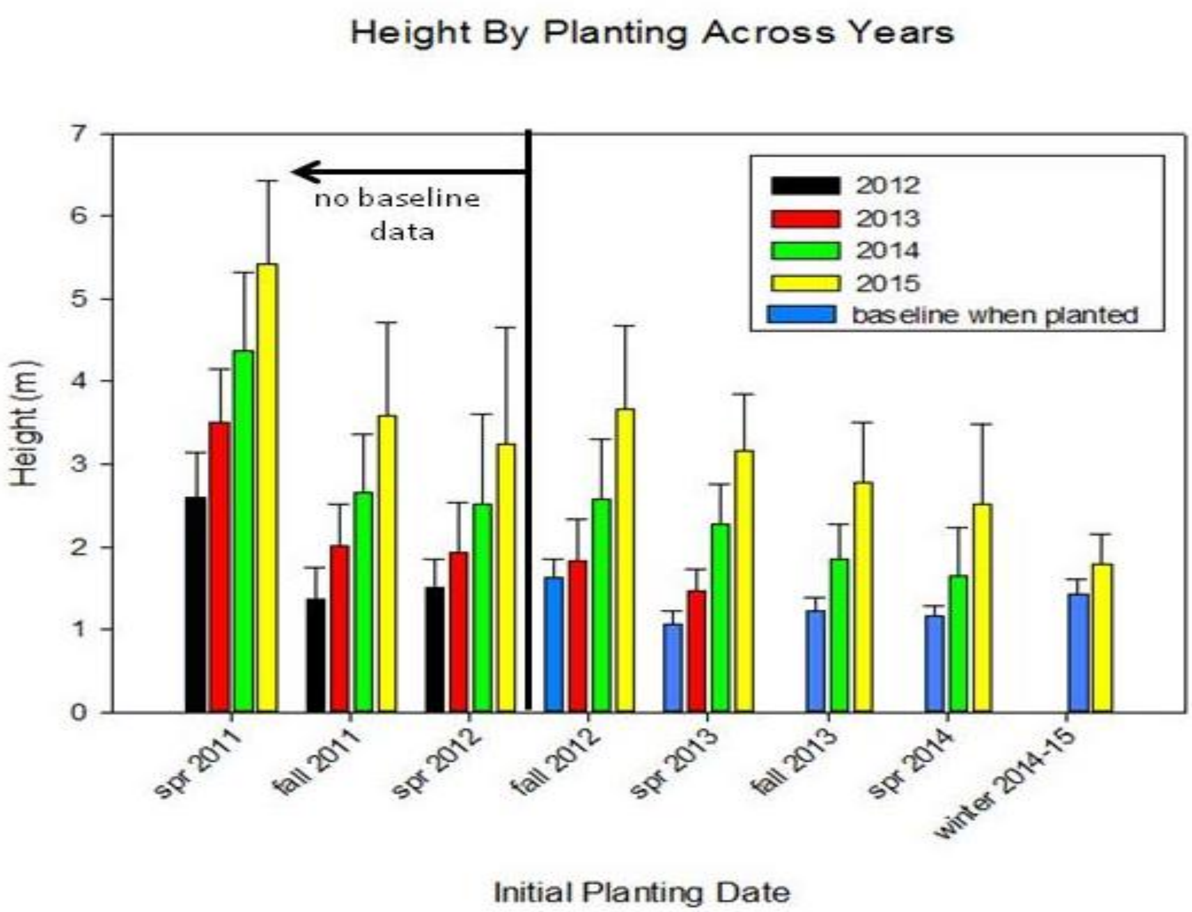


Figure 14: Tree height across all plantings. Yellow bars indicate tree height end of season (EOS) 2015. Blue bars indicate baseline data. Baseline data was not measured for the first 3 plantings.

At the end of the 2015 growing season there were five age classes of planted trees; 2, 3, 4, 5, and 6 year old trees. Trees were approximately 1 year old when planted. Trees planted in spring 2011 were not monitored at 2 years and are not represented in the 2-year age class. Trees planted in spring 2011 are also the only trees represented in the 6-year age class. Across all age classes, planted trees from the fall 2011 and spring 2012 consistently had shorter tree height than trees from all other plantings (**Figure 15**). Trees planted in fall 2012, fall 2013 and winter 2014-15 had similar heights at 2 years (1.83, 1.84 and 1.79 meters). Trees planted in fall 2011, fall 2012 and fall 2013 had similar height at 3 years, with trees planted in fall 2013 being the tallest at 3 years (2.78 m). For the 4-year age class, trees planted in spring 2011 and fall 2012 has similar heights, with fall 2012 trees being the tallest (3.66 m). In the 5-year age class spring 2011 trees were the tallest (4.38 m) and trees planted in spring 2012 were the shortest (3.56 m). Spring 2011 trees were the only trees represented in the 6-year age class (5.42 m).

