

## ABSTRACT

LAING, JOELLE MARIE. How Management Strategies Have Affected Atlantic White-Cedar Forest Recovery After Massive Wind Damage in the Great Dismal Swamp. (Under the direction of Theodore Henry Shear.)

In September 2003 Hurricane Isabel swept through eastern North Carolina and Virginia, destroying most of what formerly ranked among the most extensive remaining stands of *Chamaecyparis thyoides* (Atlantic White-cedar, cedar). As Atlantic White-cedar communities are typically dependent on irregular, large-scale disturbances, the hurricane event can be viewed as an opportunity for perpetuating cedar populations in the Great Dismal Swamp. However, differing post-storm management practices at the Dismal Swamp State Park (State Park) and the Great Dismal Swamp National Wildlife Refuge (Wildlife Refuge) have influenced the success of cedar regeneration following the storm at each site. In this study I investigated the regeneration success of Atlantic White-cedar at the State Park five years following Hurricane Isabel by sampling five stands withstanding varying impact from the storm and previous windthrow events. To determine the feasibility of future Atlantic White-cedar restoration management options in the park stands, I also sampled the available seedbank to estimate the current viability of cedar seeds and the potential for continued germination. Results showed regeneration at the State Park was limited (less than 200 seedlings per hectare), but that viable cedar seeds were still present in the seedbank. When contrasting the success of Atlantic White-cedar reestablishment at the Wildlife Refuge, results showed the passive management implemented at the State Park is insufficient for stand reestablishment and that active management is necessary to promote adequate regeneration. Because appropriate management activities vary depending on the nature of the disturbance and the individual site conditions, I discuss the factors that have led to the decline of

Atlantic White-cedar and also specific challenges that must be overcome for seedling regeneration after disturbance. By using this information, land managers can potentially take more effective measures for promoting cedar regeneration after windthrow events.

How Management Strategies Have Affected Atlantic White-Cedar Forest Recovery After  
Massive Wind Damage in the Great Dismal Swamp

by  
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## BIOGRAPHY

Born in a small town in upstate New York, Joelle's first genuine attempt at ecological restoration was at age 10. With some effort, she managed to round up some neighborhood friends to clean the litter at the small power-line easement down the street and then finished the job off by sprinkling a pack of wildflower seeds on the ground. Unfortunately the seeds did not grow...But hopefully since then she has learned a thing or two. She attributes her love for nature to long summer days outdoors and muddy canoe trips through the Adirondack Mountains with her dad and siblings.

After completing a B.S. in biology at Berry College in Rome, Georgia, Joelle spent time working with the Nature Conservancy, the USDA Forest Service, and an environmental consulting firm. During this time she lived in Maine, Arizona, and North Carolina and gained experience in fire ecology, plant ecology, restoration, and wetland ecology. Her sharp interest in restoration ecology prompted her to begin graduate studies at North Carolina State University in 2007, where she now plans to continue for a PhD in soil science upon completion of the M.S degree.

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## INTRODUCTION

In September 2003 Hurricane Isabel swept through eastern North Carolina and Virginia, destroying most of what formerly ranked among the most extensive remaining stands of *Chamaecyparis thyoides* (Atlantic white-cedar, cedar) in the Great Dismal Swamp. As Atlantic white-cedar communities are typically dependent on irregular, large-scale disturbances, the hurricane event can be viewed as an opportunity for perpetuating cedar populations in the Great Dismal Swamp and may even provide a means for expanding existing stands when managed appropriately.

The Great Dismal Swamp is managed primarily by two different preserves, the Dismal Swamp State Park (State Park) and the adjacent Great Dismal Swamp National Wildlife Refuge (Wildlife Refuge). Although the State Park and the Wildlife Refuge encountered similar amounts of damage, the two preserves implemented contrasting management approaches that yielded different results for cedar regeneration and recovery. While the Wildlife Refuge implemented an intensive management program that included debris removal and herbicide application, the State Park took a hands-off management approach in which no active management was implemented. In this study I investigated the effectiveness of a hands-off management approach for promoting post-storm Atlantic white-cedar regeneration using the Dismal Swamp State Park as a case study. Information from this case study can assist land managers following catastrophic disturbances when management goals include the promotion of successful Atlantic white-cedar regeneration.

### *Atlantic white-cedar Ecology*

Atlantic white-cedar wetlands fulfill a unique niche in coastal forest systems and therefore remain a valuable ecosystem for restoration and conservation. With a strong tolerance of harsh environmental conditions and a relatively poor competitive ability in more favorable sites, Atlantic white-cedar is typically restricted to extreme environments, favoring deep Histosols, low soil pH, and high water tables {{59 Laderman, A.D. 1989}}. In Virginia and North Carolina Atlantic white-cedar wetlands, common companion tree species include *Acer rubrum* (red maple), *Gordonia lasianthus* (loblolly bay), *Magnolia virginiana* (sweet bay), and *Nyssa biflora* (swamp tupelo) (Laderman 1989). The distinctive environmental and biological setting makes Atlantic white-cedar wetlands a haven for many rare and endangered plant species, including *Kalmia cuneata* (white wicky), *Eriocaulon compressum* , and *Rhynchospora alba* (northern white beaksedge) (Laderman 1989). As with all palustrine wetlands, Atlantic white-cedar forests play a role in filtering pollutants from nearby waterways and can therefore contribute to the maintenance of water quality (Whigham et. al. 1988).

