POST-FIRE SURVIVAL AND GROWTH OF CONTAINERIZED SEEDLINGS, ROOTED CUTTINGS, AND NATURAL REGENERANTS OF ATLANTIC WHITE CEDAR (*CHAMAECYPARIS THYOIDES*) IN THE GREAT DISMAL SWAMP NATIONAL WILDLIFE REFUGE

Emily M. Foster[1], James W. Bayley Cook[1] and Robert B. Atkinson[2]

[1]*Tetra Tech, 5700 Lake Wright Drive, Norfolk, VA 23502*
[2]*Department of Organismal and Environmental Biology, Christopher Newport University, 1 Avenue of the Arts, Newport News, VA 23606*

Abstract: *Chamaecyparis thyoides* (cedar) peat swamps are a globally-threatened ecosystem. The Great Dismal Swamp National Wildlife Refuge (GDSNWR) contained some of the largest remaining cedar stands in the world until August 2003 when Hurricane Isabel caused extensive blow-down. In 2008, the South One Fire began near the conclusion of salvage logging operations and burned approximately 1,887 ha. Options for reestablishment of cedar include planting and natural recruitment from the seed bank; however, the latter may have been compromised by peat oxidation and cedar are somewhat shade intolerant and may succumb to interspecific competition. The purpose of this study was to assess effectiveness of cedar reestablishment techniques by evaluating shade intensity and survival and growth of three sources of cedar including rooted cuttings (RC), containerized seedlings (CS), and natural regenerants (NR) in salvage logged portions of the GDSNWR. In May 2010, RC and CS were planted in thirty-two 10 m x 10 m plots. In August 2010 and 2011, height, canopy diameter, stem diameter, shade intensity and browse severity were measured for all planted cedar (n = 828) and for up to 18 randomly selected NR cedar in each study plot (n = 330). RC survived better and grew larger than CS. Higher shade intensity was correlated with less growth for each tree source, and RC grew larger than CS when exposed to moderate and high shade levels. The results of this study may help managers minimize interspecific competition during cedar reestablishment.

Key Words: *Chamaecyparis thyoides*, Great Dismal Swamp National Wildlife Refuge, rooted cuttings, containerized seedlings, deer browse, shade intensity

INTRODUCTION

Atlantic white cedar, *Chamaecyparis thyoides* (L.) B.S.P. (cedar), is an obligate wetland species (USDA Plants Database 2010) which occurs in peat swamps along the Atlantic Coast from Maine to Florida (Korstian 1924). Due to its commercial value as a pleasantly fragrant, lightweight, uniform, and rot-resistant lumber, stands were over harvested, ditched and drained leading to a reduction in acreage of > 98% since the Colonial Era (Korstian and Brush 1931, Little 1950, Noss et al. 1995). Historically growing in dense monocultures, cedar became profitable for systematic commercial harvest throughout its range. Habitat decline may also be attributed to conversion of land to agriculture, storm events, wildfires, and herbivory of seedlings by mammal species such as white-tailed deer and others (Laderman 1989, Little 1950, Harrison et al. 2003).

While there is a great deal of interest in cedar swamp restoration, efforts have met with mixed success due to the susceptibility of young cedar to drought and flood conditions in early stages (Akerman 1923, Cook et al. This Volume), shade intolerance following germination (Little 1950, Belcher et al. 2003), and herbivory (Zimmermann 1997, Harrison et al. 2003). The Great Dismal Swamp National Wildlife Refuge (GDSNWR) contained some of the largest remaining cedar stands until Hurricane Isabel (2003) and a fire that began during salvage logging operations (2008) eliminated all mature trees in these stands. Due to historic ditching and other variables within identifiable regions of the refuge, GDSNWR develops specific strategies for management of each salvage logging unit, and monitoring strategies should address each salvage logging unit to ensure applicability of findings. The purpose of this study was to assess effectiveness of cedar reestablishment techniques by evaluating survival and growth of three sources of cedar including rooted cuttings (RC), containerized seedlings (CS), and natural regenerants (NR) in salvage logging units. Shade intensity and deer browse severity were also assessed as explanatory variables that could influence survival and growth, and salvage logging units that were burned in 2008 were compared to unburned salvage logging units.