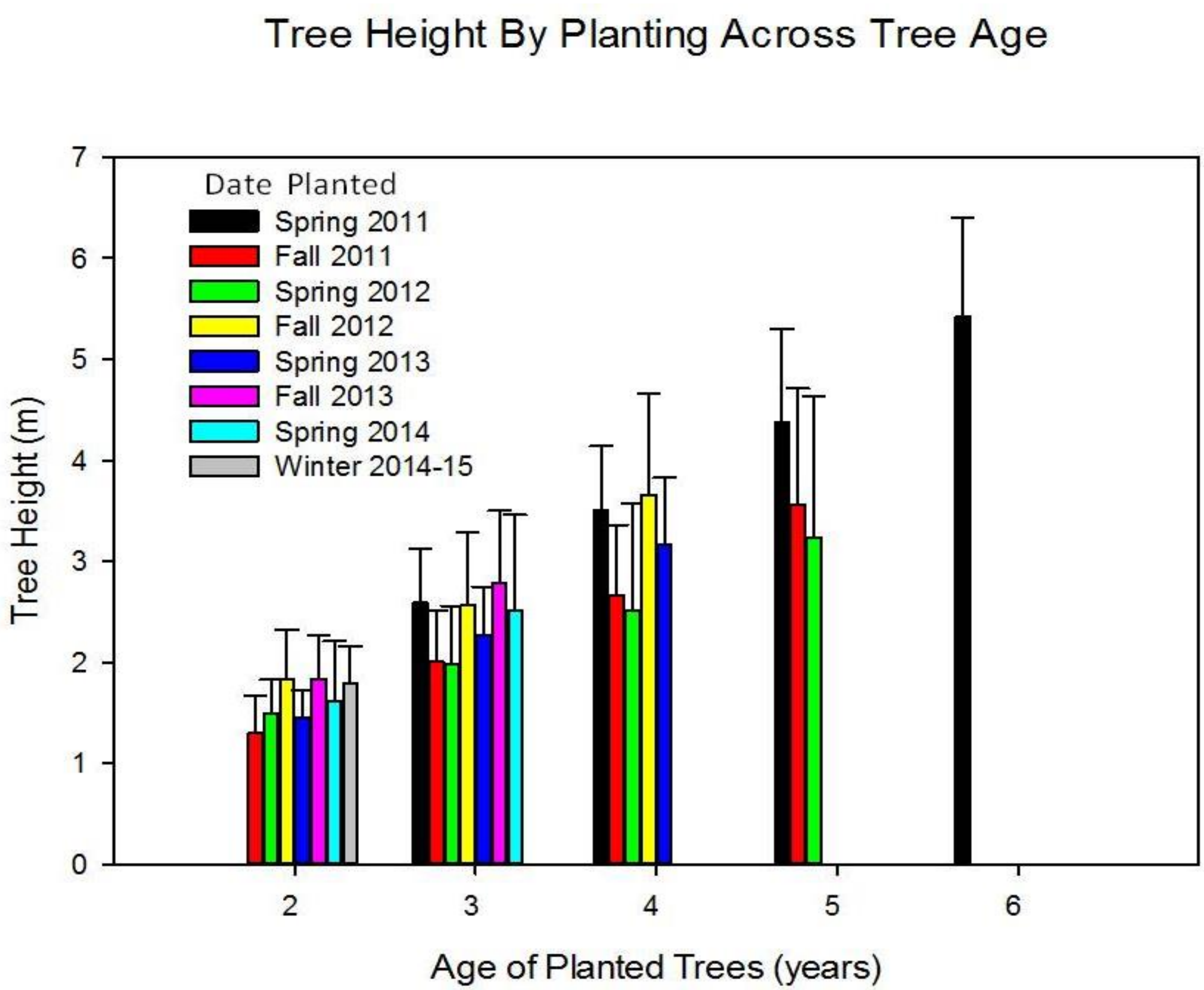


Figure 15: When comparing age classes, trees planted in the fall of 2011 and spring of 2012 consistently have shorter height than trees from other plantings.