Atlantic white-cedar forests frequently develop as dense even-aged stands sustained by irregular major disturbances that destroy mature trees and provide open conditions for germination and seedling growth (Laderman 2003). Prior to European settlement, the mosaic of fire frequencies along the Atlantic coast maintained this disturbance regime, allowing the species to proliferate. The presettlement fire regime for Atlantic white-cedar communities was likely 25-100 years, with some intervals as high as 250-300 years in the Carolinas (Frost 1987). However, when fire intervals are

shorter than 10-25 years, the cedar seedbank cannot properly reestablish between disturbance events and vegetation may shift to another plant community, such as pond pine-pocosin. The sporadic fire events on which Atlantic white-cedar depends result in optimal open-sunlight germination conditions as long as the fire does not burn deeply enough to destroy the seedbank (Laderman 2003). Therefore, because fire activity usually clears debris and shrubby vegetation, fire has historically been more important in sustaining the life cycle of cedar than wind disturbances (Frost 1987; Laderman 2003).

#### *Decline of the Species and Restoration Challenges*

At the time of European settlement, Atlantic white-cedar forests encompassed as much as 200,000 hectares of coastal land from Maine to Florida (Kuser 1995), including some 120,000 hectares in eastern North Carolina. However, development and timber harvests have reduced the extent in eastern North Carolina to less than 800 hectares (0.7% of its original statewide range). This decline was first instigated by widespread hydrologic drainage implemented for both agriculture and timber harvest, resulting in regeneration failure or sparser secondary cedar stands with more open canopies (Frost 1987). Unfortunately, cedar stands that have been disturbed are more susceptible to future windthrow events (Mylecraine and Zimmermann 2000). Additional problems such as increased deer browsing, hardwood competition, and changes in soil properties (resulting from hydrologic change), have further hindered seedling regeneration after disturbances. Because of the challenges resulting from human disturbance that now hinder Atlantic white-cedar regeneration, cedar may require deliberate post-disturbance management to address these challenges, counteract human disturbances, and thereby conserve remaining stands.

### *Purpose of Study*

My primary goal was to compare the recovery of Atlantic white-cedar stands from massive wind disturbance with and without intensive management. The Dismal Swamp provided an ideal setting for this study, as neighboring landowners implemented contrasting management strategies after Hurricane Isabel. Both the State Park and the Wildlife Refuge have similar soils, hydrology, topography, climatic conditions, stand types (at least prior to the hurricane), and impacts from the hurricane. Differences in post-storm regeneration of Atlantic white-cedar in stands that were similar before the storm should be attributable to management activities rather than environmental factors. I was particularly interested in evaluating the effectiveness of the State Park's hands-off management approach for promoting successful Atlantic white-cedar regeneration.

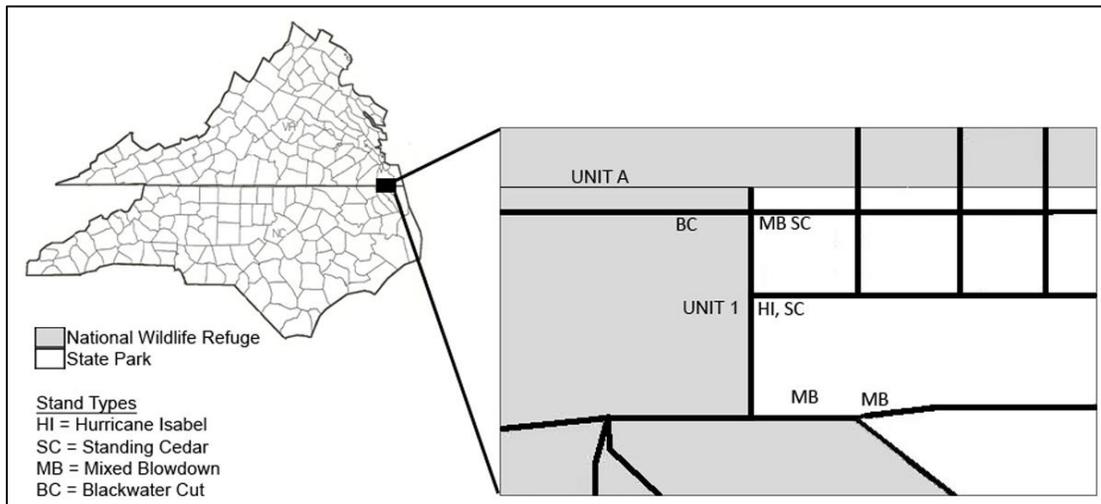
## METHODS

### *Site Description*

The Dismal Swamp State park is situated at in Camden County (lat 36°31'55"N, long 76°27'47"W) in northeastern North Carolina just south of the Virginia state line. The State Park is bordered on both the north and the west by the Great Dismal Swamp National Wildlife Refuge, straddling Virginia and North Carolina, as shown in Figure 1. Both the Wildlife Refuge and the State Park are characterized by deep Histosols with over 90% of the study area mapped as very-poorly drained Pungo Muck (Dysic, thermic typic Haplosaprists). Macrotopography is negligible, with relief less than 1.5 meters throughout most of the Dismal Swamp (Oaks and Whitehead 1979). A series of active drainage

ditches spaced roughly two to five kilometers apart extend through both the Wildlife Refuge and the State Park (Figure 1).

Salvage logging at the Wildlife Refuge was implemented from early 2004 through fall of 2008 using low-ground-pressure forwarding equipment. Although most of the timber was removed over the ground, about 120 hectares of timber were cleared by helicopter. Following salvage logging, refuge managers applied Isopropylamine salt of imazapyr at a rate of 674 milliliters/ha and Methylated Seed Oil (MSO) at a rate of 112 L/ha to approximately 239 hectares for hardwood competition control. A detailed description and schedule of post-storm management activities at the Great Dismal Swamp National Wildlife Refuge is shown in Appendix 2. In contrast to the more intensive management style employed at the Wildlife Refuge, the State Park left downed woody debris in place and the former stands were allowed to naturally revegetate.



