ANALYZING SITE SUITABILITY FOR BALDCYPRESS (*TAXODIUM DISTICHUM*) REGENERATION ALONG A HYDROLOGIC GRADIENT IN SOUTH LOUISIANA SWAMPS

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The School of Renewable Natural Resources

by
Marcus Rutherford
B.S., Southern Illinois University at Carbondale, 2012
December 2015

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The future of Louisiana's coastal cypress-tupelo forests is threatened by prolonged or permanent flooding during the growing season. Permanent inundation prevents baldcypress seedlings from becoming established. The upper limit of submergence with respect to adequate planted baldcypress seedling performance has not been effectively tested under actual field conditions. Similarly, an effective method for determining a site's regeneration potential based on present vegetation attributes has not been developed.

To test first-year performance of planted baldcypress seedlings under varying levels of submergence, I planted 900 of both 1-0 and 2-0 age-class bare-root seedlings across 12 different sites covering a range of hydrologic conditions and monitored their performance over the 2014 growing season. Water levels were continuously monitored for each individual seedling, and survival and height growth were documented. Due to their taller starting heights, 2-0 seedlings were submerged, on average, less often (1.4 days) than 1-0 seedlings (34.8 days). Survival was high across sites for both age classes (79% for 1-0 and 89% for 2-0). Survival of 1-0 seedlings decreased to only 9% following more than 90 cumulative days of submergence. Height growth across sites was greater for 1-0 seedlings (0.29 m) than 2-0 seedlings (0.13 m). Height growth of 1-0 seedlings decreased significantly following more than 30 cumulative days of submergence.

To relate present vegetation attributes to baldcypress regeneration potential, I sampled the vegetation on all 12 sites in addition to using vegetation and hydrology data from five sites monitored by the Coastwide Reference Monitoring System (CRMS). Sites were separated into three categories based on how their hydrologic regime related to

baldcypress regeneration potential. Sites with potential for natural regeneration were indicated by a species-diverse overstory and a high midstory stem density. Sites with only artificial regeneration potential were indicated by an overstory layer consisting almost exclusively of cypress-tupelo and a dense midstory layer with a high percentage of stems rooted on elevated structures. Sites with neither natural nor artificial regeneration potential were indicated by an overstory layer consisting almost exclusively of cypress-tupelo and a sparse midstory layer with a high percentage of stems rooted on elevated structures.

INTRODUCTION

Baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica and Nyssa biflora*) swamp forests (hereafter referred to as cypress-tupelo forests) have long dominated many coastal areas along the southeastern United States and its connecting rivers. Hydrology and its many influential facets are the main factors controlling the ecological dynamics of these unique systems, namely species composition, sedimentation, nutrient processes, and ecosystem productivity (Nyman 2011). Baldcypress and tupelo trees dominate wetland forest composition in Louisiana, which has more of this forest cover type than any other state (Conner and Day 1976).

The functions and services that cypress-tupelo forests provide for the wetland forest ecosystem are numerous, and not all are known or well understood (Mitsch and Gosselink 2000). Cypress-tupelo forests offer invaluable wildlife habitat to numerous bird, mammal, fish, reptile, and amphibian species. Of major importance, both ecologically and economically, cypress-tupelo forests play an integral role in coastal protection from the damaging effects from hurricanes by absorbing heavy winds and water surges from the Gulf of Mexico. Cypress-tupelo forests also act as a sink for excessive nutrients carried by river systems, essentially intercepting them to utilize and store rather than being deposited into the Gulf of Mexico (Brinson et al. 1983, Nyman 2011). Cypress lumber is renowned for its strength, durability, resistance to rot, and is a commonly used species for landscape mulch. The aesthetic beauties of cypress trees and swamps also have great historical and cultural importance to inhabitants of these unique forested areas.

Anthropogenic disturbances coupled with land subsidence have altered the historical hydrologic regime of an expansive acreage of wetland forests across much of southeast Louisiana. Urban and industrial development, oil and gas exploration, shipping, road construction and many other coastal activities have led to the impoundment of many cypress-tupelo forests and effectively isolated them from the annual flushing by fresh flood waters and deposition of sediment in riverine systems (Keim et al. 2006, Faulkner et al. 2009). Levees and water control structures have been installed to keep the water in the rivers and out of the floodplains to make land more suitable for development and agriculture, but the effects of these constructions on ecosystem function were largely ignored (Viosca 1928). Widespread logging took place to fuel this industrial movement, and vast amounts of mature cypress-tupelo forests were cleared (Mancil 1980). Following this large-scale logging, many of today's stands regenerated before they were impounded and cut off from their historical hydrologic regime. Presently, many of these second-growth stands have reached merchantable volumes, and land managers are assessing the feasibility of timber harvests. Before harvesting can be completed, land managers want to ensure that the stands can be logged in a sustainable manner to protect the integrity of the forests.

Although many wetland forest stands presently appear adequately stocked and healthy, permanent inundation, where it occurs, prevents natural regeneration, resulting in unsustainable stands (Conner et al. 1986, Conner and Day 1988). Baldcypress is considered one of the most tolerant tree species to flooding and soil waterlogging (McKnight, et al. 1981, Hook 1984, Keeland 1994). However, baldcypress seeds cannot germinate in standing water; they need a dry period of several consecutive weeks to

2

germinate and seedlings require even much longer periods to reach a critical height for permanent establishment (Demaree 1932, DuBarry 1963, Williston et al. 1980, Conner and Day 1988, Pezeshki et al. 1993, Chambers et al. 2005). The best scenario for seedlings to become established through natural regeneration occurs on sites with slow-moving, riverine inputs of freshwater that transports seeds away from the dense canopy trees to germinate in openings following drawdowns (Schneider and Sharitz 1988, De Steven and Sharitz 1997, Keeland and Conner 1999). However, relying on natural regeneration in many cases is an unsustainable practice, largely due to the stagnant nature of the surface water, the lack of riverine connectivity to supply frequent inputs of freshwater, and the limited occurrence of mineral soil exposure (Conner and Day 1988, Chambers et al. 2005). Germination dynamics in wetlands are very complex spatially due to the variable nature of water depths and flooding at different times of the year across a landscape. Because of the relationship between germination and water depth, natural baldcypress regeneration occurs more commonly at the interface between swamp forests and bottomland hardwood forests where flooding is less frequent, and is largely dependent on microsite conditions (Middleton 2000). Consequently, natural regeneration requirements for baldcypress under present conditions cannot be satisfied when temporal and spatial constraints on seedling establishment leave the forests at risk of shifting to another forest cover type or converting to marsh (Conner et al. 1986, Keim et al. 2006).

According to a report produced by the Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority (Coast 2050 1998), several river diversions have been proposed in southeastern Louisiana over the next several years, potentially impacting thousands of acres of cypress-tupelo

swamps. The objectives of these diversions are to increase the freshwater (harboring some sediment) and nutrient loads into the swamps and replace potential salinity pulses with freshwater, with the hopes of minimizing the current degradation and improving the overall health of the swamps. While it is unfeasible and unrealistic to alter all disconnected and impounded systems immediately, a more practical approach for assessing harvest potential is to determine which areas are the best candidates for regenerating stands of cypress-tupelo forests in their current condition and concentrate some effort to keeping those systems functioning. In addition, it may be possible to regenerate and establish some stands before the hydrologic regimes are restored or before a harvest occurs, thus getting an advance on the restoration process. Similarly, following these proposed hydrologic restoration projects, it is critical to understand and quantify the hydrologic regime factors affecting both natural and artificial regeneration establishment.

With the looming uncertainty of the future of Louisiana's cypress-tupelo forests, the Governor of the State of Louisiana commissioned a Science Working Group (SWG) on Coastal Wetland Forests to evaluate scientific information related to wetland forests and develop management recommendations for regeneration and utilization of coastal wetland forests (Chambers et al. 2005). The SWG developed three condition classes for regeneration (hereafter referred to as Regeneration Condition Classes or RCCs) based on site factors, both biological and physical, that define the potential for cypress to regenerate, assuming normal climatic factors.

These Regeneration Condition Classes (RCCs) were established to promote a general, systematic understanding of a site's potential for baldcypress regeneration. The RCC system was intentionally developed to help natural resource professionals better

understand the set of forested swamp conditions that restrict and control overall regeneration of cypress and tupelo. However, due to the variable, yearly conditions, it is very difficult to project long term conditions with little or no knowledge or data of each site's long-term hydrologic regime. The RCC system has limited ability to assist in management without additional decision-making tools. Microsite variability, coupled with the lack of historical water level data for most areas make it difficult to assess RCC categorization based on knowledge offered by a single site visit. Another issue is that the definitions for the RCCs are based on the practicality of planting and not specific information on performance potential of planted baldcypress and tupelo. Without knowing the nature of the flood regime or various other site factors that may affect seedling performance, it can be very difficult to categorize an area's regeneration potential. Further research to assess an area's flood regime and potential seedling performance without having long-term hydrologic data is needed.

The overall objective of the research described is to develop a system to assess baldcypress regeneration potential across a range of hydrologic conditions. Additionally, this study aims to further refine the existing SWG RCCs and simplify the application to current sites until more hydrologic data can be accumulated for the broader array of existing sites. In the short-term, this study will provide much-needed field-based data to natural resource professionals for consideration when making management decisions regarding reforestation and restoration projects. The long-term objective for this research is to improve our knowledge of tree establishment dynamics within coastal wetland forests in southern Louisiana by providing a better understanding of the relationships between hydrology and planted seedlings. This research will hopefully aid in developing

management recommendations for creating and maintaining healthy stands in

permanently flooded cypress-tupelo forests.

I.1 Literature Cited

Brinson, M.W., Bradshaw D.H., and Kane E.S. (1984). Nutrient assimilative capacity of an alluvial floodplain swamp. Journal of Applied Ecology 21: 1041-1057.

Chambers, J. L., Conner W.H., Day J.W., Faulkner S.P., Gardiner E.S., Hughes M.S., Keim R.F., King S.L., McLeod K.W., Miller C.A., Nyman J.A,, and Shaffer G.P. (2005). Conservation, Protection and Utilization of Louisiana's Coastal Wetland Forests. Final Report to the Governor of Louisiana from the Science Working Group on Coastal Wetland Forest Conservation and Use. Baton Rouge, LA, USA.

Conner, W.H., Day J.W. (1976). Productivity and composition of a baldcypress-water tupelo site and a bottomland hardwood site in a Louisiana swamp. American Journal of botany 63:10: 1354-1364.

Conner, W.H., Day J.W. (1988) Rising water levels in coastal Louisiana - implications for two coastal forested wetland areas in Louisiana. Journal of Coastal Research 4: 589-596.

Conner, W.H., Toliver J.R., and Sklar F.H. (1986) Natural regeneration of baldcypress (*Taxodium distichum* [L] Rich.) in a Louisiana swamp. Forest Ecology and Management 14: 305-317.

Demaree, D. (1932). Submerging Experiments with Taxodium. Ecology 13: 258-262.

De Steven D. and R.R. Sharitz (1997). Differential recovery of a deepwater swamp forest across a gradient of disturbance intensity. Wetlands 17: 476-484.

DuBarry, A.P. Jr. (1963) Germination of bottomland tree seed while immersed in water. Journal of Forestry 61: 225-226.

Faulkner S.P., Bhattarai Y., Allen Y., Barras J., Constant G. (2009) Identifying baldcypress-water tupelo regeneration classes in forested wetlands of the Atchafalaya Basin, Louisiana. Wetlands 29: 809-817.

Hook, D.D. (1984) Waterlogging Tolerance of Lowland Tree Species of the South. Southern Journal of Applied Forestry 8:3:136-149.

Keeland, B.D. (1994). The effects of variations in hydrologic regime on diameter growth in *Nyssa aquatica*, *Nyssa sylvatica* var. *biflora*, and *Taxodium distichum*. Dissertation, University of Georgia.

Keeland, B.D. and Conner W.H. (1999) Natural regeneration and growth of *Taxodium distichum* (L.) Rich. in Lake Chicot Louisiana after 44 years of flooding. Wetlands 19: 149–155.

Keim, R.F., Chambers J.L., Hughes M.S., Dimov L.D., Conner W.H., Shaffer G.P., Gardiner E.S., and Day J.W. Jr. (2006). Long-term success of stump sprouts in high-graded baldcypress–water tupelo swamps in the Mississippi delta. Forest Ecology and Management 234: 24-33.

Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority (1998). Coast 2050: Toward a sustainable coastal Louisiana. Louisiana Department of Natural Resources, Baton Rouge, LA, USA.

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

McKnight, J.S., Hook, D.D., Langdon, O.G. & Johnson, R.L. (1981). Flood tolerance and related characteristics of trees of the bottomland forests of the southern United States. In: Wetlands of Bottomland Hardwood Forests (eds. Clark J.R. and Benforado J.). Elsevier Amsterdam, the Netherlands: pp 26-69.

Middleton B. (2000). Hydrochory, seed banks, and regeneration dynamics along the landscape boundaries of a forested wetland. Plant Ecology 146: 169-184.

Mitsch, W.J. and Gosselink J.G. (2000). The value of wetlands: importance of scale and landscape setting. Ecological Economics 35:1: 25-33.

Nyman, J.A. (2011). Ecological functions of wetlands. In: Wetlands: Integrating Multidisciplinary Concepts (ed. B. La Page). Springer Science. pp.115-128.

Pezeshki S.R., DeLaune R.D., and Patrick W.H. Jr. (1993). Responses of forested wetland species to alteration in soil hydrology/chemistry. In: Wetlands: Proceedings of the 13th Annual Conference of the Society of Wetland Scientists, New Orleans, LA. pp. 878-889.

Schneider, R.L. and Sharitz R.R. (1988). Hydrochory and regeneration in a baldcypress-water tupelo swamp forest. Ecology 69:1055–1063.

Viosca, P., Jr. (1928). A new species of Hyla from Louisiana. Proceedings of the Biological Society of Washington 41: 89–91.

Williston, H.L., Shropshire F.W., and Balmer W.E. (1980). Cypress Management: A Forgotten Opportunity. Forestry Report SA-FR 8. USDA Forest Service, Southeastern Area, State and Private Forestry, Atlanta, GA.

CHAPTER 1: ANALYZING PERFORMANCE OF PLANTED BALDCYPRESS (*TAXODIUM DISTICHUM*) ALONG A HYDROLOGIC GRADIENT IN SOUTH LOUISIANA SWAMPS

1.1 Introduction

Cypress-tupelo forests comprise a vast acreage across the Gulf of Mexico and Atlantic coastal plains. Many of the coastal cypress-tupelo forests are at risk of converting to another cover type, such as shrub-scrub, marsh, or even open water because of unfavorable conditions for natural regeneration and successful establishment of baldcypress and water tupelo seedlings on the wetter end of the environmental gradient. Anthropogenic disturbances along with land subsidence have combined to alter the historic hydrologic regime in many of these forests, resulting in permanently flooded conditions, especially during the active growing season.

With the looming uncertainty of the future of Louisiana's coastal cypress-tupelo forests, the Governor of the State of Louisiana commissioned a Science Working Group (SWG) on Conservation, Protection and Utilization of Louisiana's Coastal Wetland Forests to evaluate scientific information related to wetland forests and to develop management recommendations for regeneration and utilization of coastal wetland forests. The SWG developed three condition classes for regeneration (hereafter referred to as Regeneration Condition Classes or RCC I, II, or III) based on site factors, both biological and physical, that define the potential for cypress to regenerate, assuming normal climatic factors (Chambers et al. 2005). They are as follows:

RCC I: Sites with Potential for Natural Regeneration. These sites are generally connected to a source of fresh surface or ground water and are flooded or ponded periodically on an annual basis (pulsing). They must have seasonal flooding and dry cycles (regular flushing with freshwater), usually have both sediment and nutrient inputs, and sites in the best condition are not subsiding.

RCC II: Sites with Potential for Artificial Regeneration Only. These sites may have overstory trees with full crowns and few signs of canopy deterioration, but are either permanently flooded (which prevents seed germination and seedling establishment in the case of baldcypress and tupelo) or are flooded deeply enough that when natural regeneration does occur during low water, seedlings cannot grow tall enough between flood events for at least 50% of their crown to remain above the high water level during the growing season. These conditions require artificial regeneration, (i.e., planting of tree seedlings).

RCC III: Sites with No Potential for either Natural or Artificial Regeneration. These sites are either flooded long enough to prevent both natural and artificial regeneration, or are subject to saltwater intrusion with salinity levels that are toxic to cypress-tupelo forests. Two trajectories are possible for these two conditions: 1) freshwater forests transitioning to either floating marsh or open fresh water, or 2) forested areas with saltwater intrusion that are transitioning to open brackish or salt water.

These Regeneration Condition Classes were established to promote a general, systematic understanding of a site's potential for baldcypress regeneration. The RCC system was developed to help natural resource professionals better understand the forested swamp conditions that restrict and control overall regeneration of cypress and

tupelo. However, due to the variable, yearly conditions and little knowledge of any site's long-term hydrological conditions, it is very difficult to predict long-term survival and growth on specific sites. In these situations, the RCC system has limited ability to assist in management without additional decision-making tools regarding site hydrology. Microsite variability, coupled with the lack of historical water level data for most areas make it difficult to assess RCC categorization based on knowledge offered by a single site visit. Another issue is that the definition for RCC II is defined by practicality of planting and not specific information on survival and growth potential of planted baldcypress and tupelo. Experts in the field developed the definitions for each RCC based on their experience with planting seedlings and having an estimate of their limits. The hydrologic threshold between RCCs I and II is relatively clear, as the definition for RCC I includes sites that are dry for periods of time long enough for baldcypress seedlings to germinate and grow tall enough to avoid prolonged periods of submergence, whereas RCC II includes sites where conditions are slightly more wet, but still shallow enough not to severely hinder survival and growth of planted baldcypress seedlings. However, the threshold between RCCs II and III is less clear due to the lack of knowledge of how planted baldcypress seedlings perform under various hydrologic regimes, especially under prolonged submergence.

There have been numerous studies that examined baldcypress regeneration under single flooding regimes or with different flooding regimes under controlled circumstances. However, results and opinions tend to be variable regarding the ability of cypress to withstand submergence. There is a paucity of published data available on how

11

planted baldcypress perform along a quantifiable hydrologic gradient of different flood levels and flood periodicity during the course of a growing season.

Conner and Flynn (1989) planted baldcypress seedlings along a flood gradient under a single closed canopy forest and periodically monitored water levels to analyze survival and growth among seedlings planted in the fall or spring, and compared performance among seedlings at different positions along a gradient. It would be more useful to have data on seedling survival and growth subjected to different types of flooding across several types of sites, and to have continuous water level monitoring to get a more accurate representation of the hydrologic conditions. Megonigal and Day (1992) analyzed flooding effects on baldcypress saplings. They correlated hydroperiod (continuously and periodically flooded) with root and shoot production, but did not attempt to correlate survival and growth with specific water levels.

To simulate the effects of river diversions, Souther and Shaffer (2000) conducted a greenhouse study analyzing the performance of two different age classes of baldcypress seedlings under different levels of submergence, nutrient levels, and light. In their study, newly-germinated seedlings exposed for up to 27 consecutive days of submergence had 100 percent survival, but survival quickly dropped off once submergence lasted for 45 consecutive days or longer. Souther and Shaffer found that one year-old seedlings had 100 percent survival when completely submerged up to 60 consecutive days, 75 percent survival when submerged up to 100 consecutive days, and mixed results following more than 100 consecutive days of submergence. Souther and Shaffer did not test the seedlings under actual field conditions. Subjecting seedlings to more realistic submergence from natural flood events would expose them to a number of additional stresses not present

12

under greenhouse conditions, thereby producing results to be more usable for interpreting or forecasting field performance. They also did not report height growth of planted seedlings following release from submergence, which is important for seedlings to survive into the next growing season. Seedling survival and growth in conjunction with different flooding depths and periodicities among different naturally-occurring flood regimes is needed in order to specifically identify the optimum growing conditions as well as the survival threshold to flooding in natural stands.

