Swamp Restoration Suitability Assessment for the Pontchartrain Basin

Lake Pontchartrain Basin Foundation

Authors: Theryn Henkel, Aimee Préau, and John Lopez

September, 2016

Lake Pontchartrain Basin Foundation

Picture on Front Cover: Bald cypress tree and palmetto on the Maurepas Land Bridge, August 1, 2016. Photo courtesy of Theryn Henkel.

Introduction

Swamp forests in Louisiana provide many important ecosystem services. Swamps improve water quality by assimilating nutrients and trapping sediment, store flood waters, provide habitat for wildlife, store carbon, provide opportunities for commercial and recreational fishing and hunting, provide recreation and tourism opportunities and are culturally important (Chambers et al. 2005). Additionally, swamp forest provides storm surge protection during hurricanes while sustaining low levels of wind damage in the hurricane, when compared to other forest types (Touliatos and Roth 1971, Doyle et al. 1995, Williams et al. 1999, Doyle et al. 2007, Shaffer et al. 2016). To this end, LPBF conducted a Pontchartrain Basin wide swamp restoration suitability assessment. This assessment was made using a variety of data sets and regional knowledge. The assessment was conducted to ascertain areas that are currently suitable for swamp restoration, areas that are likely to become suitable in the near feature and areas that are not likely to be suitable.

While swamp logging began in Louisiana as early at the 1700's, logging peaked around the turn of the 20th century when it became mechanized with the expansion of rail lines, and the invention of steam powered boats and skidders and pullboats (Mancil 1980, Conner and Toliver 1990). While no exact estimates are available for the original area of swamp that existed in Louisiana prior to logging, the best estimate is that there were 0.67 million hectares of swamp lands of which less than 2 % remained after the logging activity of the early 1900s (Conner and Toliver 1990). Since then, secondary forest growth has been limited, due to the leveeing of the Mississippi River preventing pulses of sediment, nutrients, and freshwater from nourishing the swamps, saltwater intrusion from the construction of navigation, logging and oil and gas canals, subsidence, and the introduction of the invasive nutria (*Myocastor coypus*), which destroy seedlings (Blair and Langalinais 1960, Conner and Toliver 1987). In addition to the lack of prolific secondary growth, areas where secondary growth occurred are often considered relic swamp because limited reproduction occurs (due to continuous flooding) and therefore there are few saplings and seedlings to contribute to the next generation of trees (Shaffer et al. 2009). It is necessary to restore this important habitat, in order to re-establish seed sources in areas where they have been lost and restore the ecosystem services that have been lost with the degradation of the Louisiana swamp.

In the Pontchartrain Basin, historically, swamps were killed due to logging and saltwater intrusion, especially in areas like the Maurepas Land Bridge, the LaBranche Wetlands and along the Mississippi River, where swamps were part of the gradual change from bottomland hardwood forest on the natural levee, to swamp, to freshwater, intermediate, brackish and salt marsh. In Maurepas and LaBranche, much of the saltwater intrusion into the Pontchartrain Basin came through the failed navigation channel known as the Mississippi River Gulf Outlet (MRGO hereafter). The MRGO, which was completed in 1968, was constructed as an economic development project to create a shorter route to the Port of New Orleans. The canal became an economic, environmental and social disaster as it impacted over 600,000 acres of wetlands, cost more to dredge than it generated in commerce and acted as a conduit for storm surge during Hurricane Katrina, destroying whole neighborhoods and causing fatalities (Lopez et al. 2010). The spiking salinities killed many acres of the remaining swamp forest, especially during the 1999-2000 drought (Shaffer et al. 2009). The high salinities experienced periodically across the basin put the possibility of swamp restoration in doubt. However, the MRGO was closed in 2009 (Lopez et al. 2010). Since then, freshening surface salinities and soil salinities have been observed across the basin (Folse et al. 2012, Connor et al. 2016).

