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Newport News, Virginia

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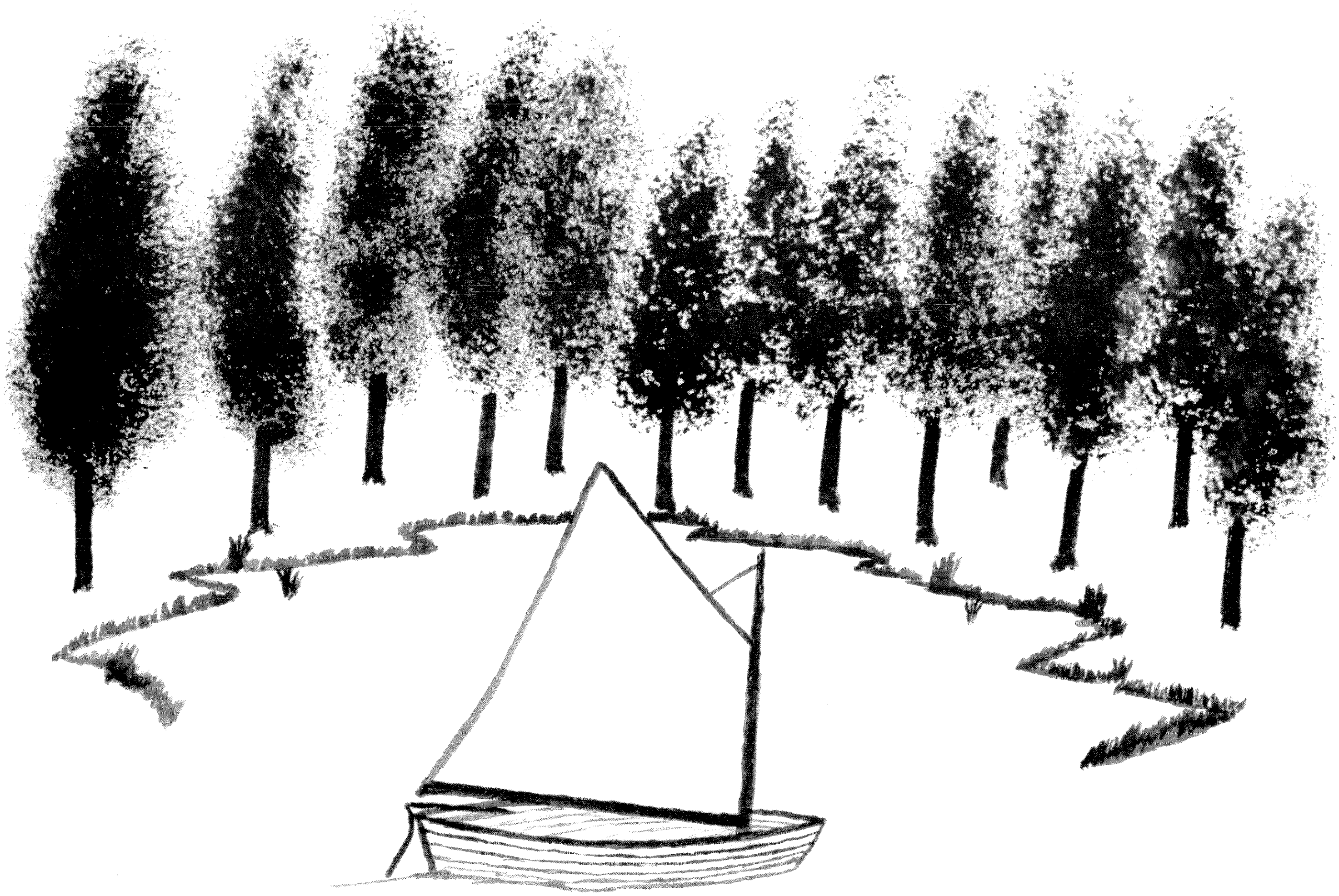

COVER:

View of restored Atlantic white-cedar cove at Arlington Echo Outdoor Education Center on the Severn River, MD. Note the Atlantic white-cedar skiff in the foreground typical of historic small wooden boats on the river. *Artist: Leif Jacobson.*

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United States Department of Interior; Fish and Wildlife Service; Alligator River National Wildlife Refuge; Manteo, NC

United States Air Force; Dare County; Manteo, NC

U.S. Department of Agriculture; Forest Service; Southern Research Station; Asheville, NC

PREFACE

Atlantic white-cedar, colloquially referred to as "juniper," was once one of the most valued timber species in North America; its wood was highly prized for light weight and durability. An obligate wetland species, Atlantic white-cedar was an important component of forested wetlands in the Coastal Plain from Maine to Louisiana. It was most commonly found on poorly drained, even saturated peats and fine sands throughout the coastal region, with the most extensive stands being in North Carolina and Virginia. Heavy cutting, wildfire, shifting land use, and altered drainage patterns have sharply reduced the area occupied by the species. Current estimates are that less than 10 percent of that found prior to colonial settlement remains, restricted to scattered and isolated stands and patches. Despite diminished economic significance, there is considerable interest in re-establishment of Atlantic white-cedar stands for both production and conservation.

The 1940's and 1950's saw development of scientific inquiry into the management of the species. Throughout the 1950's, I. Frederick Trew of the West Virginia Pulp and Paper Company (now simply Westvaco) initiated a wide variety of studies on Atlantic white-cedar production and management, including nursery studies and regeneration after harvest by seed trees. He spurred complementary work at other institutions throughout the range of the species. In October 1984, the first Atlantic white-cedar wetlands symposium was held at Woods Hole, MA. In August of 1990, the extent and characterization of Atlantic white-cedar were the subjects of an International Conference of Ecology in Yokohama, Japan. Selected papers from that meeting and another at Yale University in New Haven, CT, formed the popular 1998 book, *Coastally Restricted Forests,* edited by Dr. Aimlee Laderman. And for several years now, Dr. George Zimmerman at Richard Stockton College of New Jersey has sponsored a webpage devoted to the sharing of information about Atlantic white-cedar: see http://loki.stockton.edu/~wcedars/.

In 1995, about 20 researchers and land managers from North Carolina to Massachusetts, who were studying and managing Atlantic white-cedar, gathered in Elizabeth City, NC, to form the Atlantic White-Cedar Alliance. The Alliance is charged to focus on both the species and the ecological communities in which it occurs. Both biological and economic facets will be promoted, including preservation and conservation, restoration, management, and harvesting and utilization. (The conference reported here in this proceedings was a direct outgrowth of the Alliance.) Hopefully, it will become just one in a long series of activities aimed at the protection and management of this most beautiful and useful tree.

Bill Gardner
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ASSESSING THE SURVIVABILITY AND GROWTH OF ATLANTIC WHITE CEDAR (*CHAMAECYPARIS THYOIDES* (L.) B.S.P.) IN THE GREAT DISMAL SWAMP NATIONAL WILDLIFE REFUGE

D. A. Brown and Robert B. Atkinson[1]

Abstract—Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) is a unique wetland tree that is listed as globally threatened by The Nature Conservancy. Atlantic white-cedar has a number of uses which have made it a valuable timber crop. As a result, the species has been logged to extirpation in many areas. In this study, the effects of physical, chemical, and competitive interactions on Atlantic white-cedar growth and survivorship are examined. Plantings are currently underway to reestablish the species within the Great Dismal Swamp National Wildlife Refuge (GDSNWR), where sizable stands of Atlantic white-cedar still occur naturally. In 1990, a 2.8-hectare portion of a poorly performing mixed hardwood / Atlantic white-cedar stand at GDSNWR was cleared of existing vegetation. In February 1996, 241 rooted cuttings were planted at this site. First-year data have indicated that survivorship was high at the site (97.1 percent). Growth, soil moisture, pH, and species composition appeared to correspond to microsite elevation differences.

INTRODUCTION

Over the years, Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) wetlands have been collectively described as "depauperate," "resplendent," "distinctive," and "stoic." The natural range of these habitats is from Maine to South Carolina along the Atlantic coastal plain, although there are some scattered remnants in northern Florida and coastal Mississippi (Little 1950). The trees are valued for the growth form and aromatic qualities of their wood (Korstian and Brush 1931, Hanlon 1970). Atlantic white-cedar often occurs in dense monocultures which may not regenerate naturally after being harvested, but have historically done well after disturbance by fire (Little 1950). Labor-intensive methods to promote post-logging regeneration of the species have not been economically feasible. Atlantic white-cedar is also susceptible to drought and flood conditions in the early growth stages (Akerman 1923, Ehrenfeld 1995) and becomes shade-intolerant after establishment (Little 1950, Moore 1994), further complicating reforestation attempts. Throughout much of the historic range, efforts to restore Atlantic white-cedar are underway, and research interest is growing (Carter 1987).[2] This study was designed to assess early site performance by examining growth and environmental variables.

Growth parameters estimated for each rooted cutting included height, circumference, volume, and percent vegetative cover. Measured environmental factors included elevation, soil pH, volumetric water content, and bulk density. Statistical tests at each rooted cutting included t-tests, analysis of variance (ANOVA), and regression analysis (Clarke 1994, Sokal and Rohlf 1995) to determine the portion of the variability explained by each variable. An alpha level of 0.05 was used throughout.

Site Description

A major management objective of GDSNWR is to restore Atlantic white-cedar to areas where it previously existed (USFWS 1986). The study area, at the corner of Forest Line and Corapeake Ditches in North Carolina (fig. 1), is situated in a 2.8-hectare cutout where refuge managers cleared a mixed hardwood / Atlantic white-cedar stand to study natural regeneration of Atlantic white-cedar (Brownlie 1995). When the site was cleared in 1991, seed trees were left on the site to facilitate seedling establishment. In 1994, extensive flooding was reported at the site and few of the naturally regenerated seedlings survived. By the time of the research planting in February 1996, the site had been heavily recolonized by sweet pepperbush (*Clethra alnifolia*) and, to a much lesser extent, other wetland shrub and graminoid species.

