Ecological Engineering 64 (2014) 408–414

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Survival and growth of seven tree species from three stocktypes planted in created wetlands in Loudoun County, Virginia

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ARTICLE INFO

Article history:
Received 11 June 2013
Received in revised form
29 December 2013
Accepted 1 January 2014

Keywords:
Created wetlands
Afforestation
Tree species
Stocktype
Planting material

ABSTRACT

Successful establishment and growth of trees in created wetlands is an important factor in efforts to compensate for forested wetland losses. Proper selection of seedlings to be planted in a replacement wetland, including tree species and stocktype, is essential to the ecological and economic viability of a wetland afforestation project. In this study seven commonly-planted forested wetland tree species and three stocktypes were planted in three created wetlands in the Piedmont region of Virginia. *Quercus bicolor* in 1-gallon container stocktype had the highest survival rate (96.2 ± 2.13% SE) and *Quercus phellos* planted as tubeling stocktype had the lowest survival rate (18.8 ± 3.33% SE). High survival rate occurred in 1-gallon stocktypes overall and may be related to larger initial seedling height and root collar diameter. Both tree species and stocktype explained a significant amount of variation in relative growth rates (RGR) of height (*H*), root collar diameter (RCD), and canopy diameter (CD), with the exception of RCD_{RGR} for stocktype. *Salix nigra* and *Betula nigra* were good performers overall, and exhibited moderate survival and growth rates across stocktypes. These survival and growth results should be considered when tree species and stocktypes are selected for seasonally flooded or saturated sites.

1. Introduction

Forested wetlands have suffered significant losses in the eastern US (Dahl, 1990; Tiner and Finn, 1986; USGS, 1999), and tree establishment, is often difficult in these areas (Matthews and Endress, 2008; Sharitz et al., 2006). Tree establishment is particularly difficult in created wetlands because wetland construction practices include removal of upper soil surfaces to the depth of the season high water table which results in soil compaction, lower organic content, higher bulk density, and greater predominance of gravel and larger particle sizes when compared to natural wetlands (Campbell et al., 2002). There are numerous species of woody plants and stocktypes available for planting in afforestation projects, some better suited for created wetlands than others. Several authors report low survival and growth rates for planting materials (Bailey et al., 2007; Bergshneider, 2005; Daniels et al., 2005; Stolt et al., 2000); however, there are few data-driven studies that have addressed how the choice of woody plant species and stocktype affects the survival and growth in created wetlands.

Because *Quercus* spp. (oaks) are economically and ecologically valuable components in palustrine forested wetlands (Gardiner, 2001; Kennedy and Nowacki, 1997; Wharton et al., 1982) they are often planted in replacement wetlands (Clewell, 1999). Planting *Quercus* spp. in early stages of afforestation projects may not be the most effective approach since *Quercus* spp. are slow growing and appear later in the forest succession processes; typically many years after the canopy closes. DeBerry and Perry (2012) concluded that early site conditions 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 as *Platanus occidentalis* and *Salix nigra*. Twedt (2006) found that species diversity, stem density, and maximum tree height were increased when *Quercus* spp. plantings were supplemented with fast-growing early-successional trees.

Stocktype (which is a descriptive term used to describe treatment and duration at the nursery, 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 allows 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 (Dumroese and Owsten, 2003). However, planting containers

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http://dx.doi.org/10.1016/j.ecoleng.2014.01.001

