EFFECT OF HYDROLOGY ON POST-FIRE SURVIVAL AND GROWTH OF CONTAINERIZED SEEDLINGS, ROOTED CUTTINGS, AND NATURALLY REGENERATED ATLANTIC WHITE CEDAR IN THE GREAT DISMAL SWAMP NATIONAL WILDLIFE REFUGE

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Abstract: *Chamaecyparis thyoides* (cedar) peat swamps are globally threatened ecosystems and the acreage of this swamp type has been reduced by drainage and logging. The Great Dismal Swamp National Wildlife Refuge (GDSNWR) contained extensive stands of cedar that were severely damaged by Hurricane Isabel and in 2008 by the South One Fire. In 2010, thirty two 10-m^2 plots were established throughout the GDSNWR, and rooted cuttings (RC) and containerized seedlings (CS) were planted in June. They were monitored in August, along with natural regenerants (NR), and survival and growth were quantified again in 2011. The effect of soil saturation and inundation on survival and morphometric growth indicators including height, canopy diameter, and stem diameter were quantified. Inundation during the growing season and non-growing season reduced survival. The highest survival occurred with 55 days of inundation during the non-growing season and 28 days during the growing season. Survival of CS was more negatively impacted by inundation than were either RC or NR, perhaps as a consequence of tree height and the percentage of each tree inundated at a given water level. Saturation was generally negatively related to growth. These findings emphasize the importance of water level management to improve initial cedar recruitment and establishment.

Keywords: morphometric parameters, hydrology, growth, seedling survival, restoration, *Chamaecyparis thyoides.*

INTRODUCTION

Atlantic white cedar, *Chamaecyparis thyoides* (L.) B.S.P. (cedar), is an obligate wetland species (USDA Database 2011) that grows in a narrow belt 80 to 160 km wide along the Atlantic Coast from Southern Maine to Central Florida, typically in peat (Little 1950). Cedar stands have been reduced by 98% through overharvesting and draining (Noss et al. 1995). Cedar has been highly valued for its rot resistance and fragrance since the 18th century and has led to overharvesting (Hanlon 1970, Korstian and Brush 1931).

Cedar stands are typically characterized by a hydrological regime in which inundation occurs during the winter periods when evapotranspiration is low, and, in undrained sites, soil saturation continues throughout much of the growing season (Atkinson et al. 2003a, Laderman 1989). Cedar-dominated communities can persist over a range of saturated conditions (Golet and Lowry 1987, Hall 2006), however, cedar inhabiting intermittently flooded locations such as Great Dismal Swamp National Wildlife Refuge (GDSNWR) may experience root death during drought events (Rodgers et al. 2003). Restoration efforts for cedar have focused on hydrologic characteristics yet have not fully taken into account the effects of such conditions on newly planted cedar, which can result in negative outcomes (Akerman 1923, Little 1950) and there is limited information regarding effects of planting cedar in recently burned locations. The purpose of this study is to examine the effects of hydrologic parameters, including saturation, inundation, mean depth to water table and percent of plant inundated on survival and growth of containerized seedlings, rooted cuttings, and natural regenerants of cedar in both burned and un-burned locations. The results of this study are intended to aid management and restoration of cedar stands.

METHODS

Site Description

All plots evaluated in this study were located in the Great Dismal Swamp, in southeastern Virginia and northeastern North Carolina. The GDSNWR contained some of the largest remaining cedar stands in the world and employs management strategies to conserve these areas. The stands are characterized by hummock – hollow microtopography consisting of shallow dips and minor hills. GDSNWR soil exhibits low pH (3.2 – 3.6), somewhat low nutrient concentrations, and high organic content (Day et al. 1988, Thompson et al. 2003). Wetland hydrology can be altered through anthropogenic factors (Ehrenfeld and Schneider 1991) and historic hydrologic alteration in GDSNWR included ditching, draining, and logging; some of these activities occurred while the swamp was owned, in part, by George Washington (Dabel and Day 1977) and this history has implications for restoration (Atkinson et al. 2003a).

In 2008, the last 1,200 ha (3,000 ac) of nearly pure cedar stands was burned during the South One Fire, a severe fire that burned a total of 1,800 ha (4,664 ac) of GDSNWR (Lowie et al. 2009); and in 2011, the same area and some additional acreage burned in the Lateral West Fire and influenced year two of the study as described below.

Plot Selection and Arrangement

ArcGIS was used to select thirty-two 10-m^2 plot locations within salvage logging units of the GDSNWR. Locations for 25 plots in five salvage logging units were selected from a pre-existing regeneration study (which evaluated 150 plots following the South One Fire of 2008 (Wurst et al. This Volume), and were placed adjacent to these plots, along with 7 additional plots that were established in two unburned salvage logging units. In May 2010, 36 cedar rooted cuttings (RC, obtained from Arborgen) and containerized seedlings (CS, obtained from North Carolina State Forestry Service) were planted in each plot such that six rows each contained six trees planted on 1.6-meter centers. Cedar plantings consisted of 18 RC and 18 CS and were planted using dibble bars. Locations were recorded and flagged in order to facilitate subsequent monitoring of trees.