METHODS

Site Description and Selection

The GDSNWR is situated on the Coastal Plain of southeastern Virginia and northeastern North Carolina and contains over 45,300 ha (111,939 acres) of forested wetlands. The substrate consists of a mucky peat that is greater than 2 m deep in places, average pH is 3.4, and organic matter content is 98% (Thompson et al. 2003), but organic matter content as low as 85% has been reported (Dabel and Day 1977).

ArcGIS (version 3.8, Redlands, CA, 2008) was used to select the coordinates of thirty-two 10-m x 10-m plots in designated salvage logging units within the GDSNWR. Salvage logging units were characterized during salvage logging operations, and study plots were selected in a stratified random fashion. Twenty-five of the plots were located in salvage logging units that burned during the 2008 South One Fire (A, GO, SEV, HS, HN), and the remaining seven plots were located in salvage logging units that were not burned in 2008 (ESC and WSC).

Study Design

In each plot, 36 trees were planted with dibble bars on approximately 1.6-m spacing of 6 rows containing 6 trees per row in May 2010. While all genetic stock originated from the GDSNWR, we utilized containerized rooted cuttings (RC) from ArborGen®, and containerized seedlings (CS) from the North Carolina Forestry Service. Both sources contained approximately 10-in^3 soil plugs at the time of planting, and were planted alternating within rows. Adjustments of up to 0.5 m were made to avoid natural regenerants and tree stumps.

For survival and growth determinations, up to 18 natural regenerants (NR) were randomly selected within plots, were assigned x and y coordinates, and color-coded pin flags were inserted to facilitate relocation in the plot-grid.

Morphology of all trees was measured in August 2010 and August 2011. Measurements included tree height (HT, measured from ground level to tip of longest terminal branch), canopy diameter (CN, calculated as the mean of three subsamples measured at the height where maximum canopy width occurred), and stem basal diameter (SBD, measured 1 cm above the ground). Growth was later calculated using August 2010 and 2011 morphological data. Vegetative shade intensity was estimated via visual inspection within a 0.25-m radius circle centered on each tree and shade scores from 0 to 3 (0 = no shade, 1 = low, 2 = moderate, and 3 = high shade) were assigned. A subsample of RC (n = 133) and CS (n = 104) were randomly selected before planting and height, canopy diameter, and stem basal diameter were measured to estimate initial morphometry.

Study Challenges

In the second year of the study, aerial application of the herbicide Habitat® (28.7% Isopropylamine salt of imazapyr) was conducted via helicopter at all salvage logging units by the GDSNWR during the last week of July 2011; however, second-year morphometric data were collected during early August 2011 and no herbicide effects were evident at the time of sampling.

Only 23 of the 32 study plots were sampled in August 2011 due to The Lateral West Fire, which was first sighted on August 5th, 2011. The fire burned all plots, trees, and wells except for those salvage logging units that were located further south, which had also not burned in 2008 (ESC and WSC, the unburned salvage logging units of the current study). As a result, the nine plots in salvage logging units HS and HN, which were burned before second-year growth data could be collected, were excluded from analyses.

Statistical Analysis

Data were entered and preliminarily analyzed using Microsoft Excel (versions 2003 and 2007, Redmond, WA), and exported to SigmaPlot (version 11, Chicago, IL) for further analysis. Normality was tested using Shapiro-Wilk tests. Means and medians of annual (August 2010 to August 2011) growth parameters (H, CN, and SBD) among the three cedar sources (RC, CS, and NR) were compared using One-Way ANOVA, Kuskal-Wallis Anova on Ranks, and Dunn's Multiple Comparison Test. Initial planting sizes of RC and CS were compared for each morphometric parameter by Paired T-tests and Wilcoxon Signed Ranks tests. Environmental factors affecting survival and growth (water table depth, shade intensity, and browse intensity) were modeled using linear regressions. All statistical tests used a p = 0.05 threshold for significance unless otherwise indicated.

RESULTS

Survival

Median percent survival for RC (90%) was higher than CS (74%)(p = 0.011), but survival of each stock type did not differ from NR (78%)(figure 1). There was no significant difference in survival of RC among salvage logging units (p = 0.10), but CS exhibited lower survival in ESC (54%) than all other salvage logging units (p < 0.001)(figure 2). Survival of NR in salvage logging units ESC and WSC was significantly lower than in A and GO (p < 0.001)(figure 2). Unburned salvage logging units (ESC and WSC) exhibited significantly lower survival than burned salvage logging units (A, GO, and SEV)(p < 0.001). ESC overall survival was 54%, which was the lowest survival of all salvage logging units in this study (78%, 28%, and 57% for RC, CS, and NR, respectively). Percent survival in WSC was 69% overall, and survivorship of RC, CS, and NR, was 83%, 64%, and 56%, respectively. SEV was excluded from further regeneration analyses due to low regeneration rate (a total of 4 trees were present in 3 plots).