Average height growth rate across all plantings was 0.7 m/year. The largest average height growth is from the planting from spring 2011 at 0.94 m/year. The least height growth occurred in the most recent planting from the winter of 2014/2015 at 0.53 m/year.

Green ash had the highest average growth rate at 0.93 m/year, but suffered tip die back during its second growing season and then recovered during the third growing season, growing on average 1.16 meters (**Figure 16**). Baldcypress had the next highest height growth rate at 0.73 m/year. In general, baldcypress had lower growth rates during the first growing season in the ground, and then increased during subsequent growing seasons. Water tupelo had the next highest height growth rate at 0.53 m/year. Water tupelo, in some cases suffered from tip die back and tip herbivory (by deer) during its first growing season and then recovered. In cases where it did not suffer from tip die back, height growth rates were high during the first growing season and then slowed down in subsequent seasons. There was only one year of data for red swamp maple and blackgum, making it difficult to elucidate growth patterns. Average height growth rate for red swamp maple was 0.3 m/year and for blackgum it was -0.03 m/year as it also suffered from tip die back and deer herbivory.

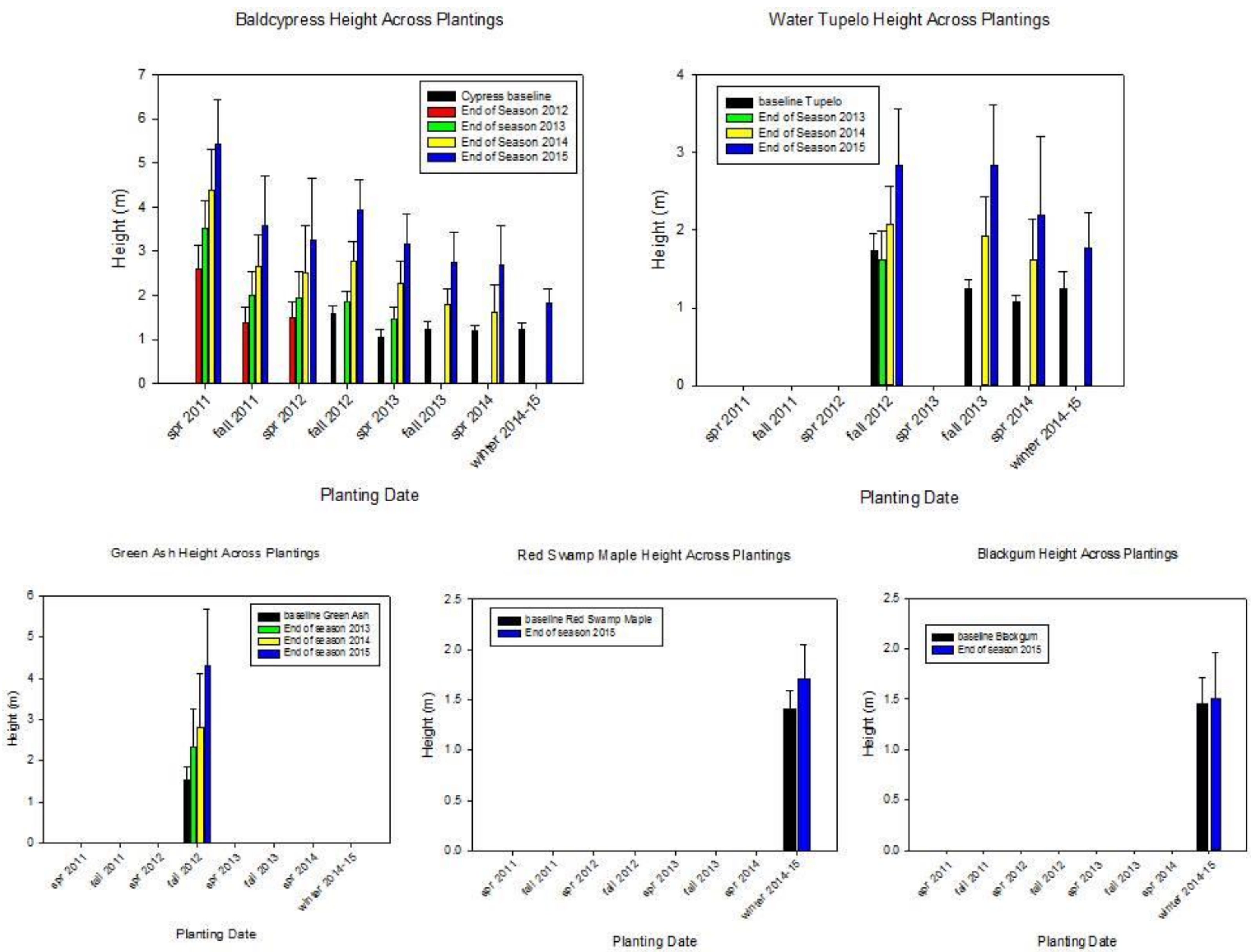


Figure 16: Tree height (2011-2015) by tree species. Black bars indicate tree height baseline data.