Morphometric parameters including height, canopy diameter, and stem diameter were measured for every tree. Height was measured as the distance from ground level to the highest portion of a tree with a meter stick. Canopy diameter was measured with calipers at three horizontal locations at the widest portion of the canopy, and stem diameter was measured using electronic calipers just above the ground surface. Trees were monitored in August of 2010 and 2011; however, due to the Lateral West Fire in August 2011, second year morphometric measurements were not conducted in two units, HN and HS, and these salvage logging units were excluded from analyses.

Installation of Wells and Elevations

Between June and July of 2010, 32 water table monitoring wells were installed adjacent to each plot. Well location was adjusted to avoid buried logs and generally did not exceed a distance of 16 ft (5 m) from a plot. Wells were installed with 5-cm (2-in) diameter pre-slotted, spike-ended, PVC sleeves that were 3 m (10.3 ft) in length with 0.2-mm-spaced slotting (Campbell Scientific). An 8-cm (3.25-in) auger tip was used for installation with AMS equipment (American Falls, Indiana) and the depth of the bore hole ranged from 1.2 m (4 ft) to 2.7 m (9 ft). Slotted PVC was placed into the hole and remaining space between well wall and PVC exterior was filled with coarse “type 2” sand for the purpose of filtering out particulates and reinforcing well placement. After anchoring the PVC pipe, a “Foot Valve” (Waterra©, Mississauga, Ontario) was used to surge the inside of the well, flushing the inner wall and removing water until visual inspection confirmed that wells emptied within 5 minutes.

Elevation of trees and adjacent wells were recorded for each study plot and was used to create a hydrograph for each tree in the study. Steel conduit pipes were used for temporary benchmarks and were inserted vertically into substrate until considered stable. An auto level scope, a fiberglass tripod, and multiple stadia rods were used for the surveying process. Instrument height was re-measured every 6-8 trees in order to avoid error caused by shifting peat, and surveyed elevation errors ranged from 0 to 0.76 cm (0 to 0.3 in). Each tree elevation was estimated as the mean of three subsamples to account for microtopography.

Well Monitoring, Well Repair, and Well Equipment

Water table depth was recorded at wells monthly. Within all five salvage logging units and one of the unburned salvage logging units, 6 wells were modified with continuous recording sensor bundles consisting of a CR 200x Datalogger, 4 CS-650 Soil Water Content

Reflectometers buried at 15-cm (6-in) increments, CS 450 Pressure Transducer, Temperature Sensor, and a Rain Gage (Campbell Scientific, Logan, Utah) (installed at study plot A 5-2). Measurements were recorded at no less than 5-minute intervals and were later modified to 1-hour intervals. Soil temperature, soil moisture, depth to water table, and precipitation were measured. However, due to Black Bear damage and the Lateral West Fire in 2011, soil moisture was excluded from analyses.

Inundation, Saturation and Climate

Continuous recording wells measured water table depth from July 15, 2010 to August 1, 2011 and were used to simulate hydrographs for manually recorded wells using linear regression models ($r^2 = 0.61 - 0.99$) following Atkinson et al. (2003b). Using elevations of trees and modeled water table depths for each plot, a simulated hydrograph was generated for each tree and several metrics were calculated following Harrison et al. (2003).

Growth of cedar was modeled using morphometric parameters including tree height, canopy diameter, and stem diameter and hydrologic parameters. For this study, non-growing season is defined as the period from October 2010 to February 2011and growing season is defined as the period of time from March 2011 to July 2011 (growing season was truncated to exclude water levels subsequent to tree sampling which was completed in early August 2011). Hydrologic parameters included:

Mean depth to water table (MDTWT): Calculated depth (in tenths of feet) to the water table during the growing season.

Days of inundation (DI): Days, during the growing season, in which the water table was above the ground surface.

Days of saturation (DS): Days, during the growing season, in which the water table was between the soil surface and a depth of 1 foot.

Percent inundation (PI): Percent of growing season in which inundation occurred (Days of inundation / days of growing season)

Soil percent saturation (SPS): Percent of the growing season in which saturation occurred (Days of Saturation / days of growing season).

Mean depth to water table variation (N-MDTWT): Variation of MDTWT that accounts for the non-growing season.

Days of inundation variation (NDI): Variation of DI that accounts for the non-growing season.

Proportion of plant inundated (PPI): Proportion of the plant that was inundated during the non-growing season based on N-MDTWT and initial height of plant.

Mean depth to water table variation 2 (G-MDTWT): Variation of MDTWT that accounts for the time period between July to September, 2010.

Modified Palmer Drought Severity Index (MPDSI), following Kingste and Chelliah (2006) and obtained through Regional Climate Data Assimilation System, was related by correlation analyses to monthly water table measurements (MDTWT) in the salvage logging units and to precipitation. The purpose of this assessment was to further define hydrologic conditions in the study portion of GDSNWR.

