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

Draft 2008-2009 Annual Report
Submitted To:

PIEDMONT WETLANDS RESEARCH PROGRAM

Prepared By:

James E. Perry[1], Lori Sutter[1], Herman W. Hudson[2],
Robert Atkinson[2], Christian Hauser[1], and Sean Charles[1]

[1]Dept. Biological Science
Virginia Institute of Marine Science
College of William and Mary

and

[2]Center for Wetland Conservation and
Dept. Biology, Chemistry and Environmental Science
Christopher Newport University

Table of Contents

Executive Summary

At the end of year one, we have made progress in several areas:

1. We have completed a detailed review of the related scientific literature base and have consulted with wetland stakeholders (designers, consultants, nursery owners) in the wetland plant growing world. We have reviewed all available techniques for growing and planting woody species in created and/or restored forested systems (Appendix 1).

2. We have successfully constructed a large Mesocosm and initiated a field study to carefully evaluate and compare the growth response of several species and planting types in relation to different water levels. First year survival and morphometrics were collected on schedule. Methods for measuring ecological parameters were used successfully for 1 species (*B. nigra*); other species could not be measured due to a failure in equipment. The equipment has been replaced and data will be collected during the next growing season.

3. Drs. Perry and Atkinson are progressing on a publication presenting this year's . The target is the new SWS Bulletin. Two "white-papers" are also being prepared for distribution to the VAWP and/or WSSI. The first is on species survival of the seven species of trees and the second on growth rates and morphometrics.

INTRODUCTION AND PROJECT DESCRIPTION

Poor survival and/or slow growth rates of planted woody vegetation in forested wetlands has been a major cause of created forested wetland poor performance (NRDC 1995, Spieles 2005, Leo Snead, Virginia Dept. Transportation, Richmond, VA, pers. comm.). There are numerous species of woody plants and planting types (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 Mesocosm studies to 1) measure the performance of several species and planting types 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. We also have established field studies at three sites to validate the findings of the Mesocosm model. The project was divided into three objectives.

Objective 1. 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 planting type(s) that would be recommended for planting in created forested wetlands in the Piedmont Province of Virginia.

<u>Background:</u> 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.

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 press) 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). We are critically 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*, see Table 1) in a coordinated Mesocosm and field study by comparing survival and growth rates (via tree morphometrics) of tree (sapling) plantings: 1) from various planting types (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 hydrologically stressed (Ideal Cell) and harshest, most hydrologically 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 in the Saturated Cell and our field data. In our analysis these species will 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. 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. 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).

<u>Background</u>: Odum (1969) identified biomass and 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. require cutting 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 tied them to growth rates and, therefore, productivity. Bailey et al. (2007) found that of seven possible morphological measurements taken for woody vegetation, 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. 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 in a set of Mesocosm cells and three field sites (see below for explanation of Mesocosm and field sites). The Mesocosm cells are also being used to compare the growth to two ecological functions: plant biomass and overall productivity. Productivity was to be measured by sacrificing three (3) individuals of each species and planting type in November of 2009; however, the loss of approximately 20% of some species meant that sacrificing them in 2009 would leave us short of species in year-7. Therefore, we will use new plantings from next year as year-1 biomass, and use this year's plantings as year-2. Net Energy Exchange (NEE, carbon flux) will be collected using a PP Systems TPS-2 Portable Gas Analyzer (a measure of efficiency of CO_2 fixation) (PP Systems 2009) (Bailey 2006, Cornell et al. 2007). We had originally planned on using a LiCor 6200 to do NEE; however, the equipment failed to work and was not repairable due to age (LiCor Tech, pers. comm. 2009). NEE measurements are available for *B. nigra* and will be included in a later report.

Two other tasks in this objective included: 1) determining the role that volunteer woody plants play 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 will begin by May 2010. 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 different planting types, sizes and species mixes.

Objective 3. Literature Review:

We reviewed available technologies for planting woody vegetation, survival data, ecological potential, and species recommendations 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., what quantity, stock size and species mix 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;

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

The results of the literature review are presented in Appendix I.

METHODS

Planting Material

Based upon our review of the literature, practical experience in the field, and availability of planting material, we compared the following planting types: 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* (sweet gum), *Platanus occidentalis* (American sycamore), *Quercus bicolor* (swamp white oak), *Q. palustris* (pin oak), *Q. phellos* (willow oak) and *Salix nigra* (black willow). Forty four of each species and each planting type were planted in the Mesocosm to allow for harvesting of three of each species and planting type per year for a total of 2772 saplings (Table 1). Five hundred twenty five saplings were planted per field site for a total of 1575 saplings (Table 2). All saplings were planted in March 2009. Care was taken to assure that each was carefully placed properly in the hole and covered to avoid formation of air-pockets (see Appendix I for planting guidelines). Saplings came from 5 nurseries (3 in Virginia, 1 in North Carolina, 1 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. All saplings were kept in cold storage at the New Kent Forestry Center until planted. No fertilizers were applied. To keep down herbaceous competition, the Ideal and Saturated Cells were mowed bi-weekly between rows and herbicide (Roundup®) was applied at the specified rate around the base of each planting. A 0.75m x 5cm (2ft x 2in) PVC pipe, cut in half, was temporarily hand placed around the plantings to avoid contact due to drift of the herbicide.

Table 1. Mesocosm experimental design including species, treatments within Mesocosm, planting type, and replication. Flooded Cell was kept flooded with a minimum 20cm throughout the growing season, Saturated Cell was kept saturated within the top 20cm of the root zone, and Ideal Cell received a minimum of 2.54cm per week as needed. Key to Planting Types: BR=bare-root, TUB=tubelings, GAL=1 gallon pots.

Species	Treatment			Planting type and replication			# Saplings
	Flooded	Saturated	Ideal	BR	TUB	GAL	
B. nigra	1	1	1	44	44	44	396
L. styraciflua	1	1	1	44	44	44	396
P. occidentalis	1	1	1	44	44	44	396
Q. bicolor	1	1	1	44	44	44	396
Q. palustris	1	1	1	44	44	44	396
Q. phellos	1	1	1	44	44	44	396
S. nigra	1	1	1	44	44	44	396
					TOTAL	SAPLINGS	2772

Table 2. Field Site experimental design including species, sites, planting type and replication. Key to Planting Types: BR=bare-root, TUB=tubelings, GAL=1 gallon pots.

Species	Sites	Planting Type and Replication			# Saplings
		BR	TUB	GAL	
B. nigra	3	25	25	25	225
L. styraciflua	3	25	25	25	225
P. occidentalis	3	25	25	25	225
Q. bicolor	3	25	25	25	225

Q. palustris	3	25	25	25		225
Q. phellos	3	25	25	25		225
S. nigra	3	25	25	25		225
					Total	1575

Mesocosm Study

This phase of the project was directed by Dr. Perry with assistance from Dr. Atkinson, and implemented and monitored by the VIMS. The Mesocosm site, located on the New Kent Forestry Center, Providence Forge, VA (Figure 1) was divided into three cells, 48.8m x 144m (160ft x 300ft) each. Soil of the Ideal and Saturated Cells were disked and tilled in February prior to planting. The Flooded Cell 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. 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. Each cell was then planted with the seven species, 44 of each planting type, for a total of 924 saplings in each Cell (Table 1). The three cells were hydrologically manipulated to include an Ideal treatment (a minimum 2.54cm (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 – see below)), and a Flooded treatment (inundated at least 90% of year). Deep and shallow groundwater wells as well as piezometers were established to measure soil saturation. Saturation was measured three times weekly using a Lincoln Soil Moisture Meter (Lincoln Irrigation, Inc., Lincoln, NE). A total of 2772 saplings were planted (see Table 1). Plants were randomly arranged in each cell to allow for 3-way Analysis of Variance (ANOVA) of species, planting type, and hydrologic regime, or 2-tailed T-test. All data were tested for normality and heterogeneity using a Kolmogorov–Smirnov test. Non-normal data were normalized when possible or tested with non-parametric means.

Figure 1. Mesocosm Site Location: New Kent County, Virginia, USA.

Survival

Survival counts of individual saplings in the Mesocosm cells were conducted in mid-April, mid-July, and mid-October. Individuals were considered live based on the presence of green leaves or a green cambium. The latter was necessary as we noted that many trees exhibited die-back and re-growth in the April to July data. (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 (indeed, many plantings that appeared dead and leafless in July re-sprouted and had green leaves in October).

Morphometrics (tree growth)

Growth morphology (basal stem diameter at soil level, crown diameter, and height of highest stem) was measured in April, July, and October of 2009. Data were collected using methods modified from Bailey et al. (2007). Total height (H) was sampled using a standard meter stick, while crown diameter (CD) and basal diameter were quantified using macro-calipers (Haglof, Inc. “Mantax Precision” Calipers) and micro-calipers (SPI 6”/.1 mm Poly Dial Calipers), respectively. CD was measured in three different angles at the visual diameter maximum and averaged to determine the final canopy cover by converting averaged crown diameter to area (pi x [1/2 average crown diameter]^2). 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 Fennessey 2001). If there was more than one stem for a planting (e.g. coppicing), basal diameter of all stems were measured and the basal diameter was the sum of the BD of the stems. Die back and re-growth (coppicing and re-sprouting) were common in many of the Mesocosm plantings (often leading to negative morphometrics readings) and were noted in the field. All saplings that were noted as dead in the October data set have been removed from the morphometrics calculations. Therefore, the number of plantings representative of each species and type varied between cells in the Mesocosm study.

Growth was calculated as the normalized difference of change in individual plantings using the following formula: (October Measurement - April Measurement)/April measurement. The growth of each species was averaged for each cell in the Mesocosm and site in the field study for use in statistical comparison. We also compared the growth of three primary succession species (*B. nigra, L. styraciflua, S. nigra*) to that of the three secondary species (*Q. bicolor, Q. palustris, Q. phellos*) (Spencer et al 2001). The fourth primary species, *P. occidentalis* was excluded from the calculations because of poor survival.

Future morphometrics will be analyzed using Principal Components Analysis (PCA), which enables the data to be analyzed simultaneously and provides a visualization of data structure not available using simple regression techniques. However, the use of PCA on this year’s data would not be appropriate as destructive sampling had to be delayed until more species could be planted (see Biomass below). Finally, since the Ideal Cell receives optimum moisture, it represents an optimum hydrologic environment. The Flooded Cell, being inundated for a majority of the year, represents a stressed hydrologic condition. Therefore, these treatments can be used to establish upper (Ideal Cell) and lower (Flooded Cell) survival and growth limits and can be used to establish potential ranges for the field data.

Biomass

While we had intended to collect above and below ground biomass in November, die-back of a number of species would have left us short for the number needed for data collecting in year seven. Instead of collecting some 1-year species this year, and other 1-year from next year's re-plantings and trying to merge the two sets of data, we decided to use re-plantings from next year for the 1-year biomass data. Therefore, both 1-year and 2-year data will be collected in November 2010.

CO_2 Flux

Due to malfunction of our LI-6200 Portable Infrared Gas Analyzer (LI-COR, Inc., Lincoln, NE), we were only able to measure gas exchange for *B. nigra* at a nearby field site. This data is being compiled for a VIMS Master's Thesis and will be finished in the Summer, 2010. A new system (PP System TPS-2) has be purchased and arrived in late December 2009. With the new gas analyzer we will be able to measure both year-1and year-2 CO2 flux in the Mesocosm by using the re-planted species as year-1 data.

Field Sites Study

Drs. Atkinson and Perry worked with Wetland Studies and Solutions, Inc., Mitigation Bank Research Team, and other groups in the Piedmont area to designate field sites. Three (3) Piedmont constructed wetland field sites were chosen for the study (Figure 2-5). Each site has a clay base soil (the most common planting medium), two to three years of documented hydrologic data and relatively uniform topography. The overall hydrology is driven principally by rainfall such that typical Piedmont Province created wetlands conditions are represented. Finally, the sites have an annual hydroperiod where the saturated zone is at the soil surface for the majority of growing season (see Appendix II for recorded site soil and hydrologic data).

Treatments mirror the Mesocosm study, consisting of the same seven species and planting types, 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: an average of 25 plots were established at each of the three sites (for a total of 525 plantings per site) (Table 2). Planting was completed in early March 2009 in conjunction with the Mesocosm study.

