Salinity and Flooding Affect Mortality of Atlantic White-Cedar (*Chamaecyparis thyoides*) Seedlings

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Abstract

Atlantic white-cedar (*Chamaecyparis thyoides* [L.] Britton, Sterns & Poggenb.) seedlings in pots were subjected to four levels of salinity in irrigation water (0.0, 0.1, 0.2, or 0.4 percent) with either continuous flooding or irrigation as needed. Mortality of continuously flooded seedlings with 0.4, 0.2, and 0.1 percent saltwater was 100 percent after 2, 4, and 8 months, respectively, compared with 20 percent mortality for seedlings flooded 17 months with fresh water. For seedlings irrigated as needed, mortality after 17 months was 100, 85, and 40 percent for 0.4, 0.2, and 0.1 percent saltwater, respectively, compared with 5 percent for seedlings that received fresh water. Results have implications for site selection for regeneration or restoration with Atlantic white-cedar in areas affected by rising sea level.

Introduction

Atlantic white-cedar, (*Chamaecyparis thyoides* [L.] Britton, Sterns & Poggenb.) (AWC) is a wetland tree species (Reed 1988) that occurs in a narrow band along the Atlantic coast from Maine to Georgia with a separate population on the Gulf of Mexico coast from Florida to Mississippi (Laderman 1989, Little and Garrett 1990). AWC is an early succession species that usually occurs in dense, natural stands (figure 1). A new AWC stand often arises when an existing stand is destroyed by fire, logging, or weather-related blowdown (Frost 1987). When new stands develop, the seed source is 1) the seed bank that accumulated in the surface layers of the soil beneath the previous AWC stand, or 2) seed from an adjacent stand. AWC grows best on organic soils (Histosols) underlain by sandy substrate (Little and Garrett 1990). The species occupies a narrow hydrologic position intermediately between deciduous swamp forest and evergreen pocosin (Frost 1987). Historically, AWC was favored by fire return intervals of 50 to 250 years (Frost 1987, 1995; Motzkin et al. 1993). Fires that are too frequent or too severe, however, will eliminate AWC. In addition, repeated logging in the absence of fire reduces the area occupied by AWC and eventually leads to extirpation (Frost 1987).

AWC wood is mechanically and chemically similar to western red cedar (*Thuja plicata* Donn ex D. Don) which was historically prized for siding, shingles, pilings, posts, lumber, shallow-draft boats, and waterfowl decoys. Early in the 20th century, stumpage prices for AWC were 2 to 5 times greater than prices for other swamp species like baldcypress (*Taxodium distichum* L. [Rich]) and blackgum (*Nyssa sylvatica* Marshall), so loggers sought it anywhere they could find it (Krinbill 1956).

An estimated 500,000 ac (202,000 ha) of the AWC forest type existed in pre-settlement times (Kuser and Zimmermann 1995). The greatest concentrations were in the Great Dismal Swamp in the coastal plain region of southeastern Virginia and northeastern North Carolina, the Albemarle/Pamlico peninsula of eastern North Carolina, and southern New Jersey (Ackerman 1931, Kuser and Zimmerman 1995, Pinchot and Ashe 1897). Logging of AWC accelerated after 1880 and rapidly depleted stands in North Carolina and the Great Dismal Swamp during the following 40 years. In addition, massive drainage projects permanently altered the landscape, mostly for conversion of swamp land to agriculture (Frost 1987, Lilly 1981). The frequency of destructive wildfires also increased in the 20th century, making it more difficult to permanently maintain AWC stands (Frost 1987, 1995).

Figure 1. Atlantic white-cedar (AWC) occurs in a patchy distribution in freshwater wetlands within a narrow coastal belt from southern Maine to northern Florida and west to southern Mississippi. (a) Historical records indicate maximum potential height and diameter of 120 ft (37 m) and 60 in (152 cm), respectively. In present-day stands on good sites, typical heights are 70 to 80 ft (21 to 24 m) and maximum diameters are 24 to 26 in (60 to 66 cm). (b) Mature AWC stands tend to maintain high stem density and basal area. (c) AWC is an early succession species that usually occurs in dense stands such as this small pole stand in Gloucester County, NJ that was thinned from 230 to 190 ft^2 basal area per acre (53 to 44 m^2 per hectare). (Photos a and c by Robert Williams, Pine Creek Forestry, Clementon, NJ and photo b by George Zimmermann)