Fallen logs and deep trenches left behind by the initial 1991 clearing effort helped to create a mound-and-pool topography on the site (fig. 2) and naturally regenerated Atlantic white-cedar throughout the site demonstrated potential for high survivorship. Current topographic characteristics are similar to those described in the literature (Laderman 1989, Ehrenfeld 1995).

METHODS AND MATERIALS

Experimental Design

One-year-old rooted cuttings were obtained from the Weyerhaeuser Nursery in North Carolina.[3] The roots of the cuttings were coated in kaolin clay to retain moisture. Cuttings were packaged in bags of 100 individuals. Six permanent parallel transect lines were established 1.5

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[2] 1997 represents the third consecutive year that an Atlantic white-cedar conference of some sort has been organized on behalf of the species. Stockton State College in New Jersey now maintains a web page for Atlantic white-cedar research (http://loki.stockton.edu/~wcedars/).

[3] Studies have shown no noticeable difference between rooted cuttings and bare-root seedlings for restoration of Atlantic white-cedar (Summerville 1995, Phillips and others 1992).

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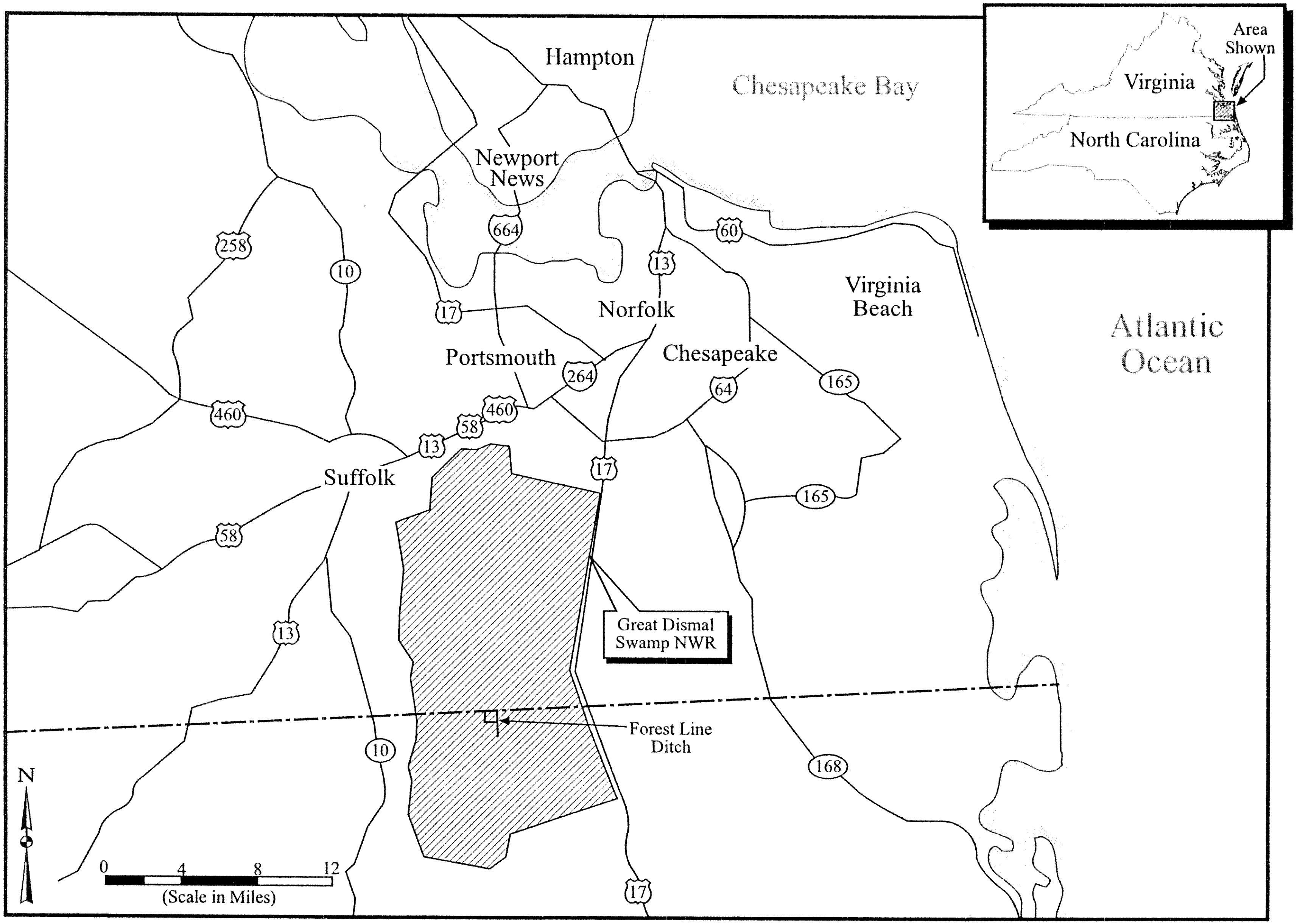

Figure 1—Location map of study area.

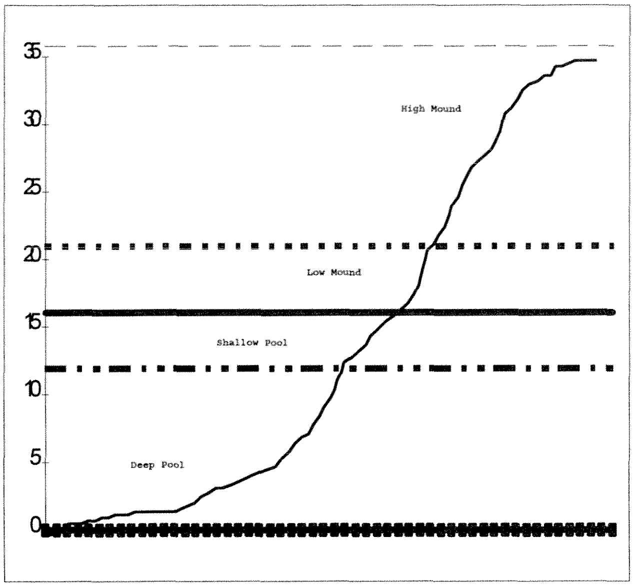

Figure 2—Microtopographic zone schematic.

meters apart to form the study area, and 241 Atlantic white-cedar rooted cuttings were numbered and planted using standard forestry dibble bars. Based on the amount of standing water, and knowledge of Atlantic white-cedar intolerance of prolonged inundation (Akerman 1923), trees were not planted at any location where standing water was greater than 4 centimeters. Naturally regenerated Atlantic white-cedar within the transect were carefully removed and transplanted elsewhere in the cutout.

Planting Densities
In the first four transects (T1-T4), rooted cuttings were planted 1.5 meters apart and rooted cuttings in the last two transects (T5-T6) were placed 0.76 meters apart. The denser spacings in this study were established to determine if there was a difference in growth between densely and sparsely spaced plantings.

Morphometric Measurements
Rooted cutting morphometry was measured initially and after 1 year to determine growth. Morphometric parameters included circumference, height, volume, and percent cover. Circumference was measured by circling the broadest width (diameter) of the rooted cutting canopy with a fiberglass metric tape. Heights were recorded by measuring from the root collar to the topmost growth of each rooted cutting. For the purposes of this study, a conical shape was assumed to approximate Atlantic white-cedar canopy volume (V). Canopy volume estimates (modified from Comeau and others 1993) were based on height (h) and circumference (c) to provide the volume of a cone ($V = [c*h]/3$). Percent cover per meter-square was estimated for each rooted cutting and for all other species in each plot.

Soil Sampling
Soils were collected within a 10 centimeter radius of each rooted cutting using a 68.6 milliliter cylinder. Soil samples were analyzed to determine wet weight, dry weight, bulk density, volumetric water content, and pH to a depth of 10 centimeters.

Elevation and Well Data Collection
Tree-wise elevation measurements were recorded using a standard survey level and rod. The measurements were relative to four Remote Data Systems RDS WL-40 continuous water monitoring wells (WL40s) installed at the site and to the base of two seed trees on either side of the study area (permanent site benchmarks). The four WL40s were placed in a transect diagonal to the plot (fig. 3) following standard installation procedures (U.S. Army Corps of Engineers 1993). Water table means and standard deviations were calculated for each well.

RESULTS

Initial and First Year Morphometric Measurements
Descriptive morphometric measurements of the rooted cuttings at the initial planting stage are provided in table 1. In March, 1996, tree-wise inspections revealed that many of the rooted cuttings suffered moderate deer or rabbit browse; however, most individuals appeared healthy and no further herbivory was noted. Rooted cuttings planted near the higher water levels seemed to be showing some signs of stress (brown leaves, partially dead stems). In October, 1996, a survey was conducted to determine survivorship. Eight mortalities (six in standing water) were recorded from 241 planted cuttings. According to GDSNWR managers, this level of survivorship (97.1 percent) was extremely high (personal communication. 1997. Brownlie, David, P.O. Box 349, Suffolk, Virginia 23439). Results of first year morphometric data were comparable to estimates for healthy stands described in the literature (Ackerman 1923). Rooted cuttings grew an average of 40.6 centimeters in the first growing season (table 2).

