Assessment of Woody Vegetation for Replacement of Ecological Functions in Created Forested Wetlands of the Piedmont Province of Virginia

2011 Annual Report
Submitted To:

PIEDMONT WETLANDS RESEARCH PROGRAM

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Executive Summary

Poor survival and/or slow growth rates of woody vegetation planted in created forested wetlands have been a major cause of poor performance of these wetlands. The purpose of our work is twofold: to establish a mesocosm and field study to 1) measure the performance of several woody species and stocktypes and 2) determine the ability of created wetlands to perform lost wetland functions such as biomass and productivity that have been described by Odum (1969) as requirements for ecosystem development.

Three objectives were proposed to address these questions:

1. to critically evaluate and improve upon the planting of woody vegetation in created forested headwater wetlands in the Piedmont Province, Virginia. The goal of this objective was to identify the most appropriate woody species and stocktype(s) that could be recommended for planting in created forested wetlands in the Piedmont Province of Virginia (NOTE: Due to RPM Ecosystems filing for bankruptcy, Forrest Keeling was unable to ship Root Production Method (RPM) nursery stock to Virginia. Therefore, we were unable to incorporate the RPM nursery stock into our study in 2011.)
2. determine the appropriate vegetative measures that will identify whether the important wetland functions are being replaced. The goals of this objective were to relate woody growth (via morphometric analysis) as a dependent variable to two independent ecological variables (above and belowground biomass, Net ecosystem exchange NEE), to determine vegetation similarity of created forested wetlands and reference sites, and to determine the role of volunteer woody species; and
3. compile an updated literature review concerning created palustrine wetlands.

This report presents results from the first three years of this study and places emphasis on Objective 1. In 2009 a Mesocosm site was established at the New Kent Forestry Center, in Providence Forge, VA. The site was divided into three cells each having dimensions of 48.8m x 144m (160ft x 300ft) and irrigated to desired effect. At the same time, three (3) Piedmont constructed wetland field sites were chosen for the study and are comprised of the three phases (Designated as Phase I, II, and III) of the Loudoun County Wetland and Stream Mitigation Bank that were designed and installed by Wetland Studies and Solutions, Inc.

Results from the mesocosm study showed that the primary species grown in gallon containers have the greatest survival and growth. However, this trend was not repeated in the field study in Loudoun County where the secondary oak species, primarily gallon stock type, had the greatest survival

and growth. These contrasting recommendations may be the result of uncontrolled herbaceous vegetation in the field study that provided a more suitable habitat for secondary species, while the lack of herbaceous competition in the mesocosm provided a more suitable habitat for the primary species. Herbaceous vegetation has been shown to have a significant impact on planted tree survival and growth during the first several years following planting (Gjerstad et al. 1984, Britt 1991, Morris et al. 1993, Davis et al. 1999, Groninger et al. 2004, Gardiner et al. 2006, Pennington and Walters 2006, Pinto et al. 2012).

Numerous presentations of this data have been given over the past three years by the PI's and their Students. Dr. Perry has presented three invited presentations: one at the Society of Ecological Restoration Eastern Chapter Annual Meeting (SER-E), one at the Society of Wetland Scientist South East Chapter (SWS-SE) SWS annual meeting, and one at the UVA Department of Environmental Science. Both PI's have presented several scholarly talks at professional annual meetings (SWS-SE and the Association of SE Biologist (ASB)). Dr. Perry chaired a special session SWS-SE on created palustrine habitats at the SWS-SE annual meeting. Graduate students from both VIMS and CNU have presented over 15 scholarly talks and posters on the project at a number of different professional meetings, including the SWS-SE, Virginia Association of Wetland Professionals annual meetings, and ASB Annual Meetings. Three high school students have completed projects in the Mesocosm studies as part of the Governors School Program. Finally, two publications have been completed and are in draft form. These will be submitted for review by December 2012 to top ranked ecological and forestry journals.

Acronyms

LCWSB – Loudoun County Wetland and Stream Mitigation Bank

BR – Bare root

TUB – Tubeling

GAL – 1 gallon container

BD – Basal Diameter

H – Height

CD – Canopy Diameter

RGR – Relative Growth Rate

BDRGR – Basal Diameter Relative Growth Rate

HRGR – Height Relative Growth Rate

CDRGR – Canopy Diameter Relative Growth Rate

NPP – Net Primary Productivity

NEE – Net Ecosystem Exchange

Introduction and Project Description

Poor survival and/or slow growth rates of woody vegetation planted in created forested wetlands have been a major cause of poor performance of these wetlands (NRDC 1995, Spieles 2005, Leo Snead, Virginia Dept. Transportation, Richmond, VA, pers. comm.). There are numerous species of woody plants and stocktypes (e.g. seeds, bare-root seedling, tubelings, 1 or 3 gal. potted) available for planting. However, there are few data driven studies that have addressed how the choice of quality (or size), quantity, species diversity of woody plants and associated planting methods affects the survival and growth of woody species in created wetlands. Therefore, restoration managers lack data to quantify the ability of created forested wetlands to achieve structural or functional maturity. The purpose of our work is twofold: to establish a mesocosm and field study to 1) measure the performance of several woody species and stocktypes and 2) determine the ability of created wetlands to perform lost wetland functions such as biomass and productivity that have been described by Odum (1969) as requirements for ecosystem development.

Objectives and Background

This study has three main objectives that are described below with additional background information.

Objective 1

The first objective of this study is to critically evaluate and improve upon the planting of woody vegetation in created forested headwater wetlands in the Piedmont Province, Virginia. The purpose of this objective is to identify the most appropriate woody species and stocktype(s) to recommend for planting in created forested wetlands in the Piedmont Province of Virginia.

Background – Objective 1

Most woody planting into forested wetlands relies on one of three methods of planting stock. Bare-root seedlings, the most common form planted, are young saplings (~1 year old) with no soil in the root-ball. Tubelings are similar to bare-root with the exception of a slightly larger rootstock. Potted plants come in various sizes (from 1 to 5 gallons or larger), can be from 1 to several years old in the larger pots, and contain a well formed root-ball, presumably with associated microfauna. The three types differ in price with potted plants often 5 to 10 times more expensive to buy and more labor intensive to plant. This study also seeks to determine if the added growth and more rapid ecological development justify the expense of potted plants. We will attempt to fulfill the latter part of the objective in an addendum to this report.

The second part of this objective is to determine whether certain species are more appropriate to plant than others. Certain hardwood species, such as oaks, are slow growing and appear later in the forest succession processes, typically many years after the canopy closes (Whittaker 1978). Spencer et al. (2001) showed that pioneer species such as *Salix nigra* (black willow) and *Betula nigra* (river birch) were the first colonizers in timbered forested wetlands in Virginia, with oak and hickory appearing after approximately 15 years, usually as coppice species. DeBerry and Perry (in review) concluded that the design methods used to construct forested wetlands lend themselves to the establishment of woody species that colonize during dry conditions but can rapidly adapt to prolonged saturation or inundation and recommended planting species such *Platanus occidentalis* (American sycamore), *S. nigra*, and *Taxodium distichum* (bald cypress). In this study, we are evaluating the performance of a minimum of seven woody species common to the forested wetlands of the Piedmont (*B. nigra*, *Liquidambar styraciflua*, *P. occidentalis*, *Quercus bicolor*, *Q. palustris*, *Q. phellos*, and *S. nigra*) in a coordinated mesocosm and field study by comparing survival and growth rates (via morphometric assessment) of tree (sapling) plantings: 1) from various stocktypes (as bare-root seedlings, tubelings, and one gallon pots) and 2) several species under three distinct hydrologic conditions: mesic (Ideal Cell), saturated within the root zone (top 20cm) during winter, fall and spring (Saturated Cell), and inundated throughout the year (Flooded Cell). Only the Saturated Cell conditions are meant to mimic natural conditions. The Ideal and Flooded Cell conditions are meant to provide data that will allow us to determine the optimal, least hydrological stressed (Ideal Cell) and harshest, most hydrological stressed (Flooded Cell) survival and growth conditions for the seven woody species. The data collected from these latter treatments will be used to determine upper (Ideal) and lower (Flooded) limits of survival and growth that we would expect to find in the Saturated Cell and our field data. These species can be divided into two groups: fast growing pioneer species (*B. nigra*, *L. styraciflua*, *P. occidentalis* and *S. nigra*) and slow growing secondary succession species (*Q. bicolor*, *Q. palustris*, and *Q. phellos*) (Radford et al. 1976, Gleason and Cronquest 1998, Spencer et al. 2001). In the future we propose to test species that have undergone specific initial growth processes (e.g. RPM, flood or inundation hardening, fertilization).

Objective 2

The second objective of this study is to determine the appropriate vegetative measures that will identify whether the important wetland functions are being replaced. The purpose of this objective are to relate woody growth (via morphometric analysis) as a dependent variable to two independent ecological variables (above and belowground biomass, net ecosystem exchange NEE), to determine vegetation similarity of created forested wetlands and reference sites, and to determine the role of volunteer woody species. The data also will provide information that will support Objective 1; i.e. what is (are) the most effective species to plant (based on maximum growth and maximum CO_2 fixation efficiency).

Background – Objective 2

Odum (1969) identified (above and below ground) biomass and net primary productivity as two major functions of wetland ecosystem development. However, measuring each of these functions in the field is time consuming and destructive (i.e. requires cutting and removing of vegetation). Therefore, many authors and regulators have turned to non-destructive measures of vegetation, such as cover and/or density, as a proxy for assessing the presence and quality of the biomass and productivity functions in wetlands (Brinson 1993, Perry and Hershner 1999).

Other structural attributes that have been used to quantify woody vegetation and tied to biomass include height, number of branches, length of branches, and basal area (Mueller-Dombois and Ellenberg 1974, Day 1985, Spencer et al. 2001, Bailey et al. 2007). However, few studies have related these structural attributes to growth rates and, therefore, productivity. Bailey et al. (2007) found individual canopy cover (measured with a caliper), stem diameter at the soil level, and maximum height were the best predictors of sapling growth in a created forested wetland in Virginia of seven possible morphological measurements taken for woody vegetation,. Structural data can also be used to calculate species diversity as an integration of evenness and richness (Mueller-Dombois and Ellenberg 1974), while a simple species list can be used to calculate metrics such as Simpson's or Jaccard's indices of similarity (Mueller-Dombois and Ellenberg 1974).

We used the methods developed by Bailey et al. (2007) to determine the growth of planted woody vegetation at both the Mesocosm and three field sites. The Mesocosm cells also are being used to compare the growth to two ecological functions: plant biomass and overall productivity. Above and belowground biomass was measured by sacrificing three (3) individuals of each species and stocktype in winter of 2010. Net Ecosystem Exchange (carbon flux) was measured with a PP Systems TPS-2 Portable Gas Analyzer (a measure of efficiency in CO_2 fixation) (Bailey 2006, Cornell et al. 2007).

Two other tasks in this objective included: 1) determining the role volunteer woody plants in created forested wetlands by using a chronosequence of sites in the Piedmont and 2) determining the distribution of volunteer species in the created systems. Work on this portion of the project has begun. We plan on quantitatively determining the woody species occurrence and diversity and relative functions in Virginia Piedmont reference wetlands, and to compare them to created wetlands that were planted with various stocktypes, sizes and species mixes.

Objective 3

The third objective of this study was to complete an in-depth literature review.

Background – Objective 3

We have continued to update available literature for available technologies for planting woody vegetation, survival reports, evaluations of ecological potential, and recommendations regarding species for created forested wetlands. This included, but was not limited to:

1. Current planting practices that are acceptable to regulatory agencies and utilized by consultants within Virginia for creating forested wetlands (i.e., determining quantity, stock size and species mix that are being used);

2. Existing use and success of incorporating a woody pioneer species (e.g., *Betula* spp., *L. styraciflua*, *Salix* spp.) for forested wetland creation; and,

3. Alternative methods to enhance establishment and growth of woody species (i.e., mycorrhizal inoculations, root production method (RPM) trees, colonization from adjacent property, etc.).

Preliminary Studies

Our initial work in eastern Virginia (Spencer et al. 2001) found that disturbed forested wetland systems did not proceed through primary succession processes after a disturbance (timbering in the study), but became re-vegetated through a combination of coppicing (a secondary succession process) and the establishment of nurse species (a primary succession process). This suggests that afforestation of created forested wetlands must begin with nurse species such as American sycamore, black willow, and river birch which can then facilitate oak and hickory establishment. DeBerry (2006) and DeBerry and Perry (in press) reported the same processes in created forested wetlands in the Piedmont and Coastal Plain of Virginia. A few of the late successional species and most of the nurse species in that study survived after 10 to 15 years. The proposed study builds on that work to quantify growth and establish ranges for future growth rate curves.

Dickenson (2007), working with Drs. Perry and Daniels (of Virginia Tech) in a created tidal freshwater swamp, documented that *Taxodium distichum* tubelings showed increase root and stem length when grown on a 15cm (6in) ridge v. those at soil level or in 15cm ditches. Bailey et al. (2007) came to similar conclusions in a created hardwood swamp: small changes in the elevation altered tree growth. Therefore, it is important to choose species that can tolerate the stress of a given wetland environment. DeBerry and Perry (in review) conclude that the process of creating a wetland, that of planting in the dry and then flooding the habitat, mimics the hydrologic process preferred by certain early-successional species. They specifically noted the potential role of American sycamore, black willow, and bald cypress for afforestation in the Piedmont and Coastal Plain of Virginia.

Principal sources of stress in the Piedmont Province are derived from soil texture and hydroperiod. The clayey soils common to the Piedmont, and frequently uncovered when earthwork is conducted, provide a challenging growth medium for most tree species (Atkinson et al. 2005). Anoxic soil conditions associated with long hydroperiods are the greatest stressor across wetland types (Mitsch and Gosselink 2007) and in created wetlands (Atkinson et al. 1993, Daniels et al. 2005), and is particularly harmful to vegetation where clay soil textures already limit soil drainage and aeration. Mesocosms supported by field validation are required to capture the effect of these conditions on potential tree species for wetland creation.

While most studies only address survival, and some compare average tree growth among species, relatively new methods exist which allow tracking of individual trees across years (Peet et al. 1998, Bailey et al. 2007). In the proposed study we intend to apply their techniques to help refine our understanding of the response for various species and planting materials to conditions in the Field study and strengthen the comparison with our Mesocosms study.

Classification of Piedmont Forest Woody Vegetation

Braun (1950) typed the Piedmont forests of Virginia as Oak-Pine (Figure 1). She described the bottomland forests of the Piedmont as having sandy soils and by being dominated by river birch, black willow, cottonwood (*Populus deltoides*), sycamore, and sweet gum along the stream sides, and the wet flats by sweet gum, willow oak, winged elm (*Ulmus rubra*), red maple (*Acer rubrum*), tulip poplar (Liriodendron tulipifera), green ash (*Fraxinus pennsylvanica*), and *Celtis laevigata* (hackberry) and water oak to the south. *Fagus grandifolia* was common on northern slopes that "…raise more or less abruptly above the bottomland…." (Braun 1950). Dyer (2006) revisited Braun's work and has reclassified the Virginia portion of the Piedmont as the Oak-Pine section of the Southern mixed system. He also includes the western most edges of the Piedmont as part of the Mesophytic region.

Figure 1. Nine regions described by Braun (1950), representing original forests of eastern North America.

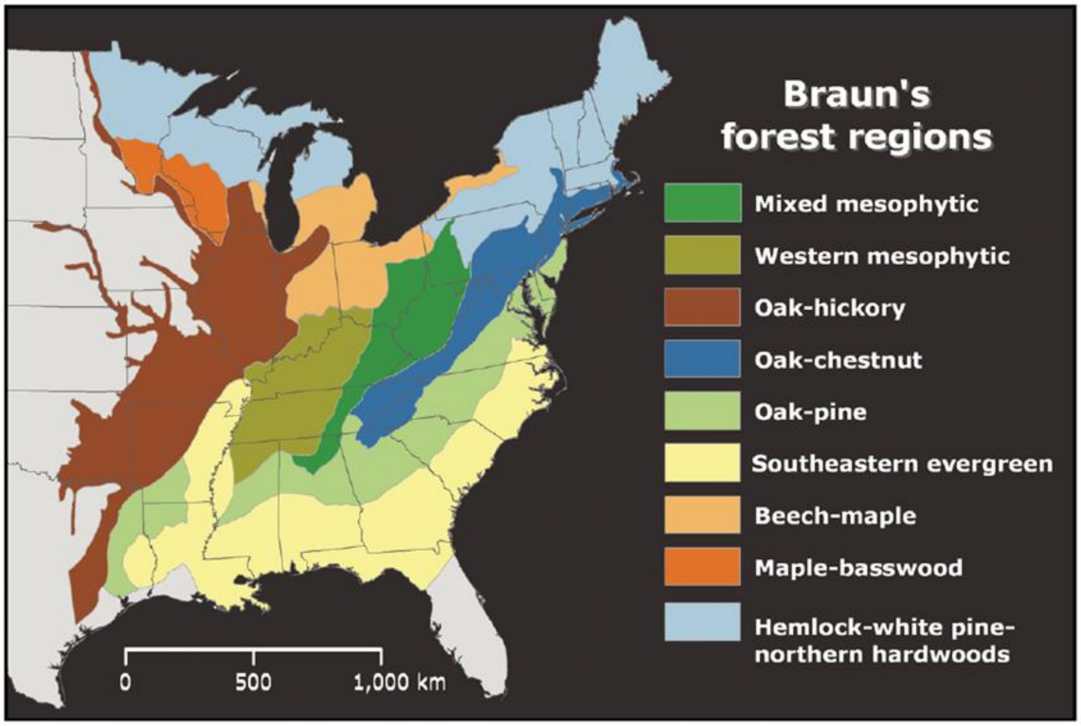
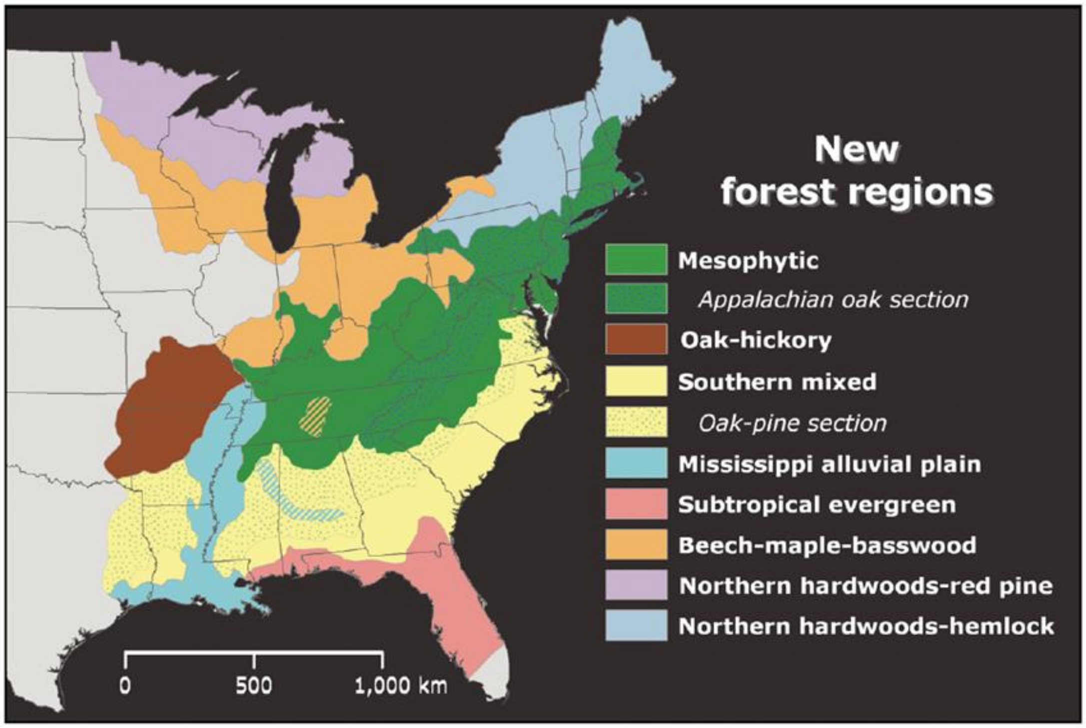


Figure 2. Regions derived from contemporary forest data. The cross-hatching in the Nashville Basin and the black belt region indicates inclusions within the larger forest regions—areas with affinities to the noncontiguous region with the same color as the cross-hatching (from Dyer 2006).



Tasks

In order to complete the objectives and goals of this study we are engaged in 4 major tasks:

1. Complete a thorough literature review: This is a detailed determination of various planting options. We, and our past students, have already completed a good deal of this work prior to preparing the proposal. The principal portion of this task fell within the first 13 months of the project. The review will, however, be updated yearly throughout the life of the study. This work will be overseen by the PIs and conducted primarily by the VIMS doctoral student.

2. Design and implement Mesocosm study: This phase of the project is being directed by Dr. Perry with assistance from Dr. Atkinson, and implemented and monitored by the VIMS Ph.D. student, Wes Hudson. Work on this task was focused primarily within the first 6 months of the project and continues with tri-annual morphometric collection.

3. Locate, implement and monitor the field experiments: Dr. Atkinson worked with WSSI, MBRT, and other groups in the Piedmont area to designate field sites. Plantings on the chosen sites began in coordination with the Mesocosm study and planting occurred in March 2009.

4. Synthesis of results: As well as the quarterly reports, in December of the 1st, 2nd, 4th and 6th year of the study we prepare annual reports that present the data and results from each of the studies, led by Dr. Perry with input from Dr. Atkinson. For the 3rd (this year), 5th, and 7th year of the study the annual report will be comprehensive and include the analysis of survival and growth rate and functional development of individual woody species of both the mesocosm and field study. The project's graduate students are heavily involved in all report preparation.

Methods

Planting Material

Based upon our review of the literature, practical experience in the field, and availability of planting material, we compared the following stocktypes: 1) bare-root seedlings, 2) tubelings, and 3) 1 gallon pots. We used seven woody tree species common to the forested wetlands of the Piedmont: *Betula nigra* (river birch), *Liquidambar styraciflua* (sweetgum), *Platanus occidentalis* (American sycamore), *Quercus bicolor* (swamp white oak), *Q. palustris* (pin oak), *Q. phellos* (willow oak) and *Salix nigra* (black willow). All saplings were planted in March 2009 in the Mesocosm and Field sites. Care was taken to assure that each was placed properly in the hole and covered to avoid formation of air-pockets. Saplings came from five nurseries (three in Virginia, one in North Carolina, and one in South Carolina): tubelings of three species (*P. occidentalis*, *Q. phellos*, and *S. nigra*) were two years old and had had their soil removed by the nursery prior to shipment (See Appendix 3 for list of Nurseries). This practice is uncommon and was noted in all analyses. Saplings were kept in cold storage at the New Kent Forestry Center until planted. In order to reduce the number of confounding variables, fertilizers were not applied following outplanting.

A total of 2,772 trees were planted in the entire mesocosm; 44 of each species and stocktype (on 7ft centers), for a total of 924 trees per cell. During the Spring of 2010, 482 new trees were purchased and planted to insure adequate sample size (See Appendix 3 for Distribution of Planted and Replanted Trees). No replanting occurred in the Field sites.

Sampling Techniques

The same sampling techniques for the survival and growth measurements were implemented at both the Mesocosm and Field sites. In the Mesocosm survival and growth were measured in April, August, and October in each of the three years. In the Field study, survival and growth were measured in April and July of the first year and August in the subsequent years. Several additional environmental variables were measured at the Mesocosm and Field study sites. At the Mesocosm site, soil physical properties and preliminary photosynthetic rates were measured during year-2 and biomass was sampled at the end of 2010. At the Field study sites, the herbaceous vegetation was analyzed during the August (2009 and 2010) sampling period.

Survival

Individuals were considered “live” based on the presence of green leaves or a green vascular cambium. The latter was necessary as we noted that many trees exhibited die-back and re-growth. To check for a live cambium a small longitudinal incision scratch was made at the highest point on the stem. If brown (i.e. not alive), a second incision was made approximately one half way down the stem. If brown, a final incision was made at the base. If any of the incision showed a green cambium, the individual was considered alive.

Growth

Tree morphology (basal stem diameter at soil level, canopy diameter, and height of highest stem) was collected using methods modified from Bailey et al. (2007). Total height (H) was sampled using a standard meter stick or 5-m stadium rod, while canopy diameter (CD) and basal diameter (BD) were quantified using macro-calipers (Haglof, Inc. “Mantax Precision” Calipers) and micro-calipers (SPI 6”/.1 mm Poly Dial Calipers), respectively. Canopy diameter was measured in three angles at the maximum visual diameter to determine the average canopy diameter. Basal diameter (BD) was measured at the base of the stem (trunk) or, if buttressing present (defined as base diameter > 10% larger than bole above swelling), at the base and also just above the visual top of stem base swelling (hypertrophy). The latter measure was necessary since buttressing often accompanies trees growing in flooded conditions (Cronk and Fennessy 2001). If there were multiple stems for a planting, basal diameter of all stems was measured. In order to calculate a single basal area for each tree, the basal diameters of all stems were summed. This total basal diameter was then used to calculate an overall basal area. Die back and re-growth (coppicing and re-sprouting) were common in many of the Mesocosm plantings (often leading to negative growth rates) and were noted in the field.

Relative growth rates (RGR) were calculated to eliminate any size related growth differences when comparing species and stocktypes (Hunt 1990). Relative growth rate was calculated from the following equation (Hunt 1978):

$$r = \frac{\ln(W_2) - \ln(W_1)}{t_2 - t_1}$$

where r = Relative Growth Rate (RGR),
W1 = Morphometric measurement of tree at time 1,
W2 = Morphometric measurement of tree at time 2,

t1 = Time of first measurement and
t2 = Time of second measurement

Relative growth rates (cm cm^{-1} $month^{-1}$) were calculated for basal diameter (BDRGR), height (HRGR) and canopy diameter (CDRGR) over two growing seasons. In addition, percent change in height was also calculated for comparison with mitigation bank woody growth rate success criteria.

Soil Physical Properties

The soil physical and chemical properties were analyzed during the summer of 2010 at the Mesocosm study site. The physical properties that were measured included soil color, texture, bulk density, volumetric water content and percent organic matter. The chemical properties measured included percent (by weight) of tissue content for total carbon, total nitrogen and total phosphorus.

Biomass

A subsample of the trees planted in 2009 and trees replanted in 2010 was removed from the field in the fall and winter of 2010. The above and belowground portions of the trees were separated and placed in individual paper bags. All trees were solar dried on-site until constant weight was obtained. The trees were weighed at the end of the summer in 2011. A linear regression described the relationship between growth and above and below ground biomass.