Since 2010, LPBF, in partnership with Restore the Earth Foundation (REF) and Coalition to Restore Coastal Louisiana (CRCL), has planted over 36,000 swamp trees in the Pontchartrain Basin. These plantings have been quite successful with high survival rates and average to above average growth rates, depending on location (Lopez et al. 2014, LPBF 2014) (LPBF unpublished data). In addition

to the successful swamp restoration plantings, LPBF has also observed the apparent occurrence of natural swamp regeneration in the Maurepas area, in areas where it was predicted that natural regeneration could not occur and had not been previously observed (Shaffer et al. 2009, Shaffer et al. 2016). With the closure of the MRGO, the introduction of freshwater into the basin from the Caernarvon Freshwater Diversion and other siphons and successful restoration plantings, there is evidence that conditions in the basin may be changing towards suitable conditions for swamp restoration.

Methods

Swamp restoration suitability was assessed by over laying a variety of surface salinity, soil salinity and vegetation data sets in ArcMap GIS software to generate restoration suitability categories.

Data Sets

Surface Salinity

The surface salinity data set used for this analysis was obtained from the record of salinity used in the 2014 and 2015 Hydrocoast Maps (Connor et al. 2016). A surface interpolation of the salinity contour lines was created for each Hydrocoast map from 2014 (24 maps) and 2015 (25 maps) (**Figure 1**). Using these, a surface of average yearly surface salinity was created for 2014 and 2015. These two surfaces, one for 2014 and one for 2015, were used to assess areas of the basin where the average surface salinity in each year was less than 2 ppt, between 2 ppt and 3 ppt and more than 3 ppt. These categories were chosen because most swamp species can thrive at salinities less than 2 ppt; bald cypress (*Taxodium distichum*), a dominant species in Louisiana swamps can survive at higher salinities, between 2 ppt and 3 ppt where other swamp species may not survive; and all swamp species, in general, do not survive in areas where salinity is consistently above 3 ppt. These three zones were delineated in ArcMap for use in the suitability analysis.
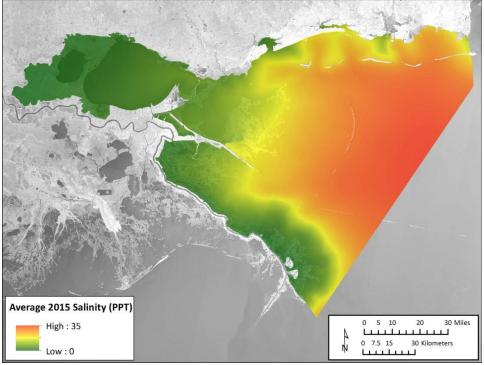

Figure 1: Example from 2015 of the interpolated salinity surface used in the swamp restoration suitability analysis.

Soil Salinity

Soil salinity data that was used for this analysis was obtained from LPBF and the Coastwide Reference Monitoring System (CRMS) (CPRA 2016). LPBF collected soil salinity data across the basin in 2014 and 2015. If soil salinity was collected at one location more than one time in the calendar year, an average was taken and used for this analysis. In each year, the data were used to divide the soil salinity into the same three categories use for the surface salinity described above. CRMS data were downloaded for 2014 and 2015 for all of the sites in the Pontchartrain Basin. The yearly average was taken for each year at all the sites then divided into the three categories. In addition, for this project specifically, soil salinity was collected in 2016 to fill in data gaps that existed in the basin, where the LPBF data and CRMS data did not cover. These areas included the LaBranche wetlands, Scarsdale and along Interstate 55 near Ponchatoula. While the 2016 data filled holes in the existing data, it did not result in any changes to the resulting map. After combining the LPBF and CRMS data into one data set for each year (**Figure 2**), the three zones were delineated in ArcMap for use in the suitability analysis.
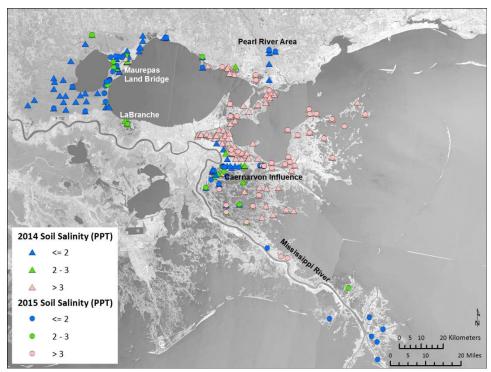

Figure 2: Location of soil salinity used in the suitability analysis from both LPBF and CRMS data sources.