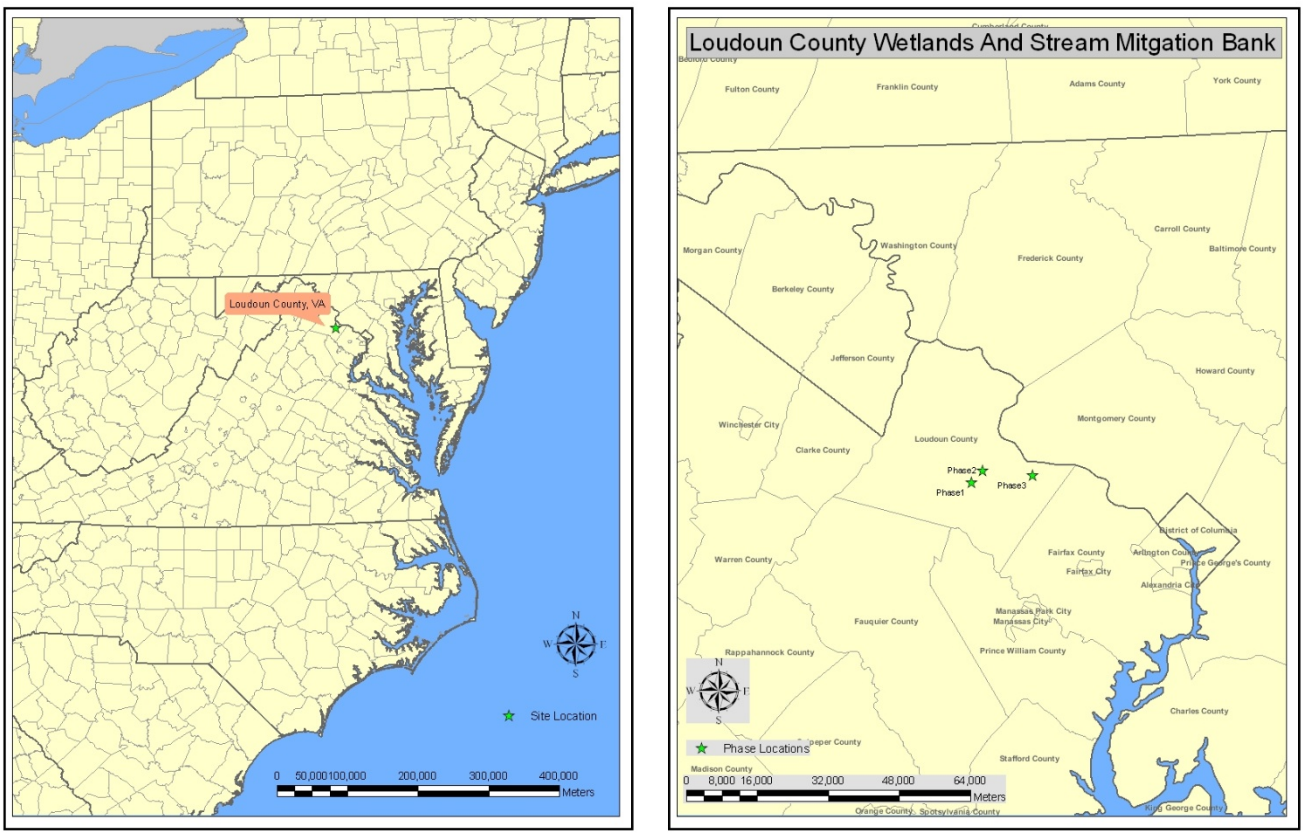
Mortality and morphometrics data were collected using methods modified from Bailey et al. (2007). Each planting was mapped using an x- and y- coordinate grid system. Survival and growth of each planting (height, canopy cover and basal diameter as in the Mesocosm study) were recorded in a one-week period in mid-April and again in August of 2009. In addition to direct comparisons with the Mesocosm results, a three-way ANOVA using sites, tree species, and planting types was conducted in order identify the best performing species and planting materials.

<u>Rationale for planting different numbers of saplings per phase</u>: 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 terms of homogeneity of site conditions and the Loudoun County Wetlands and Stream Mitigation Bank (LCWSB) was deemed suitable based on this criterion. Upon surveying the three phases of the LCWSB, the balanced arrangement was not possible due to the configuration and conditions found on the three sites and extra plots were added at Phase III.

<u>Testing for differences in tubelings (tubelings with and without soil)</u>: The two types of tubeling plantings received from the nursery were tubelings with soil around the roots (*B. nigra, L. styraciflua, Q. bicolor,* and *Q. palustris*) and tubelings that lack the soil around the roots (*P. occidentalis, Q. phellos,* and *S. nigra*). The rationale for distinguishing between the two types was that, due to lack of soil, those without soil may exhibit different survival and growth results. Therefore, we wanted to test for difference in growth for tubelings with soil and tubelings without soil. We hypothesized that tubeling plantings with potting soil still intact around the roots could hold water longer, would not expend as much energy becoming established, and would have additional supply of nutrients in the potting soil. The tubeling plantings lacking potting soil around

the roots will have to invest more energy in establishing roots and extracting water and nutrients from the new surroundings. Another reason for distinguishing between these two types of tubelings (economically, not ecologically based) was that there are cost differences between these two types. Tubelings lacking soil are very similar to bare-root seedlings and both are able to be stored and transported in smaller containers. Tubelings with the soil still intact are heavier and require more space for storage and transport and are, therefore, more expensive. Student T-Test and ANOVA were used to determine whether the tubeling plantings could be lumped or needed to be kept separate for analysis.

Figure 2. Location of the field study sites and location of individual Phases.



Construction Methods (provided by Wetland Studies and Solutions, Inc.)

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.

<u>Phase I</u> - 4 megaplots each containing 3 plots with 21 plantings in each plot (252 saplings)

Another study was being conducted in the two northern sections of the phase eliminating 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.

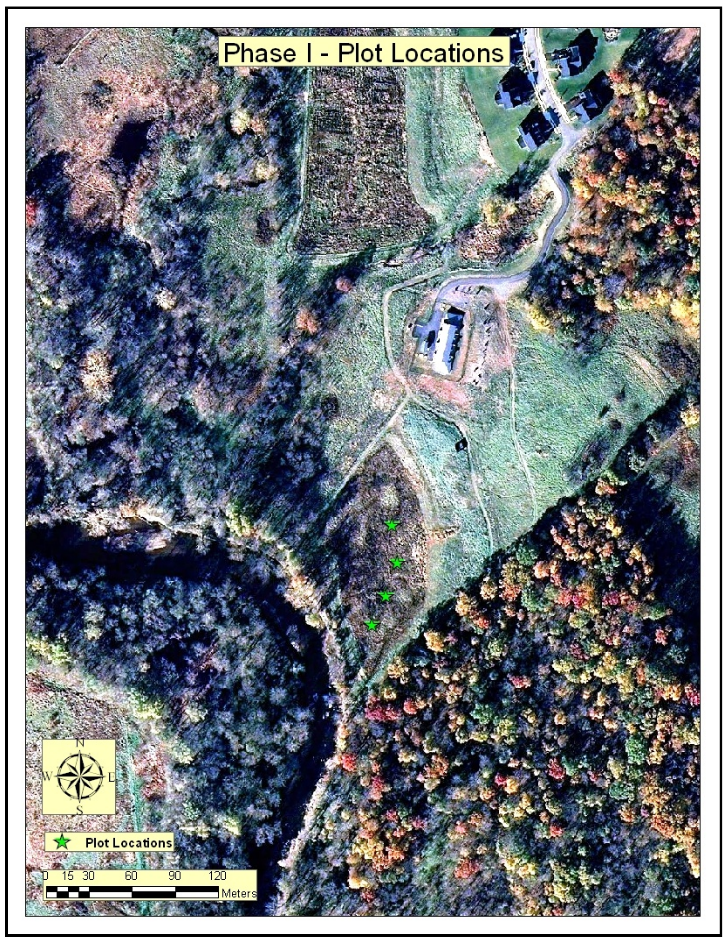


Figure 3. Location of Phase I megaplots. 2007 was the first growing season; 2008 the second. Study saplings were planted before the beginning of the third growing season (2009)

Phase II - Four megaplots each containing 3 plots with 21 saplings in each plot (252 saplings)

The majority of the site, when surveyed, exhibited hydrologic conditions that were somewhat wetter than the other two phases. A small portion that was hydrologically similar to the other phases could not fit 525 saplings with the 8' spacing requirement.

Figure 4. Location of Phase II megaplots. 2008 was the first growing season. Study saplings were planted before the beginning of the second growing season (2009).

Phase III – 17 megaplots each containing 3 or 4 plots with 21 saplings in each plot (1092 saplings)

This phase exhibited fairly uniform hydrology and vegetation and had enough space to fit the remainder of the saplings with the required 8’ spacing.

Figure 5. Location of Phase III megaplots. 2008 was the first growing season. Study saplings were planted before the beginning of the second growing season (2009).

ADDITIONAL RESEARCH

Role of Volunteer Woody Species: DeBerry (2006), DeBerry and Perry (in press), and Atkinson et al. (2008) found that volunteer woody species dominated many created forested wetland sites in the Piedmont and Coastal Plain of Virginia. Mr. Herman Hudson, under Dr. Atkinson, has undertaken this work for his Masters at CNU. We further plan on expanding this work by adding more Piedmont sites and modifying DeBerry’s methods to better capture the effect of colonization by volunteers (see DeBerry 2006 for complete methods). The second expansion of this project will be initiated by Mr. Hudson as a Ph.D. student at VIMS next year (Fall, 2010).

Diversity Measures in Reference Wetlands: DeBerry (2006) studied the diversity of 15 reference hardwood wetlands and compared them to 15 adjacent created hardwood wetlands of different ages (chronosequence), several in the Piedmont, but most in the Coastal Plain. We plan on building on DeBerry's work by using his methods and adding sites from the Piedmont. This will be a Masters Thesis project to be initiated within the first four years of the study.

RESULTS

Survival: Mesocosm

Descriptive

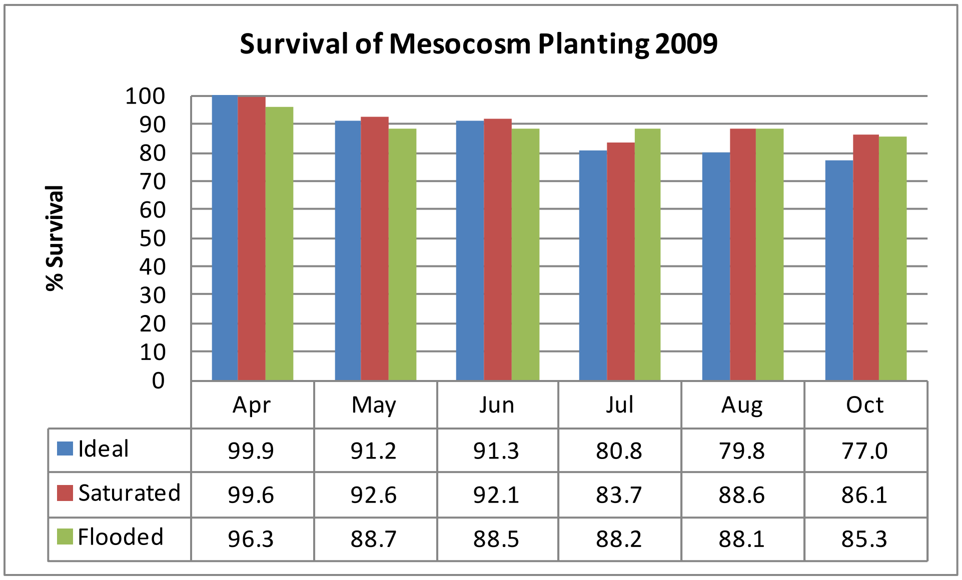
Of the 2772 saplings planted, 2295 (82.8%) survived the first growing season. The Saturated Cell had the highest survival rate (86.1%) and the Ideal the lowest (76.9%). Survival in the Saturated and Flooded Cells was not significantly different, however, survival in both was significantly greater than that of the Ideal Cell (n=25, $p<0.05$) (Figure 6). There was a period of die-back between June and July and re-sprouting in August and October in all cells that was seen as a decrease in survival in the July data and a subsequent increase in survival in the August data (data not shown).

Liquidambar styraciflua tubelings had the lowest overall survival (63.3%) while *L. styraciflua, Quercus bicolor*, and *Salix nigra* gallon had the highest survival (100.0%) (Figure 7). Tubeling plantings without soil had the lowest percent survival (75.5%) while gallon plantings had the highest percent survival (92.3%). There was no significant difference between tubelings and bare-root plantings; however survival of gallon plantings was significantly higher than both (ANOVA, n= 21, $p<0.05$). Gallon plantings were significantly greater than both bare-root plantings and tubeling plantings across cells and within cells. Bare-root and tubeling plantings were not significantly different (ANOVA, n=19, $p>0.05$).

Survival within cells

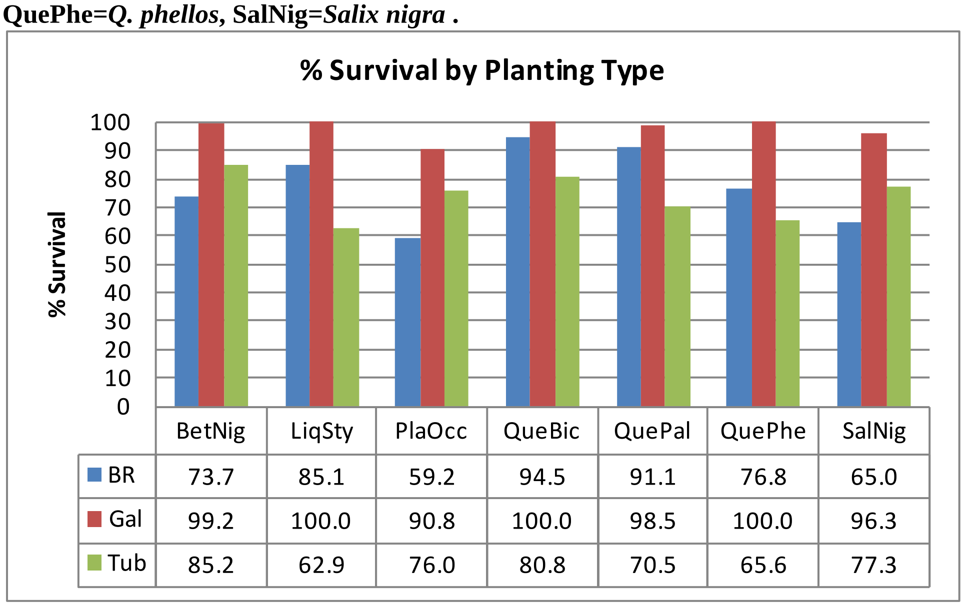
In the Ideal Cell, *L. styraciflua* tubelings and *S. nigra* bare-roots had lowest overall survival (<33%) while *B. nigra*, *L. styraciflua*, *Q. bicolor*, and *Q. palustris* gallons had the highest survival (100%) (Figure 8). There was no significant difference between tubelings and bare-root plantings; however survival of gallon plantings was significantly higher than both (ANOVA, n= 19, $p<0.05$). The Ideal Cell had the lowest survival rate of all plantings; of the 924 plantings only 711 (76.9%) survived. This was significantly lower than both the Saturated and Flooded Cells (ANOVA, n=19, $p<0.05$).