Dependent variables of cedar survival and growth including height, stem diameter, and canopy diameter were modeled using these independent hydrologic variables by linear and second order polynomial regressions, and parametric and non-parametric forms of Analysis of Variance (Microsoft Excel 2007, Microsoft, Redmond, WA; and SigmaPlot version 11, 2008 Systat Software Inc, Chicago, IL).

RESULTS

Climate and Water Table Comparison

The highest MPDSI (1.59, i.e. mild wet conditions) occurred in October, after the end of the growing season, and inundated conditions persisted until February 2011 when MPDSI was -1.42 (i.e. mild drought). The MPDSI tended to be positively correlated with MDTWT (r^2 ranged from 0.06 at ESC to 0.43 at GO).

Water level among continuously recording wells and manual wells were strongly correlated (r^2 ranged from 0.699 and 0.999). Continuously recording wells indicated that water levels differed among salvage logging units and GO exhibited the lowest (driest) mean depth to water table (-36 cm (-1.19 ft)) and unit ESC exhibited the highest (wettest) mean depth to water table (0.06 ft (2.09 cm))(figure 1). WSC was excluded due to absence of a continuously recording well, but according to manually read wells, was dryer than all units except GO. Burned and unburned salvage logging units did not differ in inundation (DI, $p = 0.516$) or in saturation (DS, $p = 0.087$).

Comparison of Plant Treatment Type to MDTWT and PPI

MDTWT differed significantly between plant treatment types. MDTWT for planted trees (CS and RC) was significantly wetter than unplanted (NR)($p < 0.001$). NR tended to occur at a 6.09 cm (0.2 ft) higher elevation above the water table compared to CS and RC. PPI during the non-growing season, on average, was significantly higher in CS compared to RC and NR ($p < 0.001$, $p = 0.004$, respectively). There was no significant difference in PPI between RC and NR ($p = 0.426$).

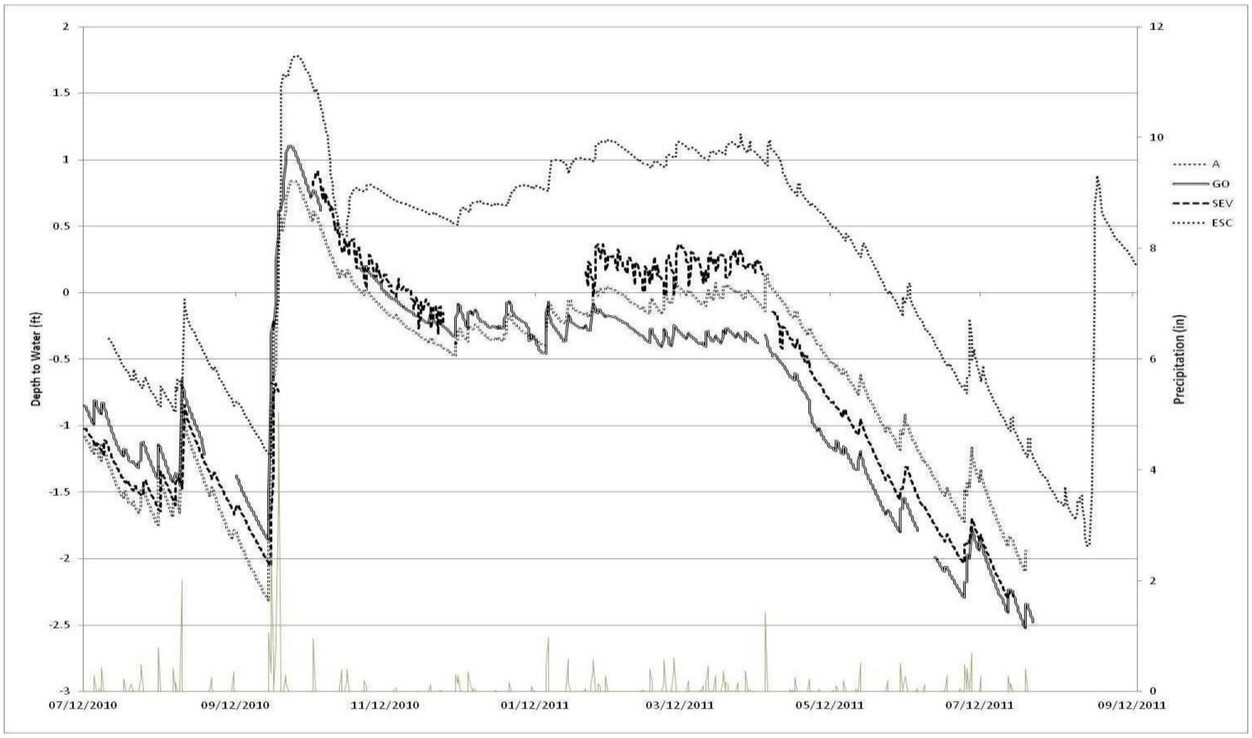

Figure 1. Depth to water table during the study period based on continuously recording wells in salvage logging units A, SEV, GO, and ESC. Left vertical axis denotes depth to water in tenths of feet and right vertical axis denotes precipitation in inches. Positive values indicate inundation.