**Figure 1. Map of the study area, including active drainage ditches.**

### *Approach to the Study*

Because regeneration data were already available from cedar stands at the National Wildlife Refuge (Belcher et. al. 2009 and unpublished data from US Fish and Wildlife Service staff), I concentrated my data collection on cedar stands in the State Park. To determine whether the hands-off management approach at the State Park was effective for ensuring sufficient cedar regeneration, I estimated cedar seedling density in stands impacted by Hurricane Isabel. I then compared my findings with regeneration data from the Wildlife Refuge to determine if the management strategy employed at the Wildlife Refuge has been more effective for regenerating cedar. At the State Park I also determined the current species composition in the stands. Finally, since future management opportunities at the State Park are dependent on the availability of sufficient viable Atlantic White-cedar seed, I determined the density of cedar seed in the State Park seedbank.

## **DISMAL SWAMP STATE PARK**

### *Arrangement of Study Sites*

Five cedar stands in the State Park were located using a vegetation inventory showing the major forest types in the park (LeGrand 1994). Since 1994, these stands have succumbed to a number of windthrow events, with the most severe and recent damage occurring during Hurricane Isabel in September 2003. Because of the varying levels of damage and time elapsed since disturbance, the study sites were divided into the following three categories (shown in Figure 1):

- 1) *Hurricane Isabel (HI)*: This stand was primarily impacted by Hurricane Isabel and has little to no remaining adult trees.
- 2) *Standing Cedar (SC)*: These stands have likely been lightly impacted by a combination of windthrow events including Hurricane Isabel. However, their distinguishing characteristic is the presence of a significant number of adult cedar trees (approximately 650 trees/ha) at the time of the study.
- 3) *Mixed Blowdown (MB)*: These stands show little evidence of damage from Hurricane Isabel but have significant downed woody debris from a number of prior windthrow events.

Although the exact timing of the windthrow damage in the Mixed Blowdown stands could not be determined, the 1994 vegetation inventory shows that these stands included enough standing cedar to be classified as Atlantic white-cedar forest at that time (LeGrand et. al. 1994). The downed woody debris in these stands is more highly decomposed than the debris present in the Hurricane Isabel stand and likely resulted from multiple more moderate windthrow events occurring between 1994 and 2003. Photographs of the three stand types are shown in Figure 2.



Figure 2. General appearance of stands at Dismal Swamp State Park. Shown clockwise from the left: 1) Study transect In Hurricane Isabel (HI) stand. 2) Mixed Blowdown (MB) stand. 3) Standing Cedar (SC) stand.

### *Study Design*

With dense vegetation and a significant amount of downed woody debris (DWD) present at the time of the study, study transects were established only through areas that were accessible. Even five years after the storm, the debris was widespread, largely intact, and often piled 5 m or higher, making the site very dangerous to access. Therefore, transects could not be laid out in straights, but had to meander safely through the debris piles. I took care to avoid trampling seedlings when traversing the transects. Transect lengths and sampling areas are shown in Table 1 (transect width was variable and was estimated at 1.2 m). The layout of data collection along the study transects is shown in Figure 3.

Table 1. Sampling areas in the Dismal Swamp State Park and the National Wildlife Refuge.

<b>Stand Type</b>	<b>Total Transect Lengths (m)</b>	<b>Seedling Sampling Area (m<sup>2</sup>)</b>	<b>Vegetation Sampling Area (m<sup>2</sup>)</b>	<b>Seedbank Sampling Area (cm<sup>2</sup>)</b>
<i>Hurricane Isabel</i>	545	1795	144	46
<i>Standing Cedar</i>	590	1945	240	47
<i>Mixed Blowdown</i>	655	2150	184	52
<b>State Park Total</b>	<b>1790</b>	<b>5885</b>	<b>568</b>	<b>144</b>
<i>Stand A</i>	1090	330	-	-
<i>Stand 1</i>	655	200	-	-
<b>Refuge Total</b>	<b>1745</b>	<b>330</b>	-	-

### *Seedling Inventory*

All cedar less than 2 m in height found within the width of the access trails and within 1 m from either edge of the trails were tallied. For each seedling I recorded seedling height and the substrate

in which the seedling was rooted (soil, stump, or log). For seedlings rooted outside the trails I centered a vegetation plot around each seedling and recorded both species data and total canopy cover (described in the following section).

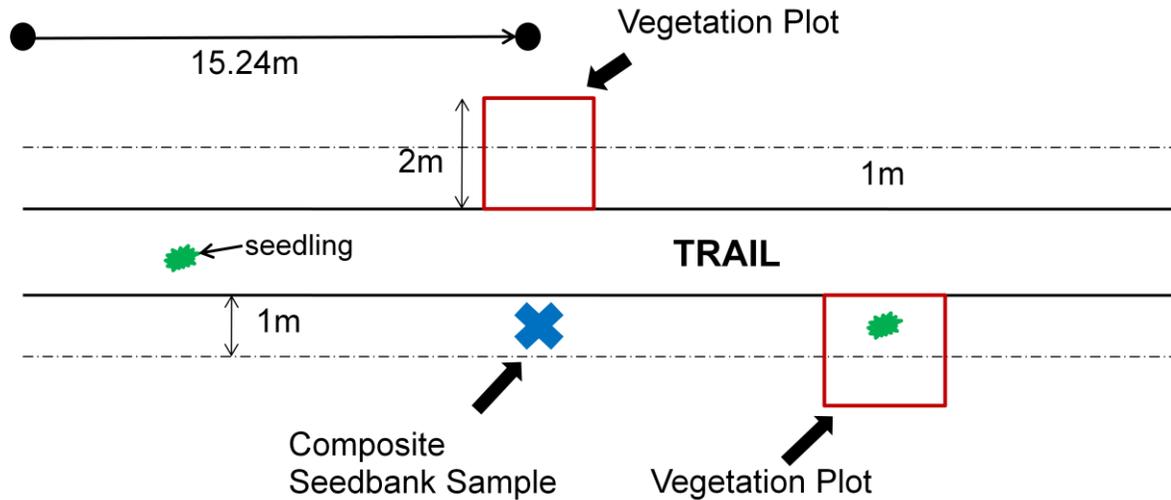


Figure 3. *Spatial Layout of sampling procedure.* Seedlings were tallied inside the transect and within 1 m from either edge of the transect. Vegetation was sampled using 1m<sup>2</sup> vegetation plots nested within 4m<sup>2</sup> vegetation plots spaced 15 m apart. These plots were also centered around each recorded seedling located outside the transect. Seedbank samples were taken every 15 m along the study transects and were located across from corresponding vegetation plots.