Figure 1. Median percent survival of all cedar sources (RC, CS, and NR) from August 2010 to August 2011 for all plots (n = 23) with all salvage logging units combined. Bars represent +1 SD, different letters indicate a statistically significant difference.

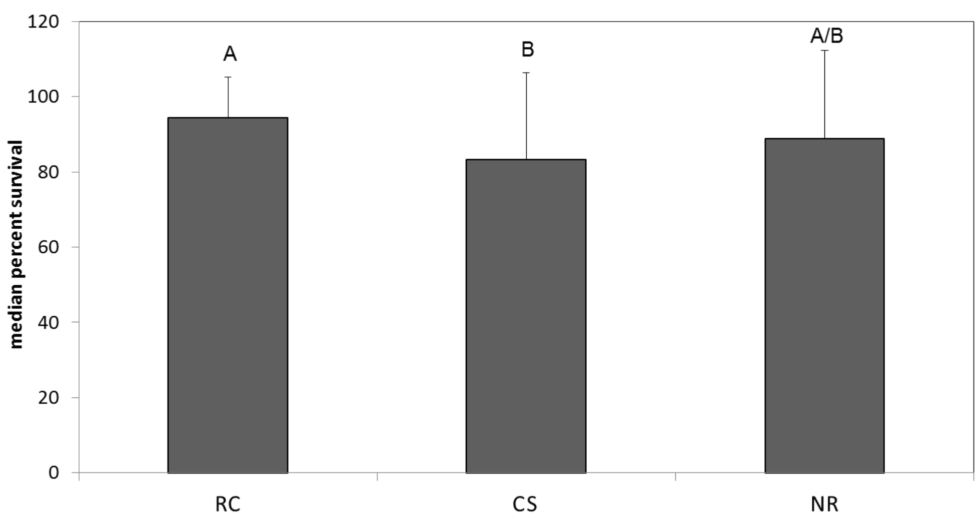
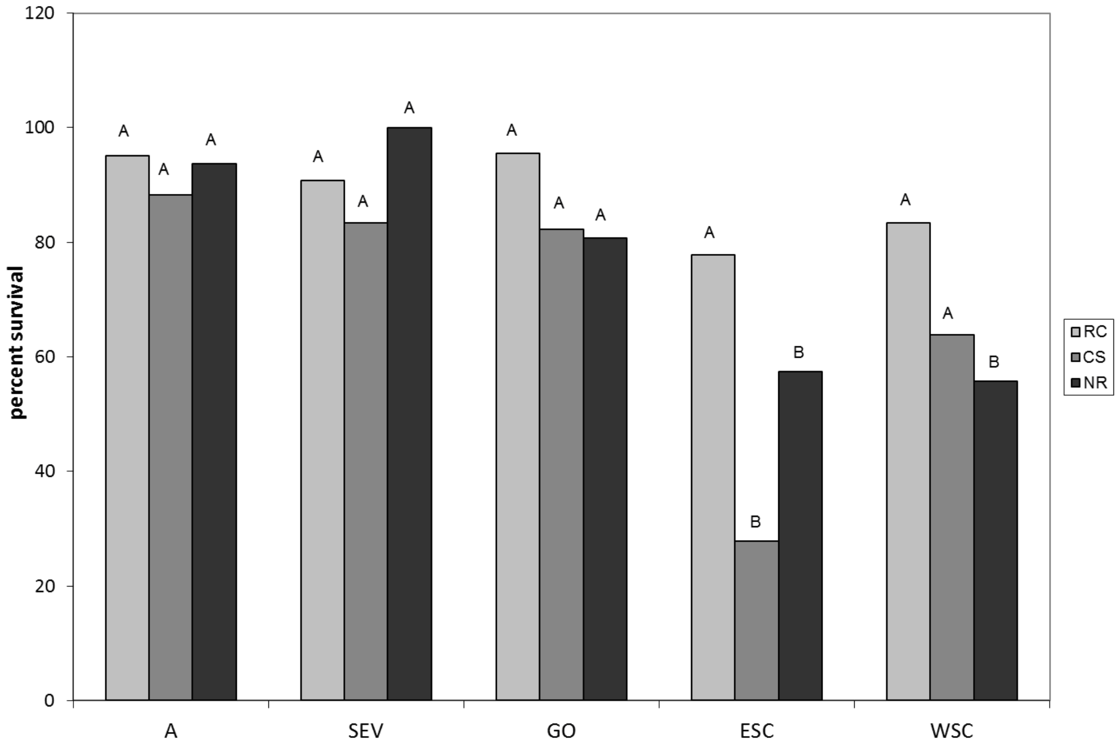