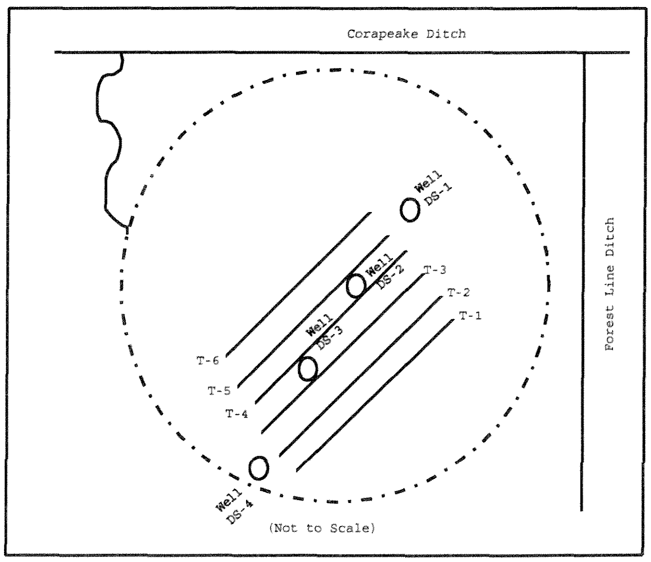

Figure 3—Site map of transects and relative well locations.

Table 1—Descriptive morphometric measurements of rooted cuttings (initial planting)

		Height			Circumference		
Transect	N	Min	Max	Mean	Min	Max	Mean
		cm					
T-1	28	15	67	26.7	23	109	36.4
T-2	32	06	74	25.4	08	086	36.5
T-3	31	14	56	20.0	13	122	32.0
T-4	31	21	72	21.4	19	113	30.2
T-5	60	13	76	23.8	01	107	34.7
T-6	59	04	75	23.7	25	085	35.4
Grand mean				23.5			34.2

N = number of rooted cuttings.

Table 2—Descriptive morphometric measurements of rooted cuttings (after first growing season)

		Height			Circumference		
Transect	N	Min	Max	Mean	Min	Max	Mean
		cm					
T-1	27	40	100	66.3	50	158	94.2
T-2	32	13	106	64.6	34	141	78.8
T-3	29	35	88	62.0	42	156	88.3
T-4	30	40	95	62.3	52	152	85.1
T-5	59	32	103	69.4	25	156	93.0
T-6	57	19	104	59.7	42	124	82.7
Grand mean				64.1			87.0

N = number of rooted cuttings.

Zonation ANOVAs

The mound-and-pool topography at the site was divided into four microsite elevation zones: high mound, low mound, shallow pool and deep pool (fig. 2). An ANOVA was performed for species and environmental variables in each zone (table 3). The mean growth of Atlantic white-cedar was greatest at intermediate elevations, i.e., in the low mound and shallow pool elevation zones. Mean height (P=0.015) and circumference (P=0.043) were highest in the shallow pool zone. Mean soil pH was lowest in the deep and shallow pool zones (3.8) and increased to 4.1 in the high mound zone. Mean percent cover for pepperbush was highest in the high mound elevation zone (38.1 percent) and lowest in the deep pool zone (14.5 percent).

Percent Cover Estimate Analysis

Site-wise mean percent cover estimates were highest for pepperbush, Atlantic white-cedar, and *Ilex glabra*, 24.3 percent, 13.7 percent and 9.2 percent, respectively (table 4). Species richness throughout the site was low (13 species). ANOVAs run on species other than Atlantic white-cedar between elevation zones, with the exception of pepperbush (P<0.001) and blue iris (*Iris virginica*) (P=0.004), did not return significant P-values. As stated previously, mean percent cover for pepperbush was highest in the high mound elevation zone (38.1 percent) and lowest in the deep pool zone (14.5 percent).

Planting Density ANOVAs

ANOVAs were also conducted to assess differences between sparse and dense planting treatments. Mean percent cover for pepperbush was 25.2 and 23.6 percent for sparse and dense planting treatments, respectively, which was not significant (P = 0.633). Mean Atlantic white-cedar cover in sparse (11.7 percent) versus dense (15.6 percent) plantings was significant at p=0.001 (only one planted Atlantic white-cedar occurred per meter square, percent cover estimate.) Height and circumference growth parameters showed no significant differences between treatments. Poison ivy (*Toxicodendron radicans*) showed higher mean percent cover in sparse (3.2 percent) versus dense (0.5 percent) plantings (P = 0.003).

Water Table Measurements

Mean water table depths (table 5) taken from the four RDS WL40 wells during the growing season differed significantly (P<0.001). The lowest mean water table depth was recorded from well DS-4 (-23.4 centimeters), while the highest mean water table depth was recorded at well DS-1 (9.4 centimeters of inundation).

CONCLUSIONS

Zonation appeared to play an important role in early growth of Atlantic white-cedar rooted cuttings. Maximum growth occurred at intermediate elevations, i.e., downslope from the high mounds and upslope from the deep pools. Elevation may have been directly responsible, however several environmental variables also exhibited significant zonation responses, precluding assessment of causality. While not designed to test this specifically, the results do support the notion that Atlantic white-cedar growth may be impaired by competition with the shrub, pepperbush, on the high mounds. Pepperbush cover was much greater on the high mounds, and decreased significantly in the deep pools. In the deep pools, Atlantic white-cedar growth may have been limited by abiotic factors such as duration of inundation. Most Atlantic white-cedar mortality observed in the study was associated with the deep pools.

Mortality was low throughout this study. However, other studies have found that Atlantic white-cedar is tolerant of shading during the first few years and later become shade intolerant (Little 1950, Moore 1994). If the two-year-old Atlantic white-cedar individuals at this site begin to exhibit shade intolerance, pepperbush cover and density on high mounds may be adequate to precipitate high mortality rates, precluding maturation of Atlantic white-cedar in this zone. Survival may be higher for Atlantic white-cedar in the deep and shallow pools since its flood tolerance appears to increase with age (Akerman 1923).

Table 3—Analysis of variance among site variables in four microsite elevation zones: high mound, low mound, shallow pool, and deep pool

Site variables	Elevation zones: Mean high mound	Mean low mound	Mean shallow pool	Mean deep pool	P-value
Water content (mL water/68mL core)	1.44	1.64	1.83	2.07	<0.001
Bulk density (*g/cm³*)	0.45	0.51	0.57	0.59	<0.001
Soil pH	4.1	3.9	3.8	3.8	<0.001
Elevation (cm)	25.07	32.03	35.86	40.27	<0.001
Canopy volume (cm^3)	1477	2004	1819	1502	0.004
Tree height (cm)	39	46	43	37	0.015
Tree circumf. (cm)	42	59	58	49	0.043
Clethra alnifolia (pct cover)	38.1	26.3	18.3	14.5	<0.001
Chamaecyparis thyoides (pct cover)	12.3	15.8	13.7	12.9	<0.165
Non-*Chamaecyparis*	66.5				<0.001
thyoides mean		53.8			<0.001
total pct			46.1		<0.001
cover per m^2				36.3	<0.001

Table 4—Plant species collected from the Great Dismal Swamp National Wildlife Refuge site

Species common name	Scientific name	Wetland indicator status	Mean cover values
			Percent
Sweet pepperbush	*Clethra alnifolia*	Fac+	24.3
Atlantic white-cedar	*Chamaecyparis thyoides*	Obl	13.7
Holly	*Ilex glabra*	FacW-	9.2
Blueberry	*Vaccinium corymbosum*	FacW-	5.3
Drummond red maple	*Acer rubrum*	FacW+	4.9
Bushy bluestem	*Andropogon glomeratus*	FacW+	2.9
Poison ivy	*Toxicodendron radicans*	Fac	1.8
Cinnamon fern	*Osmunda cinnamomea*	FacW	1.1
Greenbriar	*Smilax laurifolia*	Obl	0.4
Virginia blueflag	*Iris virginica*	Obl	0.4
Blackberry	*Rubus* sp.	Fac	0.3
Red bay	*Persea borbonia*	FacW	0.2
American holly	*Ilex opaca*	Fac	0.0
Mean total percent vegetative cover per m^2			64.3

Table 5—Well elevations and mean water table levels

Approximate corresponding elevation zone	High mound	Low mound	Shallow pool	Deep pool	P-value
Well number	DS-4	DS-3	DS-2	DS-1	
Relative well elevation (*cm*)	9.7	29.0	39.6	42.8	<0.001
Mean water table level (*cm*)	-23.4	-3.0	+5.6	+9.4	

High planting density more closely simulates natural regeneration and may increase growth and survivorship of Atlantic white-cedar. In this study, higher planting density appeared to increase Atlantic white-cedar cover for individual seedlings, while other growth parameters were not significantly different. However, total Atlantic white-cedar cover at the site was clearly greater by virtue of the more dense planting. Higher planting densities may have the benefit of providing a competitive advantage for Atlantic white-cedar over pepperbush, particularly in the high mounds where pepperbush cover is highest. It is unclear how higher planting densities may influence Atlantic white-cedar success in pools. Additional studies are needed to determine which environmental factors influence growth and survivorship, and which factors are merely a result of the mound-and-pool topography commonly associated with Atlantic white-cedar swamps.

ACKNOWLEDGMENTS

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LINKING ECOSYSTEM MANAGEMENT, REFUGE MANAGEMENT AND ATLANTIC WHITE-CEDAR RESTORATION

Michael R. Bryant[1]

Abstract–Several years ago the U.S. Fish and Wildlife Service (USFWS) embarked on an ecosystem-based approach to management. Over 50 ecosystems were identified by the USFWS. The USFWS manages a National Wildlife Refuge System (NWRS), which is embedded in the landscape of these ecosystems. The NWRS has grown to over 92 million acres. There are over 500 refuges across the United States and its territories. Three refuges in northeastern North Carolina and southeastern Virginia that are in one of the designated ecosystems have significant remnant populations of Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.). The ecosystem approach to management, the goals of the NWRS, and the purposes for which these three refuges were created all speak to the need for management of Atlantic white-cedar stands, which historically formed a major component of the mid-Atlantic forested wetland system. The ecosystem approach to management recognizes the need for broad-based partnerships when trying to accomplish landscape-based biotic community restoration. Atlantic white-cedar restoration fits this description and the successes thus far are a result of effective partnerships.