D.B.H.

Mean d.b.h. at EOS 2015 across all plantings (2-9) was 2.68 cm (SD ±2.18). The greatest d.b.h. measurements were from the planting in spring of 2011. Mean d.b.h. for this planting was 8.16 cm (SD ±2.48), with a maximum of 14.0 cm and a minimum of 3.81 centimeters. Smallest overall d.b.h. at EOS 2015 was from the winter 2014-2015 planting. Mean d.b.h. was 1.22 cm (SD ±0.37), with a maximum of 1.80 cm and a minimum of 0.38 cm (**Figure 17**).

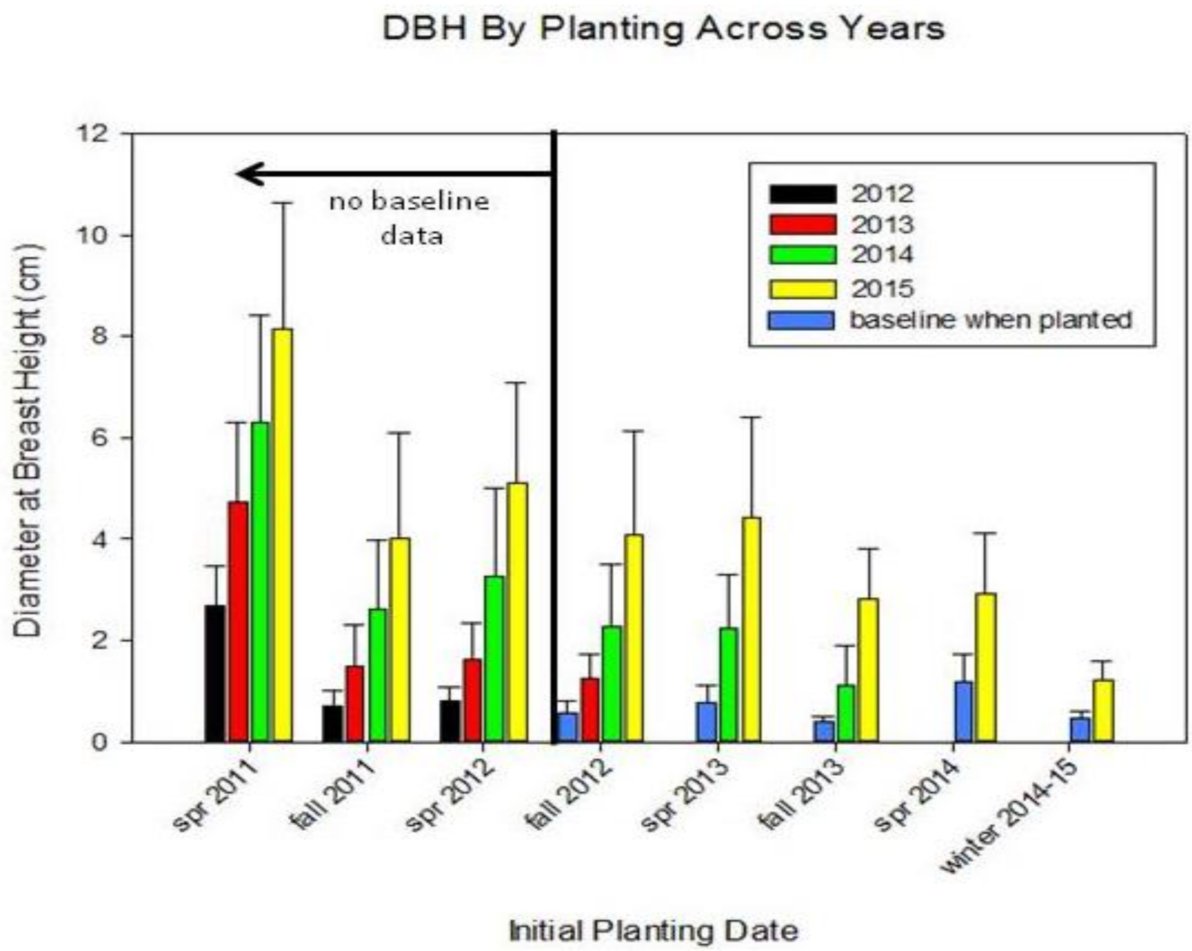


Figure 17: Diameter at breast height across all tree plantings and species. Yellow bars indicate EOS 2015. Blue bars indicate baseline data. The first three plantings (spring 2011, fall 2011, spring 2012) have no baseline data.

