POST-FIRE REGENERATION AND GROWTH OF ATLANTIC WHITE CEDAR AFTER THE 2008 SOUTH ONE FIRE IN THE GREAT DISMAL SWAMP

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Abstract: A peat-based seed bank underlies many east coast *Chamaecyparis thyoides*, Atlantic white cedar (cedar) swamps, and this globally-threatened ecosystem exhibits self-maintenance through high rates of natural regeneration after a stand-clearing fire. Cedar stands in the Great Dismal Swamp have been in decline for approximately 200 years at least in part due to the draining of water by ditches, and the potential for natural regeneration is poorly understood. Furthermore, regenerants are at risk of either desiccation or flooding until established. In this study, we report the amount of regeneration of cedar in the Great Dismal Swamp after the South One Fire of 2008 and evaluate survival and one year of cedar growth (change in height). Regeneration in 8-m^2 plots during 2009 and 2010 was quantified by counting regenerants in 143 and 41 plots, respectively. For evaluation of survivorship and growth, up to 18 cedar regenerants were located and height was measured within each of 25 10-m^2 plots in 2010 and 2011. Mean density of regenerants in 2009 (26,500 ± 23,800 stems ha^{-1}) was much lower than regeneration rates reported in the literature for natural cedar swamps and density did not increase in 2010 (29,340 ± 38,049 stems ha^{-1}), suggesting that most regeneration occurred in the first year after the fire. Survival of regenerants in 2011 was high (95%) and mean height in 2010 (46.7 ± 11.8 cm) increased in 2011 (86.5 ± 13.5 cm) suggesting that regenerants have established successfully. Low regeneration rates in the current study may be the result of low water tables coincidental with the 2008 fire.

Key Words: Atlantic white cedar, regeneration, growth, seedling survival, post-fire, hydrology, Great Dismal Swamp

INTRODUCTION

Atlantic white cedar, *Chamaecyparis thyoides* (L.) B.S.P. (cedar), was historically found along the Eastern and Gulf Coasts of the United States and was a valuable timber resource. Cedar was considered a soft wood and was harvested in order to make poles and docking timber (Korstian and Brush 1931). Current populations of cedar are drastically lower than population known to have existed before European colonization of North America (Little 1950). The opening of canals and ditches, and the subsequent change in water level, may have negatively affected the survival and growth of cedar (Akerman 1923). Some of the greatest loses have occurred within the historical limit of the Great Dismal Swamp and a recent hurricane and two fires have eliminated mature stands of this ecosystem type in the Great Dismal Swamp National Wildlife Refuge (GDSNWR). Recent restoration efforts have focused on natural regeneration supplemented by planting.

Regeneration

Cedar regeneration depends on several factors to ensure adequate germination from seeds. Abiotic factors affecting regeneration rates include moisture, light and temperature (Korstian and Brush 1931). Persistent moisture availability is required for germination; however, low moisture levels desiccate seeds and excessive moisture precludes regeneration. Light availability and temperature regime also influence germination of cedar seedlings (Jull and Blazich 1999).

Cedar trees begin producing seeds at vast quantities when young (Akerman 1923, Korstian 1924) and have the ability to do so every year (Harris 1974). Seeds remain viable in the soil for at least two growing seasons (Little 1950). Cedar seeds also show a high germination capability in a short period of time after sowing, although the germination is inherently low due to poor seed quality (Harris 1974). The germination of seedlings may also be delayed until the next growing season after sowing (Little 1950).

Peat forms a seed refugium that allows for regeneration when conditions are favorable. Cedar is usually one of the first woody species to germinate in an open landscape (Walker and Oswald 1924). Cedar regeneration is severely limited beneath a mature canopy (Laderman 1989), hurricane debris (Belcher et al. 2009), and logging slash (Akerman 1923). Shade from other plant species can also inhibit regeneration. A study in North Carolina suggested that competition with other hardwood species was the primary cause of failed regeneration by cedar (Eagle 1999). Competition with seedlings of other woody wetland species such as *Acer rubrum* (red maple), *Nyssa sylvatica* (blackgum), and *Clethra alnifolia* (sweet pepperbush) hinder regeneration rates (Kuser and Zimmermann 1995) and high germination rates may be required for cedar to grow in monotypic self-thinning stands. Herbicides have been used to limit competition from other species in areas where regeneration is not adequate. Browsing by small rodents and deer as well as the building of dams by beavers may adversely affect regeneration (Kuser and Zimmermann 1995).