Additionally, the CRMS soil salinity data was used to look at trends over time to aid with the suitability analysis. It was used in the cases where an area was not currently suitable for swamp restoration but may be suitable in the future. A downward trend in soil salinity over time indicated that an area may become suitable for swamp restoration into the future (**Figure 3**). In some cases the CRMS showed consistent soil salinity fluctuation, indicating that an area is not freshening.
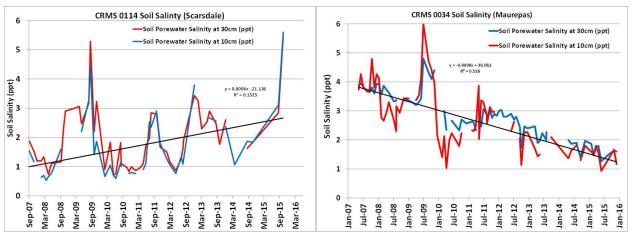
Figure 3: CRMS soil salinity data from two locations. Soil salinity from the Scarsdale (left) showed consistent fluctuation while in Maurepas (right) there is a downward trend in soil salinity.

Vegetation Delineation

Two data sets were used to delineate where swamp already exists since these areas would not be targeted for restoration. The USGS 2013 vegetation dataset was used to locate existing swamp, across the Pontchartrain Basin (Sasser et al. 2014). To refine the swamp delineation in the Maurepas area, another data set was used from NASA that was more detailed and allowed for more accuracy in this region (Spruce et al. 2012). These two data sets were combined and used in the suitability analysis.

Results

The overlay of the variety of data sets revealed four separate zones in regions across the basin. The four zones are; (1) Already swamp, (2) Restoration ready, (3) Potential future restoration, and (4) Reforestation not recommended. These categories are described below. **Figures 4 through 7** show the results of the suitability analysis across the entire Pontchartrain Basin (**Figure 4**) and then zoomed in on the Maurepas Land Bridge (**Figure 5**), the LaBranche wetlands (**Figure 6**) and the Caernarvon Freshwater Diversion influence area (**Figure 7**). The basin wide map (**Figure 4**) will be published as a separate, standalone product in addition to this report.

Already Swamp

This category was delineated using the USGS and NASA data sets described above. Areas that were already swamp in these two data sets were given this designation in the suitability analysis and therefore, restoration is not necessary in these areas.

Restoration Ready

This category was delineated using both the surface salinity and soil salinity data described above. Areas that received this designation were those that had surface and soil salinity less than 2 ppt in both years (2014 and 2015). In other words, areas that were consistently below 2 ppt for the entire study period.

Potential Future Restoration

This category was delineated using both the surface salinity and soil salinity data described above. Areas that received this designation were those where the soil or surface salinity was between 2 ppt and 3 ppt in at least one of the years. In addition, the time series of the CRMS data were used to determine if these areas were on a trajectory towards freshening over time. If a freshening trajectory

was determined, then these areas were given this designation, if the CRMS data showed consistent fluctuation in salinity and no trajectory, then these were placed in the following "Not Recommended" category. Areas under this category are not currently ready for swamp restoration because the higher salinities may affect a variety of species but could be ready for restoration in the near future.

Reforestation Not Recommended

This category was delineated using both the surface and soil salinity data described above. Areas received this designation if the soil and surface salinity was consistently above 3 ppt throughout the study period. These areas would be risky for reforestation and there is a high probability of low tree survival. Additionally, some areas were given this designation for other reasons. The Pearl River area was put in this category because portions of the area are already healthy swamp and other portions are healthy bottomland hardwood forest or marsh and therefore restoration efforts are not recommended in this area. Additionally, on or just north of the Bird's Foot, reforestation is not recommended because of the proximity to saltwater sources and little land buffer between where trees would be planted and open water. So, although some of the soil salinity or surface salinity was acceptable in this area, restoration is not recommended.