Survival Trends

Median survival was significantly lower in the unburned salvage logging units (77%) than the burned salvage logging units (92%) when all plant treatment types were combined ($p < 0.001$, Anova on Ranks and Dunn's Test). With burned and unburned salvage logging units combined, median survival for RC (95%) was significantly higher than CS (83%)($p < 0.001$) and NR (86%)($p = 0.014$, Wilcoxon Signed Rank Test). There was no significant difference in survival between CS and NR ($p = 0.307$, Paired T-test).

Unburned Salvage Logging Unit Survival

Within the unburned salvage logging units, increasing PPI did not significantly affect RC survival ($p = 0.063$, One-Way Anova). Higher PPI was associated with reduced survival of CS ($r^2 = 0.824$)($p = 0.001$) and NR ($r^2 = 0.787$)($p = 0.009$).

Burned Salvage Logging Unit Survival

CS survival and PPI in burned salvage logging units were modeled by polynomial regression ($r^2 = 0.535$)($p < 0.001$), but CS and NR survival were not related to PPI ($r^2 = 0.122$ and 0.0952, respectively). Survival did not differ between treatment types in the burned salvage logging units ($p > 0.05$).

Comparison of Survival to Hydrologic Metrics

Survival across the entire study was most closely related to NDI, particularly by a polynomial relationship ($r^2 = 0.84$)($p < 0.001$) such that optimum survival occurred at moderate NDI of 55 days. Optimum survival occurred at a DI of 28 days ($r^2 = 0.67$)($p < 0.001$). Individual treatment types showed similar survival responses to NDI, though the modeled relationship of CS ($r^2 = 0.78$)($p < 0.0001$)(figure 2A) was more pronounced than either RC ($r^2 = 0.48$)($p = 0.001$)(figure 2B) or NR ($r^2 = 0.62$)($p = 0.0002$)(figure 2C). N-MDTWT and MDTWT exhibited strong relationships to overall survival ($r^2 = 0.45$ and $r^2 = 0.46$, respectively). Overall survival and DSDD were correlated by a negative linear equation ($r^2 = 0.40$)($p < 0.001$). SPS and DS had no significant effect on overall survival ($p = 0.387$ and 0.831, respectively).