Mesocosm Study

This phase of the project was directed by Dr. Perry with assistance from Dr. Atkinson and implemented and monitored by VIMS. The Mesocosm site is located at the New Kent Forestry Center, in Providence Forge, VA (Appendix 1). The site was divided into three cells each having dimensions of 48.8m x 144m (160ft x 300ft). Soil of the Ideal and Saturated Cells were disked and tilled in February 2009 prior to planting. The Flooded Cell was excavated to a depth of 1m (3.1ft) to an existing clay layer. An on-site irrigation system capable of producing a minimum of 2.54cm (1in) of irrigation per hour was established in each cell. The pump inlet is located approximately 8km (5mi) upriver above the Rock-a-hoc Dam (Lanexa, VA; therefore non-tidal) and irrigation water was drawn from the Chickahominy River. The hydrology of the three cells was manipulated to include an Ideal treatment (a minimum 2.5cm (1in) irrigation or rain per week), a Saturated treatment (kept saturated at a minimum of 90% of the growing season within the root-zone (10cm) of the plantings and irrigated as needed), and a Flooded treatment (inundated above the root collar at least 90% of year). To exclude herbaceous competition as a confounding variable, the Ideal and Saturated Cells were mowed approximately every 10 days and herbicide (Roundup®) was applied at the rate specified on the package label around the base of each planting.

Field Study

Drs. Atkinson and Perry worked with Wetland Studies and Solutions, Inc., Mitigation Bank Research Team, and other groups in the Piedmont Province to designate field sites. Three (3) Piedmont constructed wetland field sites were chosen for the study (Appendix 1) and are comprised of the three phases (Designated as Phase I, II, and III) of the Loudoun County Wetland and Stream Mitigation Bank (LCWSB) that were designed and installed by Wetland Studies and Solutions, Inc. Each site has a clay base soil (the most common planting medium), two to three years of documented hydrologic data and relatively uniform topography (see Appendix 2 for detailed construction methods). The overall hydrology is driven principally by rainfall such that typical Piedmont Province created wetland conditions are represented. Finally, the sites have an annual hydroperiod in which the saturated zone is at the soil surface for the majority of growing season.

The original study concept contained 3 study sites with 525 planted at each site for a total of 1575 individuals. High priority was given to consistency in homogeneity of site conditions and the three Phases of the LCWSB were deemed suitable based on this criterion. Upon further inspection at the three phases of the LCWSB, the balanced arrangement was not possible due to the configuration and conditions found on the three sites so extra plots were added at Phase III.

At Phase I, 4 “megaplots” each containing 3 plots with 21 plantings (a complete subsample) in each plot (252 saplings) were installed in late winter 2009. An unrelated study conducted in the two northern sections of the phase eliminated them as a possibility for this study. The size of the remaining area was not adequate to fit 525 saplings with the 8’ spacing requirement. The first post-construction growing season at Phase I was 2007 and the study saplings were planted before the beginning of the third growing season (2009).

At Phase II, 4 megaplots each containing 3 plots with 21 saplings in each plot (252 saplings) were installed in late winter 2009. The majority of the site, when surveyed, exhibited hydrologic conditions that were somewhat wetter than the other two phases. Hydrology in a small portion was similar to the other phases but could not fit 525 saplings with the 8’ spacing requirement. The first growing season at Phase II was 2008 and study saplings were planted before the beginning of the second growing season (2009).

At Phase III, 17 megaplots each containing 3 or 4 plots with 21 saplings in each plot (1092 saplings) were installed in late winter 2009. This phase exhibited fairly uniform hydrology and vegetation and had enough space to fit the remainder of the saplings with the required 8’ spacing. The first growing season at Phase III was 2008 and the study saplings were planted before the beginning of the second growing season (2009).

The saplings planted in the Field study were from the same stock as the saplings planted in the Mesocosm study, consisting of the same seven species and stocktypes, including 1) bare-root seedlings, 2) tubelings, and 3) 1 gal pots, which totals 21 (7 x 3) experimental units. Each site is completely replicated and randomized within each planting area such that every hydrological unit of the Mesocosm study will be represented in each plot. Planting was completed in early March 2009 in conjunction with the Mesocosm study.

Mortality and morphometric data were collected using methods modified from Bailey et al. (2007). Each sapling was mapped using an x- and y- coordinate grid system to aid with location in the future. Survival and growth of each planting (height, canopy cover and basal diameter as in the Mesocosm study) were recorded in a one-week period in mid-April and again in August of 2010. In addition to direct comparisons with the Mesocosm results, analysis of the data collected from the Field study was conducted independently to identify which species and stocktype performed the best in these field conditions.

Results

Objective 1

To determine the appropriate species/stocktype planting combinations in created wetlands, the survival and percent change in height of all trees were calculated in the Mesocosm and Field studies. The USACE Norfolk District and the VADEQ (2004) recommend 200 to 400 stems/acre as a minimum woody stem count for compensatory mitigation sites. However, many projects have been required to have >400 stems/acre (Mike Rolband, pers. comm.). The VADEQ also requires a woody height growth rate of 10% per year for mitigation banks (VADEQ 2010). However, few projects have agreed to this newer requirement (Mike Rolband, pers. comm.).

To meet these requirements we calculate that planting trees on 8ft centers would yield 681 stems/acre. To ensure the required >400 stems/acre, we would need a percent survival of planted trees be greater than 58.8%. Therefore, the appropriate species/stocktype combinations are those species that have greater than 58.8% survival and greater than 10% increase in height per year. Results are determined by data on the 21 species/stocktype combinations that were planted in the Mesocosm and Field.

The 21 species/stocktype combinations are:

Primary Species
Betula nigra bare root
Betula nigra gallon
Betula nigra tubeling
Liquidambar styraciflua bare root
Liquidambar styraciflua gallon
Liquidambar styraciflua tubeling
Platanus occidentalis bare root
Platanus occidentalis gallon
Platanus occidentalis tubeling NO SOIL
Salix nigra bare root
Salix nigra gallon
Salix nigra tubeling NO SOIL

Secondary Species
Quercus bicolor bare root
Quercus bicolor gallon
Quercus bicolor tubeling
Quercus palustris bare root
Quercus palustris gallon
Quercus palustris tubeling
Quercus phellos bare root
Quercus phellos gallon
Quercus phellos tubeling NO SOIL

Survival

After three years the species that were grown in the gallon containers had greater than the required 58.8% survival in the Ideal Cell and Saturated Cell (Table 1). In the Flooded cell only six species/stocktype combinations had greater than 58.8% survival; the *B. nigra* gallon and tubeling, the *L. styraciflua* gallon, and all three stocktypes of *S. nigra*. In the field study gallon stocktypes of all species except *P. occidentalis,* had greater than 58.8% survival. None of the species that were planted as bare root stocktype had greater than 58.8% survival after three years.

After three years the highest survival rate was the gallon *B. nigra*, *Q. palustris* and *Q. bicolor* in the Ideal cell (all > 92.9% survival), *Q. bicolor* gallon in the Saturated cell (92.9%), and *B. nigra* gallon in the Flooded cell (83.7%). In the Field study, *Q. bicolor* gallon had 94.7% survival. For complete survival results see Appendix 4.

Table 1. Percent survival for 2009, 2010, 2011. Red represents < 58.8% survival.

		Ideal			Saturated			Flooded			Field		
Species	**Stocktype**	**2009 % Survival**	**2010 % Survival**	**2011 % Survival**	**2009 % Survival**	**2010 % Survival**	**2011 % Survival**	**2009 % Survival**	**2010 % Survival**	**2011 % Survival**	**2009 % Survival**	**2010 % Survival**	**2011 % Survival**
Betula nigra	Bare root	52.1	45.8	39.6	73.5	63.3	57.1	67.8	52.5	28.8	89.5	48.7	46.1
Betula nigra	Gallon	100.0	100.0	92.9	97.6	97.6	90.5	100.0	100.0	83.7	97.4	75.0	69.7
Betula nigra	Tubeling	40.5	37.8	29.7	84.2	78.9	71.1	94.9	92.3	69.2	89.5	50.0	48.7
Liquidambar styraciflua	Bare root	76.6	74.5	68.1	88.4	81.4	69.8	90.2	78.0	36.6	84.2	59.2	48.7
Liquidambar styraciflua	Gallon	100.0	93.3	88.9	100.0	97.7	90.7	100.0	95.3	76.7	94.7	77.6	68.4
Liquidambar styraciflua	Tubeling	31.0	26.2	19.0	65.2	52.2	39.1	92.5	82.5	45.0	62.3	22.1	22.1
Platanus occidentalis	Bare root	65.3	63.3	57.1	66.7	66.7	33.3	44.7	34.2	0.0	69.7	35.5	30.3
Platanus occidentalis	Gallon	93.3	86.7	80.0	97.7	97.7	90.9	83.7	51.2	25.6	71.1	46.1	38.2
Platanus occidentalis	Tubeling NO SOIL	97.2	97.2	88.9	78.4	78.4	64.9	52.4	33.3	4.8	90.8	60.5	50.0
Quercus bicolor	Bare root	92.5	88.7	77.4	100.0	95.7	89.1	95.7	63.0	28.3	89.5	63.2	57.9
Quercus bicolor	Gallon	100.0	100.0	92.5	100.0	100.0	92.9	100.0	88.1	57.1	98.7	96.1	94.7
Quercus bicolor	Tubeling	75.5	62.3	50.9	83.0	80.9	70.2	81.6	38.8	10.2	90.7	78.7	74.7
Quercus palustris	Bare root	88.2	80.4	70.6	97.6	92.9	81.0	89.1	54.5	7.3	96.1	67.1	55.3
Quercus palustris	Gallon	97.6	100.0	92.9	100.0	100.0	89.1	97.9	74.5	27.7	97.4	89.5	85.5
Quercus palustris	Tubeling	59.5	48.6	29.7	76.3	63.2	50.0	76.9	28.2	7.7	86.8	72.4	65.8
Quercus phellos	Bare root	76.3	67.8	50.8	81.2	73.9	60.9	72.2	37.5	12.5	86.8	36.8	31.6
Quercus phellos	Gallon	100.0	97.6	85.4	100.0	97.5	87.5	100.0	69.8	37.2	92.1	84.2	80.3
Quercus phellos	Tubeling NO SOIL	66.7	46.7	36.7	72.5	66.7	58.8	54.8	19.4	0.0	67.1	18.4	7.9
Salix nigra	Bare root	32.4	16.2	5.4	71.4	49.0	32.7	91.3	91.3	80.4	77.6	38.2	34.2
Salix nigra	Gallon	97.7	97.7	86.0	95.5	95.5	86.4	95.6	93.3	77.8	98.7	72.4	71.1
Salix nigra	Tubeling NO SOIL	61.7	55.3	38.3	76.3	54.2	37.3	92.9	85.7	78.6	89.5	64.5	60.5

Growth

Six species/stocktype in the Ideal cell did not meet the required 10% height increase in 2009 (Table 2), However, in 2010 and 2011 all species/stocktype achieved the required >10% increase in height. In the Saturated cell 15 species/stocktype did not meet percent height increase 2009 and two did not meet it in 2010 (Table 2). All 21 combinations had >10% increase in height in the Saturated Cell in 2011. In the Flooded cell 17 species/stocktype had less than 10% increase in height in 2009, 15 species/stocktype did not meet the requirement in 2010, and 17 in 2011. In the Field sites 18 species/stocktype did not meet the >10% requirement in 2009, while in 2010 it declined to 9 species/stocktype with less than 10% increase and only two in 2011 (Table 2).

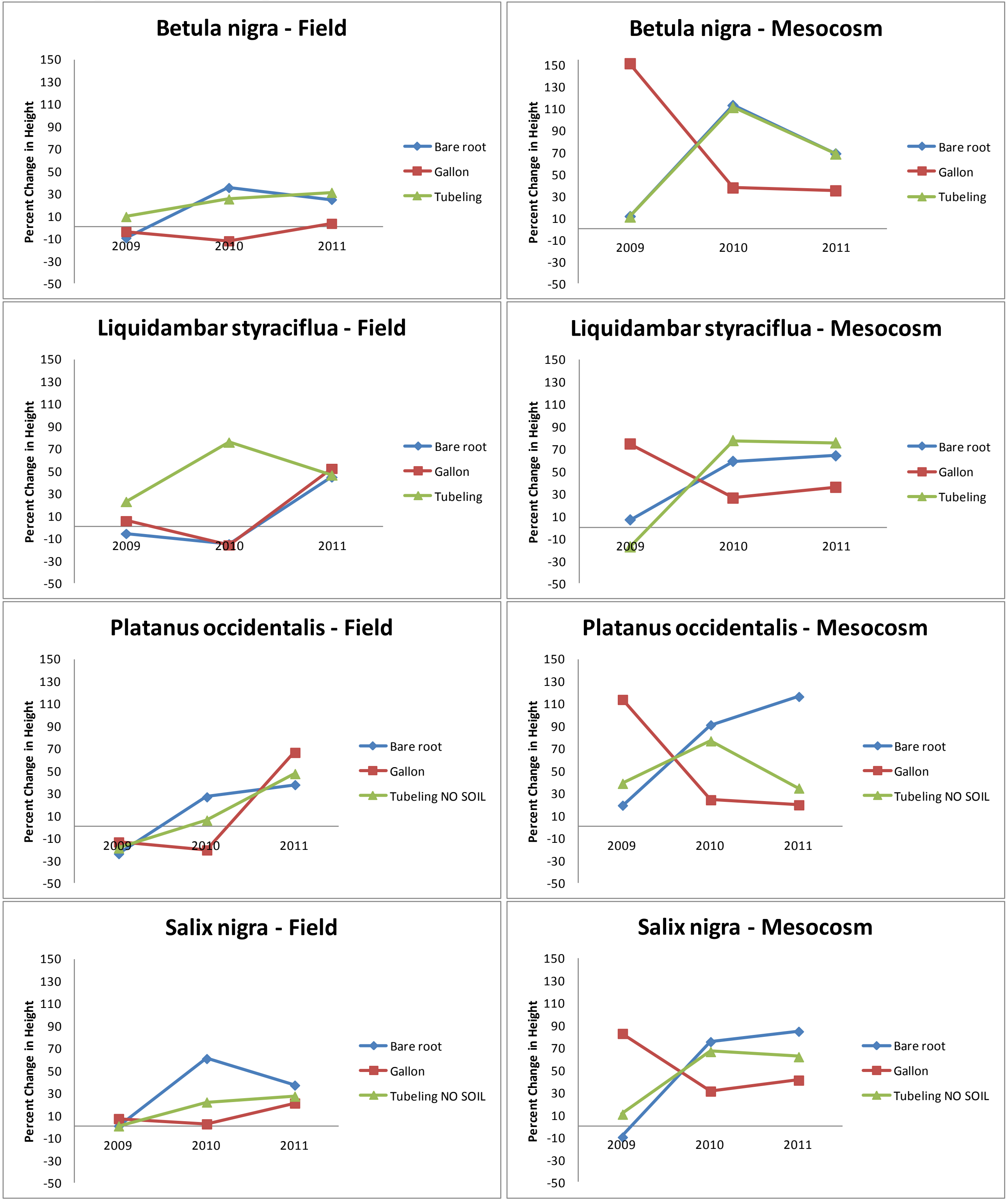
Table 2. Average percent change in height for 2009, 2010, 2011. Percentage represents change over one year. Red indicates dieback and orange indicates <10% increase.

		Ideal			Saturated			Flooded			Field		
Species	**Stocktype**	**2009 % Height**	**2010 % Height**	**2011 % Height**	**2009 % Height**	**2010 % Height**	**2011 % Height**	**2009 % Height**	**2010 % Height**	**2011 % Height**	**2009 % Height**	**2010 % Height**	**2011 % Height**
Betula nigra	Bare root	18.3	221.6	92.2	-0.8	114.7	81.3	16.5	3.0	33.0	-9.5	35.4	24.7
Betula nigra	Gallon	241.9	68.6	53.2	203.6	41.8	58.2	8.7	2.3	-6.7	-4.0	-12.3	3.3
Betula nigra	Tubeling	42.0	199.8	116.2	-18.1	120.7	92.4	8.8	13.3	-2.7	9.4	25.2	31.0
Liquidambar styraciflua	Bare root	54.0	122.3	83.2	-35.2	52.5	113.9	1.3	2.3	-5.1	-5.9	-15.1	44.6
Liquidambar styraciflua	Gallon	151.4	59.9	56.2	49.3	18.3	51.4	23.1	0.4	0.0	5.5	-16.1	52.3
Liquidambar styraciflua	Tubeling	0.3	131.1	93.1	-64.8	84.7	131.7	12.3	17.1	2.0	22.7	75.8	46.4
Platanus occidentalis	Bare root	121.5	165.6	78.9	-35.2	117.3	154.0	-28.7	-9.6	NA	-24.1	26.7	37.6
Platanus occidentalis	Gallon	243.5	51.5	39.6	124.8	45.0	38.7	-26.9	-24.1	-19.6	-13.6	-20.8	66.4
Platanus occidentalis	Tubeling NO SOIL	137.1	137.5	62.6	5.8	97.6	119.4	-26.6	-4.8	-78.3	-19.0	5.9	47.5
Quercus bicolor	Bare root	39.9	21.8	40.4	-4.0	0.2	47.3	0.0	-2.0	-18.2	2.5	-17.2	13.7
Quercus bicolor	Gallon	40.8	74.4	45.7	-19.1	52.7	51.2	5.4	-2.3	-10.8	10.5	6.5	19.1
Quercus bicolor	Tubeling	-55.6	70.4	49.0	-71.7	11.9	63.0	-0.8	-4.9	-12.1	4.2	54.9	37.5
Quercus palustris	Bare root	42.0	48.0	43.0	-46.0	55.8	77.4	-1.6	-4.6	103.8	-1.2	-13.3	36.3
Quercus palustris	Gallon	95.5	42.4	30.9	51.9	9.7	26.5	0.3	-5.9	-14.3	3.6	11.8	1.2
Quercus palustris	Tubeling	-51.3	75.9	57.8	-67.5	129.1	55.2	-9.0	10.3	15.0	-25.7	73.9	53.3
Quercus phellos	Bare root	-4.7	73.1	57.2	-34.8	33.7	55.4	-0.1	-13.7	-2.2	-15.7	-39.3	30.2
Quercus phellos	Gallon	254.4	39.2	31.7	194.4	10.6	32.0	-2.5	-2.4	-14.4	11.6	4.8	29.6
Quercus phellos	Tubeling NO SOIL	-43.3	80.6	58.4	-42.3	65.8	63.2	-34.4	24.9	NA	-31.8	-55.6	117.0
Salix nigra	Bare root	-28.5	80.4	147.9	-14.4	97.1	87.5	14.7	50.2	20.1	0.7	60.8	37.0
Salix nigra	Gallon	166.0	36.9	42.6	79.2	62.7	82.0	4.6	-4.5	-0.1	7.1	2.4	21.0
Salix nigra	Tubeling NO SOIL	42.6	93.2	103.0	-13.7	61.6	78.5	4.2	46.4	5.8	0.6	21.9	27.1

The percent change in height over time in the mesocosm displays a similar trend for both the primary species (Figure 3) and secondary species (Figure 4). The gallon stocktype has an initial percent change in height that is greater than the bare root and tubeling stocktypes. However, in 2010 and 2011 the percent change in height of the gallon stocktype decreases and in most species, below the percent change in height of the other stocktypes.

This trend is not repeated in the field study for the primary species (Figure 3) or secondary species (Figure 4). The trend that is observed in the field study is that the percent change in height is similar among the stocktypes in 2009, diverges in 2010 and then become similar in 2011.

Figure 3. Percent change in height of the primary successional species over three years. Mesocosm graphs represent average percent change in height over all cells.



Betula nigra - Field

Betula nigra - Mesocosm

Liquidambar styraciflua - Field

Liquidambar styraciflua - Mesocosm

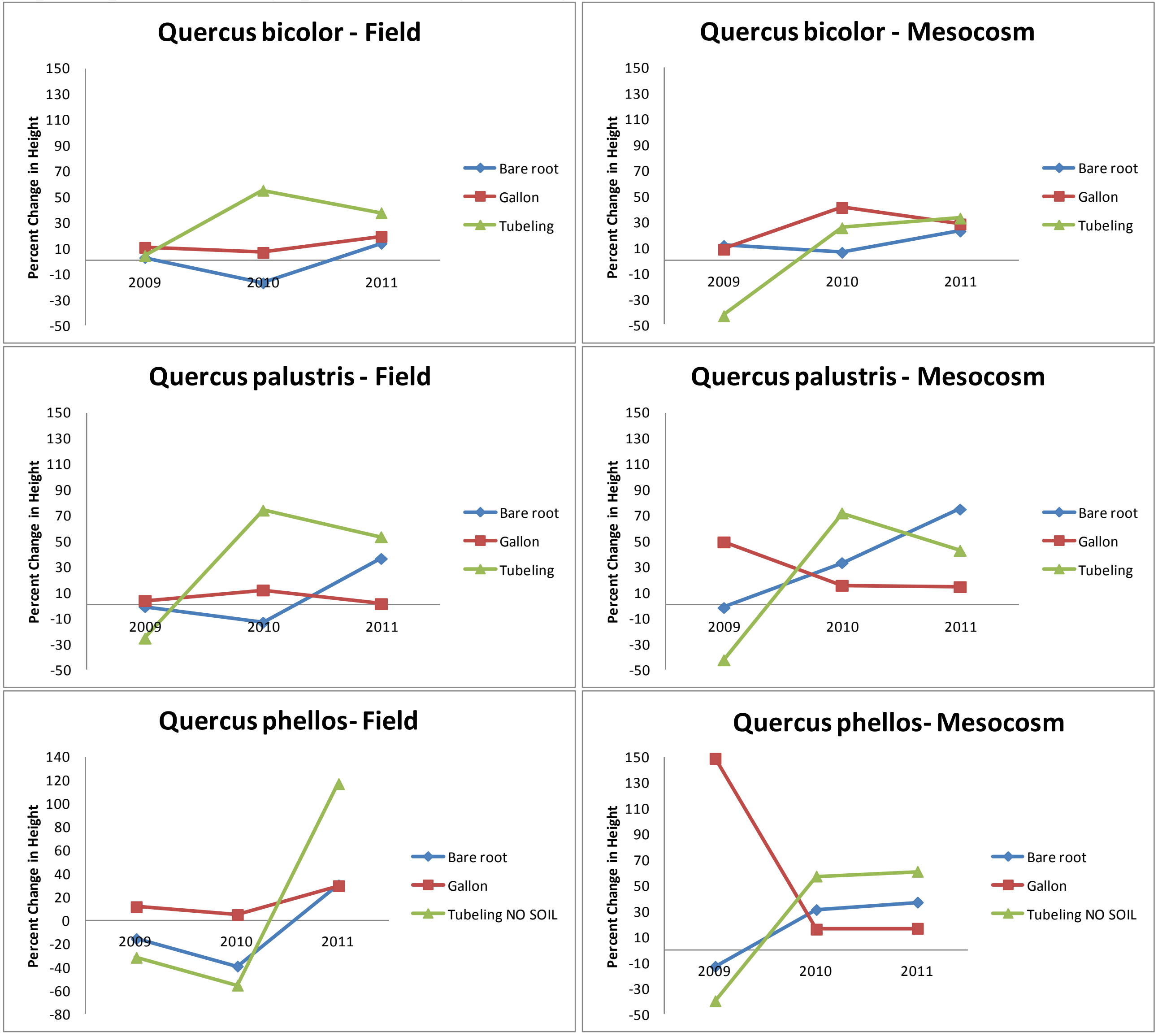
Platanus occidentalis - Field

Platanus occidentalis - Mesocosm

Salix nigra - Field

Salix nigra - Mesocosm

Figure 4. Percent change in height of the secondary successional species over three years. Mesocosm graphs represent average percent change in height over all cells.

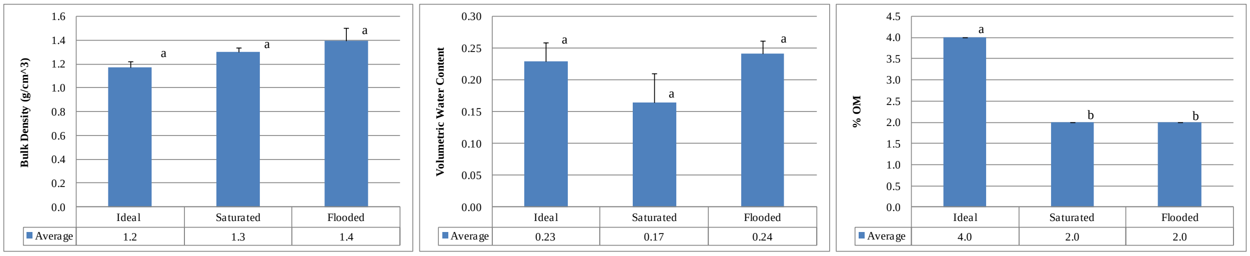


Soil Analysis

This preliminary soil analysis suggests that there are differences in the soil physical and chemical properties that may be having impacts on tree growth and survival in addition to the hydrology treatment parameter represented within each cell (Fig. 5). Further soil analysis will allow us to statistically account for the effect of soil physical and chemical properties on growth and survival, therefore providing greater precision in fulfilling Objective 1.

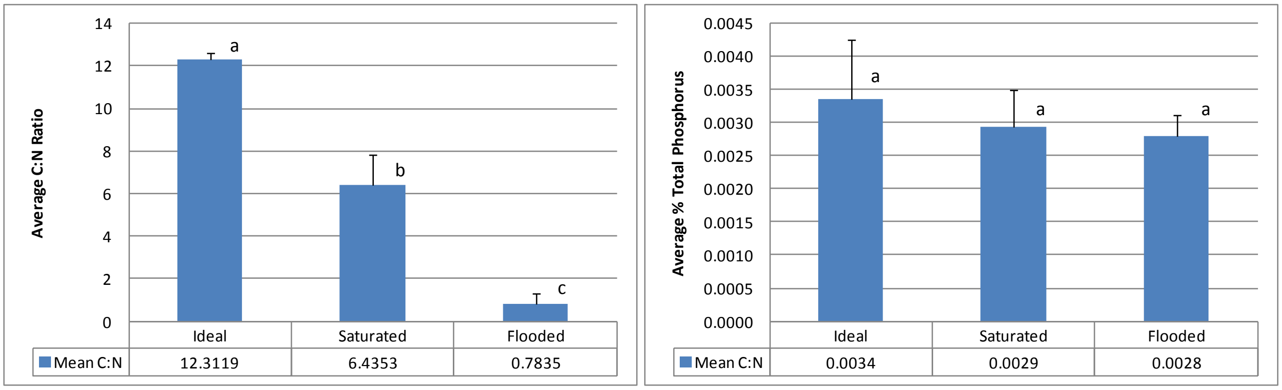
There was no significant difference ($p<0.001$) in bulk density or volumetric water content among the three cells. There was a significant difference in percent organic matter among the three cells. The Saturated and Flooded cells had significantly lower percent organic matter than the Ideal cell. The lower organic matter within the Flooded cell is most likely the result of topsoil removal during construction which mimics common wetland creation techniques The soil physical parameters may be a minor confounding variable when predicting tree growth within each cell and will be explored more fully in research planned for the Field study.