The objectives of this study were to evaluate the effect of submergence over the course of one growing season to first-year changes in planted baldcypress seedling survival and growth across a range of hydrologic conditions, provide recommendations for defining the threshold between RCCs II and III, and to develop predictive models across a range of submergence levels.

1.2 Materials and Methods

Study Area. An attempt was made to select four representative sites in each of the three RCCs proposed by the SWG (Chambers et al. 2005). Site selection was based on several criteria, including: overstory tree species dominated by baldcypress and water tupelo, apparent water level during the growing season as it related to the different characterizations of the RCCs, an apparent lack of salinity in both flood waters and soils, and access by foot or boat. Site visits were conducted in several different areas throughout south Louisiana in 2013 to locate suitable areas for study, namely in the Maurepas Swamp Wildlife Management Area (WMA) and areas within the Atchafalaya Basin (Figure 1.1).
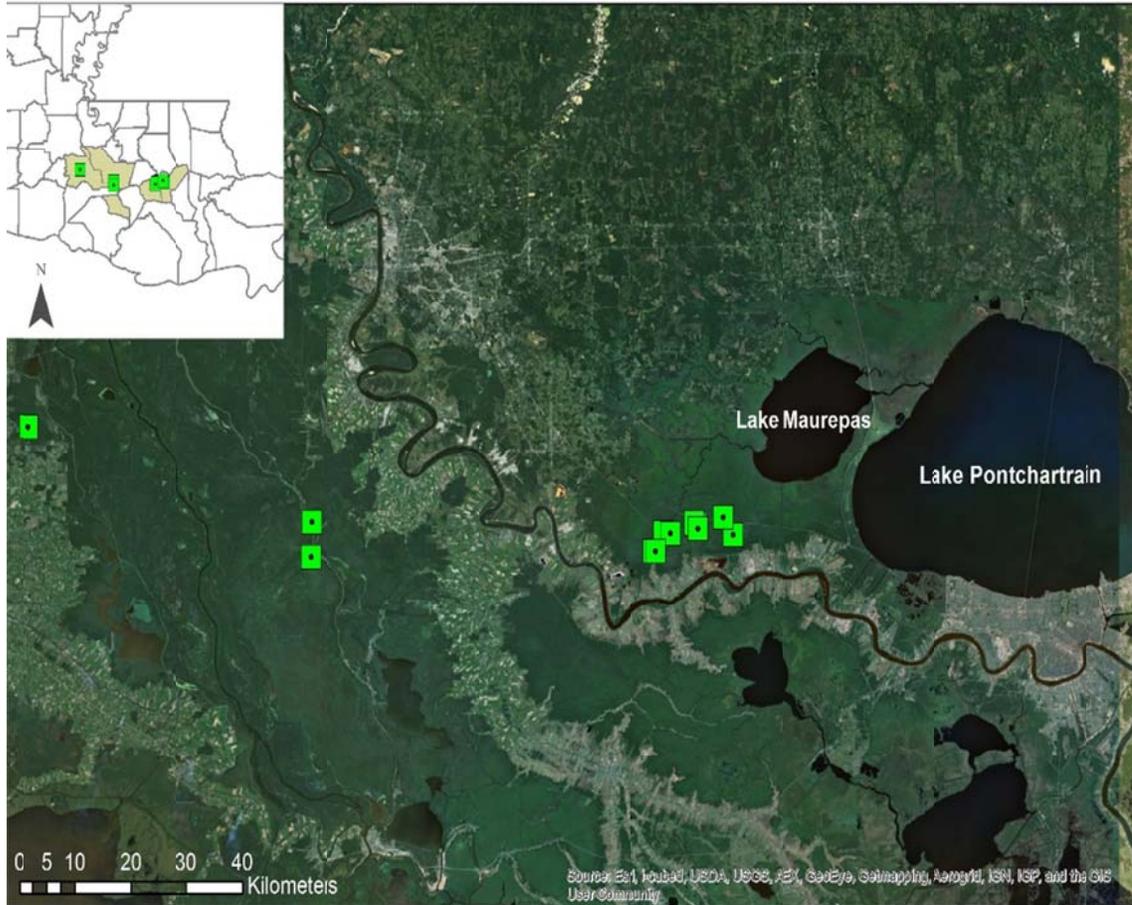
Figure 1.1. Location of Study Sites.

Twelve study sites, all located in south Louisiana, were selected to collectively cover a perceived range of hydrologic conditions, and, by assumption, to potentially cover the three SWG RCC categories (Figure 1.2). Nine sites were located within the Maurepas Swamp WMA in St. James and St. John Parishes, one site in St. Martin Parish south of Henderson, LA, one in Iberville Parish near Bayou Pigeon inside of the Atchafalaya Basin, and one site was located in Iberville Parish near the Bayou Sorrel Lock just outside the Atchafalaya Basin (Table 1.1).

14
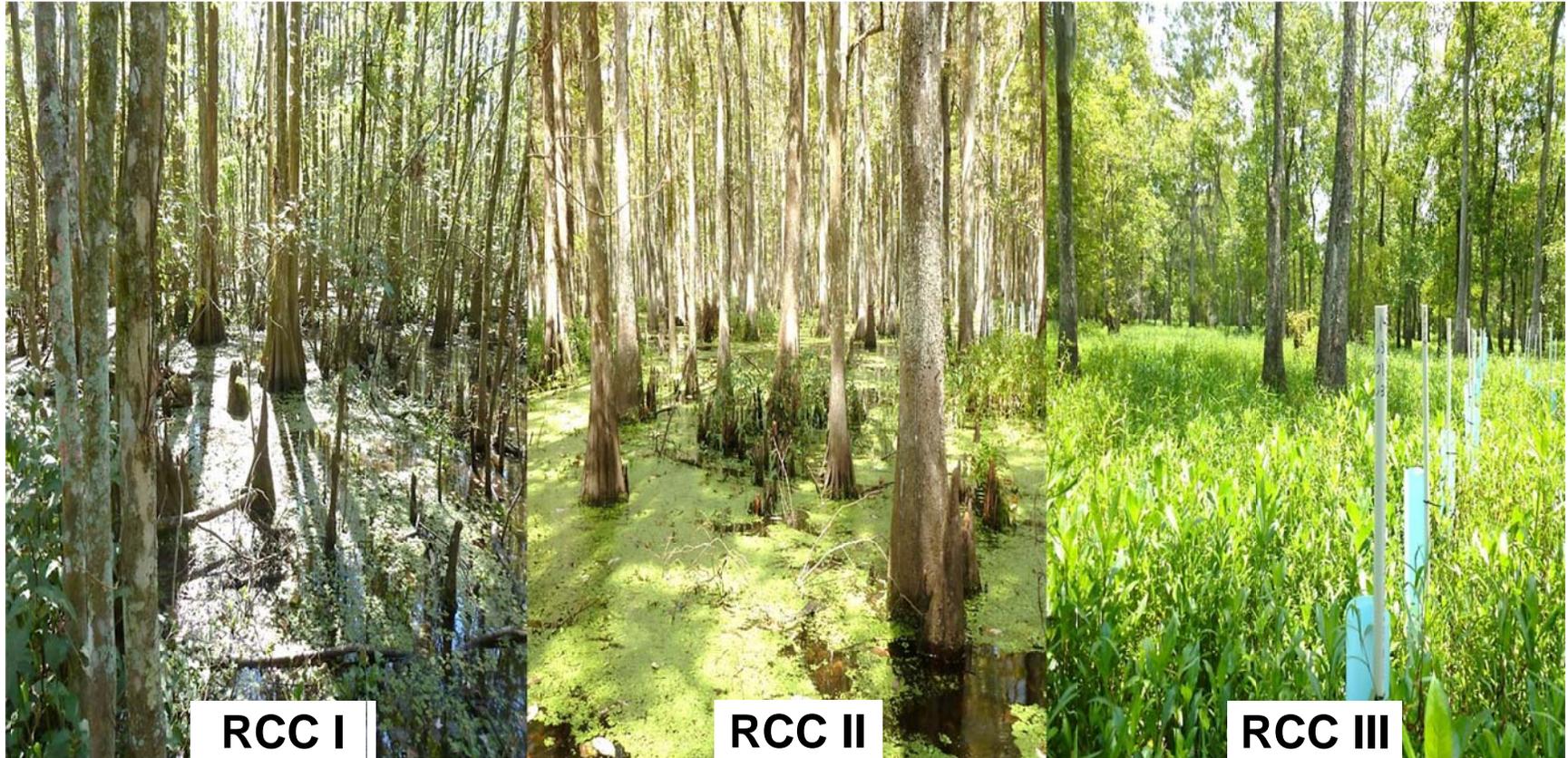
Figure 1.2. Examples of sites from the three assumed Regeneration Condition Class (RCC).

Table 1.1. List of study sites, site indicators, percent soil carbon and nitrogen, and assumed SWG RCCs[1].

Site Code	Soil % Nitrogen	Soil % Carbon	Assumed RCC[1]	Key Factors for RCC Assumption
BYI-01	1.92	26.41	I	Abundance of naturally regenerated baldcypress seedlings
STM-01	0.40	4.71	I	Mineral soil with an apparent lack of surface flooding at some times
BLR-01	1.92	28.14	I	Directly connected to bayou; apparent possibility of soil exposure in normal years
GPT-02	0.84	12.01	I	Directly connected to bayou; apparent possibility of soil exposure in normal years
GPT-01	0.78	11.66	II	Impounded site with low possibility of soil exposure in normal years
SJM-01	1.90	31.81	II	Impounded site with low possibility of soil exposure in normal years
HCN-01	1.18	16.73	II	Impounded site with low possibility of soil exposure in normal years
641-01	2.48	40.31	II	Impounded site with low possibility of soil exposure in normal years
641-02	1.25	19.99	III	Dense, widespread floating mat of aquatic vegetation; apparent water levels > 1m
641-03	1.86	28.97	III	Dense, widespread floating mat of aquatic vegetation; apparent water levels > 1m
HCN-02	2.44	38.70	III	Dense, widespread floating mat of aquatic vegetation; apparent water levels > 1m
BYP-01	0.29	3.86	III	Within Atchafalaya Basin; apparent water levels up to > 3m during growing season

[1]RCC I = semi-permanently flooded sites with high potential for natural regeneration success
[1]RCC II = semi-permanent to permanently flooded sites with low potential for natural regeneration but high potential for artificial regeneration success
[1]RCC III = semi-permanent to permanently flooded sites with low potential for both natural and artificial regeneration success

Plantation Establishment and Monitoring. At each site, I located areas for plantations. Since I was not permitted to fell mature trees on LDWF managed lands, I selected areas with natural canopy gaps in order to maximize light exposure for planted seedlings. I was granted permission to girdle a few trees bordering or shading the selected canopy gaps in order to widen the openings and allow for more direct sunlight to reach the seedling plantations. Girdling was performed in February and March 2014 at the time of planting. Felling of a few trees was permitted on private lands at the BYP-01 and STM-01 sites for the purpose of widening the gaps near the plantations.

Each canopy gap selected for a plantation was mechanically cleared of any existing woody vegetation using handsaws and hatchets. Any trees bordering or overhanging the plantation area were girdled with a hatchet and treated with triclopyr, a systemic herbicide (Figure 1.3). Girdling was successful on *Nyssa, Acer, and Fraxinus* spp. Unfortunately, the resilience of mature baldcypress trees was underestimated, and the girdling procedures were unsuccessful.

Figure 1.3. Overstory girdling of large trees at plantation edges. Left: girdling a water tupelo (*Nyssa aquatica*). Right: failed girdling of baldcypress.

Plantations (approximately 10 m by 15 m) were established by installing PVC stakes as seedling markers. Stakes were placed on a 1m x 1m spacing with ten columns and fifteen rows. Dense spacing was selected to maximize the number of seedlings that could fit within a canopy gap. Additionally, for the purposes of this study, I was only concerned with first-year survival and growth of the seedlings. With the age and size of seedlings planted, planting density was not a factor affecting survival and growth. Each plantation was divided in half by seedling age-class, with each age class planted in five adjacent columns. When existing roots or unmovable coarse woody debris hindered the placement of a stake from being placed at the correct spacing, that space was skipped and the corresponding stake placed at the end of the row.

I planted two different seedling age-classes, one year-old, non-transplanted (1-0) and two-year old, non-transplanted (2-0) nursery-grown bare-root baldcypress seedlings to analyze the performance of each when subjected to the conditions on each site. Seedlings were planted in February and March, 2014 (Table 1.2). Seventy-five seedlings of each age class were planted at each site (150 total seedlings per site). I chose 1-0 and 2-0 bare-root nursery-grown seedlings for their affordability and likeliness to be used for reforestation efforts. I did not evaluate a seedling size per se or containerized seedlings in this study. The 1-0 seedlings were sourced from ArborGen® and grown in Shellman, Georgia. The 2-0 seedlings were sourced from the Louisiana Department of Agriculture and Forestry and grown in Monroe, Louisiana. All seedlings were delivered in mid-January 2014 and kept in cold storage (4° Celsius) until the day they were planted. Roots were periodically sprayed with water to prevent dessication. Initial sorting of the seedlings took place to eliminate individuals that were poorly formed or much smaller in

diameter and total height than the average. Lateral roots were clipped the morning of or
before planting day, leaving only the tap roots to make them easier to plant into the soft
substrate and reduce the risk of the root systems drying out (Figure 1.4). Barton et al.
(2000) showed that this step can make the planting process easier and more effective than
planting with a full root system intact, with little to no difference in baldcypress seedling
performance. Prior to transportation to the field, the seedlings were wrapped in a
protective tarp and secured with bungee cords to ensure the root systems did not dry out
during travel.

Table 1.2. Date of planting in 2014, final height measurement dates, and number of
growing days by study site.

Site	Dates Planted in 2014	Final Measurements	Growing Days[1]
641-01	February 2nd & 3rd	October 8th	247
641-03	February 7th	November 10th	276
SJM-01	February 14th	October 15th	243
641-02	February 17th & 18th	October 29th	253/254
HCN-01	February 21st	October 13th	234
GPT-01	February 24th & 25th	October 22nd	239/240
GPT-02	February 28th & March 5th	October 22nd	231/236
HCN-02	March 10th	November 11th	245
BYP-01	March 18th	October 20th	216
BLR-01	March 21st	October 15th	208
STM-01	March 24th & 26th	October 6th	194
BYI-01	March 28th	October 27th	213

[1]Growing Days = number of days between the planting date and the final measurement date.

Figure 1.4. Seedlings' primary lateral roots (left) were clipped off (right) to make planting easier and reduce the risk of the root systems drying out during the planting process.

Just prior to planting, each seedling was measured for total length, height to base of live crown, and diameter. Total length was measured from the root tip to the apical meristem. Height to the base of live crown was measured from the root collar to the height of the first live woody branch, if present. Diameter was measured in millimeters with calipers just above the root collar. Mean seedling height, diameter, and height to base of live crown for 1-0 seedlings were 0.61 m, 8.5 mm, and 0.48 m, respectively. Mean seedling height, diameter, and height to base of live crown for 2-0 seedlings were 1.10 m, 12.0 mm, and 0.40 m, respectively. At most sites, seedlings were then held at the root collar and pushed into the soil until the root collar met the mineral soil line. Due to the mucky nature of the soils at some sites, the mineral soil line was hard to determine in some instances, so placement was not exact in these cases. Because of a heavy clay component at the STM-01 site and a lack of standing water, seedlings were

planted with a dibble bar. Seedlings were randomly selected for planting; no attempt was made to use shorter seedlings in shallower water or vice versa. Some 1-0 seedlings were completely submerged at the time of planting. Once planted, seedling height and water depth at each seedling were measured. Height was measured from the root collar to the dominant apical meristem when more than one apical meristem was present. When apical dominance was not obvious, the most centrally located shoot was used as the apical meristem. Every seedling in the study was planted and measured by the same person to ensure consistent planting and measurement techniques.

Following planting and measurement collection, tree shelters were placed around each seedling. Shelters (Protex® Pro/Gro Solid Tube Tree Protectors, Source: Forestry Suppliers) were used to protect the seedlings from damage by nutria (*Myocastor coypus*), an invasive mammal known to wipe out newly-planted baldcypress seedlings in wetland systems of the southeast coastal regions of the U.S. (Conner and Toliver 1987). Shelters were attached to schedule 40 PVC pipe markers 2.03 m in length (Figure 1.5). Shelters were fixed to the markers using black zip ties, one each on the bottom and top of the shelter. Identification labels were attached to each pipe, which included the site code, age, and tree number (1-75).

Seedlings were re-measured in the summer (2014) for interim survival and height. If a seedling did not display any live foliage, it was marked as dead with an indication of whether the seedling appeared to have leafed out or not. The main objectives of this mid-season measurement were to check the condition of all plantations and ensure that I had data for survival and growth in the event that a disturbance was to decimate the seedlings at any or all of the sites.

21

Final seedling measurements were made between October 6th and November 10th, 2014 prior to leaf senescence. Survival, height, and height to the base of live crown were all measured. For survival, if a seedling did not display any live foliage, it was marked as dead with an indication of whether the seedling appeared to have leafed out or not. Some seedlings were recorded as alive even though they had very little foliage and appeared unhealthy, but condition was noted. The base of the live crown was measured at the lowest living woody branch, where present. Not all seedling developed branches during the first growing season. During the final measurements, shelters were removed from seedlings to allow for easier measurements. Stakes were left in place to indicate

Figure 1.5. Typical plantation (e.g. BLR-01) on planting day. Seedlings were planted on a 1m x 1m spacing and protected by 1m tall tree shelters.

individual tree identification. Canopy cover was estimated for each plantation using a concave spherical densiometer, with readings taken in five locations: at the center and at each of the four corners of the plantation. This led to considerable overestimation of canopy cover, since canopy outside the plantations was not excluded. I include the measurements only as a relative measure of surrounding canopy impact on solar radiation levels for the seedling within the plantations and not as direct overhead solar radiation at midday.

Water Level Monitoring. A water-level sampling well was installed at each site consisting of a 5 cm diameter PVC pipe, 1.5 m in length. A PVC cap was placed on both ends. Holes were drilled in the pipe sidewalls every 5 cm along its length. Wells were inserted approximately 60 cm into the soil. A HOBO[®] Water Level Logger (Onset[®]) was suspended by galvanized steel wire attached through a hole in the cap with a steel stopper crimped around the wire. Loggers were suspended approximately 30-40 cm below the ground surface, and depth below the soil was measured. Water level data was downloaded during each site visit with the HOBO[®] Waterproof Shuttle. Reference water levels were taken at the well following installation and each subsequent time data was downloaded. All data was processed using HOBOware software and pressure compensated. Water levels at each seedling were calibrated from the difference in ground elevation from the seedling to the well. Water levels for each seedling were summarized to daily mean depths by calculating the mean of all water level recordings taken during each day.

Statistical Analyses. Following data collection, all measurements were entered into Excel[®] for further analysis. From the measurements I collected and in addition to the

data recovered from continuously monitoring water levels, I was able to create new

variables to describe the condition of the seedlings' environment with respect to flooding

(Table 1.3). To quantify flood impact on seedlings, specifically submergence, I calculated

the number of days the water level was above each seedling's most recently measured

height (H_i and H_m); water levels recorded between planting date and the midseason

measurement were analyzed using H_i, and water levels recorded between the midseason

measurement and the final measurement were analyzed using H_m. This variable is

calculated for each individual seedling and will hereafter be referred to as cumulative

days submerged.