Figure 6. Percent (%) of survival of combined species in the three Mesocosm treatments (Ideal=minimum1" moisture week^{-1}, Saturated = saturated at a minimum 90% of the growing season within the root-zone (10cm) , Flooded=inundated 90% of year).



	Apr	May	Jun	Jul	Aug	Oct
Ideal	99.9	91.2	91.3	80.8	79.8	77.0
Saturated	99.6	92.6	92.1	83.7	88.6	86.1
Flooded	96.3	88.7	88.5	88.2	88.1	85.3

Figure 7. Percent (%) of survival of species by planting type (treatments combined) BR=bare-root, Gal=gallon pot, Tub=tubelings Percent (%) of survival of species by planting type of Ideal Cell. BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra* .

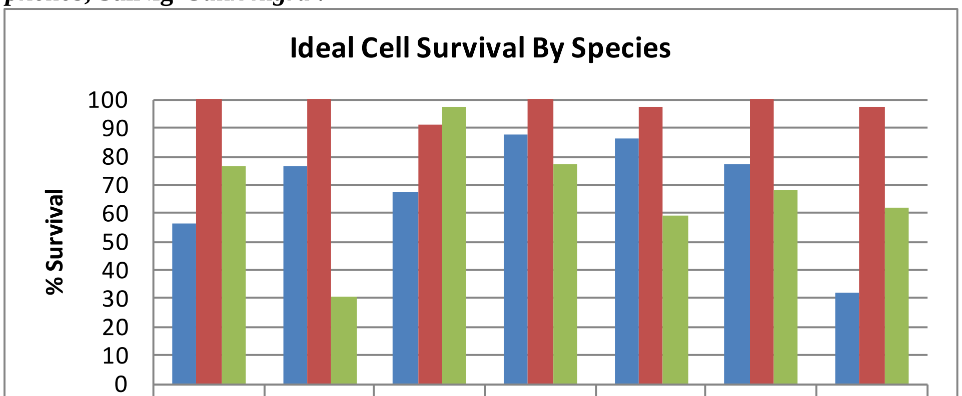


	BetNig	LiqSty	PlaOcc	QueBic	QuePal	QuePhe	SalNig
BR	73.7	85.1	59.2	94.5	91.1	76.8	65.0
Gal	99.2	100.0	90.8	100.0	98.5	100.0	96.3
Tub	85.2	62.9	76.0	80.8	70.5	65.6	77.3

Of the 924 saplings planted in the Saturated Cell, 796 (86.1%) survived. *L. styraciflua* tubeling plantings and *P. occidentalis* bare-root plantings had the lowest overall survival in the Saturated Cell (<67%). *L. styraciflua*, *Q. bicolor*, Q. *palustris* and *Q.s phellos* gallons had the highest survival (100%) (Figure 9). There was no significant difference in survival between tubeling and bare-root plantings, however survival of gallon plantings were significantly higher than both (ANOVA, n=19, p<0.05).

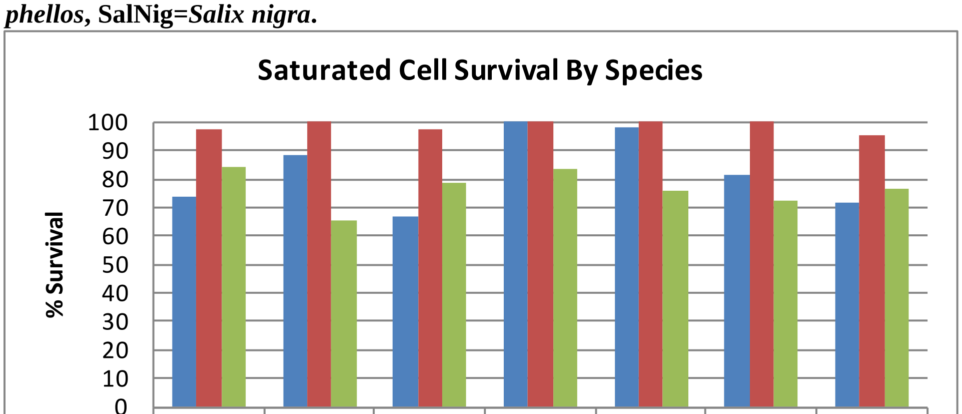
Survival in the Flooded Cell was slightly lower (788 plantings survived for 85.3% survival), but not significantly different (ANOVA, n=19, $p<0.05$), to that of the Saturated Cell. *P. occidentalis* bare-root plantings had lowest overall survival in the Flooded Cell (<67.0%) while *B. nigra*, *L. styraciflua*, *Q. bicolor*, and *Q. phellos* gallons had the highest survival (100%) (Figure 10). There was no significant difference between tubeling and bare-root plantings; however survival of gallon plantings was significantly higher than *both (ANOVA, n=19, p<0.05).*

Figure 8. Percent (%) of survival of species by planting type of Ideal Cell. BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra* .



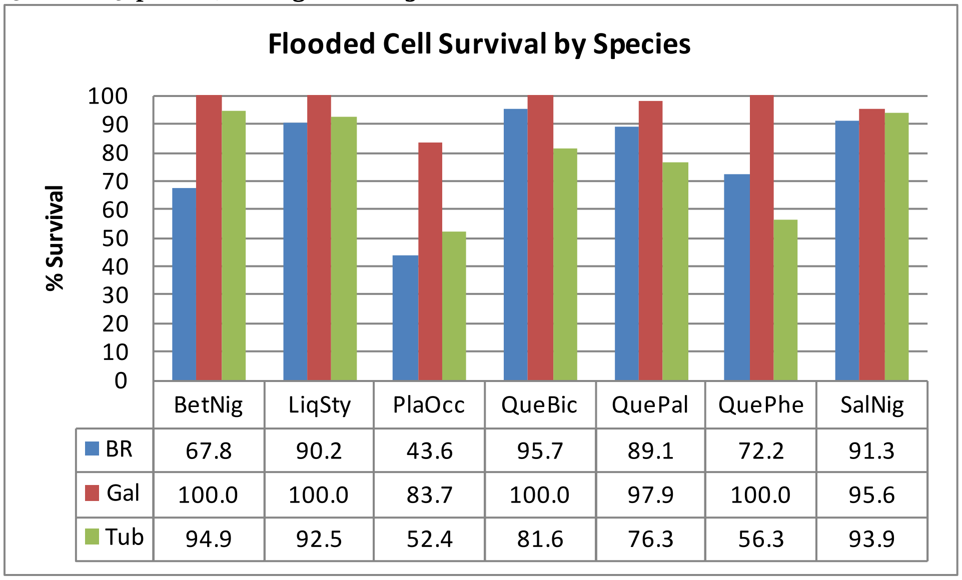
	BetNig	LiqSty	PlaOcc	QueBic	QuePal	QuePhe	SalNig
BR	56.3	76.6	67.3	87.7	86.3	77	32.4
Gal	100	100	91.1	100	97.6	100	97.7
Tub	76.6	31	97.2	77.6	59.5	67.9	61.7

Figure 9. Percent (%) of survival of species by planting type of Saturated Cell. BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra*.



	BetNig	LiqSty	PlaOcc	QueBic	QuePal	QuePhe	SalNig
BR	73.5	88.4	66.7	100	98	81.2	71.4
Gal	97.6	100	97.7	100	100	100	95.5
Tub	84.2	65.2	78.4	83.3	75.7	72.5	76.3

Figure 10. Percent (%) of survival of species by species and planting type of Flooded Cell. BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra* .



	BetNig	LiqSty	PlaOcc	QueBic	QuePal	QuePhe	SalNig
BR	67.8	90.2	43.6	95.7	89.1	72.2	91.3
Gal	100.0	100.0	83.7	100.0	97.9	100.0	95.6
Tub	94.9	92.5	52.4	81.6	76.3	56.3	93.9

Survival: Field

Descriptive

Of the 1596 saplings planted, 1375 (86.2%) survived the first growing season. L. styraciflua tubelings had the lowest overall survival (57.3%) while Q. bicolor gallon and S. nigra gallon had the highest survival (98.7%). Tubeling plantings without soil had the lowest percent survival (75.5%) while the gallon plantings had the highest percent survival (92.3%). The overall survival at Phase 1 was 72.6%, Phase 2, 88.1% and Phase 3 had an overall survival of 88.8% (Table 3).

Differences in survival among phases

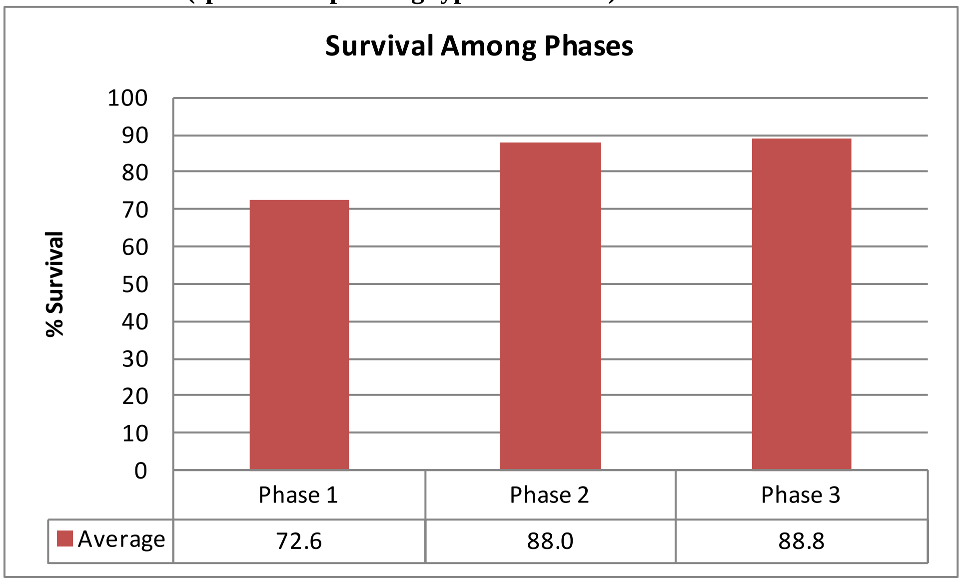
There was a significantly lower percent survival of the bare-root plantings at Phase 1 than at Phase 3 (ANOVA, n=10, $p<0.05$). Gallon plantings had a significantly lower percent survival at Phase 1 than at Phase 2 (ANOVA, n=10, p=0.026), and tubeling plantings had no significant difference in percent survival among phases (ANOVA, n=10, p=0.290, and p=0.527). There was no significant difference between combined (among phases) tubelings with and without soil (ANOVA, n=10, p=0.165).

Table 3. Survival of species by Phase. Number of plantings at each Phase varied according to geomorphology. Sites were located in Loudon Co., Virginia.

Species	Planting Type	Total Planted	Total Alive in Fall	Overall Percent Survival	Total Planted Phase 1	Total Dead Phase 1	% Survival Phase 1	Total Planted Phase 2	Total Dead Phase 2	% Survival Phase 2	Total Planted Phase 3	Total Dead Phase 3	% Survival Phase 3
Betula nigra	Bare Root	76	68	89.47	12	2	83.33	12	2	83.33	52	4	92.31
Betula nigra	Gallon	75	73	97.33	12	0	100.00	11	0	100.00	52	2	96.15
Betula nigra	Tubeling	76	68	89.47	12	4	66.67	12	0	100.00	52	4	92.31
Liquidambar styraciflua	Bare Root	76	64	84.21	12	5	58.33	12	2	83.33	52	5	90.38
Liquidambar styraciflua	Gallon	77	73	94.81	12	3	75.00	12	0	100.00	53	1	98.11
Liquidambar styraciflua	Tubeling	75	43	57.33	12	6	50.00	12	3	75.00	51	23	54.90
Platanus occidentalis	Bare Root	76	52	68.42	12	7	41.67	12	7	41.67	52	10	80.77
Platanus occidentalis	Gallon	75	51	68.00	12	4	66.67	12	0	100.00	51	20	60.78
Platanus occidentalis	Tubeling NO SOIL	76	69	90.79	12	2	83.33	12	3	75.00	52	2	96.15
Quercus bicolor	Bare Root	75	67	89.33	12	4	66.67	12	0	100.00	51	4	92.16
Quercus bicolor	Gallon	76	75	98.68	12	0	100.00	13	0	100.00	51	1	98.04
Quercus bicolor	Tubeling	76	69	90.79	12	1	91.67	12	0	100.00	52	6	88.46
Quercus palustris	Bare Root	76	73	96.05	12	2	83.33	12	0	100.00	52	1	98.08
Quercus palustris	Gallon	76	74	97.37	12	2	83.33	12	0	100.00	52	0	100.00
Quercus palustris	Tubeling	78	68	87.18	12	3	75.00	13	2	84.62	53	5	90.57
Quercus phellos	Bare Root	77	67	87.01	12	2	83.33	12	1	91.67	53	7	86.79
Quercus phellos	Gallon	77	71	92.21	12	3	75.00	12	0	100.00	53	3	94.34
Quercus phellos	Tubeling NO SOIL	76	51	67.11	12	10	16.67	12	2	83.33	52	13	75.00
Salix nigra	Bare Root	76	57	75.00	12	7	41.67	12	4	66.67	52	8	84.62
Salix nigra	Gallon	76	75	98.68	12	1	91.67	12	0	100.00	52	0	100.00
Salix nigra	Tubeling NO SOIL	75	67	89.33	12	1	91.67	11	4	63.64	52	3	94.23
	Total	1596	1375	86.15	252	69	72.62	252	30	88.10	1092	122	88.83

Combining the survival of planting types and species, Phase 1 has significantly lower percent survival than Phase 2 (p=0.007) and Phase 3 (p=0.003) (Figure 11); however, there was no significant difference in percent survival between Phase 2 and Phase 3 (p=0.392) (Figure 11).