Figure 5. Bulk density, volumetric water content and percent organic matter within each cell. Same numbers denote no significant difference (p>0.05).



There was a significant difference in the C:N ratio among the three cells ($p<0.001$). The Flooded cell had a significantly lower C:N ratio compared to the Saturated and Ideal cells, while the Saturated cell had significantly lower ratio compared to the Ideal cell. The lower C:N ratio in the Flooded cell may be the result of excavation. There was no difference in total phosphorus among the three cells.

Figure 6. C:N ratio and total phosphorus within each cell. Same letters denote no significant difference (p>0.05).



Species and Stocktype Ranking

In order to better address Objective 1, 30 ranked lists of the 21 species/stocktype combinations were constructed using survival, percent change in height and biomass data from the Mesocosm. For each ranked list, species/stocktype combinations were ranked from highest to lowest. Average ranks for each location were then calculated by averaging the ranks of each species/stocktype combination and then arranging the averages from lowest to highest (Table 3). This method necessarily conceals some variation in the data in order to combine three years of data on survival, growth and biomass into one list.

The optimum species/stocktype combination when all locations are combined was *B. nigra* gallon. *Quercus bicolor* gallon did best in the field study and ranked fifth overall. *Salix nigra* bare root ranked highest in the flooded cell.

Table 3. The ranking of all species and stocktype in the Mesocosm, Field and Overall.

Species	**Stocktype**	**Ideal Rank**	**Saturated Rank**	**Flooded Rank**	**Field Rank**	**Overall Rank**
Betula nigra	Gallon	1	1	2	11	1
Liquidambar styraciflua	Gallon	4	6	3	4	2
Salix nigra	Gallon	9	2	5	6	3
Betula nigra	Tubeling	6	3	8	8	4
Quercus bicolor	Gallon	8	10	6	1	5
Quercus phellos	Gallon	7	8	10	3	6
Quercus palustris	Gallon	12	9	9	5	7
Salix nigra	Tubeling NO SOIL	14	17	4	9	8
Liquidambar styraciflua	Bare root	2	13	13	16	9
Platanus occidentalis	Tubeling NO SOIL	3	5	20	13	10
Liquidambar styraciflua	Tubeling	13	16	7	12	11
Salix nigra	Bare root	19	15	1	14	12
Betula nigra	Bare root	11	11	11	15	13
Platanus occidentalis	Gallon	10	4	15	18	14
Platanus occidentalis	Bare root	5	7	21	19	15
Quercus bicolor	Bare root	16	14	12	17	16
Quercus palustris	Bare root	17	12	14	10	17
Quercus palustris	Tubeling	20	20	16	7	18
Quercus bicolor	Tubeling	21	21	17	2	19
Quercus phellos	Bare root	18	18	18	20	20
Quercus phellos	Tubeling NO SOIL	15	19	19	21	21

Discussion

Objective 1

The first objective of this study is to critically evaluate and improve upon the planting of woody vegetation in created forested headwater wetlands in the Piedmont Province, Virginia. The goal of this objective is to identify the most appropriate woody species and stocktype(s) that would be recommended for planting in created forested wetlands in the Piedmont Province of Virginia.

Mesocosm

The species/stocktype combinations that meet the regulatory success criteria for created forested wetlands in the Piedmont Province of Virginia are those that have greater than 58.8% survival and >10% increase in height per year. The results from this experiment suggest that the most appropriate species/stocktype combinations are not the same among the cells within the mesocosm and between the mesocosm and field experiment. This suggests that the hydrologic conditions that are present at a site have a large effect on which species/stocktype combinations may fulfill the success criteria. Therefore, the recommendations from this study for planting into created forested wetlands are based upon the results from the Saturated and Flooded cells and from the Field experiment, since these represent the hydrologic conditions most likely to be encountered in created forested wetlands.

In saturated conditions the combinations that had the highest survival and percent increase in height are *B. nigra, S. nigra* and *P. occidentalis* of the gallon stocktype (Table 3). This combination of species/stocktype would therefore be recommended since they overcame initial transplant shock - a temporary setback in growth which, if severe enough, can result in tree mortality (Kozlowski and Davies 1975; Acquaah 2005; Grossnickle 2005; South and Zwolinski 1996). Transplant shock is associated with decreased water absorption as a result of poor root-soil contact, low permeability of suberized roots (older woody roots that have reduced absorption of water) and a low root to shoot ratio (Beineke and Perry 1965; Carlson and Miller 1990; South and Zwolinski 1996; Grossnickle 2005). The suberized roots become more important since the unsuberized fine roots (young, highly water permeable roots) are often lost during lifting and transplanting (Brissete and Chambers 1992). The loss of these roots could decrease the ability of the stock to overcome transplant shock since new saplings would not be able to absorb enough water to satisfy normal evapotranspiration and metabolic/physiologic processes.

The gallon stocktype may have absorbed a sufficient amount of water for these processes and overcome transplant shock because of the increased root mass and intact potting soil. These factors would have allowed the trees to acquire sufficient water and nutrients after transplanting because their roots would have remained in direct contact with the nutrient-rich potting soil. The roots surrounded by potting soil may have maintained their association with mycorrhizal fungi after transplanting which could have increased the water uptake ability of the fine roots. In addition, potting soil is often high in organic matter which is able to retain water longer than mineral soils. Trees grown to the gallon stocktype size are typically greater than 3 years old and have increased biomass. These older trees are often more resilient than smaller seedlings and may have increased stored resources available for surviving transplanting shock. The smaller seedlings may not be able to overcome transplant shock because following transplanting their primary roots will typically die back and positive growth will not occur until new secondary roots develop (Hook, 1984).

This combination of species may have satisfied the survival and growth criteria because they are primary species that are characterized by higher acclimation potential and broader physiological responses than secondary species suggesting that they can be more adaptable to stressors (Bazzaz, 1979). These primary species are typically found in wetlands greater than 67% of the time and have particular adaptations that allow them to grow in these conditions including adventitious roots, rapid vertical growth, shallow root systems, and hypertrophied lenticels (Day et al. 2006; Donovan et al. 1988; Mitsch and Gosselink 2007; Reed 1996).

In flooded conditions the recommended species/stocktype combinations are *B. nigra*, *S. nigra* and *L. styraciflua*, primarily gallon stocktype. The Flooded cell represents hydrologic conditions that are stressful for planted trees. However, all three stocktypes of *S. nigra* survived and grew better than the other species/stocktype combinations (Table 3). We observed that the *S. nigra* had substantial adventitious rooting (roots that originate above ground) and multiple stems which are adaptations that would allow them to overcome the low soil oxygen conditions.

When analyzing the percent change in height for each stocktype over the three years, the gallon stocktype exhibited higher percentages the first year compared to the other stocktypes for both the primary (Figure 3) and secondary species (Figure 4). However, in 2010 and 2011 the percent change in height for the gallon stocktype is less than or equal to the percent change in height of the bare root and tubeling stocktypes (Figures 3 and 4). This suggests that when examining the percent change in height, the stocktype may only be important the first year following outplanting because stocktypes have similar percent changes in height after the first year.

Comparing the survival and growth results of the third year to the results present in the pending publication (See Appendix 5) also provides insight into the changes over time. Based on the thorough analysis of the first two years of survival and growth, the results suggest that the gallon stocktype had higher survival and growth for many species across all three cells. For both the second and third year results there does not appear to be a difference in survival and growth among bare root and tubeling stocktypes. For both years the *S. nigra* had higher survival and growth in the flooded cells while having decreased survival and growth in the other, dryer cells.

Field Study

Herbaceous vegetation was not controlled in the field study, therefore shade tolerance among oak species may have enhanced their survival and growth (Horn 1974). Some studies suggest presence of primary species can be beneficial as they alter the microhabitat to be more suitable for secondary species (Dulohery et al. 2000) and increase overall species diversity, stem density, and maximum tree height (Twedt 2006). Under the conditions of the field portion of this study, early establishment of secondary species may not require planted, primary tree species.

Gallon stocktype exhibited higher survivorship (except for *L. styraciflua*) and may be a better choice to overcome created wetland stresses. The larger tree size and transfer of containerized soil upon planting of gallon stocktype may be beneficial for these species in overcoming initial hydrologic and soil stressors allowing for more successful establishment of these species (see discussion on Mesocosm above). In the field portion of this study, tree mortality was highest and growth rate was lowest between the first and second growing season as compared to the third growing season. When compared to the first two growing seasons, the third growing season had less mortality (Table 1), less (none) stem dieback (no negative change in tree height)(Table 2), and less disparity in percent change in height between stocktypes (Figures 3 and 4). During the first years after planting, tree seedlings are most subject to mortality and most sensitive to environmental factors (McLeod and McPherson 1973, Alm and Schantz-Hansen 1974). Both high mortality and slow growth seen in the early-establishment years are likely a result of physiological stress due transplant shock combined with wetland hydrology and soil compaction. The trees remaining in the third year of the study are those with adaptations that most closely match the site conditions and are best suited to survival and growth in the field sites. As this study continues we expect to see a continuing trend of higher survival and higher growth rates when compared to years one and two.

Selection of species and stocktype may also be influenced by project budget, time constraints, regulatory conditions and ecological goals. Trees in gallon containers can be an order of magnitude more expensive than bare root seedlings. In certain situations, lower survival may be offset by higher planting densities. In projects where ecological function (such as wildlife utilization by a target species) is desired in a shorter time frame, the added expense of gallon tress may be justified.

While tree colonization rates may be slow in some created wetlands (Atkinson et al. 2005), rates may be high for some species depending on distance from seed sources (Hudson 2010) and planting strategies should be adjusted accordingly.

In conclusion, use of the mesocosm with field validation is a strength of the study and most of the results from both studies coincide. Both the field and mesocosm results suggest that the gallon stocktype may yield increased survival and growth. However, the results from the mesocosm suggest primary species may yield increased survival and growth, while the field results suggest the secondary species may be more appropriate. This may have resulted from the difference in herbaceous vegetation competition between the mesocosm and field studies. Analysis from both of these studies has also provided a method of combining multiple morphometric measures that may prove a useful tool for predicting survival and growth of planted trees.

Objective 2

The second objective of this study is to determine the appropriate vegetative measures that will identify whether the suitable wetland functions are being replaced. The goals of this objective are to relate woody growth (morphometrics) as a dependant variable to two independent ecological variables (above and belowground biomass, NEE), to determine vegetation similarity of created forested wetlands and reference sites, and to determine the role of volunteer woody species.

A dissertation and thesis are currently being designed by Herman Hudson and Sean Charles to address this objective. Preliminary data collection was begun in 2010 and 2011 when 350 trees were removed for biomass sampling. See appendix 4 for details.

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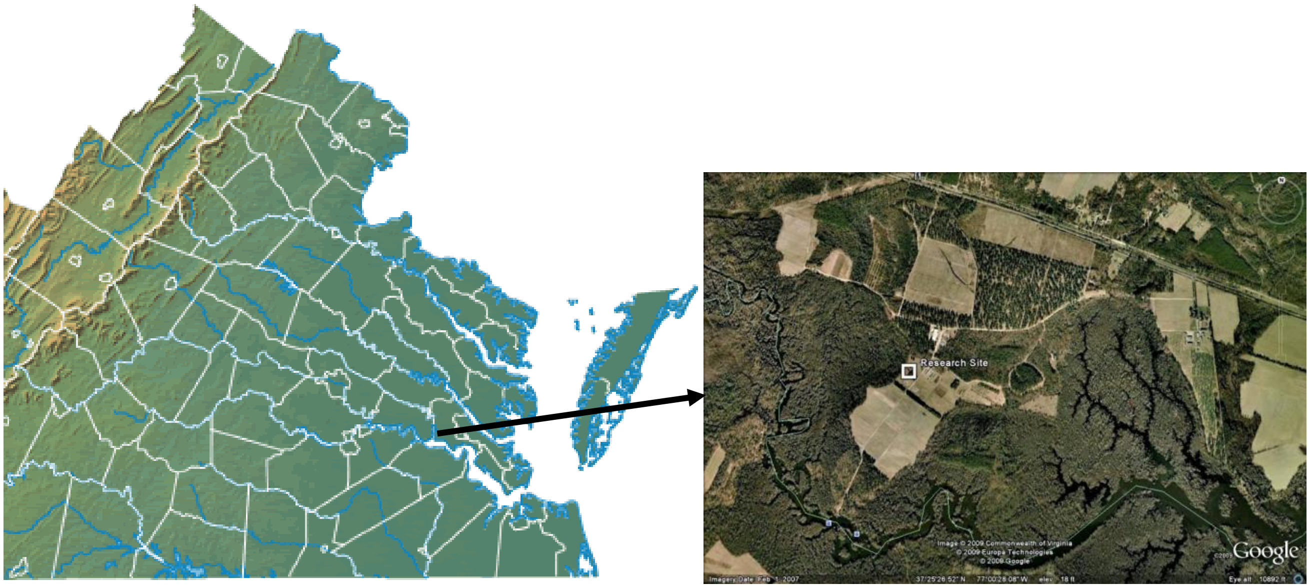
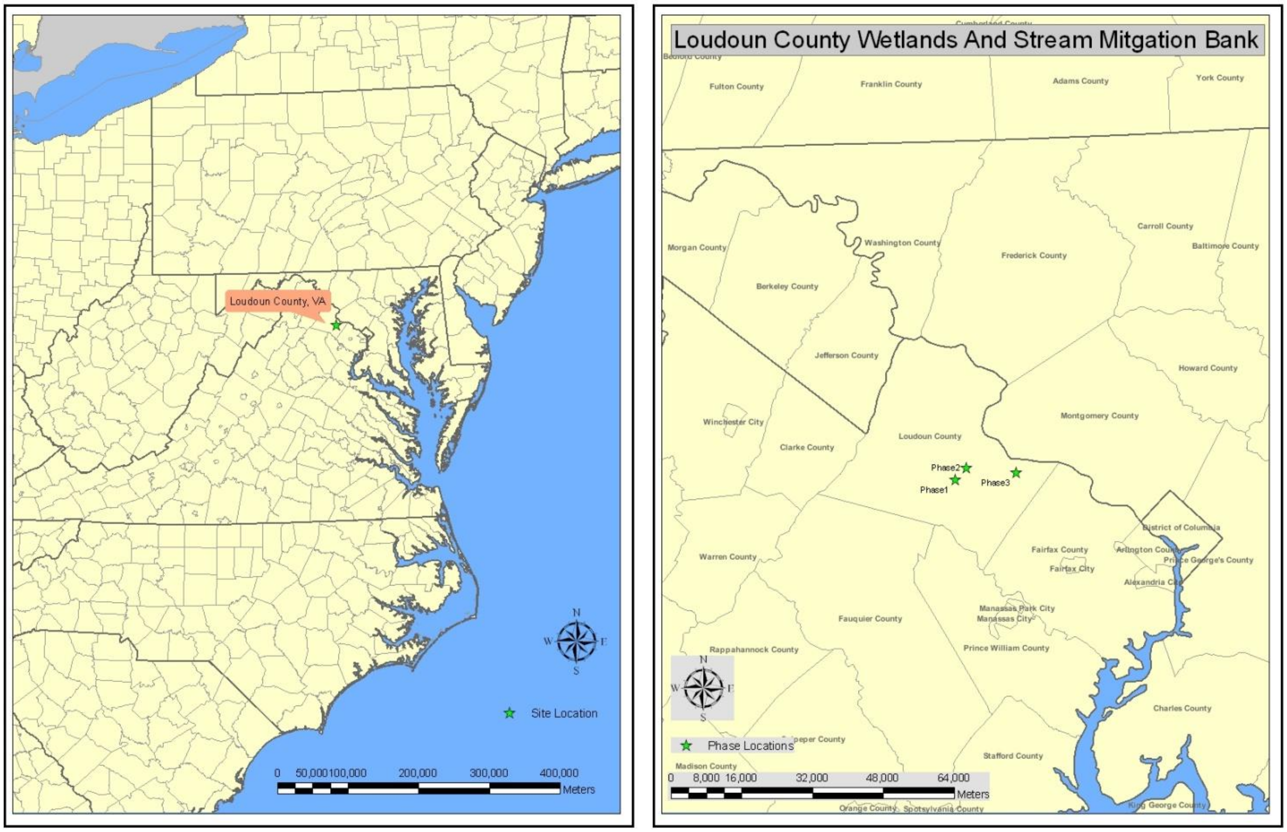
Appendix 1 - Location of Mesocosm and Field Studies

Mesocosm Location



Mesocosm Site Location: New Kent County, Virginia, USA.

Field Study Site Locations



Field Study Sites Location: Loudoun County, Virginia, USA

Field Study Plot Locations

Location of Phase I, II and III megaplots.

Appendix 2 - Field Study Construction Methods

Below are the typical construction methods of the constructed wetland areas at the Loudoun County sites. Depending on the soil fertility results, lime may also be disked into the soil.

B. Constructed Wetlands Substrate

1. The substrate of all constructed wetlands areas shall consist of a minimum of 9" of topsoil atop a 12" (or greater) thick low permeability (1 x 10-6 cm/sec or lower) subsoil layer.
2. Topsoils shall be stripped from areas proposed for grading and stockpiled for replacement upon all graded surfaces (9 inch in wetlands and 6 inch on all berms and embankments). Topsoil shall be re-spread in a loose uncompacted state in all planting areas by disking at least 6 inches deep after placement except on berms and embankments where it shall be compacted with 4 passes of a track dozer and then raked. It is expected that 4-6 passes of a disk shall be required to obtain a loose topsoil seedbed free of large (1") clumps satisfactory to WSSI.
3. After subsoil grades are achieved by either fill or excavation as needed, a low permeability subsoil substrate shall be achieved by compacting the subsoil material with a sheepsfoot roller, preferably a Caterpillar 815. Where the subsoil consists of fill, the upper 12" or more shall be placed in loose lifts not exceeding 8 inches in thickness and compacted. Where the subsoil grade is reached by excavation, the compaction effort shall be applied to the subgrade surface. Compaction shall be achieved by five passes of a sheeps foot roller with the subsoil between 3% and 7% on the wet side of the optimum moisture content. Pumping of the substrate is acceptable during this compaction process.
4. The compacted subsoil substrate shall continue ±5 feet past the outside edge of constructed wetlands areas following the rising grades proposed so that the elevation of the compacted subgrade edge is at least 0.5 feet above its elevation beneath each proposed wetlands area.
5. The referenced Soil Investigation indicates that the desired permeability can be achieved with the in-situ soils when compacted to at least eighty-five (85%) of the maximum dry density determined in accordance with ASTM D698, Standard Proctor Method between 3% and 7% on the wet side of the optimum moisture content.
6. Owner may conduct any necessary testing to assure that permeability is achieved.

C. Berms & Existing Stream Channel Fill Areas

1. Berms (small embankments 1 to 2 feet tall and 10 feet wide - except for the 4 foot wide berm between the southern wetland areas) and existing stream channel fill areas, shall be placed in 8 inch horizontal loose lifts and compacted to at least ninety-five percent (95%) of the maximum dry density determined in accordance with ASTM D698, Standard Proctor Method between 3% and 7% on the wet side of the optimum moisture content. Pumping of this material during compaction is acceptable.
2. These fill areas shall be covered with 6 inches of topsoil compacted with 4 passes of a track dozer, and then raked.
3. Berms shall be composed of cohesive materials classified as ML, CL, MH, or CH per ASTM D-2487.

Appendix 3. Distribution of Planted Trees

Distribution of trees planted in 2009 at the Mesocosm and Field

Species	Stocktype	Nursery	Location	Price ($/Tree)	Age	Ideal	Saturated	Flooded	Mesocosm Total	Phase I	Phase II	Phase III	Field Total
Betula nigra	Bare root	Native Roots Nursery	Clinton, NC	0.65		48	49	59	156	12	12	52	76
Betula nigra	Gallon	Native Roots Nursery	Clinton, NC	3.25		42	42	43	127	12	11	52	75
Betula nigra	Tubeling	Native Roots Nursery	Clinton, NC	1		37	38	39	114	12	12	52	76
Liquidambar styraciflua	Bare root	Native Roots Nursery	Clinton, NC	0.65		47	43	41	131	12	12	52	76
Liquidambar styraciflua	Gallon	Native Roots Nursery	Clinton, NC	3.25		45	43	43	131	12	12	53	77
Liquidambar styraciflua	Tubeling	Native Roots Nursery	Clinton, NC	1		42	46	40	128	12	12	51	75
Platanus occidentalis	Bare root	Warren County Nursery	McMinnville, TN	0.56		49	9	38	96	12	12	52	76
Platanus occidentalis	Gallon	Native Roots Nursery	Clinton, NC	3.25		45	44	43	132	12	12	51	75
Platanus occidentalis	Tubeling NO SOIL	Against the Wind Nursery	Atlantic, VA	1	2	36	37	21	94	12	12	52	76
Quercus bicolor	Bare root	Native Roots Nursery	Clinton, NC	0.65		53	46	46	145	12	12	51	75
Quercus bicolor	Gallon	Native Roots Nursery	Clinton, NC	3.25		40	42	42	124	12	13	51	76
Quercus bicolor	Tubeling	Native Roots Nursery	Clinton, NC	1		53	47	49	149	12	12	52	76
Quercus palustris	Bare root	Native Roots Nursery	Clinton, NC	0.65		51	42	55	148	12	12	52	76
Quercus palustris	Gallon	Native Roots Nursery	Clinton, NC	3.25		42	46	47	135	12	12	52	76
Quercus palustris	Tubeling	Native Roots Nursery	Clinton, NC	1		37	38	39	114	12	13	53	78
Quercus phellos	Bare root	Native Roots Nursery	Clinton, NC	0.65		59	69	72	200	12	12	53	77
Quercus phellos	Gallon	Native Roots Nursery	Clinton, NC	3.25		41	40	43	124	12	12	53	77
Quercus phellos	Tubeling NO SOIL	Against the Wind Nursery	Atlantic, VA	1	2	30	51	31	112	12	12	52	76
Salix nigra	Bare root	Warren County Nursery	McMinnville, TN	0.48		37	49	46	132	12	12	52	76
Salix nigra	Gallon	Pinelands Nursery	Columbus, NJ	7.95		43	44	45	132	12	12	52	76
Salix nigra	Tubeling NO SOIL	Against the Wind Nursery	Atlantic, VA	1	2	47	59	42	148	12	11	52	75

Distribution of trees planted in 2010 at the Mesocosm

Species	Stocktype	Nursery	Location	Price ($/Tree)	Age	Ideal	Saturated	Flooded	Total Replant
Betula nigra	Bare root	Warren County Nursery	McMinnville, TN	0.32		17	7	3	27
Betula nigra	Gallon	Naturescapes Wetland Plants	Suffolk, VA	5		2	2	3	7
Betula nigra	Tubeling	Pinelands Nursery	Columbus, NJ	1.1	1	25	10	4	39
Liquidambar styraciflua	Bare root	Warren County Nursery	McMinnville, TN	0.4		10	6	5	21
Liquidambar styraciflua	Gallon	Pinelands Nursery	Columbus, NJ	5.75	2	4	3	3	10
Liquidambar styraciflua	Tubeling	Pinelands Nursery	Columbus, NJ	1.1	1	20	12	3	35
Platanus occidentalis	Bare root	Warren County Nursery	McMinnville, TN	0.5		11	30	20	61
Platanus occidentalis	Gallon	Naturescapes Wetland Plants	Suffolk, VA	5		3	3	7	13
Platanus occidentalis	Tubeling	Pinelands Nursery	Columbus, NJ	1.1		8	11	22	41
Quercus bicolor	Bare root	Warren County Nursery	McMinnville, TN	0.6		3	4	3	10
Quercus bicolor	Gallon	Naturescapes Wetland Plants	Suffolk, VA	5		4	3	3	10
Quercus bicolor	Tubeling	Pinelands Nursery	Columbus, NJ	1.1	1	4	0	3	7
Quercus palustris	Bare root	Warren County Nursery	McMinnville, TN	0.4		3	2	6	11
Quercus palustris	Gallon	Naturescapes Wetland Plants	Suffolk, VA	5		3	3	4	10
Quercus palustris	Tubeling	Pinelands Nursery	Columbus, NJ	1.1	1	20	13	10	43
Quercus phellos	Bare root	Warren County Nursery	McMinnville, TN	0.35		4	1	6	11
Quercus phellos	Gallon	Pinelands Nursery	Columbus, NJ	9.5		4	4	4	12
Quercus phellos	Tubeling	Naturescapes Wetland Plants	Suffolk, VA	1.25		24	6	22	52
Salix nigra	Bare root	Warren County Nursery	McMinnville, TN	0.45		21	7	1	29
Salix nigra	Gallon	Naturescapes Wetland Plants	Suffolk, VA	5		5	3	3	11
Salix nigra	Tubeling	Pinelands Nursery	Columbus, NJ	1.1	1	16	3	3	22