Table 1.3. Descriptions and measurement times or formulas for variables considered in analysis of seedling performance.

Variable	Description	Measurement Time or Formula
Diameter (D)	Diameter of seedling at the root collar	Measured at planting
Initial Height (H_i)	Length from root collar to apical meristem (m)	Measured at planting
Midseason Height (H_m)	Length from root collar to apical meristem (m)	Measured mid-summer (not necessarily midpoint)
Final Height (H_f)	Length from the root collar to apical meristem (m)	Measured at end of growing season
Change in Height (ΔH)	Difference between the final and initial heights (m)	$\Delta H = H_f - H_i$
Survival	Indication of whether or not the seedling was alive	Measured at end of growing season
Daily Water Depth (W)	Water depth at seedling for any given day (m)	Measured hourly during growing season
Cumulative Days Submerged (x)	Cumulative sum of days water levels exceeded previous height measurement (H_i or H_m)	$x = \text{Frequency } (Y > H_i \text{ and } Y > H_m)$
Canopy Cover (C)	Estimate of overhead canopy cover in plantation	Measured at end of growing season
Growing Period (G)	Length of the growth assessment period	$G = \text{Days between planting and final measurement}$

Seedling performance was analyzed for each age-class by first separating the seedlings into incremental flooding categories based on the cumulative days submerged. Statistical differences in overall performance between age classes and performance between flooding categories within the same age class were determined with least squared means using ANOVA through Proc GLM in SAS (SAS version 9.4, SAS Institute[©]). Differences were determined significant at the alpha=0.05 level using a Tukey-Kramer adjustment.

Modeling Survival. For future management applications, prediction of seedling survival based on known or expected water levels would help natural resource professionals select sites or seedlings for planting. To predict seedling survival based on flood impact, I used Proc Logistic in SAS to model survival as affected by cumulative days submerged (x) for both age classes. Logistic regressions are typically used to predict binary responses from binary predictors (Bishop 2006), in this case 0 = dead and 1 = alive. First, a logistic function was produced using the following formula:

$$F(x) = \frac{1}{1 + e^{(\beta 0 + \beta 1 X)}}$$

Where: F(x) = probability of survival
β_0 = intercept
β_1 = slope or regression coefficient
x = cumulative days submerged
e = exponential function, decrease in survival probability for every increase in x

Next, a simple linear regression was produced using a logit, or the logarithm of the odds of survival, using the following formula:

$$g[F(x)] = ln\frac{F(x)}{1 - F(x)} = \beta_0 + \beta_{1x}$$

Where: g = logit function

ln = natural logarithm

Finally, I back-transformed the odds ratio by using an anti-log to produce the probability of a seedling surviving based on the cumulative number of days the seedling was submerged, including if it was never submerged at all.

$$Probability\ of\ Survival\ (\hat{Y}) = \frac{e^{\beta_0 + \beta_{1x}}}{1 + e^{\beta_0 + \beta_{1x}}}$$

Modeling Height Growth. Prediction of change in height (growth, if positive) or final heights is necessary for evaluating a seeding performance under different flood regimes and also for evaluating the potential for escape from submergence and survival for the next year. To model first-year seedling growth under different hydrologic conditions, I modeled the final total height of seedlings by cumulative days submerged (x) as well as the number of growing days (G). Initial height (H_i), initial diameter (D), and canopy cover (C) were significant as co-variables. I selected two different models, a power model and an exponential decay model, to determine which was best suited for the actual data. The Akaike Information Criterion (AIC) was used as the determining factor for model selection. AIC rewards goodness of fit and penalizes overfitting caused by having too many model parameters. In addition, I evaluate fit by which model has the lower AIC value.

26

1.3 Results

   Seedling Performance. Overall survival across sites was high for both age

classes even though flooding was continuous on most sites. Across all sites, 1-0 age-class

seedlings were submerged on average for much longer (34.8 cumulative days) during the

growth assessment period than 2-0 seedlings (1.4 cumulative days). An overwhelming

majority (83 percent) of 2-0 seedlings were never submerged during the growth

assessment period, compared to only 10 percent of

Table 1.4. Mean initial seedling measurements, summary statistics, and cumulative days
flooded (± standard error) during the growth assessment period across sites by age class.

Variable	Age Class	
	1-0	**2-0**
Mean Initial Root Length (m) ± SE	0.13 ± 0.001	0.21 ±0.002
Mean Initial Diameter (mm) ± SE	8.50 ± 0.07	12.04 ±0.10
Mean Initial Seedling Height (m) ± SE	0.61 ± 0.002	1.10 ±0.004
Mean Final Height (m) ± SE	0.91 ± 0.008	1.23 ±0.006
Mean Change in Height (m) ± SE	0.29 ± 0.008	0.13 ±0.005
Mean Survival (%)	78.67	89.22
Mean Cumulative Days Submerged[1] ± SE	34.8 ± 1.2	1.4 ± 0.2

[1]Cumulative days submerged = cumulative number of days water levels were above the seedling height (i.e.
submerged) during the growing season

1-0 seedlings. There were no 2-0 age-class seedlings submerged for more than 53

cumulative days, but 24 percent of 1-0 age class seedlings were submerged for more than

60 cumulative days.

The 2-0 age-class seedlings had significantly higher (p <0.001) overall survival than 1-0 seedlings. Overall first-year seedling survival was 89 percent for 2-0 seedlings compared to 79 percent for 1-0 seedlings at the end of the growth assessment period (Table 1.4). Survival for the 1-0 age-class seedlings submerged for more than 90 cumulative days was significantly lower (p <0.001) than survival for seedlings submerged for less than 90 cumulative days (Figure 1.6). Only 9 percent of all 1-0 seedlings that were submerged for more than 90 cumulative days survived, and no 1-0
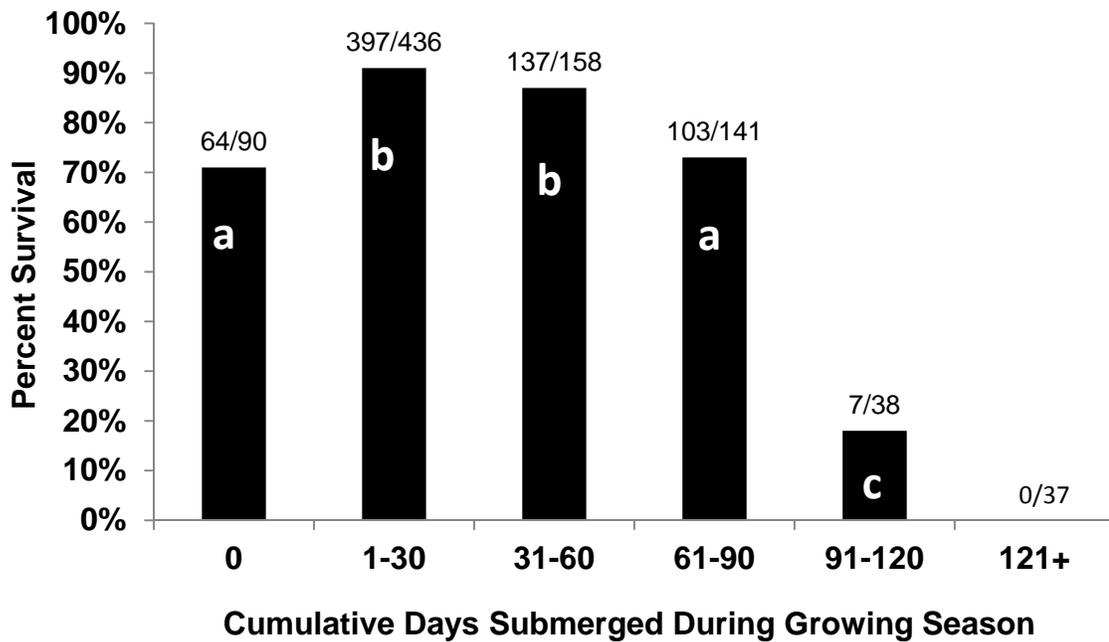
Figure 1.6. Survival of 1-0 baldcypress seedlings grouped by increasing levels of submergence. Significant differences at the alpha = 0.05 level are indicated by different letters above the bars. Sample sizes for the different submergence levels are: 0 days n = 90, 1-30 days n = 436, 31-60 days n = 158, 61-90 days n = 141, 91-120 days n = 38, 121+ days n = 37.

seedlings survived submergence for more than 120 cumulative days. There was no significant difference in survival between the categories of 0, 1-30, and 31-60 cumulative days submerged for 2-0 seedlings (p <0.001).

The 1-0 age-class seedlings significantly outperformed 2-0 age-class seedlings in height growth. Overall mean change in height across all sites was 0.29 m for 1-0 seedlings and 0.13 m for 2-0 seedlings (Table 1.4). Change in height of the surviving 1-0 age-class seedlings that were never submerged was significantly higher (p <0.001) than seedlings that were submerged for at least some period of time, and mean change in height was significantly lower (p <0.001) for all categories of greater than 30 cumulative days of submergence (Figure 1.7).
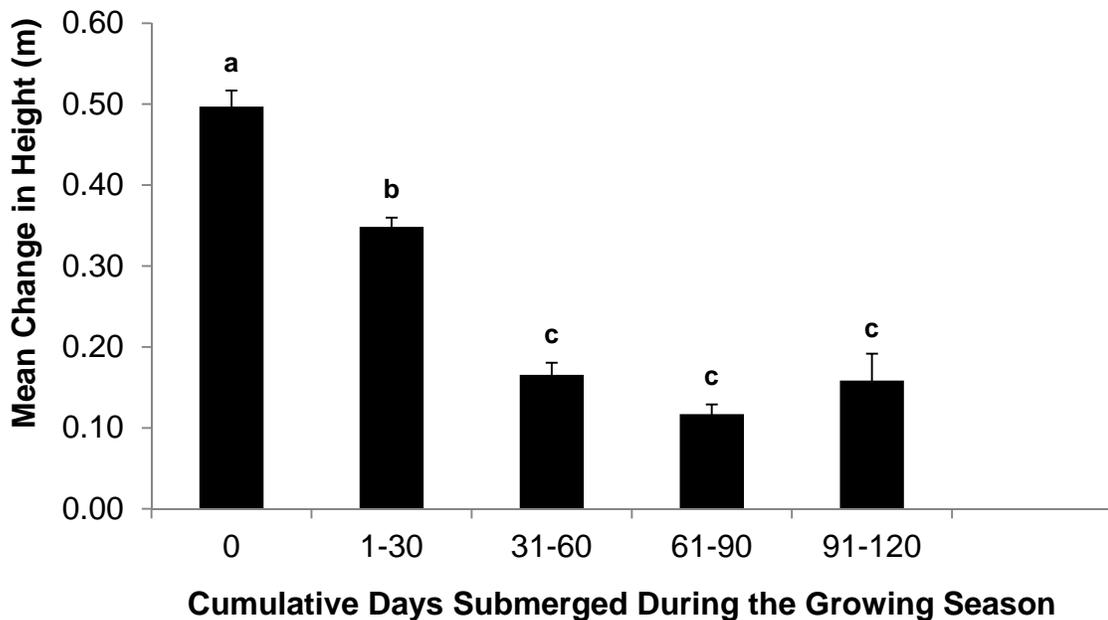
Figure 1.7. Change in height and standard error bars of surviving 1-0 baldcypress seedlings grouped by increasing levels of submergence. Significant differences at the alpha = 0.05 level are indicated by letter above the error bars (SEM). Sample sizes for the different submergence levels are: 0 days n = 64, 1-30 days n = 397, 31-60 days n = 137, 61-90 days n = 103, 91-120 days n = 7.

Table 1.5. Growing season mean, minimum, and maximum water levels and cumulative days flooded at each site's plantation[1]. Sites are listed by increasing mean water depth.

Site	Mean Seasonal Water Depth (m)	Minimum Seasonal Water Depth (m)	Maximum Seasonal Water Depth (m)	Cumulative Days Flooded Above 0 cm
BLR-01	0.110	-0.177	0.649	152
STM-01	0.183	-0.207	0.797	165
GPT-02	0.251	-0.236	0.852	165
GPT-01	0.322	0.058	0.854	184
641-03	0.443	0.232	0.734	184
BYP-01	0.467	0.076	1.005	184
SJM-01	0.495	0.305	0.935	184
641-02	0.522	0.339	0.910	184
HCN-01	0.587	0.423	0.876	184
641-01	0.608	0.416	0.979	184
HCN-02	0.688	0.496	1.017	184
BYI-01	0.707	0.457	1.154	184
Mean ± SD	0.449 ± .186	0.182 ± .260	0.897 ± .130	178 ± 11

[1]Water levels taken from April 1st to October 1st, 2014. Water levels are based on the mean well difference for all planted seedlings at a given site's plantation.

On two sites, GPT-01 and GPT-02, survival was 100 percent for both age classes, and one additional site, BLR-01, had 100 percent survival for 1-0 seedlings and 86.7 percent survival for 2-0 seedlings (Tables 1.6 and 1.7). The sites with the worst survival were HCN-01 for 1-0 seedlings (48 percent) and STM-01 for 2-0 seedlings (35 percent). Among sites, the greatest change in height for 1-0 seedlings occurred at BLR-01 and SJM-01 (0.54 m at both), and the greatest change in height for 2-0 seedlings also
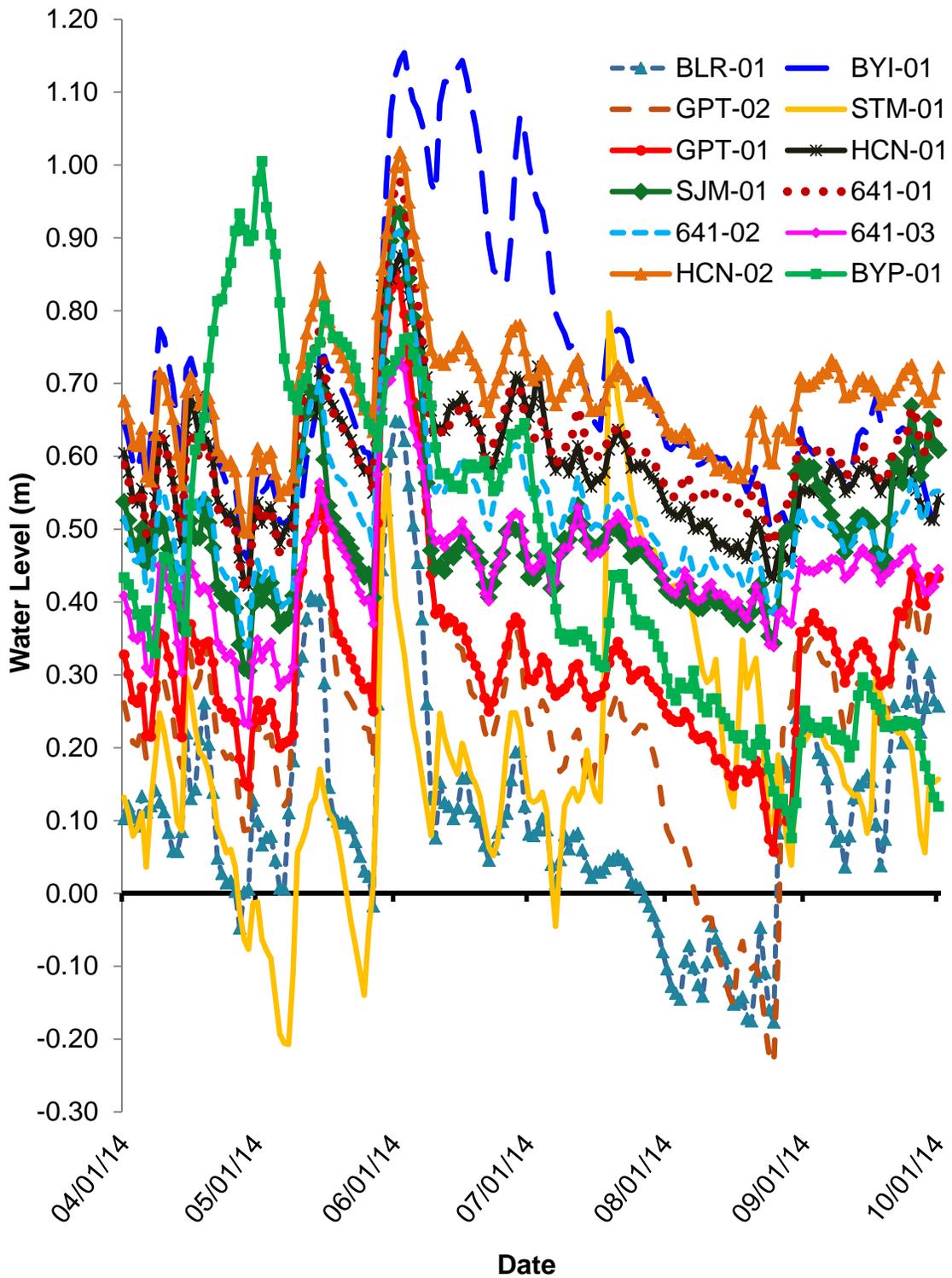
Figure 1.8. Composite hydrograph for all study sites. Period displayed is from April 1st – October 1st, 2014. Water levels are corrected for the average well difference of all seedlings at a given site. Negative values indicate the water table was below the soil surface.

Table 1.6. Summary statistics for 1-0 seedling age-class by site, listed in order of increasing mean cumulative days submerged during the growing season.

Site	Mean Initial Height (m±SEM)	Mean Final Height (m±SEM)	Mean Change in Height (m±SEM)	Survival (%)	Canopy Cover (%)	Mean Cumulative Days Submerged (±SEM)
BLR - 01	0.63 ± 0.005	1.16 ± 0.02	0.54 ± 0.02	100.0	18.67	1.48 ± 0.20
STM - 01	0.60 ± 0.006	1.02 ± 0.02	0.43 ± 0.02	53.3	66.30	1.59 ± 1.08
GPT - 02	0.62 ± 0.006	0.82 ± 0.02	0.21 ± 0.02	100.0	82.94	8.29 ± 0.21
GPT - 01	0.62 ± 0.002	0.88 ± 0.01	0.26 ± 0.01	100.0	80.03	8.73 ± 0.13
641 - 02	0.62 ± 0.006	1.00± 0.03	0.37 ± 0.03	69.3	42.80	10.19 ± 2.53
SJM - 01	0.60 ± 0.007	1.14± 0.03	0.54 ± 0.03	93.3	45.40	22.24 ± 3.43
641 - 03	0.52 ± 0.010	0.81 ± 0.03	0.24 ± 0.03	57.3	32.61	32.39 ± 1.06
BYP - 01	0.62 ± 0.004	0.70 ± 0.02	0.08 ± 0.01	98.7	70.46	53.16 ± 0.31
641 - 01	0.61 ± 0.007	0.88 ± 0.02	0.25 ± 0.02	81.3	76.91	54.44 ± 5.81
BYI - 01	0.65 ± 0.004	0.80 ± 0.01	0.15 ± 0.01	88.0	84.40	66.57± 1.31
HCN - 02	0.63± 0.004	0.90 ± 0.02	0.26 ± 0.02	54.7	31.36	73.57 ± 3.00
HCN - 01	0.59 ± 0.009	0.77 ± 0.02	0.14 ± 0.01	48.0	83.78	84.33 ± 4.53

Table 1.7. Summary statistics for 2-0 seedling age-class by site, listed in order of increasing mean cumulative days submerged during the growing season.