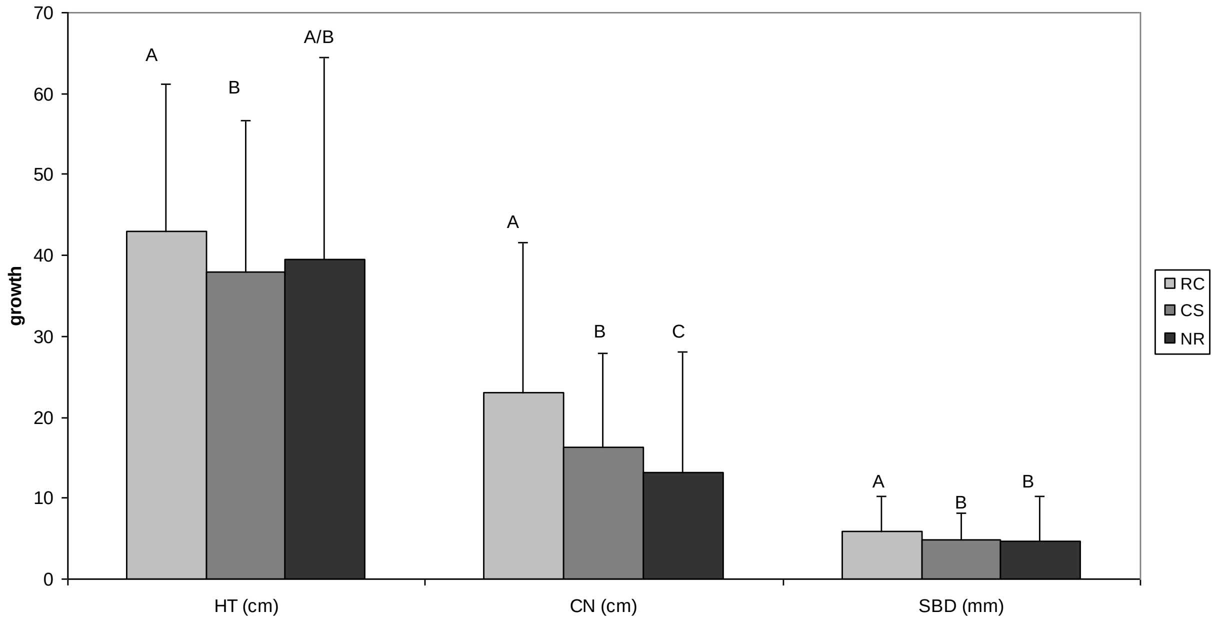
Figure 2. Percent survival of all cedar sources (RC, CS, and NR) in each salvage logging unit. Significant differences among salvage logging units (by planting source) are indicated by different letters.



Growth and Cedar Source

Initial sizes of RC were significantly larger than CS for height, canopy diameter, and stem basal diameter ($p < 0.001$). When all 5 salvage logging units were combined after one year, median increase in height of RC (48.5 cm) was greater than for CS (40.5 cm)($p < 0.001$), but neither differed from NR (44.0 cm). Median change in canopy diameter of RC (23.5 cm) was larger than for both CS (16.0 cm) and NR (19.5 cm)($p < 0.001$). Median stem basal diameter growth was larger for RC (6.62 mm) than for CS (4.39 mm)($p < 0.001$), but did not differ from NR (figure 3).

Figure 3. Median growth in height (HT), canopy diameter (CN) and stem basal diameter (SBD) of all cedar sources (RC, CS, and NR) one year after planting, with all salvage logging units combined. For each growth parameter, statistically significant differences among tree types are indicated by different letters. Bars indicate +1 SD.