Survival and Growth

Cedar is an evergreen species that grows mostly in the coastal plain of the Southeastern US (USDA 2011, Laderman 1989). Young cedar require adequate sunlight (Belcher et al. 2003), but are tolerant of low nutrient concentrations and very acidic and shallow soils with poor drainage, and may outcompete other plants under these conditions (Laderman 1989). Cedar in the Great Dismal Swamp are known to grow up to 20-25 meters tall with diameters at breast height of more than 0.5 meters, but the species is very slow growing and stands may require more than 100 years to reach a mature state (Akerman 1923).

Cedar is an obligate freshwater wetland species (USDA 2011) but has a relatively narrow range of tolerance for water level. Seedlings cannot survive if inundated during the growing season especially during the first few years (Akerman 1923, Eagle 1999, Brown and Atkinson 1999, Harrison et al. 2003, Trew 1957). Harrison et al. (2003) reported that lower water tables (drier conditions) were associated with increased growth of young cedar; however, drought conditions may be lethal or may limit growth. Related to water levels, survival and growth of cedar are affected by microtopography of sites, and growth rates tend to be higher on intermediate elevations (Brown and Atkinson 2003, Belcher et al. 2009).

Natural regeneration, survival and growth represent key functions for the self-maintenance of cedar. The requirement of fire for cedar stand regeneration (Akerman 1923, Laderman 1989) coupled with its destructive capabilities suggests that the South One Fire of 2008 may have either facilitated or inhibited reestablishment of cedar stands. The purpose of the current study is to quantify regeneration of cedar in the Great Dismal Swamp after the South One Fire of 2008 and evaluate survival and change in height as an indicator of annual cedar growth.