INTRODUCTION

The USFWS began an ecosystem approach to management in 1994. To facilitate this management approach, the USFWS identified more than 50 ecosystems. This approach to management encourages us to manage for the benefit of the ecosystem even when our responsibilities are for the management of a specific land-base such as a national wildlife refuge.

ECOSYSTEM APPROACH TO MANAGEMENT

In at least one of these ecosystems, the Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) wetland community was historically a significant component of the forested wetland system. This ecosystem is referred to as the Roanoke-Tar-Neuse-Cape Fear (RTNCF) ecosystem, and consists of the watersheds of the four named rivers and covers parts of southeastern Virginia and eastern North Carolina. There are three refuges in the RTNCF ecosystem having significant remnant populations of Atlantic white-cedar. These are Pocosin Lakes National Wildlife Refuge, Great Dismal Swamp National Wildlife Refuge, and Alligator River National Wildlife Refuge. Within the previous two decades and during implementation of the ecosystem policy, the USFWS established and managed these refuges. These refuges were established, in part, to conserve and manage their unique wetlands, including Atlantic white-cedar wetland forests.

The RTNCF Ecosystem Plan (1994) states as its vision the management of biodiversity by restoring, conserving, and improving the quality and quantity of functioning terrestrial and aquatic ecosystems for the benefit of native species in the wild. The plan emphasizes the need for partnerships to meet its nine goals and numerous objectives. One goal is the restoration and maintenance of viable levels of natural diversity across the landscape, with emphasis on a number of plant community types including Atlantic white-cedar.

NATIONAL WILDLIFE REFUGE SYSTEM

The NWRS began in 1903 and has evolved and grown to over 92 million acres in size. It now includes over 500 refuges, one in every state, and over 3,000 Waterfowl Production Areas. The original mission was clear–preserve wildlife and habitat for people today and for generations to come. In 1996, Presidential Executive Order 12996 reemphasized that the NWRS's mission was to preserve a national network of lands and waters for the conservation and management of fish, wildlife, and plant resources of the United States for the benefit of present and future generations. At that time, the USFWS produced a "Promises" document stating its responsibility to protect, restore, and manage wildlife and habitat and to provide compatible, wildlife-dependant recreational opportunities for the public. Challenges identified in the "Promises" document include declining habitat and insufficient resources. The document stressed meeting the challenges and fulfilling our promises by strengthening existing partnerships and forging new ones.

Atlantic white-cedar is an important plant resource, providing habitat for wildlife. To meet the goals of the NWRS we must attempt to restore this wetland forest community. Successful restoration and conservation of Atlantic white-cedar will help provide quantity and quality of habitat that supports America's diverse wildlife heritage. Restoration efforts will employ an ecosystem approach to resource conservation that considers landscapes beyond refuge boundaries. Also, this project will serve as a demonstration area for private land conservation and as a model for sound land use and ethics.

ALLIGATOR RIVER NATIONAL WILDLIFE REFUGE

Alligator River National Wildlife Refuge (ARNWR) was established in 1984 under the authority of two Federal laws: the Fish and Wildlife Act of 1956 and the Refuge

[1] Refuge Manager, U.S. Fish and Wildlife Service, Alligator River National Wildlife Refuge, P.O. Box 1969, Manteo, NC 27954.

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Recreation Act, amended 1972. A synopsis of the refuge purposes follows: "for the development, advancement, management, conservation, and protection of fish and wildlife resources" and "suitable for ... the protection of natural resources, [and] the conservation of endangered species or threatened species."

A master plan was developed for ARNWR and revised in 1994. The plan states that the primary objectives of the refuge are to manage and protect the area's unique wetland habitats and associated wildlife species. Management efforts will be directed at restoring water levels that existed prior to alteration of this habitat. Past and present management have reaffirmed that one of the primary objectives for this refuge is wetland restoration. This restoration includes the re-establishment of former hydrologic regimes and forest communities.

ARNWR has at least 8,000 acres of clearcuts. Many of these clearcut acres contained Atlantic white-cedar stands. The Atlantic white-cedar biotic community has been identified as critically endangered. The RTNCF ecosystem, the NWRS, and the ARNWR plans have as their goals the restoration, management, and conservation of the Atlantic white-cedar community. It was recognized early on that the refuge did not have the resources to accomplish Atlantic white-cedar restoration by itself. Partnerships would have to be developed.

ARNWR nearly surrounds the 46,000-acre U.S. Air Force Dare County Range. The habitat is contiguous and similar to that of the ARNWR. The ARNWR formed partnerships with the U.S. Air Force, U.S. Forest Service Seed Lab at Mississippi State University, the NC Division of Forest Resource Nursery, and NC State University Forestry Department in an effort to determine the best methods for Atlantic white-cedar restoration. Most of the work was funded through the Department of Defense Legacy Resource Management Program. The work has inventoried cutover tracts and remnant Atlantic white-cedar stands, established and utilized geographical information systems and global positioning systems, developed natural and artificial regeneration methods through applied research, improved management capabilities by improving roads and restoring additional wetlands, and increased public awareness of these efforts.

REASON AND NEED FOR LINKAGES

Many agencies interested in and tasked with restoring, managing, and conserving native biotic communities have limited resources. Successful forested wetland conservation requires a landscape-based management approach. Thus, Atlantic white-cedar restoration goals can only be achieved through joint efforts. The USFWS, along with all of its partners, has recognized this. The current Atlantic white-cedar conservation effort is a model for success and is necessary to achieve our goal of Atlantic white-cedar restoration in its historic range.

EVALUATION OF EXISTING TAPER EQUATIONS TO PREDICT BOLE DIAMETERS OF ATLANTIC WHITE-CEDAR

Stephen M. Daniels[1]

Abstract–This study compares existing taper equations and determines the models that most accurately predict upper stem diameters of Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.). Standing trees were sampled non-destructively in the inner coastal plain of North Carolina. Models tested are representative of the wide array of functional forms that have been used with other species, ranging from simple quadratic and logarithmic models to complex segmented polynomials. Selections include those that are compatible with volume equations and others that are not. All models tested produced comparable results that should be suitable for most field applications. A relatively simple, two-parameter model was selected as the most precise, though the choice for particular application would depend on intended use.

INTRODUCTION

The prudent management of forest resources requires their accurate measurement. Tree sizes and volumes are needed for planning, valuations, and forecasting. Most volume equations require diameter at breast height (d.b.h.) and total height as inputs. Difficulties arise when volumes for less than the whole tree are desired. Merchantable volumes to a specified minimum top diameter or volumes to a given height are often required. These upper stem diameters are difficult and time consuming to measure in the field and are usually estimated occularly with questionable accuracy. Taper equations provide a means for estimating these upper stem diameters so that they may be used with merchantable volume equations. Taper equations predict upper diameters based on d.b.h. and total height, both of which can be accurately and precisely measured. Most of the functions can be rearranged to predict the height at which a given top diameter occurs, and some can be integrated to produce volume equations. Those that can be directly converted to (or are derived from) volume equations are termed compatible.

The earliest taper data for Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) were published as tables of inside bark diameters for 10 foot increments of height (Korstian and Brush 1931). Modern taper equations allow prediction to any height increment, and can be easily incorporated into software for rapid calculations. Equations can also be adapted to other regions by changing the model parameters, an advantage not possessed by tables. This study evaluated five existing taper equations representing the wide array of functional forms available. Models requiring estimates of volume were not considered. The models were compared to determine which model best fit the stem profile of Atlantic white-cedar. Models selected for study are shown in table 1.

METHODS

Data was collected from 80 trees in the inner and lower coastal plain of North Carolina. Upper stem measurements (outside bark) were measured on standing trees with a Wheeler Pentaprism. Diameters were measured at 1 foot above ground, at d.b.h., and every 5 feet thereafter until the crown became too thick to see the stem. The top third or fourth of the stem was typically obscured by dense foliage and is not well represented in the data. This essentially treats the tree section from the highest measurement to the tip as a cone. Other taper models treat tree tops this way intentionally (Max and Burkhart 1976). Fortunately, the top third of the tree is of little concern from a volume standpoint, and treating it this way allows the models to better predict lower stem diameters which have a much greater impact on volume and value.

Equations were fit to 60 of the trees, with the remaining 20 being reserved for independent testing of the parameterized models. Models were evaluated based on their ability to predict diameters of the 20 independent trees. The criteria used to evaluate the models followed that of Cao and others (1980). The three measures used to rank accuracy were: (1) bias (the mean of the differences between the actual diameters and the predicted diameters), (2) the mean of the absolute values of the differences, and (3) the standard deviation of the differences.

Model 5 is a segmented polynomial that recognizes the tree as three separate geometric solids. It treats each as a separate submodel, then joins the submodels at join points into the final model. These join points must be estimated from the data based on the tree form. Model 1 is designed to estimate diameters above d.b.h. only, and for this reason the 1-foot measurements were eliminated in determining its accuracy rank. (When this allowance was made for the other models, there was some change in accuracy but little change in the ranking.) Models 1, 4, and 5 do not require intercepts.