When comparing growth of all planted trees (RC and CS) to unplanted trees (NR) in all salvage logging units, no significant difference was found in height ($p = 0.660$), though planted trees had significantly greater increase in canopy diameter and stem basal diameter than NR ($p < 0.001$ and $p = 0.025$, respectively).

Growth of all trees in all three morphometric parameters in the burned salvage logging units (A, GO, SEV)(n = 702) was compared to the un-burned salvage logging units (from the 2008 South One Fire, ESC and WSC)(n = 221). Although the un-burned salvage logging units had the lowest survival (ESC = 54%, WSC = 69%), they also had significantly higher growth in all three morphometric parameters ($p < 0.001$).

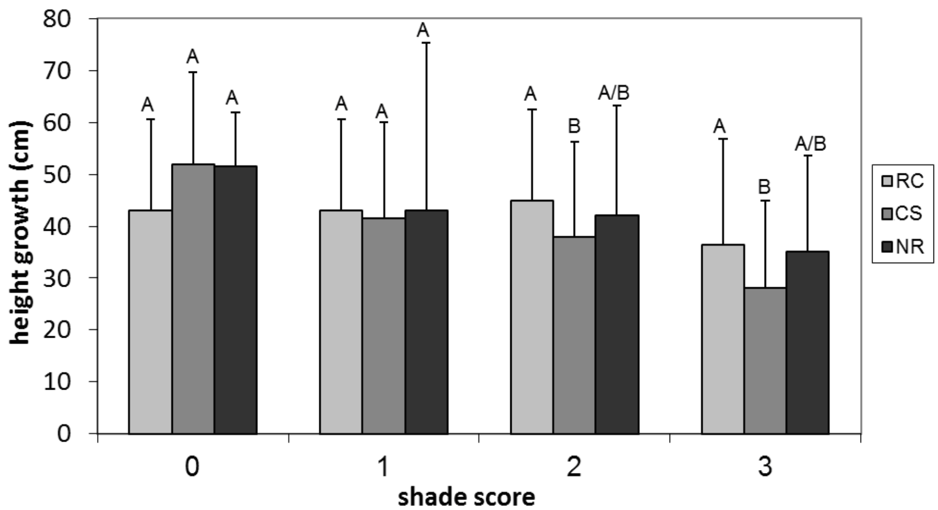
Effect of Shade Intensity on Growth

In August 2011, shade intensity in the burned salvage logging units (A, GO, and SEV)(1.9) was higher than in the un-burned salvage logging units ESC and WSC (1.6)($p = 0.023$). When comparing all salvage logging units by shade intensity in August 2011, WSC (1.0) and SEV (1.0) were found to contain the least shade, and A (2.0) and GO (2.0) were found to contain the most.

The effect of August 2011 shade intensity on tree growth was evaluated for all trees. Highest increase in canopy diameter and stem basal diameter occurred with no shade to low shade ($p < 0.001$), and greatest increase in height occurred with low to moderate shade ($p < 0.001$).

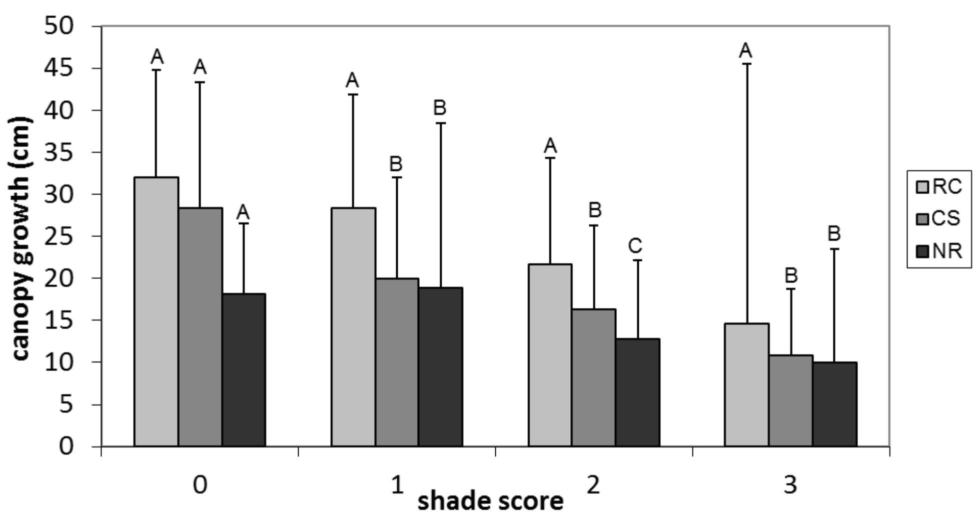
Growth of RC, CS, and NR among shade intensities was also compared. At either no or low shade intensity, height growth among planting types did not differ including RC, CS, and NR ($p = 0.352$ for no shade and $p = 0.445$ for low shade, respectively). However, height growth associated with moderate or high shade was greater for RC than CS ($p = 0.005$ for moderate shade and p = 0.002 for high shade, respectively)(figure 4).