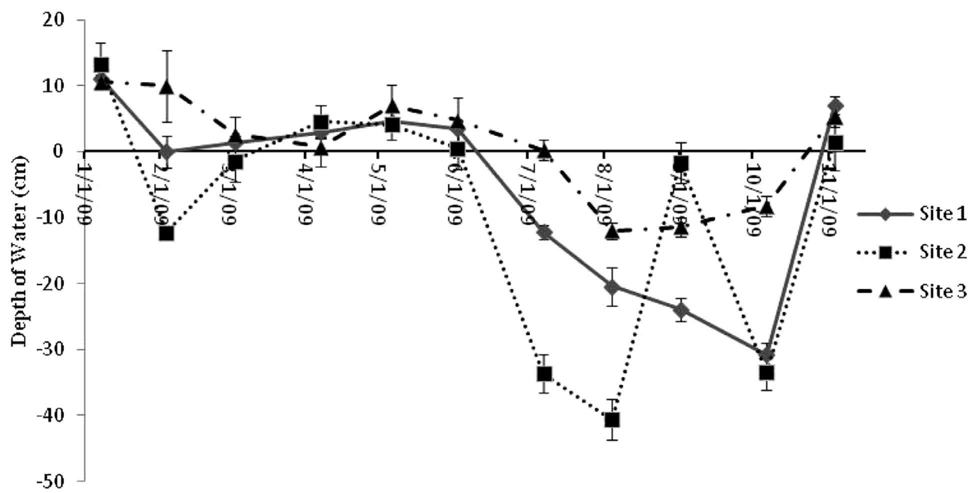

Fig. 1. Mean depth of water at wells adjacent to each site in 2009. Error bars represent standard error.

can restrict seedling root growth (Alm and Schantz-Hansen, 1974) which can impact survival of trees once planted (South et al., 2005) and containerized seedlings tend to be costlier than other stocktypes.

Sensitivity to environmental factors and risk of mortality is most intense during the first years after planting of tree seedlings (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 after two growing seasons were evaluated among seven commonly-planted forested wetland tree species and three stocktypes that were planted in three created wetlands in order to improve selection of planting materials.

2. Methods

2.1. Study sites

Created wetlands in Loudon County, Virginia, USA ranging in size from 3.3 to 3.9 ha and constructed between 2006 and 2008 as part of the Loudoun County Wetland and Stream Mitigation Bank (LCWSB) were selected for this study. Construction, which is intended to compensate for palustrine forested wetlands, included stripping and stockpiling of topsoil, adding a lime amendment, and disking to a minimum depth of 15 cm after topsoil replacement. Post-construction soils were classified as silt loam and silty clay loam. The topography at all sites is relatively uniform and the overall hydrology is driven principally by rainfall which averages 108.2 cm per year. Water level was monitored monthly in the initial year of the study (2009) at wells adjacent to the study sites. For all sites, the soil was inundated or saturated to in the upper 30 cm for the majority of growing season (Fig. 1) which extended 207 days from April 5th to November 1st; therefore hydrology at these sites is classified as seasonally flooded or saturated (Cowardin et al., 1979).

2.2. Study design

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

A total of 1596 trees in 25 plots across the 3 sites were planted in March 2009. Each sapling was flagged and mapped using an *x*- and *y*- coordinate grid system to facilitate resampling. Trees were planted on 2.4-meter centers (planting density of 1683 stems/ha). The 7 species and 3 stocktypes (Table 1) were planted in 21-tree replicate arrays within each plot and, depending on space availability; either 3 or 4 planting arrays were established.

2.3. Sampling methods

Survival counts and morphometric measurements were made in August 2009 and August 2010. Individuals were considered live when green leaves or a green vascular cambium was present. Occurrences of stem sprouting (epicormic shoot formation) and root suckering (adventitious shoot formation by roots) were recorded. Seedling morphology, height of highest stem (*H*), root collar diameter at soil level (RCD), and canopy diameter (CD), were measured on live trees following methods modified from Bailey et al. (2007). Height was measured using a meter stick. Root collar diameter was measured using micro-calipers (Haglof, Inc. "Man-