Site	Mean Initial Height (m±SEM)	Mean Final Height (m±SEM)	Mean Change in Height (m±SEM)	Survival (%)	Canopy Cover (%)	Mean Cumulative Days Submerged (±SEM)
BLR - 01	1.11 ± 0.015	1.22 ± 0.02	0.10 ± 0.01	86.7	18.67	0.00 ± 0.00
STM - 01	1.13 ± 0.012	1.26 ± 0.02	0.15 ± 0.02	34.7	66.30	0.00 ± 0.00
GPT - 02	1.07 ± 0.011	1.30 ± 0.02	0.22 ± 0.01	94.7	32.61	0.00 ± 0.00
GPT - 01	1.11 ± 0.014	1.32 ± 0.02	0.22 ± 0.01	98.7	42.80	0.03 ± 0.05
641 - 02	1.13 ± 0.013	1.23 ± 0.02	0.10 ± 0.02	100.0	82.94	0.04 ± 0.03
SJM - 01	1.11 ± 0.014	1.23 ± 0.03	0.12 ± 0.02	100.0	80.03	0.05 ± 0.69
641 - 03	1.09 ± 0.011	1.21 ± 0.02	0.12 ± 0.01	98.7	83.78	0.07 ± 0.00
BYP - 01	1.10 ± 0.011	1.08 ± 0.01	-0.02 ± 0.01	97.3	70.46	0.79 ± 0.23
641 - 01	1.08 ± 0.013	1.39 ± 0.02	0.31 ± 0.02	98.7	45.40	1.24 ± 0.39
BYI - 01	1.09 ± 0.012	1.16 ± 0.02	0.06 ± 0.01	90.7	31.36	1.52 ± 1.11
HCN - 02	1.04 ± 0.012	1.12 ± 0.02	0.08 ± 0.01	74.7	76.91	2.71 ± 0.30
HCN - 01	1.12 ± 0.011	1.22 ± 0.02	0.09 ± 0.01	96.0	84.40	10.21 ± 0.07
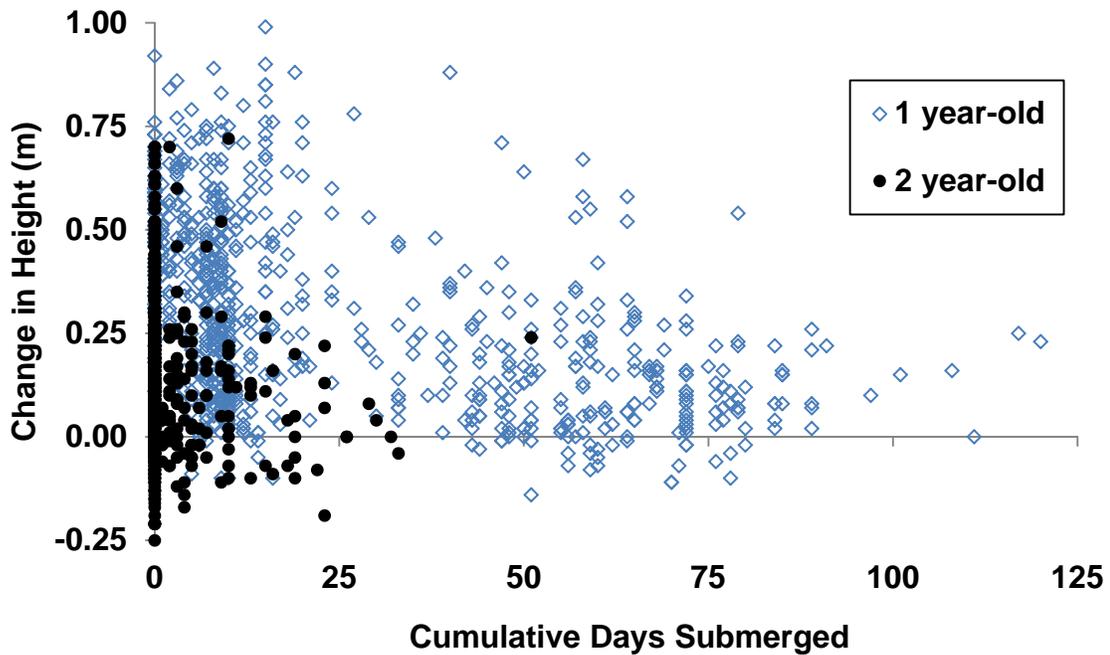
Figure 1.9. Change in individual seedling height for both age-classes based on cumulative days submerged. Negative height changes signify dieback or failure of leader.

occurred at SJM-01 (0.31 m). The least change in height for both 1-0 (0.08 m) and 2-0 (-0.02 m) seedlings occurred at BYP-01.

Survival and Height Growth Models. Survival probability based on cumulative days submerged was modeled for 1-0 predict survival based on submergence in future situations. Logistic regression produced an intercept and a slope for both age-classes (Table 1.8), which is used to calculate the survival probability. Interpretation of the model reveals what appears to be a quadratic relationship between cumulative days flooded and seedling survival for 1-0 seedlings (Figure 1.10). Survival was high across the range of hydrologic conditions examined for 2-0 seedlings, so I felt it unnecessary
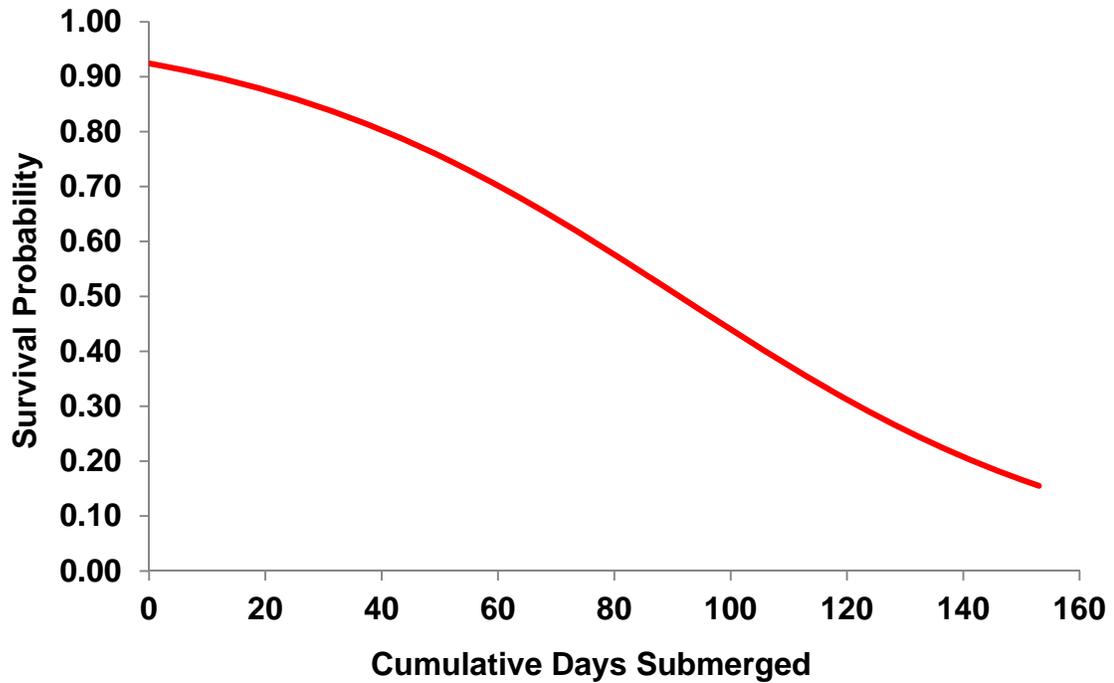
Figure 1.10. Logistic regression model results for the 1-0 age-class survival probability versus cumulative days submerged. Probability values are back-transformed from log values produced by the model.

Table 1.8. One year-old seedling survival model parameter estimates and equations.

Parameter	Estimate/Equation
Intercept	2.5010 SE = 0.1500
Slope	-0.0274 SE = 0.0024
Model Equation	$\hat{Y} = \dfrac{e^{2.5010+(-0.0274x)}}{1 + e^{2.5010+(-0.0274x)}}$

to model survival probability for 2-0 seedlings based on the conditions experienced by individuals in this study.

None of the 1-0 seedlings that experienced submergence for greater than 50 percent of their growing season (cumulative days flooded/growing days *100) survived to the end of the study. Only seven 2-0 seedlings experienced more than 25 cumulative days flooded, and all survived to the end of the growing season.

Seedling final height for each age class was modeled to predict the relative effects that flood impact, growing conditions, and initial seedling specifications have on seedling height growth in future situations. The total cumulative days submerged, cumulative days submerged in June and July, Cumulative days floodeded above 80 percent of the seedling's initial height, mean water depth during the growth assessment period, and total growing season length were selected as primary variables from results of a correlation analysis. Initial height, initial diameter, and canopy cover were included as co-variates to improve model fit. The AIC values of both models tested can be found in Table 1.9. The

Table 1.9. AIC and regression equations for the final height models for each age-class.

Age Class	Power Model AIC	Exponential Decay AIC	Selected Model Equation[1]
1-0	-2084	-1618	$\hat{Y} = e^{(1.46)} + e^{(-0.014x)} + e^{(-0.064y)} + e^{(0.026z)}$ $+ e^{(0.246a)} + e^{(-0.200g)}$
2-0	-2504	-2250	$\hat{Y} = e^{(0.816)} + e^{(0.023x)} + e^{(-0.054y)} + e^{(0.004z)}$ $+ e^{(0.224a)} + e^{(-0.087g)}$

[1]Independent Variables: x = cumulative days submerged during the growing season, y = cumulative days flooded during the growing season above 80% of the seedling's initial height, z = cumulative days submerged in June and July, a = mean water depth during the growing season experienced by the seedling, g = growing days (i.e. growing season length)
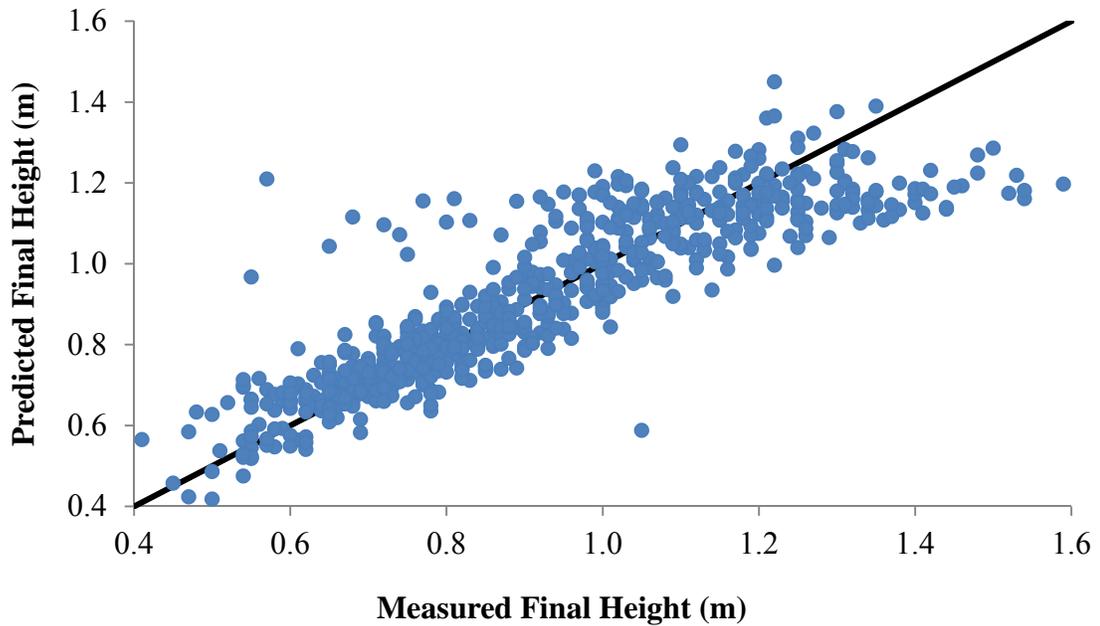
Figure 1.11. The 1-0 age-class measured seedling final heights vs. predicted seedling final heights. Line represents a 1:1 ratio between measured and predicted.
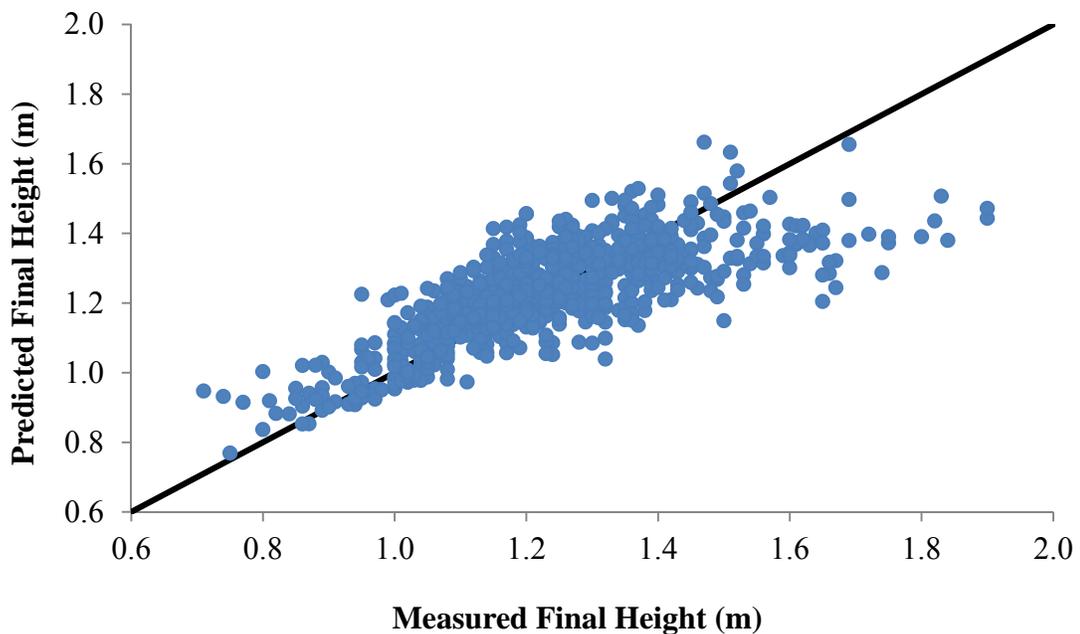
Figure 1.12. The 2-0 age class measured seedling final heights vs. predicted seedling final heights. Line represents a 1:1 ratio between measured and predicted.

power model proved to be a better fit according to the AIC for both the 1-0 and 2-0 seedlings. The final height model predictions had an R^2 value of 0.79 for 1-0 seedlings when compared to measured final height results, and an R^2 value of 0.59 for 2-0 seedlings. Graphics displaying the predicted seedling heights plotted against their measured final heights represent the contrast between predicted and measured heights to show how well the model describes the data (Figures 1.11 and 1.12).

1.4 Discussion

Overall Seedling Performance. Submergence, for a prolonged portion of the growing season, dramatically reduced seedling survival and height growth of planted 1-0 bare-root baldcypress seedlings after certain lengths of time. Submergence was uncommon and therefore had less impact on the performance of 2-0 seedlings. Survival of 1-0 and 2-0 bare-root baldcypress seedlings was very high across most sites, averaging 79 and 89 percent, respectively. Growth was higher, on average, for 1-0 seedlings (0.29 m) compared to 2-0 seedlings (0.29 m).

Mortality of 1-0 seedlings was most closely associated with the number of cumulative days the seedlings were overtopped by flood waters (submergence). Figure 1.6 demonstrates that following more than 90 cumulative days of submergence, 1-0 seedling survival was only nine percent, compared to nearly 85 percent when submerged for less than 90 days. While 1-0 baldcypress seedlings submerged up to 90 days had relatively good survival until the end of the growing season, the impact of long-term submergence on survival into the next growing season is not well documented. Mean height growth with continued submergence fell rapidly across the different submergence

38

levels. Height growth was significantly higher for 1-0 seedlings submerged between 0 and 30 cumulative days (0.37 m) compared to seedlings only submerged for 31 cumulative days or more (0.15 m), underlining the negative effect that prolonged submergence has on seedling performance. The 1-0 seedlings appear to have adequate height growth even when flooded at some level for most, if not all, of the growing season. However, height growth is greatly diminished when submerged for more than 30 cumulative days.

The length of time seedlings are submerged has been the focus of many previous controlled experiments related to baldcypress survival and growth. Early studies reported poor performance at relatively short submergence durations. Demaree (1932) reported that newly-germinated baldcypress seedling survival was very low following only 10-12 days submergence. Bull (1949) also reported low survival thresholds following submergence, with 67 percent survival of 1-0 planted baldcypress seedlings submerged for less than 20 days, 55 percent for 1-0 seedlings submerged 20-29 days, and only 31 percent survival for those submerged 30-45 days. However, Loucks and Keen (1973) reported 100 percent survival for 1-0 baldcypress seedlings submerged for 4 weeks. Sun (1995) reported 100 percent survival for newly-germinated baldcypress seedlings submerged for 0, 10, 20, and 30 consecutive days, and there was no significant difference between height growth for seedlings never submerged and those submerged for 10, 20, and 30 consecutive days. Souther and Shaffer (2000) studied the effect of submergence on newly-germinated and 1-0 baldcypress seedlings grown in containers, reporting that survival decreased greatly following 45 days of submergence for newly-germinated seedlings, while 1-0 seedling survival was 75 percent or greater following 100 days or

less of submergence. Survival results were variable following longer periods of submergence. Our data were collected from a relatively large sample size of seedlings subjected to a wide range of conditions, and our results support the evidence that baldcypress seedling survival is severely affected by submergence, especially for more than 90 cumulative days during the growing season.

The effect of submergence on height growth for 2-0 seedlings was not as clear, as so few were ever submerged for an extended length of time. When planted on the same sites as 1-0 seedlings, 2-0 seedlings have better survival than 1-0 seedlings. Survival was very high for 2-0 seedlings (89.22 percent) across the range of conditions tested in this study. Because the 2-0 age-class seedlings were taller when planted, they experienced much fewer total cumulative days submerged than 1-0 seedlings. The overwhelming majority of 2-0 seedlings (83.7 percent) were never submerged during this study, but they did experience substantial water depths (>0.50 m) for prolonged stretches of the growing season, and their survival was noticeably high. Survival is an extremely critical measure of seedling performance because if a tree is alive, it has the opportunity to take advantage of conditions favorable to net primary production (NPP), if and when those conditions occur. Because they have taller starting heights than the 1-0 seedlings, 2-0 seedlings are less likely to be submerged and have a high survival probability. Still, I do not know how well 2-0 seedlings would respond to more extreme levels of flooding, especially submergence, to make direct comparisons to the performance of 1-0 seedlings. Height growth for 2-0 seedlings was relatively low across all sites, especially compared to 1-0 age-class seedlings. Because the overwhelming majority of 2-0 seedlings were never submerged during the growing season, it is more appropriate to look at the effect of

flooding on a different level. The benchmark of 70 percent above the initial height serves as an evaluation point in which to analyze growth when seedling's foliage is subjected to prolonged flooding. The average midpoint of the initial crown measurement was 68 percent of the seedling's initial height for all 2-0 age-class seedlings, so 70 percent serves as a close approximation. When flooded for 0 and 30 cumulative days above 70 percent of the seedling's height, 2-0 seedlings had a mean change in height of 0.13 m. However, 2-0 seedlings flooded for more than 30 cumulative days above 70 percent of their initial height had a mean change in height of only 0.08 m.