Figure 4. Median height growth (cm) for all cedar sources (RC, CS, and NR) for shade intensities of 0 (no shade, n = 44), 1 (low shade, n = 271), 2 (moderate shade, n = 380), and 3 (high shade, n = 228). Different letters indicate statistically significant differences within shade scores. Bars represent +1 SD.



There was no difference in median canopy diameter growth of RC (38 cm), CS (28.3 cm), and NR (18.2 cm) with no shade (p = 0.228); however canopy diameter growth decreased under low, moderate and high shade (figure 5).

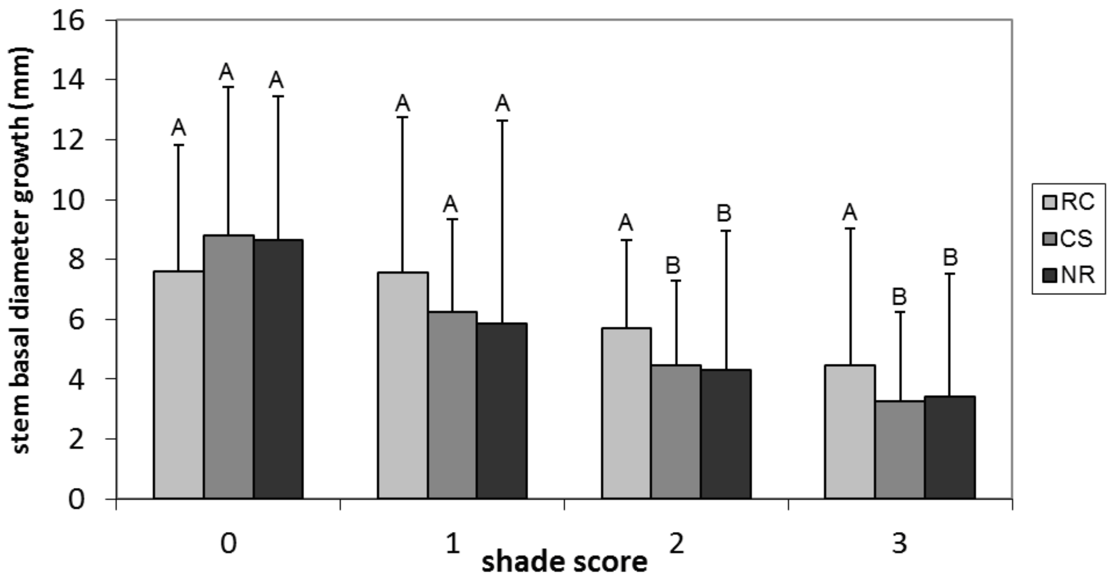
Figure 5. Median canopy diameter growth (cm) of all cedar sources (RC, CS, and NR) under shade intensities of 0 (no shade, n = 44), 1 (low shade, n = 271), 2 (moderate shade, n = 380), and 3 (high shade, n = 228). Different letters indicate statistically significant differences within shade scores. Bars represent +1 SD.



For trees exposed to either no or low shade intensity, there was no difference in median stem basal diameter growth (p = 0.852 and p = 0.142, respectively). But with moderate or high shade, median growth of RC (5.7 cm and 4.5 cm, respectively) was greater than that for CS (4.5 cm and

3.3 cm, respectively) and NR (4.3 cm and 3.4 cm, respectively)($p < 0.001$ and $p < 0.003$, respectively)(figure 6).