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+

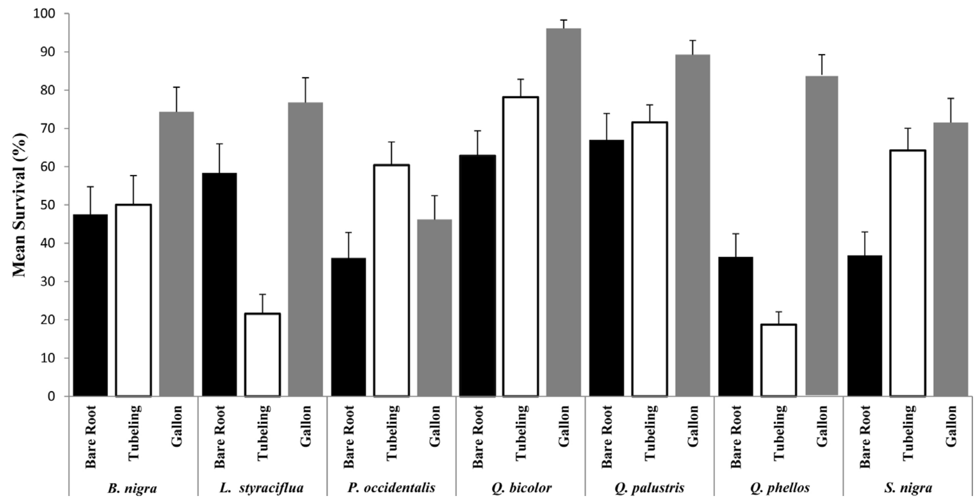

Fig. 2. Survival of tree species and stocktypes at the conclusion of the second growing season. Survival was analyzed at the array level (n = 76) and error bars represent standard error within plots.

tax Precision" Calipers). If there was more than one stem for a tree, root collar diameter of all stems was measured and the sum was recorded as the RCD. Canopy diameter was measured in three horizontal directions (including the visual maximum diameter and visual minimum diameter) to determine the average canopy diameter (SPI 6″/0.1 mm Poly Dial Calipers).

2.4. Data analysis

Relative growth rate (RGR) was calculated using the equation:

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

where r is the relative growth rate (RGR), W_1 the morphometric measurement of tree at time 1, W_2 the morphometric measurement of tree at time 2, t_1 the time of first measurement and t_2 is the time of second measurement (Hunt, 1990; Hoffmann and Poorter, 2002). Relative growth rates were calculated for height (H_{RGR}), root collar diameter (RCD_{RGR}), and canopy diameter (CD_{RGR}) over two growing seasons. Trees that died before the end of the second growing season were excluded from RGR calculations. RGR is reported in cm/cm/growing season for all parameters. Mixed procedure analysis of variance was performed for H_{RGR}, RCD_{RGR}, and CD_{RGR}. For each parameter (H, CD, RCD) an analysis of variance (ANOVA) blocked by sites was performed with a Bonferroni multiple comparison correction. The Mann–Whitney Rank Sum test was used to compare H_{RGR}, RCD_{RGR}, and CD_{RGR} of primary successional species to secondary species and to compare H_{RGR}, RCD_{RGR}, and CD_{RGR} of trees with a wetland indicator status of FAC or FAC+ to trees with a wetland indicator status of FACW−, FACW, or FACW+.

3. Results

3.1. Tree survival and growth

Overall survival after two years was 59.0%. *Quercus bicolor* in 1-gallon containers had the highest survival rate (96.2 ± 2.13% SE) and tubelings of *Quercus phellos* had the lowest survival rate (18.8 ± 3.33% SE) (Fig. 2).

Of the trees surviving through the second growing season, *Betula nigra* in 1-gallon containers were the tallest and had the largest CD (161 ± 10.8 cm SE, 62 ± 4.1 cm SE, respectively), and *S. nigra* in 1-gallon containers had the largest RCD (2.50 ± 0.12 cm SE). A significant amount of variation was explained in RGR for H, RCD, and CD ($p < 0.0001$ for each) by species, and a significant amount of variation in RGR for H and CD ($p = 0.002$, $p < 0.001$ respectively) was explained by stocktype; and there was a significant species × stocktype interaction for H_{RGR}, RCD_{RGR}, and CD_{RGR} ($p < 0.001$ for each) (Table 2). Created wetland site did not have a significant interaction with species or stocktype ($p = 0.053$, $p = 0.590$, $p = 0.354$ for H, RCD, and CD respectively). Differences were found between stocktypes within species (Figs. 3a, 4a and 5a) and between species within stocktypes (Figs. 3b, 4b and 5b). When RGRs of primary successional species were compared to RGRs of secondary species, using a Mann–Whitney Rank Sum test, the primary species exhibited higher RGR for RCD ($p < 0.001$) and CD ($p = 0.029$). A Mann–Whitney Rank Sum test found that RGR of species with a wetland indicator status of FAC or FAC+ had lower growth rates for H ($p < 0.001$), RCD ($p < 0.001$), and CD ($p = 0.004$) than those species with a wetland indicator status of FACW−, FACW, or FACW+.