Swamp Restoration Suitability Assessment
For the Pontchartrain Basin
2013 - 2015

Restoration Ready

Potential Future Restoration

Reforestation Not Recommended

Already Swamp

Pearl River Area

Mississippi River

Caernarvon Influence

Maurepas Land Bridge

LaBranche

LPBF
SAVE OUR LAKE
SAVE OUR COAST

RESTORATION CATEGORY	ACRES	HECTARES	MILES²
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			
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			
SOIL			
	<2 ppt all years	2 - 3 ppt at least one year	>3 ppt all years

*ppt = parts per thousand

Information on the Lake Pontchartrain Basin Foundation swamp restoration assessment study can be found at saveourlake.org. Map citation: Preau, A.P., T. Henkel and J. Lopez, Swamp Restoration Suitability Assessment for the Pontchartrain Basin 2013-2015 [map], 1:750,000, Lake Pontchartrain Basin Foundation, New Orleans, LA, 2016.

N

0   5   10   20 Kilometers
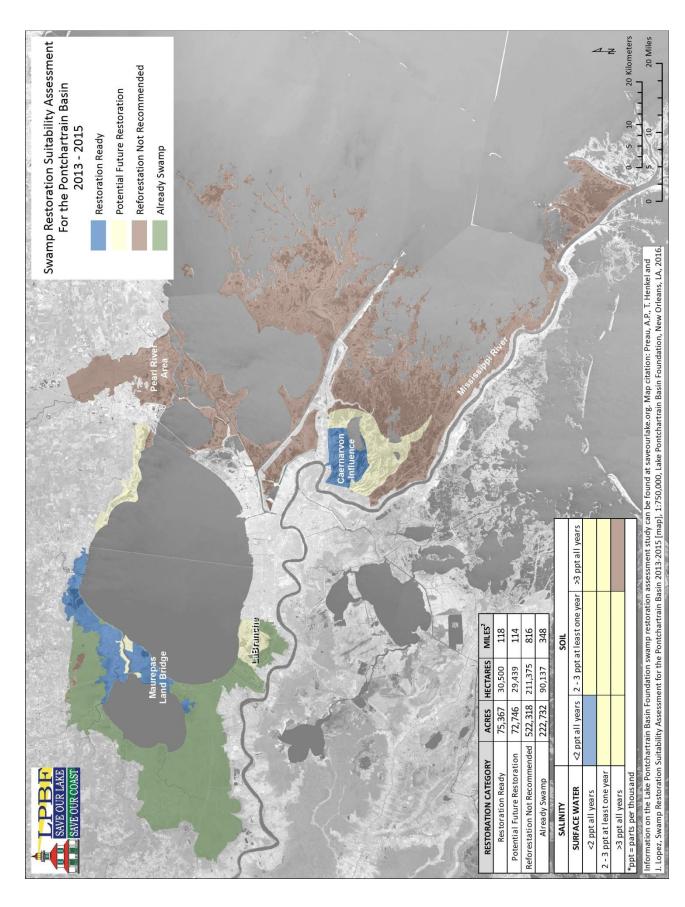0   5   10   20 Miles

Figure 4: Results of the swamp restoration suitability analysis showing areas that are already swamp (green), restoration ready (blue), potential for future restoration (yellow) and where restoration is not recommended (brown).
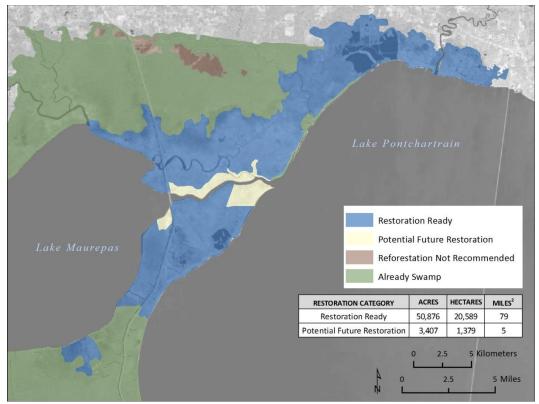
8

Figure 5: Results of the swamp restoration suitability analysis on the Maurepas Land Bridge.
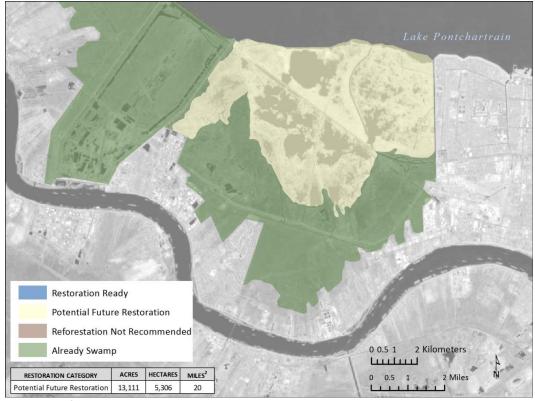
RESTORATION CATEGORY	ACRES	HECTARES	MILES^2
Restoration Ready	50,876	20,589	79
Potential Future Restoration	3,407	1,379	5

Figure 6: Results of the swamp restoration suitability analysis in the LaBranche wetlands.