Figure 6. Median stem basal diameter growth (mm) of all cedar sources (RC, CS, and NR) under shade intensities of 0 (no shade, n = 44), 1 (low shade, n = 271), 2 (moderate shade, n = 380), and 3 (high shade, n = 228). Different letters indicate statistically significant differences within shade scores. Bars represent +1 SD.



DISCUSSION

Survival

Survival of RC (90%) was higher than CS (74%), and did not differ from NR (78%). Although survival of all three cedar sources was high compared to planted cedar in some studies (Harrison et al. 2003), survival was actually lower than reported by Brown and Atkinson (1999) who found 97% survival of planted cedar in the GDSNWR one year after planting.

Survival of cedar has been found to vary widely based upon site conditions such as hydrology and herbivory (Harrison et al. 2003), and survival in this study may have been affected by inundation rates. Salvage logging unit ESC had the highest water table during the growing season, the most consecutive days of inundation, and had the lowest survival (Cook et al. This Volume). Laderman (1989) states that cedar seedlings are intolerant of prolonged inundation, thus the wetter conditions in ESC likely led to decreased survivorship. The lowest survival rates in this study were found for CS cedar source in ESC. Because CS were initially shorter than RC, a higher proportion of their height was inundated, which may have led to the observed mortality in ESC (Cook et al. This Volume). Battaglia et al. (2000) reported lower survivorship among smaller tree seedlings of planted swamp chestnut oak, *Quercus michauxii*, and sweetgum, *Liquidambar styraciflua* (i.e., taller trees were more likely to survive inundated conditions).

Salvage logging unit WSC was the driest of the study sites, with no more than 3 days of inundation during the growing season and no more than 7 days of inundation during the nongrowing season, and drought was thought to contribute to tree mortality in this salvage logging unit (Cook et al. This Volume). Little (1950) describes young cedar as susceptible to drought, and Akerman (1923) describes cedar seedlings in higher areas (i.e., tops of hummocks) as more susceptible to desiccation. Brown and Atkinson (1999) and Belcher et al. (2006) reported greater cedar stem density in intermediate elevations and concluded that cedar in lower elevations were drowned and cedar in higher elevations were shaded out by competitors such as *Clethra alnifolia* (sweet pepperbush).

Growth and Cedar Source

Median height growth of all sources were similar to published values, with RC (48.5) higher than CS (40.5) one year after planting, though neither was significantly different than NR (44 cm). Estimates of natural cedar growth rate reported elsewhere are 46 cm/year for the first 10 years (Akerman 1923), 20-30 cm/year for several years (Little and Garret 1990), 38 cm/year in a restored peatland (Harrison et al. 2003), and average growth of RC in GDSNWR was 40.6 cm after one growing season (Brown and Atkinson 1999). The overall growth rate has been found to decrease with age, and growth rate declines rapidly as trees reach an age 40 years, and is nearly constant after ages 55-60 years (Daniels 2003).

Two consecutive cedar studies investigating growth of RC compared to bare-root seedlings in five sites in NC found that the growth of RC and bare-root seedlings were nearly indistinguishable after 3 and 20 years in the field, though both studies found that bare-root seedlings may have a slight advantage (Phillips et al. 1993, Pickens et al. 2009). While the results of this study found RC (clones of individuals selected for fitness) to have an early advantage over cedar grown from seed (CS), our results may differ from the findings of Phillips et al. (1993) and Pickens et al. (2009) due to several factors not addressed in the current study, such as initial age, soil nutrient concentration, moisture, temperature, substrate, container volume, and temperature regimes of source material during initial production (RC in our study were produced by Arborgen®, GA, whereas RC in Pickens et al. (2009) were produced by Weyerhauser®). In one study assessing production of cedar seedlings, a significant positive relationship was observed between container volume and seedling height/dry weight (Jull et al. 1999), and day/night temperature cycles (30/22°C) have been found to yield the highest growth in terms of dry weight, total plant dry weight, root:shoot ratio, mean relative growth rate, final stem diameter, and canopy diameter (Derby and Hinesley 2005).

Our study used CS and RC tubelings containing a root ball with soil, whereas Pickens et al. (2009) planted bare-root seedlings. In a study comparing survival and growth of bald cypress planted in a wetland restoration site, Rushton (1984) found that bare-root seedlings survived better than tubelings, though there was no difference in growth. RC and CS of *Pinus taeda* (loblolly pine) were found to exhibit similar growth results after 10 years (Stelzer et al. 1998).