### *Vegetation Description*

To determine the current species composition of the stands, I established vegetation plots throughout the study area. In the 4 m<sup>2</sup> plots spaced every 15 m (50 ft) along the study transects, I inventoried all vascular plants and identified them to species using the nomenclature of Weakley (2006). Additionally, I established plots around all cedar seedlings found within 1 m of the edge of the access trails. In each plot, cover was determined for each species, within increments of 10%.

Species covering less than 5% were classified as “Trace.”

I estimated total canopy cover as an indirect measure of light availability for seedling growth. This was also recorded in 10% increments and was measured using a densitometer (Lemmon 1956). Using the species cover estimations, I converted these values to relative species cover percentages by dividing the cover of each species across all plots in each stand type by the total cover of all species in each stand type. Additionally, I calculated percent frequency, or the number of plots in which a species occurred relative to the total number of plots, for each species.

#### *Seedbank*

I collected seedbank samples every 15 m along the vegetation transects. The corer used to collect samples had a surface area of 32 cm<sup>2</sup>, and was pushed into the soil approximately 10 cm deep (with some small variation due to interference by the thick root mat), for a sample of approximately 320 cm<sup>3</sup>. Four samples each spaced 0.5 m from a center point and equidistant from one another were collected and combined at each sampling point. Samples were kept at 18-23°C for approximately one week and then stratified at 5°C for 90 days. After stratification, I spread the samples approximately 2-3 cm deep in a tray and placed them in a greenhouse from late November 2008 through March 2009. Therefore, although greenhouse amenities were limited and temperatures could not be tightly controlled, I used these temperatures as a guide when choosing the appropriate greenhouse environment. Temperatures in the greenhouse were kept at approximately 26°C during the day and 18°C at night, with minimum and maximum temperatures of 14°C and 32°C during the

study period (Jull et. al. 1999). No artificial lighting was used to alter day length. Research has shown that soil depth impacts germination percentages in seedbank studies (Dalling et. al. 1994) and that seed is less likely to germinate when buried deep in the soil. Because it was not possible to reduce soil depth, I mixed the samples thoroughly twice during the germination period to increase the probability that all seed would be close enough to the surface for germination at some point. I recorded the time of germination of every emerging seedling. For seedlings other than Atlantic white-cedar (which are readily recognizable), I recorded species if the seedling grew to an identifiable size.

#### **GREAT DISMAL SWAMP NATIONAL WILDLIFE REFUGE**

Regeneration at the Wildlife Refuge was monitored in three former cedar stands, Unit A, Unit 1, and a separate 28-ha Unit known as the Blackwater Cut. Seedling sampling for Management Units A (101 ha) and 1 (27 ha) was completed by refuge staff in late 2007 and early 2008 (see Appendix 2 for comparison with timing of management activities). With fewer accessibility problems in the refuge sites that had been cleared of debris, investigators established sampling transects for Units A and 1 methodically by using computer-generated random placements for transect center points. The researchers tallied all Atlantic white-cedar seedlings in the study transects and separated them into height classes. The 13.3 m x 0.6 m transects were established at a rate of one per five hectares, yielding a sample ratio of 1.6 m<sup>2</sup> per hectare. Sampling methods for the 28 ha Blackwater Cut can be found in Belcher et. al. (2009). Researchers sampling this stand created separate study plots in skidder trails, salvage logged stands, and stands that were not salvaged or treated in any other way.

## RESULTS

### *Seedling Regeneration*

In all three sites at the Wildlife Refuge, seedling densities are more than an order of magnitude greater than seedling densities found at the State Park (Table 2). At the State Park, density in the Standing Cedar stands was more than six times higher than in the Mixed Blowdown stands and more than four times higher than in the Hurricane Isabel stands. Apparently the seeds provided by remaining adult trees were more important for regeneration than seed that were deposited prior to the hurricane. However, only 3% of the seedlings in the Standing Cedar stands exceeded 60 cm in height, compared to 25% of seedlings in the Hurricane Isabel stands and 34% of those in the Mixed Blowdown stands. Many of the seedlings throughout the State Park were growing in adverse conditions, with some rooted in cedar logs elevated above the ground and others growing under dense vegetation. Almost 75% of the seedlings were rooted in stumps or logs, while 25% were rooted in soil without woody debris.

Although seedling densities at the Wildlife Refuge were higher in all size classes, all Wildlife Refuge stands showed trends in size class similar to those found at the State Park, with only 2% of seedlings in each stand exceeding 60 cm. However, as the survey at the Blackwater Cut was conducted in early 2006, seedlings have since grown significantly, with many currently exceeding 2 m in height. Results of the Blackwater Cut from Belcher et. al. (2009) are shown in Table 3.

Table 2. Seedling and seedbank densities at the Dismal Swamp State Park and at the Great Dismal Swamp National Wildlife Refuge.