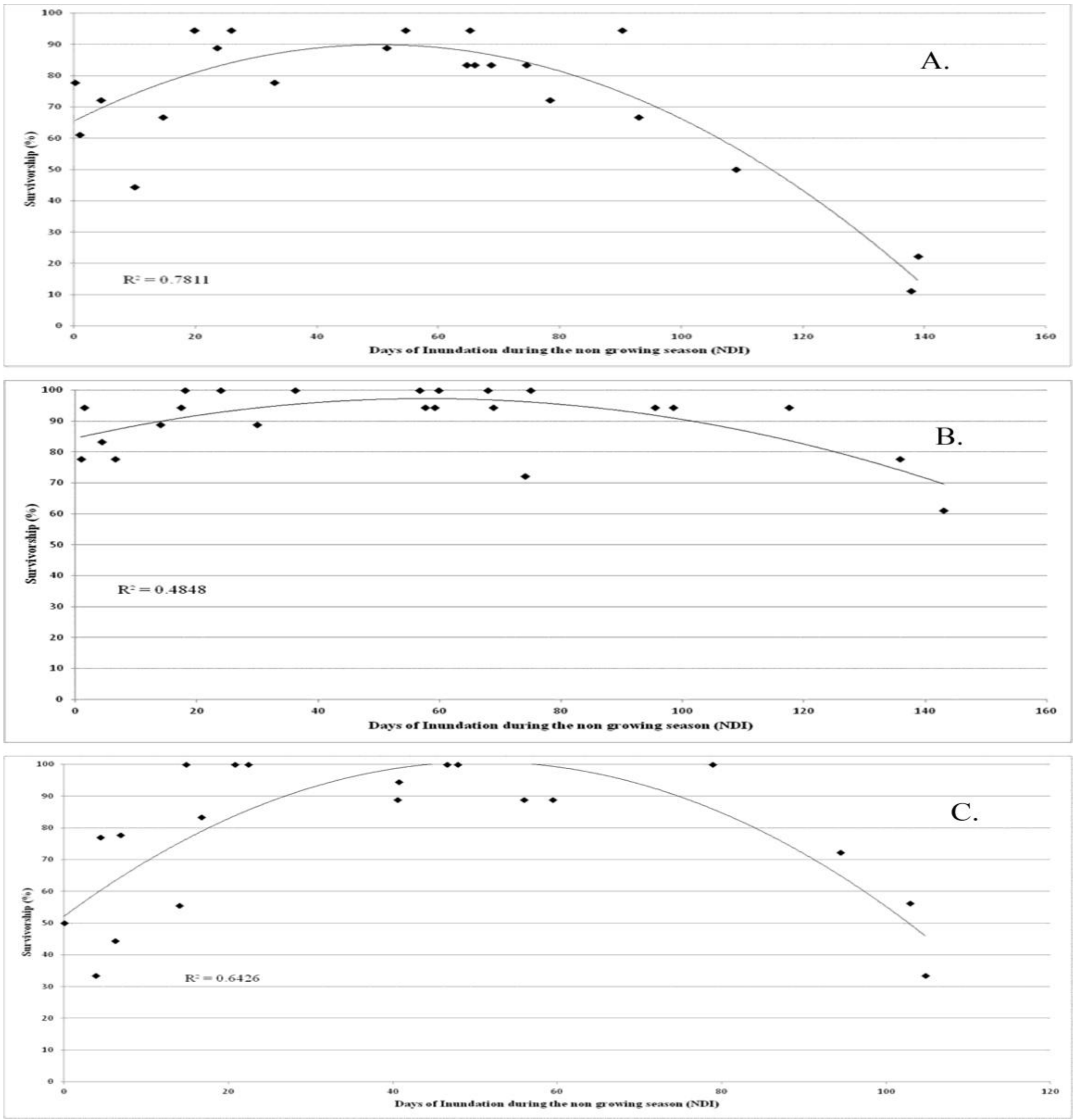

Figure 2. Survival and Days of Inundation during the non-growing season for A. containerized seedlings ($r^2 = 0.78$), B. rooted cuttings ($r^2 = 0.49$), and C. natural regenerants ($r^2 = 0.64$, $n > 20$)($p \leq 0.002$). Samples include burned and unburned salvage logging units.

Growth by Planting Type

Height growth for all three treatment types showed a significant relationship to MDTWT including RC ($r^2 = 0.423$)($p = 0.004$), CS ($r^2 = 0.372$)($p = 0.002$), and NR ($r^2 = 0.366$)($p = 0.02$). A negative effect of SPS on growth in canopy diameter was exhibited for RC ($r^2 = 0.28$)($p = 0.009$) and CS ($r^2 = 0.19$)($p = 0.037$), while NR showed a moderately weak relationship between canopy diameter growth and N-DI ($r^2 = 0.32$)($p = 0.039$). For RC a negative correlation between stem diameter growth and SPS was detected ($r^2 = 0.30$)($p = 0.007$), while for CS, no relationship was revealed and NR exhibited a non-linear relationship between stem diameter growth and NDI ($r^2 = 0.38$)($p = 0.017$). Stem diameter growth was related to N-MDTWT through second order polynomial regression for both RC ($r^2 = 0.56$)($p < 0.001$) and NR ($r^2= 0.37$)($p = 0.02$), but no such relationship was apparent for CS.

Comparison of Growth in Burned and Unburned Salvage Logging Units

Comparison of growth between burned and unburned salvage logging units (with all treatment types combined) revealed a significant relationship with soil saturation. SPS was positively correlated with overall growth in height ($r^2 = 0.302$)($p < 0.001$), canopy diameter ($r^2 = 0.407$)($p < 0.001$), and stem diameter ($r^2 = 0.420$)($p < 0.001$)(figure 3A, 3B, 3C respectively). DS was positively correlated with overall growth in height ($r^2 = 0.383$)($p < 0.001$), canopy diameter ($r^2 = 0.297$)($p < 0.001$), and stem diameter ($r^2 = 0.260$)($p < 0.001$) in the burned salvage logging units. The unburned salvage logging units showed no significant relationship between growth of height, canopy diameter, and stem diameter to SPS and DS ($p > 0.05$). Across the entire study, G1-MDTWT showed no significant relationship to any survival or growth parameters for any planting treatment type ($p > 0.05$, Regression Analysis).