In 1998, the estimated land area of AWC stands was 108,000 ac (44,000 ha) (Sheffley et al. 1998). Hurricane Isabelle (2003) destroyed 2,000 ac (810 ha) of mature AWC (figure 2) in the Great Dismal Swamp in northeastern North Carolina (Laing et al. 2003). Hurricane Sandy (2012) caused significant losses of AWC in southern New Jersey as a result of blowdown (figure 3) and saltwater flooding (figures 4 and 5). Today, less than 10,000 ac (4,050 ha) of AWC remain in eastern North Carolina, mostly in coastal Dare County. New Jersey currently has less than 30,000 ac (12,000 ha) (Widman 2005) of AWC, possibly as low as 13,000 ac (5,240 ha) (Williams 2021). In addition, the threat of catastrophic wildfire is high owing to accumulated debris from Hurricane Sandy (figure 3). Additional losses have occurred in some locations as a result of prolonged flooding by beavers (*Castor canadensis*) (figure 6).

The AWC forest type is also facing a threat from accelerating rates of rising sea level. The New Jersey Meadowlands and other parts of the East Coast have been experiencing submergence and influx of salt water since historical records have been recorded (Zimmermann and Mylecraine 2003) not only in coastal habitats but also in many previously freshwater marshes farther inland. Dead stands of AWC (ghost forests) are becoming a familiar landscape feature of the New Jersey Pinelands. In coastal Dare County (North Carolina), satellite imagery indicates that 11 percent of the forests in Alligator River National Wildlife Refuge have transitioned to ghost forests in the last 35 years, with a pronounced peak following flooding by Hurricane Irene in 2011 (Ury et al. 2021). Most remaining AWC stands in eastern North Carolina are in Dare County and will become ghost forests if sea level rises 3.2 ft (1 m) as projected in the 21st century (Bhattachan et al. 2018).

Figure 3. Vast areas of Atlantic white cedar were blown down during Hurricane Sandy in 2012 such as this stand in Burlington County, New Jersey. Most of that timber was not salvaged, thus creating a serious wildfire threat in southeastern New Jersey. (Photo by Robert Williams, Pine Creek Forestry, Clementon, NJ)

Figure 2. This large tract of peatland in the Great Dismal Swamp National Wildlife Refuge was destroyed by wildfire in the aftermath of a salvage operation to remove residue from 2,000 ac (810 ha) of mature Atlantic white-cedar blown down by Hurricane Isabelle in 2006. Owing to a low water table, the fire burned deep into the peat and killed the dense natural regeneration of AWC already on the site. The fires also eliminated the remaining seed bank from the previous AWC stand. The resulting landscape is mostly open water unsuitable for forest vegetation, probably for hundreds of years. (Photo by Bill Pickens, North Carolina Forest Service, retired)

The effects of flooding and increasing salinity on forests depend on the species and can vary among families within a species (Allen et al. 1996, Pezeshki et al. 1990, Ruter 2017). Coastal habitats have species that can withstand prolonged flooding and increased salinity, but many inland species are unable to cope. Frost (1995) and Ruter and Pennisi (2017) broadly categorized AWC as intolerant of salt water but included no experimental data. The objective of this study was to determine the effects of flooding and salinity on survival and growth of AWC seedlings.

Figure 4. This aerial view (January 2013) shows dead and dying Atlantic white-cedar (red foliage) in southern New Jersey after Hurricane Sandy in October 2012. (Photo by James Dunn, New Jersey Department of Environmental Protection)

Methods

In December 2003, 200 1-year-old AWC seedlings were transplanted into 2-gal (7.8-L) pots filled with *Sphagnum* peat substrate and placed in a greenhouse. Seedlings were uniform in size and came from a single seed source. Temperatures in the greenhouse ranged from a minimum of 65 °F (18 °C) in the winter to 90 °F (32 °C) in the summer.

Commercially available sea salt (Instant Ocean Synthetic Sea Salt, Aquarium Systems Inc., Mentor, OH) was used to prepare solutions representative of salinity ranges in the lower watersheds of the Mullica, Egg Harbor, and Tuckahoe rivers (figure 7) in southeastern New Jersey. Seedlings were treated with four saline solutions (0.1, 0.2, or 0.4 percent salt plus a tap-water control) applied with two water regimes (as needed with periodic irrigation or with continuous flooding) for a total of 8 treatments. Treatments began in July 2004. For each treatment, 20 seedlings were randomly assigned and randomized on the greenhouse benches. Pots assigned to flooding treatments were placed inside 3-gal (10.4-L) pots lined with plastic bags to retain irrigation water (figure 8). Water levels in flooded pots were maintained near the substrate surface. Non-flooded pots were allowed to drain following watering.