	Seedling Density (stems/ha)	Percentage of seedlings in each size class				Seed Density (seed/ha)
		0-15 cm	>15-30 cm	>30-60 cm	>60 cm	
<b>State Park</b>						
Standing Cedar	370	43	31	24	3	1,259,428
Hurricane Isabel	89	25	25	26	25	1,031,142
Mixed Blowdown	56	0	25	41	34	269,691
All Stands	170	35	29	26	10	831,380
<b>Wildlife Refuge</b>						
Unit A	17,752	82	12	5	1	Not sampled
Unit 1	6,052	70	18	11	1	Not sampled

Table 3. Seedling density and size class distribution in the Blackwater Cut at the Great Dismal Swamp National Wildlife Refuge (Adapted from Belcher et. al. 2009).

Treatment	Seedling Density (stems/ha)	Percentage of seedlings in each size class			
		0-10 cm	10-20 cm	20-30 cm	≥ 30 cm
Salvage logged	584	66	25	6	2
Skidder trails	440	77	20	<1	<1
Unsalvaged	0	0	0	0	0
<b>Total</b>	<b>1024</b>	<b>69</b>	<b>24</b>	<b>5</b>	<b>2</b>

### *Seedbank*

There were considerable quantities of viable Atlantic white-cedar seeds in the seedbank throughout the State Park (Table 2). Seed densities were lowest in the Mixed Blowdown stands where the longest times had passed since disturbance. The Standing Cedar and Hurricane Isabel stands contained approximately four times more seed. For all stands, seed densities generally corresponded to number of seedlings, with denser seed banks having higher regeneration rates. In

addition to Atlantic white-cedar, a number of other species were present in the seed bank, including *Vitis rotundifolia* (muscadine), *Clethra alnifolia* (coastal white-alder), and *Toxicodendron radicans* (poison ivy) (the three most commonly found). Most of these species were also found frequently in vegetation plots at the State Park. A list of all identified species is provided in Table 4.

Table 4. Species emerging from Dismal Swamp State Park seed bank.

Species also present in State Park Vegetation Plots	Other emerging species
<i>Aralia spinosa</i>	<i>Aronia arbutifolia</i>
<i>Chamaecyparis thyoides</i>	<i>Baccharis</i> spp.
<i>Clethra alnifolia</i>	<i>Callicarpa japonica</i>
<i>Gelsemium sempervirens</i>	<i>Erechtites hieraciifolia</i>
<i>Ilex coriacea</i>	<i>Eupatorium capillifolium</i>
<i>Itea virginica</i>	<i>Gamochaeta purpurea</i>
<i>Parthenocissus quinquefolia</i>	<i>Phytolacca americana</i>
<i>Persea palustris</i>	
<i>Rhus copallinum</i>	
<i>Rubus</i> spp.	
<i>Smilax laurifolia</i>	
<i>Toxicodendron radicans</i>	
<i>Vaccinium</i> spp.	
<i>Vitis rotundifolia</i>	

### Vegetation

Total canopy cover in all stands was generally high, with 79% of vegetation plots yielding a canopy cover estimate of 80-100%. Canopy was most open in the Standing Cedar stands, with 17% of plots having a canopy cover < 70% and in Mixed Blowdown and Hurricane Isabel stands, which had having 2% and 14% of plots with < 70% cover.

At the State Park, red maple was present in over 70% of all plots, and *Persea palustris* (swamp bay), *Lyonia lucida* (shining fetterbush), and coastal white-alder dominated the understory. These four species accounted for 53-58% of the relative cover (Table 5). Muscadine and *Gelsemium sempervirens* (Carolina jessamine) were also prominent in the Mixed Blowdown stands, and the Standing Cedar stands included Atlantic white-cedar in the canopy.

Table 5. Relative cover and frequency of species found in a series of 4 m<sup>2</sup> vegetation plots at the Dismal Swamp State Park 2008.

Species	Hurricane Isabel		Mixed Blowdown		Standing Cedar	
	Relative % Cover	Frequency (%)	Relative % Cover	Frequency (%)	Relative % Cover	Frequency (%)
<i>Persea palustris</i>	23	89	17	89	14	72
<i>Clethra alnifolia</i>	14	68	7	33	16	78
<i>Acer rubrum</i>	13	65	23	83	14	65
<i>Lyonia lucida</i>	8	59	6	33	11	57
<i>Vaccinium</i> spp.	5	35	2	24	4	27
<i>Toxicodendron radicans</i>	4	59	3	48	6	58
<i>Rubus</i> sp.	3	32	1	30	3	40
<i>Smilax laurifolia</i>	3	32	3	30	6	60
<i>Ilex glauca</i>	3	22	<1	2	3	23
<i>Ilex coriacea</i>	3	14	1	9	2	13
<i>Parthenocissus quinquefolia</i>	2	35	2	22	1	18
<i>Gelsemium sempervirens</i>	2	32	7	78	2	32
<i>Itea virginica</i>	2	24	1	11	1	12
<i>Ilex opaca</i>	2	11	4	24	<1	10
<i>Vitis rotundifolia</i>	2	11	8	59	<1	10
<i>Magnolia virginiana</i>	2	8	-	-	3	22
<i>Aralia spinosa</i>	1	11	<1	4	<1	5
<i>Chamaecyparis thyoides</i>	1	11	1	15	10	68
<i>Bignonia capreolata</i>	1	8	-	-	-	-
<i>Lyonia ligustrina</i>	1	8	<1	7	<1	3
<i>Pinus taeda</i>	1	8	-	-	2	15
<i>Ilex verticillata</i>	1	5	-	-	-	-
<i>Symplocos tinctoria</i>	1	5	-	-	-	-

Table 5 (continued).