RESULTS AND DISCUSSION

The estimated parameters are shown in table 2. Table 3 shows the bias, mean absolute value, and the standard

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Table 1—Models from past work selected for comparison

Model
Amidon (1984) $d = b_l * dbh(TH-h)/(TH - bh) + b_2 * (TH^2 - h^2)(h - bh)/TH^2$
Kozak (1969) $d^2/dbh^2 = b_0 + b_l*(h/TH - 1) + b_2*(h^2/TH^2 - 1)$
Demaershalk (1972) $\ln(d) = b_0 + b_l * \ln(dbh) + b_2 * \ln(h) + b^3 * \ln(TH)$
Bruce (1968) $d^2/dbh^2 = bl * (((TH-h)/(TH-4.5))^{1.5})/10 + b^2*((TH-h) / (TH-4.5))^{1.5}*((TH-h) / (TH-4.5)^3*dbh / 100 + b^3*((TH-h) / (TH-4.5))^{1.5}*((TH-h) / (TH-4.5)^3*(TH) / 1000 + b^4*((TH-h) / (TH-4.5))^{1.5}*((TH-h) / (TH-4.5)^{32}*(TH)*(dbh) / 10000 + b^5*((TH-h) / (TH-4.5))^{1.5}*((TH-h) / (TH-4.5)^{32}*(TH^{0.5}) / 1000 + b^6*((TH-h) / (TH-4.5))^{1.5}*((TH-h) / (TH-4.5)^{40}*(TH^2) / 1000000$
Max and Burkhart (1976) $d^2/dbh^2 = b_l*(h/TH - 1) + b_2*(h^2/TH^2 - 1) + b_3 * (a_l - h/TH)^2 I_1 + b_4 * (a_2 - h/TH)^2 I_2$

where

$I = l, h/TH <= a_i, i = 1,2$
$I = 0, h/TH > a_i,$

where

d = upper stem outside bark diameter, inches
dbh = diameter
bh = 4.5 feet
TH = total height, feet
h = height on stem
ln = natural logarithm
a_i = join points for segmented model
b_0-b_6 = parameters estimated from the data
I = indicator variable

Table 2—Estimated parameters

Model	b_0	b_1	b_2	b_3	b_4	b_5	b_6	a_1	a_2
Amidon		0.98767	0.02894						
Kozak	0.35124	-3.0426	2.1171						
Demaerschalk	0.07329	0.96702	0.71113	-0.7112					
Bruce		9.46183	-1.4697	-1.2008	0.89207	0.34689	-5.885		
Max & Burkhart		1.26243	-1.1426	2.36872	64.26374			0.7	0.1

Table 3—Bias, standard deviation, and mean absolute value for each of the equations based on the independent data

	Actual minus predicted mean, BIAS	Standard deviation	Absolute value of difference
Amidon	0.15024	1.16915	0.791696
Kozak	0.30477	1.184729	0.81728
Logarithmic	0.1378	1.3297	0.9417
Max & Burk.	0.57823	1.35477	0.89815
Bruce	0.24474	2.15900	1.07403
	Logarithmic	Amidon	Amidon
	Amidon	Kozak	Kozak
	Bruce	Logarithmic	Max & Burk.
	Kozak	Max & Burk.	Logarithmic
	Max & Burk.	Bruce	Bruce

deviation for each of the equations. Below each table are the rankings based on the three criteria.

The model by Amidon (1984), equation 1, ranked highest according to two criteria and was second according to the third. It is judged to be the best model of those tested. It is simple to model and requires only two parameters. Part of its success may be due to the fact that it does not attempt to model the stem below breast height, which accounts for much of the stem variability. The second-highest-ranking model is the one by Kozak and others(1969). This model has the advantage of being easily transformed into models to predict heights to a given diameter and to predict volumes. One of these two models would be the best choice depending on the intended use. The species appears to have a fairly uniform rate of taper above any butt swell.

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ATLANTIC WHITE-CEDAR ECOSYSTEM RESTORATION ON ALLIGATOR RIVER NATIONAL WILDLIFE REFUGE AND UNITED STATES AIR FORCE DARE COUNTY RANGE

Thomas R. Eagle, Jr.[1]

Abstract—Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) was historically a major component of the mid-Atlantic forested wetland ecosystem. Nearly 10,000 acres of Atlantic white-cedar were clearcut on the Dare County mainland of North Carolina prior to the establishment of Alligator River National Wildlife Refuge and U.S. Air Force Dare County Range. In 1992, a cooperative project involving Alligator River National Wildlife Refuge, U.S. Air Force Dare County Range, North Carolina Division of Forest Resources and North Carolina State University was initiated for the purpose of performing large-scale restoration of Atlantic white-cedar in clearcut areas. The project was funded through the Department of Defense Legacy Resource Management Program. Intensive regeneration surveys on 3,000 acres of clearcuts on Refuge and Range lands were initiated in 1995 to determine the status of natural regeneration. Preliminary results indicate that adequate natural regeneration exists in most of the cut-over tracts sampled to date. However, data analyses and field observations suggest that the occurrence and establishment of Atlantic white-cedar are extremely variable and are directly correlated with soil disturbance, shrub competition, and hydrologic condition. Immediate plans to restore stands characterized by adequate Atlantic white-cedar regeneration and dense competing vegetation consist of chemically releasing the struggling Atlantic white-cedar seedlings and saplings from competing hardwood species.

INTRODUCTION

Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.), known locally as juniper, was once a major component of the forested wetland ecosystem throughout the Dare County peninsula. Intense logging, wildfire and drainage coupled with the lack of proper forest management have resulted in a near 90 percent decrease in the coverage of Atlantic white-cedar in North and South Carolina from that which existed before European settlement (Smith 1995). During WWI (1916-19), all of the available Atlantic white-cedar was harvested by numerous operators on 159,997 acres (64,750 ha) of the Alligator River region. Throughout this period of intense harvesting, no attempts were made to encourage natural regeneration, and harvest methods indicate little concern for future timber production. The harvest of Atlantic white-cedar and associated species, prior to 1920, had a significant effect on the vegetation patterns that exist today. The timber practices determined regeneration densities and species composition. However, the hydrology of the organic substrate was apparently not substantially altered, for the use of oxen and later narrow gauge rails to move timber did not necessitate elaborate permanent road construction.

Since the mid-1970s, Atlantic white-cedar has been the most valuable timber species in the Alligator river region. An elaborate network of roads, canals and ditches were constructed to provide direct access to the pure, dense stands (Laderman 1989). Recent large-scale harvesting of Atlantic white-cedar began on the Alligator River National Wildlife Refuge and Dare County Range in 1975, prior to the establishment of the Refuge in 1984. The U.S. Fish and Wildlife Service (USFWS) received a large portion of the land through a donation from The Nature Conservancy who received the land through a temporary donation from Prudential. However, the timber rights, which did not expire until 1996, were owned by Atlantic Forest Products. The timber rights were sold to Atlantic Forest Products by First Colony Farms prior to ownership by Prudential. Most of the Atlantic white-cedar stands on the Refuge had already been harvested by the late 1980's or early 1990's. Very little logging took place on the Refuge during the final years of the outstanding timber deeds. The Range, established in 1964, was in a similar situation. Timber rights to Range property were not purchased by the Department of Defense until 1981. These recent logging operations left both landowners with approximately 10,000 acres of Atlantic white-cedar clearcuts and scattered disjunct remnants of Atlantic white-cedar stands.

Poor logging practices, lack of post-harvest forest management, and hydrologic alterations have collectively resulted in poor Atlantic white-cedar regeneration in some areas. One of the major objectives in the overall management of the Refuge is the preservation of unique habitats. Therefore, restoration of Atlantic white-cedar habitat is a priority in Refuge management practices.

Regeneration surveys to determine the status of natural regeneration in nearly 30 cut-over stands on the Refuge were conducted in 1986-88. Surveys results revealed that adequate natural regeneration was very patchy. Follow-up surveys of the same areas, conducted in 1991-92, confirmed this trend but also revealed several other facts of

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interest: regeneration continued to occur in clearcut areas where it was found to be occurring in 1986-88; and those clearcuts in which no regeneration was occurring in 1986-88 were completely captured by broadleaf trees and shrubs.

Hydrologic conditions throughout the Dare County peninsula have been significantly altered over the past 50 years resulting in the drainage or flooding of forested and previously forested wetlands. Prior to the recent logging operations, approximately 5,000 acres of forested wetlands were drained, cleared and converted to agricultural land. Aside from the deliberate destruction of forested wetlands, the construction of access roads has indirectly resulted in significant changes in the hydrologic regime. Access roads were constructed using material excavated from adjacent borrow canals. At the time of construction of the more recent roads, the U.S. Army Corps of Engineers prohibited the alteration of the hydrology of an area; therefore, they did not allow connecting the man-made canals to an existing natural drain. By not providing an outlet for the canals, ground and surface water which once followed natural drainage contours became impounded by the roads. The actual impact of a road or canal on a given stand depended on the orientation of the road and on which side of the road the canal was dug. The roads essentially serve as dikes which restrict the flow of water into or out of a stand. The overall effects of the road and canal system have been steady declines in forest health and atypical shifts in species composition of most forested ecosystems. It is our intent to restore historic drainage patterns as best we can in order to again perpetuate Atlantic white-cedar and other native ecosystems.

In 1992 the US Air Force Dale County Range received special funding through the Department of Defense Legacy Resource Management Program to perform large-scale wetland forest restoration, specifically Atlantic white-cedar restoration. The Range soon formed a cooperative partnership with the USFWS at the Refuge, North Carolina Division of Forest Resources (NCDFR) and North Carolina State University. A steering committee consisting of representatives from all of the above agencies was established for the primary purpose of combining knowledge and expertise in the field of wetland restoration and to ensure that only those projects directly related to the establishment of Atlantic white-cedar were provided funding. Several of the goals set forth by the committee are as follows: (1) inventory cut-over Atlantic white-cedar stands using Differential Global Positioning Systems (DGPS) to determine status of natural regeneration; (2) establish a Geographic Information System (GIS); (3) promote and enhance natural regeneration; (4) develop seed and seedling sources; (5) develop and implement methods of artificial regeneration; and (6) establish water control and management to restore hydrology.

For the purpose of this project, restoration efforts will be concentrated on 3,000 acres of nearly contiguous cut-over Atlantic white-cedar stands located on the Refuge and Range property.