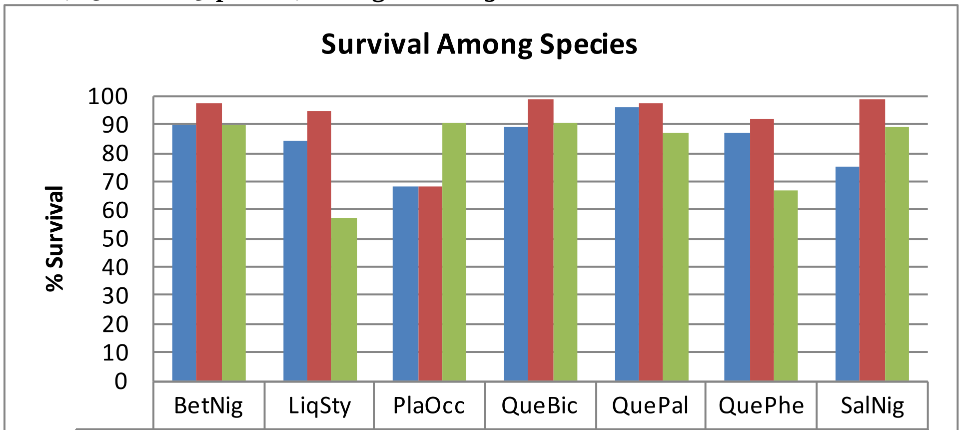
Figure 11. Overall % survival (species and planting types combined) at each the three Phases of the Field Study.



Differences in survival among species

Bare-root *P. occidentalis* had significantly lower percent survival than *Q. palustris* bare-root (p=0.05) (Figure 12). There was no significant difference in percent survival of gallon plantings among the seven species (p=0.101) (Figure 12). *L. styraciflua* tubelings with soil had significantly lower percent survival than *Q. bicolor* tubelings with soil (p=0.016) (Figure 12). There was no significant difference in percent survival of tubelings with and without soil (p=0.431) and there was no significant difference in percent survival among combined tubeling plantings, with and without soil, of the seven species (p=0.248) (Figure 12). Therefore, tubelings with soil and without soil are combined for further comparison.

Figure 12. Percent Survival among species (Phases combined). BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra*.

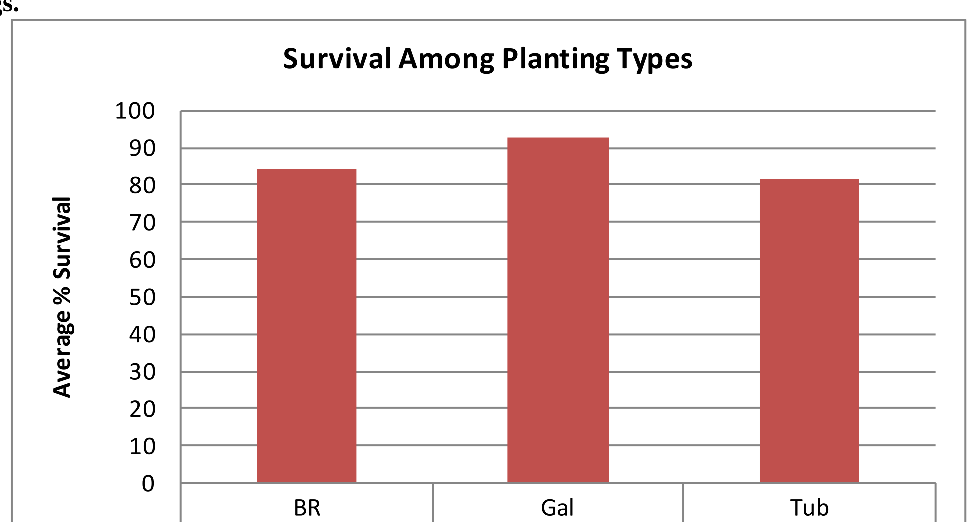


	BetNig	LiqSty	PlaOcc	QueBic	QuePal	QuePhe	SalNig
BR	89.5	84.2	68.4	89.3	96.1	87.0	75.0
Gal	97.3	94.8	68.0	98.7	97.4	92.2	98.7
Tub	89.5	57.3	90.8	90.8	87.2	67.1	89.3

Differences in survival among planting type

Comparing the survival of different planting types with species combined, the gallon species had significantly greater percent survival than the tubelings (p=0.002) and bare-root plantings (p=0.002) (Figure 13).

Figure 13. Percent survival among planting type (Phases combined). BR=bare-root, Gal=gallon pot, Tub=tubelings.



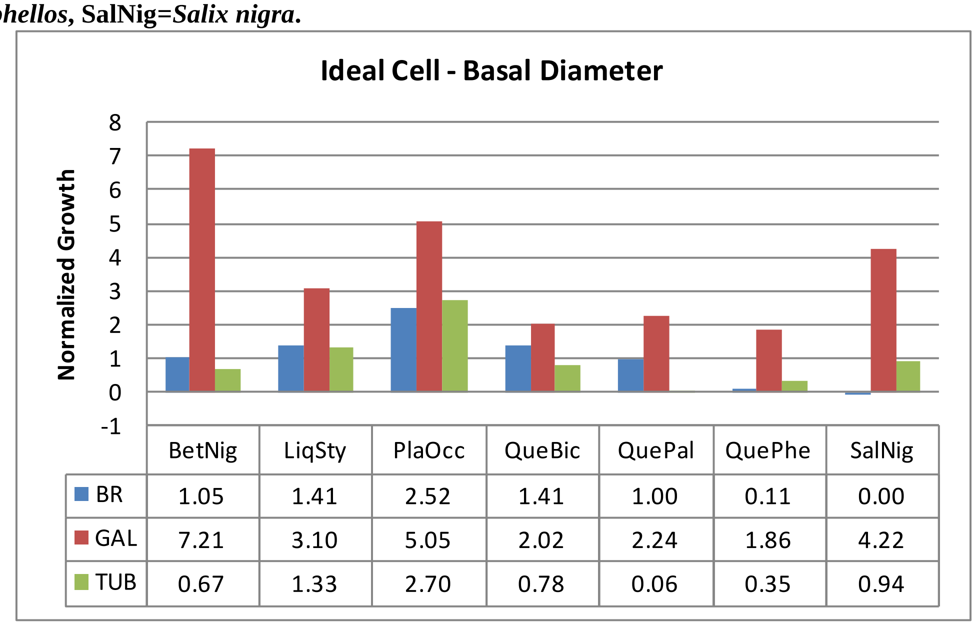
	BR	Gal	Tub
Average	84.2	92.5	81.8

Growth: Mesocosm

Change in Basal Diameter

Overall the Ideal Cell had significantly more basal diameter growth than the Saturated and Flooded Cells ($p<0.05$) while there was no difference between the Saturated and Flooded Cells (T-test, $n=19$, $p=0.2546$). (Figure 14 A-C). Gallon plantings had significantly more change than both bare-root and tubelings in all Cells while there was no difference in change between bare-root and tubelings in all three Cells (paired T-test, $n=19$, $p<0.05$).

Figure 14A. Change in basal diameter by species and planting type in the Ideal Cell of the Mesocosm Study. Data was normalized prior to calculating. BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra*.



	BetNig	LiqSty	PlaOcc	QueBic	QuePal	QuePhe	SalNig
BR	1.05	1.41	2.52	1.41	1.00	0.11	0.00
GAL	7.21	3.10	5.05	2.02	2.24	1.86	4.22
TUB	0.67	1.33	2.70	0.78	0.06	0.35	0.94

Figure 14B. Percent change in basal diameter by species and planting type in the Saturated Cell of the Mesocosm Study. Data was normalized prior to calculating. BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra*.

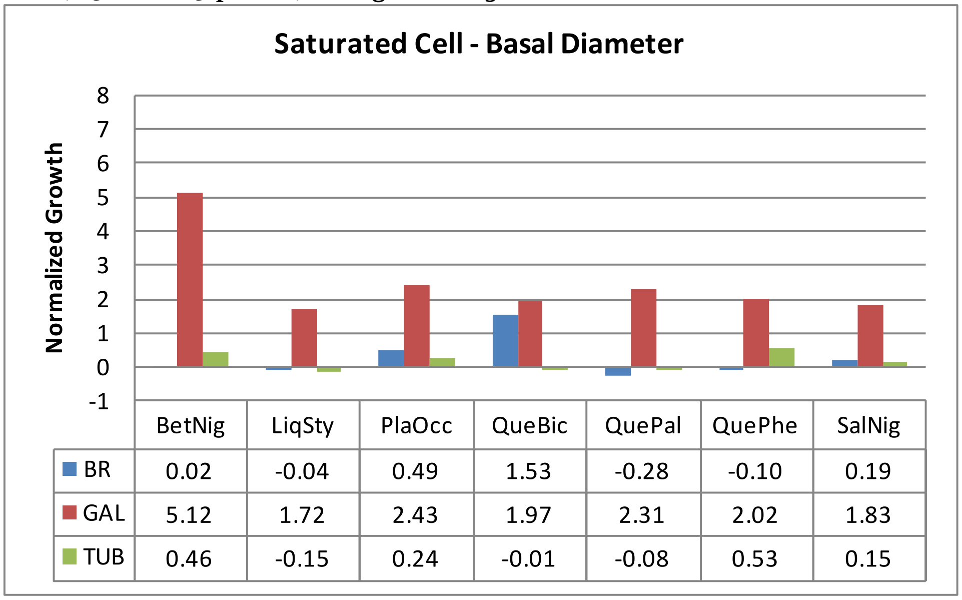
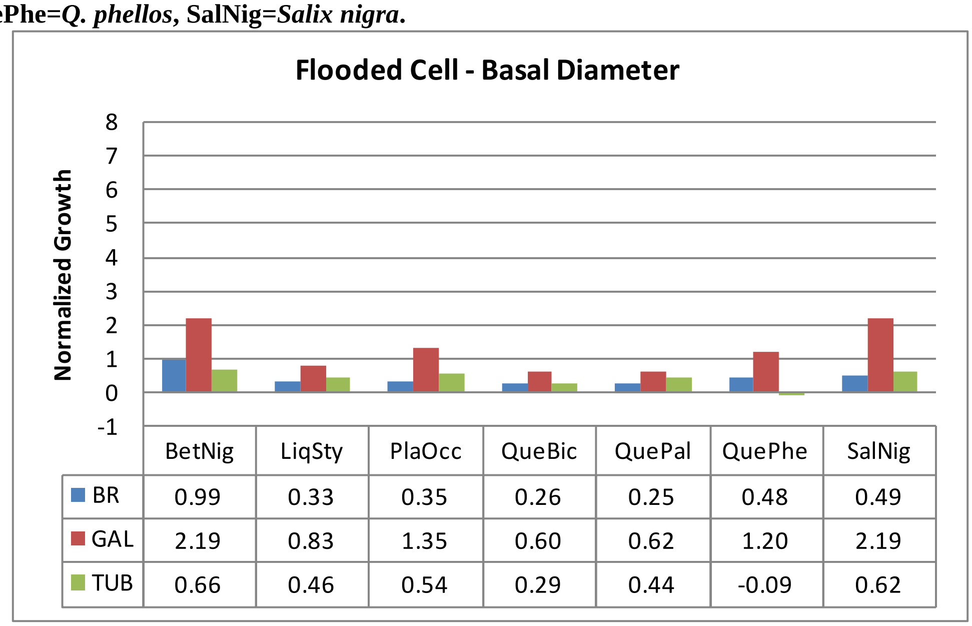


Figure 14.C. Percent change in basal diameter by species and planting type in the Flooded Cell of the Mesocosm Study. Data was normalized prior to calculating. BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra*.



Canopy Cover

Since data was collected in both mid-summer (late July) and early fall (early November), we are able to compare canopy cover data to determine maximum (peak) growth time for measuring purposes. When all Cells were combined and July canopy cover compared to November canopy cover, there was no significant difference (T-test, n=19, p=0.24224). When broken down by planting type, canopy cover was not significantly different for July verses November gallon planting measurements (T-test, n=19, p=0.59541). Tubeling plantings, while not significant at the p=0.05 level, did show a trend toward increased growth in November (T-test, n=19, p=0.05726) and bare-root plantings showed a significant increased in November (T-test, n=19, p=0.01566). When planting type was combined, July canopy cover showed no difference between Cells (T-test, n=19, p>0.05) (Table 3), but in November the Ideal Cell canopy cover was significantly greater than that of both the Saturated and Flooded Cell (T-test, n=19, p= 0.00614 and 0.01921, respectively), with no difference between the Saturated and Flooded (T-test, n=19, p= 0.65161). When planting types were separated out, the Ideal Cell was significantly higher than in November than in late July (T-test, n=19, p= 0.0614 and 0.01921, respectively), but not in the Saturated (T-test, n=19, p=0.200349) or Flooded Cells (T-test, n=19, p=0.220324). Therefore, in order to measure peak canopy cover, it appears that it would be best to collect final canopy cover, at least for the gallon species, in early fall before senescence.