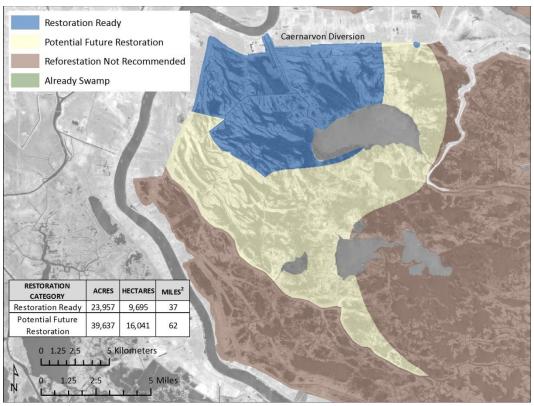| RESTORATION CATEGORY	ACRES	HECTARES	MILES^2
Potential Future Restoration	13,111	5,306	20

Figure 7: Results of the swamp restoration suitability analysis in the Caernarvon Freshwater Diversion influence area.

Area by Category

In the Pontchartrain Basin there are 30,500 hectares (75,367 acres, 118 mi^2) that are restoration ready (**Table 1**). In addition, there are 29,439 hectares (72,746 acres, 114 mi^2) that are potential future restoration for a total area of over 59,000 hectares (145,000 acres, 230 mi^2) that could be restored now or in the near future. On the Maurepas Land Bridge there are 20,589 hectares (50,876 acres, 79 mi^2) that are restoration ready, mostly bordering areas that are already swamp (**Table 2**). In addition there are 1,379 hectares (3,407 acres, 5 mi^2) that have the potential for future restoration. In the LaBranche wetlands, there are 5,306 hectares (13,111 acres, 20mi^2) that have the potential for future restoration (**Table 3**). There is no area in the LaBranche wetlands that is restoration ready. In the Caernarvon Freshwater Diversion influence area there are 9,695 hectares (23,957 acres, 37 mi^2) that are ready for restoration and 16,051 hectares (39,637 acres, 62 mi^2) that have the potential for future restoration (**Table 4**).

Table 1: Area by restoration category in the Pontchartrain Basin.

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

Table 2: Area of restoration ready and potential future restoration categories on the Maurepas Land Bridge.

RESTORATION CATEGORY	ACRES	HECTARES	MILES^2
Restoration Ready	50,876	20,589	79
Potential Future Restoration	3,407	1,379	5

Table 3: Area of potential future restoration in the LaBranche wetlands. There is no area that is currently ready for restoration.

RESTORATION CATEGORY	ACRES	HECTARES	MILES^2
Potential Future Restoration	13,111	5,306	20

Table 4: Area of restoration ready and potential future restoration categories in the Caernarvon Freshwater Diversion influence area.

RESTORATION CATEGORY	ACRES	HECTARES	MILES^2
Restoration Ready	23,957	9,695	37
Potential Future Restoration	39,637	16,041	62

Discussion

There is a large area of the Pontchartrain Basin that is restoration ready and almost the same amount that is predicted to be ready in five to ten years (future restoration). It is believed that this large area of restoration ready land is due to changing conditions in the basin, caused mostly by the introduction of Mississippi River water (Caernarvon Freshwater Diversion especially) and the closure of the MRGO. Both of these projects have caused the surface and soil salinities in the affected regions to decrease over time, to levels acceptable for swamp restoration. There is opportunity for these areas to expand over time or for the areas designated "future restoration" to become restoration ready more quickly, as proposed diversions in the Pontchartrain Basin come online, namely, the Maurepas Swamp Freshwater Diversion and the Mid-Breton Sediment Diversion (CPRA 2012).