METHODS

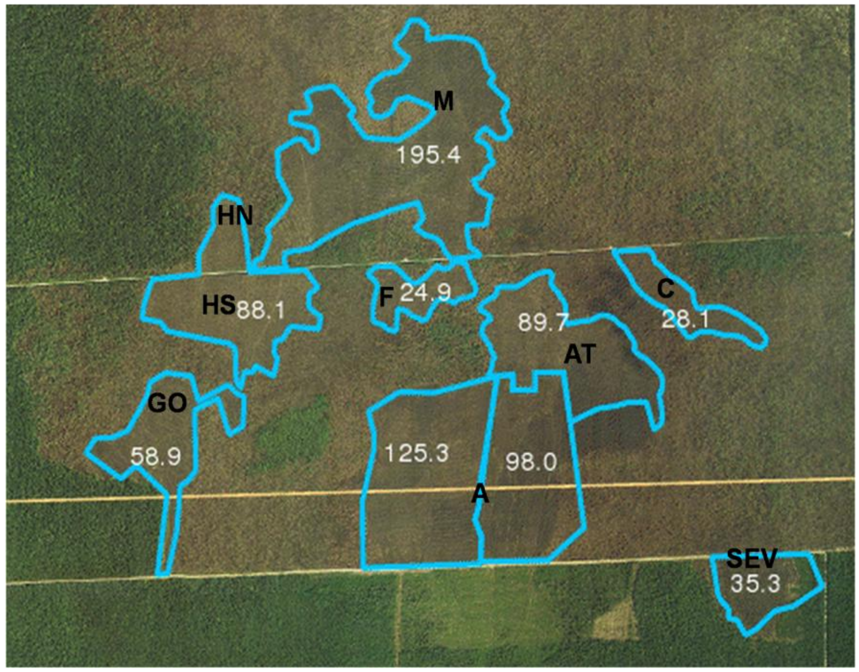
Study Site

Plots were selected to measure cedar regeneration inside GDSNWR which consists of approximately 112,000 acres (45,325 hectares) of forested wetlands and is located on the eastern border of North Carolina and Virginia. The GDSNWR is located between the cities of Suffolk and Chesapeake in Virginia and in Gates, Pasquotank and Camden counties in North Carolina; it is approximately 40 km from the Atlantic Ocean. The Great Dismal Swamp (GDS) is underlain by mostly peat soils which have a high amount of organic matter and had historically supported extensive stands of cedar until it was extensively drained and logged during the 19th and 20th centuries. The GDSNWR was established in 1974 with a goal of preserving remaining cedar stands; however, in 2003 all of the remaining mature cedar stands were blown down by Hurricane Isabel. Salvage logging was performed in order to allow for natural regeneration of cedar, but the South One Fire of 2008 burned the peat soils that underlay these salvage logging units (salvage units). Study plots were established within nine of the Hurricane Isabel salvage units, all of which were within the area of the South One Fire of 2008. Salvage unit hydrology is altered by ditches and water control structures provide limited water level control; inundation persists for much of the winter and spring.

Study Methods

Regeneration

Figure 1. Map of cedar salvage logging units (in black) with acres shown in white.



The number of naturally regenerating cedar was recorded within plots that were established at random intervals within each of the nine salvage units including A, AT, CS, FS, GO, HN, HS, M, and SEV (figure 1). Plot dimensions were 13.4 m x 0.6 m and coordinates were determined using ArcGIS and GPS units in the field. Plots that occurred on a skid trail (trails used by logging machines which consist of several logs laid down side by side) were avoided by random relocation in a cardinal direction. Inundation precluded some sampling but a total of 143 plots were sampled in fall 2009. In fall 2010, a subsample consisting of 41 plots were resampled in five salvage units (AT, CS, FS, HS, and M).

Survival and Growth

In fall of 2010, 25 10-m^2 plots were randomly selected as a subset of plots established within five salvage units (A, GO, HN, HS, and SEV) in 2009. In each plot, the height of up to 18 regenerating cedar was measured using a meter stick. In 2011, the Lateral West Fire occurred and limited resampling to 16 of the 25 plots (including salvage units A, GO, and SEV), and the same trees measured in 2010 were remeasured to estimate survival rate and assess change in height.

In the regeneration study, the number of regenerating cedar per salvage unit and per year was compared using paired t-Tests using Sigmastat 3.1. In the survival and growth study, the percentage of surviving trees from the initial planting to the end of the study was calculated. Growth of cedar trees in salvage units was estimated as change in height and compared using paired t-Tests using Sigmastat 3.1.

RESULTS

Regeneration

Mean regenerating cedar density for each plot sampled in 2009 (26,531.8 ± 23,821.3 stems ha^{-1}) did not differ from cedar density in 2010 (29,339.8 ± 38,048.8 stems ha^{-1}, $p = 0.32$)(figure 2). Salvage unit AT exhibited the highest stem density both years (2009: 36,544.8 ± 31,149.8 stems ha^{-1}; 2010: 39,544.3 ± 46,483.1 stems ha^{-1})(figure 3). Of the plots that were resampled, only HS had a significant change in cedar stem density, a decrease from 16,402 ± 8,998 stems ha^{-1} to 5,202 ± 2,714 stems ha^{-1} ($p = 0.02$). Cedar stem density was unchanged among the other three salvage units (AT: $p = 0.49$, FS: $p = 0.34$, and M: $p = 0.12$).

Survival and Growth

The rate of survival from 2010 to 2011 was 95.1%. The mean height of regenerating cedar in 2010 (46.7 ± 11.8 cm) increased in 2011 (86.5 ± 13.5 cm, $p < 0.01$)(figure 4). Mean height increased from 2010 to 2011 in each salvage unit (A: $p < 0.01$, GO: $p < 0.01$ and SEV: $p = 0.03$)(figure 5).

Figure 2. Regeneration (stem density per ha) for plots sampled in both 2009 (n = 34) and 2010 (n = 34). Error bars represent +1 standard deviation.