Across all age classes, planted trees from the fall 2011 and spring 2012 consistently had smaller d.b.h. than trees from all other plantings (**Figure 18**). Trees planted in spring 2014 had the largest d.b.h. in the 2-years age class (1.69 cm). Trees planted in fall 2012 had the largest d.b.h. in the 3-year age class 3 years (2.83 cm). In the 4-, 5-, and 6-year age class, trees planted in the spring 2011 had the largest d.b.h. (4.73, 6.32 and 8.16 cm). Trees planted in spring 2012 consistently had the smallest d.b.h. across all age classes.

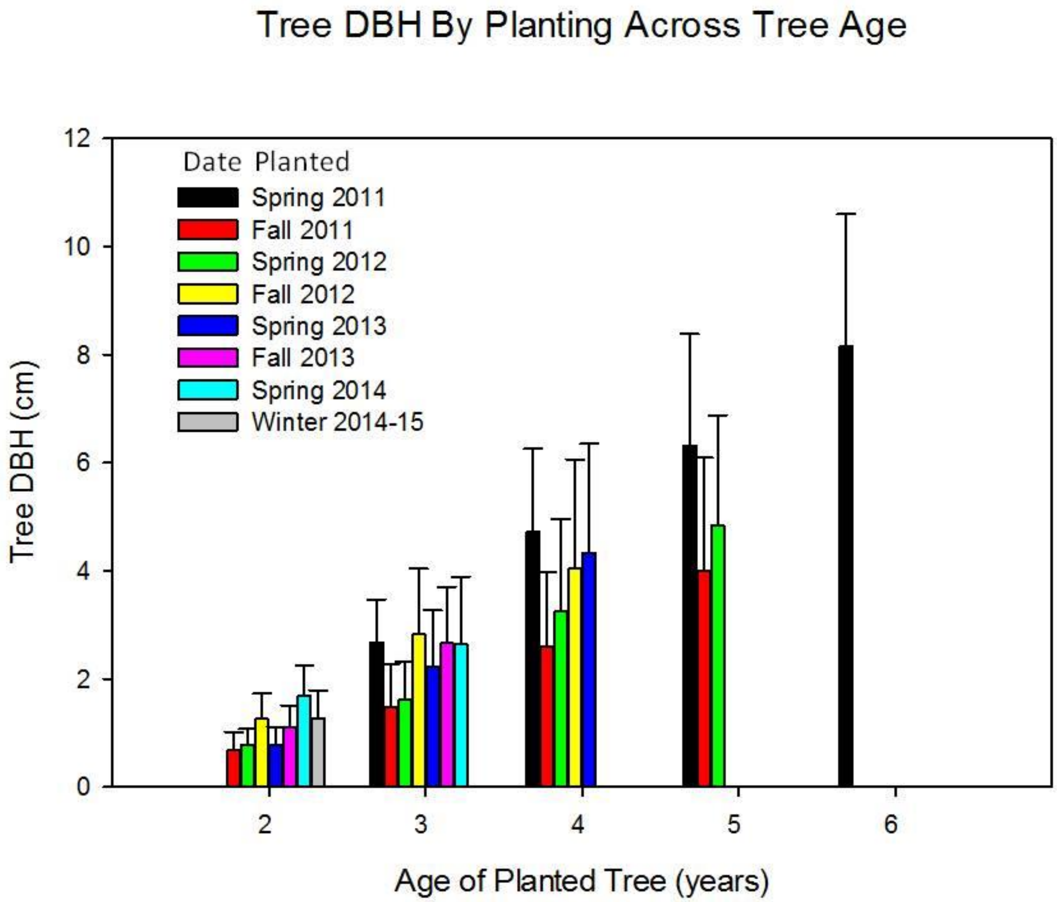
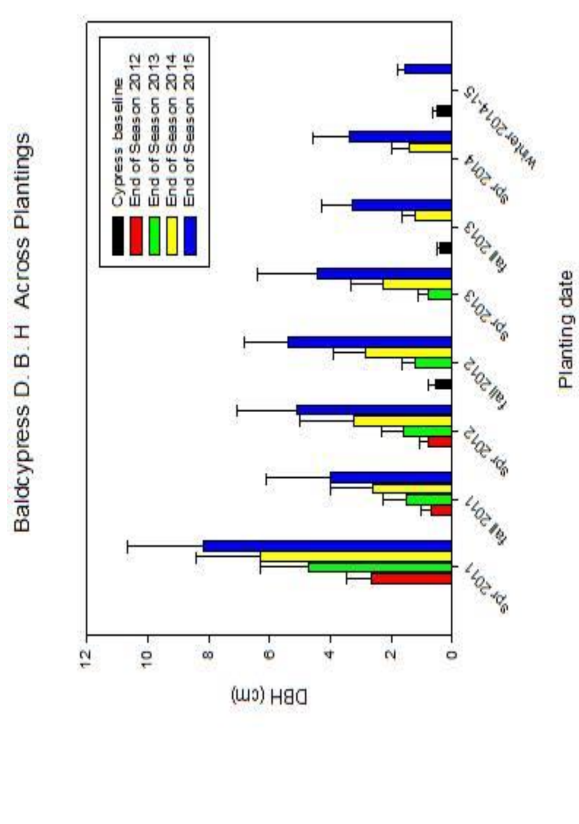
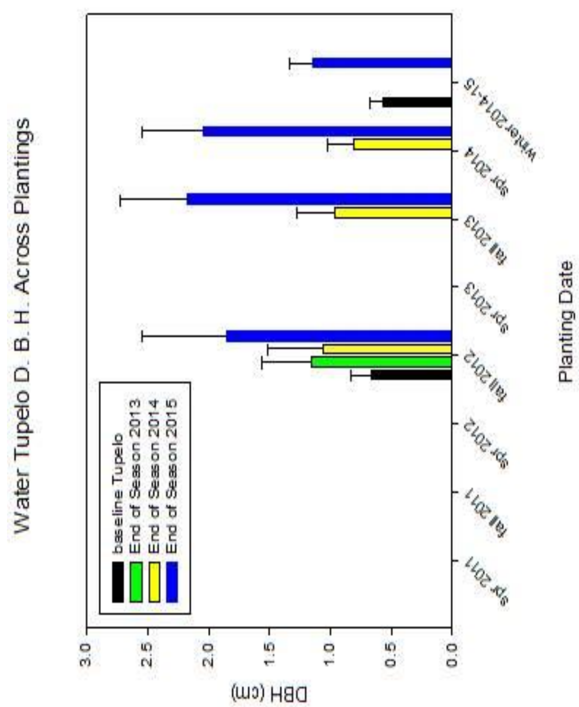