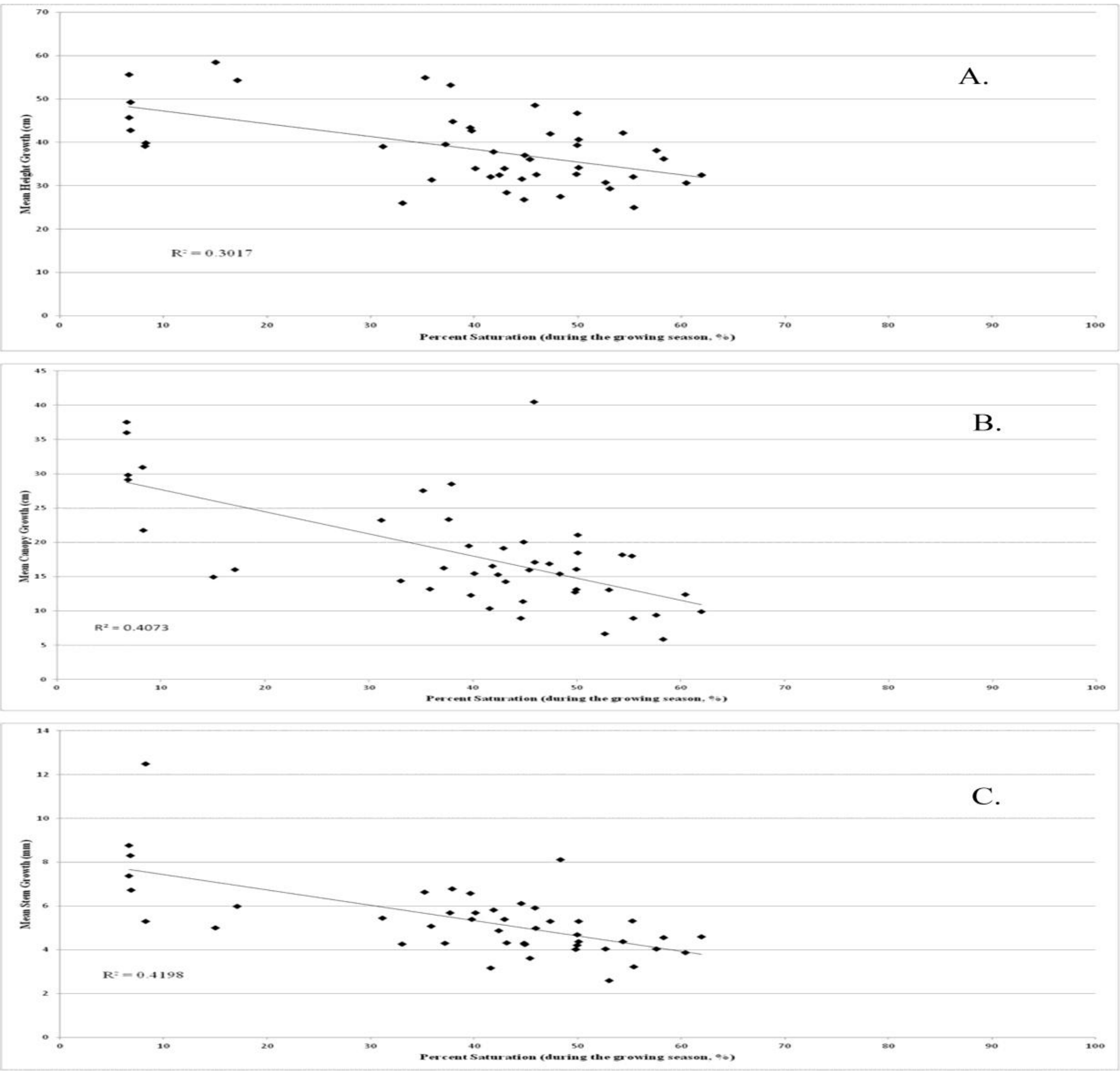

Figure 3. Soil percent saturation and tree morphometric growth indicators in burned salvage logging units including A. mean height growth ($r^2 = 0.30$), B. mean canopy diameter growth ($r^2 = 0.41$), and C. mean stem diameter growth ($r^2 = 0.42$, $n = 45$)($p < 0.001$). All planting treatment types were included.

DISCUSSION

Comparison of Water Tables at Other Cedar Sites

Mean depth to water table from July 2010 to August 2011, in the burned salvage logging units ranged from -0.70 to -1.19 ft (21 – 36 cm below ground surface). The unburned salvage logging unit showed a wider range, from 0.06 ft (2 cm above ground surface) to -1.02 ft (31 cm below surface). Brown and Atkinson (2003) reported similar average depth to water table,18 cm below ground surface during the 1997 growing season, in another 2-yr old cedar stand in GDSNWR. Atkinson et al. (2003b) also worked in intermediate and mature-aged cedar stands in GDSNWR and observed that mean 1999 growing season depth to water table was > 30 cm below the surface, and had exceeded 70 cm below the surface in mid-summer (Atkinson et al. 2003b). That study included cedar swamps in Alligator River National Wildlife Refuge in northeastern North Carolina, and mean 1999 growing season depth to water table was 3.8 to -2.1 cm for an intermediate and a mature-aged stand, which represents a much wetter site than reported for any salvage logging units in the current study.

Golet and Lowry (1987) compared hydrologic attributes of six cedar swamps during seven years in a study in Rhode Island. They reported average depth to water table of –0.8 cm (just below surface) with a mean range of 12.8 cm above ground surface (wettest year, 1979) to 10.9 cm below surface (driest year, 1981). The current study reported much drier mean water table depths during the growing season (for all salvage logging units combined was 30.78 cm (0.84 ft)), particularly in burned salvage logging units (32.57 cm (0.89 ft)) which were drier than unburned salvage logging units (26.69 cm (0.73 ft)).