3.2. Indicators of tree stress

During the second growing season, frequency of resprouting was surveyed and found to occur in all species (Table 3) and stocktypes (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 2
Mixed procedure analysis of variance results for H_{RGR}, RCD_{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
Stocktype	2	925	8.68	0.0002
Species × Stocktype	12	925	13.63	<0.0001
Root collar diameter				
Site	2	923	6.29	0.0019
Species	6	923	26.33	<0.0001
Stocktype	2	923	2.68	0.0693
Species × Stocktype	12	923	3.69	<0.0001
Canopy diameter				
Site	2	914	22.67	<0.0001
Species	6	914	5.72	<0.0001
Stocktype	2	914	15.93	<0.0001
Species × Stocktype	12	914	6.08	<0.0001

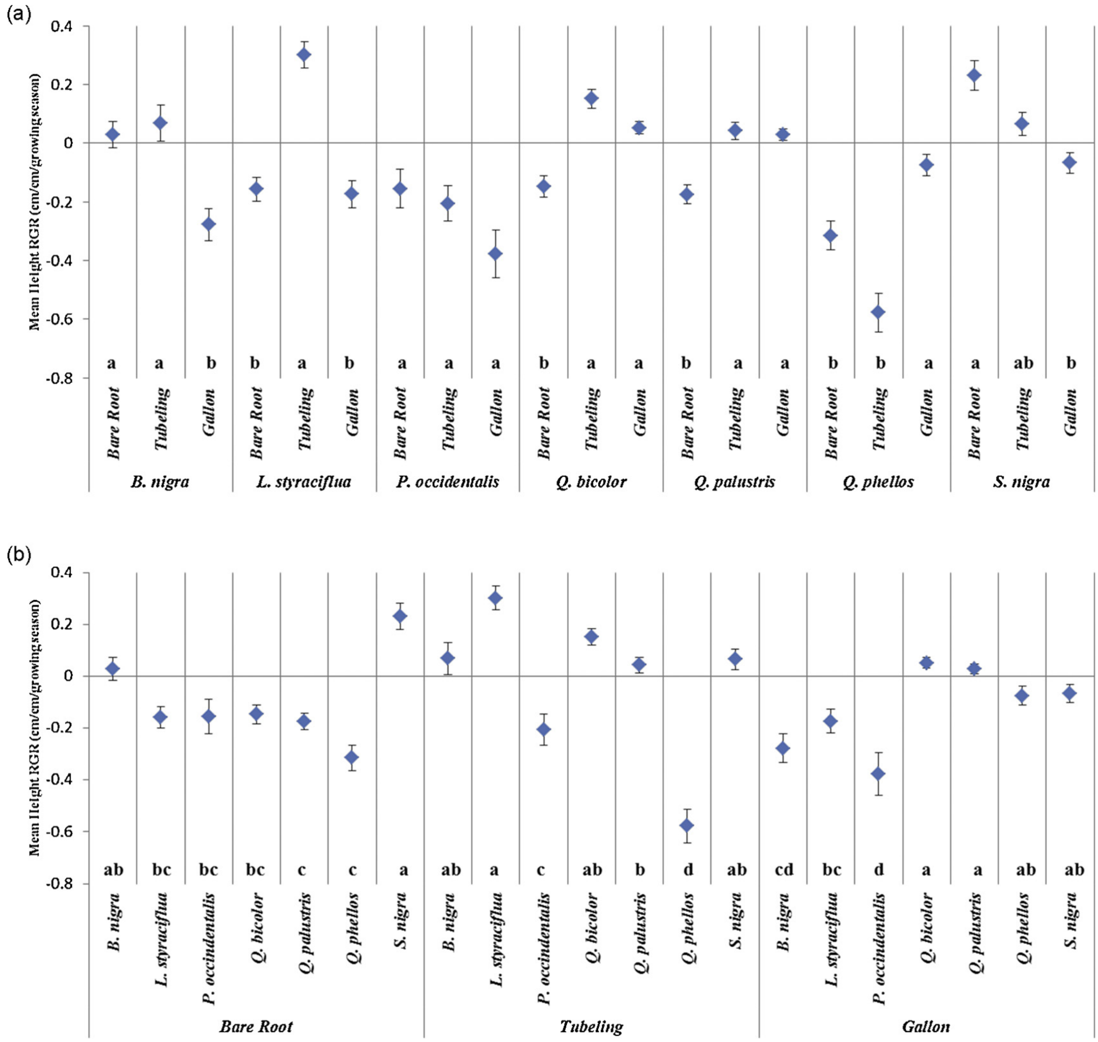

Fig. 3. (a) Simple effects model for H_{RGR} by stocktypes within species. Error bars represent standard error. Means with the same letter did not differ in growth rate among stocktypes for individual species (Bonferroni multiple comparison correction, $p < 0.05$). (b) Simple effects model for H_{RGR} by species within stocktypes. Error bars represent standard error. Means with the same letter did not differ in growth rate among individual species for stocktypes (Bonferroni multiple comparison correction, $p < 0.05$).

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

4. Discussion

4.1. Tree survival