Species	Hurricane Isabel		Hurricane Isabel		Standing Cedar	
	Relative % Cover	Frequency (%)	Relative % Cover	Frequency (%)	Relative % Cover	Frequency (%)
<i>Smilax glauca</i>	<1	5	1	24	<1	7
<i>Woodwardia areolata</i>	<1	5	<1	11	-	-
<i>Amelanchier canadensis</i>	<1	3	-	-	-	-
<i>Asplenium platyneuron</i>	<1	3	<1	7	-	-
<i>Lonicera japonica</i>	<1	3	<1	9	<1	2
<i>Onoclea sensibilis</i>	<1	3	-	-	-	-
<i>Rhus copallinum</i>	<1	3	-	-	<1	3
<i>Thlypteris palustris</i>	<1	3	2	20	<1	7
<i>Arundinaria gigantea</i>	-	-	1	13	-	-
<i>Asimina triloba</i>	-	-	<1	7	-	-
<i>Diospyros virginiana</i>	-	-	-	-	<1	2
<i>Euonymus americanus</i>	-	-	<1	4	-	-
<i>Kalmia carolina</i>	-	-	-	-	<1	5
<i>Liriodendron tulipifera</i>	-	-	1	2	-	-
<i>Microstegium vimineum</i>	-	-	<1	2	-	-
<i>Nyssa biflora</i>	-	-	3	11	<1	2
<i>Nyssa sylvatica</i>	-	-	<1	2	-	-
<i>Quercus nigra</i>	-	-	<1	4	-	-
<i>Smilax rotundifolia</i>	-	-	3	26	-	-
<i>Taxodium distichum</i>	-	-	1	4	-	-

## DISCUSSION

### *Regeneration success and prospects*

Atlantic white-cedar seedling density at the Dismal Swamp State Park is low compared to the National Wildlife Refuge, and that many seedlings are growing in adverse environmental conditions. Many cedar seedlings in the Park were growing under thick competing vegetation or on debris that was suspended in the air. Higher mortality may be expected than in stands where seedlings are growing in more open, favorable conditions. If unable to compete with other species, the cedar seedlings in the State Park may die shortly after germination or may be stunted from a lack of resources. This is evident from the low density of cedar seedlings in the tallest size class (>60 cm) five years after the storm. With high relative cover of competing species such as red maple and Coastal white-alder, and an average of only 182 cedar seedlings/ha in the State Park stands, cedar is not expected to become a major component of the canopy in the absence of active management.

Seedling densities at the Wildlife Refuge were markedly higher than at the State Park. Although only 2% of the seedlings at the Wildlife Refuge were greater than 60 cm in height, the abundance of seedlings in the smaller size classes indicates a flush of germination took place after debris removal (one year prior to the surveys). Surveyors of the Blackwater Cut also reported a low percentage of seedlings greater than 30cm at the time of their study (Belcher et. al. 2009). Although the Blackwater Cut has not been surveyed recently, the site now appears as a dense juvenile cedar stand with many seedlings exceeding 1 m in height (see photo in Figure 4).

Seedlings densities at the Wildlife Refuge are comparable with those found by Korstian and Brush in a 1931 post-logging study of the effects of timber slash on Atlantic white-cedar regeneration in the Dismal Swamp. Eight years after logging, there were 28,417 cedar seedlings/ha in plots cleared of debris, and only 358 seedlings/ha in uncleared plots (Table 6). Together, this study and ours demonstrate that active management is necessary for ensuring recovery of Atlantic white-cedar forests after disturbances that result in widespread distribution of woody debris.

Table 6. Effect of timber slash on Atlantic white-cedar reproduction at Dismal Swamp (Adapted from Korstian & Brush 1931)

Years since Logging	Number of Seedlings Surviving/Ha	
	<i>Sites Covered with Dense Slash</i>	<i>Sites Cleared of Slash</i>
1	334	30,676
2	388	11,152
8	358	28,418

The presence of viable Atlantic white-cedar seed in the seedbank at the State Park indicates that active management could potentially still be implemented to achieve regeneration five years post-storm. This assumes that there is sufficient viable seed to achieve desirable seedling densities, especially in the Mixed Blowdown stands. Korstian and Brush (1931) also examined the seedbank after logging, and found that densities of viable Atlantic white-cedar seed were 6,347,900/ha in the upper 2.5 cm of soil and 3,877,900 seed/ha in the second 2.5 cm of soil. If these densities are typical for Atlantic white-cedar forest seedbanks, then the seed densities I found at the State Park may not be adequate ensure a new stand in which cedar is a major component.

### *Future stand composition*

Given the current seedling and seed densities at the State Park and the prevalence of other woody species, the stands impacted primarily by Hurricane Isabel is likely to become dominated by red maple with an understory of red bay, sweet pepperbush, and fetterbush over the next two decades. Because of the longer time elapsed since disturbance events, the Mixed Blowdown stands can provide insight into the probable composition and structure of the Hurricane Isabel stand over the next two decades. These stands have a more closed canopy than the Hurricane Isabel stand and are dominated primarily by red maple, with swamp tupelo also found occasionally in the overstory. Although the shrub layer is also thick and dominated by swamp bay, coastal white-alder, shining fetterbush, and muscadine, the combined relative cover of these species is only 38%, compared to 47% in the Hurricane Isabel Stand. The understory in the Mixed Blowdown plots is therefore more open in appearance. Swamp tupelo, recorded in both the Standing Cedar and the Mixed Blowdown stands, was not found in the canopy or in the understory in the Hurricane Isabel plots. I expect the red maples in the Hurricane Isabel stand to form a closed canopy underlain with a diminished shrub layer in the absence of fire.

Unlike the Hurricane Isabel and the Mixed Blowdown stands, the Standing Cedar stands may mature to Atlantic white-cedar because the remaining cedar trees continue to produce seed. However, wind exposure could increase the likelihood of future disturbance events and result in tree mortality and further loading of downed woody debris. The future composition of this stand, therefore, is

dependent on the success of seedling growth and on the frequency and impact of future disturbances.