METHODS

Inventory Cut Over Stands

Plans to perform regeneration surveys on the 3,000 acres of Atlantic white-cedar clearcuts were initiated in 1994. The plans originally called for bids from private contractors to conduct surveys and provide the desired final products. Bids received from nearly all prospective contractors greatly exceeded budget allocations. The committee then decided to hire temporary USFWS employees to conduct the surveys and provide oversight for all field operations. The purpose of the survey that began during the summer of 1995 was to determine the success or failure of natural Atlantic white-cedar regeneration in clearcuts and to identify critical limiting factors that might affect the germination and long-term survival of the species.

The survey is being performed on an individual-stand basis. Stand delineation is determined by the intersecting road network. Four tenths of 1 percent of the entire project area will be inventoried using systematic sampling techniques. Two fixed-area circular plots that are 1/500 of an acre in size are sampled per acre. Plots are installed 104 feet apart along transects that are 208 feet apart. As a rule, transects are laid out perpendicular to the access roads. Field crews must suffer through vicious insects, even more vicious catbrier and extremely unstable ground to blaze numerous trails through the nearly impenetrable vegetation and mark plot centers. Once the plots are laid out along a transect an additional set of crew members locate the plots and collect the data. A total of 400 permanent plots will be established in stands approximately 20 acres in size or in 20 acre blocks within larger stands.

Actual data collected in the field consists of: (1) the number of stems of Atlantic white-cedar and other economically and ecologically significant species such as black gum (*Nyssa sylvatica*), bald cypress (*Taxodium distichum*), pond pine (*Pinus serotina*) and loblolly pine (*Pinus taeda*) in several height classes (< 1 foot, 1–3 feet, 3–5 feet, 5–7 feet and > 7 feet); (2) the estimated percent cover of the top three plant competitors on the plot; (3) the depth of standing water; (4) the depth of peat layer: and (5) a brief description of the plot and surrounding area.

All data are recorded with hand-held data loggers that are an integral component of a DGPS. A digital data sheet referred to as a data dictionary is created and stored within the data logger. The data dictionary ensures that all required data are collected and recorded in the proper format. As a backup, data are also recorded on data sheets. Generally, at the end of each work week, all of the stored data files are downloaded from the data logger to a PC where they are processed further. In addition to the descriptive data collected at each plot, the geographic location of the plot center is generated by a DGPS and stored in the data logger. Unfortunately, raw DGPS positions generated in the field are usually very inaccurate as a result of inherent errors in satellite orbits and clocks. Due to these inherent inaccuracies, raw coordinate data must be corrected through a process called differential correction, which utilizes data generated by a DGPS base station to more accurately calculate the location of a given position. A DGPS base station consists of a DGPS receiver located at a known position with a clear view of the sky that records data from the same satellites and at the same time as the rover unit (Trimble 1996). Since a base station knows its precise location, it is able to calculate the amount of error transmitted in raw satellite data. This error data is then utilized in a post-processing program to recalculate more precise locations. Through differential correction, DGPS units utilized are capable of achieving sub-meter accuracy and routinely achieve 3-meter accuracy.

Once all of the geographic positions have been differentially corrected, the data files for a given stand are combined, downloaded into a spread sheet and statistically analyzed. Stand averages, ranges and variations are calculated for the following variables: number of stems per acre of all species in all height classes, as well as for Atlantic white-cedar stems over 5 feet tall; percent cover of the top three competitors; water depth; and peat depth. Both raw field data and calculated stand statistics are then incorporated into a GIS.

Geographic Information System

A GIS has been developed for the Dare County Peninsula that consists of the following base layers: landmass, roads, lakes, creeks, canals and V-ditches. In the near future, all of the data generated by the regeneration survey will also be incorporated into the GIS. Once integrated into the GIS, the raw database will display the geographic location of individual plots and transects and can be manipulated to display geographic ranges of different levels of Atlantic white-cedar regeneration, percent competition, stocking of other tree species, water depth and peat depth. The statistical database for each stand will be linked to the entire stand and can be used to display data such as number of stems per acre of each species, average percent coverage of the top three competitors, and much more. More detailed thematic maps can also be generated that display Atlantic white-cedar stands differently based on the following stocking ranges: <850, 850-1000, and >1000 stems per acre. The actual outline of the cut-over areas will be digitized from 1996 digital orthographically corrected aerial photography. Future plans not only include the use of digital aerial photography for the mapping of vegetation but also the use of satellite imagery.

Promote and Enhance Natural Regeneration

Although natural regeneration of Atlantic white-cedar is occurring in all of the stands inventoried, stocking levels vary significantly between and within stands. For the purpose of this project, a stand is considered to be adequately stocked if it contains an average of 850 Atlantic white-cedar trees per acre, greater than 5 feet in height. Due to the ingrowth of new germinates and accelerated mortality rates of seedlings and smaller saplings, more emphasis is placed on the stocking of trees in the larger height classes that may have a better chance of survival.

Successful regeneration of Atlantic white-cedar has been hindered due to the shade intolerance of the species. Atlantic white-cedar seedlings growing under a closed canopy are believed to survive no longer than three years (Little 1950). Nearly all Atlantic white-cedar cut-over areas on the Refuge and the Range are characterized by an extremely dense layer of hardwood shrubs, vines and trees that compete with Atlantic white-cedar for light and nutrients.

In order to promote seed germination and ensure the survival of Atlantic white-cedar seedlings and saplings, the competing hardwood vegetation must be controlled. Plans to release Atlantic white-cedar from competition from undesirable woody vegetation consist of herbicide application. The brand Arsenal (Isopropylamine salt of Imazapyr) will be applied aerially at a rate of 16-20 ounces per acre. Sites chemically treated with approved tank mixes, applied at a rate of 16 to 23 ounces per acre, are guaranteed to be at least 80 percent free to grow for two years following application. The release from competing vegetation will increase the amount of sunlight reaching the forest floor, which will enhance seed germination and seedling survival. The duration of the free-to-grow period will give Atlantic white-cedar trees in all stages of development at least a 2-year head start toward establishing themselves and dominating the stand. This method must be performed in conjunction with hydrologic restoration to improve conditions for seed germination and seedling survival. Under the right conditions, existing seed sources will germinate in response to the increase in light, and Atlantic white-cedar seedlings and saplings will be able to out-compete encroaching hardwood vegetation.

Stands that contain an average of 850 Atlantic white-cedar trees per acre > 5 feet tall will be a higher priority for restoration due to the greater probability of success. Stands that contain fewer trees will be a lower priority since they may require more costly and labor-intensive treatments such as site preparation and planting.

Develop Seed and Seedling Source

As the efforts to regenerate and restore Atlantic white-cedar increase, so will the demand for Atlantic white-cedar seedlings. Extensive research has been conducted to test seed quantity, seed quality, environmental parameters needed for germination, nursery conditions, and seedling size. Although most of the seedling production techniques are not yet perfected, nurseries have been successful in producing large quantities of Atlantic white-cedar seedlings. Aside from the cost, the primary limitation of consistently producing large quantities of seedlings is availability and quality of seed. Atlantic white-cedar cone collection is an extremely labor-intensive operation. The process usually involves the felling of dominant to co-dominant trees in order to reach the tree crown and harvest cones. Research has shown that seed collected from smaller, immature trees is just as viable as seed collected from mature trees (Bonner 1996). However, mature trees usually produce larger, more dense crops of cones which make collection more productive. Cones are also collected from smaller trees that are growing along the roadside or in a plantation-type stand. Atlantic white-cedar cone production is cyclical; therefore, the availability of cones fluctuates from year to year. Flooding can cause additional stress to trees resulting in poor cone production.

At the Refuge, we dedicate a minimum of one month per year to Atlantic white-cedar cone collection. Cones collected are sent to the NCDFR tree nursery, where the seeds are extracted, cleaned, tested for viability and either planted the following spring to meet our seedling demands or put in cold storage for future needs. Additional research has been performed to develop methods of producing Atlantic white-cedar trees from cuttings. Weyerhaeuser Company has been successfully producing and selling rooted cuttings from mature trees for several years; however, the cost of the trees is significantly higher than the price of seedlings. If the demand for seedlings continues to increase, and easier methods for collecting seed are not developed, cuttings may be the only practical means of producing Atlantic white-cedar nursery stock.

Develop and Implement Methods of Artificial Regeneration

Artificial regeneration of Atlantic white-cedar on the Refuge and Range has been performed on a limited basis. Nearly 100 acres have been hand planted, including a 5-acre genetic test plot, a 5-acre Atlantic white-cedar cone production site and approximately 90 acres of recent clearcuts on the Range. In most cases, the cut-over areas were planted within a year after harvest; therefore, accessibility and site preparation were not issues. Conducting large-scale artificial regeneration in clearcuts that are 5 to 10 years old is much more problematic due to the dense vegetation. It would be nearly impossible for a planting crew to efficiently maneuver through the brush while maintaining proper spacing of the seedlings. Additionally, any seedlings planted under the dense shrub layer would soon die due to the competition for nutrients and light.

In 1996, a study to test various methods of site preparation for planting Atlantic white-cedar was attempted. The study was developed to determine the effectiveness of herbicide, mowing, drum chopping, and burning plus the combination of burning and each of the other three methods. Due to the extremely wet conditions, the only type of preparation successfully performed was mowing which proved to be too expensive and impractical for large-scale site preparation. Due to the failure of the other three methods, herbicide application was not attempted and no Atlantic white-cedar seedlings were planted. Plots that were mowed displayed vigorous growth of undesirable trees, shrubs, grasses, and ferns that completely dominated the site within two growing seasons. This method, unless followed up with chemical control, would provide little benefit to seedling growth. Artificial means of regenerating Atlantic white-cedar in cut-over stands on the Refuge will be performed only in situations where methods to promote or enhance natural regeneration have failed. As it now stands, there are more naturally regenerating stands in need of restoration than we can afford to manage in the near future. Artificially regenerating Atlantic white-cedar is not only more costly but also has a much lower probability of success than restoring stands in which natural regeneration is occurring. Regardless of the method of site preparation, the planted seedling will most likely require some type of silvicultural treatment in order to keep them relatively free to grow.