Seedling mortality was observed weekly or biweekly until February 2006 (17 months). Ratings were based on foliage color and branch pliability.

The study used a completely randomized design with a 2 by 4 factorial (water regime and salt level) arrangement of treatments and 20 replications of each treatment (160 seedlings total). Survival percentages were transformed (arcsin) to meet ANOVA assumptions and subjected to analysis of variance (ANOVA) using SAS (SAS Institute 2003). Treatment means were compared using Dunnett's Test.

Results

Analyses found a significant interaction ($p \leq 0.001$) for salinity and flooding treatments (figure 9). Mortality of control seedlings (no flooding, no salt) was 5 percent, whereas continuous flooding with fresh water (no salt) resulted in 20 percent mortality. Seedlings continuously flooded with 0.4 percent or 0.2 percent salt concentrations all died within 2 to 4 months after initiation of treatments, and those flooded with 0.1 percent salt water reached 100 percent mortality after 8 months. The same salt treatments, when applied only in irrigation water, caused 100, 85, and 40 percent mortality, respectively, after 17 months (figure 9).

Figure 5. Atlantic white-cedar near the Mullica River in Atlantic County, New Jersey in January 2013. Dying Atlantic white-cedar on the left side of highway resulted from a surge of brackish water that did not drain back into the Mullica River after Hurricane Sandy (October 2012). In contrast, the storm surge retreated on the right side of the highway. (Photo by George Zimmermann)

Discussion

AWC stands often experience shallow flooding (fresh water) during the winter months when trees are dormant and evapotranspiration is low. Water regimes can fluctuate widely during the growing season, including short-term flooding from rain, but AWC tends to grow best in wetlands where the water table is 5 to 8 in (10 to 20 cm) below the surface during much of the growing season (Atkinson et al. 2003, Little 1950). In the current study, 80 percent of seedlings survived 17 months of continuous flooding with fresh water, but those flooded with salt water all died (figure 9).

Figure 6. Beavers can kill stands of Atlantic white-cedar. This site is in Atlantic County, New Jersey near the Great Egg Harbor River was flooded due to the beaver dam (foreground). Land managers should monitor beaver activity to avoid excessive losses of valuable timber from prolonged flooding. (Photo by Robert Williams, Pine Creek Forestry, Clementon, NJ)

The lowest salt concentration (0.1 percent) caused significant mortality of AWC seedlings although at a slower rate in non-flooded treatments (figure 9). This suggests that AWC might have a threshold salt tolerance between 0.0 and 0.1 percent. Follow-up observations in rivers in southeastern New Jersey, however, noted up to 50 percent mortality of mature AWC where salinity was only 0.03 percent, and healthy stands only occurred where salinity was 0.0 percent further upriver. Therefore, based on greenhouse results and observations of river salinity, it seems reasonable to conclude that AWC has no tolerance of salt water.

The sensitivity of AWC to low salt concentrations, especially when combined with continuous flooding, helps explain AWC mortality following inland flooding by Hurricane Sandy (2012) in New Jersey (figures 4 and 5) and Hurricane Irene (2011) in eastern North Carolina. Field observations suggest that mature AWC can survive longer than seedlings when

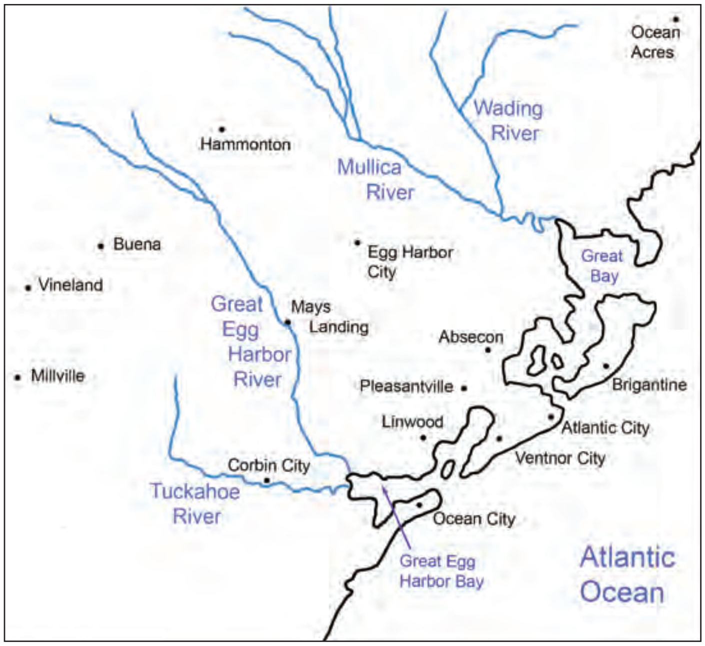

Figure 7. Atlantic white-cedar is abundant in river watersheds (Mullica, Great Egg Harbor, and Tuckahoe) in southeastern New Jersey. (Adapted from a portion of a New Jersey road map, https://www.new-jersey-map.org/road-map.htm)

subjected to prolonged flooding, but the overall health and longevity of the stands will be affected by factors such as river salinity, distance from rivers, severity and frequency of storms, and rates of salt dissipation from soils following flooding.