Appendix 4. Data Tables

Mesocosm Study Survival

Cell	Species	Stocktype	2009 N	April 2009 % Survival	July 2009 % Survival	Oct 2009 % Survival	Oct 2009 Dead	April 2010 Replaced	2010 N	April 2010 % Survival	Aug 2010 % Survival	Oct 2010 % Survival	Oct 2010 Dead	Oct 2010 Removed	2011 N	April 2011 % Survival	Aug 2011 % Survival	Oct 2011 % Survival
Ideal	*Betula nigra*	Bare root	48	100.0	62.5	52.1	23	23	25	96	92	88	3	3	22	86.4	86.4	86.4
Ideal	*Betula nigra*	Gallon	42	100.0	100.0	100.0	0	0	42	100	100	100	0	3	39	100.0	100.0	100.0
Ideal	*Betula nigra*	Tubeling	37	100.0	43.2	40.5	22	22	15	93.333	93.333	93.333	1	3	12	91.7	91.7	91.7
Ideal	*Liquidambar styraciflua*	Bare root	47	100.0	74.5	76.6	11	11	36	97.222	97.222	97.222	1	3	33	97.0	93.9	97.0
Ideal	*Liquidambar styraciflua*	Gallon	45	100.0	100.0	100.0	0	0	45	97.778	95.556	93.333	3	3	42	95.2	95.2	95.2
Ideal	*Liquidambar styraciflua*	Tubeling	42	100.0	42.9	31.0	29	29	13	100	84.615	84.615	2	3	10	80.0	80.0	80.0
Ideal	*Platanus occidentalis*	Bare root	49	100.0	65.3	65.3	17	17	32	100	96.875	96.875	1	3	29	96.6	93.1	96.6
Ideal	*Platanus occidentalis*	Gallon	45	100.0	93.3	93.3	3	3	42	100	95.238	92.857	3	3	39	94.9	92.3	92.3
Ideal	*Platanus occidentalis*	Tubeling NO SOIL	36	100.0	97.2	97.2	1	1	35	100	100	100	0	3	32	100.0	100.0	100.0
Ideal	*Quercus bicolor*	Bare root	53	100.0	98.1	92.5	4	4	49	100	97.959	95.918	2	3	46	93.5	91.3	89.1
Ideal	*Quercus bicolor*	Gallon	40	100.0	100.0	100.0	0	0	40	100	100	100	0	3	37	100.0	100.0	100.0
Ideal	*Quercus bicolor*	Tubeling	53	100.0	79.2	75.5	13	12	41	97.561	82.927	80.488	8	3	38	73.7	71.1	71.1
Ideal	*Quercus palustris*	Bare root	51	100.0	94.1	88.2	6	7	44	100	95.455	93.182	3	3	41	90.2	90.2	87.8
Ideal	*Quercus palustris*	Gallon	42	100.0	100.0	97.6	1	0	42	100	100	100	0	3	39	100.0	100.0	100.0
Ideal	*Quercus palustris*	Tubeling	37	100.0	64.9	59.5	15	15	22	95.455	86.364	81.818	4	3	19	78.9	57.9	57.9
Ideal	*Quercus phellos*	Bare root	59	100.0	79.7	76.3	14	14	45	100	93.333	88.889	5	3	42	85.7	71.4	71.4
Ideal	*Quercus phellos*	Gallon	41	100.0	100.0	100.0	0	0	41	100	97.561	97.561	1	3	38	94.7	92.1	92.1
Ideal	*Quercus phellos*	Tubeling NO SOIL	30	100.0	73.3	66.7	10	9	21	80.952	66.667	66.667	7	3	18	61.1	61.1	61.1
Ideal	*Salix nigra*	Bare root	37	100.0	37.8	32.4	25	25	12	100	75	50	6	3	9	22.2	22.2	22.2
Ideal	*Salix nigra*	Gallon	43	100.0	97.7	97.7	1	1	42	100	100	100	0	3	39	100.0	97.4	94.9
Ideal	*Salix nigra*	Tubeling NO SOIL	47	100.0	59.6	61.7	18	18	29	100	89.655	89.655	3	3	26	76.9	73.1	69.2
Saturated	*Betula nigra*	Bare root	49	100.0	81.6	73.5	13	13	36	100	88.889	86.111	5	3	33	84.8	84.8	84.8
Saturated	*Betula nigra*	Gallon	42	97.6	97.6	97.6	1	1	41	100	100	100	0	3	38	100.0	100.0	100.0
Saturated	*Betula nigra*	Tubeling	38	100.0	89.5	84.2	6	6	32	100	93.75	93.75	2	3	29	93.1	93.1	93.1
Saturated	*Liquidambar styraciflua*	Bare root	43	100.0	88.4	88.4	5	5	38	100	94.737	92.105	3	3	35	88.6	85.7	85.7
Saturated	*Liquidambar styraciflua*	Gallon	43	100.0	100.0	100.0	0	1	42	100	100	100	0	3	39	100.0	100.0	100.0
Saturated	*Liquidambar styraciflua*	Tubeling	46	100.0	71.7	65.2	16	16	30	100	76.667	80	6	3	27	74.1	66.7	66.7
Saturated	*Platanus occidentalis*	Bare root	9	100.0	55.6	66.7	3	3	6	100	100	100	0	3	3	100.0	100.0	100.0
Saturated	*Platanus occidentalis*	Gallon	44	100.0	97.7	97.7	1	1	43	100	100	100	0	3	40	100.0	100.0	100.0
Saturated	*Platanus occidentalis*	Tubeling NO SOIL	37	100.0	78.4	78.4	8	8	29	100	96.552	100	0	3	26	96.2	96.2	92.3
Saturated	*Quercus bicolor*	Bare root	46	100.0	100.0	100.0	0	1	45	95.556	100	97.778	1	3	42	97.6	97.6	97.6
Saturated	*Quercus bicolor*	Gallon	42	100.0	100.0	100.0	0	0	42	100	100	100	0	3	39	100.0	100.0	100.0
Saturated	*Quercus bicolor*	Tubeling	47	100.0	87.2	83.0	8	8	39	97.436	94.872	97.436	1	3	36	94.4	94.4	91.7
Saturated	*Quercus palustris*	Bare root	42	100.0	100.0	97.6	1	1	41	100	97.561	95.122	2	3	38	92.1	86.8	89.5
Saturated	*Quercus palustris*	Gallon	46	100.0	100.0	100.0	0	0	46	100	100	100	0	3	43	97.7	95.3	95.3
Saturated	*Quercus palustris*	Tubeling	38	100.0	81.6	76.3	9	9	29	93.103	89.655	82.759	5	3	26	80.8	73.1	73.1
Saturated	*Quercus phellos*	Bare root	69	100.0	84.1	81.2	13	15	54	98.148	94.444	94.444	3	3	51	90.2	82.4	82.4
Saturated	*Quercus phellos*	Gallon	40	100.0	100.0	100.0	0	0	40	97.5	97.5	97.5	1	3	37	97.3	94.6	94.6
Saturated	*Quercus phellos*	Tubeling NO SOIL	51	100.0	76.5	72.5	14	14	37	97.297	94.595	91.892	3	3	34	91.2	91.2	88.2
Saturated	*Salix nigra*	Bare root	49	100.0	77.6	71.4	14	14	35	97.143	65.714	68.571	11	3	32	62.5	50.0	50.0
Saturated	*Salix nigra*	Gallon	44	100.0	95.5	95.5	2	2	42	100	100	100	0	3	39	97.4	97.4	97.4
Saturated	*Salix nigra*	Tubeling NO SOIL	59	100.0	81.4	76.3	14	15	44	97.727	70.455	72.727	12	3	41	65.9	53.7	53.7
Flooded	*Betula nigra*	Bare root	59	98.3	72.9	67.8	19	19	40	97.5	85	77.5	9	3	37	51.4	43.2	45.9
Flooded	*Betula nigra*	Gallon	43	100.0	100.0	100.0	0	0	43	100	100	100	0	3	40	100.0	92.5	90.0
Flooded	*Betula nigra*	Tubeling	39	100.0	92.3	94.9	2	1	38	97.368	94.737	94.737	2	3	35	91.4	85.7	77.1
Flooded	*Liquidambar styraciflua*	Bare root	41	97.6	95.1	90.2	4	3	38	100	94.737	84.211	6	3	35	71.4	42.9	42.9
Flooded	*Liquidambar styraciflua*	Gallon	43	100.0	100.0	100.0	0	0	43	100	100	95.349	2	3	40	90.0	85.0	82.5
Flooded	*Liquidambar styraciflua*	Tubeling	40	100.0	97.5	92.5	3	3	37	100	100	89.189	4	3	34	73.5	61.8	52.9
Flooded	*Platanus occidentalis*	Bare root	38	92.1	57.9	44.7	21	21	17	94.118	76.471	76.471	4	3	14	21.4	0.0	0.0
Flooded	*Platanus occidentalis*	Gallon	43	100.0	90.7	83.7	7	6	37	89.189	75.676	59.459	15	3	34	44.1	26.5	32.4
Flooded	*Platanus occidentalis*	Tubeling NO SOIL	21	81.0	52.4	52.4	10	10	11	72.727	63.636	63.636	4	3	8	12.5	12.5	12.5
Flooded	*Quercus bicolor*	Bare root	46	97.8	95.7	95.7	2	2	44	95.455	86.364	65.909	15	3	41	56.1	39.0	31.7
Flooded	*Quercus bicolor*	Gallon	42	100.0	100.0	100.0	0	0	42	97.619	95.238	88.095	5	3	39	82.1	61.5	61.5
Flooded	*Quercus bicolor*	Tubeling	49	95.9	79.6	81.6	9	9	40	97.5	72.5	47.5	21	3	37	27.0	18.9	13.5
Flooded	*Quercus palustris*	Bare root	55	98.2	94.5	89.1	6	6	49	95.918	79.592	61.224	19	3	46	23.9	13.0	8.7
Flooded	*Quercus palustris*	Gallon	47	100.0	97.9	97.9	1	2	45	97.778	82.222	77.778	10	3	42	45.2	33.3	31.0
Flooded	*Quercus palustris*	Tubeling	39	97.4	89.7	76.9	9	9	30	90	53.333	36.667	19	3	27	18.5	11.1	11.1
Flooded	*Quercus phellos*	Bare root	72	88.9	76.4	72.2	20	20	52	82.692	65.385	51.923	25	3	49	20.4	14.3	18.4
Flooded	*Quercus phellos*	Gallon	43	100.0	100.0	100.0	0	1	42	97.619	73.81	71.429	12	3	39	41.0	33.3	41.0
Flooded	*Quercus phellos*	Tubeling NO SOIL	31	87.1	61.3	54.8	14	14	17	82.353	35.294	35.294	11	3	14	7.1	0.0	0.0
Flooded	*Salix nigra*	Bare root	46	95.7	93.5	91.3	4	4	42	100	100	100	0	3	39	100.0	100.0	94.9
Flooded	*Salix nigra*	Gallon	45	97.8	95.6	95.6	2	3	42	100	100	100	0	3	39	100.0	100.0	89.7
Flooded	*Salix nigra*	Tubeling NO SOIL	42	92.9	90.5	92.9	3	5	37	100	97.297	97.297	1	3	34	97.1	94.1	97.1

Mesocosm Height Percent Change

Cell	Species	Stocktype	2009 N	2009 % Height Change (STERR)	2010 % Height Change (STERR)	2011 % Height Change (STERR)
Ideal	*Betula nigra*	Bare root	48	18.3 (12.7)	221.6 (12.3)	92.2 (5.9)
Ideal	*Betula nigra*	Gallon	42	241.9 (28.6)	68.6 (5.1)	53.2 (3.1)
Ideal	*Betula nigra*	Tubeling	37	42 (18.3)	199.8 (30.2)	116.2 (17.5)
Ideal	*Liquidambar styraciflua*	Bare root	47	54 (16.6)	122.3 (12)	83.2 (5.4)
Ideal	*Liquidambar styraciflua*	Gallon	45	151.4 (22.3)	59.9 (4.5)	56.2 (3.1)
Ideal	*Liquidambar styraciflua*	Tubeling	42	0.3 (9.3)	131.1 (11.5)	93.1 (18)
Ideal	*Platanus occidentalis*	Bare root	49	121.5 (26.7)	165.6 (11.1)	78.9 (5)
Ideal	*Platanus occidentalis*	Gallon	45	243.5 (29.3)	51.5 (5.9)	39.6 (4.9)
Ideal	*Platanus occidentalis*	Tubeling NO SOIL	36	137.1 (24.5)	137.5 (12)	62.6 (3.8)
Ideal	*Quercus bicolor*	Bare root	53	39.9 (13.1)	21.8 (5.8)	40.4 (5.7)
Ideal	*Quercus bicolor*	Gallon	40	40.8 (15.2)	74.4 (7)	45.7 (5.2)
Ideal	*Quercus bicolor*	Tubeling	53	-55.6 (4.8)	70.4 (12.2)	49 (4.5)
Ideal	*Quercus palustris*	Bare root	51	42 (14.7)	48 (5.8)	43 (5.5)
Ideal	*Quercus palustris*	Gallon	42	95.5 (19.6)	42.4 (7)	30.9 (3.9)
Ideal	*Quercus palustris*	Tubeling	37	-51.3 (7.4)	75.9 (20.4)	57.8 (9.5)
Ideal	*Quercus phellos*	Bare root	59	-4.7 (10.8)	73.1 (13.2)	57.2 (7.3)
Ideal	*Quercus phellos*	Gallon	41	254.4 (29.9)	39.2 (6.5)	31.7 (3.6)
Ideal	*Quercus phellos*	Tubeling NO SOIL	30	-43.3 (8.6)	80.6 (19.7)	58.4 (17.1)
Ideal	*Salix nigra*	Bare root	37	-28.5 (10.3)	80.4 (22.5)	147.9 (72.5)
Ideal	*Salix nigra*	Gallon	43	166 (21.4)	36.9 (7.7)	42.6 (4.7)
Ideal	*Salix nigra*	Tubeling NO SOIL	47	42.6 (20.6)	93.2 (17.4)	103 (15.3)
Saturated	*Betula nigra*	Bare root	49	-0.8 (11.8)	114.7 (10.4)	81.3 (10.5)
Saturated	*Betula nigra*	Gallon	42	203.6 (41.3)	41.8 (5.2)	58.2 (4.8)
Saturated	*Betula nigra*	Tubeling	38	-18.1 (9.4)	120.7 (12.2)	92.4 (8.3)
Saturated	*Liquidambar styraciflua*	Bare root	43	-35.2 (9)	52.5 (8.8)	113.9 (8.6)
Saturated	*Liquidambar styraciflua*	Gallon	43	49.3 (22.3)	18.3 (2.4)	51.4 (4.1)
Saturated	*Liquidambar styraciflua*	Tubeling	46	-64.8 (5.1)	84.7 (16.2)	131.7 (11.9)
Saturated	*Platanus occidentalis*	Bare root	9	-35.2 (8.7)	117.3 (26.7)	154 (40.1)
Saturated	*Platanus occidentalis*	Gallon	44	124.8 (22)	45 (9)	38.7 (8.3)
Saturated	*Platanus occidentalis*	Tubeling NO SOIL	37	5.8 (16.2)	97.6 (15.7)	119.4 (10.6)
Saturated	*Quercus bicolor*	Bare root	46	-4 (11.4)	0.2 (4.7)	47.3 (7.8)
Saturated	*Quercus bicolor*	Gallon	42	-19.1 (9)	52.7 (7.4)	51.2 (6.5)
Saturated	*Quercus bicolor*	Tubeling	47	-71.7 (3.5)	11.9 (5.7)	63 (11.5)
Saturated	*Quercus palustris*	Bare root	42	-46 (5.8)	55.8 (9.4)	77.4 (8.1)
Saturated	*Quercus palustris*	Gallon	46	51.9 (16.2)	9.7 (1.9)	26.5 (3.6)
Saturated	*Quercus palustris*	Tubeling	38	-67.5 (3.9)	129.1 (18.7)	55.2 (9.4)
Saturated	*Quercus phellos*	Bare root	69	-34.8 (6.2)	33.7 (6.5)	55.4 (7.2)
Saturated	*Quercus phellos*	Gallon	40	194.4 (35)	10.6 (3.5)	32 (3.6)
Saturated	*Quercus phellos*	Tubeling NO SOIL	51	-42.3 (6.8)	65.8 (12)	63.2 (8.1)
Saturated	*Salix nigra*	Bare root	49	-14.4 (12.4)	97.1 (24)	87.5 (15)
Saturated	*Salix nigra*	Gallon	44	79.2 (22.2)	62.7 (10.7)	82 (6.2)
Saturated	*Salix nigra*	Tubeling NO SOIL	59	-13.7 (12.5)	61.6 (21.5)	78.5 (15.6)
Flooded	*Betula nigra*	Bare root	59	16.5 (4.9)	3 (2.7)	33 (17.2)
Flooded	*Betula nigra*	Gallon	43	8.7 (1)	2.3 (0.6)	-6.7 (2.7)
Flooded	*Betula nigra*	Tubeling	39	8.8 (3.7)	13.3 (2.5)	-2.7 (3.1)
Flooded	*Liquidambar styraciflua*	Bare root	41	1.3 (1.1)	2.3 (1.2)	-5.1 (2.7)
Flooded	*Liquidambar styraciflua*	Gallon	43	23.1 (1.4)	0.4 (0.4)	0 (0.7)
Flooded	*Liquidambar styraciflua*	Tubeling	40	12.3 (2.6)	17.1 (2.9)	2 (1.5)
Flooded	*Platanus occidentalis*	Bare root	38	-28.7 (5.5)	-9.6 (9.6)	0 (0)
Flooded	*Platanus occidentalis*	Gallon	43	-26.9 (5.5)	-24.1 (6.6)	-19.6 (9)
Flooded	*Platanus occidentalis*	Tubeling NO SOIL	21	-26.6 (10.6)	-4.8 (6.7)	-78.3 (0)
Flooded	*Quercus bicolor*	Bare root	46	0 (1.1)	-2 (1.4)	-18.2 (9.7)
Flooded	*Quercus bicolor*	Gallon	42	5.4 (1.8)	-2.3 (2.5)	-10.8 (4.8)
Flooded	*Quercus bicolor*	Tubeling	49	-0.8 (1)	-4.9 (3)	-12.1 (7.1)
Flooded	*Quercus palustris*	Bare root	55	-1.6 (1.2)	-4.6 (2.8)	103.8 (92.8)
Flooded	*Quercus palustris*	Gallon	47	0.3 (1.2)	-5.9 (1.9)	-14.3 (12.3)
Flooded	*Quercus palustris*	Tubeling	39	-9 (3.5)	10.3 (6.6)	15 (0)
Flooded	*Quercus phellos*	Bare root	72	-0.1 (1)	-13.7 (4.5)	-2.2 (10.7)
Flooded	*Quercus phellos*	Gallon	43	-2.5 (1.3)	-2.4 (0.8)	-14.4 (6.3)
Flooded	*Quercus phellos*	Tubeling NO SOIL	31	-34.4 (8)	24.9 (19.6)	0 (0)
Flooded	*Salix nigra*	Bare root	46	14.7 (6.3)	50.2 (6.9)	20.1 (4)
Flooded	*Salix nigra*	Gallon	45	4.6 (1.4)	-4.5 (2.9)	-0.1 (2.7)
Flooded	*Salix nigra*	Tubeling NO SOIL	42	4.2 (6.7)	46.4 (5.8)	5.8 (4.5)

Mesocosm Biomass

Cell	Species	Stocktype	Planted	N	BG AVG	BG StdErr	AG AVG	AG StdErr	AG/BG	AB/BG StdErr	BA/BG	BA/BG StdErr
Ideal	*Betula nigra*	Bare root	2009	3	392.0	79.2	401.0	205.0	0.9	0.3	1.4	0.5
Ideal	*Betula nigra*	Gallon	2009	3	1066.7	366.3	1713.3	704.5	1.6	0.3	0.7	0.1
Ideal	*Betula nigra*	Tubeling	2009	3	893.3	37.1	1013.0	308.9	1.2	0.4	1.2	0.6
Ideal	*Liquidambar styraciflua*	Bare root	2009	3	664.0	228.5	1260.0	630.0	1.6	0.5	0.9	0.4
Ideal	*Liquidambar styraciflua*	Gallon	2009	3	1940.0	374.7	1320.0	410.0	0.7	0.2	1.7	0.5
Ideal	*Liquidambar styraciflua*	Tubeling	2009	3	485.0	132.6	713.3	365.2	1.3	0.5	0.9	0.2
Ideal	*Platanus occidentalis*	Bare root	2009	3	682.7	300.2	535.3	404.2	0.7	0.3	3.4	2.3
Ideal	*Platanus occidentalis*	Gallon	2009	3	250.0	150.0	550.7	362.4	0.6	0.4	4.7	3.7
Ideal	*Platanus occidentalis*	Tubeling NO SOIL	2009	3	398.0	371.3	390.3	365.0	1.4	0.5	0.9	0.2
Ideal	*Quercus bicolor*	Bare root	2009	3	100.0	33.0	46.0	7.0	0.5	0.2	2.1	0.5
Ideal	*Quercus bicolor*	Gallon	2009	3	300.0	57.7	133.3	63.6	0.4	0.1	2.9	0.7
Ideal	*Quercus bicolor*	Tubeling	2009	3	11.0	3.6	5.0	1.5	0.8	0.6	2.9	1.2
Ideal	*Quercus palustris*	Bare root	2009	3	39.7	6.6	19.5	8.5	0.5	0.1	2.2	0.4
Ideal	*Quercus palustris*	Gallon	2009	3	308.3	136.6	142.7	68.8	0.4	0.0	2.2	0.1
Ideal	*Quercus palustris*	Tubeling	2009	3	66.3	45.4	34.5	15.5	0.6	0.2	2.2	0.9
Ideal	*Quercus phellos*	Bare root	2009	3	40.7	29.7	44.3	39.3	0.7	0.3	1.7	0.5
Ideal	*Quercus phellos*	Gallon	2009	3	406.7	165.9	609.0	302.4	1.1	0.5	4.2	3.6
Ideal	*Quercus phellos*	Tubeling NO SOIL	2009	3	159.7	104.1	296.3	124.7	7.9	6.8	0.6	0.3
Ideal	*Salix nigra*	Bare root	2009	3	46.3	37.4	11.0	3.0	1.2	0.1	0.8	0.0
Ideal	*Salix nigra*	Gallon	2009	3	235.3	118.1	386.7	148.9	1.8	0.3	0.6	0.1
Ideal	*Salix nigra*	Tubeling NO SOIL	2009	3	126.7	70.6	209.3	138.3	1.4	0.2	0.7	0.1
Saturated	*Betula nigra*	Bare root	2009	3	30.0	25.5	37.3	31.3	1.3	0.1	0.8	0.0
Saturated	*Betula nigra*	Gallon	2009	3	748.7	467.1	593.3	123.5	1.3	0.4	1.1	0.5
Saturated	*Betula nigra*	Tubeling	2009	3	108.7	25.2	207.0	136.6	1.6	0.8	1.0	0.4
Saturated	*Liquidambar styraciflua*	Bare root	2009	3	26.7	17.6	50.0	45.1	1.1	0.6	1.7	0.7
Saturated	*Liquidambar styraciflua*	Gallon	2009	3	179.0	19.0	98.7	21.9	0.5	0.1	1.9	0.3
Saturated	*Liquidambar styraciflua*	Tubeling	2009	3	28.3	21.9	32.0	28.0	0.9	0.1	1.1	0.1
Saturated	*Platanus occidentalis*	Bare root	2009	3	59.0	40.6	68.0	56.1	0.8	0.2	1.4	0.4
Saturated	*Platanus occidentalis*	Gallon	2009	3	110.3	25.0	120.0	30.6	1.1	0.0	0.9	0.0
Saturated	*Platanus occidentalis*	Tubeling NO SOIL	2009	3	16.3	6.7	161.3	139.3	49.5	48.6	0.7	0.3
Saturated	*Quercus bicolor*	Bare root	2009	3	34.7	15.0	23.0	8.5	0.9	0.4	1.5	0.5
Saturated	*Quercus bicolor*	Gallon	2009	3	86.7	26.7	35.7	3.3	0.5	0.1	2.3	0.5
Saturated	*Quercus bicolor*	Tubeling	2009	3	10.7	0.9	2.7	0.3	0.3	0.0	4.2	0.9
Saturated	*Quercus palustris*	Bare root	2009	3	60.0	22.5	31.0	16.2	0.4	0.1	2.6	0.7
Saturated	*Quercus palustris*	Gallon	2009	3	212.7	106.4	180.0	120.0	0.7	0.2	1.5	0.4
Saturated	*Quercus palustris*	Tubeling	2009	3	15.0	9.6	29.3	25.4	3.6	3.2	2.4	1.7
Saturated	*Quercus phellos*	Bare root	2009	3	35.0	19.9	17.3	7.6	0.6	0.3	2.2	0.8
Saturated	*Quercus phellos*	Gallon	2009	3	249.7	92.3	226.7	66.7	1.1	0.3	1.1	0.2
Saturated	*Quercus phellos*	Tubeling NO SOIL	2009	3	11.7	1.5	4.3	1.3	0.4	0.1	3.1	0.9
Saturated	*Salix nigra*	Bare root	2009	3	58.0	38.6	40.3	21.3	1.7	0.9	1.0	0.4
Saturated	*Salix nigra*	Gallon	2009	3	70.3	18.9	115.0	75.0	1.3	0.4	0.8	0.3
Saturated	*Salix nigra*	Tubeling NO SOIL	2009	3	4.0	2.0	47.7	42.7	22.8	21.8	0.7	0.3
Flooded	*Betula nigra*	Bare root	2009	3	3.7	0.9	3.0	1.2	0.8	0.1	1.4	0.3
Flooded	*Betula nigra*	Gallon	2009	3	106.7	17.6	133.3	35.3	1.2	0.1	0.8	0.1
Flooded	*Betula nigra*	Tubeling	2009	3	5.7	1.7	8.3	1.8	1.6	0.3	0.7	0.1
Flooded	*Liquidambar styraciflua*	Bare root	2009	3	4.3	1.9	3.3	0.3	1.0	0.3	1.2	0.4
Flooded	*Liquidambar styraciflua*	Gallon	2009	3	80.0	11.5	53.3	6.7	0.7	0.0	1.5	0.1
Flooded	*Liquidambar styraciflua*	Tubeling	2009	3	9.7	6.2	4.7	2.7	0.5	0.1	1.9	0.2
Flooded	*Platanus occidentalis*	Bare root	2009	3	2.3	0.7	4.7	1.3	2.0	0.0	0.5	0.0
Flooded	*Platanus occidentalis*	Gallon	2009	3	28.0	6.1	60.0	20.0	2.1	0.2	0.5	0.1
Flooded	*Platanus occidentalis*	Tubeling NO SOIL	2009	3	3.7	1.5	6.7	3.2	1.6	0.3	0.7	0.2
Flooded	*Quercus bicolor*	Bare root	2009	3	29.0	11.5	15.7	5.9	0.6	0.1	1.8	0.2
Flooded	*Quercus bicolor*	Gallon	2009	3	65.0	15.0	18.7	1.9	0.3	0.1	3.4	0.5
Flooded	*Quercus bicolor*	Tubeling	2009	3	10.7	0.3	5.7	1.5	0.5	0.2	2.3	0.7
Flooded	*Quercus palustris*	Bare root	2009	3	7.0	2.3	3.3	0.9	0.5	0.1	2.0	0.3
Flooded	*Quercus palustris*	Gallon	2009	3	62.3	29.1	73.3	24.0	1.3	0.2	0.8	0.1
Flooded	*Quercus palustris*	Tubeling	2009	3	7.0	4.0	2.0	0.0	0.5	0.2	3.5	2.0
Flooded	*Quercus phellos*	Bare root	2009	3	6.3	1.2	5.7	0.9	0.9	0.1	1.1	0.1
Flooded	*Quercus phellos*	Gallon	2009	3	50.0	10.0	64.3	38.6	1.7	0.7	0.7	0.3
Flooded	*Quercus phellos*	Tubeling NO SOIL	2009	3	8.0	4.6	9.3	6.3	1.1	0.3	1.0	0.3
Flooded	*Salix nigra*	Bare root	2009	3	51.0	25.0	56.7	43.7	0.8	0.3	1.6	0.6
Flooded	*Salix nigra*	Gallon	2009	3	340.0	167.7	560.0	480.1	1.4	0.6	2.1	1.6
Flooded	*Salix nigra*	Tubeling NO SOIL	2009	3	71.0	37.1	22.7	9.3	0.5	0.2	3.4	1.8