Hydrologic Restoration

Efforts to restore the hydrology on the Refuge were first initiated in 1989 with the installation of water-control structures in the outlets of several major canals. In 1992, Legacy funding provided means to expand our restoration efforts and provide water-control capabilities in areas having a direct impact on Atlantic white-cedar regeneration. A significant number of structures have been installed that provide water control for thousands of acres. However, hydrologic restoration has not yet been achieved in all of the 3,000-acre study area. Several structures are to be installed in canals directly adjacent to the study area, while the remaining structures that still require permitting and purchasing will most likely be installed in the near future. It is essential to achieve some level of hydrologic restoration before any regeneration efforts can be attempted.

In addition to establishing water control, a hydrology study is planned to monitor water quality and flow throughout the 3,000-acre study area. Long-term monitoring will generate baseline data for determining current conditions, management needs, and the effect of restoration efforts.

RESULTS AND DISCUSSION

Preliminary results of stand inventories reveal that natural regeneration of Atlantic white-cedar is occurring in nearly all stands. However, stocking levels between and within stands are extremely variable. Variations in stocking between stands appear to be directly associated with hydrology, site disturbance, and density of competing vegetation. Although it was not a variable in this inventory, the time of year a stand was harvested can also be correlated to the success of natural regeneration (Smith 1995). The variability, or patchiness of regeneration within a stand is most likely a result of micro-topography, site disturbance, and variation in shrub density. It has been suggested that micro-topography is a primary component of Atlantic white-cedar regeneration (Akerman 1923, Little 1950). As a result of drastic soil disturbance in the skid trails, nearly all vegetation growth occurs between the trails, where it tends to be higher and drier. Skid trails within all of the stands are wetter than surrounding areas and are devoid of any soil properties essential for supporting tree growth. Seed stored within the area of skid trails prior to logging was also most likely destroyed by equipment traffic.

Despite some minor variation in species composition between the stands, the one variable which remains constant is the extremely dense shrub layer. In all stands inventoried, the primary cause of failed regeneration is competing hardwood vegetation. Aside from the competition for nutrients, Atlantic white-cedar must also compete for light which is essential for seedling survival and seed germination. Hardwood growth is usually so dense that it creates a nearly closed canopy. In addition to the shrub canopy, the leaf litter deposited by the deciduous species also acts as a barrier to light, thus inhibiting seed germination. Throughout the majority of the stands, the primary hardwood competitors, are fetter bush (*Lyonia lucida*), laurel or bamboo green briar (*Smilax laurifolia*), green briar (*S. walteri*), gallberry (*Ilex coriacea*), bitter gallberry or inkberry (*I. glabra*) and waxmyrtle (*Myrica cerifera*).

Also correlated with the success of Atlantic white-cedar regeneration is the presence of *Sphagnum* moss (Smith 1995). *Sphagnum* is the most common substrate on which Atlantic white-cedar seed germination occurs (Little 1950). The presence of *Sphagnum* also appears to be directly correlated with light availability. Dense carpets of *Sphagnum* are present only within areas that receive nearly full sunlight, such as skid trails. Unfortunately, these sites often remain too wet for seed germination and seedling survival.

Although regeneration within a stand is patchy or occurs in rows between skid trails, many of the stands were found to contain an average of at least 850 trees per acre in the > 5-foot height class. One stand was determined to be regenerating successfully on its own with little competition and will require no treatment. Most of the other stands, although adequately stocked, will require silvicultural treatment. Plans to alleviate the effects of competing vegetation consist of herbicide application which will be administered in the near future. To date, chemical release from competing vegetation appears to be the only viable means of enhancing natural Atlantic white-cedar regeneration. Long-term monitoring of the effects of the chemical release will be accomplished by resurveying permanent plots that were established in several of the stands.

Development of a complete GIS will be a continuing effort. All ecosystem-related data will eventually be incorporated into a GIS, which will become one of our most valuable tools for managing all aspects of the Refuge and Range.

Although necessary at times, planting Atlantic white-cedar has proved to be so difficult that natural regeneration is preferred in areas where the opportunity exists (Laderman 1989). Planting seedlings or cuttings is more costly and usually requires some type of follow-up treatment to minimize ingrowth of potential competition. The collection of seed for use in nursery production continues to be extremely labor-intensive. Producing Atlantic white-cedar trees from cuttings seems to be a simpler approach; however, the price of cuttings remains significantly higher than seedlings.

As a result of the altered hydrology, some of the stands are flooded for extended periods. Standing water prevents the germination of seeds, induces additional stress, and kills nearly all new germinates. Completing the hydrologic restoration project on the Refuge and Range will take a considerable amount of time. We anticipated having water control throughout the majority of the entire 3,000-acre study area by the end of spring 1998. By installing water-control structures at key locations at the intersections of roads adjacent to cut-over stands, surface and ground water will be able to flow in and out of stands more naturally.

Hydrologic restoration in conjunction with chemical release is essential to the success of natural regeneration of Atlantic white-cedar in most of the inventoried cut-over tracts. With any luck, the inventory of the 3,000 acres will be completed by the end of the 1997 field season. Once the inventory, data analysis, and hydrology restoration are complete, plans to release Atlantic white-cedar regeneration can be implemented. The overall goal of this project is to restore the entire 3,000-acre study area; however, the number of acres restored will be determined by the limited amount of funds available. Due to limited funding, stands with the greatest amount of natural regeneration will be treated first, while the rest of the stands will be prioritized accordingly and treated as additional funding becomes available. The 3,000 acres of Atlantic white-cedar clearcuts sampled during this study is only a fraction of the total clearcut acreage in need of restoration on the Refuge and Range. Therefore, restoration efforts should be incorporated into the overall management of the ecosystem.

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EFFECTS OF HERBIVORE PRESSURE ON ATLANTIC WHITE-CEDAR ROOTED-CUTTING SURVIVAL ON A NORTH CAROLINA COASTAL PLAIN PEATLAND

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Abstract—In 1996, a study was initiated to evaluate the planting of Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) as part of a habitat restoration project taking place on the Pocosin Lakes National Wildlife Refuge, North Carolina. In the summer of 1993, 6,000 rooted white-cedar stem-cuttings were planted on 180 hectares of peatland previously used for agriculture. In 1994, 57,000 cypress and pond pine (*Pinus serotina* Michaux) were planted on the site. In 1995, 3,500 water oak (*Quercus nigra* L.), 2,500 willow oak (*Quercus phellos* L.), 2,000 pond pine, 400 cherrybark oak (*Quercus falcata* var. *pagodaefolia* Ell.), 200 bald cypress (*Taxodium distichum* (L.) Richard) and 100 green ash (*Fraxinus pennsylvanica* Marshall) were planted. Due to extremely dry conditions at the time of planting, fire-plow ditches were used as planting beds for Atlantic white-cedar. The objective of this study was to determine Atlantic white-cedar survival within the fire-plow ditches from 1993 and to report the survival of bald cypress, pond pine and oak species. Initial findings indicated that survival of most planted species was low due to deer browsing.

In 1997, a follow-up study was initiated to focus on the effects of herbivore pressure on newly planted Atlantic white-cedar and bald cypress. Tree shelters ("Super Tubes"; Treessentials Co., St. Paul, Minnesota) were placed over half the trees in a small plantation of Atlantic white-cedar and bald cypress. Survival and growth were compared among trees in control and "Super Tube" treatments.

This paper presents the evaluation of the success of the 1993 planting of Atlantic white-cedar and offers recommendations for the use of "Super Tubes" as a beneficial practice in establishing Atlantic white-cedar and bald cypress on the Pocosin Lakes Refuge.

INTRODUCTION

Recognition of Atlantic white-cedar's (*Chamaecyparis thyoides* (L.) B.S.P.) many commercial and ecological values coupled with a well-documented loss of its historical range has provided an impetus for many recent projects concerning the restoration of Atlantic white-cedar ecosystems (Phillips and others 1992, Smith 1995, Moore 1996). Whenever possible, natural regeneration should be the preferred method of establishing Atlantic white-cedar (Laderman 1989). However, in many locations where Atlantic white-cedar restoration is planned, a natural seed source is not available; therefore, many projects rely on artificial means to recreate a Atlantic white-cedar habitat (Phillips and others 1992).

With large- and small-scale restoration of Atlantic white-cedar, feeding by deer, field mice and rabbit populations can have detrimental effects on an Atlantic white-cedar crop (Little and Somes 1958, Zampella 1987, Phillips and others 1992). The need to provide protective measures to reduce depredations upon newly planted Atlantic white-cedar has been widely recognized (Little and Somes 1958, Laderman 1989, Kuser and Zimmerman 1995). Commonly used barriers for protecting tree crops are, for individual plants, plastic or metal mesh cages, and, for larger plantations, electric fence exclosures. Chemical repellants are often used in combination with physical barriers to further enhance control over deer feeding.

Preference of a protective method is usually determined by the scale of planting, ease of installation and the cost per planted tree. This study used tree shelters ("Super Tubes"; Treessentials Co., St. Paul, Minnesota) for a small plantation of Atlantic white-cedar and bald cypress (*Taxodium distichum* (L.) Richard) due to cost and time efficiency for such a small-scale planting. "Super Tubes" can also prevent damage by smaller animals that other methods may not. However, the protection afforded by the "Super Tubes" is relatively expensive ($2.60/tree) and may not be practical for large-scale planting (Kays 1995). Kays (1995) calculated that tree shelters were more affordable than electric fencing for plantations of one acre or less but become more costly than electric fencing for plantations of three acres or more.