Canopy cover for early November, with all species combined, was significantly greater in the Ideal Cell than the Saturated and Flooded Cells (p>0.05, Table 3). There was no difference in the Saturated and Flooded Cell (p>0.05, Table 3).

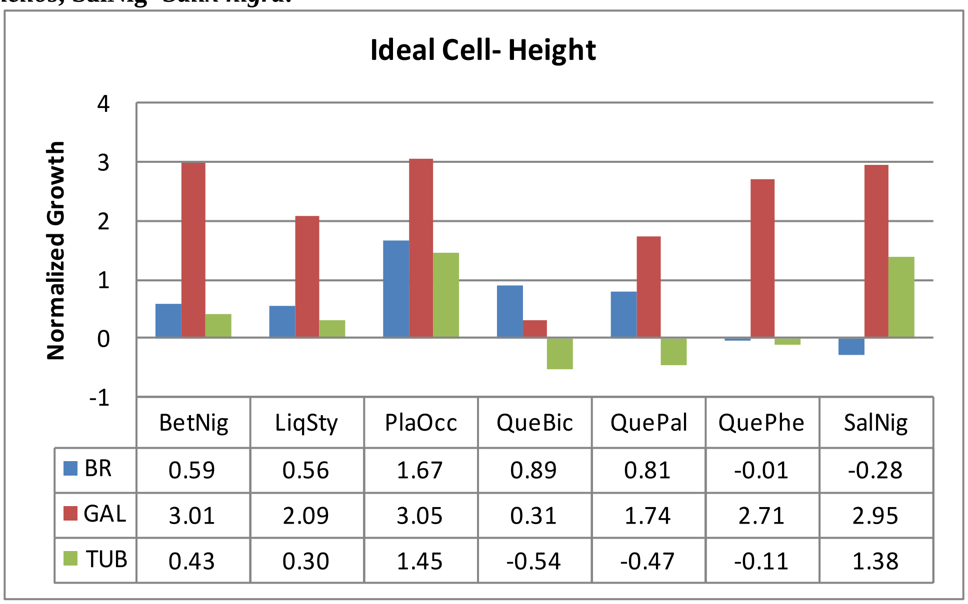
Table 4. Two-Tailed Paired T-test comparing July and November Canopy Cover of Mesocosm Cells. (*) indicates significant difference (N=19).

July/November	Ideal	Saturated	Flooded
Ideal	**X**	**0.00614***	**0.01921***
Saturated	**0.21233**	**X**	**0.65161**
Flooded	**0.42906**	**0.64582**	**X**

Change in Height

The Ideal cell had significantly greater growth in height than both the Saturated (T-test, n=19, p=0.02146) and the Flooded Cells (paired T-test, n=19, p=0.0107 (Figure 15 A-C). The Saturated Cell had significantly greater change in height (paired T-test, n=19, p=0.0538) (Figure 15 A-C).

Figure 15A. Percent change in height by species and planting type in the Ideal Cell of the Mesocosm Study. Data was normalized prior to calculating. BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra*.

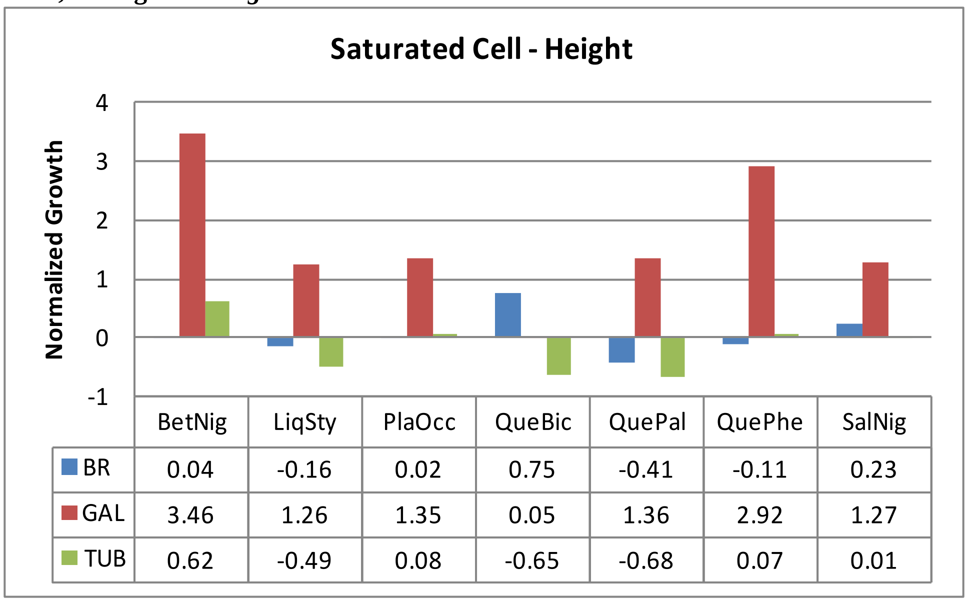


	BetNig	LiqSty	PlaOcc	QueBic	QuePal	QuePhe	SalNig
BR	0.59	0.56	1.67	0.89	0.81	-0.01	-0.28
GAL	3.01	2.09	3.05	0.31	1.74	2.71	2.95
TUB	0.43	0.30	1.45	-0.54	-0.47	-0.11	1.38

Comparison of Planting Type

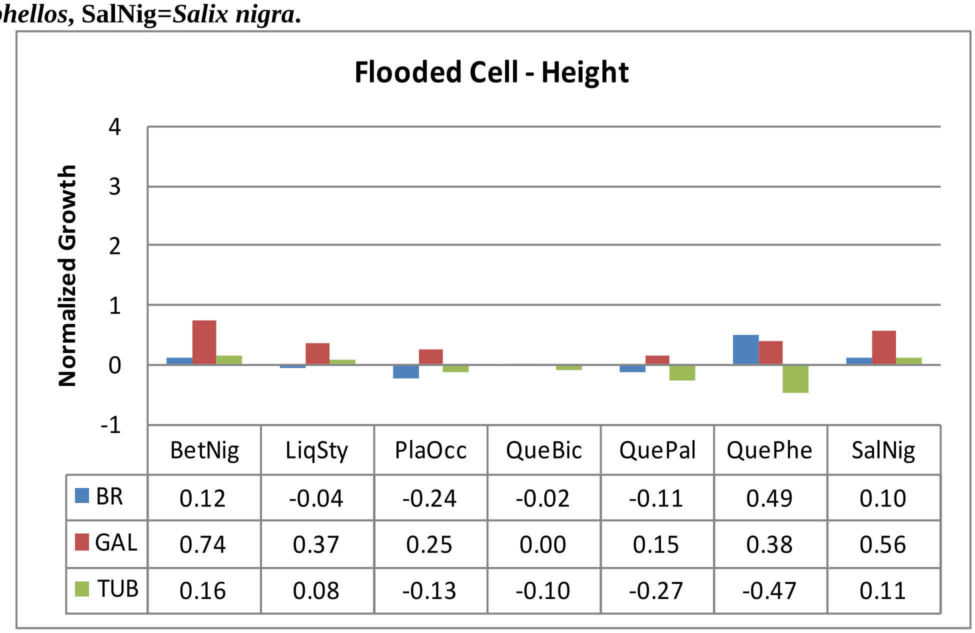
Gallon plantings had significantly greater basal area, canopy cover, and height than bare-root and tubeling plantings (ANOVA, n=7, p=0.0495). There was no significant difference, however, in basal area, canopy cover, and height between bare-root and tubeling plantings (T-test, n=7, p=0.6481, 0.2065, 0.0699, respectively). Overall, there was a significant difference with the primary species (*B. nigra*, *L. styraciflua*, *S. nigra*) showing greater growth in basal area, canopy cover, and height than the secondary species (*Q. bicolor, Q. palustris, Q. phellos*) (T-test, n=7, p=0.0317, 0.0101, 0.0284, respectively). Note that *P. occidentalis*, because of its poor survival, was removed from the calculation since the few remaining plantings would skew the data.

Figure 15 B. Percent change in height by species and planting type in the Saturated Cell of the Mesocosm Study. Data was normalized prior to calculating. BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra*.



	BetNig	LiqSty	PlaOcc	QueBic	QuePal	QuePhe	SalNig
BR	0.04	-0.16	0.02	0.75	-0.41	-0.11	0.23
GAL	3.46	1.26	1.35	0.05	1.36	2.92	1.27
TUB	0.62	-0.49	0.08	-0.65	-0.68	0.07	0.01

Figure 15C. Percent change in height by species and planting type in the Flooded Cell of the Mesocosm Study. Data was normalized prior to calculating. BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra*.



	BetNig	LiqSty	PlaOcc	QueBic	QuePal	QuePhe	SalNig
BR	0.12	-0.04	-0.24	-0.02	-0.11	0.49	0.10
GAL	0.74	0.37	0.25	0.00	0.15	0.38	0.56
TUB	0.16	0.08	-0.13	-0.10	-0.27	-0.47	0.11

Herbivory

Herbivory was noted in the all cells; however it was common in only the Saturated Cell and then only on *P. occidentalis* and *S. nigra* (<20% for each). In the other cells, and the other species in the Saturated Cell, herbivory was minimal.

Seasonal dieback

Dieback was common in all cells during June and July and is responsible for the negative change in growth in the Saturated Cell basal diameter (Figure 14 B) height (Figure 15 B) and Flooded Cell height (Figure 15 C). Bare-root and tubeling plantings of *P. occidentalis* and *Quercus* spp. were particularly susceptible (Figure 15 A-C). Many of the plantings had re-sprouted by August (data not shown). Coppicing (a form of re-sprouting from the roots) was common in the Saturated Cell but rare in the other two cells (data not shown).

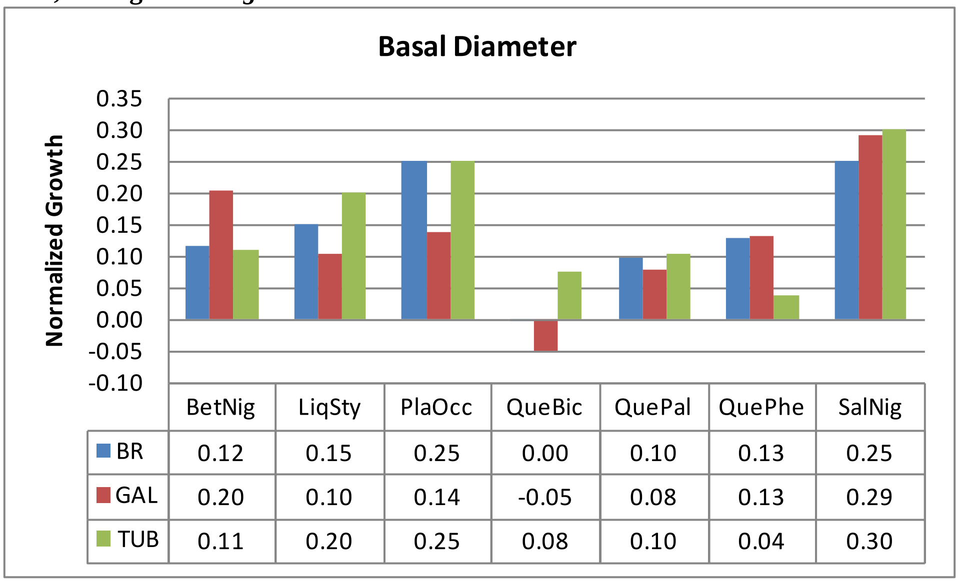
Growth: Field

Change in Basal Diameter

There was no significant difference in stem basal diameter growth among the three phases ($p=0.066$).

Q. bicolor gallon plantings had significantly less basal diameter growth than gallon plantings of *S. nigra* ($p<0.001$), *B. nigra* ($p<0.001$), *P. occidentalis* ($p<0.001$), *L. styraciflua* ($p<0.001$), and *Q. phellos* ($p<0.001$) (Figure 16). *Q. bicolor* bare-root plantings had significantly less basal diameter growth than bare-root plantings of *P. occidentalis* ($p<0.001$), *S. nigra* ($p<0.001$), and *B. nigra* ($p=0.002$) (Figure 16). There were no significant changes in stem basal diameter among all species of tubelings (Figure 16).

Figure 16. Percent change in basal diameter by species and planting type in the Field Study (Phases combined). Data was normalized prior to calculating. BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra*.

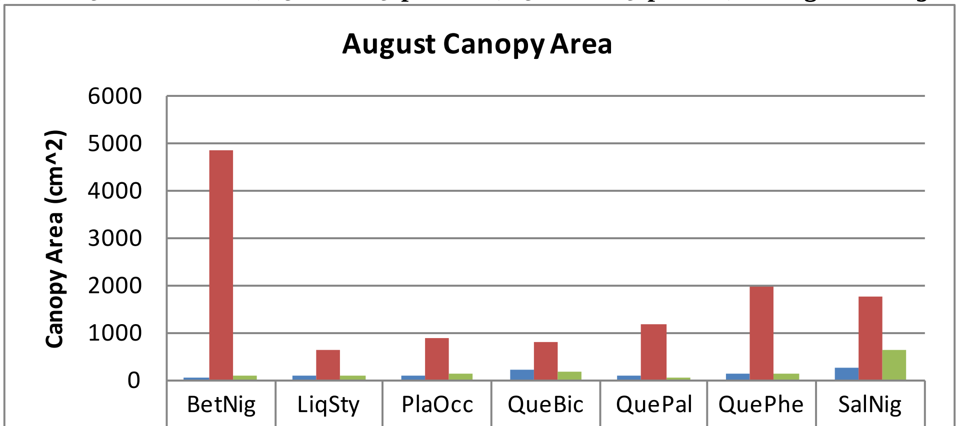


	BetNig	LiqSty	PlaOcc	QueBic	QuePal	QuePhe	SalNig
BR	0.12	0.15	0.25	0.00	0.10	0.13	0.25
GAL	0.20	0.10	0.14	-0.05	0.08	0.13	0.29
TUB	0.11	0.20	0.25	0.08	0.10	0.04	0.30

Canopy Cover

Trees planted in Phase 2 had significantly larger canopy areas than Phase 3 (p=0.008). Gallon plantings of *B. nigra* had significantly greater canopy area than all of the other species (p<0.05) (Figure 17). Bare-root plantings of *Q. bicolor* had significantly greater canopy area than bare-root plantings of *Q. phellos* (p<0.001), *Q. palustris* (p<0.001), *P. occidentalis* (p<0.001), *L. styraciflua* (p<0.001), and *B. nigra* (p<0.001) (Figure 17). *S. nigra* tubelings had significantly greater canopy area than all other species (p<0.05) (Figure 17).