The first-year height growth for 1-0 age class seedlings compared to 2-0 seedlings can be attributed to several different factors. All seedlings were trimmed of their lateral roots prior to planting. Therefore, the fine, lateral root systems of individuals in each age class was relatively similar at the time of planting, leaving the 2-0 seedlings with a lower root-to-shoot ratio, which has been cited as a factor affecting height growth under flooded conditions (Megonigal and Day 1992). Another potential differential effect on the two age-classes may relate to a "greenhouse effect", as tree shelters used were made of polypropylene, a material noted for its ability to enhance photosynthesis in tree seedlings. Sharew and Hairston-Strang (2005) tested a variety of different shelters to compare their effects on seedling growth and reported a marked increase of seedling height growth in all shelters made of polypropylene compared to unsheltered control seedlings. Shelters 0.91 m in height were used for both age classes; virtually all of 1-0 seedling crowns were completely surrounded by the tubes at the time of planting, and virtually all of the 2-0 seedlings had some or all of their crowns extending past the top of the tube. Differences in crown environment, such as humidity and solar radiation levels, could have provided

the 1-0 seedlings an early advantage in height growth. Conner et al. (2000) reported

height growth for baldcypress seedlings protected by shelters was significantly higher in

the first year than unprotected seedlings in a South Carolina study (52 cm vs 23 cm);

however, growth differences declined dramatically once the seedlings emerged from the

top of the shelter. Seedling origin or quality differences could have resulted in the

difference in change of height; the 1-0 seedlings were sourced from ArborGen[®]

(Shellman, Georgia) and the 2-0 were grown and purchased from a Louisiana Department

of Agriculture and Forestry nursery (Monroe, Louisiana).

Site Factors. Clear trends in seedling performance (survival and height growth)

were related to cumulative days submerged in 1-0 seedlings; however, some variation in

seedling performance among sites was obvious in some cases. Flooding depth, duration,

and timing are all key factors for baldcypress seedling performance. Nevertheless, the

interaction of factors related to sites can sometimes offset part of the outcomes in survival

and growth. For instance, light availability has been proven to be a critical factor in the

growth of young baldcypress (Neufield 1983, Souther and Shaffer 2000, deGravelles et

al. 2014). There is some indication in our results that canopy cover had an effect on

seedling height growth; however, our canopy cover estimates were taken in the fall

between October 6th and November 10th when leaf senescence of some overstory species

had begun to occur. Additionally, canopy cover was analyzed as a mean estimate for all

seedlings at a given site and is therefore not representative of conditions at the individual

seedling level.

While water depth and duration of flooding are extremely important in

determining survival and growth, even of flood tolerant baldcypress, the distribution of

42

flood events and distribution of high water across the growing season have also been shown to be important. Variation in flood timing may, in fact, have affected the degree of differentiation in survival or growth in our study. Microtopography within a given site can have a dramatic impact on individual seedling performance. Although the elevation within cypress-tupelo forests is usually compressed, small microtopographic changes (a few centimeters) are often present and can make a large difference in the number of days of seedling submergence. Slight changes in rainfall or planting elevation could have a profound difference on the cumulative days submerged for planted seedlings.

The subsidy-stress model (Odum et al. 1979) suggests that areas experiencing periodic, nutrient-rich flooding could have higher growth rates compared to areas containing stagnant water for long durations or areas never flooded at all. Megonigal et al. (1997) concluded that there was no difference in rates of aboveground NPP between seasonally-flooded and upland forests, but they did show that there was a significant negative correlation between aboveground NPP and mean water depth in areas with prolonged flooding by seemingly stagnant flood waters. The composition of the standing water at each of these sites could differ in many ways because the sites in this study received flood inputs from different sources and at different levels of timing and intensity. The two sites with the largest mean change in height for 1-0 seedlings, BLR-01 and SJM-01 (0.54 m at each), both have a direct connection to the Blind River, which acts as a drain for a vast area of swamp into Lake Maurepas. When the river channel rises, these sites receive a pulse of nutrients and sediments suspended in the water column. The majority of the other sites were believed to be primarily driven by local rainfall. The negative effect of stagnant flooding water on tree seedling growth has been

43

previously documented (Shanklin and Kozlowski 1985, Effler and Goyer 2006).

Nutrient-rich wastewater has been shown to increase baldcypress diameter growth of

both seedlings and mature (Hesse et al. 1998, Lundberg et al. 2011, Keim et al. 2012)

In the case of the Bayou Island site, BYI-01, the 1-0 seedlings showed a relatively

high survival rate (88.0 percent) even though the seedlings were submerged, on average,

for 67 cumulative days during the growing season. Higher survival could be attributed to

both formation of adventitious roots above the soil surface (Figure 1.13) and moving

flood water from the adjacent bayou. Gomes and Kozlowski (1980) demonstrated that the

formation of adventitious roots was a critical factor for flood tolerance in green ash

(*Fraxinus pennsylvanica*) seedlings. The formation of adventitious roots on seedlings at

Figure 1.13. Adventitious root formation on 1/0 seedling at Bayou Island (BYI-01).

some sites, although not common outside of BYI-01, likely aided in the survival of the 1-0 seedlings despite deep, prolonged flooding during much of the growing season.

STM-01 had very low final survival rates for both 1-0 (53 percent) and 2-0 (35 percent) seedlings, even though it was the least flood-impacted site. The site has a very heavy-clay soil (Sharkey series), a shrink-swell clay that has been shown to cause problems with seedling survival of other bottomland species (Stanturf et al. 1998 and 2004). When the water table dropped below the soil surface, large cracks formed in the soil and, as a result, the root systems of some seedlings were exposed and left vulnerable to drying out. The survival of 1-0 seedlings that were never submerged was lower than mean survival for seedlings submerged between 1 and 60 cumulative days, and the majority of 1-0 seedlings that were never submerged were planted at STM-01. In addition the taller 2-0 seedlings at STM-01 had the lowest survival of any site by a wide margin.

Although the understory at STM-01 was dominated by an invasive grass, *Phanopyrum gymnocarpon*, commonly found in bottomland forest stands, it may not have caused severe competition, even though it was generally taller than some 1-0 seedlings (Figure 1.14). The height and prevalence of this grass was not nearly as pronounced in the middle of the growing season as it was near the end, and the grass was much more prominent in canopy gaps where more light was available than under heavy shade. A study done in South Carolina showed 91 percent of baldcypress seedlings survived heavy competition from *Eupatorium capillifolium* (Conner 2003), emphasizing the effect that soil conditions at STM-01 had on seedling survival.

Figure 1.14. Dense stand of *Phanopyrum gymnocarpon* competing with planted baldcypress seedlings at the STM-01 plantation.

Survival and Height Growth Models. Models serve as an effective method to assess or predict planted baldcypress seedling performance for management applications in both reforestation and restoration projects. Among other factors, the future of coastal cypress-tupelo forests depends on the ability to effectively assess an area's regeneration potential and successfully establish the next cohort of trees. The 1-0 age-class survival and height growth models can, along with other evidence of site hydrology factors, provide natural resource professionals an effective way to predict 1-0 bare-root planted baldcypress seedling performance under different levels of submergence.

Many plantings of baldcypress will likely occur on sites conducive to planting 1-0 nursery stock. The 1-0 stock is cheaper, easier to store and transport, and much easier to plant on flooded sites. The 1-0 seedling survival model helps to predict planted baldcypress first-year seedling survival probability based on the cumulative days submerged. This model is limited by the use of only one size of 1-0 planting stock and needs to be expanded to evaluate the effects of additional size and age classes, seedling sources, as well as different types of seedlings (i.e. containerized or potted). The survival of 2-0 seedlings was relatively high across most conditions observed in this study, eliminating the need to model survival and justifying the need to test for 2-0 age-class seedling performance for longer periods of submergence.

The 1-0 seedling height growth model helps to predict planted baldcypress first-year seedling final height based on the cumulative days submerged. This model is useful for predicting height expectations for 1-0 seedlings on sites where the hydrologic regime is either controlled or well-understood. Final height (not necessarily growth) was modeled to predict the height the seedlings will reach by the end of the first year. Seedling height is essential for correlating with water levels to determine the length of submergence that seedlings could expect to endure for the following growing season or seasons. Most importantly, the height growth models provide an effective first-year assessment for final height expectations of planted baldcypress seedlings across a wide range of cumulative days submerged.

The results of the final height model indicate that the total cumulative days submerged over the growing season, cumulative days submerged in June and July, mean water level during the growing season, the cumulative days flooded above 80% of the

seedling's height, and the length of the growing season were all significant factors affecting seedling height growth. Initial height, initial diameter, and canopy cover were influential to a lesser extent. These variables seemingly explained the observed height growth of 1-0 seedlings better than 2-0 seedlings because of the higher occurrence of submergence and greater variability in height growth between individuals of the 1-0 age-class seedlings. The model appears to underestimate growth on the best-performing seedlings for both age-classes, but especially on the 2-0 seedlings, suggesting that there are factors driving height growth not associated with submergence that are not accounted for in the model. The inclusion of the submergence variables in the model highlights the notion that submergence, especially during the middle of the growing season, can have a detrimental effect on seedling height growth. The significance of the hydrologic variables that are not a direct measure of submergence (mean water level during the growing season and the cumulative days flooded above 80% of the seedling's height) indicate that deep, prolonged flooding has a negative impact on seedling height growth even when flood levels do not completely submerge the seedling.

Management Implications. Permanently flooded cypress-tupelo forests do not lend themselves to planting containerized seedlings in large quantities. Bare-root seedlings are much cheaper and easier to plant in arduous conditions that typify many permanently flooded sites. First-year results suggest that 1-0 bare-root nursery-grown seedlings can be planted successfully under certain hydrologic conditions, and they can grow at an acceptable level if planted on the appropriate sites. First-year survival was very good for 2-0 seedlings due to their lower submergence susceptibility compared to 1-0 seedlings, but height growth was relatively poor. Within a site, efforts should be made

48

to selectively plant seedlings in spots where they are most likely to succeed, whether that includes avoiding planting in microtopographic low spots altogether, reserving the tallest individuals to be used in the low spots, or using multiple age classes to account for microtopographical differences. Plantings will likely perform better in areas receiving flood waters from riverine or alluvial inputs as opposed to more stagnant, rainfall-driven sites. Protecting the seedlings from nutria is paramount. Although there was no seedling mortality caused from nutria during the growing season while protected by shelters, follow-up visits in the winter and spring after shelters had been removed revealed a significant number of seedlings that had either been uprooted or clipped by nutria or rabbits.

Our results indicate that 30 cumulative days of submergence appears to be the hydrologic threshold for adequate first-year 1-0 planted baldcypress seedling survival and height growth. When feasible, water level monitoring should be used to evaluate the true hydrologic regime of a given site. Connectivity of surface water should be evaluated and accounted for across a site in order to understand or quantify the range of hydrologic conditions that seedlings would potentially be exposed to. To gain a better understanding of the true nature of water levels at a given site, efforts should be made to determine if the site is hydrologically connected to a body of water containing water level monitoring equipment. Monitoring across several years will provide a more accurate estimate of the range of hydrologic conditions across a site. These recommendations should serve as tools for evaluating sites based on their regeneration potential and increasing the probability for successful performance of planted baldcypress seedlings.

1.5 Conclusions

The survival for 1-0 planted baldcypress seedlings was extremely poor following submergence for greater than 90 days. The first-year height growth for 1-0 planted baldcypress seedlings, which is critical to the seedling's future performance, was greatly diminished following just 30 cumulative days submerged. Across the range of conditions tested in this study, 2-0 planted baldcypress survival was higher than 1-0 seedling survival, but height growth was much lower. Submergence of 2-0 seedlings was rarely observed, and the effect that submergence has on 2-0 seedling performance is not clear.

Efforts should also be made to identify low and high spots within the microtopography of a site and selectively using seedlings that will be submerged less often, increasing the probability of seedling success. Due to permanent flooding and relatively static water levels at many sites classified as RCCs II and III in south Louisiana, a difference in elevation of only a few centimeters can potentially have a great impact on the cumulative number of days a seedling is submerged throughout the growing season. Our results suggest submergence can be overcome in many areas by using 2-0 or older/taller seedlings. Although this study defines hydrologic thresholds for first-year planted baldcypress seedling performance under closely monitored hydrologic conditions, accurate estimates of the number of days submerged are scarce for most of the cypress-tupelo forest acreage. Further research needs to be conducted to establish connectivity of vast acreages of cypress-tupelo forests to existing hydrologic monitoring stations where the hydrologic regime of a given site is unknown or not well-understood.

1.6 Literature Cited

Barton C., Nelson E.A., Kolka R.K., McLeod K.W., Conner W.H., Lakly M., Martin D., Wigginton J., Trettin C.C. & Wisniewski J. (2000). Restoration of a severely impacted riparian wetland system - the Pen Branch Project. Ecological Engineering 15: S3-S15.

Bishop, C.M. (2006). Pattern recognition and machine learning. Springer.

Bull, H. (1949) Cypress planting in southern Louisiana. Southern Lumberman 179: 227-230.

Chambers, J. L., Conner W.H., Day J.W., Faulkner S.P., Gardiner E.S., Hughes M.S., Keim R.F., King S.L., McLeod K.W., Miller C.A., Nyman J.A,, and Shaffer G.P. (2005). Conservation, Protection and Utilization of Louisiana's Coastal Wetland Forests. Final Report to the Governor of Louisiana from the Science Working Group on Coastal Wetland Forest Conservation and Use. Baton Rouge, LA, USA.

Conner, W.H. (2003). Tree growth in three South Carolina (USA) swamps after Hurricane Hugo: 1991-2001. Forest Ecology and Management 182: 371-380.

Conner, W.H., Inabinette L.W., and Brantley E.F. (2000). The use of tree shelters in restoring forest species to a floodplain delta: 5-year results. Ecological Engineering 15: S47-S56.

Conner, W.H. and Flynn K. (1989). Growth and survival of baldcypress (*Taxodium distichum* L. *Richard*) planted across a flooding gradient in a Louisiana bottomland hardwood forest. Wetlands 9:2: 207-217.

deGravelles, W.W., Hutchinson S., and Conner W.H. (2014). Survival and growth of suppressed baldcypress reproduction in response to canopy gap creation in a North Carolina, USA Swamp. Wetlands 34: 79-87.

Demaree, D. (1932). Submerging Experiments with Taxodium. Ecology 13: 258-262.

Effler, R.S. and Goyer R.A. (2006). Baldcypress and water tupelo sapling response to multiple stress agents and reforestation implications for Louisiana swamps. Forest Ecology and Management 226: 330-340.

Gomes, A.R. and Kozlowski T.T. (1980). Growth responses and adaptations of *Fraxinus pennsylvanica* seedlings to flooding. Plant Physiology 66:2: 267-271.

Hesse, I.D., Doyle T.W., and Day J.W. (1998). Long-term growth enhancement of baldcypress (*Taxodium distichum*) from municipal wastewater application. Environmental Management 22:1: 119-127.

Keim, R.F., Izdepski C.W., and Day J.W. (2012). Growth responses of baldcypress to wastewater nutrient additions and changing hydrologic regime. Wetlands 32:1: 95-103.

Loucks, W.L. and Keen R.A. (1973). Submersion tolerance of selected seedling trees. Journal of Forestry 71:8: 496-497.

Lundberg, C.J., Shaffer G.P., Wood W.B., and Day J.W. Jr. (2011). Growth rates of baldcypress (Taxodium distichum) seedlings in a treated effluent assimilation marsh. Ecological Engineering 37:4: 549-553.

Megonigal, J.P., Conner W.H., Kroeger S., and Sharitz R.R. (1997). Aboveground production in Southeastern floodplain forests: A test of the subsidy-stress hypothesis. Ecology 78: 370-384.

Megonigal, J.P. and Day F.P. (1992). Effects of flooding on root and shoot production of baldcypress in large experimental enclosures. Ecology 73: 1182-1193.

Neufield, H.S. (1983). Effects of light on growth, morphology, and photosynthesis in baldcypress (*Taxodium distichum* (L.) Rich.) and pondcypress (*T. ascendens* Brongn.) Seedlings. Bulletin of the Torrey Botanical Club. 110:1: 43-54.

Odum, E.P., Finn J.T., and Franz E.H. (1979). Perturbation theory and the subsidy-stress gradient. BioScience 29:6: 349-352.

Shanklin, J. and Kozlowski T.T. (1985). Effect of flooding of soil on growth and subsequent responses of Taxodium distichum seedlings to SO2. Environmental Pollution Series A, Ecological and Biological 38:3: 199-212.

Sharew, H. and Hairston-Strang A. (2005). A comparison of seedling growth and light transmission among tree shelters. Northern Journal of Applied Forestry 22: 102-110.

Souther R.F. and Shaffer G.P. (2000). The effects of submergence and light on two age classes of baldcypress (*Taxodium distichum* L. *Richard*) seedlings. Wetlands 20:4: 697-706.

Stanturf, J.A., Conner W.H., Gardiner E.S., Schweitzer C.J., and Ezell A.W. (2004). Recognizing and overcoming difficult site conditions for afforestation of bottomland hardwoods. Ecological Restoration 22:3: 183-193.

Stanturf, J.A., Schweitzer, C.J., and Gardiner, E.S. (1998). Afforestation of marginal agricultural land in the lower Mississippi River Alluvial Valley, U.S.A. Silva Fennica 32:3: 281-297.

Sun, J. (1995). Submergence impacts on selected wetland/bottomland tree species. Ph.D. Dissertation. Louisiana State University, Baton Rouge, LA, USA.

CHAPTER 2: USING PRESENT VEGETATION TO ASSESS LIMITED HYDROLOGICAL INFORMATION AND BALDCYPRESS (*TAXODIUM DISTICHUM*) REGENERATION POTENTIAL ALONG A HYDROLOGIC GRADIENT IN SOUTH LOUISIANA

2.1 Introduction

Cypress-tupelo forests dominate much of the forested acreage in south Louisiana. Widespread logging occurred near the turn of the 20th century, when many of our present stands germinated under much different hydrologic conditions than conditions that exist today (Mancil 1980). Urban and industrial development, oil and gas exploration, shipping, road construction and many other coastal activities have led to the impoundment of many cypress-tupelo stands and effectively isolated them from the annual flushing by fresh flood waters and deposition of sediment from riverine systems (Keim et al. 2006, Faulkner et al. 2009). Presently, many of these second-growth stands have reached merchantable volumes, and land managers are looking into the feasibility of timber harvests. Before harvesting can be completed, land managers want to ensure that the stands can be sustainable to protect the integrity of the wetland forest.

Although many wetland forest stands presently appear adequately stocked and healthy, permanent inundation, where it occurs, prevents natural regeneration, resulting in unsustainable stands (Conner et al. 1986, Conner and Day 1988). Periodic flooding, although essential to baldcypress in the natural environment, has changed in many areas, often becoming more prolonged and deeper. Baldcypress is considered one of the most tolerant tree species to flooding and soil waterlogging (McKnight, et al. 1981, Hook 1984, Keeland 1994). However, baldcypress seedlings cannot germinate in standing

water; they need a dry period of several consecutive weeks just to germinate and much longer periods to reach a critical height for permanent establishment (Demaree 1932, DuBarry 1963, Williston et al. 1980, Conner and Day 1988, Pezeshki et al. 1993).With the looming uncertainty of the future of Louisiana's cypress-tupelo forests, the governor commissioned a Science Working Group on Conservation, protection, and Utilization of Louisiana's Coastal Wetland Forests (SWG) to evaluate scientific information related to wetland forests and develop management recommendations for regeneration and utilization of coastal wetland forests (Chambers et al. 2005). Although the SWG produced a number of findings and presented a number of recommendations, one of the most important statements was that "regeneration is a critical process of specific concern in maintaining coastal wetland forest resources." The SWG developed three Regeneration Condition Classes (RCCs) based on site factors, both biological and physical, that define the potential for cypress to regenerate. They are as follows:

> SWG Regeneration Condition Class I (RCC I): Sites with Potential for Natural Regeneration. These sites are generally connected to a source of fresh surface or ground water and are flooded or ponded periodically on an annual basis (pulsing). They must have seasonal flooding and dry cycles (regular flushing with freshwater), usually have both sediment and nutrient inputs, and sites in the best condition are not subsiding.