Field Study Survival

Species	**Stocktype**	**N**	**March 2009 % Survival**	**July 2009 % Survival**	**July 2010 % Survival**	**July 2011 % Survival**
Betula nigra	Bare Root	76	100	89.5	48.7	46.1
Betula nigra	Gallon	76	100	97.4	75.0	69.7
Betula nigra	Tubeling	76	100	89.5	50.0	48.7
Liquidambar styraciflua	Bare Root	76	100	84.2	59.2	48.7
Liquidambar styraciflua	Gallon	76	100	94.7	77.6	68.4
Liquidambar styraciflua	Tubeling	77	100	62.3	22.1	22.1
Platanus occidentalis	Bare Root	76	100	69.7	35.5	30.3
Platanus occidentalis	Gallon	76	100	71.1	46.1	38.2
Platanus occidentalis	Tubeling NO SOIL	76	100	90.8	60.5	50.0
Quercus bicolor	Bare Root	76	100	89.5	63.2	57.9
Quercus bicolor	Gallon	76	100	98.7	96.1	94.7
Quercus bicolor	Tubeling	75	100	90.7	78.7	74.7
Quercus palustris	Bare Root	76	100	96.1	67.1	55.3
Quercus palustris	Gallon	76	100	97.4	89.5	85.5
Quercus palustris	Tubeling	76	100	86.8	72.4	65.8
Quercus phellos	Bare Root	76	100	86.8	36.8	31.6
Quercus phellos	Gallon	76	100	92.1	84.2	80.3
Quercus phellos	Tubeling NO SOIL	76	100	67.1	18.4	7.9
Salix nigra	Bare Root	76	100	77.6	38.2	34.2
Salix nigra	Gallon	76	100	98.7	72.4	71.1
Salix nigra	Tubeling NO SOIL	76	100	89.5	64.5	60.5

Field Study Growth

Species	**Stocktype**	**2009 % Height Change (STERR)**	**2010 % Height Change (STERR)**	**2011 % Height Change (STERR)**
Betula nigra	Bare Root	-9.5 (7.8)	35.4 (10.7)	24.7 (7.9)
Betula nigra	Gallon	-4 (2.2)	-12.3 (15.8)	3.3 (10.6)
Betula nigra	Tubeling	9.4 (2.8)	25.2 (8.9)	31 (6.8)
Liquidambar styraciflua	Bare Root	-5.9 (2.6)	-15.1 (6.4)	44.6 (7.2)
Liquidambar styraciflua	Gallon	5.5 (3.1)	-16.1 (7.4)	52.3 (28.3)
Liquidambar styraciflua	Tubeling	22.7 (6.8)	75.8 (14)	46.4 (8.2)
Platanus occidentalis	Bare Root	-24.1 (4.7)	26.7 (20.8)	37.6 (9)
Platanus occidentalis	Gallon	-13.6 (7.4)	-20.8 (11.1)	66.4 (45.6)
Platanus occidentalis	Tubeling NO SOIL	-19 (4.2)	5.9 (9.6)	47.5 (6.2)
Quercus bicolor	Bare Root	2.5 (3.4)	-17.2 (5.9)	13.7 (6.3)
Quercus bicolor	Gallon	10.5 (1.9)	6.5 (3.3)	19.1 (3.6)
Quercus bicolor	Tubeling	4.2 (4.4)	54.9 (14.6)	37.5 (9.5)
Quercus palustris	Bare Root	-1.2 (3.7)	-13.3 (8.3)	36.3 (7.9)
Quercus palustris	Gallon	3.6 (2.7)	11.8 (4.9)	1.2 (3.2)
Quercus palustris	Tubeling	-25.7 (3.7)	73.9 (10.3)	53.3 (8.7)
Quercus phellos	Bare Root	-15.7 (5.5)	-39.3 (6.6)	30.2 (14.8)
Quercus phellos	Gallon	11.6 (7.9)	4.8 (9.6)	29.6 (15.9)
Quercus phellos	Tubeling NO SOIL	-31.8 (4.7)	-55.6 (6.6)	117 (67.1)
Salix nigra	Bare Root	0.7 (6.8)	60.8 (12.4)	37 (6.4)
Salix nigra	Gallon	7.1 (12.5)	2.4 (8.3)	21 (6.9)
Salix nigra	Tubeling NO SOIL	0.6 (3.7)	21.9 (6.7)	27.1 (5.1)

Appendix 5 – Draft Mesocosm Publication

GROWTH AND SURVIVAL OF WOODY WETLAND VASCULAR PLANTS: A FIELD STUDY WITH CONTROLLED HYDROLOGY

HERMAN W. HUDSON III, JAMES E. PERRY

Introduction

Most of the wetlands lost in Virginia over the past few decades have been palustrine forested wetlands; the most abundant wetland type in Virginia (Tiner and Finn 1986, USGS 1999). Wetland impacts are regulated by the Clean Water Act (CWA) of 1977 (33 U.S.C. 1344) and permittees are required in order of priority, to avoid, to minimize or to mitigate (aka restore or create compensatory wetland mitigation sites (CMS)) their impacts. CMS include creation of a new wetland, restoration, enhancement, or in some cases, preservation of existing natural systems (USACE 2008). Compensatory mitigation sites have a number of project specific goals that must be met in order to be considered 'successful' under existing federal regulations. A typical goal for forested CMS in Virginia is 495-990 stems ha^{-1} (200-400 stems $acre^{-1}$) or until the canopy cover is 30% or greater (USACE Norfolk District and VADEQ 2004). This woody stem density goal can be accomplished through natural colonization of woody vegetation from surrounding seed sources (Hudson 2010) and/or through tree planting.

Several studies have suggested that CMS did not meet their prescribed structural goals (Brown and Veneman 2001; NRC 2001; Cole and Shafer 2002;) including failing to meet the woody stem density requirements (Sharitz et al. 2006; Matthews and Endress 2008). Failure to meet the woody stem density goals may result from inadequate colonization from surrounding seed sources or through poor survival of planted woody vegetation (Robb 2002; Morgan and Roberts 2003). Poor survival of planted trees results from unfavorable site conditions (inappropriate hydrology, low organic material, high bulk density, increased rock fragments), improper species or stocktype selection, and/or improper planting techniques (Stolt et al. 2000; Campbell et al. 2002; Bruland and Richardson 2004; Bergshneider 2005; Daniels et al. 2005; Bailey et al. 2007).

There are numerous species of woody plants and stocktypes (e.g. seeds, bare-root seedlings, tubelings or plugs, 1- or 3-gallon containers) available for afforestation or reforestation projects including CMS, carbon sequestration projects, wildlife preserves or other conservation reserve programs. Previous studies investigating planted tree survival and growth have focused on: bottomland hardwood forests species and exclusion of herbaceous vegetation (Krinard and Kennedy 1987; Schweitzer et al. 1999; Twedt and Wilson 2002), nursery source of planting material (Gardiner et al. 2007), influence of deer browse (Taylor et al. 2004), restoration intensity (natural vs. planted, Stanturf et al. 2009), effects of early season flooding (McCurry et al. 2010), effects of flooding duration (Niswander and Mitsch 1995), establishment under nurse species (McLeod et al. 2001) and the survival of particular stocktypes (Henderson et al 2009). Several greenhouse and mesocosm controlled experiments have investigated the effects of soil moisture (McLeod and McPherson 1973), and water temperature (Donovan et al. 1988) on the survival of planted trees. Due to the number of species and stocktypes available and lack of studies focused how the choice of species and stocktype affects the survival of woody species in CMS, managers have difficulty ensuring that forested sites will meet their woody stem density goals.

In addition to the woody stem density regulatory goal, an important and often overlooked indication of functional success of forested CMS is tree growth. Few states have established goals for woody growth in restored or created wetlands (Streever 1999). This may be due to a lack of specific growth goals; possibly the result of limited information on growth rates of planted trees in created or restored wetlands (Denton 1990; Niswander and Mitsch 1995; Gamble and Mitsch 2006; Pennington and Walters 2006; Henderson et al 2009). Washington state estimates changes in woody species aerial cover to determine tree growth and requires 70% to 80% cover of woody species after five years (Bergdolt 2005; WSDOT 2008). In addition to the woody stem density goal for CMS, Virginia has currently implemented woody growth success criterion for mitigation banks in particular. The criterion requires that until the canopy coverage exceeds 30%, all woody stems (including colonizing trees) must have an average increase in height of 10% per year until the 5th and 10th year following construction. An alternative goal requires the average tree height in the buffer areas is 5 feet during the 5th monitoring year and 10th monitoring year. (VADEQ 2010).

The purpose of this study was to investigate the differences in survival and growth among seven native woody vascular plants common to the mid-Atlantic region of the US. Three different stocktypes (bare roots, tubelings, and 1-gallon containers) were grown under three distinct hydrologic conditions. This work will hopefully assist wetland managers in choosing the appropriate species and stocktypes to match hydrologic conditions present at forested CMS in the Mid-Atlantic Region of the US.

Methods

Study Site

A field site consisting of three hydrologically distinct cells (Ideal (IC), Saturated (SC) and Flooded (FC)) was established at the New Kent Forestry Center, in Providence Forge, VA in 2008-2009. Each cell is 48.8m x 144m (160ft x 300ft) in size. Soil of the IC and SC were disked and tilled in February 2009 prior to planting. The FC was excavated to a depth of 1m (3.1ft.) to an existing clay layer. Each cell was set up with an on-site irrigation system capable of producing a minimum of 2.54cm (1in.) of irrigation per hour. Irrigation water was drawn from the non-tidal portion of the Chickahominy River approximately 8km (5mi.) upriver above the Rock-a-hoc Dam, Lanexa, VA. The three cells were hydrologically manipulated to include an ideal treatment (a minimum 2.54cm (1in.) irrigation or rain per week), saturated treatment (kept saturated at a minimum of 90% of the growing season within the root-zone (10cm) of the plantings and irrigated as needed), and a flooded treatment (saturated to the soil surface at least 90% of year).

The seven species planted were *Betula nigra* (river birch) (FACW), *Liquidambar styraciflua* (sweetgum) (FAC), *Platanus occidentalis* (American sycamore) (FACW-), *Quercus bicolor* (swamp white oak) (FACW+), *Quercus palustris* (pin oak) (FACW), *Quercus phellos* (willow oak) (FAC+) and *Salix nigra* (black willow) (FACW+). Three stocktypes of each species were used: bare-root (BR), Tubeling (TB), and 1-Gallon containers (GAL) (tubelings of *P. occidentalis, Q. phellos*, and *S. nigra* had their soil removed by the nursery prior to shipment and will be referred to as tubelings NO SOIL). Each combination of species and stocktype were planted randomly and evenly within each cell in spring 2009. A total of 2,772 trees were planted; 44 of each species and stocktype (on 8ft centers), for a total of 924 trees per cell. Seedlings came from five nurseries;

three in Virginia, one in North Carolina, and one in South Carolina. No fertilizers were applied prior to or following planting and herbaceous competition was controlled around plantings.

Survival and Morphometric Measurements

Survival counts and morphometric measurements were made in mid-April, mid-August, and mid-October. Individuals were considered live based on the presence of green leaves or a green vascular cambium. The latter was necessary since we noted that many trees exhibited die-back and re-growth. To check for a live cambium a small scratch was made at the highest point on the stem. If brown [i.e. not alive], a second scratch was made approximately one half way down the stem. If brown, we proceeded to scratch the base for a final determination. If any of the scratches showed a green cambium, the individual was considered alive. Differences in survival probabilities among species and stocktypes within cells including interactions were analyzed using Cox Proportional Hazards Model using the Firth adjustment for monotone likelihood and the Breslow method for ties (PROC PHREG - SAS 2008).

Morphology measurements were 1) root-collar diameter (RCD), 2) height of highest stem (H), and 3) canopy diameter (CD). Data were collected using methods modified from Bailey et al. (2007). Total height was sampled using a standard meter stick or 5-m stadia rod, while canopy diameter and root-collar diameter were quantified using macro-calipers (Haglof, Inc. “Mantax Precision” Calipers) and micro-calipers (SPI 6”/.1 mm Poly Dial Calipers), respectively. Canopy diameter was measured in three different angles at the visual diameter maximum to determine the average canopy diameter. Root-collar diameter was measured at the base of the stem at soil level. If there was more than one stem for a planting (e.g. multiple stems), root-collar diameter of all stems were measured and summed to obtain total root-collar diameter. Die back and re-growth (coppicing and re-sprouting) were common (often leading to negative growth rates) and were noted in the field.

Relative Growth Rate

Relative growth rates (RGR) were calculated to eliminate any size related growth differences (Hunt 1990). Relative growth rate was calculated from the following equation (Hunt 1978):

$$r = \frac{\ln(W_2) - \ln(W_1)}{t_2 - t_1}$$

where r = Relative Growth Rate (RGR),

W1 = Morphometric measurement of tree at time 1,

W2 = Morphometric measurement of tree at time 2,

t1 = Time of first measurement and

t2 = Time of second measurement

Relative growth rates ([cm cm^{-1}] month^{-1}) were calculated for root-collar diameter (RCD_{RGR}), height (H_{RGR}) and canopy diameter (CD_{RGR}) over two growing seasons. If the tree died before the end of the second growing season the RGR for two years was calculated using the last available measurement. The three growth rates were combined into a single variable using Principal components analysis (PCA). Differences among the cells, species, and stocktypes were analyzed using analysis of variance (ANOVA) of the first principal component scores calculated from the PCA. Combining the growth rates of three morphometric measurements provides a more complete indication of the overall tree growth and allows equal credit for growth in all three parameters. This allows for comparisons of trees that may have different growth patterns; for example, *S. nigra* exhibited substantial canopy growth while *P. occidentalis* exhibited increased height growth. Combining the three measurements allows for equal comparison of overall growth between the all species. Differences in the 1st principal component scores (which represented 65.7% of the variance among the three relative growth rates) among cells, species and stocktypes were determined using a three-way ANOVA.

In order to determine the most appropriate species and stocktypes to satisfy CMS success criteria, differences in the probabilities of survival beyond two growing seasons and overall growth among species and stocktypes were analyzed separately. A simple effects model was used to determine differences in survival probabilities among stocktypes of each species and vice versa (Winer 1991). Multiple comparisons were used to determine significant differences in survival probability after the analysis of simple effects and a Bonferroni multiple comparison correction was used.

Results

Survival

When determining differences in survival probability among cells, species and stocktypes the Cox model failed to converge. The non-convergence resulted from including all two way interactions which caused the model to be over parameterized. However, when the two way interactions were not included, the model successfully converged and a significant three way interaction was found between cells, species and stocktypes (Table 1). As a result we determined differences in survival probabilities of species and stocktypes within each cell independently. Significant two way interactions were found between species and stocktypes in the IC and FC while a marginally non-significant two-way interaction was found within the SC (Table 1). This interaction suggests that species do not have the same survival probabilities for all stocktypes and vice versa.

In order to ensure 495-990 stems ha^{-1} the probability of survival for a particular species/stocktype combination must be greater than 0.294 (based on 8ft centers yielding 1683 stems ha^{-1}). No species/stocktype combinations had less than this probability of survival within the IC and SC. However, in the FC, the *P. occidentalis* tubeling NO SOIL (0.284) and the *Q. phellos* tubeling NO SOIL (0.217) had less than this probability of survival.

Table 1. Cox proportional hazards model analysis of cell, species, and stocktype effect on probability of survival beyond two growing seasons and analysis of variance for the effect of cell, species and stocktype on overall growth.

		Survival		Growth	
		Wald Chi-Square	P-Value	F-Value	P-Value
Overall					
	Cell	6.30820	0.0427	319.27	<0.0001
	Species	34.9702	<0.0001	86.94	<0.0001
	Planting Type	78.1787	<0.0001	41.91	<0.0001
	Species X Planting Type	*	*	4.83	<0.0001
	Cell X Planting Type	*	*	15.76	<0.0001
	Cell X Species	*	*	27.01	<0.0001
	Cell X Species X Planting Type	162.3196	<0.0001	3.98	<0.0001
Ideal Cell					
	Species	26.2717	0.0002	44.08	<0.0001
	Planting Type	26.6238	<0.0001	15.94	<0.0001
	Species X Planting Type	36.3760	0.0001	5.37	<0.0001
Saturated Cell					
	Species	14.7670	0.0221	27.97	<0.0001
	Planting Type	13.0337	0.0046	22.19	<0.0001
	Species X Planting Type	17.5191	0.0934	3.95	<0.0001
Flooded Cell					
	Species	67.7044	<0.0001	38.37	<0.0001
	Planting Type	18.2764	0.0004	6.31	<0.0001
	Species X Planting Type	27.7084	0.0036	3.93	<0.0001

* Model with all two way interactions would not converge.

Ideal Cell

Within the IC cell there was a significant interaction between species and stocktype (p=0.0001) when determining differences in survival probability (Table 1). Therefore, a simple effects model was used to determine differences in survival probabilities among stocktypes for individual species and vice versa. There was a significant difference in survival probability among stocktypes for *B. nigra* (p=0.0141), *L. styraciflua* (p<0.001), *P. occidentalis* (p=0.0059), *Q. bicolor* (p=0.0017), *Q. palustris* (p=0.0007), *Q. phellos* (p=0.0020) and *S. nigra* (p<0.0001) (Figure 1). There was a significant difference in survival probability among species for bare root (p<0.0001), tubeling (p=0.0296) and tubeling NO SOIL (p=0.0050) stocktypes (Figure 1). There was not a significant difference in survival probability among species for the gallon stocktype (p=0.2018).

Saturated Cell

Within the SC there was marginally non-significant interaction between species and stocktype (p=0.0934) when determining differences in survival probability (Table 1). Despite the non-significant interaction a simple effects model was used to determine differences in survival probabilities among stocktypes for individual species and vice versa. There was a significant difference in survival probability among stocktypes for *B. nigra* (p=0.0060), *L. styraciflua* (p=0.0015), *P. occidentalis* (p=0.0415), *Q. palustris* (p=0.0051), *Q. phellos* (p=0.0253) and *S. nigra* (p=0.0018) (Figure 3). There was no significant difference in survival probability among stocktypes for *Q. bicolor* (p=0.0679) (Figure 2). There was a significant difference in survival probability among species for bare root (p<0.0001), and tubeling (p=0.0131) stocktypes (Figure 2). There was not a significant difference in survival probability among species for the gallon (p=0.9508) and tubeling NO SOIL (p=0.1836) stocktypes (Figure 2).

Flooded Cell

Within the FC there was a significant interaction between species and stocktypes (p=0.0036) when determining differences in survival probability (Table 1). A simple effects model was used to determine differences in survival probabilities among stocktypes for individual species and vice versa. There was a significant difference in survival probability among stocktypes for *B. nigra* (p=0.0001), *Q. bicolor* (p=0.0005), *Q. palustris* (p=0.0001) and *Q. phellos* (p<0.0001) (Figure 3). There was not a significant difference in survival probability among stocktypes for *L. styraciflua* (p=0.1418), *P. occidentalis* (p=0.0566) and *S. nigra* (p=0.5442) (Figure 3). There was a significant difference in survival probability among species for bare root (p<0.0001), gallon (p=0.0003), tubeling (p<0.0001) and tubeling NO SOIL (p<0.0001) (Figure 3).

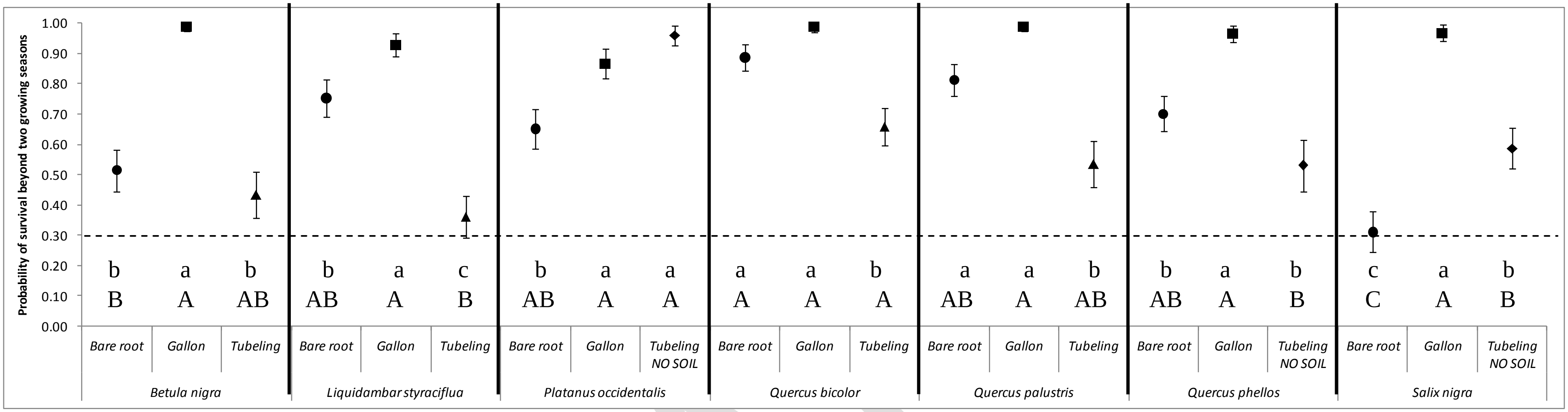


Figure 1. Probability of survival beyond two growing seasons within the IC. Error bars represent standard errors. Same lower case letters indicate no significant difference in probability of survival among stocktypes for individual species ($p>0.05$). Same uppercase letters indicate no significant difference in probability of survival among species for individual stocktypes ($p<0.05$). Dashed line represents 495 stems ha^{-1} success criterion (8ft centers).

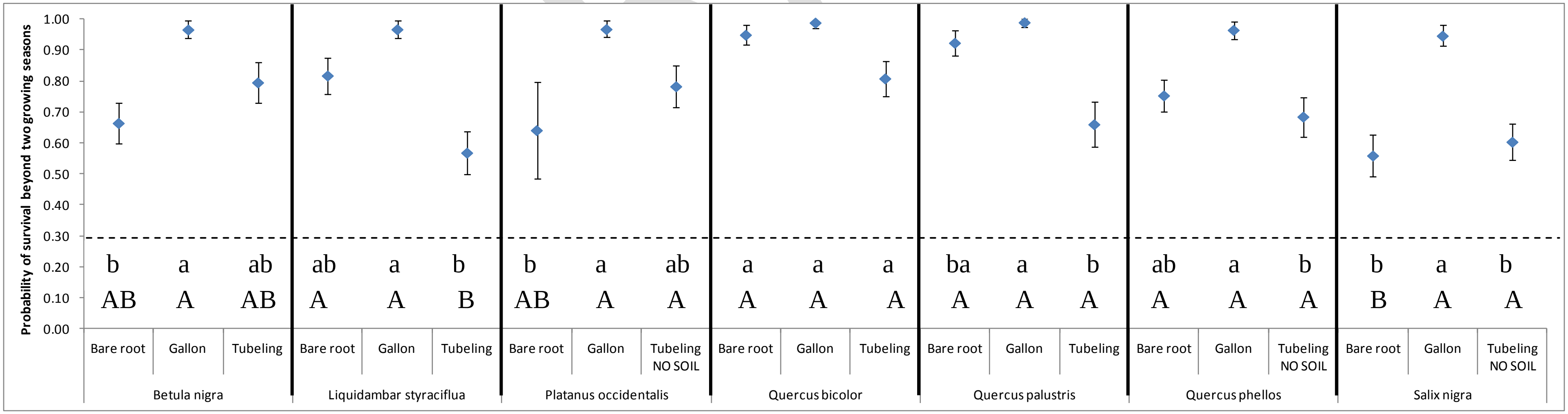


Figure 2. Probability of survival beyond two growing seasons within the SC. Error bars represent standard errors. Same letters indicate no significant difference in probability of survival among stocktypes for individual species (p>0.05). Same uppercase letters indicate no significant difference in probability of survival among species for individual stocktypes (p<0.05). Dashed line represents 495 stems ha^{-1} success criterion (8ft centers).

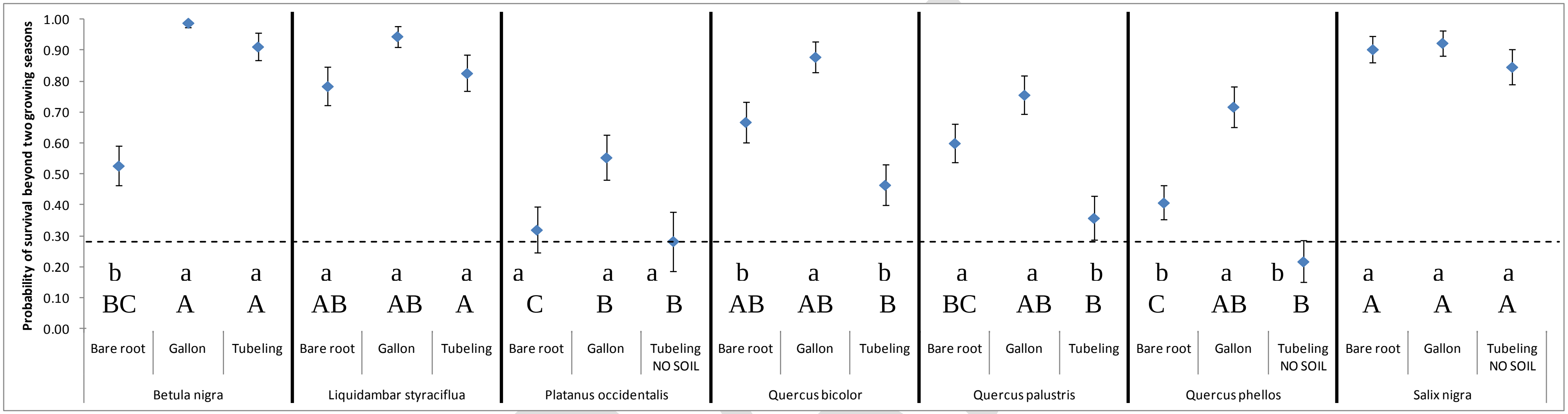


Figure 3. Probability of survival beyond two growing seasons within the FC. Error bars represent standard errors. Same letters indicate no significant difference in probability of survival among stocktypes for individual species (p>0.05). Same uppercase letters indicate no significant difference in probability of survival among species for individual stocktypes (p<0.05). Dashed line represents 495 stems ha^{-1} success criterion (8ft centers).