Figure 17. Canopy coverer by species and planting type in the Field Study (Phases combined). BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra*.

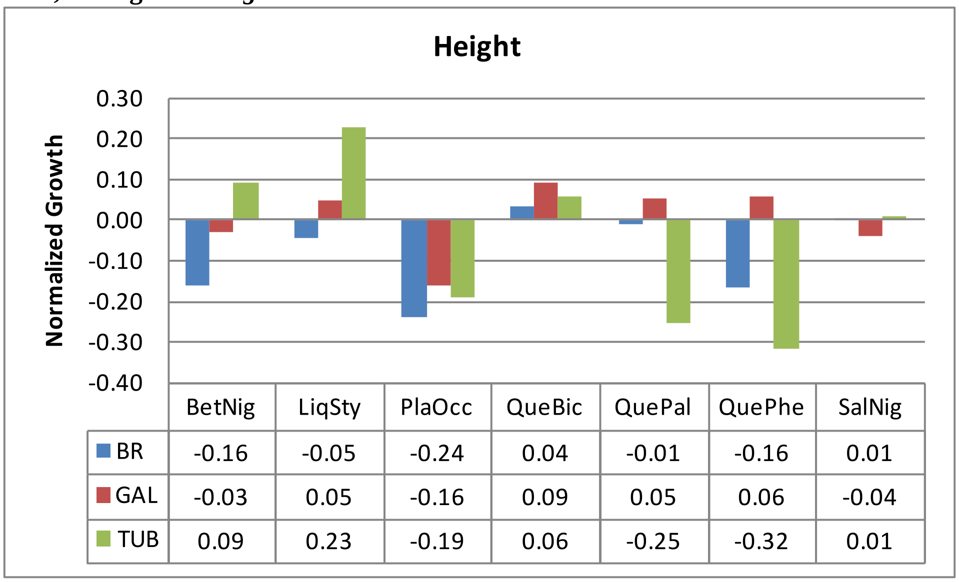


	BetNig	LiqSty	PlaOcc	QueBic	QuePal	QuePhe	SalNig
BR	59.40	68.58	67.68	230.49	86.69	115.98	241.62
GAL	4825.58	610.61	899.92	781.13	1180.65	1967.58	1761.39
TUB	96.96	90.05	137.51	152.10	58.22	110.85	610.46

Change in Height

Phase 2 had significantly greater increase in height than Phase 1 (p=0.016) and Phase 3 (p=0.009). Gallon plantings of *P. occidentalis* had a significant negative decrease in height compared to gallon plantings of *L. styraciflua* (p<0.001), *Q. bicolor* (p<0.001), *Q. palustris* (p<0.001), *Q. phellos* (p<0.001), and *S. nigra* (p<0.001) (Figure 18). Bare-root plantings of *P. occidentalis* had a significant negative decrease in height in compared to bare-root plantings of *L. styraciflua* (p<0.001), *Q. bicolor* (p<0.001), *Q. palustris* (p<0.001), and *S. nigra* (p=0.005) (Figure 18). Tubeling plantings of *P. occidentalis* had a significant negative decreases in height compared to *B. nigra* (p<0.001), *L. styraciflua* (p<0.001), and *S. nigra* (p<0.001) tubeling plantings (Figure 18).

Figure 18. Percent change in height by species and planting type in the Field Study (Phases combined). Data was normalized prior to calculating. BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra*.



	BetNig	LiqSty	PlaOcc	QueBic	QuePal	QuePhe	SalNig
BR	-0.16	-0.05	-0.24	0.04	-0.01	-0.16	0.01
GAL	-0.03	0.05	-0.16	0.09	0.05	0.06	-0.04
TUB	0.09	0.23	-0.19	0.06	-0.25	-0.32	0.01

Comparison of Planting Type

When all species were combined, there was no significant difference in stem basal area growth among the three planting types (p=0.202) (Figure 19). Gallon planting type had significantly greater canopy area than the tubelings and the bare-root plantings (p<0.001) (Figure 20). Gallon plantings had a significantly greater increase in height than the bare-root plantings (p<0.001)) and tubeling plantings (p=0.004) (Figure 21).

Comparison of Species

When planting types are combined, *Q. bicolor* had significantly less stem basal diameter growth than *P. occidentalis* (p<0.001), *S. nigra* (p<0.001), *L. styraciflua* (p<0.001), and *B. nigra* (p<0.001) (Figure 22 A). *Betula nigra* had significantly greater canopy area than all of the other species (Figure 22 B). *P. occidentalis* had significant decrease in height compared to *S. nigra* (p<0.001), *Q. bicolor* (p<0.001)), *L. styraciflua* (p<0.001), and *B. nigra* (p<0.001) (Figure 22 C).

Figure 19. Percent change in basal diameter by planting type in the Field Study (Phases combined). Data was normalized prior to calculating. BR=bare-root, Gal=gallon pot, Tub=tubelings.

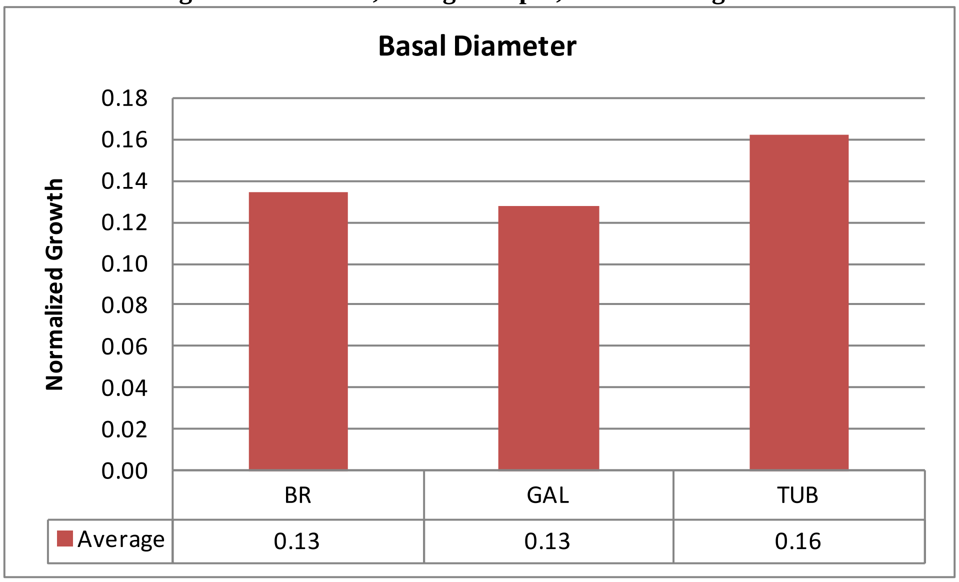


Figure 20. Percent change in canopy cover by planting type in the Field Study (Phases combined).BR=bare-root, Gal=gallon pot, Tub=tubelings.

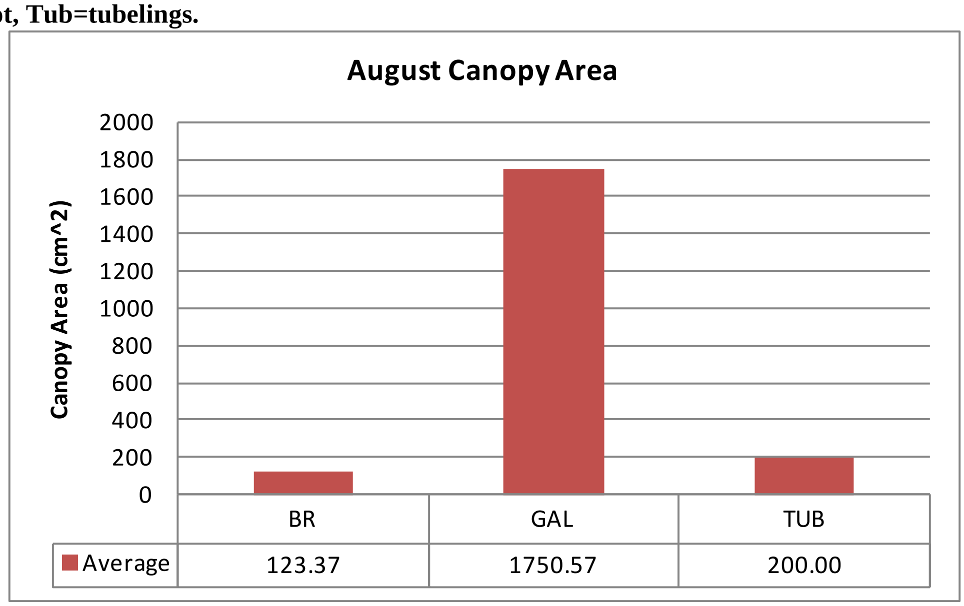


Figure 21. Percent change in height by planting type in the Field Study (Phases combined). Data was normalized prior to calculating. BR=bare-root, Gal=gallon pot, Tub=tubelings.

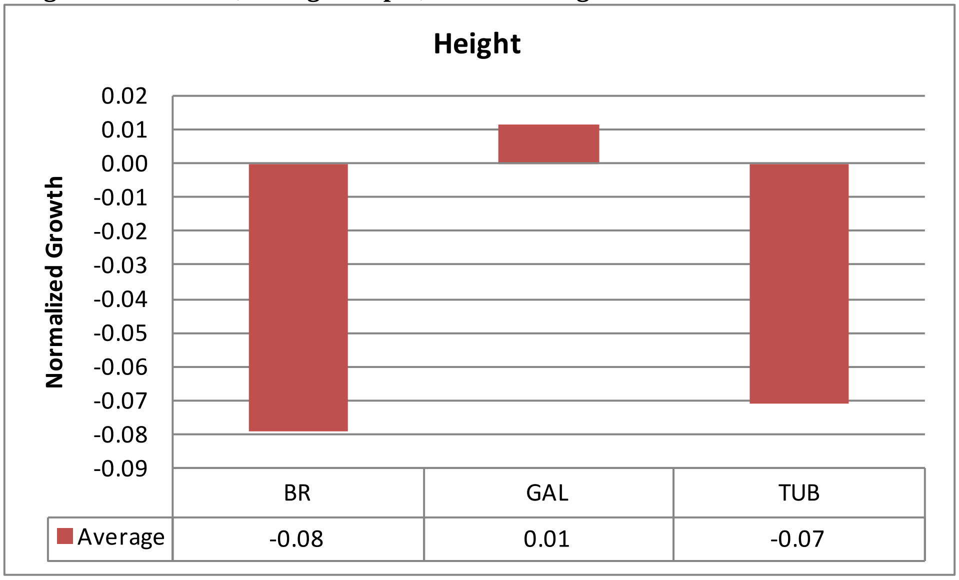
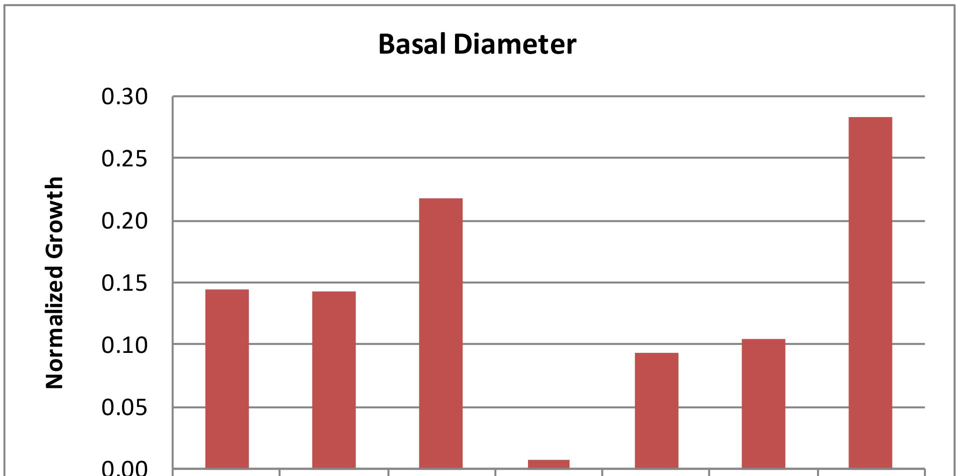
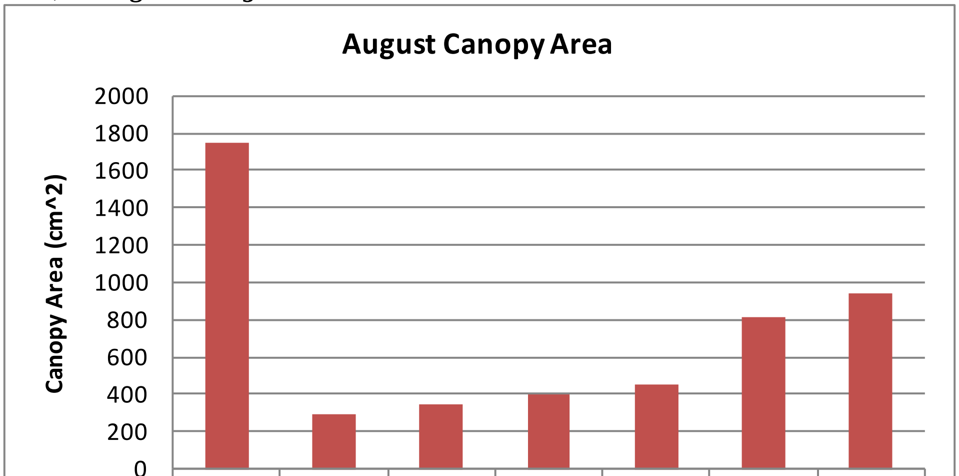


Figure 22A. Percent change in basal diameter by species in the Field Study (Phases and planting type combined). Data was normalized prior to calculating. BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra*.