### *Management as Restoration*

Drainage (by ditch digging), harvesting, landscape fragmentation, historically high deer populations, other anthropogenic and natural disturbance combining to make cedar forest restoration a complex challenge. If management goals of public lands in the Great Dismal Swamp include conservation and restoration of Atlantic white-cedar, then disturbances are opportunities to regenerate and expand cedar stands. As opposed to trying to establish new cedar forests on sites where they does not currently exist, restoration of disturbed existing cedar stands takes advantage of existing resources such as the seedbank, mature fruiting trees, and site conditions that are known to be well-suited for the species. Restoration through natural regeneration is less expense and better maintains the intrinsic genetic diversity of the stand than afforestation by planting seedlings (Mylecraine and Zimmermann 2000).

The disturbance with perhaps the greatest impact on Atlantic white-cedar is widespread hydrologic alterations. Drainage ditches lower water tables and shorten periods of soil saturation. Many soils in eastern North Carolina have change since European settlement as a result of subsidence, which is a decrease in soil surface elevation as a result of organic matter loss. In a typical Carolina bay in

North Carolina, the soils subsided approximately 139 cm during 30 years of drainage (Vepraskas et. al. 2006). The organic soils of the Dismal Swamp are similar to the soils of the bay, and are affected similarly by hydrologic change. These organic soils can ignite when dry, and result in catastrophic fires that destroy the stands and burn away as much as a meter or more of soil. As the water table has been lowered in Dismal Swamp and soil subsidence has occurred, the cedar stands are more susceptible to catastrophic fire due to the higher combustibility of the soils (Akerman 1923, Frost 1987). Some areas of the Dismal Swamp now have ignition probabilities that are up to 100 times higher than during presettlement times (Frost, personal communication). The shorter fire return intervals favor the establishment of woody species other than Atlantic white-cedar.

Raising the water table by managing drainage ditches can increase the competitive advantage of Atlantic white-cedar over other vegetation. Care must be taken to not make the site too wet if there has been substantial soil subsidence. The pre-disturbance hydrology is usually not obtainable because access roads must be maintained, which requires that the water table at the road be kept lower than typically required for a cedar forest. To reduce competition further during stand establishment, many land managers use herbicides. In a recent study comparing untreated plots with plots treated with herbicide at Lynn Ditch in the Dismal Swamp, the number of regenerating Atlantic white-cedar was 400% greater in plots treated with herbicide. Total shrub cover was also reduced accordingly, with 87% less shrub cover in herbicide plots ( $p=0.07$ ) (Ware 2001).

Although herbicide application can increase regeneration success, the timing of herbicide application is also an important management consideration. At the Great Dismal Swamp National

Wildlife Refuge managers have observed that when herbicide is applied too soon after a disturbance event, deer browse is more intense and the younger seedlings are more subject to mortality when browsed. As an alternative, herbicide may be applied two or three years after a disturbance so that seedlings have an opportunity to grow and surrounding vegetation can protect them from browse during their most vulnerable stages (Bryan Poovey, personal communication). Deer browse has become an increasingly important issue when managing for cedar re-establishment. In an assessment of Virginia white-tailed deer populations, researchers estimated that population density was similar to that in other states throughout the southeast at approximately 8.1 deer/km<sup>2</sup> (900,000 deer) statewide (Knox 1997). Although herds in most areas of Virginia did not exceed carrying capacity, the population was significantly higher than the pre-settlement estimation of 400,000 (3.6 deer/km<sup>2</sup>) (Seton 1909). Researchers have attempted to address the problem of deer browse by testing various protection devices for preventing deer browse. When protected by these structures, cedar trees grew up to 1.8 m in three years (Heinsley et. al. 2003). However, since these devices are expensive, further creativity and research are needed in devising economical methods for preventing deer herbivory.

As illustrated in this study, Atlantic white-cedar stands may not effectively regenerate after severe storm events and are generally more susceptible to windthrow because of the lower stand densities that result from timber harvest and hydrologic change. Given the long disturbance interval required by Atlantic white-cedar and the intensive management necessary to remove post-storm debris, further research addressing strategies for windthrow protection could help prevent further species

decline and also minimize costs associated with debris removal. However, when storm events do impact cedar stands, the results of the management practices implemented at the Great Dismal Swamp National Wildlife Refuge demonstrate that their active management activities are effective for promoting higher regeneration densities. Whether implemented as a preventative measure or as a responsive activity, appropriate active management addressing the effects of windthrow can help counteract effects of human disturbances that have resulted in Atlantic white-cedar decline. When used in conjunction with management actions that address problems such as deer herbivory and competing vegetation, land managers can increase the likelihood of Atlantic white-cedar stand maintenance and contribute to the overall protection and restoration of the species.

## LITERATURE CITED

- Akerman, A. 1923. The white-cedar of the Dismal Swamp. Virginia Forestry Publication **30**:1-21.
- Belcher, R. T., T.R. Comer, and R.B. Atkinson. 2009. Atlantic white-cedar regeneration in the Great Dismal Swamp following Hurricane Isabel: 2006 Blackwater Cut results. Pages 23-27 in G.L. Zimmermann, editor. Proceedings of the Ecology and Management of Atlantic White-Cedar: Symposium 2006. The Richard Stockton College of New Jersey, Atlantic City, New Jersey.
- Dalling, J.W., M.D. Swaine, and N.C. Garwood. 1994. Effect of soil depth on seedling emergence in tropical soil seed-bank investigations. *Functional Ecology* **9**:119-121.
- Ewing, J. M. and M.J. Vepraskas. 2006. Estimating primary and secondary subsidence in an organic soil 15, 20, and 30 years after drainage. *Wetlands* **26**:119-130.
- Frost, C. C. 1987. Historical overview of Atlantic white-cedar in the Carolinas. Pages 257-263 in A. D. Laderman, editor. Atlantic white-cedar wetlands. Westview Press, Boulder, Colorado.
- Harshberger, J. W. 1916. The vegetation of the New Jersey Pine-Barrens: an ecologic investigation. Christopher Sower, Philadelphia, Pennsylvania.
- Hinesley, E. L., S.A. Derby, and A.M. Wicker. 2003. Protecting newly established Atlantic white-cedar and baldcypress with electric fences, treeshelter tubes, wire mesh cages, and tall fences. Pages 257-262 in Atlantic white-cedar Restoration Ecology and Management, Proceedings of a Symposium. Christopher Newport University, Newport News, Virginia.
- Jull, L.G., F.A. Blazich, and L.E. Hinesley. 1999. Seedling growth of Atlantic white-cedar as influenced by photoperiod and day/night temperature. *Journal of Environmental Horticulture*. **17**:107-113.
- Knox, W. M. 1997. Historical changes in the abundance and distribution of deer in Virginia. Pages 27-36 in W.J. McShea, H. B. Underwood, and J. H. Rappole, editors. The science of overabundance: deer ecology and population management. Smithsonian Institution Press, Washington D.C.
- Korstian, C. F. and Brush, W. D. 1931. Southern white-cedar. USDA Technical Bulletin no 251. United States Department of Agriculture, Washington DC.
- Kuser, J. E. and Zimmermann, G. L. 1995. Restoring Atlantic white-cedar swamps: Techniques for propagation and establishment. *Tree Planter's Notes* **46**:78-85.