Overall Growth

As expected there were significant three way interactions among cell, species and stocktype, therefore, differences in overall growth among species and stocktypes were analyzed within each cell using two-way ANOVA (Table 1). Two way interactions were also significant between species and stocktype in all cells (Table 1).

Ideal Cell

Within the IC there was a significant difference in overall growth among the stocktypes for *Q. bicolor* (p<0.0001), *Q. palustris* (p<0.0001), *Q. phellos* (p<0.0001) *and S. nigra* (p<0.0001) and there was no difference in overall growth among the stocktypes for *B. nigra* (p=0.1266), *L. styraciflua* (p=0.3359), *and P. occidentalis* (p=0.1957) (Figure 4). *Q. bicolor* tubeling stocktype had significantly lower overall growth than the gallon (p=0.0018) stocktype. *Q. palustris* tubeling stocktype had significantly lower overall growth than the gallon (p=0.0071) stocktype. *Q. phellos* bare root stocktype had significantly lower overall growth than gallon (p=0.0039) stocktype. *S. nigra* bare root stocktype had significantly lower overall growth than gallon (p<0.0001) and tubeling NO SOIL (p<0.0001) stocktypes. Within the IC there was a significant difference in overall growth among the species for the bare root (p<0.0001), gallon (p<0.0001), tubeling (p<0.0001), and tubeling NO SOIL (p<0.0001) stocktypes (Figure 4). Bare root stocktype *B. nigra, L. styraciflua,* and *P. occidentalis* had significantly greater overall growth compared to *Q. bicolor* (p<0.0001, p<0.0001, p<0.0001), *Q. palustris* (p<0.0001, p=0.00163, p<0.0001), *Q. phellos* (p<0.0001, p<0.0001, p<0.0001), and *S. nigra* (p<0.0001, p<0.0001, p<0.0001). Gallon stocktype *B. nigra* had greater overall growth than *L. styraciflua* (p=0.0499), *Q. bicolor* (p<0.001), *Q. palustris* (p<0.001) *Q. phellos* (p=0.002) and *S. nigra* (p=0.0179). Tubeling stocktype *B. nigra* and *L. styraciflua* had greater overall growth than *Q. bicolor* (p<0.0001, p=0.007) and *Q. palustris* (p<0.0001, p=0.0027). Tubeling NO SOIL stocktype *P. occidentalis* had greater overall growth than *Q. phellos* (p<0.001).

Within the SC there was a significant difference in overall growth among the stocktype for *L. styraciflua* (p<0.0001), *Q. bicolor* (p<0.0001), *Q. palustris* (p=0.0015), *Q. phellos* (p=0.0004), *S. nigra* (p=0.0002) (Figure

5). *L. styraciflua* gallon stocktype had significantly greater overall growth than the tubeling (p<0.0001) stocktype. *Q. bicolor* tubeling stocktype had significantly lower overall growth than bare root (p=0.0009) and gallon (p<0.0001) stocktypes. *Q. palustris* gallon stocktype had significantly higher overall growth than the tubeling (p=0.0006) stocktype. *Q. phellos* gallon had significantly greater overall growth than the bare root (p=0.0274) stocktype. *S. nigra* gallon had significantly greater overall growth than the tubeling NO SOIL (p=0.0075) stocktype. Within the SC there was a significant difference in overall growth among the species for the bare root (p<0.0001), gallon (p<0.0001), tubeling (p<0.0001), and tubeling NO SOIL (p=0.003) stocktypes (Figure 5). Bare root *P. occidentalis* had significantly greater overall growth than bare root *L. styraciflua* (p=0.0165), *Q. bicolor* (p=0.0004), *Q. palustris* (p<0.0001), *Q. phellos* (p<0.0001) and *S. nigra* (p=0.0002). Gallon *B. nigra* had significantly greater overall growth than gallon *Q. bicolor* (p=0.0028), *Q. palustris* (p=0.0004), *Q. phellos* (p=0.0008) and *S. nigra* (p=0.0039). Tubeling *B. nigra* had significantly greater overall growth than *L. styraciflua* (p<0.001), *Q. bicolor* (p<0.0001) and *Q. palustris* (p<0.0001). Tubeling NO SOIL *P. occidentalis* had significantly greater overall growth than *Q. phellos* (p=0.046) and *S. nigra* (p<0.001).

Flooded Cell

Within the FC there was a significant difference in overall growth among the stocktypes for, *Q. bicolor* (p=0.0006), *Q. palustris* (p<0.0001) (Figure 6). *Q. bicolor* gallon stocktype had significantly greater overall growth than the tubeling stocktype (p=0.026). *Q. palustris* gallon stocktype had significantly greater overall growth than the bare root (p=0.0002) stocktype. Within the FC there was a significant difference in overall growth among the species for the bare root (p<0.0001), gallon (p<0.0001), tubeling (p<0.0001), and tubeling NO SOIL (p<0.0001) stocktypes (Figure 6). Bare root *S. nigra* had significantly greater overall growth than bare root, *L. styraciflua* (p<0.0001), *P. occidentalis* (p<0.0001), *Q. bicolor* (p<0.0001), *Q. palustris* (p<0.0001) and *Q. phellos* (p<0.0001). Gallon *S. nigra* had significantly greater overall growth than gallon *P. occidentalis* (p=0.0362) and *Q. bicolor* (p=0.0154). Tubeling *B. nigra* had significantly greater overall growth than tubeling *Q. bicolor* (p<0.0001) and *Q. palustris* (p=0.0002). Tubeling NO SOIL *S. nigra* had significantly greater growth than tubeling NO SOIL *Q. phellos* (p=0.0014).

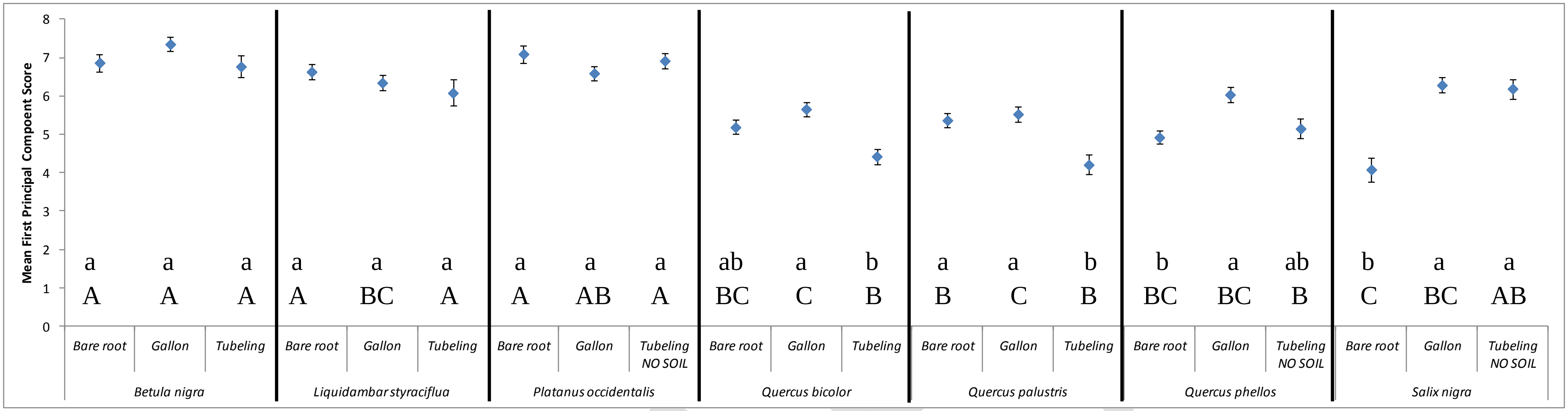


Figure 4. Overall growth in the IC. Error bars represent standard errors. Same letters indicate no significant difference in overall growth among stocktypes for individual species (p>0.05). Same letters indicate no significant difference in overall growth among species for individual stocktypes (p>0.05).

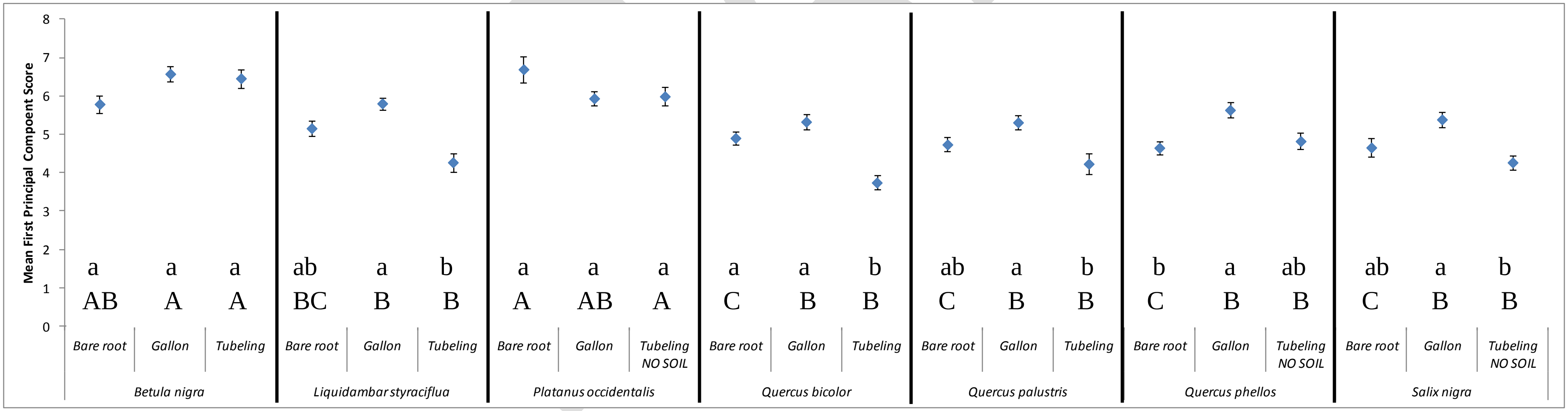


Figure 5. Overall growth in the SC. Error bars represent standard errors. Same letters indicate no significant difference in overall growth among stocktypes for individual species (p>0.05). Same letters indicate no significant difference in overall growth among species for individual stocktypes (p>0.05).

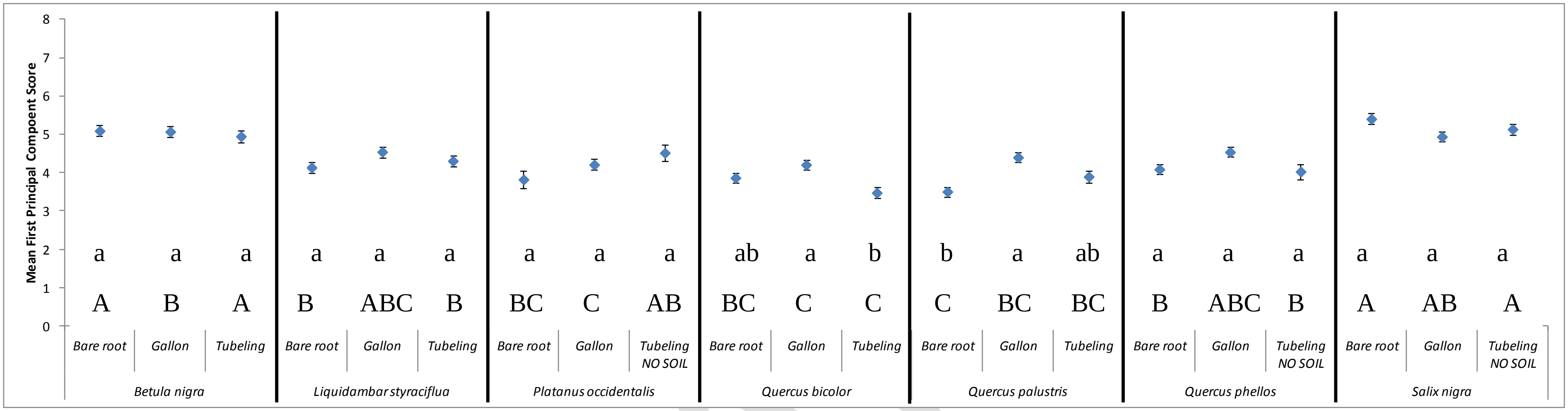


Figure 6. Overall growth in the FC. Error bars represent standard errors. Same letters indicate no significant difference in overall growth among stocktypes for individual species (p>0.05). Same letters indicate no significant difference in overall growth among species for individual stocktypes (p>0.05).

Ranking

Table 2. Species/stocktype combinations sorted based on overall rank from all three cells. Ranks based on probability of survival beyond 2 growing seasons and overall growth.

Species	**Planting Type**	**Ideal Rank**	**Saturated Rank**	**Flooded Rank**	**Overall Rank**
Betula nigra	Gallon	1	1	1	1
Liquidambar styraciflua	Gallon	4	3	3	2
Salix nigra	Gallon	3	7	3	3
Quercus bicolor	Gallon	5	4	5	4
Platanus occidentalis	Gallon	5	2	8	5
Quercus palustris	Gallon	5	4	6	5
Quercus phellos	Gallon	6	5	5	6
Betula nigra	Tubeling	8	6	3	7
Platanus occidentalis	Tubeling NO SOIL	2	7	9	8
Betula nigra	Bare root	7	11	4	9
Liquidambar styraciflua	Bare root	6	10	7	10
Quercus bicolor	Bare root	8	9	10	11
Platanus occidentalis	Bare root	5	8	15	12
Salix nigra	Tubeling NO SOIL	9	17	3	13
Liquidambar styraciflua	Tubeling	11	17	5	14
Quercus palustris	Bare root	9	12	12	14
Salix nigra	Bare root	15	16	2	14
Quercus phellos	Bare root	10	14	11	15
Quercus phellos	Tubeling NO SOIL	13	13	14	16
Quercus bicolor	Tubeling	12	15	14	17
Quercus palustris	Tubeling	14	16	13	18

Within each of the cells the gallon stocktype often ranked higher than the other stocktypes. Overall the highest ranking species/stocktype combinations were the primary successional species and gallon stocktypes.

Percent Change in Height

A current woody growth success criterion for wetland mitigation banks established in Virginia is the planted and colonizing trees exhibit an average of 10% increase in height per year. A 20% increase in height over 2 growing seasons corresponds to a RGR_H of 0.0101 [cm cm^{-1}] month^{-1}.

Table 3. Average RGR_H for each species and stocktype combination within each cell. Asterisk represents $RGR_H < 0.0078$ [cm cm^{-1}] month^{-1}.

Species	**Planting Type**	**Ideal Height RGR**	**Saturated Height RGR**	**Flooded Height RGR**
Betula nigra	Bare root	0.0600	0.0273	*0.0021
Betula nigra	Gallon	0.0936	0.0842	*0.0085
Betula nigra	Tubeling	0.0705	0.0289	0.0108
Liquidambar styraciflua	Bare root	0.0542	*-0.0087	*-0.0061
Liquidambar styraciflua	Gallon	0.0726	0.0636	0.0112
Liquidambar styraciflua	Tubeling	0.0129	*-0.0413	0.0166
Platanus occidentalis	Bare root	0.0833	0.0289	*-0.0178
Platanus occidentalis	Gallon	0.0850	0.0554	*-0.0325
Platanus occidentalis	Tubeling NO SOIL	0.0849	0.0301	0.0236
Quercus bicolor	Bare root	0.0101	0.0142	*-0.0046
Quercus bicolor	Gallon	0.0378	0.0131	*0.0079
Quercus bicolor	Tubeling	*-0.0312	*-0.0502	*-0.0102
Quercus palustris	Bare root	0.0287	*-0.0173	*-0.0157
Quercus palustris	Gallon	0.0533	0.0411	*0.0042
Quercus palustris	Tubeling	*-0.0264	*-0.0232	0.0155
Quercus phellos	Bare root	*0.0045	*0.0058	*0.0088
Quercus phellos	Gallon	0.0809	0.0700	*0.0009
Quercus phellos	Tubeling NO SOIL	0.0449	*-0.0009	*-0.0269
Salix nigra	Bare root	*-0.0181	*0.0031	0.0256
Salix nigra	Gallon	0.0636	0.0293	*0.0023
Salix nigra	Tubeling NO SOIL	0.0338	*-0.0156	0.0318

Of the 21 combinations of species and stocktypes planted in the IC, four combinations did not satisfy the required average increase in height and three exhibited dieback (Table 3). Within the SC nine combinations did not satisfy the required average increase in height and seven exhibited dieback. Within the FC 14 combinations did not satisfy the average increase in height and seven exhibited dieback.

Discussion

When analyzing the differences in probability of survival and overall growth there were significant three way interactions among cells, species and stocktypes. This suggests that the probability of surviving beyond two growing seasons and the overall growth after two growing seasons was not uniform among the three cells for the species/stocktype combinations. This interaction was anticipated because the distinct hydrologic conditions were anticipated to have unique affects on each species/stocktype combination. For example the *S. nigra* bare root had decreased survival probability in the IC and increased survival probability in the FC, while, *P. occidentalis* bare root exhibited increased survival in the IC and decreased survival in the FC. Significant two way interaction between species and stocktype within each cell suggests that survival and growth was not uniform for the stocktypes among each species and vice versa. For example, the gallon stocktype did not have the highest probability of survival for all species within the IC and the *Q. bicolor* did not have the highest probability of survival for all of the stocktypes. These interactions were important in directing the statistical analysis.

No species/stocktype combinations had less than the probability of survival necessary to meet the required stem density criterion in the IC and SC, suggesting that under these hydrologic conditions the choice of species and stocktype do not have a large influence on fulfilling the required stem density when planting with 8ft spacing (Table 1). However, in the FC, the *P. occidentalis* tubeling NO SOIL and the *Q. phellos* tubeling NO SOIL had less than this probability of survival, suggesting that these species/stocktype combinations may not be appropriate for planting into CMS where increased water stress may be present. In a similar field study, Niswanter and Mitsch (1995) found that inundation during the first year after planting decreased survival rates of planted trees.

While all the trees in the IC and SC satisfied the survival criterion, several species/stocktype combinations did not fulfill the percent increase in height requirement. In the IC four combinations had less than the required percent change in height, while in the SC and FC nine and 14 combinations respectively did not reach the criterion (Table 2). This suggests that these species/stocktypes, mainly secondary species with bare root and tubeling stocktype, may not be appropriate to plant in CMS under these hydrologic conditions if a particular increase in height is required for success.

Within each cell there were few significant differences in the survival probability among the species for each stocktype, however there were significant differences in growth among the species for several stocktypes. This suggests that selecting the appropriate species is more important when seeking to ensure adequate growth and less so when seeking to ensure adequate survival. This also suggests that stocktype may be a more important factor than species when choosing appropriate tree stock for planting into CMS.

In the IC, the bare root *S. nigra* had significantly lower probability of survival and overall growth than the other species with bare root stocktypes. However, in the FC the *S. nigra* showed generally higher probability of survival and growth than the other species. This suggests that *S. nigra* may be a more appropriate species for planting in CMS where increased water may be present since *S. nigra,* a facultative wetland species, has several adaptations that allow it to survive increased water stress including fast growth rates (Table 3; Day et al. 2006; Donovan et al. 1988) and adventitious rooting (Donovan et al. 1988; Pitcher and McKnight 1990). As a pioneer successional species, *S. nigra* also has higher acclimation potential (plasticity) and broader physiological responses than secondary (oak) species (Bazzaz, 1979).

In the IC, the gallon stocktype had higher survival probability than either the bare root and/or tubeling stocktypes for all seven species. The gallon also had significantly greater overall growth than the bare root and/or the tubeling stocktypes for *Q. bicolor*, *Q. palustris, Q. phellos* and *S. nigra*. In the SC and FC, again, the gallon stocktype had higher survival probability than either the bare root and/or tubeling stocktypes. Gallon stocktype for all species in the SC, except *Q. bicolor*, had significantly greater overall growth than the bare root and/or tubeling stocktypes for *L. styraciflua*, *Q. bicolor*, *Q.*

palustris, *Q. phellos*, and *S. nigra*. In the FC, the gallon stocktype had higher survival probability than either the bare root and/or tubeling stocktypes for *B. nigra*, *Q. bicolor*, *Q. palustris,* and *Q. phellos*; the gallon stocktype also had significantly greater overall growth than the bare root and/or tubeling stocktypes for *Q. bicolor* and *Q. palustris*. The gallon stocktype had similar probabilities of survival and growth among all seven species in all cells.

Our data suggests that the gallon stocktype may be more appropriate for planting into various hydrologic conditions present at CMS than other stocktypes. This may be due to the characteristics of the gallon stocktype which may increase the probability of overcoming transplant shock. Transplant shock (also called planting check) is a temporary setback in growth that occurs after outplanting, which if severe enough can result in tree mortality (Kozlowski and Davies 1975; Acquaah 2005; Grossnickle 2005; South and Zwolinski 1996). Transplant shock is associated with decreased water absorption as a result of poor root-soil contact, low permeability of suberized roots (older woody roots) and a low amount of roots in relation to shoots (Beineke and Perry 1965; Carlson and Miller 1990; South and Zwolinski 1996; Grossnickle 2005). In order to overcome transplant shock, saplings must absorb enough water to satisfy evapotranspiration and metabolic/physiologic processes. The initial height and root-collar diameter of the gallon stocktype in this study were significantly greater than the heights and root-collar diameter of the bare root and/or tubeling stocktypes for *B. nigra, P. occidentalis, Q. palustris, Q. phellos* and *S. nigra*. Tree height and root-collar diameter have been shown to be positively correlated with belowground biomass (Konopka 2011). This relationship suggests that the gallon stocktype had greater initial belowground biomass than the bare root and tubeling stocktypes. Increased belowground biomass has been shown to increase the amount of water absorbed by roots (Carlson 1986). This suggests that the gallon stocktype had enough root biomass to absorb a volume of water sufficient enough to satisfy evapotranspiration and other metabolic/physiological processes, overcome transplant shock and therefore have significantly greater probability of survival and overall growth than the bare root and/or tubeling stocktypes. In addition to increased belowground biomass, these larger trees may have increased stored nutrients available for surviving transplanting shock when new nutrients are not able to be obtained.

The gallon stocktype is also characterized by being planted with organic rich potting soil surrounding the root mass, which could enhance the probability for survival and overall growth because the roots would remain in contact with the potting soil and continue to take up water and nutrients. The roots surrounded by potting soil may have maintained their association with mycorrhizal fungi after outplanting (don't know if they had it to begin with). The effect of mycorrhizal-root relationship on water absorption has not been completely determined (Pallardy 2008), however, several studies have found that tree roots that have symbiotic mycorrhizal fungi present exhibit increased water uptake potential (CITATION). Burkett et al. (2005) found that container grown *Q. texana* seedlings inoculated with vegetative mycelia had greater survival than noninoculated seedlings. In addition, potting soil is often high in organic matter which is able to retain water longer than mineral soils (CITATION).

Several studies have shown that new root growth enhances seedling survival following outplanting (Ritchie and Dunlap 1980, Grossnickle 2005). Container grown seedlings can have greater root growth their first growing season after outplanting compared to bare root seedlings (Burdett et al. 1984). Container seedlings had lower resistance to water flow through the soil-plant-atmosphere continuum (SPAC) compared to bare-root seedlings (Dixon et al. 1984, Grossnickle and Blake 1987). South et al. (2005) found that containerized seedlings of longleaf pine had 20% better survival than bare root seedlings having similar root-collar diameters. All of these factors may have contributed to the gallon stocktype having increased probability of survival and growth and suggests that the gallon stocktype may be appropriate for planting into CMS with varying levels of hydrologic stress.

Within the IC the bare root stocktype had significant greater survival probabilities than the tubeling stocktype for *L. styraciflua*, *Q. bicolor* and *Q. palustris.* Within the SC there was no difference in survival between the bare root and tubeling stocktypes for all seven species. Within the FC only two species (*B. nigra* and *Q. palustris*) had significant differences in survival probability between the bare-root and tubeling stocktype. Only two species/stocktype combinations among all three cells had a significant difference in overall growth between the bare root and tubeling stocktype. There was no significant difference in initial height or root-collar diameter between the bare root and tubeling stocktype for all species and both stocktypes came from the same nursery. These results suggest that the choice between bare root and tubeling stocktypes may only be important when considering survival.

The overall ranking of all species/stocktype within each cell provides a method for investigating the combination of survival and growth. Using this method the overall top species/stocktype is *B. nigra* gallon and the lowest ranking is *Q. palustris* tubeling. The gallon stocktype of all species are near the top in all sites while the bare root is ranked second followed closely by the tubeling stocktype. In general, primary species ranked higher than the secondary species.

Conclusion

The most appropriate species and stocktype for use in CMS depends on the hydrologic conditions and site specific goals. The hydrologic conditions present at CMS range from dry to increasingly saturated therefore a variety of species and stocktype should be utilized (Campbell et al. 2002, Bruland and Richardson 2004, DeBerry and Perry 2004). The results from this study suggest that focusing on primary species and utilizing the gallon stocktype may be appropriate to ensure survival and growth in CMS. However, these results could be used for a variety of situations including afforestation, reforestation, carbon sequestration, wildlife habitat creation and other conservation projects.

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Appendix 6 – Draft Field Publication

A comparison of survival and growth of seven tree species from three stock types in created wetlands in Loudoun County, Virginia

Jacqueline D. Roquemore, Herman W. Hudson, III, Robert B. Atkinson, and James E. Perry

Forested wetlands are the wetland type most frequently lost in the eastern US (Dahl 1990, Tiner and Finn 1986; USGS 1999) and tree reestablishment is often the most difficult task in offsetting these losses (Matthews and Endress 2008, Sharitz et al. 2006). In wetland areas, woody species must tolerate high water tables and compete with herbaceous vegetation for resources. Created wetland construction practices include removal of upper soil surfaces to the depth of the season high water table, resulting in soil compaction, lower organic material, higher bulk density, and more rock fragments when compared to natural wetlands (Campbell et al. 2002). Created wetland conditions compound unfavorable conditions and decreased woody vegetation survival and growth (Bailey 2007, Bergshneider 2005, Daniels et al. 2005, Stolt et al. 2000). There are numerous species of woody plants and stock types available for planting in afforestation projects, some better suited for created wetlands than others, but there are few data-driven studies that have addressed how the choice woody plant species and stock type effects the survival and growth of woody species in created wetlands.