Climate

MPDSI (July 2010 to August 2011) was positively correlated with depth to water table values from all burned units ($r^2 = 0.27 – 0.43$), but not with unburned units ($r^2 = 0.06$). MPDSI correlations with water tables were likely lowered by manipulation of water control structures by GDSNWR personnel, especially for ESC. Also working in GDSNWR cedar stands, Atkinson et al. (2003b) reported lower correlations between PDSI and depth to water table at wetter locations. The value of MPDSI in determining hydrologic conditions of GDSNWR may be limited in wetter locations such as ESC.

Burn and Unburned Conditions

Mean water table values were generally wetter in unburned than in burned locations. These results appear to contradict studies in which burned sites exhibit prolonged inundation (Akerman 1923). However, the unburned salvage logging unit, ESC, which was significantly wetter than all burned salvage logging units, may have been influenced by hydrologic management of a nearby water control structure (Wurster, personal communication); and WSC (the other unburned salvage logging unit) was among the driest in the study.

Survival

Harrison et al. (2003) reported optimum survival of cedar at -5 cm to -40cm (water table below the surface, based on growing season data) in prior converted agricultural sites in Virginia. Similarly, Mylecraine et al. (2003) in a study of restored cranberry bogs in New Jersey, observed that planted cedar seedlings exhibited highest survival at a mean water table of -9 cm to -29 cm (water table below the surface). Findings from both of those studies are similar to those of the current study in that second order polynomial regression equations characterized optimum survival at a MDTWT of approximately -3 cm (water table below the surface), suggesting that cedar mortality may result from either drought or inundation.

In the initial seedling stages, cedar is susceptible to mortality caused by drought, increased water table, flooding, and inundation (Akerman 1923). In our study, overall survival seemed to be favorably affected by inundation during the non-growing season for a period up to 55 days for all planting treatment types, but the relationship may be associated with reduced drought effects in the subsequent growing season. Negative effects of inundation on cedar survival have been reported by several authors (Harrison et al. 2003, Zampella 1987, Brown and Atkinson 2003) and inundation may prevent germination (Harshberger 1916, Zimmermann 1997). Low survival associated with inundation was more evident in CS than RC planting treatments, perhaps related to the smaller initial size of CS (Foster, personal communication), which can decrease survival in flooding conditions (Battaglia et al. 2000). PPI is responsive (inverse, linear relationship) to plant height and as PPI increased, survival decreased, supporting the assertion that height of RC, compared to CS and NR, allows the RC planting treatment to better tolerate inundation conditions.

Lowest survival was found in the unburned salvage logging units, WSC and ESC. However, the water regimes at the two sites differed and ESC was comparatively wetter with a prolonged period of winter time inundation (Days of inundation during the non-growing season = 120 days), compared to the GDSNWR average of 50 days and the WSC average of 3 days. ESC was comparatively wetter in terms of growing season saturation, with an average Mean depth to water table of 8.39 cm (0.22 ft) compared to a GDSNWR average of 30.78 cm (0.84 ft) and the WSC average of 40.42 cm (1.11 ft). With the exception of CS, survival between the two salvage logging units was similar, and ranged from 75-80% for RC and 50-51% for NR. CS survival for WSC was much lower (64%), compared to RC survival, and is likely due to the lower height that in turn, may dictate a lower root depth which reduces availability of moisture (Zimmermann 1997). Because this location was extremely dry, this may have negatively impacted survival. CS survival for ESC was the lowest of any unit in the study (28%) and likely can be attributed to the increased amount of PPI and DI that could possibly reduce the survival of cedar that results from increased inundation (Harrison et al. 2003, Akerman 1923, Battaglia et al. 2000). These results also express the severity of stress that can be caused by inundation versus drought. Whereas root desiccation may stress cedar (Rodgers et al. 2003) or reduce cedar survival (Zimmermann 1997), inundation may exert a greater negative effect on survival and may suppress growth as described below.

Effect of Hydrology on Growth

Soil percent saturation during the growing season and days of saturation were not significantly related to survival, but were important variables for linear models of growth.

Analysis revealed positive relationships of growth for both soil percent saturation and depth to water table during the growing season, but not inundation. Several authors report that optimum cedar growth coincides with a saturated root zone but water should not inundate the stems of cedar (Allison and Ehrenfeld 1999, Laderman 1989, Little 1950). The relationship was moderate between saturation and stem diameter growth, yet hydrology has previously seemed to only explain a small fraction of the growth parameter (Golet and Lowry 1987). Growth and saturation were modeled by a negative linear relationship in a prior converted agricultural field in Virginia (Harrison et al. 2003).