> SWG Regeneration Condition Class II (RCC II): Sites with Potential for Artificial Regeneration Only. These sites may have overstory trees with full crowns and few signs of canopy deterioration, but are either permanently flooded (which prevents seed germination and seedling establishment in the case of baldcypress and tupelo) or are flooded deeply enough that when natural regeneration does occur during low water, seedlings cannot grow tall enough between flood events

for at least 50% of their crown to remain above the high water level during the growing season. These conditions require artificial regeneration, (i.e., planting of tree seedlings).

SWG Regeneration Condition Class III (RCC III): Sites with No Potential for either Natural or Artificial Regeneration. These sites are either flooded long enough to prevent both natural and artificial regeneration, or are subject to saltwater intrusion with salinity levels that are toxic to cypress-tupelo forests. Two trajectories are possible for these two conditions: 1) freshwater forests transitioning to either floating marsh or open fresh water, or 2) forested areas with saltwater intrusion that are transitioning to open brackish or salt water.

These RCCs were established to promote a general understanding of a site's potential for baldcypress regeneration. The RCC system was intentionally developed to help natural resource professionals better understand the set of forested swamp conditions that restrict and control overall regeneration of cypress and tupelo. However, due to the variable, yearly conditions and little knowledge of any site's long-term hydrological conditions, it is very difficult to predict long-term survival and growth on specific sites. In these situations, the RCC system has limited ability to assist in management without additional decision-making tools. Microsite variability, coupled with the lack of historical water level data for most areas make it difficult to assess RCC categorization based on knowledge offered by a single site visit. It is often difficult for natural resources professionals to make multiple site visits during the growing season to determine RCC classification. There is a great need to be able to assess a site's hydrologic regime, especially as it relates to baldcypress regeneration potential, using a combination of

present vegetation and site factors to avoid the time and costs that accompany conventional methods of long-term hydrologic monitoring.

The relationship between flooding and vegetation responses has been well documented over the years. Several studies have analyzed the forest composition of expansive gradients ranging from bottomland hardwood systems down to cypress-tupelo swamps. When viewed in its entirety, a flooding gradient can often be separated into several distinct communities based on species' relative abilities to tolerate flooded conditions. In some cases, the effect of flooding on vegetation composition and structure along an elevation gradient is quite distinct and obvious (Theriot 1993). However, because cypress-tupelo forests comprise such a narrow portion of a very complex matrix of hydrologic conditions, our understanding of these forests as it relates to vegetation establishment and growth remains limited.

Vegetation has been used as an indicator for moisture and successional stages in upland settings to great success (Curtis and McIntosh 1951, Johnson et al. 2007).Very few studies have been conducted on the use of present vegetation as an indicator for predicting an area's flood regime. Cowardin et al. (1979) designed a widely used classification system for the various types of wetlands found in the world, centering on substrate type and vegetation as an indicator. However, their study's focus was too broad to capture the necessary precision of differences in water depth along a hydrologic gradient to distinguish between RCCs II and III sites in cypress-tupelo wetlands.

Bedinger (1971) determined four distinct forest communities along the White River in Arkansas based on elevation, and therefore being subjected to differences in flood regimes. However, he focused on classifying bottomland hardwood communities

and did not include cypress-tupelo forests. Theriot (1993) developed a system to use present woody vegetation to predict the flood regime in bottomlands and wetlands and to determine the optimal hydrologic regime for several different tree species. Theriot's study covered a wide variety of flooded sites, but did not look at the closer division across cypress-tupelo dominated sites. In addition, his study used only two sites from Louisiana. Bledsoe and Shear (2000) analyzed the vegetation along different gradients, including a hydrologic gradient, to correlate species' responses to flood frequency, but did not include permanently inundated sites that are of great concern regarding baldcypress regeneration.

Faulkner et al. (2009) attempted to use remote sensing technology to categorize different sites into RCCs by comparing aerial photos from drought and flooded years. Their study involved comparing aerial imagery of the same area during an abnormally dry year and during an abnormally wet year. Faulkner et al. then classified certain areas as RCC I based on having dry ground during both the wet and dry years, RCC III based on water present during both the wet and dry years, and RCC II for all areas that were wet in the wet year but dry in the dry year. Their method is useful for large-scale estimates, but remains unsatisfactory for small-scale analysis and does not take into account the fact that many of these sites can potentially shift from one classification to another due to sedimentation or salinity pulses. Unfortunately, they were not able to effectively differentiate the division between RCCs II and III solely via aerial imagery. In order to accurately characterize sites with recent changes, the method relies on having both a very wet and very dry year in a short time-frame, which is not always a possibility.

While many sites can be evaluated in general, selection of specific sites are a challenge because of clouds and other factors that preclude analysis from specific sites.

No studies were found that attempted to characterize a site's present vegetation and structure as indicators of its flood regime within the cypress-tupelo forest portion of the wetland forest moisture gradient, particularly with respect to a site's suitability for supporting baldcypress seedlings. Assessment of the flood regime is critical for evaluating whether existing cypress-tupelo forests can regenerate either by natural or artificial means. Assessment of flood regimes is important for ongoing forestry practices, especially harvests, and for regeneration and restoration projects. It is important to begin the process by developing a conceptual and descriptive relation between the composition and structural characteristics for sites with short-term and long-term water level data.

The primary objective of this study is to relate forest composition, forest structural characteristics, and other site factors to assess the flood and likely impacts to the potential initial survival and establishment of natural and planted baldcypress seedlings.

2.2 Materials and Methods

Study Area. In southeast Louisiana swamps, I selected 12 representative sample sites in each of three apparent Hydrologic Categories similar to the aforementioned SWG RCCs along a gradient of flooding conditions where cypress or tupelo are dominant members of the overstory. Sites included freshwater forested wetlands with surface flooding for less than half the growing season (Hydrologic Category A); semi-permanently to permanently flooded areas with relatively shallow water levels

(Hydrologic Category B); and permanently flooded sites with relatively deep water levels (Hydrologic Category C). Hydrologic Categories were used for site classification in place of the SWG RCCs to potentially expand the application of information beyond baldcypress regeneration purposes. Still, the underlying principles of each of the three Hydrologic Categories were developed to correspond with the three RCC definitions. Site selections were based on several basic criteria, including: cypress or tupelo trees as the dominant species, apparent average water level during the growing season as it related to the different characterizations of the SWG RCCs, and an apparent lack of salinity in both flood waters and soils.

Vegetation Sampling. Potential sample locations were located after a general on-site visit to several areas to assess whether they met the basic criteria. A 200 m x 200 m study site was remotely delineated in each area using Google Earth. Study areas were delineated to include a uniform space consistent with the desired type of forest to be sampled. Five sample plots were chosen at each study site. Locations of plot centers were determined using Google Earth; 30 m x 30 m grids were laid upon each of the 12, 200 m x 200 m study areas. Each intersection of the grid was numbered and put into a random number generator. The first five numbers produced by the random number generator and their corresponding points on the grid were selected as plot centers at each site. At each site, the centers of each of the five sample plots were located using a GPS unit and marked with a PVC pipe. I sampled both the overstory and midstory vegetation layers at each plot center. Each vegetation layer shared the same plot center (i.e. midstory layer plots were nested within the larger overstory layer plots). The overstory layer was

sampled within a 10 m radius plot (314 m^2) and the midstory was sampled within a 5 m radius plot (78.5 m^2).

The overstory layer included measurement of all trees ≥10 cm diameter at 3 m to achieve a consistent diameter measurement and avoid any sampling error caused by pronounced butt-swell common to many wetland tree species (Parresol et al. 1987). A 3 m pole was held parallel to the trunk of the tree for accurate determination of the diameter measurement reference point. Overstory tree diameters were measured with a Wheeler Pentaprism Caliper (JIM-GEM®). The midstory layer included all trees 1.0 to 9.9 cm diameter at breast height (DBH), or 1.37 m with Vernier Calipers. Canopy cover estimates were also taken on each plot with a concave spherical densiometer; four readings were taken 10 m from the plot center in the four cardinal directions and the mean was then calculated for each plot.

Water Level Monitoring. A well was installed at each site consisting of a 5 cm diameter PVC pipe, 1.5 m in length. A PVC cap was placed on both ends. Holes were drilled in the pipe sidewalls every 5 cm along its length. Wells were inserted approximately 60 cm into the soil. A HOBO® Water Level Logger (Onset®) was suspended by galvanized steel wire attached through a hole in the cap with a steel stopper crimped around the wire. Loggers were suspended approximately 30-40 cm below the ground surface, and depth below the soil was measured. Water level data was downloaded during each site visit with the HOBO® Waterproof Shuttle. Reference water levels were taken at the well following installation and each subsequent time data was downloaded. All data was processed using HOBOware. Water levels at each plot were calibrated from the difference in ground elevation from the plot center to the well. Water

levels for each plot were summarized to daily mean depths by calculating the mean of all water level recordings taken during each day.

2.3 CRMS Sites

In 2003, the Coastwide Reference Monitoring System (CRMS) was established in Louisiana to monitor and evaluate the effectiveness of wetland restoration projects at many different spatial scales along the Louisiana coast (Steyer 2003). Sites included for monitoring include brackish, saline, intermediate, and freshwater marshes, as well as forested swamp sites. Forested swamp sites were used to monitor the conditions before and after river diversion projects to develop goals for future diversion projects.

To supplement our data, especially with data from sites on the drier end of the cypress-tupelo forest hydrologic gradient, I used data collected on forested swamp sites by CRMS. I selected five forested swamp sites based on similar basic criteria used for selecting our own sites.

CRMS data collection for both vegetation and hydrology was similar to data collected for our sites, and is outlined in full detail in Folse et al. (2014). Although the CRMS data set and our data set are similar, some differences existed in the diameter parameters for each layer and in the sizes and quantity of plots. CRMS data were made compatible to our data by first selecting all individuals in the CRMS dataset that were sampled in the overstory layer and were greater than 5 cm and less than 10 cm diameter sampled and moved them into the midstory data. Next, I took the number of species that were subtracted from the overstory layer and adjusted their total midstory density on a proportional basis to the percentage of the area that the midstory plots comprised of the

61

overstory plots. These adjustments allowed trees on the CRMS sites to be analyzed in the same manner as our study site data. I also excluded any stems smaller than 1 cm at DBH.

Data Summarization. Data for both our sites and the CRMS sites were summarized by the following categories: seasonal mean water level, minimum water level, maximum water level, mean cumulative days flooded above 0 cm, 15 cm, 30 cm, 45 cm, 60 cm, and 75 cm; mean canopy cover; overstory basal area/hectare; midstory tree density/hectare; number of woody species/hectare; and the top three species based on importance value.

The reference points or benchmark water levels between 0 cm and 75 cm were used to calculate cumulative days flooded because they could represent critical benchmarks affecting the success of seed germination, seedling establishment, and artificial regeneration survival and/or growth typical of 1-0 seedlings, respectively. Nursery-grown 1-0 bare-root baldcypress seedlings typically range between 30-60 cm in height, and submersion of seedlings, both planted and newly-germinated, has a negative impact on their first-year survival and growth (Souther and Shaffer 2000, Rutherford and Chambers, Chapter 1). Therefore, evaluating different water levels as they relate to different seedling height stages is critical for assessing potential regeneration success The cumulative days flooded above each benchmark water level was calculated by adjusting the site's water levels by the mean well difference at each of the plot centers (5 plots for each of our sites and 3 plots for each of the CRMS sites). Only water level data from April 1st to October 1st, 2014 was analyzed, effectively defining a 184 day growing season (actual growing season differs substantially across years). This 184 day window

was selected because it was the longest period of time where I had water level data for each of the study sites.

Sites were first classified into their respective Hydrologic Categories (A, B, or C) by their hydrologic regime as it relates to baldcypress regeneration potential. Sites with fewer than 120 cumulative days flooded above 0 cm were classified as Category A, sites with 120 cumulative days flooded or more above 0 cm but fewer than 30 days flooded above 45 cm were classified as Category B, and sites with 30 cumulative days flooded or more above 45 cm were classified as Category C. These benchmarks were chosen as thresholds between categories for a conservative estimate of the requirements for natural germination and establishment of baldcypress seedlings (< 120 cumulative days of surface flooding, Souther and Shaffer 2000) and for adequate performance of planted baldcypress seedlings (< 30 cumulative days flooded above 45 cm, which is the typical height for 1-0 bare-root nursery grown baldcypress seedlings, Chapter 1). Of the 17 sites (ours plus the CRMS) included in our analysis, three were classified as Hydrologic Category A, eight were classified as Hydrologic Category B, and six were classified as Hydrologic Category C.

Mean canopy cover is the mean of the canopy cover estimates across all plots on a given site. Overstory basal area per hectare and midstory tree density per hectare were calculated by totaling the individual overstory tree basal areas across all plots on a given site and scaling up to a per hectare level. The number of woody species is the total number of individual species or species group (i.e. undistinguished multiple species of wet site oaks, *Quercus* spp., or tupelos, *Nyssa* spp.) measured on a site regardless of canopy layer. Vegetation and hydrologic characteristics between Hydrologic Categories

were tested for significance with ANOVA using Proc GLM in SAS$^{®}$. Least-square means

were used to account for variances in sample sizes between Categories. Significance was

determined at the alpha = 0.05 level using a Tukey-Kramer adjustment.

The principal species or species groups for the overstory layer were determined

using importance values (IVs). IVs, which range from 0 – 100, are calculated using a

species' relative dominance (relative basal area), relative density, and relative frequency

at a given site as shown below. The top three species or species groups by IV in the

overstory layer and the three species or species groups with the highest relative density in

the midstory layer were included as the primary species for each site.

$$Relative\ Dominance\ of\ Species\ x = \frac{Basal\ Area\ of\ species\ x}{Basal\ Area\ of\ all\ species}\ X\ 100$$

$$Relative\ Density\ of\ Species\ x = \frac{Density\ of\ species\ x}{Density\ of\ all\ species}\ X\ 100$$

$$Relative\ Frequency\ of\ Species\ x = \frac{Frequency\ of\ occurence\ of\ species\ x}{Combined\ frequency\ of\ occurence\ for\ all\ species}\ X\ 100$$

$$Importance\ Value\ of\ Species\ x = \frac{Relative\ Dominance + Relative\ Density + Relative\ Frequency}{300}$$

2.4 Results

Sites were differentiated by a combination of flood regime characteristics for the single season for which water level data were available. A significant difference in mean cumulative days flooded above 0 cm and 15 cm existed among Hydrologic Category A sites and Hydrologic Categories B and C sites combined (Figure 2.1 and Table 2.1). A significant difference across the mean cumulative days flooded above 30 cm, 45cm, and 60 cm also existed between Hydrologic Category C sites and Hydrologic Categories A and B sites combined. In addition, there was also a significant difference among sites in all three Categories relative to the seasonal mean and maximum water levels. Finally, a significant difference occurred in the seasonal minimum water level between Hydrologic Category C sites and Hydrologic Categories A and B sites combined.
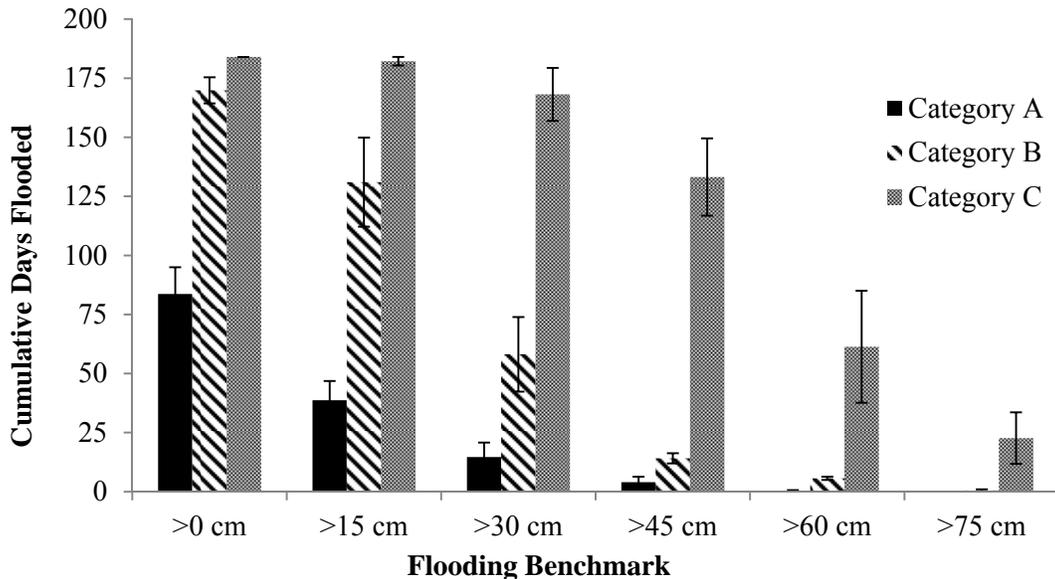

Figure 2.1. Mean cumulative days flooded above benchmarks ranging from 0 cm to 75 cm for all seventeen sites grouped by Hydrologic Category. Values and standard error bars are derived from all sites within a given Hydrologic Category.

Table 2.1. Mean water levels and mean cumulative days flooded for selected benchmark flood heights within hydrologic categories. Values include the mean and standard error (±) from all sites within a given Hydrologic Category. Values were analyzed using an ANOVA with the least-square means from each of the sites within a given Hydrologic Category. Statistical differences between categories at the alpha = 0.05 level are indicated by different superscript letters.

Hydrologic Category	Min Water Level	Mean Water Level	Max Water Level	Days Above[1] >0 cm	Days Above >15 cm	Days Above >30 cm	Days Above >45 cm	Days Above >60 cm	Days Above >75 cm
A	-0.34 ± 0.04^a	0.01 ± 0.03^a	0.51 ± 0.09^a	84 ± 11^a	39 ± 8^a	15 ± 6^a	4 ± 2^a	0 ± 0.3^a	0 ± 0^a
B	-0.07 ± 0.07^a	0.23 ± 0.03^b	0.70 ± 0.02^b	170 ± 6^b	131 ± 19^b	58 ± 16^a	14 ± 2^a	6 ± 0.7^a	1 ± 0.5^a
C	0.30 ± 0.07^b	0.54 ± 0.05^c	0.91 ± 0.05^c	184 ± 0^b	182 ± 2^b	168 ± 11^b	133 ± 16^b	61 ± 24^b	23 ± 11^a

[1]Days above refers to the cumulative days flooded above the given reference heights from April 1st to October 1st, 2014, a 184 day growing season.

The number of species/species groups per hectare was significantly different among the vegetation characteristics at alpha = 0.10, with Hydrologic Category C sites having a statistically significant (Pr > |t| = 0.09) lower mean number of species or species groups per hectare (3.7) than sites in Category A (7.7) (Table 2.3). Mean canopy cover was very similar among Hydrologic Categories, with means of 92 percent for Hydrologic Category A, 86 percent for Hydrologic Category B, and 86 percent for Hydrologic Category C. Mean overstory basal area per hectare also did not differ significantly among Hydrologic Categories, with 38.5 m^2 ha^{-1} for Hydrologic Category A, 32.9 m^2 ha^{-1} for Hydrologic Category B, and 33.7 m^2 ha^{-1} for Hydrologic Category C. The overstory species composition varied among categories, with a mix of *Taxodium distichum*, *Acer* spp., *Fraxinus* spp., *Nyssa* spp., and *Triadica sebifera* in Category A, *Nyssa* spp., *Taxodium distichum*, and *Acer* spp. dominating Category B, and primarily *Taxodium distichum* and *Nyssa* spp. dominating in Category C.