RC may exhibit greater survivorship and growth than CS due to divergent morphological and physiological responses associated with source and age. Ritchie et al. (2002) compared RC, CS, and transplants of *Pseudotsuga menziesii* (Douglas Fir) and found that RC had greater stem diameter, higher stem diameter to height ratio, greater root weight, and greater winter hardiness than either CS or transplants after 1.5 years, and suggested that the age of source material (RC from 3 year old trees, CS from 2 year old trees) may affect growth and cold hardiness.

Comparisons in growth among salvage logging units may be useful for managers to determine which areas of the swamp are most likely to have successful reestablishment, so that efforts may be focused in areas that best meet management goals. While survivorship was higher in the burned salvage logging units, the unburned salvage logging units showed higher growth. Eagle (1997) defined sites suitable for reestablishing cedar as requiring >2,100 stems/ha of cedar that are taller than 1.5 m. Median stem densities of 8,050 stems/ha in unburned and 6,600 stems/ha in burned areas of the current study would, if all trees persist, exceed stem densities for 60-yr old stands in GDSNWR (1,750 stems/ha) and Alligator River NWR (4,983 stems/ha) as reported by DeBerry et al. (2003).

Effect of Shade on Growth

Light intensity (affected by competition) is a key factor for adequate survival and growth of cedar seedlings (Akerman 1923, Korstian and Brush 1931, Little 1950, Laderman 1989). Because it removes competitors and allows more light to reach the surface of the soil, fire is a necessary component for cedar persistence (Laderman 1989). Belcher et al. (2003) found that shade from competitors may be lethal to RC two years after a fire or timber harvest, and that RC growth was reduced by exposure to 27% shade, but growth increased with 55% shading in warm months (between June and August). Our findings suggest cedar are impacted by shading as early as 1-2 years old, and shade intensity (e.g. light availability) seemed to effect growth of canopy diameter and stem basal diameter, such that trees found with lower shade intensity exhibited increased canopy diameter and stem basal diameter growth. Differences in response of RC and CS to shade may be due to initial height differences, but may be due to various other factors including propagule age. Observations of divergent physiological responses related to age have been reported for RC and CS of *Pseudotsuga menziesii* (Ritchie et al. 1992). The increased growth observed for RC under higher shade intensity may indicate a higher shade tolerance than CS and NR, making RC potentially more desirable for planting in sites where interspecific competition is anticipated.

These findings indicate that reduction in vegetative competition may enhance the growth of planted cedar as early as one year after planting, therefore manual or chemical removal of vegetation could be beneficial. In a study of RC of cedar grown under a series of shade intensities, Belcher et al. (2003) suggested that 27% shade was the threshold above which resource managers should actively treat a restoration site with herbicide or hand-clearing to reduce competition and improve cedar growth.

Genetics

Because RC are able to capture the full genetic potential of specifically selected source trees, their use allows trees with desirable or superior qualities such as increased vigor and hardiness (Ritchie et al. 1992) and can be mass-produced (Thulin and Faulds 1968). In this study, RC were observed as larger and appearing more vigorous than CS of approximately the same age. However, RC are typically more expensive than CS and may contain less genetic variability than CS and NR seedlings (Thulin and Faulds 1968). If RC is the only source utilized, some consideration should be given to the potential for a loss of genetic variation. Kuser and Zimmermann (1995) stated that seedlings have an advantage due to genetic differences which would make them less likely to be decimated by pathogens than clones. A lack of genetic variation between the seedlings could also lead to reduced fitness of the population. Blocks of up to 20 clones or mixtures of clones were recommended to reduce the risks associated with genetic weakness (Kuser and Zimmermann 1995).

CONCLUSIONS

Although the results are limited to one year duration due to the destruction of nearly all plots by the Lateral West Fire in August 2011, some clear patterns emerged and findings presented here may be useful for future cedar restoration efforts. The higher survivorship and growth of RC may make supplemental plantings of this source more effective, particularly given young cedar susceptibility to drowning. However, statistical differences detected in this study may not be significant from a management perspective. Both survival and growth, though statistically different, were somewhat similar among RC and CS trees and pricing could influence selection in sites where competition and inundation are not expected to impact plantings.

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