Results of this study have important implications for future regeneration and restoration of AWC. Significant acreage of AWC, especially in eastern North Carolina and southern New Jersey, will be lost if sea level rises as projected. In addition, hurricanes pose an ongoing threat of blowdown and/or flooding (Lang et al. 2011, McCoy and Keeland 2009, Ury 2021). Potential impacts are likely to become more extreme as sea level rises. Future AWC restoration plantings should be established on suitable sites farther inland at elevations high enough to allow sufficient time for stands to complete one or more life cycles without the risk of salt water inundation.

Figure 8. Potted Atlantic white-cedar seedlings were subjected to various levels of salinity (0 to 0.4 percent) and two flooding regimes (flooded or not flooded). Pots designated for flooding treatments were placed inside larger pots lined with plastic. The two plants in the center of the image (second row) were flooded and the one on the right has died from higher salinity. (Photo by George Zimmermann)

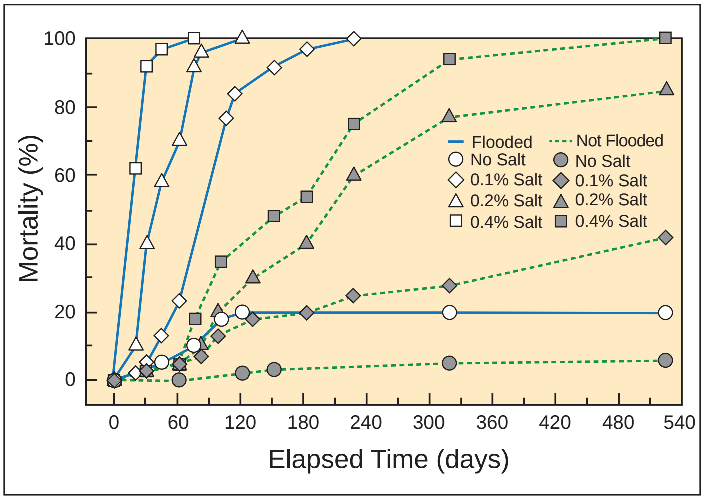

Figure 9. Atlantic white-cedar seedlings subjected to factorial combinations of two water regimes (flooded vs. not flooded) and four concentrations of salt water (0 percent, 0.1 percent, 0.2 percent, and 0.4 percent) had varying mortality rates during a 17-month greenhouse experiment. Each mean is based on 20 plants.

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REFERENCES

Akerman, A. 1931. The white cedar of the Dismal Swamp. Virginia Forestry Publication 30. Charlottesville, VA: Virginia Geological Commission and University of Virginia, Charlottesville. 21 p.

Allen J.A; Pezeshki, S.R.; Chambers, J.L. 1996. Interaction of flooding and salinity stress on baldcypress (*Taxodium distichum*). Tree Physiology. 16: 307–313.

Atkinson, R.B.; DeBerry, J.W.; Loomis, D.T.; Crawford, E.R.; Belcher, R.T. 2003. Water tables in Atlantic white cedar swamps: implications for restoration. In: Atkinson, R.B.; Belcher, R.T.; Brown, D.A.; Perry, J.E. III, editors. Proceedings, Atlantic white cedar restoration ecology and management symposium. Newport News, VA: Christopher Newport University: 137–150.

Bhattachan, A.; Jurjonas, M.D.; Moody, A.C.; Morris, P.R.; Sanchez, G.M.; Smart, L.S.; Taillie, P.J.; Emanuel, R.E.; Sekamp, E.L. 2018. Sea level rise impacts on rural coastal social-ecological systems and the implications for decision making. Environmental Science and Policy. 90: 122–134.

Frost, C.C. 1987. Historical overview of Atlantic white cedar in the Carolinas. In: Laderman, A.D., editor. Atlantic white cedar wetlands. Boulder, CO: Westview Press: 257–264.