Midstory density was significantly lower at alpha = 0.10 for Category C (P > |t| = 0.06), with only 325 trees per hectare (TPH) compared to 1344 TPH for Hydrologic Category A and 1033 trees per hectare for Hydrologic Category B. The midstory layer also had differences in species composition among Hydrologic Categories, with Hydrologic Category A mostly comprised of *Acer* spp., *Fraxinus* spp., *Quercus* spp., and *Taxodium distichum*, Hydrologic Category B consisting primarily of *Acer* spp., *Fraxinus* spp., with some *Morella cerifera* and *Nyssa* spp., and Hydrologic Category C containing individuals of *Acer* spp., *Cephalanthus occidentalis*, *Morella cerifera*, and *Triadica sebifera*, although at relatively lower total densities than the other two categories.

Table 2.2. Vegetation summary data by site. Sites are listed in order of increasing mean seasonal water level.

Site	Category	Canopy Cover (%)	Overstory Basal Area/Ha (m²)	Midstory Tree Density/ Ha	No. of Woody Species	Top 3 Overstory Species[1] (Importance Value)	Top 3 Midstory Species[1] (Relative Density)
CRMS 0324	A	96.8	34.7	1407	10	ACSP (32.8), TADI (28.2), NYSP (14.0)	ACSP (69.6), ULSP (14.4), CEOC (4.0)
STM-01	A	96.7	31.4	1045	5	TADI (82.3), TRSE (13.7)	TRSE (56.1), ACSP (24.4), CEOC (9.8)
CRMS 0046	A	82.7	49.3	1582	8	NYSP (50.8), TADI (25.4), FRSP (11.7)	FRSP (73.4), ACSP (13.8), ILSP (6.4)
BLR-01	B	65.5	18.5	1452	6	NYSP (79.1), TADI (12.8), ACSP (4.1)	ACSP (79.0), FRSP (15.8), QUSP (3.5)
GPT-02	B	95.1	38.8	713	7	TADI (34.6), NYSP (31.6), ACSP (22.2)	ACSP (89.2), FRSP (3.6), QUSP (3.6)
CRMS 5452	B	77.9	44.5	1983	7	NYSP (66.3), TADI (29.4), ACSP (3.9)	ACSP (43.7), NYSP (17.6), MOCE (16.8)
CRMS 0063	B	92.3	46.4	648	6	NYSP (39.1), TADI (26.6), ACSP (18.1)	FRSP (77.1), ACSP (12.5), MOCE (8.3)
641-01	B	93.2	35.7	26	3	NYSP (66.8), TADI (33.2)	COFO (100)

1Not all species are listed, only the top 3 by Importance Value (overstory) and relative density (midstory). Species code: ACSP = *Acer* spp., CEOC = *Cephalanthus occidentalis*, COFO = *Cornus foemina*, FRSP = *Fraxinus* spp., ILSP = *Ilex* spp., MOCE = *Morella cerifera*, NYSP = *Nyssa* spp. (only *Nyssa aquatica* and *Nyssa biflora*), QUSP = *Quercus* spp., SANI = *Salix nigra*, TADI = *Taxodium distichum*, TRSE = *Triadica sebifera*, ULSP = *Ulmus* spp.

Table 2.2 (continued) Vegetation summary data by site. Sites are listed in order of increasing mean seasonal water level.

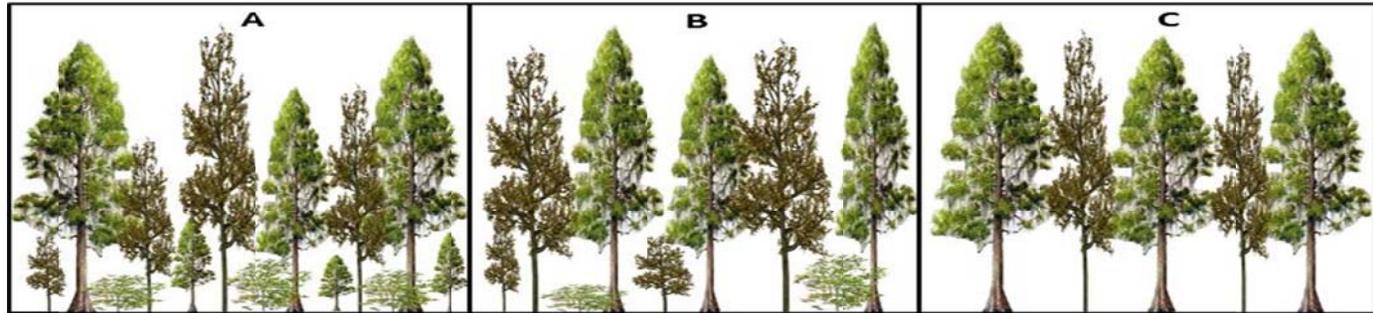| Site	Category	Canopy Cover (%)	Overstory Basal Area/Ha (m²)	Midstory Tree Density/ Ha	No. of Woody Species	Top 3 Overstory Species[1] (Importance Value)	Top 3 Midstory Species[1] (Relative Density)
SJM-01	B	89.6	25.5	2242	7	NYSP (46.8), TADI (28.0), ACSP(17.1)	FRSP (59.1), ACSP (31.8), TRSE (6.8)
GPT-01	B	93.9	29.5	1096	5	NYSP (55.6) TADI (16.6) ACSP (13.5)	ACSP (69.8), FRSP (20.9), NYSP (9.3)
HCN-02	B	77.1	24.3	102	5	NYSP (57.4), TADI (34.8), ACSP (4.3)	CEOC (50.0), ACSP (25.0), FRSP (25.0)
BYP-01	C	96.6	38.7	0	2	TADI (70.4), NYSP (29.6)	None
CRMS 0403	C	92.6	64.9	143	3	TADI (61.3), NYSP (38.7)	TADI (66.7), ACSP (33.3)
641-02	C	58.6	16.1	26	3	NYSP (72.4), TADI (27.6)	MOCE (100)
HCN-01	C	94.5	34.8	866	4	NYSP (61.2), ACSP (18.1), TADI (13.6)	ACSP (79.4), FRSP (17.6)
BYI-01	C	94.1	24.7	764	5	NYSP (59.7), TADI (31.4), SANI (4.5)	CEOC (93.3), ACSP (3.3) SANI (3.3)
641-03	C	77.1	22.9	153	5	NYSP (55.5), TADI (40.7), ACSP (3.8)	MOCE (83.3), TRSE (16.7)

[1]Not all species are listed, only the top 3 by Importance Value (overstory) and relative density (midstory). Species code: ACSP = *Acer* spp., CEOC = *Cephalanthus occidentalis*, COFO = *Cornus foemina*, FRSP = *Fraxinus* spp., ILSP = *Ilex* spp., MOCE = *Morella cerifera*, NYSP = *Nyssa* spp. (only *Nyssa aquatica* and *Nyssa biflora*), QUSP = *Quercus* spp., SANI = *Salix nigra*, TADI = *Taxodium distichum*, TRSE = *Triadica sebifera*, ULSP = *Ulmus* spp.

Table 2.3. Representation of typical forest structure within each category, accompanied by the mean value for each vegetation summary statistic. Statistical differences among categories at the alpha = 0.10 level are indicated by superscript letters. The top five species are listed by importance value for the overstory and relative density for the midstory among all sites within a Category.

Variable	Hydrologic Category A (3 sites)	Hydrologic Category B (8 sites)	Hydrologic Category C (6 sites)
Canopy Cover (%) ± SE	92.0 ± 4.7^a	85.6 ± 3.8^a	85.6 ± 6.1^a
Overstory Basal Area ($m^2ha^{-1)}$ ± SE	38.5 ± 5.5^a	32.9 ± 3.6^a	33.7 ± 7.1^a
Midstory Tree Density (trees ha$^{-1)}$ ± SE	1344.3 ± 158.2^a	1032.7 ± 289.0^a	325.3 ± 157.5^b
Number of Woody Species ha^{-1} ± SE	7.7 ± 1.5^a	5.6 ± 0.5^a	3.7 ± 1.0^b
Top Overstory Species[1]	TADI, NYSP, ACSP, TRSE, FRSP	NYSP, TADI, ACSP	TADI, NYSP, ACSP, SANI
Top Midstory Species	ACSP, FRSP, TRSE, ULSP, CEOC	ACSP, FRSP, MOCE, QUSP, CEOC	MOCE, ACSP, CEOC, TADI, TRSE

[1]Species code: ACSP = *Acer* spp., CEOC = *Cephalanthus occidentalis*, FRSP = *Fraxinus* spp., ILSP = *Ilex* spp., MOCE = *Morella cerifera*, NYSP = *Nyssa* spp. (only *Nyssa aquatica* and *Nyssa biflora*), QUSP = *Quercus* spp., SANI = *Salix nigra*, TADI = *Taxodium distichum*, TRSE = *Triadica sebifera*, ULSP = *Ulmus* spp.

2.5 Discussion

Hydrology. Sites were easily separated into apparent Hydrologic Categories or RCC classes using daily water levels from one year of near-normal conditions. Our sampling took place in an area that experienced 1268 mm of rainfall from April-October 2014, a somewhat higher than average growing season rainfall based on the previous 20 year average (1001 mm SD ± 215). Sites classified as Hydrologic Category A were flooded for significantly fewer cumulative days above 0 cm and 15 cm during the growing season than sites classified as Hydrologic Categories B or C. This distinction is important for differentiating between sites that have the potential to support natural baldcypress regeneration and those that do not (Chambers et al. 2005). Newly-germinated baldcypress seedlings have shown poor survival following submergence of 45 days or greater (Souther and Shaffer 2000). If seedlings are able to germinate during dry periods and grow to 15 cm or greater in height before water levels reach 15 cm or higher, they could be expected to have high survival in the hydrologic conditions observed on Hydrologic Category A sites, which had a mean of 39 cumulative days submerged above 15 cm (Sun 1995).

The threshold for adequate performance of planted seedlings is critical for differentiating between sites that have the potential to support artificial baldcypress regeneration and those that do not (Chambers et al. 2005). Sites classified as Hydrologic Categories A and B were flooded for significantly fewer days above 30 cm, 45 cm, and 60 cm during the growing season than sites classified as Hydrologic Category C. Ease of planting and cost-effectiveness make bare-root 1-0 baldcypress seedlings the most commonly used for artificial regeneration purposes. In one study, planted 1-0 baldcypress

71

seedlings had 55 percent survival following just 20-29 days of submergence and only 31 percent following 30-45 days submerged (Bull 1949). Other studies have reported poor survival following 90 days of submergence (Souther and Shaffer 2000), and substantial reductions in height growth of surviving seedlings with just 30 to 60 days of submergence (see Chapter 1). Seedling height relative to flood water levels seems to be a very important aspect of seedling survival. Nursery-grown, bare-root 1-0 baldcypress seedlings are typically 45-60 cm in height. Planted baldcypress seedlings 45-60 cm in height at the start of the growing season are capable of high first-year survival and good height growth under hydrologic conditions observed on Hydrologic Category A site, which had a mean of 4 cumulative days submerged above 45 cm, and on Hydrologic Category B sites, which had a mean of 14 cumulative days submerged above 45 cm and only 6 cumulative days submerged above 60 cm. However, the survival potential would be very low for the same seedlings if planted on Hydrologic Category C sites, where I observed a mean of 133 cumulative days submerged above 45 cm and 23 cumulative days submerged above 60 cm. In addition, even though submerged seedlings can have good survival following 60 cumulative days of submergence, height growth declines rapidly following just 30 cumulative days of submergence (see Chapter 1).

Vegetation. The effect of increasing flood depth and duration drives different attributes of forest structure and composition in cypress-tupelo forests. A site's hydrologic regime does not seem to have a significant effect on overstory basal area and canopy cover on sites dominated by cypress and/or tupelo, as many sites were similar in these attributes regardless of Hydrologic Category. The nearly closed canopy would be common for established stands without recent substantial disturbance and sites without

degradation from long-term deep flooding or increased salinity (deGravelles et al. 2014). However, a closer look at the species composition, and specifically the number of different species, reveals much about the hydrologic influence. The lesser flood-impacted sites in Hydrologic Category A included individuals of several different oaks (*Quercus* spp.), elms (*Ulmus* spp.), and Chinese tallow (*Triadica sebifera*), even though these species did not have high importance values. Although the oak species observed (*Quercus laurifolia, Quercus michauxii, Quercus nigra, Quercus texana*) are considered flood tolerant relative to other oak species, they are still not tolerant to prolonged inundation during the growing season, especially compared to baldcypress (Pezeshki and Anderson 1997), and the same can be said for elms (*Ulmus* spp.) (Hook 1984). Conner et al. (1981) saw similar composition in a water-controlled swamp, with baldcypress and water tupelo comprising over 50 percent of the basal area (trees > 2.5 cm DBH) but with high densities of maple and ash species and a small oak component. The overstory layers on Hydrologic Category B sites lacked oak and elm species but supported a higher number of tupelo (*Nyssa* spp.), baldcypress, ash (*Fraxinus* spp.), and maple (*Acer* spp.) stems. Conner et al. (1981) reported baldcypress and water tupelo comprised 94 percent of the basal area (trees > 2.5 cm DBH) in a semi-permanently flooded swamp. Hydrologic Category C sites were even less species-diverse in the overstory, composed almost entirely of tupelo and baldcypress stems, which are the two overstory tree species most adapted to tolerate conditions resulting from prolonged inundation (Hook 1984, Theriot 1993). Sites containing a component of lesser flood tolerant species, such as oaks or elms, in the overstory layer are likely to have a hydrologic regime that is classified as Hydrologic Category A. Sites consisting almost entirely of cypress and tupelo are more

likely to have a hydrologic regime classified as Category B or C. In our study, the overstory composition difference alone did not clarify the division between Hydrologic Categories B and C, suggesting that both overstory baldcypress and tupelo can continue to survive under both sets of hydrological conditions for lengthy intervals.

Even if overstory species continue to exist for perhaps decades under Hydrologic Category C conditions, there may be changes that occur in the midstory and understory that differentiate Hydrologic Category B and C sites. For the sites included in our study, midstory density and structure were greatly influenced by flood depth and duration. Sites classified under Hydrologic Categories A and B had high midstory stem densities (1334 and 1033 TPH, respectively), while Hydrologic Category C sites had much lower midstory stem densities (325 TPH). This is due to the fact that sites in Hydrologic Category A have longer and more frequent periods where soil or substrate is exposed during the growing season, allowing germination and adequate growth to avoid submersion (Keeland and Conner 1999). Sites in Category B, even though they are nearly permanently flooded, have relatively shallow water levels and feature enough microtopographic variability to have small areas exposed during low-water events or dry years for seedling germination and establishment. Hydrologic Category C sites had deep, prolonged flooding, preventing substrate exposure and not allowing baldcypress and tupelo to germinate and become established before the end of the growing season. Conner et al. (1981) reported a lower tree (>2.5 cm DBH) density (943 TPH) in an impounded, permanently flooded Louisiana swamp compared to higher tree densities in both a water-controlled swamp (1564 TPH) and a natural swamp (1303 TPH) that experiences natural flooding and drawdown cycles.

74

Flood depth and duration impacts midstory seedling establishment. Although CRMS vegetation data did not indicate the rooting origin for trees measured in the midstory layer, I differentiated whether the trees on our study sites were rooted in the soil/substrate, on elevated structures such as old stumps, or on coarse woody debris between closely-spaced cypress knees, or even on soil between closely-growing mature trees (i.e. hummocks). Hydrologic Categories B and C sites were flooded for significantly longer periods than Hydrologic Category A sites. Six of the eight Category B sites were flooded above an elevation of 15 cm for more than half the growing season. Four of the eight Hydrologic Category C sites were flooded above an elevation of 30 cm for the entire growing season, above 45 cm for better than half the growing season, and above 60 cm for at least a portion of the growing season. On the Hydrologic Categories B and C sites that I measured, 64 percent of midstory stems in Category B and 69 percent of midstory stems in Category C were rooted on elevated structures, seemingly because those were the only areas intermittently exposed long enough to support seedling germination and growth. Huenneke and Sharitz (1986) emphasized the importance of microtopography within cypress-tupelo swamps by showing distinct patterns of woody seedling germination on different types of elevated substrate. Drummond red maple (*Acer rubrum* var. *drummondii*) appeared to be very proficient at rooting on elevated structures (Figure 2.2). Buttonbush (*Cephalanthus occidentalis*) was nearly the only midstory species on the study plots observed growing in the soil or substrate (as opposed to rooted on elevated structures) in relatively deep standing water. Buttonbush has the ability to germinate in standing water (DuBarry 1963). All other midstory tree species observed on the Hydrologic Category C sites were rooted on elevated structures. Conner et. al (1981)

Figure 2.2. Drummond red maple (*Acer rubrum* var. *drummondii*) rooted on an elevated structure in a permanently flooded swamp.

reported similar results, with buttonbush comprising the majority of the tree density for a permanently flooded swamp in south Louisiana. He reported similar rooting habits for Drummond red maple in a semi-permanently flooded swamp in southeast Louisiana. Sites with a relatively dense midstory layer and a high percentage of stems rooted on elevated structures are likely to have a hydrologic regime classified as Hydrologic Category B. Sites with a relatively sparse midstory layer with a high percentage of stems rooted on elevated structures are likely to have a hydrologic regime classified as Hydrologic Category C (Table 2.3).

Herbaceous vegetation was observed but not measured or analyzed because of its tendency to respond to present or recent conditions and, therefore, they tend to reflect

76

current changes and not the long-term trends in hydrology that many woody species do (Theriot 1993). However, some general observations can be made about conditions observed within apparent Hydrologic Categories during the growing season covered by this study. Small, floating aquatic species such as duckweed (*Lemna* spp.) and salvinia (*Salvinia* spp.) were generally not observed on Hydrologic Category A sites. STM-01, a Category A site, was almost completely covered with savannah panicgrass (*Phanopyrum gymnocarpon*), which was likely present because of the heavy-clay soil on the site and the lack of a defined organic soil layer.

Emergent aquatic vegetation was not as prolific in Hydrologic Category C sites as it was in Categories A and B. Floating aquatic vegetation was observed on most Hydrologic Category C sites. However, there was variability among sites in Hydrologic Category C in the type of floating vegetation present. Sites 641-02 and 641-03 were characterized by dense, floating mats of herbaceous vegetation primarily composed of *Bidens* and *Hydrocotyle* spp. (Figure 2.3). These "flotants" typically occur in open pools of freshwater marshes and have been theorized to act as a successional pioneer community before transitioning to shrub-dominated vegetation and eventually climaxing with cypress-tupelo forests (Russell 1942, Huffman and Lonard 1983). In the case of our sites, their presence may be indicative of sites transitioning back to marsh or open water. The direction of change may be uncertain in some cases, but open canopies of overstory mature cypress and tupelo already exist, and the floating vegetation seems to be an intruder where the canopy is breaking up.

BYP-01, located in the Atchafalaya Basin, is influenced by deep, prolonged flooding during the middle of the growing season followed by a dry period in late

Figure 2.3. Floating mat of vegetation composed largely of *Bidens* and *Hydrocotyle* spp. at 641-03

summer/early fall. A prominent layer of duckweed and salvinia was observed at BYP-01 during the growing season, but little to no emergent vegetation was noted (Figure 2.4).