Annual tree height growth of rooted cuttings was negatively impacted by MDTWT in studies by Harrison et al. (2003) and Mylecraine et al. (2003), but only for CS treatment types in the current study. RC and NR exhibited improved growth at the high depth to water table (dry conditions) and saturated conditions, with the most unfavorable conditions between 18.29 – 36.5 cm (0.6 -1.2 ft below surface). Similarly, both RC and NR displayed significant trends when compared to N-MDTWT, suggesting that drier and wetter conditions during non-growing season alike promote stem growth, with an unfavorable range of 0 to 0.25 ft (0 to 7.6 cm below ground surface). While containerized seedlings began growth in 2010, natural regenerants in the burned salvage unit could have begun growing as early as March of the year following the 2008 South One Fire. Because height growth can range from 20 to 46 cm (Little and Garret 1990, Brown and Atkinson 1999, Akerman 1923) in the first year, and more than 30 cm each year thereafter (Little and Garrett 1990), differences in growth of natural regenerants and planting material may be age-dependent, and the age of NR in the current study could be as much as nearly 3 years old.

In one of the sites of a Rhode Island study of mature cedar stands, Golet and Lowry (1987) found that 83% of the variation in radial growth in a specific site was explained by mean water level during June and July, what our study defined as the drought period. While survival in all planting treatment types was negatively related to saturation during this period (June and July 2011), growth was not affected. The mid-summer time period coincided with low days of saturation, which can be a stressor for cedar and should be avoided when planting cedar (Ehrenfeld 1995).

CONCLUSION

Variables related to inundation (DI, NDI, and PPI) was the most significant for predicting survival; however, saturation variables (SPS, DS, and MDTWT) were the most significant for predicting growth (table 1). Managers in GDSNWR may have greater control of swamp hydrology once more weirs are constructed, and these results may assist them in efforts to reestablish cedar.

Table 1. Simplified display of significance between variables of hydrology and parameters of survivorship and growth. The following abbreviations are indicated below: "B" – burned salvage logging units, "U" –unburned salvage logging units, "NS" – not significant, "S" – significant. One asterisk denotes an r value between 0.25 and 0.5 and two asterisks denote an r value above 0.5.

	Survival			Tree Planting Type Growth			"B" Vs. "U" Growth		
	Over - all	"B"	"U"	Mean Stem	Mean Canopy	Mean Height	Mean Stem	Mean Canopy	Mean Height
MDTWT	S*	RC – NS	RC – NS	RC - NS	RC - NS	RC – S*	U - NS B - NS	U - NS B - NS	U - NS B - NS
		TB – NS	TB – NS	TB – NS	TB – NS	TB – S*			
		NR – NS	NR – NS	NR – NS	NR – NS	NR – S*			
DI	S**	RC – NS	RC – NS	RC - NS	RC - NS	RC - NS	U - NS B - NS	U - NS B - NS	U - NS B - NS
		TB – NS	TB – NS	TB – NS	TB – NS	TB – NS			
		NR – NS	NR – NS	NR – NS	NR – NS	NR – NS			
DS	NS	RC – NS	RC – NS	RC - NS	RC - NS	RC - NS	U - NS B – S*	U - NS B – S*	U - NS B – S*
		TB – NS	TB – NS	TB – NS	TB – NS	TB – NS			
		NR – NS	NR – NS	NR – NS	NR – NS	NR – NS			
PI	NS	RC – NS	RC – NS	RC - NS	RC - NS	RC - NS	U - NS B - NS	U - NS B - NS	U - NS B - NS
		TB – NS	TB – NS	TB – NS	TB – NS	TB – NS			
		NR – NS	NR – NS	NR – NS	NR – NS	NR – NS			
PS	NS	RC – NS	RC – NS	RC – S*	RC – S*	RC - NS	U - NS B – S*	U - NS B – S*	U - NS B – S*
		TB – NS	TB – NS	TB - NS	TB - S	TB – NS			
		NR – NS	NR – NS	NR - NS	NR - NS	NR – NS			
N - MDTWT	S*	RC – NS	RC – NS	RC – S**	RC - NS	RC - NS	U - NS B - NS	U - NS B - NS	U - NS B - NS
		TB – NS	TB – NS	TB - NS	TB – NS	TB – NS			
		NR – NS	NR – NS	NR – S*	NR – NS	NR – NS			
NDI	S**	RC – NS	RC – NS	RC - NS	RC - NS	RC - NS	U - NS B - NS	U - NS B - NS	U - NS B - NS
		TB – NS	TB – NS	TB – NS	TB – NS	TB – NS			
		NR – NS	NR – NS	NR – S*	NR – S*	NR – NS			
PPI	S*	RC – S*	RC – S**	RC - NS	RC - NS	RC - NS	U - NS B - NS	U - NS B - NS	U - NS B - NS
		TB - S	TB – S**	TB – NS	TB – NS	TB – NS			
		NR - NS	NR – S**	NR – NS	NR – NS	NR – NS			
G - MDTWT	NS	RC – NS	RC – NS	RC – NS	RC – NS	RC - NS	U - NS B - NS	U - NS B - NS	U -NS B - NS
		TB – NS	TB – NS	TB – NS	TB – NS	TB – NS			
		NR - NS	NR - NS	NR - NS	NR - NS	NR – NS			
DSDD	S*								

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