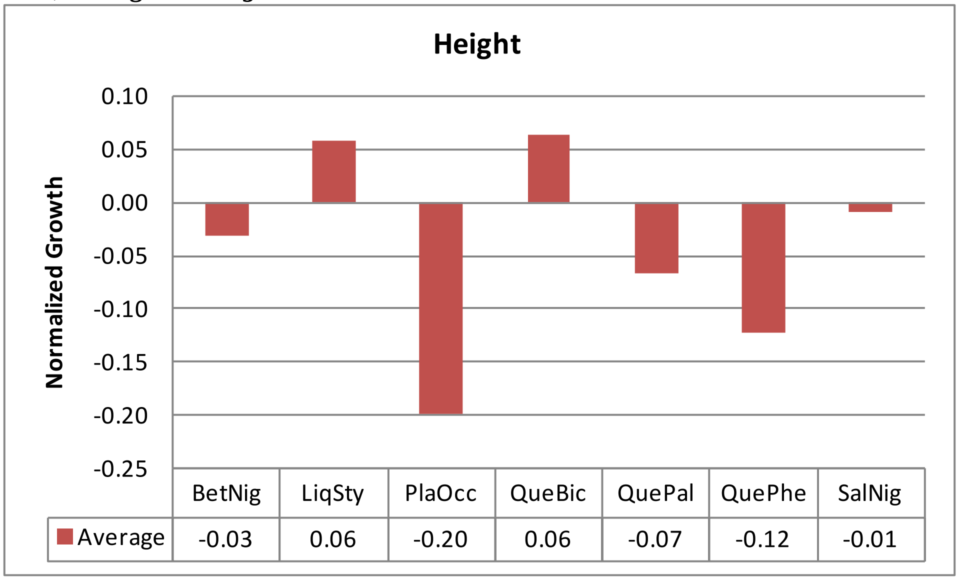
	BetNig	LiqSty	PlaOcc	QueBic	QuePal	QuePhe	SalNig
Average	0.14	0.14	0.22	0.01	0.09	0.10	0.28

Figure 22B. Canopy cover by species in the Field Study (Phases and planting type combined). Data was normalized prior to calculating. BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra*.



	BetNig	LiqSty	PlaOcc	QueBic	QuePal	QuePhe	SalNig
Average	1744.42	292.29	342.10	400.58	455.73	810.17	942.70

Figure 22C. Percent change in height by species in the Field Study (Phases and planting type combined). Data was normalized prior to calculating. BR=bare-root, Gal=gallon pot, Tub=tubelings, BetNig=*Betula nigra*, LiqSty=*Liquidambar styraciflua*, PlaOcc=*Platanus occidentalis*, QueBic=*Quercus bicolor*, QuePal=*Q. palustris*, QuePhe=*Q. phellos*, SalNig=*Salix nigra*.



Herbivory

Herbivory reached a peak in *S. nigra* (19%) but was less than 10% of all other species and planting type (Table 5). No herbivory was found on *Q. bicolor*. Main herbivore appeared to be a leaf aphid (yet unidentified)

Table 5. Overall percent herbivory

Species	Planting Type	Total Alive	# Plantings with Herbivory Signs	% Herbivory
Betula nigra	Bare-root	68	2	2.94
Betula nigra	Gallon	73	5	6.85
Betula nigra	Tubeling	68	1	1.47
Liquidambar styraciflua	Bare-root	64	2	3.13
Liquidambar styraciflua	Gallon	73	4	5.48
Liquidambar styraciflua	Tubeling	43	0	0.00
Platanus occidentalis	Bare-root	52	2	3.85
Platanus occidentalis	Gallon	51	0	0.00
Platanus occidentalis	Tubeling NO SOIL	69	1	1.45
Quercus bicolor	Bare-root	67	0	0.00
Quercus bicolor	Gallon	75	0	0.00
Quercus bicolor	Tubeling	69	0	0.00
Quercus palustris	Bare-root	73	0	0.00
Quercus palustris	Gallon	74	2	2.70

Quercus palustris	Tubeling	68	1	1.47
Quercus phellos	Bare-root	67	0	0.00
Quercus phellos	Gallon	71	3	4.23
Quercus phellos	Tubeling NO SOIL	51	0	0.00
Salix nigra	Bare-root	57	11	19.30
Salix nigra	Gallon	75	7	9.33
Salix nigra	Tubeling NO SOIL	67	6	8.96
	Total	1375	47	3.42

Seasonal Dieback

There were 579 saplings out of 1375 (42.1%) that exhibited negative % change in height. No change in height was exhibited by 82 saplings out of 1375 (5.9%) (Table 5). *Q. palustris* tubelings had the highest percentage of plantings with dieback (85.29%) (Table 6).

Table 6. Percent dieback.

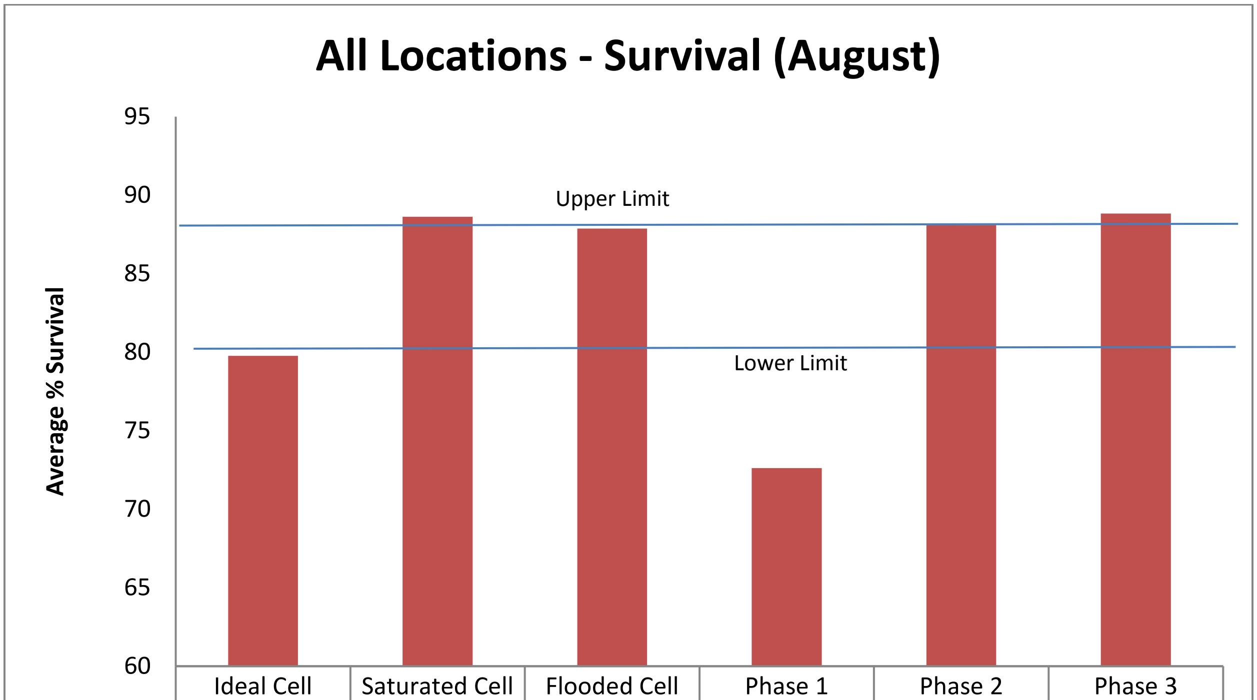
Species	**Planting Type**	**Total Alive**	**# Plantings with Dieback**	**% Dieback**	**# Plantings with no change in height**	**% no change**
Betula nigra	Bare-root	68	35	51.47	4	5.88
Betula nigra	Gallon	73	22	30.14	1	1.37
Betula nigra	Tubeling	68	18	26.47	2	2.94
Liquidambar styraciflua	Bare-root	64	28	43.75	5	7.81
Liquidambar styraciflua	Gallon	73	13	17.81	1	1.37
Liquidambar styraciflua	Tubeling	43	7	16.28	2	4.65
Platanus occidentalis	Bare-root	52	38	73.08	1	1.92
Platanus occidentalis	Gallon	51	32	62.75	4	7.84
Platanus occidentalis	Tubeling NO SOIL	69	43	62.32	1	1.45
Quercus bicolor	Bare-root	67	23	34.33	6	8.96
Quercus bicolor	Gallon	75	9	12.00	7	9.33
Quercus bicolor	Tubeling	69	23	33.33	4	5.80
Quercus palustris	Bare-root	73	29	39.73	9	12.33
Quercus palustris	Gallon	74	23	31.08	8	10.81
Quercus palustris	Tubeling	68	58	85.29	3	4.41
Quercus phellos	Bare-root	67	47	70.15	12	17.91
Quercus phellos	Gallon	71	19	26.76	3	4.23
Quercus phellos	Tubeling NO SOIL	51	38	74.51	6	11.76
Salix nigra	Bare-root	57	27	47.37	1	1.75
Salix nigra	Gallon	75	26	34.67	2	2.67
Salix nigra	Tubeling NO SOIL	67	21	31.34	0	0.00
	Total	1375	579	42.11	82	5.96

Comparison of Parameters of Field to Mesocosm

Survival

Overall there was no significant difference between Phases and Mesocosm data (ANOVA, $n=510$, $p>0.05$). The design of our model dictated that the Ideal Cell, having lowest survival, would represent the lower limit of expected survival and the Flooded Cell the upper limit. While this is the opposite of what had been expected, it is probably due to the use of flood tolerant species (see discussion below). Phase 2 and 3 fit well within the upper limits of the model confines of the Ideal and Flooded Cells (Figure 23) while Phase 1 fell below Ideal.

Figure 23. Survival of all Cells and Phases. Upper limit is defined by the Flooded Cell and lower limit by Ideal Cell.

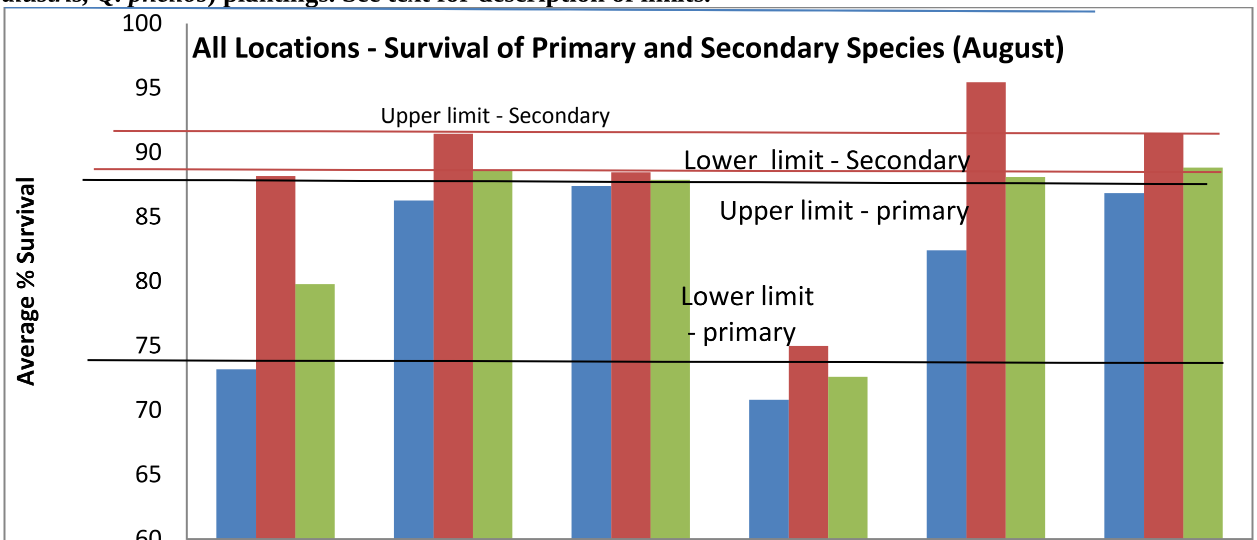


	Ideal Cell	Saturated Cell	Flooded Cell	Phase 1	Phase 2	Phase 3
Average	79.8	88.6	87.9	72.6	88.1	88.8

Primary verses Secondary Species

Again we use the highest and lowest % survival of species in the cell to represent the upper and lower limits. Both primary and secondary % survival of Phase 1 fell below the lower limits (Figure 24). All others were within the set range. The narrow range of the secondary species implies a consistency in survival rates across hydric conditions.

Figure 24. % survival of primary (*B. nigra, L. styraciflua, P. occidentalis, S. nigra*) and secondary (*Q. bicolor, Q. palustris, Q. phellos*) plantings. See text for description of limits.