When planting trees, choosing species that match both site conditions and project goals is critical to success. Where natural colonization occurs, plant community composition is influenced by environmental factors (Casanova and Brock 2000) as adaptations determine the range of environmental conditions in which species survive (Keddy 1992, Beatty 1984). In afforestation projects, rather than choosing tree species that have a strong likelihood for establishment and growth, a mixture of species is often planted resulting in high mortality of those species that fail to match the site conditions (Stanturf et al. 2004). Because *Quercus* spp. (oaks) are a common component in palustrine forested wetlands (Wharton et al. 1982) which are frequently impacted and are both economically and ecologically valuable (Gardiner 2001, Kennedy and Nowacki 1997) they are frequently planted in replacement wetlands (Clewell 1999). However, *Quercus* spp. are slow growing and appear later in the forest succession processes, typically many years after the canopy closes (Whittaker 1978). Planting *Quercus* spp. in early stages of afforestation projects may not be the most effective approach. DeBerry and Perry (in press) concluded that early site conditions after forested wetlands construction favor establishment of woody species that colonize during drawdown but can rapidly adapt to prolonged saturation or inundation; therefore these authors recommended planting species such *Platanus occidentalis* and *Salix nigra*. Tweedt (2006) found that when *Quercus* spp. plantings were supplemented with fast-growing early-successional trees the species diversity, stem density, and maximum tree height were increased.

Stock type (such as bare root or containerized) can also influence tree establishment success. Bare root seedlings are often readily available and relatively inexpensive but lack mycorrhizal associations found in soil (Smith and Read 2008). Use of containerized seedlings allow for planting to occur during the middle of the growing season (Alm and Schantz-Hansen 1974) and are a better choice for planting on shallow or rocky soil (Dumrose and Owston 2003). Studies suggest that containers can restrict seedling root growth (Alm and Schantz-Hansen 1974), can impact survival of trees once planted (South 2005), and tend to have higher cost than other stock types.

To quantify success in forested areas, stem density is often measured. Functional parameters such as seed production, biomass accumulation, photosynthetic rate, and growth rate are valuable but are often difficult or time consuming to obtain. However, other functional parameters have been used or could be adapted to characterize community dynamics including tree survival rate (McCurry et al. 2010, Sharitz et al. 2006, Beckage and Clark 2003). Tree height is valuable when projects have concerns about shade stress from competing vegetation (Battaglia et al. 2000). Basal diameter, or root collar, is measured when considering timber production (McCurry et al. 2010, Chaar et al. 2008) or carbon sequestration (find reference). Canopy diameter is considered with concerns about availability of forage material for wildlife (Daubenmire 1959) and the microrelief effects of canopy on soil properties and vegetative patterns (Stolt et al. 2000, Beatty 1984).

During the first years after planting tree seedlings are most sensitive to environmental factors and most subject to mortality (McLeod and McPherson 1973, Alm and Schantz-Hansen 1974). Early indicators of successful tree establishment are needed so that adaptive management efforts can proceed. In this study, survival and growth from the second growing season of seven commonly-planted bottomland tree species and three stock types in three created wetlands were compared to determine optimum selections of planting materials.

Site Description

This study was conducted at three created wetlands in the Piedmont region of Virginia. The sites (designated as Phase I, II, and III) are part of the Loudoun County Wetland and Stream Mitigation Bank (LCWSB) that were designed and installed by Wetland Studies and Solutions, Inc—{reference differently}. Each site has a clay base soil (the most common planting medium), and relatively uniform topography. The overall hydrology is driven principally by rainfall and the saturated zone is at the soil surface for the majority of growing season. {insert size of sites}

Methods

Seven woody tree species common to the forested wetlands of the Piedmont were selected for this study (Table 1). For each species, 3 stock types were obtained including (1) Bare-root (BR) seedlings that were up to one year of age with no root ball or soil, (2) Tubelings (TB) up to two years of age with a more developed root system and a small amount of soil, and (3) trees in 1-gallon containers (GAL) which had a well-developed root balls and were planted with the soil that was present in the container. Planting material sources included five nurseries, three in Virginia, one in North Carolina, and one in South Carolina. No fertilizers were applied after purchase.

A total of 1596 trees in 25 plots across the three sites were planted in March 2009. Each sapling was flagged and mapped using an x- and y- coordinate grid system to aid with location in the future. Trees were planted on 2.4-meter (8-foot) centers. The 7 species and 3 stock types (Table 1) were planted in 21-tree replicate arrays and, depending on space available, either 3 or 4 planting arrays were established in each plot.

Table 1. Trees species planted in created wetlands in Loudoun County, Virginia. Indicator status from NRCS Plant Database (2011).

Species	**Common Name**	**Family**	**Successional Status**	**Wetland Indicator Status in Region 1**
Betula nigra L.	river birch	Betulaceae	primary	FACW
Liquidambar styraciflua L.	sweetgum	Hamamelidaceae	primary	FAC
Platanus occidentalis L.	American sycamore	Platanaceae	primary	FACW-
Quercus bicolor Willd.	swamp white oak	Fagaceae	secondary	FACW+
Quercus palustris Münchh.	pin oak	Fagaceae	secondary	FACW
Quercus phellos L.	willow oak	Fagaceae	secondary	FAC+
Salix nigra Marsh.	black willow	Salicaceae	primary	FACW+

Survival counts and morphometric measurements were collected in August 2009 and August 2010. Individuals were considered live based on the presence of green leaves or a green vascular cambium. Occurrence of stem sprouting and root suckering was recorded. Growth morphology (height of highest stem (H), basal stem diameter at soil level (BD), canopy diameter (CD) were measured on live trees following methods modified from Bailey et al. (2007). Height was measured using a meter stick. Basal diameter was measured using micro-calipers (Haglof, Inc. "Mantax Precision" Calipers).. If there was more than one stem for a tree, basal diameter of all stems were measured and the sum was recorded as the BD. Canopy diameter was measured in three angles (including the visual maximum diameter and visual minimum diameter) to determine the average canopy diameter (SPI 6"/0.1mm Poly Dial Calipers.

Relative growth rate (RGR) was calculated from the equation by Hoffman (2002):

$$r = \frac{\ln(W_2) - \ln(W_1)}{t_2 - t_1}$$

where r = Relative Growth Rate (RGR), W_1 = morphometric measurement of tree at time 1, W_2 = morphometric measurement of tree at time 2, t_1 = time of first measurement and t_2 = time of second measurement.

Relative growth rates were calculated for basal diameter (BD_{RGR}), height (H_{RGR}) and canopy diameter (CD_{RGR}) over two growing seasons. If the tree died before the end of the second growing season the RGR for two years was calculated using the last available measurement.

Results

Q. phellos tubelings had the lowest overall survival (18.8% ± 3.3 SE) while *Q. bicolor* gallon had the highest survival (96.1% +2.1 SE). Gallon stock types of all species have a higher survival than both bare root and tubeling stock types, except for *P. occidentalis* for which the tubeling stock type had higher survival (60.4%) (Figure 1). When stock types were combined, *P. occidentalis* and *Q. phellos* had the lowest percent survival (47% and 46%, respectively). When species were combined, bare root seedlings had the lowest percent survival (49%). Trees with initial height greater than 101cm had greater survival at the conclusion of the second growing season when compared to trees with lower initial height (Figure 2). Trees with initial basal diameter between 1.1 and 1.5cm had highest percent survival at the conclusion of the second growing season (Figure 3).

Of the trees surviving after the first growing season, *B. nigra* gallon were the tallest and had the largest CD (161 cm ± 10.8 SE, 62 cm ± 4.1 SE, respectively), and *S. nigra* gallon had the largest BD (2.50 cm ± 0.12 SE).

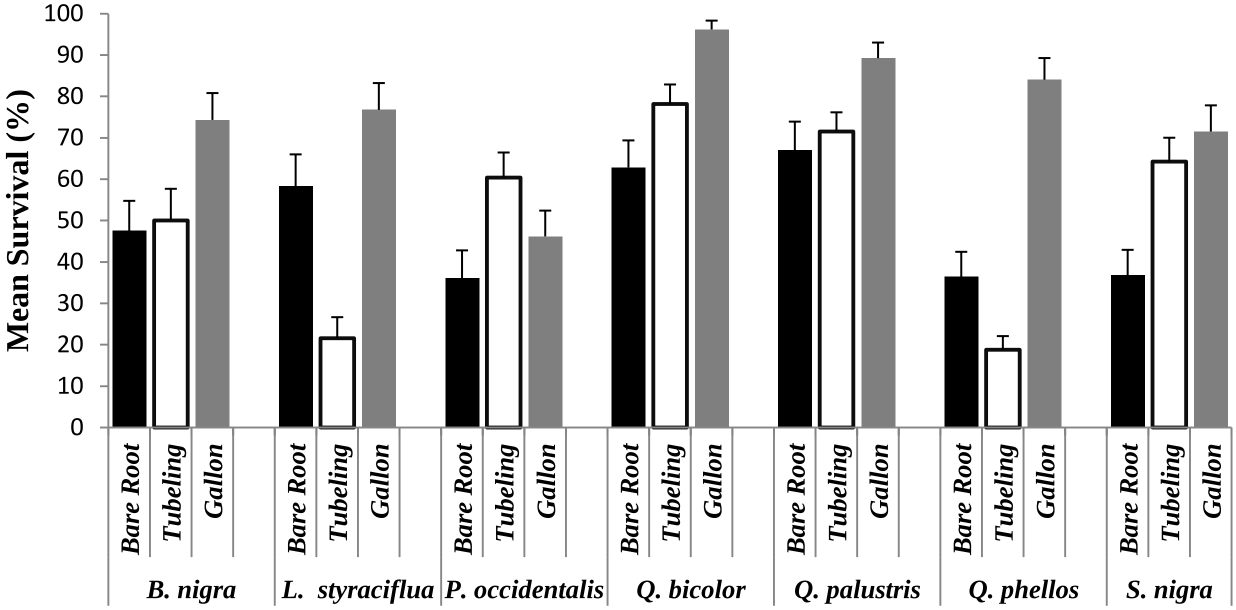

Figure 1. Survival of tree species and stock types at the conclusion of the second growing season. Survival was analyzed at the array level and error bars represent standard error within plots.

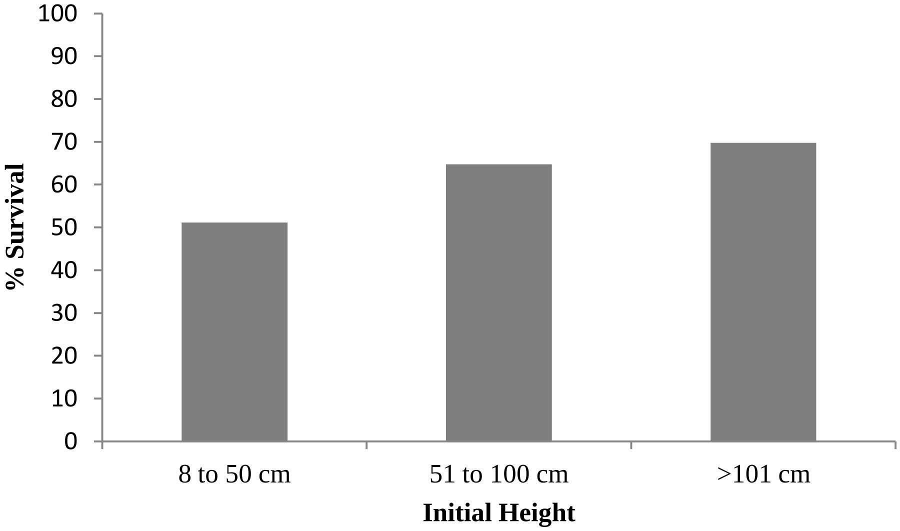

Figure 2. Initial height and percent survival at the conclusion of the second growing season.

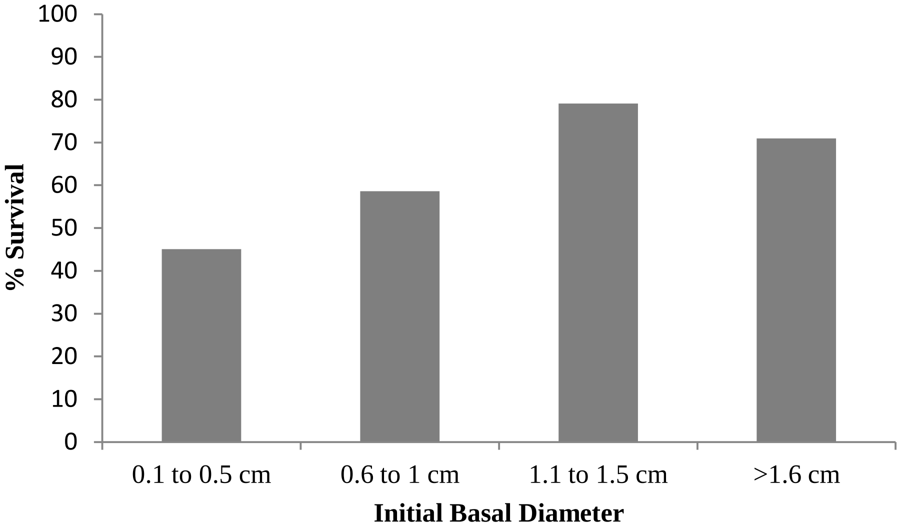

Figure 3. Initial basal diameter and survival at the conclusion of the second growing season.

Table 2. Mixed procedure analysis of variance results for H_{RGR}, BD_{RGR}, and CD_{RGR} at the conclusion of the second growing season.

	Source of Variation	Num DF	Den DF	F Value	Pr > F
Height					
	Site	2	925	4.99	0.0070
	Species	6	925	23.98	<0.0001
	Stock type	2	925	8.68	0.0002
	Species*Stock type	12	925	13.63	<0.0001
Basal Diameter					
	Site	2	923	6.29	0.0019
	Species	6	923	26.33	<0.0001
	Stock type	2	923	2.68	0.0693
	Species*Stock type	12	923	3.69	<0.0001
Canopy Diameter					
	Site	2	914	22.67	<0.0001
	Species	6	914	5.72	<0.0001
	Stock type	2	914	15.93	<0.0001
	Species*Stock type	12	914	6.08	<0.0001

Species had a significant effect on RGR for H, BD, and CD ($p<0.0001$ for each), stock type had a significant effect on RGR for H and CD ($p=0.002$, $p<0.001$ respectively), and there was a significant species*stock type interaction for HRGR, BDRGR, and CDRGR ($p<0.001$ for each) (Table 2). Created wetland site did not have a significant interaction with species or planting site ($p=0.053$, $p=0.354$, p=0.59 for H, CD, and BD respectively). For each parameter (H, CD, BD) an analysis of variance (ANOVA) blocked by sites was performed and differences were found between stock types within species (Figure 4, Figure 6, Figure 8) and between species within stock types (Figure 5, Figure 7, Figure 9). When RGRs of primary species were compared to RGRs of secondary species, using a Mann-Whitney Rank Sum test, the primary species exhibited higher RGR for BD (p<0.001) and CD (p=0.029). A Mann-Whitney Rank Sum test found that RGR of species with a wetland indicator status of FAC (including FAC, and FAC+) had lower growth rates for H (p<0.001), BD (p<0.001), and CD (p=0.004) than those species with a wetland indicator status of FACW (including FACW-, FACW, and FACW+).

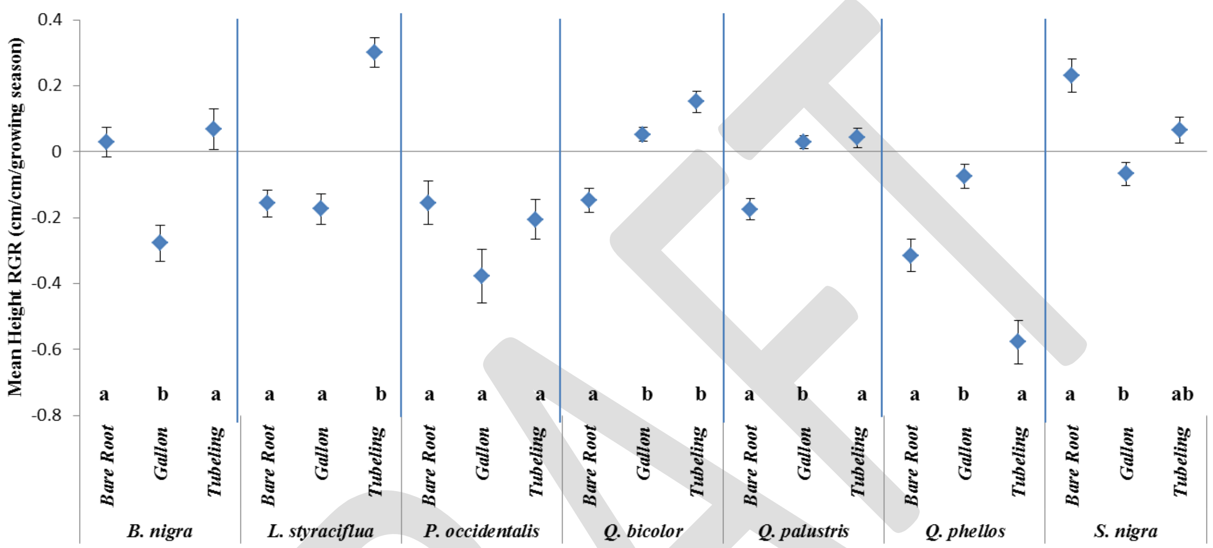

Figure 4. H_{RGR} sliced by stock types within species. Error bars represent standard error. Means with the same letter did not differ in growth rate among stock types for individual species (Bonferroni multiple comparison correction, p>0.05).

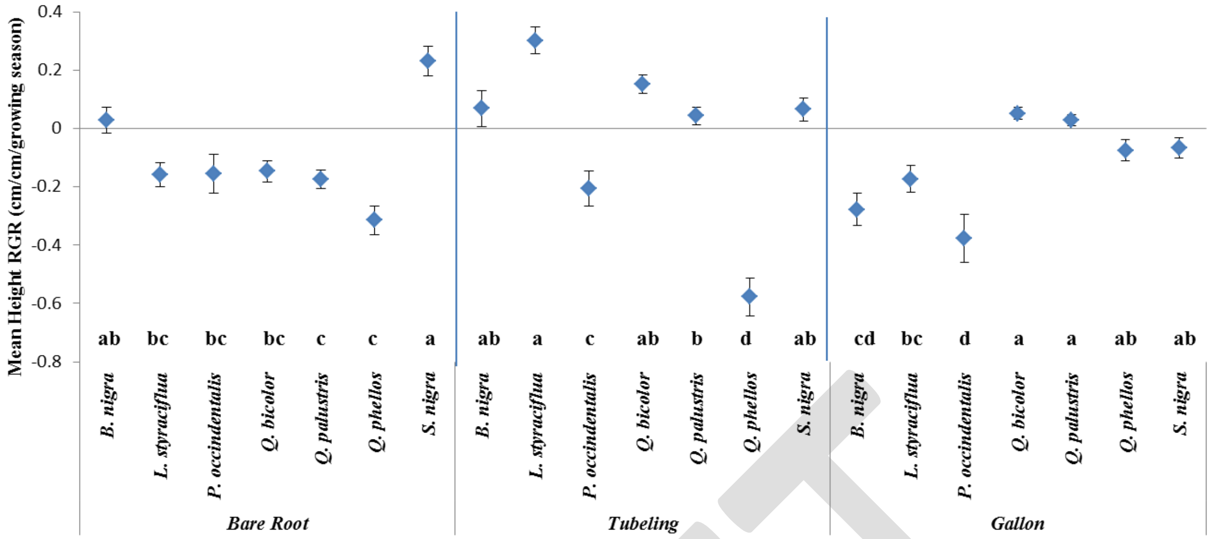

Figure 5. H_{RGR} sliced by species within stock types. Error bars represent standard error. Means with the same letter did not differ in growth rate among individual species for stock types (Bonferroni multiple comparison correction, p>0.05).

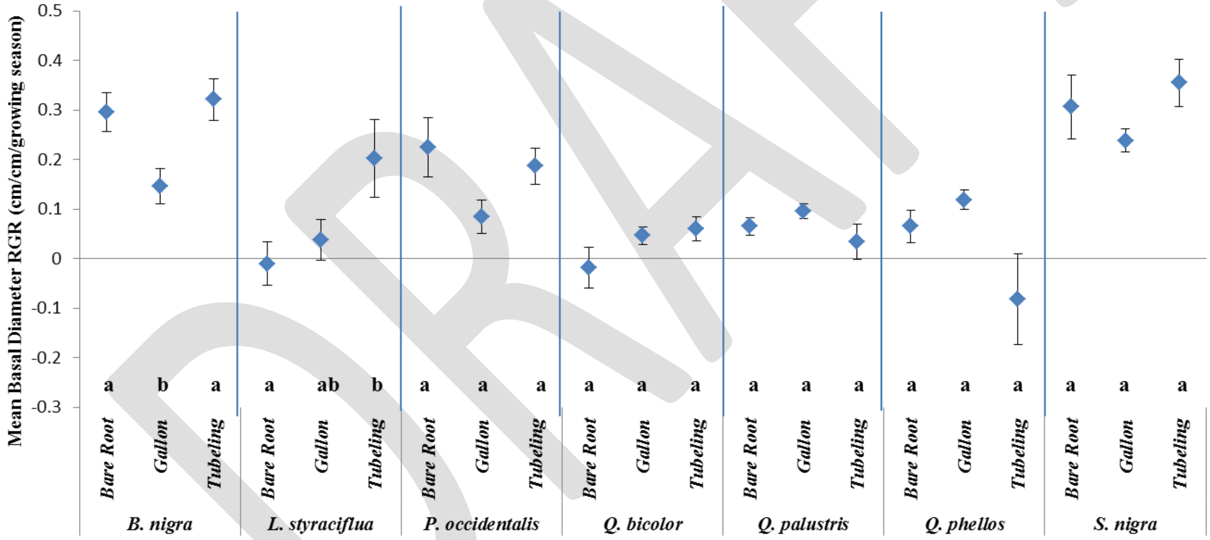

Figure 6. BD_{RGR} sliced by stock types within species. Error bars represent standard error. Means with the same letter did not differ in growth rate among stock types for individual species (Bonferroni multiple comparison correction, p>0.05).

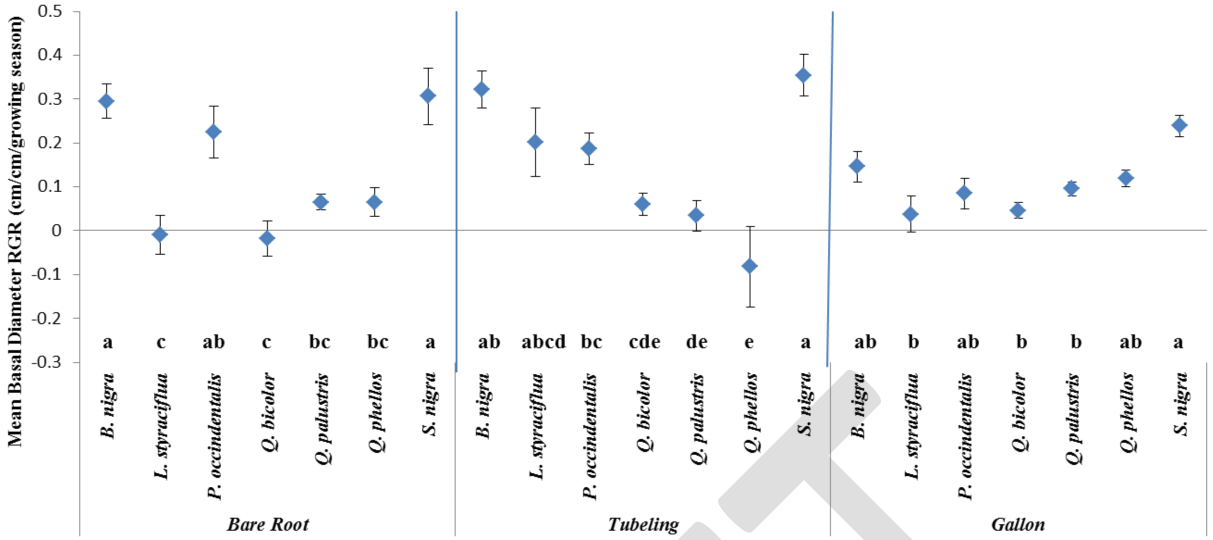

Figure 7. BD_{RGR} sliced by species within stock types. Error bars represent standard error. Means with the same letter did not differ in overall growth among individual species for stock types (Bonferroni multiple comparison correction, p>0.05).

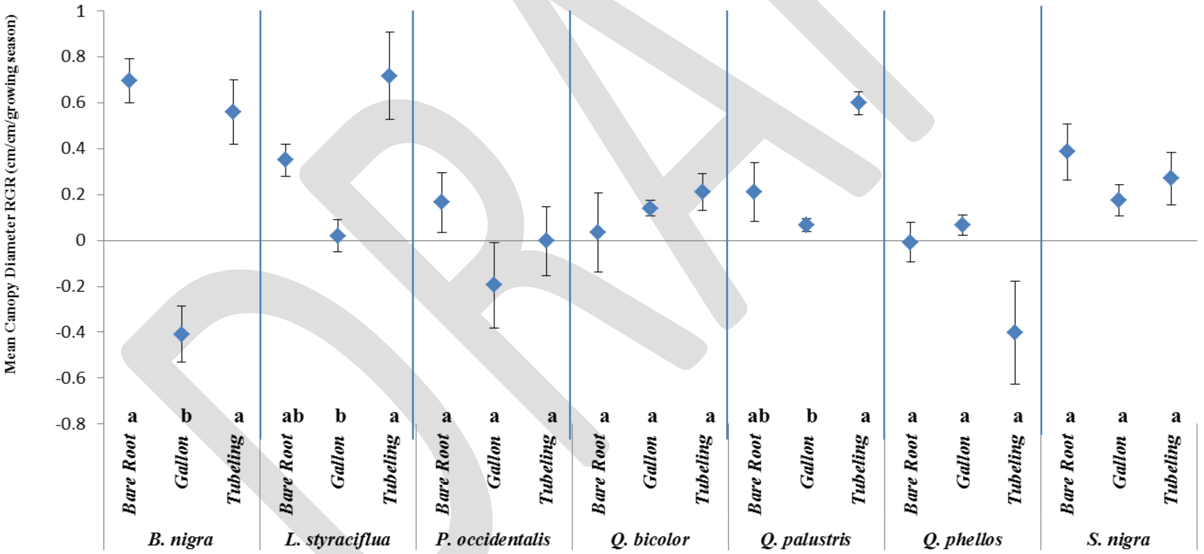

Figure 8. CD_{RGR} sliced by stock types within species. Error bars represent standard errors. Means with the same letter did not differ in growth rate among stock types for individual species (Bonferroni multiple comparison correction, p>0.05).