The survival rate in this study (59.0% survived to the end of the second growing season) is slightly higher than that reported in an assessment of wetland compensation sites (including creation, restoration, enhancement, and preservation) which reported a combined (bare root and containerized seedlings) average of 47% survival rate across a wide range of site ages (Morgan and Roberts, 1999). Our tree survival rate was also slightly higher than that for a review of compensatory mitigation projects in Illinois in which there was 54% survival of planted trees after one year and 45% survival of planted trees after four years (Matthews and Endress, 2008).

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

Stocktype	% stem sprouting	% root suckering
Bare root	49.1	10.9
Tubeling	36.3	12.2
Gallon	25.8	15.6

Planted tree mortality may decrease after an initial establishment period. Jones and Sharitz (1998) studied colonizing woody plant seedlings in years 1 through 3 after planting and found survival was initially poor but increased with seedling age. The susceptibility of seedlings to early-establishment mortality was also observed by Alm and Schantz-Hansen (1974) where 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 numerically highest survival were secondary successional species (*Q. bicolor* and *Quercus palustris*) (Fig. 2). Secondary species are characterized by greater shade tolerance and slower growth (Horn, 1974), which may be advantageous given conditions found at our sites. Trees in 1-gallon containers had a numerically higher median initial height (116 ± 2.44 cm SE) when compared to tubelings and