Frost, C.C. 1995. Presettlement fire regimes in southeastern marshes, peatlands, and swamps. In: Cerulean, S.I.; Engstrom, R.T., editors. Fire in wetlands: a management perspective. Proceedings, 19th Tall Timbers Research Conference, No. 19. Tallahassee, FL: Tall Timbers Research Station: 39–60.

Krinbill, H.R. 1956. Southern white cedar: the forgotten tree. Southern Lumber Journal. 60(11): 26, 28, 36, 45.

Kuser, J.E.; Zimmermann, G.L. 1995. Restoring Atlantic white-cedar swamps: techniques for propagation and establishment. Tree Planters' Notes. 46(3): 78–85.

Laderman, A.D. 1989. The ecology of Atlantic white cedar wetlands: a community profile. Biological Report 85(7.21). Washington, DC: U.S. Fish and Wildlife Service, National Wetlands Research Center. 114 p.

Laing, J.L.; Shear, T.H.; Blazich, F.A. 2011. How management strategies have affected Atlantic white-cedar forest recovery after massive wind damage in the Great Dismal Swamp. Forest Ecology and Management. 262: 1337–1344.

Lilly, J.P. 1981. A history of swamp land development in North Carolina. In: Richardson, C.J., editor. Pocosin wetlands: an integrated analysis of Coastal Plain freshwater bogs in North Carolina. Stroudsburg, PA: Hutchinson Ross: 20–39.

Little, S. 1950. Ecology and silviculture of whitecedar and associated hardwoods in southern New Jersey. Bulletin No. 56. New Haven, CT: Yale University School of Forestry. 103 p.

Little, S.; Garrett, P.W. 1990. Atlantic white-cedar *Chamaecyparis thyoides* (L.) B.S.P. In: Burns, R.M.; Honkala, B.H., tech. coords. Silvics of North America: 1. Conifers. Agriculture Handbook 654. Washington, DC: U.S. Department of Agriculture, Forest Service. 877 p.

McCoy, J.W.; Keeland, B.D. 2009. Species composition and hurricane damage in an Atlantic white cedar stand near the Mississippi/Alabama border. In: Zimmermann, G.L., editor. Proceedings, Ecology and management of Atlantic white-cedar. Pomona, NJ: The Richard Stockton College of New Jersey: 8–14.

Motzkin, G.; Patterson III, G.; Drake, N.E.R. 1993. Fire history and vegetation dynamics of a *Chamaecyparis thyoides* wetland on Cape Cod, Massachusetts. Journal of Ecology. 81: 391–402.

Pezeshki S.R.; DeLaune, R.D.; Patrick, W.H. 1990. Flooding and saltwater intrusion: potential effects on survival and productivity of wetland forests along the U.S. Gulf Coast. Forest Ecology and Management. 33/34: 287–301.

Pinchot, G.; Ashe, W.W. 1897. Timber trees and forests of North Carolina. North Carolina Geological Survey Bulletin No. 6. Winston, NC: M.I. & J.C. Stewart, public printers. 227 p.

Reed, P.B., Jr. 1988. National list of plant species that occur in wetlands: National summary. Biological Report 88(24). Washington, DC: U.S. Fish and Wildlife Service. 245 p.

Ruter, J.M.; Pennisi, B.V. 2017. Selecting salt tolerant native trees for the Georgia coast. Cooperative Extension Bulletin 1477. Athens, GA: University of Georgia. 8 p.

SAS Institute, Inc. 2003. SAS OnlineDoc®; Version 9; Cary, NC: SAS Institute, Inc.

Sheffley R.M., Birch, T.W.; McWilliams, W.H.; Tansey, J.B. 1998. *Chamaecyparis thyoides* (Atlantic white cedar) in the United States: extent and characterization using broad-scale inventory data. In: Ladermann, A.D., editor. Coastally restricted forests. New York, NY: Oxford University Press: 111–124.

Ury, E.A.; Xi, Y.; Wright, J.P.; Bernhardt, E.S. 2021. Rapid deforestation of a coastal landscape driven by sea-level rise and extreme events. Ecological Applications. 0(0): e02339.

Widmann, R.H. 2005. Forests of the garden state. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 20 p.

Williams, R. 2021. Personal communication. Pine Creek Forestry, Clementon, NJ.

Zimmermann, G.L.; Mylecraine, K.A. 2003. Reconstruction of an old-growth Atlantic white-cedar stand in the Hackensack Meadowlands of New Jersey. In: Atkinson, R.B.; Belcher, R.T.; Brown, D.A.; Perry, J.E. III, editors. Proceedings, Atlantic white cedar restoration ecology and management symposium. Newport News, VA: Christopher Newport University: 125-135.