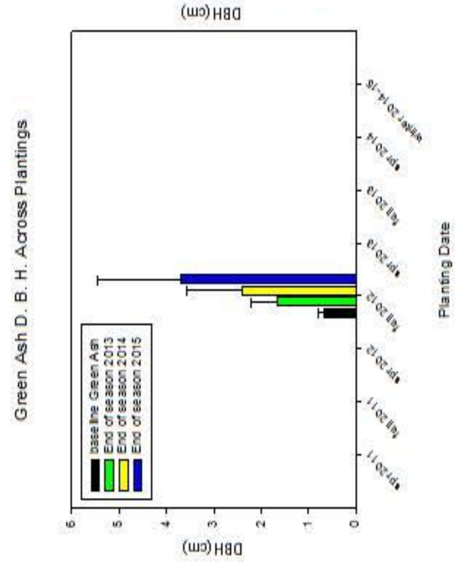
Figure 18. When comparing age classes, trees planted in the fall of 2011 and spring of 2012 consistently have slower growth-rates (d.b.h.) than trees from other plantings.

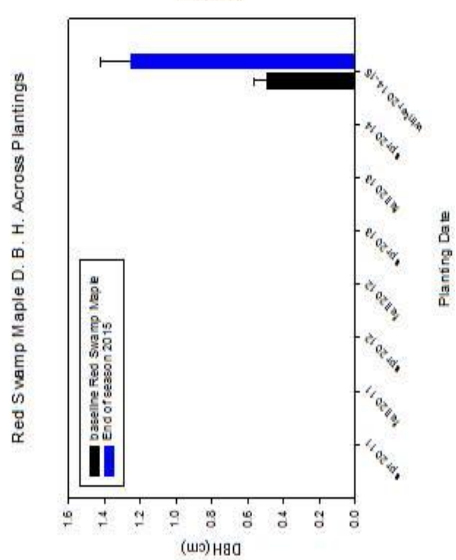
Average d.b.h. growth rate across all plantings was 1.4 cm/year. The largest average growth rate was from the spring 2011 planting at 2.16 cm/year. The lowest growth rate was from the most recent planting, winter of 2014/2015, at 0.7 cm/year.

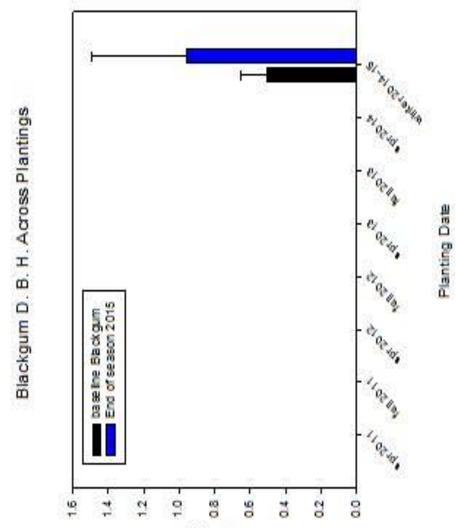
The species with the greatest average d.b.h. growth rate was baldcypress at 1.5 cm/year (**Figure 19**). Green ash had the next highest growth rate at 0.9 cm/year. Red swamp maple d.b.h. grew at 0.8 cm/year and water tupelo grew at 0.7 cm/year. Blackgum tupelo had the smallest d. b. h. growth rate at 0.35 cm/year.


Baldcypress D. B. H Across Plantings
Cypress baseline
End of Season 2012
End of Season 2013
End of Season 2014
End of Season 2015
DBH (cm)
Planting date
Spr 2011
fall 2011
Spr 2012
fall 2012
Spr 2013
fall 2013
Spr 2014
winter 2014-15


Water Tupelo D. B. H. Across Plantings
baseline Tupelo
End of Season 2013
End of Season 2014
End of Season 2015
DBH (cm)
Planting Date
Spr 2011
fall 2011
Spr 2012
fall 2012
Spr 2013
fall 2013
Spr 2014
winter 2014-15


Green Ash D. B. H. Across Plantings
baseline Green Ash
End of season 2013
End of season 2014
End of season 2015
DBH (cm)
Planting Date


Red Swamp Maple D. B. H. Across Plantings
baseline Red Swamp Maple
End of season 2015
DBH (cm)
Planting Date


Blackgum D. B. H. Across Plantings
baseline Blackgum
End of season 2015
DBH (cm)
Planting Date

Planting Challenges

Nutria herbivory continues to be a challenge in the area (**Figure 20A**), but not uniformly across all planting sites. Although there is a healthy alligator population in the CFD area (**Figure 20B**), pervasive nutria activity was seen at sites on the south side of Delacroix canal. Therefore, consistent use of nutria excluders and proper installation of excluders on all trees continues to be an essential part of the success of this project. Another, more recent challenge, is the presence of deer that chew on planted saplings above the height of the nutria excluders (**Figure 20C**). This problem has been most persistent at planting sites in the southwest corner of Big Mar Pond and has been evident over the past 2 years. Unlike nutria herbivory, deer activity doesn't seem to kill a large number of trees, but affects their height growth rates.

Figure 20: Nutria herbivory is still a challenge at some planting sites (A), despite a healthy alligator population (B). Deer activity was also observed at some sites (C).

Lessons Learned

1. Planting within Big Mar Pond may not be safe if the discharge through the Caernarvon Freshwater Diversion exceeds 3,500 cfs.
2. Soil conditions on the Caernarvon Delta vary dramatically (very soft to firm) in the planting areas and can be difficult or impossible to walk on for planting.