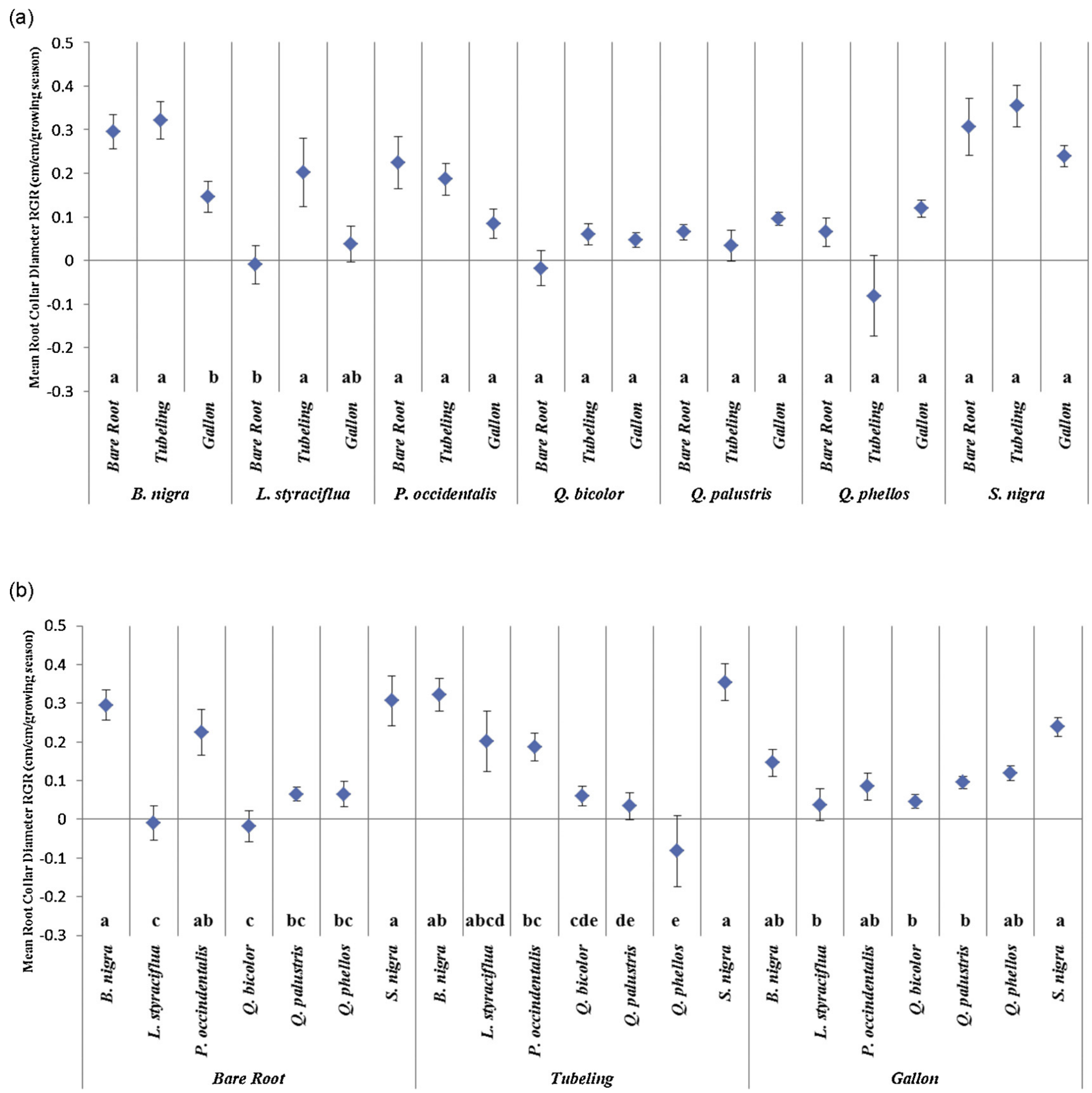

Fig. 4. (a) Simple effects model for RCD_{RGR} by stocktypes within species. Error bars represent standard error. Means with the same letter did not differ in growth rate among stocktypes for individual species (Bonferroni multiple comparison correction, $p < 0.05$). (b) Simple effects model for RCD_{RGR} by species within stocktypes. Error bars represent standard error. Means with the same letter did not differ in overall growth among individual species for stocktypes (Bonferroni multiple comparison correction, $p < 0.05$).

bare roots (45 ± 0.94 cm SE and 44 ± 0.58 cm SE, respectively) which may have contributed to the increased survival. Increased initial height common among trees grown in 1-gallon containers could also increase survival when trees are exposed to periodic flooding. Battaglia et al. (2000) found that survival of *Liquidambar styraciflua* and *Quercus michauxii* was disproportionately lower in smaller seedlings, regardless of experimental conditions, suggesting that taller trees were more tolerant of inundation. Similarly, Cook (2012) reported that taller seedlings of *Chamaecyparis thyoides* were less susceptible to mortality associated with inundation.

High survival of the 1-gallon stocktypes could be related to the median initial root collar diameter (1.4 cm) which was numerically larger than that for bare root seedlings (0.50 cm) and tubelings (0.60 cm). In a study of the effect of seedling container type on survival of *Pinus palustris*, South et al. (2005) found that container-grown seedlings had higher survival rates than bare root seedlings (75.9% and 53.5%, respectively) which was thought to be related to increased root collar diameter (analogous to our RCD) and associated root growth potential of the container-grown seedlings. The use of container stocktype also allows for a great height at time of planting which may confer better survival (Jones and Sharitz, 1998) particularly during inundation (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 created wetlands and may further enhance survival if mycorrhizal associations are present in containerized soil.