On the Maurepas Land Bridge, the restoration ready areas could accommodate over 9.8 million trees (assuming 4.5 meter spacing). An additional 650,000 trees could be planted in the future if the potential restoration areas become restoration ready. In total, there is a potential to plant over 10.4 million trees on the Maurepas Land Bridge and the adjacent Northshore area (from the land bridge to the Tchefuncte River). The Maurepas Land Bridge has become restoration ready mostly due to the closure of the MRGO. CRMS data from the land bridge show a decline in surface and soil salinity coinciding with the closure in 2009 (CPRA 2016). Trees planted prior to 2009 on the land bridge had low survival rates, especially those that were planted prior to the 1999/2000 drought that hit southeast Louisiana (Gary Shaffer, pers. comm, Shaffer et al. 2009). Trees planted over the last two years by LPBF and partners have survival rates of over 80%, indicating that the region is suitable for plantings, although this data set is short term and cannot show long-term trends in the area. In the future, the proposed Maurepas Freshwater Diversion (influence area includes the land bridge), would help to maintain low salinities in the region as well as provide nutrients and small amounts of sediment.

In the LaBranche wetlands, there are no restoration ready areas. The potential future restoration areas could accommodate over 2.5 million trees. The LaBranche wetlands have moved towards potential restoration most likely due to the closure of the MRGO. CRMS data in the LaBranche wetlands show a decline in surface and soil salinity coinciding with the closure of the MRGO. In addition,

three years of surface salinity from LPBF's Hydrocoast maps, near the wetlands, show consistently low surface salinities over the past three years and there is a pump station that pumps fresh storm water into the wetlands, providing a sporadic source of freshwater.

In the Caernarvon Freshwater Diversion influence area, the restoration ready areas could accommodate over 4.6 million trees. The potential restoration areas could accommodate an additional 7.6 million trees in the future. In total, there is the potential to plant over 12.2 million trees in the Caernarvon Freshwater Diversion influence area over the next five to ten years. This area has become restoration ready due to the influence of the Caernarvon Freshwater Diversion. Prior to its construction and operation in 1991, the region consisted mostly of brackish marsh with a small area of intermediate marsh, which is not suitable for swamp restoration (Chabreck and Linscombe 1988). By 1997, much of the area had converted to fresh marsh (Chabreck and Linscombe 1997), a pattern that still holds today (Sasser et al. 2014). The fresh habitat created by the diversion has created the restoration ready conditions present in the region. Additionally, LPBF and partners have been doing swamp restoration plantings in the area since 2010 with over 75% survival, indicating that the area is suitable for swamp restoration. The diversion operation has the potential to maintain restoration ready conditions by introducing freshwater, nutrients and sediment into influence area, maintaining proper salinity conditions, fertilizing the trees and building new land for future plantings.

The number of trees that could be planted in the restoration ready areas across the Pontchartrain Basin is over 14.5 million trees (assuming 4.5 meter spacing). The number of trees that could be planted on the "future restoration" sites is over 13.6 million. Therefore, over the next five to ten years, there could be acceptable conditions in the Pontchartrain Basin to plant over 28.1 million trees. At the current rate of LPBF, CRCL and REF's partnership planting program, where approximately 12,000 trees are planted in one season, it would take over 1,000 planting seasons to accomplish the planting of 15 million trees. Of course, the areas that are designated as "restoration ready" are not 100% plantable as there are open water areas, areas where some tree canopy already exists or the ground is not solid enough. However, the numbers illustrate the scope of the need and that the current capacity does not exist to meet that need.

There are two possible solutions to the need for large-scale swamp restoration in the "restoration ready" areas in the Pontchartrain Basin. First is the natural regeneration of swamp species from nearby seed sources. LPBF has observed natural regeneration in several areas on the Maurepas Land Bridge and is currently studying the extent and density of the natural regeneration. For natural regeneration to be a viable option there needs to be a nearby seed source. Therefore, relying on natural regeneration in the Caernarvon area may not be possible since there is not a large seed source but could be viable in the Maurepas region since numerous seed sources exist. In the LaBranche Wetlands (slated for "future restoration") there are nearby seed sources as well. Over time, if the conditions remain suitable for natural regeneration, the forest could slowly recover on its own. Additionally, the trees that have been planted as part of the planting program represent future seed sources.