3. Trees should be planted on stable ground indicated by the presence of at least some emergent vegetation.
4. Trees should be planted 10-15 feet apart.
5. Statistical robustness, by species, should be considered when determining sample size of monitoring cohort
6. Each tree species per planting should be considered an individual monitoring cohort.
7. Tree baseline characteristics (height & d.b.h. and/or basal stem diameter) should be acquired prior to planting and protocols for monitoring tree survival and growth should be established at the onset of the project.
8. Trees should be identified with numbered tags.
9. A thicker gauge wire is preferable for tagged saplings. Thinner wire often corrodes within the first year, which leads to lost tags and re-tagging during the next monitoring season.
10. Monitoring should start immediately after each planting.
11. Use of gps is preferable to maintain accurate records of tree locations.
12. Monitored trees should be clearly marked with fluorescent tape or flags, because finding a particular tree is difficult once the dense native vegetation has grown up around a young tree, even with gps coordinates.
13. Writing tag numbers on tree flagging is a good back-up in case tree tags are lost during the planting process or throughout the year between yearly monitoring.
14. Longer bamboo stakes (5 foot) increase the stability of nutria protectors
15. Nutria protection tubes should be used on all planted trees, regardless of species, and installed at the time of planting, regardless of local alligator populations or the visible presence of the invasive rodents.
16. As land continues to build near the diversion access to planting sites for monitoring needs to be continually evaluated.
17. Some larger trees had damage which may have been from hogs or deer, this may require herbivory abatement which will persist after the trees have grown significantly.
18. Trees planted near the convergence of canals may be more susceptible to damage from storm surge.
19. Larger trees (3+ growing seasons) have outgrown wired tags and must bere- tagged using nails.
20. Survival rates seem to be affected by exposure to storm surge and stability of land when planted.
21. The long-term success of swamp re-forestation and continued land growth may be dependent on the continued operation of the Caernarvon Freshwater Diversion.
22. Overall cost of swamp reforestation restoration projects in southeast Louisiana is about $8,000/acre, which includes trees, nutria protectors, staff time, boat usage and miscellaneous supplies, planting at a density of approximately 200 trees/acre.

Conclusions

Tree monitoring at the end of 2015 showed that tree plantings in the vicinity of the Caernarvon Freshwater Diversion have thus far been successful. We continue to monitor positive growth in height and d.b.h. for five different wetland tree species (baldcypress, water tupelo, green ash, blackgum and red swamp maple). Adaptive management from lessons learned and an increasingly stable land platform have contributed to higher tree survival rates year after year. Therefore, LPBF, REF and CRCL plan to plant another 7,000 trees in the winter of 2016/2017.

Trees planted in the fall of 2011 and spring of 2012 have the smallest growth rates in height and d.b.h. compared against all other plantings, in all age classes. This has been the case for each year of monitoring. The fall 2011 trees were planted in still relatively new, soft and water logged land and demonstrated relatively high mortality (≈40%) and although some wetland trees, especially baldcypress and water tupelo, are adapted to prolonged flooding, it nevertheless is a stress and can cause mortality (Conner et al. 1981, Keim et al. 2006). Sites chosen for the spring 2012 trees that were hit with 12-18' storm surge during Hurricane Isaac, within 3 months of being planted, were buried with wrack and also suffered significant losses (≈55% mortality). It is likely that these two factors separately were a significant stress on the planted trees that survived and have affected their growth rates. Other plantings have higher growth rates for either height or d.b.h. likely because they were planted on higher, more stable ground and/or were not impacted by hurricane storm surge. The operation of the diversion, which has only briefly and infrequently run at a capacity to facilitate overland flow since 2011 (USGS 2016), likely has not had as much of an effect on tree survival and growth rates as land elevation and storm surge. Even small increases in elevation decrease stress and create a more favorable growing environment. Further, these sites, especially for trees planted in spring 2011, continue to remain the most stable areas on the delta, as new land expands out around them.

The Caernarvon Freshwater Diversion has created and is supporting a thriving, fresh to intermediate ecosystem and providing suitable conditions for swamp restoration. Prior to the construction and operation of the diversion, most of Big Mar Pond and the rest of the diversion receiving basin was classified as brackish marsh, with a small area of intermediate marsh (Chabreck and Linscombe 1988). By 1997, much of the area had converted to fresh and intermediate marsh (Chabreck and Linscombe 1997), a pattern that has remained through 2013 (Sasser et al. 2014) and to the present. The diversion, in essence, re-established the fresh end of the Breton Sound estuary, increasing the diversity in the region by adding fresh habitat for many species. It will be important for the diversion to be operated in the future in order to continue to maintain ideal conditions for the swamp plantings. The construction of the diversion as a salinity control project has had unintentional benefits in the basin from building new land that can provide hurricane storm surge risk reduction, to creating fresh habitat and providing opportunities to study landscape scale changes resulting from reconnecting the Mississippi River to its delta.

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