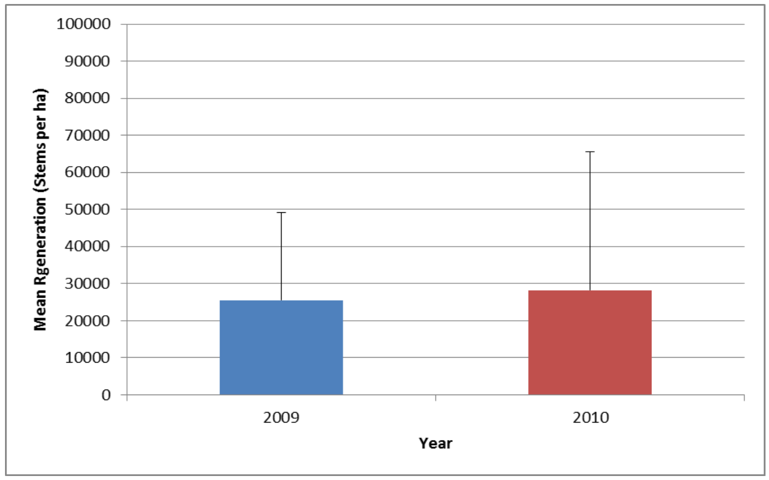


Figure 3. Regeneration per salvage unit in 2009 (n = 117) and 2010 (n = 34). Error bars represent +1 standard deviation. ⁺Not measured in 2010.

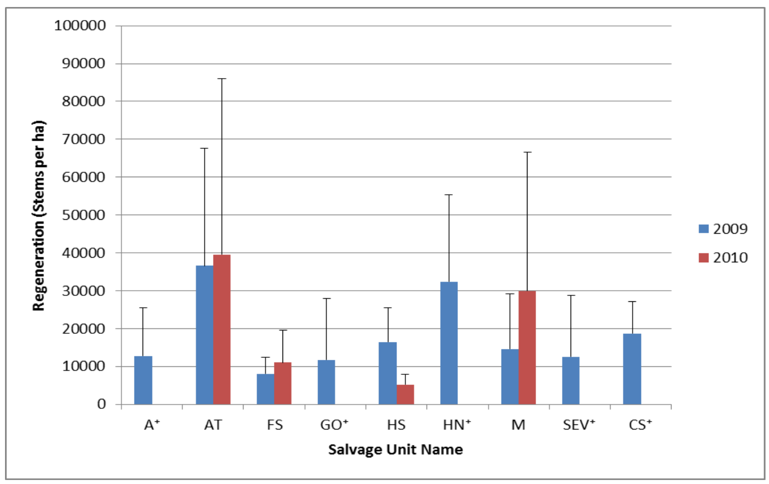
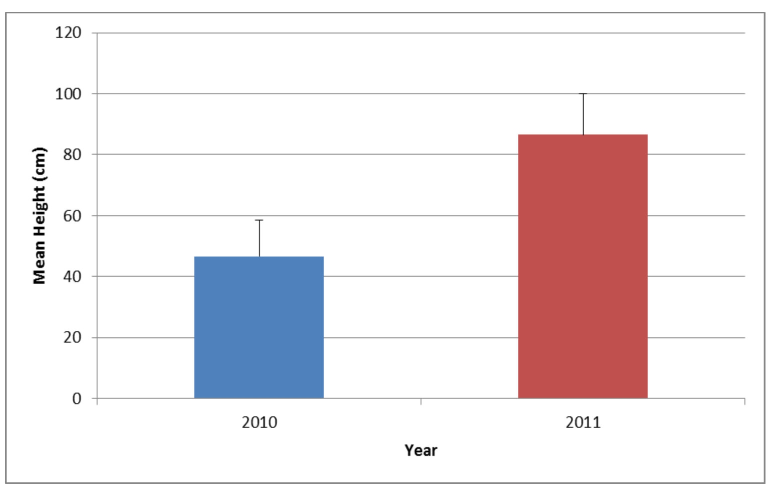


Figure 2. Mean cedar height for plots sampled in both 2010 (n = 15) and 2011 (n = 15). Error bars represent +1 standard deviation.