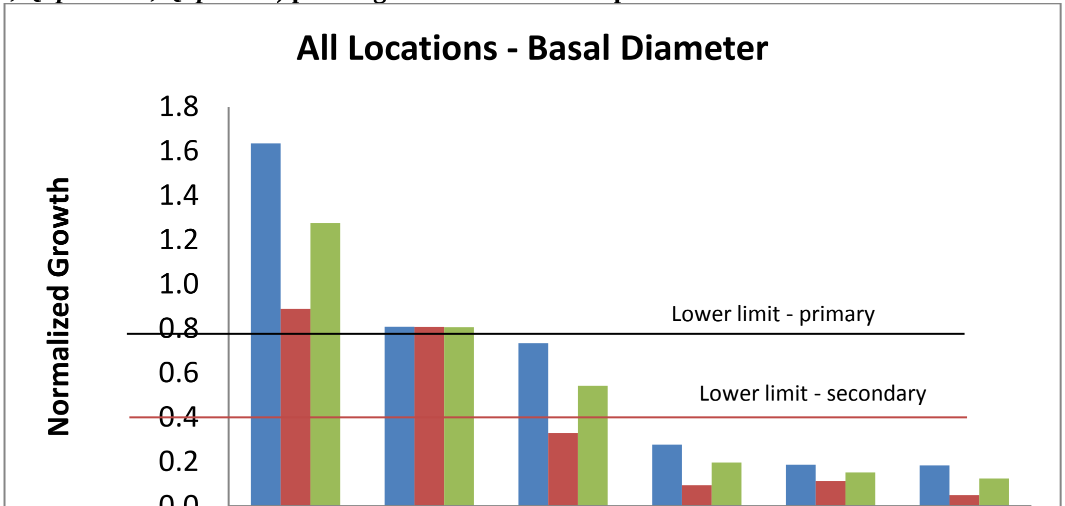


	Ideal Cell	Saturated Cell	Flooded Cell	Phase 1	Phase 2	Phase 3
Primary	73.2	86.3	87.4	70.8	82.4	86.8
Secondary	88.2	91.4	88.4	75.0	95.5	91.5
Overall	79.8	88.6	87.9	72.6	88.1	88.8

Growth Parameters

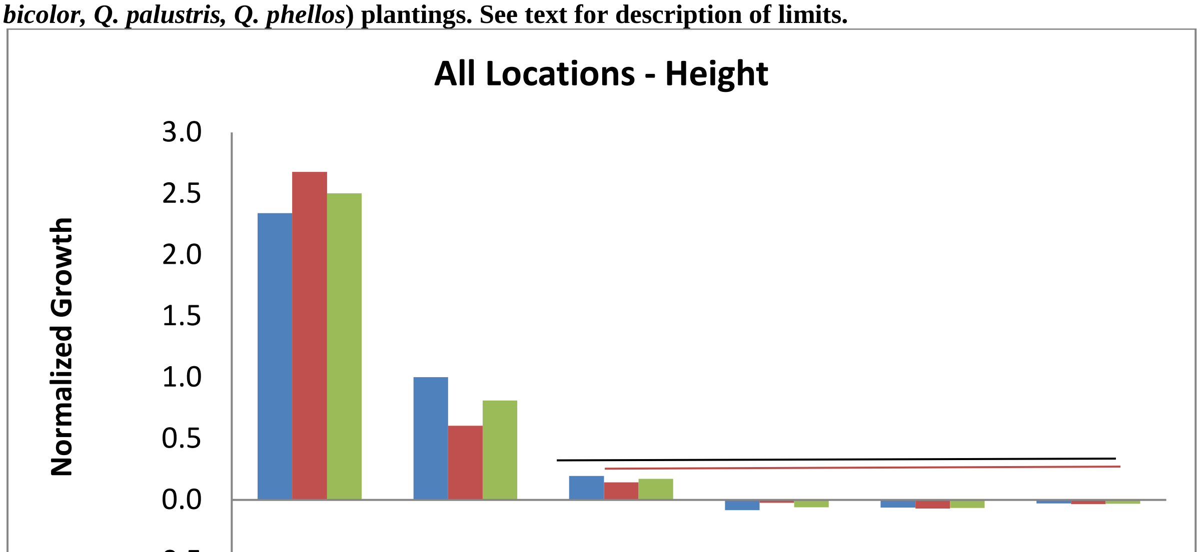
Neither the secondary or primary plantings of the Phase sites met the minimum basal diameter or height growth model of the Cells (Figure 25 A and B). Primary species of Phase 2 and 3 were within the model parameters, however, secondary species did not meet the minimum (Figure 25 A-C).

Figure 25A. Upper and lower limits of primary (*B. nigra, L. styraciflua, P. occidentalis, S. nigra*) and secondary (*Q. bicolor, Q. palustris, Q. phellos*) plantings. See text for description of limits.



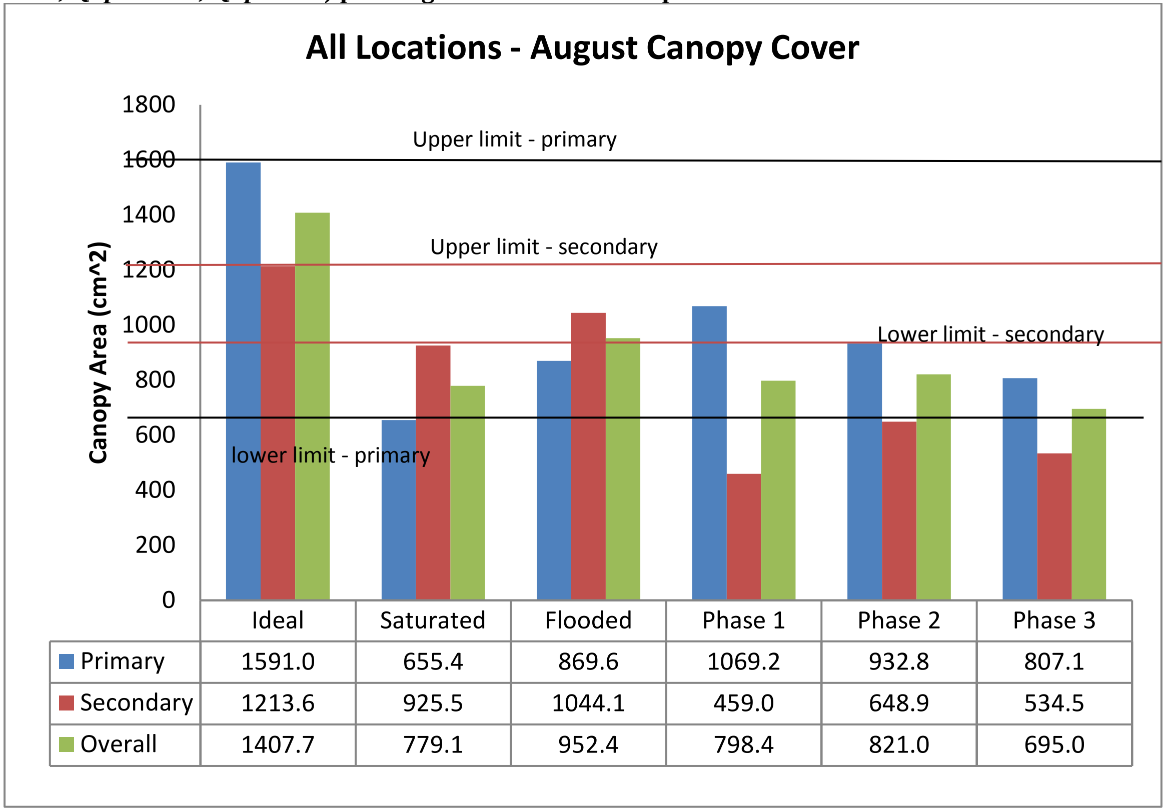
	Ideal	Saturated	Flooded	Phase 1	Phase 2	Phase 3
Primary	1.6	0.8	0.7	0.3	0.2	0.2
Secondary	0.9	0.8	0.3	0.1	0.1	0.1
Overall	1.3	0.8	0.5	0.2	0.2	0.1

Figure 25B. Upper and lower limits of primary (*B. nigra, L. styraciflua, P. occidentalis, S. nigra*) and secondary (*Q. bicolor, Q. palustris, Q. phellos*) plantings. See text for description of limits.



	Ideal	Saturated	Flooded	Phase 1	Phase 2	Phase 3
Primary	2.3	1.0	0.2	-0.1	-0.1	0.0
Secondary	2.7	0.6	0.1	0.0	-0.1	0.0
Overall	2.5	0.8	0.2	-0.1	-0.1	0.0

Figure 25C. Upper and lower limits of primary (*B. nigra, L. styraciflua, P. occidentalis, S. nigra*) and secondary (*Q. bicolor, Q. palustris, Q. phellos*) plantings. See text for description of limits.



	Ideal	Saturated	Flooded	Phase 1	Phase 2	Phase 3
Primary	1591.0	655.4	869.6	1069.2	932.8	807.1
Secondary	1213.6	925.5	1044.1	459.0	648.9	534.5
Overall	1407.7	779.1	952.4	798.4	821.0	695.0

LITERATURE CITED

Atkinson RB, RT Belcher, DA Brown and JE Perry (eds) (2003) Restoration and Management of Atlantic White Cedar Swamps: Proceedings of a Symposium at Christopher Newport University, May 31-June 2, 2000.

_____ RB, JE Perry, and J Cairns, Jr. (2005) Vegetative communities of 20-year old created depressional wetlands. Wetlands Ecology and Management 13(4): 469-478.

_____ RB and J Cairns, Jr. (2001) Plant decomposition and litter accumulation in depressional wetlands: Functional performance of two wetland age classes that were created via excavation. Wetlands 21(3): 354-362.

_____ RB, JE Perry, EP Smith, and J Cairns, Jr. (1993a) Use of constructed wetland delineation and weighted averages as a component of assessment. Wetlands 13(2): 185-193.

_____ RB, J Cairns, Jr. and PR Benzing (1993b) Constructed wetland potential for performing wetland functions dependent on anaerobic soil conditions. Pp. 15-30 IN Proc. 20th Annual Conference on Wetlands Restoration and Creation, Hillsboro Com. Col., Plant City, FL.

_____RB, JD Roquemore and HW Hudson (2008) Nontidal wetland compensation monitoring for an in-lieu fee program in Virginia: Results from a third party university report on seven sites. Abstract presented at SWS, Washington, DC.

Bailey DE (2006) Wetland vegetation dynamics and ecosystem gas exchange in response to organic matter loading rates. MS Thesis. Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, USA.

_____ DE, JE Perry, and WL Daniels (2007) Vegetation dynamics in response to an organic matter loading experiment in a created freshwater wetland in southeastern Virginia. Wetlands 27: 936-950.

Brinson MM (1993) A hydrogeomorphic classification for wetlands. Technical Report WRP-DE-4, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg.

Cornell JA, CB Craft, and JP Megonigal (2007) Ecosystem gas exchange across a created salt marsh chronosequence. Wetlands 27: 240-250.

Cronk JK and MS Fennessey (2001) Wetland plants: biology and ecology. Lewis Publishers, Boca Raton.

Daniels WL, G Fajardo, CR Bergschneider, JE Perry, RG Whittecar, AD Despres, and GM Fitch (2005) Effects of soil amendments and other practices upon the success of the Virginia Department of Transportation's non-tidal wetland mitigation efforts. Pages 64 *in* V. D. Transportation, editor. Virginia Transportation Research Council. http://vtrc.virginiadot.org/PubDetails.aspx?PubNo=05-CR25.

Day, F.P., Jr. 1985. Tree Growth Rates in the Periodically Flooded Great Dismal Swamp, *Castanea*, 50(2): 89-95

DeBerry DA (2006) Floristic Quality Index: ecological and management implications in created and natural wetlands. Dissertation, College of William and Mary.

_____ DA and JE Perry (in press) Floristic composition across a fifteen-year chronosequence of created wetland sites in Virginia. J. Wetland Ecology and Management.

_____ DA and Perry JE (2004) Primary succession in a created freshwater wetland. Castanea 63: 185-193.

Dickinson SB (2007) Influences of Soil Amendments and Microtopography on Vegetation at a Created Tidal Freshwater Swamp in Southeastern Virginia. MS Thesis, Virginia Tech, Blacksburg, VA.

Minitab (2005) Minitab® statistical software, release 14. *in*, State College, PA.

Mueller-Dombois D and H Ellenberg (1974) Aims and methods of vegetation ecology. Wiley and Sons, London.

NOAA (2008) DS3505 - Surface Data, Hourly Global 72029799999 *in*. National Climatic Data Center, NNDC Climate Data Online.

Odum EP (1969) The strategy of ecosystem development. Science 164: 262-270.

Peet R, T Wentworth, and P White (1998) A flexible, multipurpose method for recording vegetation composition and structure. Castanea: 63(3): 262- 274.

Perry JE and C Hershner (1999) Temporal changes in the vegetation pattern in a tidal freshwater marsh. Wetlands 19(1): 90-99.

Spencer DR, JE Perry and GM Silberhorn (2001) Early secondary succession in bottomland hardwood forests of Southeastern Virginia. Environmental Management 27: 559-570.

Spieles DJ (2005) Vegetation development in created, restored, and enhanced mitigation wetland banks of the United States. Wetlands 25:51-63.

Systat (2004) SigmaPlot ® Software for Windows version 9.01. *in*. Systat Software, Inc, Point Richmond, CA.

Whittaker RH (1978) Direct gradient analysis. p. 9-50. In RH Whittaker (ed.) Ordination of plant communities. W. Junk, The Hague, The Netherlands.