A second possible method would be to come up with a solution to plant the "restoration ready" areas much more quickly than current rates. Hand planting 1-year old potted trees using volunteers or a commercial planter (current method) can be time consuming, although thus far have yielded high survival rates (LPBF 2014). In this case, each tree is planted with a substantial root ball and a nutria protector. However, there could be methods to either drop seedlings or seeds, in bulk, from the air where they germinate or root when landing on the ground. Seedlings could be grown in small weighted receptacles that biodegrade over time (Arnold 1982). The weight would ensure that the trees would land right side up and penetrate the soil surface. While a design for this methodology could be found (Arnold 1982), no literature sources could be found where this was deployed in the field at any real scale or any indication of tree survivorship using this method. Also, since the trees would be most likely deployed without nutria protectors, herbivory is still a concern. In contrast, seeds could be released

from a plane over a large area. If many seeds are deployed, then even if germination or survivorship rates are lower, there would be enough trees germinating to effect restoration. The same potential problem of herbivory exists with this method as well. Ideally, these methods would be tested by deploying trees or seeds in an area that is readily accessible so that success or failure could be monitored. If either of these methods proved successful, it could then be applied over larger and interior areas where the logistics of access for planting and monitoring are impossible.

The swamp restoration suitability analysis revealed that there are large areas in the Pontchartrain Basin that are ready for swamp restoration. The next steps for LPBF will be to assess different methods for planting at a landscape scale in these areas, using novel methods. In the meantime, LPBF will continue to plant trees under the current planting program. Additionally, LPBF and partners will continue to monitor the areas designated as potential future restoration areas to determine when those areas become suitable for planting. This analysis also shows the potential for swamp restoration to occur in conjunction with hydrologic restoration projects such as river diversions or canal filling. Synergy between different restoration types and techniques will be especially important going forward with large, landscape scale restoration as the goal (CPRA 2012). As restoration projects become larger they also become more expensive. By having one project benefit from another or create suitable conditions for another, helps justify projects costs and can make projects more sustainable into the future. Sustainability, through project synergy, is especially important as sea-level rise predictions become more extreme and under which, the resiliency of south Louisiana becomes tenuous.

References

Arnold, R. L. 1982. Air drop plantings system and improved panting device for same. Patent 4333265. 8 June 1982. United States.

Blair, R. M. and M. J. Langalinais. 1960. Nutria and swamp rabbits damage baldcypress plantings. Journal of Forestry **58**(5):388-389.

Chabreck, R. H. and G. Linscombe. 1988. Vegetative type map of the Louisiana coastal marshes: Baton Rouge, Louisiana Department of Wildlife and Fisheries, set of 10 maps.

Chabreck, R. H. and G. Linscombe. 1997. Vegetative type map of the Louisiana coastal marshes: Baton Rouge, Louisiana Department of Wildlife and Fisheries.

Chambers, J. L., W. H. Conner, J. W. Day, Jr., S. P. Faulkner, E. S. Gardiner, M. S. Hughes, R. F. Keim, S. L. King, C. A. Miller, J. A. Nyman, and G. P. Shaffer. 2005. Conservation, protection, and utilization of Louisiana's coastal wetland forests. Final report to the Governer of Louisiana from the Coast Wetland Forest Conservation and Use Science Working Group: Baton Rouge, LA, USA. 121pp.

Conner, W. H. and J. R. Toliver. 1987. The problem of planting Louisiana swamplands when nutria (*Myocastor coypu*) are present.*in* Proceedings of the Third Eastern Wildlife Damage Control Conference. University of Nebraska-Lincoln. http://digitalcommons.unl.edu/ewdcc3/9/.

Conner, W. H. and J. R. Toliver. 1990. Long-term trends in bald cypress (*Taxodium disichum*) resource in Louisiana (USA) Forest Ecology and Management **33-4**(1-4):543-557.

Connor, P., J. Lopez, T. Henkel, E. Hillmann, A. Preau, A. Baker, D. Baker, I. Kelly, and P. Smith. 2016. Hyrdocoast Maps. Map, 1:1,100,000. Lake Pontchartrain Basin Foundation http://www.saveourlake.org/coastal-hydromap-archives.php.