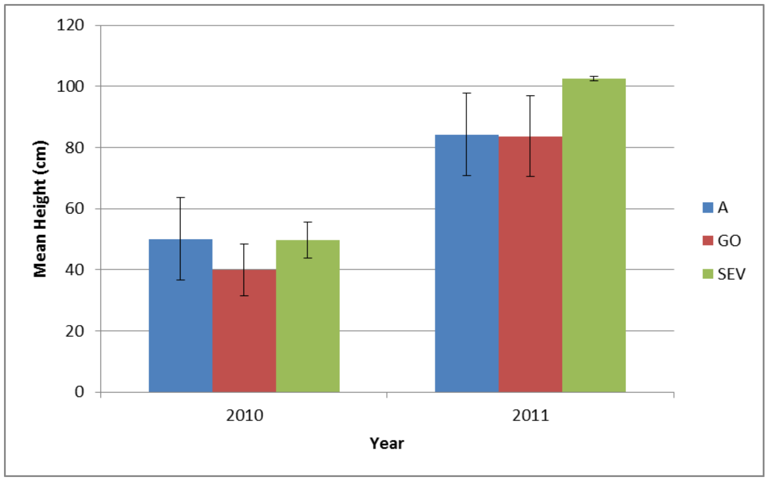


DISCUSSION

Regeneration

The amount of regeneration found after one growing season was between 26,500 and 29,500 stems ha^{-1} and highly variable. Stem densities in newly regenerating stands can range from 6.2 million stems ha^{-1} (Walker and Oswald 1924) to 8.8 million stems ha^{-1} (Korstian 1924). The stem density measured here is also lower than stem densities of 31,500 stems ha^{-1} reported for a 25-year old stand in a more saturated soil habitat of Alligator River National Wildlife Refuge in North Carolina (DeBerry et al. 2003), and that estimate excludes self-thinning.

Figure 3. Mean cedar height per salvage unit for 2010 (n = 25) and 2011 (n = 15). Error bars represent ±1 standard deviation.



The lower rate of regeneration detected in the current study may be attributed to the conditions present in the stands at the time of the fire. Water levels, normally low in summer, were artificially lowered in order to facilitate the salvage-logging operation. The highly organic nature of the soil (Thompson et al. 2003) and dry conditions led to a mean soil loss of approximately1 to 2 m of peat.

After the second growing season, the stem density (29,300 stems ha^{-1}) was not different from the first growing season. Lower regeneration rate in 2011 may have resulted from shading since cedar requires an open environment for germination (Harris 1974, Walker and Oswald 1924, Little and Garrett 1990).

Survival and Growth

Survival of cedar seedlings was high in this study (95.1%). Seedlings are very susceptible to drowning and failed to reestablish in wetter hollows, as reported by Little (1950) and half a century later by Belcher et al. (2009), Harrison et al. (2003) and Mylecraine et al. (2003).

The relatively rapid increase in height (increased from 46.7 cm to 86.5 cm in 1 year) is slightly higher than growth rates found by Little (1950) of ~30 cm for seedlings planted in moist hardwood swamps. Excessive shading from competing hardwoods has been shown to inhibit growth of planted seedlings post stand-clearing disturbance in the Great Dismal Swamp (Belcher et al. 2003), but does not appear to be a factor at this early post-fire period. Browsing by wildlife and competition from other hardwoods has also hindered the growth of seedlings in a study by Bianchetti et al. (1994), but minimal herbivory was noted in the current study.

CONCLUSION

The low regeneration rates reported here are likely the combined result of seed elimination and increased hydroperiod, both caused by the South One Fire. Regeneration of cedar is dependent on stand clearing fires to open the canopy and allow for light penetration; however, a high water table is required in order to prevent elimination of the seed refugium (Laderman 1989). In addition, wetter hydroperiods that result from fires and catastrophic peat loss can preclude cedar regeneration, as predicted by Akerman (1923).

The patchy distribution of cedar and the relatively high growth rates suggest that cedar stem density is highest on mounds where water tables are low. Cedar in these locations may become stressed by intraspecific competition and undergo self-thinning. A failure to close canopy within salvage units may necessitate supplemental planting for establishment of cedar stands.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Chris Lowie and the conference planning team. Support for the project was provided by the Great Dismal Swamp National Wildlife Refuge and the CNU Department of Organismal and Environmental Biology. Help in the field came from Bryan Poovey of the GDSNWR and numerous graduate and undergraduate students from CNU. Comments from anonymous reviewers are appreciated.

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