Vegetation as an Indicator of Flood Regime. The overstory species composition coupled with the midstory density and rooting origin can, to some extent, aid in interpreting a site's hydrologic regime as it relates to baldcypress regeneration potential. Based on hydrologic regime classification developed from water level differences in one slightly greater than average year of rainfall, Hydrologic Categories A, B, and C correspond closely to the SWG Regeneration Condition Classes (RCC) I, II, and III, respectively. General site descriptions for each Hydrologic Category or RCC are as follows:

Hydrologic Category A Sites (RCC I): tend to have vegetation composed of cypress or tupelo but containing small to moderate levels of lesser flood tolerant species, such as oaks or elms, in the overstory layer. The midstory layer is relatively dense with the majority of the midstory trees rooted in the mineral soil. These sites have the potential to support natural baldcypress regeneration unless a recent change in hydrologic conditions (increased flood depth or duration) has occurred.

Hydrologic Category B Sites (RCC II): tend to be composed primarily of cypress and tupelo in the overstory layer. The midstory layer is moderately dense with a high percentage of the midstory trees rooted on elevated substrate. However, many of the midstory stems will not likely contribute to overstory basal area without drier conditions. These sites have the potential for supporting artificial baldcypress regeneration, but natural regeneration success is highly unlikely unless a recent change in hydrologic conditions (increased flood depth or duration) has occurred. Unless drained, these sites will be flooded to some degree throughout more than half of the growing season and in some sites all of the growing season.

Hydrologic Category C Sites (RCC III): Until permanent flooding begins to degrade the overstory and reduce tree basal area, the overstory tends to consist almost entirely of cypress and tupelo. The midstory layer is relatively sparse, but when some midstory is present, a high percentage of the trees are rooted on elevated substrate. In all likelihood, these sites have little to no potential for supporting either natural or artificial baldcypress regeneration, since even the overstory will eventually succumb to the deeper water levels. Many, but not all, of these sites will have flood waters during the entire growing season. Caution must be taken as some sites are deeply flooded (several meters deep) in the middle portion of the growing season, preventing successful seedling establishment.

Figure 2.4. Water levels at BYP-01 in June (left) and October (right). Deep, prolonged flooding during the middle of the growing season prevents tree seedling establishment.

Table 2.4. General vegetation attributes and regeneration potential of cypress-tupelo forests for each Hydrologic Category or apparent SWG Regeneration Condition Class.

Vegetation Attribute	Hydrologic Category A (RCC I)	Hydrologic Category B (RCC II)	Hydrologic Category C (RCC III)
Overstory Species Composition	Mostly cypress and/or tupelo, with a minor component of oaks, elms, and other bottomland hardwoods	Primarily cypress and/or tupelo, often with a minor component of maples and/or ashes	Primarily cypress and/or tupelo
Midstory Tree Density	Dense	Dense to moderately dense	Sparse
Midstory Tree Rooting Origin	Mostly in mineral soil	Mostly on elevated structures	Mostly on elevated structures
Regeneration Potential	Natural and artificial	Artificial only	Neither natural or artificial

These new tentative site characterizations of vegetation supplement or expand upon the SWG RCC definitions by establishing vegetation-based thresholds to aid in the evaluation of a site's baldcypress regeneration potential where records of hydrology are lacking. These stand characteristics help effectively define how cypress-tupelo forests transition in vegetation structure and composition from least flood impacted to most flood impacted sites. However, the information is only for freshwater swamps and based only on first-year data.

Sites within the same Hydrologic Category were considerably inconsistent in some hydrologic and vegetation attributes that were either not measured in this study or in traits that were difficult to quantify. Sites within a Hydrologic Category often differed in flood timing, intensity, and water quality. These flood characteristics are mostly attributable to the nature of the flood inputs (i.e. impounded sites primarily fed by local rainfall vs. sites directly connected to riverine or lacustrine systems fed with waters higher in sediment, nutrients, and dissolved oxygen). The mean overstory basal area per hectare was highly variable and midstory stem density was different between categories, yet there was a lot of variation among sites within the Categories. Sites with recent changes in hydrology could contribute to discrepancies in expected vegetation structure and composition, especially in Hydrologic Categories B and C where the present vegetation would not have germinated or developed under the present conditions. To effectively assess a site's regeneration potential, it is critical to understand that present hydrologic conditions are sometimes much different than the conditions that existed when a stand was established. It is also important to understand that current conditions can and will change at some point in the future (DeLaune et al 1987). Natural resource

professionals must also recognize that climatic and hydrological conditions are often very dynamic from year to year. Although I was able to observe a wide range of hydrologic conditions among several different cypress-tupelo forest sites, I did not fully test the range of conditions at either the drier or wetter ends of the flood spectrum. Preliminary site visits to several different areas showed that drier sites containing individuals of cypress and/or tupelo were usually dominated by lesser flood tolerant species. Similarly, areas that had deeper water levels than the sites used in this study, did not have an adequate number of trees to be considered a forest. The latter were likely once Hydrologic Category C sites that have, for all practical purposes, completed the transition to either open water or marsh.

It is important to note that even though cypress and tupelo are most often found in swamps and similar hydrologic conditions, they are typically growing along a gradient in hydrologic conditions across their distribution in southeast Louisiana. Although, I have classified these sites as Hydrologic Category A, B or C, the actual sites or portion of sites are, from a hydrological perspective, transitioning or grading from one to another and boundaries are most often not actually distinct. There are overlaps in physical and biological attributes within and among sites. Also, site attributes are never static in the long-term, but always transitioning in some way.

2.6 Conclusions

Certain similarities of conditions exist among cypress-tupelo forests within the hydrologic range of seasonally flooded to permanently flooded sites, such as dominant species and flooding during some portion of the growing season. However, characteristics such as overstory species composition used in conjunction with midstory

tree density and rooting origin of cypress-tupelo forests appear to be indicative of the site's hydrologic regime. Furthermore, although species diversity is relatively low across cypress-tupelo sites, the number of species declines with increasing flood depth and duration. More importantly, low overstory species diversity coupled with the lack of a well-developed midstory possibly serves as an indicator of sites that will not regenerate baldcypress naturally and a have a low potential for artificial regeneration success.

The species composition of sites included in this study and their corresponding hydrologic regimes, coupled with the low occurrence of baldcypress seedlings and saplings reveals a very specific set of hydrologic conditions that will allow naturally regenerated baldcypress seedlings to both thrive without competition from less flood tolerant species and become established to withstand deep flooding and avoid prolonged inundation. Consequently, a large acreage of cypress-tupelo forests across south Louisiana has the potential to regenerate by artificial means only or has little to no regeneration potential at all (Conner et al. 1986). Therefore, when it comes to predicting the success of planted baldcypress seedlings, it is critical for the future of coastal forests to be able to differentiate between areas that have artificial regeneration potential and areas that are not suitable for either natural or artificial regeneration. Employing an approach similar to the one proposed by Faulkner et al. (2009) to approximate estimation of the locations and amount of land area categorized by RCC or Hydrologic Category using remote sensing, combined with the methodology outlined in this study to categorize areas using vegetation sampling could create a high-resolution assessment of the regeneration potential for cypress-tupelo forests across south Louisiana.

While this study has proposed a hypothetical way of identifying the apparent

Hydrologic Categories or RCCs based on current vegetation, it is based only on one year

of hydrologic data, dominated by one aspect of flooding (cumulative days flooded at

specific depths). Additional years of survival and growth data are needed to confirm or

solidify the vegetation variables and change overtime. Long-term seedling establishment

is critical. Still, other aspects of flooding need to be tested. Many more sites need to be

added and years of variable flooding need to be tested. Cypress-tupelo forests are very

complex systems due to elements associated with frequent and prolonged flooding, and

we still do not fully comprehend how various factors contribute to the manner in which

these forests function. Further research is needed to isolate and quantify the numerous

hydrologic factors and processes controlling vegetation structure and composition and to

gain a better understanding of how the matrix of hydrologic factors and processes

influence stand dynamics in cypress-tupelo forests. This study is, at least, a first step

towards improving the management and sustainability of cypress-tupelo forests.

2.7 Literature Cited

Bedinger, M.S. (1971) Forest species as indicators of flooding in the Lower White River
    Valley, Arkansas. USGS Professional Paper 750: C248-C253.

Bledsoe, B.P., Shear, T.H. (2000). Vegetation along hydrologic and edaphic gradients in
    a North Carolina coastal plain creek bottom and implications for restoration.
    Wetlands 20:1: 126–147.

Bull, H. (1949) Cypress planting in southern Louisiana. Southern Lumberman 179: 227-
    230.

Chambers, J. L., Conner W.H., Day J.W., Faulkner S.P., Gardiner E.S., Hughes M.S.,
    Keim R.F., King S.L., McLeod K.W., Miller C.A., Nyman J.A,, and Shaffer G.P.
    (2005). Conservation, Protection and Utilization of Louisiana's Coastal Wetland

Forests. Final Report to the Governor of Louisiana from the Science Working Group on Coastal Wetland Forest Conservation and Use. Baton Rouge, LA, USA.

Conner, W.H., Day J.W. (1988). Rising water levels in coastal Louisiana - implications for two coastal forested wetland areas in Louisiana. Journal of Coastal Research 4: 589-596.

Conner, W.H., Gosselink J.G., and Parrondo R.T. (1981). Comparison of the vegetation of three Louisiana swamp sites with different flooding regimes. American Journal of Botany 68:3: 320-331.

Conner, W.H., Toliver J.R., and Sklar F.H. (1986). Natural regeneration of baldcypress (*Taxodium distichum* [L] Rich.) in a Louisiana swamp. Forest Ecology and Management 14:305-317.

Cowardin, L.M., Carter V., Golet F.C., LaRoe E.T. (1979). Classification of Wetlands and Deepwater Habitats of the United States. U.S. Fish and Wildlife Service Report No. FWS/OBS/-79/31 Washington, D.C.

Curtis J.T., McIntosh R.P. (1951). An upland forest continuum in the prairie-forest border region of Wisconsin. Ecology 32: 476-496.

deGravelles, W.W., Hutchinson S., and Conner W.H. (2014). Survival and growth of suppressed baldcypress reproduction in response to canopy gap creation in a North Carolina, USA Swamp. Wetlands 34: 79-87.

DeLaune, R.D., Pezeshki S.R., and Patrick W.H. Jr. (1987). Response of coastal plants to increase in submergence and salinity. Journal of Coastal Research 3:4: 535-546.

Demaree, D. (1932). Submerging Experiments with Taxodium. Ecology 13: 258-262.

DuBarry, A.P. Jr. (1963) Germination of bottomland tree seed while immersed in water. Journal of Forestry 61: 225-226.

Faulkner S.P., Bhattarai Y., Allen Y., Barras J., Constant G. (2009) Identifying baldcypress-water tupelo regeneration classes in forested wetlands of the Atchafalaya Basin, Louisiana. Wetlands 29: 809-817.

Folse T.M., Sharp L.A., West J.L., Hymel M.K., Troutman J.P., McGinnis T.E., Weifenbach D., Boshart W.M., Rodrigue L.B., Richardi D.C., Wood W.B., and Miller C.M.. (2014). Revised. A Standard Operating Procedures Manual for the Coastwide Reference Monitoring System-Wetlands: Methods for Site Establishment, Data Collection, and Quality Assurance/Quality Control. Louisiana Coastal Protection and Restoration Authority. Baton Rouge, LA.

Hook, D.D. (1984). Waterlogging Tolerance of Lowland Tree Species of the South. Southern Journal of Applied Forestry 8:3: 136-149.

Huenneke, L.F. and Sharitz R.R. (1986). Microsite abundance and distribution of woody seedlings in a South Carolina cypress-tupelo swamp. American Midland Naturalist 115:2: 328-335.

Huffman R.T. and Lonard R.I. (1983). Successional patterns on floating vegetation mats in a southwestern Arkansas baldcypress swamp. Castanea 48:2: 73-78.

Johnson, C.A., Bedford B.L., Bourdaghs M., Brown T., Frieswyk C., Tulburne M., Vaccaro L., Zedler J.B. (2007). Plant species indicators of physical environment in Great Lakes coastal wetlands. Journal of Great Lakes Research 33: 106–124 (Special Issue 3).

Keeland, B.D. (1994). The effects of variations in hydrologic regime on diameter growth in *Nyssa aquatica*, *Nyssa sylvatica* var. *biflora*, and *Taxodium distichum*. Dissertation, University of Georgia.

Keeland, B.D. and Conner W.H. (1999). Natural regeneration and growth *ofTaxodium distichum* (L.) Rich. in Lake Chicot, Louisiana after 44 years of flooding. Wetlands 19:1: 149-155.

Keim, R.F., Chambers J.L., Hughes M.S., Dimov L.D., Conner W.H., Shaffer G.P., Gardiner E.S., and Day J.W. Jr. (2006). Long-term success of stump sprouts in high-graded baldcypress–water tupelo swamps in the Mississippi delta. Forest Ecology and Management 234: 24-33.

McKnight, J.S., Hook, D.D., Langdon, O.G. & Johnson, R.L. (1981). Flood tolerance and related characteristics of trees of the bottomland forests of the southern United States. In: Wetlands of Bottomland Hardwood Forests (eds. Clark J.R. and Benforado J.). Elsevier Amsterdam, the Netherlands: pp 26-69.

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

Parresol B. R., Hodvedt J.E., Cao Q.V. (1987) A volume and taper prediction system for baldcypress. Canadian Journal of Forest Research. 17: 250-259.

Pezeshki, S.R., and Anderson P.A. (1997). Responses of three bottomland woody species with different flood-tolerance capabilities to various flooding regimes. Wetlands Ecology and Management 4: 245-256.

Pezeshki S.R., DeLaune R.D., and Patrick W.H. Jr. (1993). Responses of forested wetland species to alteration in soil hydrology/chemistry. In: Wetlands: Proceedings of the 13th Annual Conference of the Society of Wetland Scientists, New Orleans, LA. pp. 878-889.

Russell R.J. (1942). Flotant. Geographical Review 32:1: 74-98.

Shaffer G.P., Wood W.B., Hoeppner S.S., Perkens T.E., Zoller J., and Kandalepas D. (2009). Degradation of baldcypress–water tupelo swamp to marsh and open water in southeastern Louisiana, U.S.A.: an irreversible trajectory?. Journal of Coastal Research: Special Issue 54: 152–165.

Souther R.F. and Shaffer G.P. (2000). The effects of submergence and light on two age classes of baldcypress (*Taxodium distichum* L. *Richard*) seedlings. Wetlands 20:4: 697-706.

Steyer, G.D., Sasser C.E., Visser J.M., Swenson E.M., Nyman J.A., and Raynie R.C. (2003). A proposed coast-wide reference monitoring system for evaluating wetland restoration trajectories in Louisiana. Environmental Monitoring and Assessment. 81: 107-117.

Sun, J. (1995). Submergence impacts on selected wetland/bottomland tree species. Ph.D. Dissertation. Louisiana State University, Baton Rouge, LA, USA.

Theriot, R.F. (1993). Flood tolerance of plant species in bottomland forests of the southeastern United States. U.S. Army Corps of Engineers Technical Report: WRP-DE-6. 191 pp.

Williston, H.L., F.W. Shropshire, and W.E. Balmer. (1980). Cypress Management: A Forgotten Opportunity. Forestry Report SA-FR 8. USDA Forest Service, Southeastern Area, State and Private Forestry, Atlanta, GA.
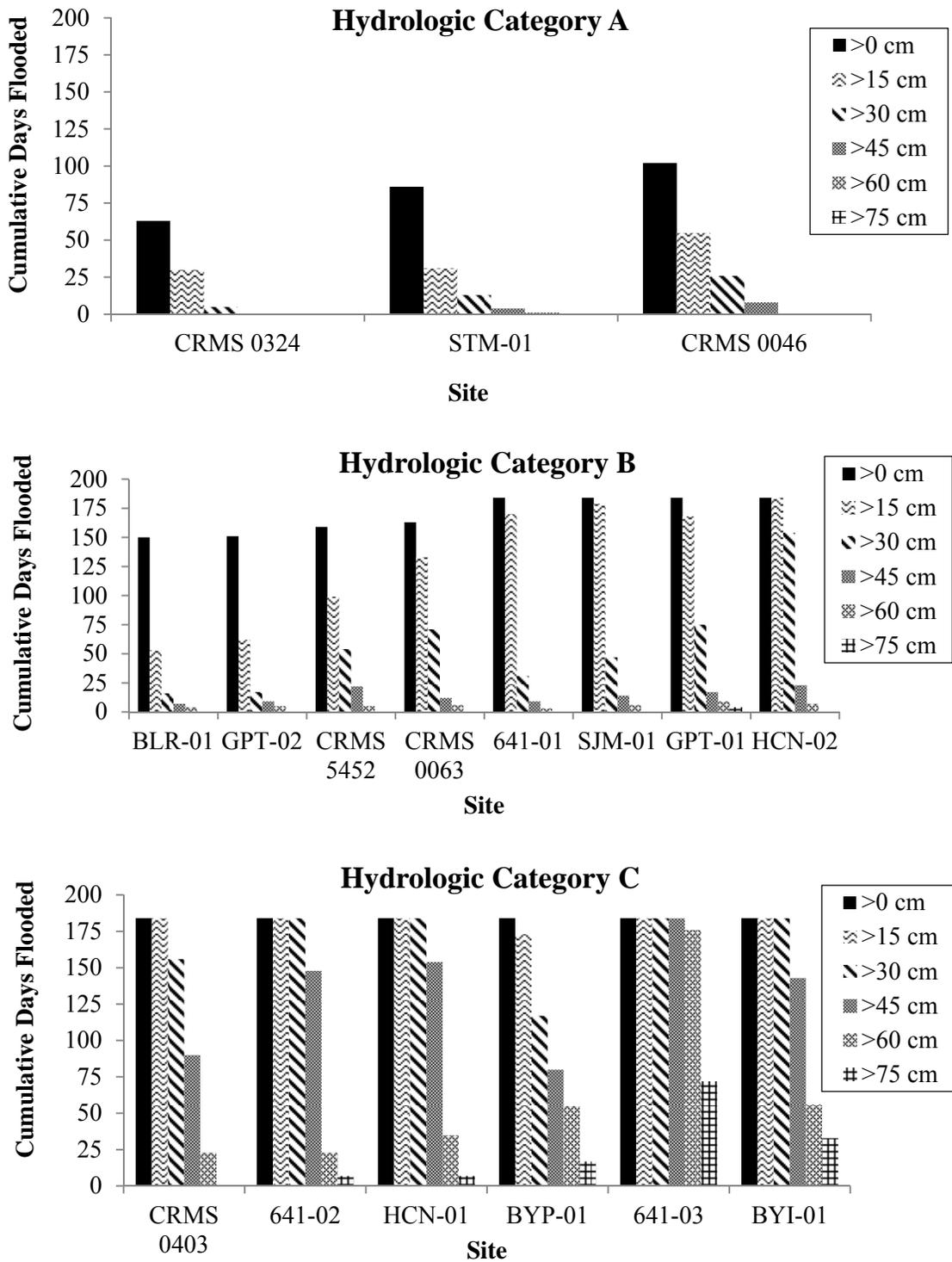
APPENDIX

Figure 1. Cumulative days flooded above benchmarks ranging from 0 cm to 75 cm for individual sites classified in their respective Hydrologic Categories.

VITA

Marcus Rutherford, a native of Chesterfield, Illinois, received his bachelor's degree in forest resource management from Southern Illinois University in 2012. Thereafter, he immediately entered graduate school in the School of Renewable Natural Resources at Louisiana State University. He will receive his master's degree in December 2015 and has been hired as a forester with A. Wilbert's sons LLC in Plaquemine, Louisiana.