CPRA. 2016. Coastwide Reference Monitoring System-Wetlands Monitoring Data. Coastal Protection and Restoration Authority of Louisiana. Retrieved from Coastal Information Management System (CIMS) database. http://cims.coastal.louisiana.gov.

CPRA. 2012. Louisiana's Comprehensive Master Plan for a Sustainable Coast. Baton Rouge, Louisiana: Coastal Protection and Restration Authority, 188 p.

Doyle, T. W., W. H. Conner, R. H. Day, K. W. Krauss, and C. M. Swarzenski. 2007. Wind damage and salinity effects of Huricanes Katrina and Rita on coastal baldcypress forests of Louisiana.*in* G. S. Farris, G. J. Smith, M. P. Crane, C. R. Demas, L. L. Robbins, and D. L. Lavoie, editors. Science and the storms—the USGS response to the hurricanes of 2005: U.S. Geological Survey Circular 1306, 283 p.

Doyle, T. W., B. D. Keeland, L. E. Gorham, and D. J. Johnson. 1995. Structural impact of Hurricane Andrew on the forested wetlands of the Atchafalaya Basin in south Louisiana. Journal of Coastal Research **SI**(21):354-364.

Folse, T. M., J. L. West, M. K. Hymel, J. P. Troutmann, L. Sharp, D. Weifenbach, T. McGinnis, and L. B. Rodrigue. 2012. A standard operating procedures manual for the Coast Wide Referencing System-wetlands: Methods for site establishments, data collection, and quality assurance/quality control. The Louisiana Coastal Protection and Restoration Authority. Baton ROuge, LA. 207 pp.

Lopez, J., T. Henkel, A. Moshogianis, A. Baker, E. Boyd, E. Hillmann, P. Connor, and D. B. Baker. 2014. Examination of deltaic processes of Mississippi River outlets - Caernarvon Delta and Bohemia Spillway in Southeast Louisiana. Gulf Coast Association of Geological Sciences **3**:79-93.

Lopez, J., A. Moore, and J. Constible. 2010. Mister go isn't gone yet: Creating community and environmental resiliency in the wake of a man-made catastrophe. MRGO Must Go Coalition, New Orleans, Louisiana.

LPBF. 2014. Caernarvon Delta & Diversion Study: Status April 2014. Lake Pontchartrain Basin Foundation http://saveourlake.org/PDF-documents/our-coast/Caernarvon/Caernarvon%20Delta%20and%20Diversion%20Study_LPBF_5-6-2014.pdf:22 pgs.

Mancil, E. 1980. Pullboat logging. Journal of Forest History **24**(3):135-141.

Sasser, C. E., J. M. Visser, E. Mouton, J. Linscombe, and S. B. Hartley. 2014. Vegetation types in coastal Louisiana in 2013: U.S. Geological Survey Scientific Investigations Map 3290, 1 sheet. scale 1:550,000, http://dx.doi.org/10.3133/sim3290.

Shaffer, G. P., J. W. Day, D. Kandalepas, W. B. Wood, R. G. Hunter, R. R. Lane, and E. R. Hillmann. 2016. Decline of the Maurepas Swamp, Pontchartrain Basin, Louisiana and approaches to restoration. Water **8**(101):1-28.

Shaffer, G. P., W. B. Wood, S. S. Hoeppner, T. E. Perkins, J. Zoller, and D. Kandalepas. 2009. Degradation of Baldcypress-Water Tupelo Swamp to Marsh and Open Water in Southeastern Louisiana, USA: An Irreversible Trajectory? Journal of Coastal Research SI 54:152-165.

Spruce, J., S. Sader, and J. Smoot. 2012. A project to map and monitor baldcypress forests in coastal Louisiana using Landsat, MODIS, and ASTER satellite data. Presentation at 2012 Louisiana Remote Sensing and GIS Workshop. Baton Rouge, LA. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120007429.pdf.

Touliatos, P. and E. Roth. 1971. Hurricanes and trees - 10 lessons from Camille. Journal of Forestry **69**(5):285-289.

Williams, K., Z. S. Pinzon, R. P. Stumpf, and E. A. Raabe. 1999. Sea level rise and coastal forests on the Gulf of Mexico. USGS-99-441, 63p.