4.2. Tree growth

As expected, H_{RGR}, RCD_{RGR}, and CD_{RGR} were highly variable between species (Fig. 3a,b–5a,b). Species selection has been shown to be a dominant factor in seedling success (Beckage and Clark, 2003; Dulohery et al., 2000; Poorter, 1999). Secondary species are known to have lower growth rates (Horn, 1974) and primary species had higher growth rates than secondary species in this study. Similarly, Farmer (1980) compared first-year growth of deciduous species grown under nursery conditions and found a significant difference in growth between primary species (*Liriodendron tulipifera* and *Pinus serotina*) and secondary species (*Quercus rubra, Quercus prinus, Quercus alba*, and *Quercus ilicifolia*). In addition, growth rates vary in response to continually changing abiotic

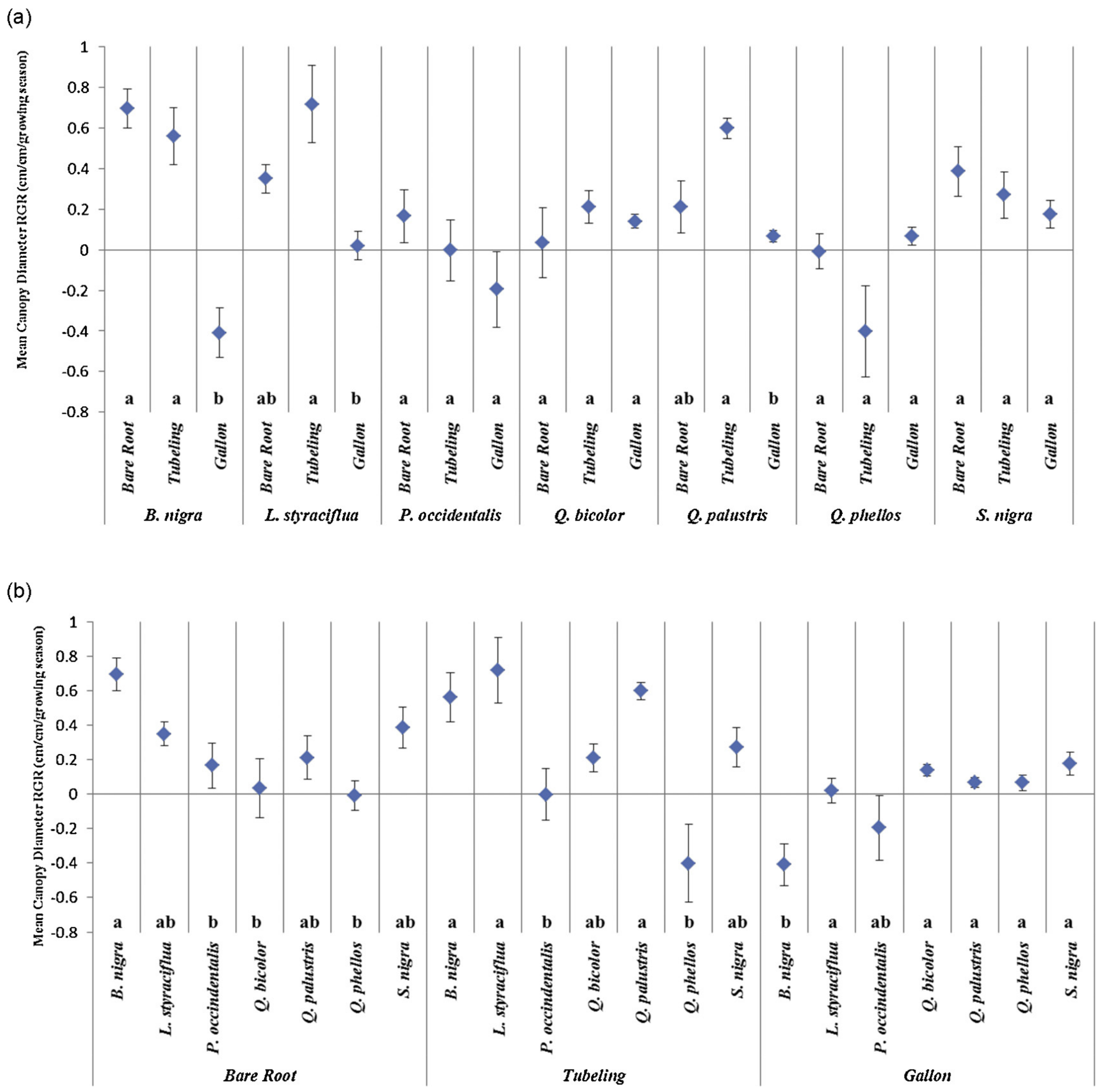

Fig. 5. (a) Simple effects model for CD_{RGR} by stocktypes within species. Error bars represent standard errors. Means with the same letter did not differ in growth rate among stocktypes for individual species (Bonferroni multiple comparison correction, $p < 0.05$). (b) Simple effects model for CD_{RGR} by species within stocktypes. Error bars represent standard error. Means with the same letter did not differ in growth rate among individual species for stocktypes (Bonferroni multiple comparison correction, $p < 0.05$).

and biotic environmental factors (Poorter and Garnier, 2007) which were not reported here.

Stem-dieback, (negative H_{RGR}), occurred in 5 of the 7 species (71%) (Fig. 3a and b) and we presume that transplant shock was the cause. Watson (2006) attributed stem dieback for both bare root and container-grown seedlings during the first year to damaged or missing lateral roots, which results in insufficient transport of water to peripheral leaves and stems, but were not measured in this study. Williams et al. (1999) found extensive stem die back in both bare root and container-grown seedlings of *Quercus texana* that were exposed to flooded conditions.

4.3. Indictors of tree stress

In our study, 13.3% of the trees that were alive at the end of the second growing season had stem sprouting and 35.3% had root suckering. Propensity for stem sprouting and root suckering vary according to tree species. Guerrero-Campo et al. (2006) found species with coarse, deep tap roots had more root-borne shoots when compared to species with fine, long main roots. Vegetative resprouting has also been shown to increase in response to plant stress (Watson, 2006). In a study of revegetation of clear-cut forests in southeastern Virginia, Spencer et al. (2001) found that coppice regeneration occurred more often in mixed hardwood stands when compared to more flooded stands dominated by *Taxodium distichum* or *S. nigra*. In our study, the frequent occurrence of stem sprouting and root suckering (Table 3) across all species is likely in response to stressful environmental conditions which are not reported here.

Tree species classified as FAC (wetland indicator classification scheme, NRCS Plant Database 2011) had lower survival rates and lower H_{RGR}, RCD_{RGR}, and CD_{RGR} than species classified as FACW. 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 our seasonally flooded or saturated sites favor trees with adaptations to limited oxygen availability to roots (Hale and Orcutt, 1987).

Of the species and stocktypes we compared, *Q. bicolor* in 1-gallon containers had the numerically 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, and exhibited moderate survival and growth across stocktypes. Although trees grown in 1-gallon containers, in general, had the best survival rates, tubelings had high RGR for all parameters measured.

We found that species and stocktype RGRs varied among sites for all parameters (with the exception of RCD_{RGR} for stocktype) (Table 2) which suggests that environmental factors should be carefully evaluated prior to selection of species and stocktypes. 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 stocktype will be influenced by project budgets, time constraints, regulatory conditions, and ecological goals. Trees in 1-gallon containers can be an order of magnitude more expensive than bare root seedlings. Lower survival rates of bare root trees may be offset by higher planting densities which have lower overall cost than the purchase of trees in larger containers. In projects where ecological function (such as wildlife utilization by mast producing oak species) is desired in a shorter time frame, the added expense of trees grown in 1-gallon containers may be justified.

Acknowledgements

This study was funded by the Peterson Family Foundation. Field support was provided by Wetland Studies and Solutions Inc., the Virginia Institute of Marine Science, and the CNU Department of Organismal and Environmental Biology. This paper is Contribution No. 3345 of the Virginia Institute of Marine Science, The College of William & Mary.

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