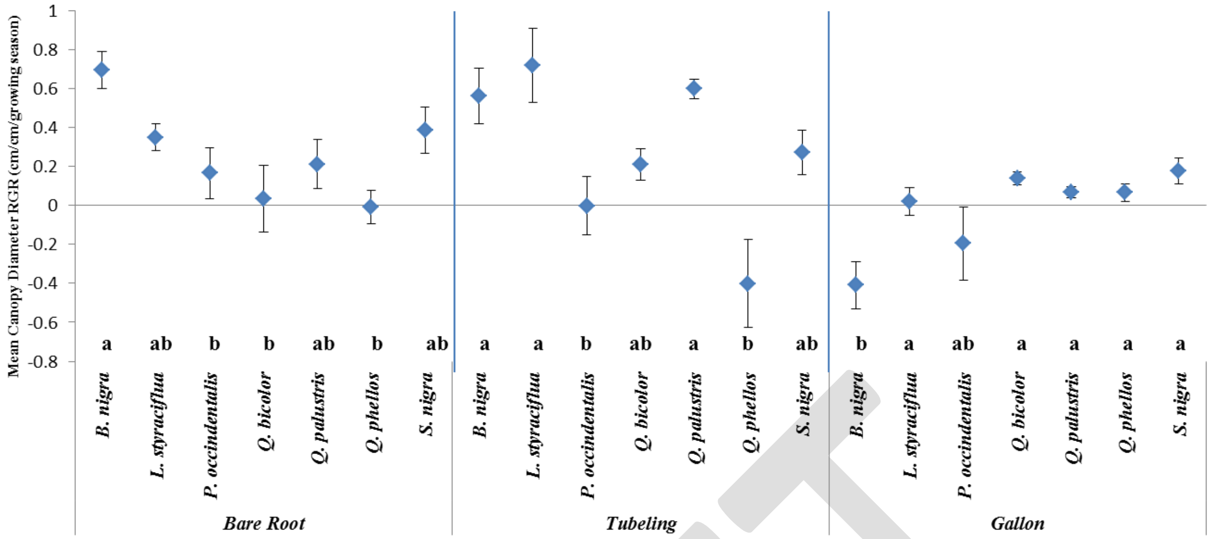

Figure 9. CD_{RGR} sliced by species within stock types. Error bars represent standard error. Means with the same letter did not differ in growth rate among individual species for stock types (Bonferroni multiple comparison correction, p>0.05).

During the second growing season, frequency of resprouting was surveyed and found to occur in all species (Table 3) and stock types (Table 4) and new stems emerged from both existing stems (stem sprouting, 35.3% of surviving trees) and roots (root suckering, 13.3% of surviving trees).

Table 3. Occurrence of sprouting in tree species during the second growing season.

Species	**% Stem Sprouting**	**% Root Suckering**
Betula nigra	23.5	7.6
Liquidambar styraciflua	47.5	26.7
Platanus occidentalis	40.7	18.5
Quercus bicolor	28.9	6.1
Quercus palustris	35.6	4.6
Quercus phellos	37.7	7.5
Salix nigra	38.3	28.6

Table 4. Occurrence of sprouting in stock types during the second growing season.

Stock type	**% Stem Sprouting**	**% Root Suckering**
Bare Root	49.1	10.9
Tubeling	36.3	12.2
Gallon	25.8	15.6

Discussion

Survival

Of the trees planted in this study, 59.0% survived until the end of the second growing season. This is slightly higher survival than reported by Morgan and Roberts (1999) in an assessment of 50 wetland compensation sites (including creation, restoration, enhancement, and preservation) in Tennessee which reported a combined (bare root and containerized seedlings) average of 47% survival. Our tree survival rate was slightly lower than that for a review of 67 compensatory mitigation projects in Illinois in which 54% survival of planted trees after one year and 45% survival of planted trees after four years was reported by Matthews and Endress (2008). In a study of six planted tree species in three floodplain restoration areas in Illinois, Plocher (2002) found year-3 survivorship ranged from 32 to 61%. Jones and Sharitz (1998) studied colonizing woody plant seedlings in years 1 through 3 after establishment in the understory of floodplain forests in South Carolina and found per capita survival was initially poor but increased with seedling age. The susceptibility of seedlings to early-establishment mortality was also observed by Alm and Schantz (1974) in a six-growing season study of optimum planting times for jack pine and red pine and reported 37.7% overall survival rate and 80% of the mortality occurred by the beginning of the third growing season.

Of the seven species planted in the current study, the two with the highest survival were secondary successional species (*Q. bicolor and Q. palustris*) (Figure 1). Secondary species are characterized by higher shade tolerance and slower production (Horn 1974), which may be advantageous given conditions found at our sites. Trees in gallon containers had a higher median initial height (116cm ± 2.44 SE) when compared to tubelings and bare roots (45cm ± 0.94 SE and 44cm ± 0.58 SE respectively) which may have contributed to the increased survival (Figure 2). Increased initial height found in trees grown in gallon containers could also be beneficial for survival of periodic flooding. In a study of light and water availability for seedlings in bottomland hardwood forests, Battaglia et al. (2000) found that survival of *L. styraciflua* and *Q. michauxii* was disproportionately lower in the smaller seedlings, regardless of experimental conditions, likely due to greater ability of taller trees to tolerate inundation.

In our study, gallon stock types showed the highest percent survival. This could be related to the median initial basal diameter of the gallon trees (1.4cm) which was larger than that for bare root (0.50cm) and tubelings (0.60cm). In an study of the effect of seedling container type on survival of *P. palustris* (long-leaf pine) South et al. (2005) found that container-grown seedlings had higher survival than bare root seedlings (75.9% and 53.5% respectively) that was thought to be related to increased root collar diameter (analogous to our BD) and associated root growth potential of the container-grown seedlings. The use of containers also allows for a taller initial planted tree height which may confer better survival (Jones and Sharitz 1998) particularly during flooding (Stanturf et al. 2004, Williams et al. 1999). The transfer of soil from the container along with the root ball could also improve survival by minimizing the impact of compacted soil in the created wetlands and transferring existing mycorrhizal associations from the containerized soil.

Growth

As expected in this study, H_{RGR}, BD_{RGR}, and CD_{RGR} were highly variable between species (Table 2). Secondary species are known to have lower productivity (Horn 1974) and primary species had higher growth rates than secondary species in this study. Similarly Farmer (1980) compared first-year growth of six deciduous species grown in nursery conditions and found significant difference between primary species (*L. tulipifera* and *P. serotina*) and secondary species (*Q. rubra, Q. prinus, Q. alba,* and *Q. ilicifolia*) with regard to dry weight and leaf growth rate. In addition, growth rates vary in response to continually changing abiotic and biotic environmental factors (Pooter and Garnier 2007) which were not reported here.

Stem-dieback occurred in 5 of the 7 species (71%) (Table 2). Planting check (transplant shock) in combination with high water tables and compacted soil is the likely cause for slow growth and dieback as reported by Watson (2006) who attributed the result to damage to (or lack of) lateral roots, which results in insufficient transport of water to peripheral leaves and stems. Stem dieback was observed for both bare root and container seedlings during the first year after planting. In a study of the effect of seedling stock-type and direct seeding on *Q. texana*, Williams et al. (1999) found extensive stem die back in both bare root and container seedlings under flooded conditions making first-year survival unable to be measured. Propensity for stem sprouting and root suckering vary according to tree species. In a study of 123 plant species from eroded lands in North-east Spain, Guerrero-Campo et al. (2006) found that species with course, deep tap roots had more root-borne shoots when compared to species with fine, long main roots. However, vegetative resprouting increases in response to plant stress (Watson 2006). Of the trees alive at the end of the second growing season, 13.3% had stem resprouting and 35.3% had root suckering. In a study of forest recovery of varying species composition and age ranges after fire and logging in Venezuela and Paraguay, Kammescheidt (1999) found stem sprouting to occur in 19.6% of trees in logged stands and 7.1% in burned stands while root suckering occured in 17.9% of trees in the logged stands and 28.6% of burned stands. In our study, the frequent occurrence of stem sprouting and root suckering (Table 4, Table 5) across all species in this study are likely in response to stressful environmental conditions.

When stock types were compared, tubeling trees had higher growth rates than bare root or gallon. Growth rates vary with tree age in a sigmoidal pattern with early slow growth followed by a period of rapid growth that levels off at tree maturity (Zeide 1993). The three stock types differ in tree age (with bare root youngest and gallon oldest) and would be at a later stage of the sigmoidal growth curve.

Tree species with a lower frequency of occurrence in wetlands, i.e. with a wetland indicator status of FAC, had lower H_{RGR}, BD_{RGR}, and CD_{RGR} than species with a FACW indicator status. According to Stanturf et al. (2004), matching planted tree species to site conditions, especially site hydrology is a key factor for success in afforestation of bottomland hardwood forests. The increased RGRs for FACW species suggest that plants with adaptations to wetland hydrology are more suitable to the created wetlands in our study.

Both high mortality and slow growth are likely a result of physiological stress due to wetland hydrology and soil compaction found in created wetland conditions. Inundation stresses trees as an anaerobic soil environment is formed in which tree roots cannot obtain oxygen. Lack of aerobic respiration in roots decreases the energy available for the tree to maintain functions of existing tissues (Hale and Orcutt 1987). Soil compaction reduces water and mineral absorption in woody plants and which threatens survival and decreases growth (Kozlowski 1999). Physiological and morphological differences between tree species result in variation in response to these environmental stressors.

Conclusion

Of the species and stock types compared, *Q. bicolor* in gallon containers had the highest survivorship and would be a good choice for projects in which stem count and tree height in early-establishment years are immediate goals. *S. nigra* and *B. nigra* were good performers overall, with moderate survival and growth across stock types. Although gallon trees, in general, had the best survival rates tubelings had the highest RGR for all parameters measured.

We found that species and stock type RGRs varied among sites for all parameters (with the exception of BD_{RGR} for stock type) (Table 2). This suggests that environmental factors should be evaluated prior to selection of species and stock types. Where conditions cannot be reliably predicted, a greater number of species and a higher planting density should be considered. While tree colonization rates may be slow in some created wetlands (Atkinson et al. 2005), rates may be high for some species depending on distance from seed sources (Hudson 2010) and planting strategies should be adjusted accordingly.

Selection of species and stock type may also be influenced by project budget, time constraints, regulatory conditions and ecological goals. Trees in gallon containers can be an order of magnitude more expensive than bare root seedlings. In certain situations, lower survival may be offset by higher planting densities. In projects where ecological function (such as wildlife utilization by a target species) is desired in a shorter time frame, the added expense of gallon tress may be more than justified.

Acknowledgements

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Appendix 7 – List of presentations, posters and student reports

Below is a list of conference and class presentations and posters that have been presented based on results from this project.

Conference and Meeting Presentations and Posters By VIMS Students and Faculty

Invited Presentations

Perry, J. E. 2010. Primary Ecological Succession in Tidal and Non-tidal Wetlands. Univ. Virginia Dept. Environmental Science Seminar Series. Charlottesville, Virginia, USA.

Abstract: With losses of wetlands in the United States continuing to be problematic, efforts to minimize the net loss of ecological and societal functions remain focused on the creation or restoration of similar habitats. In order to provide a manageable protocol for monitoring the success of created or restored wetlands, emphasis is now being directed towards establishing "reference" sites that are representative of regional and local conditions. Unfortunately, little effort has been made to better understand the role of primary- and secondary-succession in the time period over which created or restored wetlands would resemble natural, mature systems. This project, in part, examined the early primary-succession properties of a chronosequence of three tidal oligohaline salt marshes and primary- and secondary-succession of 17 forested wetlands. Vegetation in primary-succession tidal wetlands, as well as net carbon exchange, equaled natural systems within the first few years of establishment, while carbon sequestering may take longer than existing models indicate. In the secondary-succession forested wetlands, ordinations indicated three general types of communities in the mid-Atlantic states: one dominated by bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*), one dominated by black willow (*Salix nigra*), and one with a species composition similar to that of a mature stand of bottomland hardwoods. Data on primary succession in the forested wetland showed a large variation in vegetation community dynamics, but no similarity to secondary-succession or mature forested wetlands. The latter finding throws into question the wisdom of using existing mature non-tidal wetlands as reference sites.

Perry, J. E. 2010. Quantifying the replacement of lost wetland functions in Created and Restored Wetlands: the role of science in policy and regulatory decisions. Society of Ecological Restoration Mid-Atlantic Section Annual Meeting. Invited Keynote Speaker. College Park, Maryland, USA.

Abstract: Wetlands are known to serve numerous important ecological functions, including their ability to store carbon, provide habitat through species diversity, and provide nutrient cycling. Wetland protection, which started with the Clean Water Act of 1972 (through both regulatory and court interpretation), now requires that the destruction of wetlands for the purpose of profit must be avoided or the functions that the wetlands served the ecosystem must be replaced by mitigation; that is the lost ecological functions must be replaced by creating a new wetland or restoring a non-functional wetland that would then be expected to provide the lost functions. Therefore, since the late 1980's "No net loss" has become the mantra of federal and state wetland regulators. Currently, regulatory emphasis has been placed on replacing wetlands (mitigation) instead of avoiding them. This has lead to the construction (and to a minor degree, restoration) of many acres of tidal and non-tidal wetlands throughout the US over the past several decades. Unfortunately, it is only within the last decade that we have been able to take a close look at whether these created and restored wetlands actually do replace lost ecological functions. Initial data indicates that some simple functions, such as species richness and vegetation biomass, may be obtainable. However, data on more complex functions, such as nutrient processes and vegetation composition, are less promising. As scientists, we need to start providing more quantitative data to determine which ecological functions are being successfully replaced by creation and/or restoration and to identify those that are not. We also need to find a way to better present the results of our work to the policy makers and regulators who are tasked to write and enforce our wetland protection/mitigation laws in an understandable format. Without doing so, we may find that we are leveraging the long term ecological services of our wetlands for short term economic gain.

Conference and Meeting Presentations

Hudson III, H. W., S. P. Charles, J. E. Perry and R. B. Atkinson. 2011. Modeling growth rates of woody wetland plants common to the Piedmont region of the Mid-Atlantic States. Society of Ecological Restoration Mid-Atlantic 6th Annual Conference. College Park, Maryland.

Abstract: Success criteria in Virginia for forested wetland compensation requires a tree density of >495 stems/ha. The purpose of this study was to investigate which woody species and planting types survive and grow best in compensatory wetlands. A long-term large-scale mesocosm study consisting of three hydrologically controlled cells (Ideal (IC), Saturated (SC), and Flooded (FC)) was established in New Kent County, Virginia and three compensatory wetland (CW) sites in Loudoun County, Virginia were selected for comparison against mesocosm. All were planted in Spring of 2009 with seven wetland tree species (*Betula nigra, Liquidambar styraciflua, Platanus occidentalis, Quercus bicolor, Q. palustris, Q. phellos,* and *Salix nigra*) of three planting types (bare-root, tubeling, 1-gallon) totaling 2,772 trees in the mesocosm and 1,596 in the CW. After two growing seasons, survival and growth rates in the mesocosm were generally greater than those in the CW. *Salix nigra* had greatest survival in FC (83.5%) and *Q. bicolor* greatest in IC (70.5%), SC (85.9%) and CW (78.9%). In the mesocosm, survival of the 1-gallon planting type (92.2%) was greater than that of tubeling (59.4%) and bare-root planting type (65.4%). Similarly, survival of the 1-gallon (76.9%) was greater than tubeling (51.5%) and bare-root planting type (48.7%) in the CW. *Betula nigra* (1-gallon) had the greatest increase in height (7.7 cm/month), basal diameter (0.28 cm/month) and canopy diameter (6.0 cm/month) in the mesocosm, while in the CW, *S. nigra* (bare-root) had the greatest increase in height (1.6 cm/month), *S. nigra* (1-gallon) the greatest increase in basal diameter (0.06 cm/month) and *B. nigra* (tubeling) the greatest increase in canopy diameter (1.0 cm/month). The lower survival and growth rates in the CW may have resulted from factors associated with site hydrology, soil properties and herbaceous competition, which are under investigation. These results suggest that several species and planting types may be appropriate for forested compensatory wetlands in Virginia.

Hudson III, H. W. and J. E. Perry. 2011. Growth and survival of seven wetland tree species in three hydrologically distinct habitats. South Atlantic and Mid Atlantic Chapters Society of Wetland Scientists Regional Meeting. Reston, Virginia.

Abstract: Success criteria in Virginia for forested wetland compensation requires a tree density of >495 stems/ha. In order to investigate which species and planting types survive and grow successfully in three controlled hydrologic conditions (Ideal, Saturated, and Flooded), a long term large scale mesocosm study consisting of three cells were planted in the Spring of 2009. A total of 924 trees were planted in each cell and consisted of 44 plantings of each species (*Betula nigra, Liquidambar styraciflua, Platanus occidentalis, Quercus bicolor, Q. palustris, Q. phellos,* and *Salix nigra*) and three different planting types (bare root, tubeling, 1 gallon, 308 of each species per cell) for a total of 2772 planted trees. The overall percent survival of all planted trees after two growing seasons was 72.3 %. Within each of the cells the gallon planting type had greater survival than bare root and tubeling planting types. *Salix nigra* had greatest percent survival in the Flooded cell and *Q. bicolor* had greatest percent survival in the Ideal and Saturated cells. Basal diameter, height and canopy diameter growth rates increased during the second growing season. *Salix nigra* had the highest growth rate in the Flooded cell and *B. nigra* the highest in the Ideal and Saturated cell. After two growing seasons *S. nigra* and the gallon planting type of all species exhibited greater percent survival and growth rates suggesting that they may be appropriate planting stock for forested compensatory wetland sites in Virginia.

Wurst, S.J., J.D. Roquemore, H.W. Hudson, III, J.M. Campo and R.B. Atkinson. 2011. Tree survival and growth in created wetland mitigation sites in Virginia: a field validation study. South Atlantic and Mid Atlantic Chapters Society of Wetland Scientists Regional Meeting. Reston, Virginia.

Abstract: Poor survival and slow growth rates of planted woody vegetation in forested wetlands have been a major limitation of created forested wetland performance. Few studies have addressed how planting material (species and planting type) affects the survival and growth of woody species. Species including *Betula nigra, Liquidambar styraciflua, Platanus occidentalis, Quercus bicolor, Q. palustris, Q. phellos,* and *Salix nigra* were planted as bare root, potted (3.8-L pots), tubeling with soil around the roots, and tubeling without soil around the roots. Three wetland mitigation sites were selected for planting in the northern Piedmont physiographic province of Virginia. Planting occurred on March 9-10, 2009 and survivorship and growth (canopy width, stem width at base, and height) of individual trees was monitored immediately after planting and also in Aug 2009 and 2010. There were 1594 trees planted and 942 survived both growing seasons (59% survival). Two-way analysis of variance found *Q. phellos* tubelings had the lowest overall survival (17.1%) while *Q. bicolor* potted had the highest survival (96.1%). Bare roots had the lowest survival (48.7%) while the potted planting type had the highest survival (76.9%). *P. occidentalis* potted showed the worst overall change in height (-3.9 cm/month) while *S. nigra* bare root had the highest height change (1.6 cm/month). Knowledge of the woody plants and initial planting types that result in optimum density will help improve future forested wetland compensation projects. Further analysis of field conditions at these sites is planned in order to improve selection of planting materials.

Conference and Meeting Posters

Hudson, H. W. III, and J. E. Perry. 2011. Growth and Survival of Woody Wetland Vascular Plants: A Large Scale Mesocosm Study. Virginia Association of Wetland Professionals Annual Meeting. Richmond, VA.

Charles, S. P. and J. E. Perry 2011. Quantifying Growth and Survival of Wetland Tree Species Grown Under Separate Hydrological Regimes. Society of Wetland Scientists South Atlantic Chapter Annual Meeting. Reston, VA. USA.

Abstract: When creating or restoring forested wetlands in the Mid-Atlantic region of the US, a wide variety of tree species and planting types are used. To help identify the most appropriate trees to use we have established a long term mesocosm study in New Kent, Virginia. Constructed in 2009, the study includes 2772 saplings of seven tree species (*Betula nigra, Liquidambar styraciflua, Platanus occidentalis, Quercus bicolor, Q. palustris, Q. phellos,* and *Salix nigra*) common to the Piedmond Provence of Virginia. 924 saplings of each species were planted in three hydological regimes (Ideal, Saturated in root zone, and Flooded). These included 308 saplings of three planting type (bare root, tubeling, and gallon). Canopy cover, basal diameter, height, and above and below ground biomass were collected as growth measurements. After two years of data we found that, as expected, wetter hydrology led to decreased survival and growth rates. Ideal cell showed highest growth followed by the Saturated and Flooded cell. Similarly, the Flooded cell exhibits the lowest survival rate (65.4% survival over two growing seasons), while the Saturated cell showed highest survival (80.2%) and the Ideal cell fell between the two (71.2%). Gallons had the highest survival (92.2%) followed by bare roots (65.4%) and then tubelings (59.4%). *Salix nigra* had the highest survival rate in the Flooded cell, while *P. occidentalis* had the lowest. The results of this data help to quantitatively determine which woody species, and planting type, would prove the most useful in forested wetland compensation in the Mid-Atlantic US.

College Class Presentations and Posters

Moses, M. Bromberg-Martin, B. Frye, K. 2010. Growth Rate Comparison of *Salix nigra* and *Quercus palustris* in Three Hydrologic Conditions of Created Wetlands. Christopher Newport University BIO 306 Class Poster and Project.

Ernst, C. B. Wildasin, A. Gray, J. Danielson, A. Ledin, and D. Bernhalter. 2011. Preliminary Results: Evaluating the Productivity of Seven Wetland Tree Species in a Created Wetland Site Through an Analysis of Above and Below Ground Biomass. Christopher Newport University BIO 306 Class Poster and Project.

High School Projects

Grzegorczyk, Shane. 2011. Effects of Initial Tree Size on Survival of Seven Wetland Tree Species Charlottesville High School. Governor School Program

Clayborne, Chris. 2011. The Effect of Water Stress on Tree Root Growth. Gloucester High School Senior Board Project.

Conference Presentations By CNU Students and Faculty

*Wurst, S., J. Roquemore, and R.B. Atkinson. 2011. A characterization of soils in created wetlands in Loudoun County, Virginia. MARCUS, Sweet Briar College, Sweet Briar, Virginia.

Abstract: Soil compaction and low nutrient availability have hindered efforts to create functioning wetlands. The purpose of this study is to characterize soils at three created wetlands to determine the effect of soil variables on growth. Seven species of trees were planted as bare roots, potted (3.8-L) pots, or tubelings at sites in Northern Virginia. Planting occurred on March 9-10, 2009 and growth of individual trees was monitored immediately after planting and each subsequent August. Soil samples were gathered at the sites this May. The samples went through a KCl extraction to measure Nitrogen levels as well as a Mehlich 3 extraction to measure Phosphorus. Samples were also run through a LISST to quantify the particle sizes in the soil. Averages for bulk density (1.04±0.14), Nitrate/Nitrite (3.6±3.7) and Potassium (66.1±64.3) suggest that each may influence observed growth trends among tree species.

Atkinson, R.B., H.W. Hudson, III and J.E. Perry. 2010. Tree survival and growth in created wetland mitigation sites in Virginia. Presented at Association of Southeastern Biologists Annual Meeting, Asheville, NC.

Hudson III, Herman W. and R.B. Atkinson. 2010. The effect of adjacent forests on colonizing tree density in restored wetland compensation sites in Virginia. Presented at Association of Southeastern Biologists Annual Meeting, Asheville, NC.

Hudson, H.W., III and R.B. Atkinson. 2010. The effect of adjacent forests on colonizing tree density in restored wetland mitigation sites in Virginia. SigmaXi, Newport News, VA.

Perry, J.E., R.B. Atkinson, L. Sutter, H.W. Hudson, and S. Charles. 2010. Assessment of woody vegetation for replacement of ecological functions in created forested wetlands of the Piedmont Province of Virginia. Annual Meeting of the Virginia Association of Wetland Professionals, Williamsburg, VA.

Wurst, S., and R.B. Atkinson. 2010. Survivorship of seven tree species in three planting types planted in Northern Virginia. MARCUS, Sweet Briar College, Sweet Briar, Virginia.

Wurst, S., H.W. Hudson, J. Roquemore, and R.B. Atkinson. 2010. Tree survival and growth in created wetland mitigation sites in Virginia: A field validation study. South Atlantic/Mid-Atlantic Society of Wetland Scientists Joint Chapter Meeting, Reston, VA.

Heeter, F., T. Brubach, J. Coley, H. Hudson III, I. Knight, D. Riedl, J.D. Roquemore, K. Sweet, S. Wurst and R.B. Atkinson. 2009. Evaluation of planted tree morphometry within three wetland compensation sites in the Piedmont Region of Virginia. Paideia, Newport News, VA.

Hudson, H.W., III and R.B. Atkinson. 2009. The effect of adjacent forests on colonizing tree density in restored wetland mitigation sites in Virginia. International Meeting of the Society of Wetland Scientists in Madison, Wisconsin.

Knight, I., and R.B. Atkinson. 2009. Growth of seven wetland tree species in three compensatory wetlands in Northern Virginia. MARCUS, Sweet Briar College, Sweet Briar, Virginia.

Hudson, H.W., III and R.B. Atkinson. 2009. The effect of surrounding forests on colonizing tree density in restored wetland mitigation sites in southeastern Virginia. Virginia Council of Graduate Schools, Graduate Student Forum in Richmond.

Merz, N. Hudson, H.W., III and R.B. Atkinson. 2009. First-year survivorship of seven wetland tree species in three non-tidal freshwater wetland compensation sites in Loudoun County, Virginia. MARCUS, Sweet Briar College, Sweet Briar, Virginia.

*(NOTE: The Wurst et al. (2011) paper addressed both the newly-funded-by-Peterson-Foundation research on explanatory variables that is not part of the contract we are reporting on; however, some of the tree survival and growth findings were discussed in that presentation.)