- Laderman, A. D. 1989. The ecology of Atlantic white-cedar wetlands: A community profile. United States Department of the Interior, Fish and Wildlife Service Research & Development, National Wetlands Research Center, Washington, DC.
- Laderman, A. D. 2003. Why does the freshwater genus *Chamaecyparis* hug marine coasts? Pages 1-30 in Atlantic white-cedar Restoration Ecology and Management, Proceedings of a Symposium. Christopher Newport University, Newport News, Virginia.
- LeGrand, H.E. Jr., J.O. Fussell III, and W.D. Webster. 1994. Biological inventory of Dismal Swamp State Natural Area, North Carolina. North Carolina Department of Environment, Health, and Natural Resources, North Carolina Natural heritage Program.
- Lemmon, P. E. 1956. A spherical densiometer for estimating forest overstory density. *Forest Science*2:314–320.
- Little, S. 1950. Ecology and silviculture of white-cedar and associated hardwoods in southern New Jersey. *Yale School of Forestry Bulletin* **56**:1-103.
- Mylecraine, K. A. and G.L. Zimmermann. 2000. Atlantic white-cedar ecology and best management practices manual. New Jersey Forest Service, Trenton, New Jersey.
- National Weather Service, National Hurricane Center. 2003. Tropical cyclone report, Hurricane Isabel. (available from <http://www.nhc.noaa.gov/2003isabel.shtml>) accessed 12 September 2003.
- Oaks Jr, R. Q. and D.R. Whitehead. 1979. Geologic setting and origin of the Dismal Swamp, southeastern Virginia and northeastern North Carolina. Pages 1-24 in P.W. Kirk, Jr., editor. *The Great Dismal Swamp*. University of Virginia Press, Charlottesville, Virginia.
- Philips, R. W., J.H. Hughes, M.A. Buford, W.E. Gardner, F.M. White, and C.G. Williams. 1998. Atlantic white-cedar in North Carolina, USA: A brief history and current regeneration efforts. Pages 156-170 in A. D. Laderman, editor. *Coastally restricted forests*. Oxford University Press, New York, New York.
- Ruffin, E. 1861. *Sketches of lower North Carolina and the similar adjacent lands*. Institute for the Deaf and Dumb, Raleigh, North Carolina.
- Seton, E. T. 1909. *Life histories of northern animals*. Charles Scribner's Sons, New York, New York.
- United States Fish and Wildlife Service. 2004. Environmental assessment for the Atlantic white-cedar salvage and restoration at the Great Dismal Swamp National Wildlife Refuge. United States Fish and Wildlife Service, Northeast Region Office, Hadley, Massachusetts .

Weakley, A. S. 2006. Flora of the Carolinas, Virginia, Georgia, and surrounding areas. University of North Carolina Herbarium, North Carolina Botanical Garden, Chapel Hill, North Carolina.

Whigham, D. F., C. Chitterling, and B. Palmer. 1988. Impacts of freshwater wetlands on water quality: A landscape perspective. *Environmental Management* **12**:663.

## APPENDIX

## APPENDIX

*Schedule of post-storm management practices at the Great Dismal Swamp National Wildlife Refuge.* The mechanical salvage process began by cutting timber with processing heads on-site. Non-merchantable material was then used to build slash trails so low-ground-pressure equipment could be used to remove merchantable timber from the area. In the helicopter salvage process, material was cut and piled on-site and then removed by helicopter. Where utilized, herbicide was applied at a rate of 2.35 liters/ha of Habitat and 112.34 liters/ha of Methylated Seed Oil (MSO). Locations of all below units are shown in Figure XX.

<i>Management Unit</i>	<i>Date of Salvage Completion</i>	<i>Type of Salvage Process</i>	<i>Date of Herbicide Application</i>
A	9/2005 and 12/2006	Mechanical	9/2006 and 9/2007
C	5/2008	Mechanical	None
D	2/2007	Mechanical	None
E	2/2007	Mechanical	None
F	2/2007	Mechanical	None
G	2/2007	Mechanical	None
H	6/2007	Mechanical	None
M	9/2007	Mechanical	None
N	6/2007	Mechanical	None
O	2/2007	Mechanical	None
T	5/2008	Mechanical	None
1	11/2005	Helicopter	9/2007
2	4/2007	Mechanical	9/2007
3	2/2006	Helicopter	9/2007
4	6/2006	Helicopter	9/2007
5	6/2006	Mechanical/Helicopter	9/2007
7	6/2005	Mechanical	9/2006
8	6/2005	Mechanical	9/2006
Blackwater Cut	10/2004	Mechanical	9/2004