Study Area

This study was conducted on a 180-hectare parcel of land that had been cleared of timber for agriculture. The parcel, known as the Selby Tract, was abandoned in 1985 and is now part of the Pocosin Lakes National Wildlife Refuge which is located in Hyde, Tyrell, and Washington Counties, North Carolina. In 1993, Refuge managers initiated a restoration project on the Selby Tract that included the planting of 6,000 rooted Atlantic white-cedar cuttings. Besides planting, managers attempted to restore the wetland's hydrology by mechanically plugging the tract's sixteen drainage ditches at the point where they drain into a first order canal. Due to extremely dry soil conditions, managers created ditches with a fire-plow to be used as planting beds. These ditches were intended to provide greater moisture for the rooted cuttings. No other site preparation was done before planting.

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The Selby Tract has several qualities that make it suitable for Atlantic white-cedar restoration. The organic soils are of the Pungo (dysic, thermic Typic Medisaprist), Scuppernong (loamy, mixed, dysic, thermic Terric Medisaprist), and Belhaven (loamy, mixed, dysic, thermic Terric Medisaprist) series. All are deep, well-decomposed, low pH soils and are similar to those found in natural Atlantic white-cedar wetlands (Laderman 1989). The Selby Tract is also within the recent, historical geographic range of Atlantic white-cedar and close to the Alligator Wildlife Refuge that contains some of the most extensive, natural Atlantic white-cedar stands in North Carolina (Frost 1987, Moore and Carter 1987).

The hydrology of the Refuge is controlled through an extensive drainage network of field ditches and canals constructed during the early 1900's and expanded as recently as the 1950's (Lilly 1981). Flash-board risers are in place in several main canals, giving managers the capability of controlling hydrology for the purposes of habitat restoration, wildfire and flood control. Typically, water levels are kept just below the soil surface for most of the Refuge, similar to that of natural of Atlantic white-cedar areas (Golet and Lowry 1987, Zampella 1987, Erhenfeld and Schneider 1991).

METHODS

In summer, 1997, ten planting rows were surveyed along their total length for presence or absence (mortality) of Atlantic white-cedar. On average, a row contained 100 Atlantic white-cedars. Survival was determined as the percentage of trees that had survived since 1993. The planting locations of bald cypress, pond pine and oak species were also surveyed for remaining trees.

Prompted by high tree mortality and strong evidence of herbivore damage to the surviving Atlantic white-cedar (e.g., snipped terminal buds, broken stems, etc.), a follow-up study was conducted to determine the effects of herbivore feeding on the survival of planted, rooted-cuttings of Atlantic white-cedar and bald cypress. Fifty Atlantic white-cedar and fifty bald cypress trees were planted on a 3 m x 3 m spacing on February 1, 1997 in a random block design (20 trees per block, replicated 5 times). Trees of similar initial heights, of each species, were grouped together in blocks. Blocks consisted of 10 trees from both species with half the trees having "Super Tubes" (1.2 m high, translucent shelters) placed over them after planting. Site preparation consisted of physically clearing the native vegetation within a square meter around each planted tree. Trees were measured for initial height at the time of planting. Frequent inspections of the site were made to repair "Super Tubes", remove competing vegetation, and make note of herbivore damage to individual trees. Tree mortality and heights were recorded again on July 1, 1997.

An analysis of variance was performed with tree mortality and mean tree growth data as the dependent variables; tests for significance used an alpha-level of 0.10. Dead trees were excluded from statistical analysis when mean growth was used as the dependent variable. The procedure of excluding dead individuals has also been used in similar tree shelter experiments (Minter and others 1992, Smith 1992).

RESULTS AND DISCUSSION

1993 Atlantic White-cedar Planting

Twenty-one percent of the Atlantic white-cedar rooted-cuttings survived (208 living trees from 1,000 planting locations). The total area sampled was 6192 square meters, resulting in an estimated Atlantic white-cedar density of 336 trees/hectare (136 trees/acre). Most of the surviving trees have had their main stems severed near ground level, resulting in poor growth and form; sign of deer was present at nearly all tree locations.

The survival of the 1994 planting of bald cypress was surveyed at 969 tree locations within the fire-plow ditches; trees were found in 109 locations, and overall survival was 11.2 percent. Surveys of those bald cypress planted outside of the fire-plow ditches was 8 percent (200 planting locations surveyed).

Surveys of pond pine (*Pinus serotina* Michaux) found that 46% of the original trees remained at planting locations (230 living trees from 500 planting locations).

The survival of *Quercus* species was 51 percent (148 trees remained at 292 planting locations); most of the surviving trees were heavily browsed and less than 0.25 m in height.

Tree Shelter Results

Survival of Atlantic white-cedar and bald cypress differed among both the control and "Super Tubes" treatments (table 1). Mortality of all trees within the control treatment was attributable to deer browse, i.e., snapped stems or uprooting. Mortality within the "Super Tube" treatment was caused by the uprooting of trees due to vandalism ("Super Tubes" and stakes were knocked over and damaged by gunshot). There was significantly less mortality between trees with "Super Tubes" for both Atlantic white-cedar and bald cypress ($p = 0.05$ and $p \leq 0.01$, respectively) (table 2).

Among the trees without "Super Tubes," eight of the 16 surviving Atlantic white-cedars and 9 of the 10 surviving bald cypress had been browsed. Tree heights after 5

Table 1—Survival and height growth of Atlantic white-cedar and bald cypress

Treatment	n	Survival	Height growth
		Percent	*cm*
		White-cedar	
Control	25	64	4.1
Super tubes	25	84	13.8
		Bald cypress	
Control	25	40	-12.7
Super tubes	25	96	6.9

Table 2—ANOVA results for survival and height growth of Atlantic white-cedar and bald cypress. Treatments are with or without "Super Tubes"

Source	df	White-cedar	Cypress
		Survival	
Replicates	4	NS	NS
Treatments	1	*	**
Error	4		
		Growth	
Replicates	4	NS	NS
Treatments	1	**	*
Error	4		

months in the field are presented in table 1. Among the surviving trees, relative growth of a tree was determined by the difference between initial height and height after 5 months; these values were negative in many instances. Growth of surviving Atlantic white-cedar and bald cypress without "Super Tubes" averaged 4.1 centimeters and -12.7 centimeters, respectively, while trees within "Super Tubes" averaged 13.8 centimeters and 6.9 centimeters over 5 months (table 1). Differences in mean growth were significant for Atlantic white-cedar and bald cypress ($p = 0.01$ and $p = 0.02$, respectively) (table 2).

CONCLUSIONS

While Phillips and others (1992) have found animal impacts to be minimal in some areas of eastern North Carolina, herbivore pressure on Atlantic white-cedar may be especially intense on the Pocosin Lakes Refuge. Newly planted trees are likely to be preferred by deer over pocosin vegetation; Atlantic white-cedar, an evergreen, might be especially susceptible to winter browsing (Little and Somes 1958). This notion is supported by a similar cedar planting project on the Refuge, which experienced 75% mortality in the first 2 years, even though electric fencing was in place (Hinesley and Wicker 1997).

The relationship of the fire-plow ditches to Atlantic white-cedar survival is unknown since no trees were planted outside of this site preparation. However, creating fire-plow ditches as a site preparation appears to have been effective at both providing adequate moisture to the Atlantic white-cedar and avoiding permanent flooded conditions in the planting beds. Over the past 2 years, evidence of flooding in the ditches was only observed once (after Hurricane Bertha in 1996). Plans to install a flash-board riser in a main canal downstream of the Selby Tract will undoubtedly raise water tables in the future. Atlantic white-cedar wetlands typically have a water-tables 20 to 61 centimeters below the surface (Erhenfeld and Schneider 1991, Golet and Lowry 1987, Zampella 1987). Since the fire-plow ditches are approximately 50 centimeters in depth, restoring a more natural Atlantic white-cedar hydrological regime to the Selby Tract would likely flood the remaining trees. Atlantic white-cedar is likely to die in such a situation due to its intolerance to flooding for long periods of time (Laderman 1989, Moore 1996). This site preparation seems ill-suited for the local environmental changes that will eventually occur.

The Pocosin Lakes Refuge and the Selby Tract have excellent potential for Atlantic white-cedar restoration. However, based on the low survival of Atlantic white-cedar without deer protection in this and other studies and considering the positive effects of "Super Tubes" on tree mortality and growth, further cedar restoration in this study area should be accompanied by a sound plan for controlling herbivore feeding damage.

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EFFECTS OF PROPAGULE TYPE, GEOGRAPHIC ORIGIN, AND FERTILIZATION ON FIRST-YEAR PERFORMANCE OF ATLANTIC WHITE-CEDAR (*CHAMAECYPARIS THYOIDES*) IN NEW JERSEY

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Abstract—We are investigating the impact of several factors on the establishment and growth of Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) in the field: (1) the type of propagule planted and the age of the parent tree, (2) the geographic origin of the planting stock, and (3) amendment of poor soils with fertilizers at the time of planting. The results of the first year of these studies are reported here. To investigate the effects of propagule type and the age of the parent tree, seedlings and rooted cuttings (stecklings) were prepared from immature, from middle aged, and from very old trees. After 1 year in the field, seedlings from the very old trees showed the greatest growth, while stecklings from this same group and stecklings from immature parent trees performed the poorest. To investigate the role of geographic origin, stecklings derived from mature Atlantic white-cedars in northern, central and southern New Jersey, and from a site in North Carolina, were planted in a common garden plot. Trees from the isolated northern-most site grew significantly slower than the others. The investigation of the role of fertilizer treatments was conducted on the barren, low-nutrient sand beach of a freshwater lake. The fertilizer types investigated were a time-release inorganic fertilizer, a course, undegraded mulch, and a fine, highly degraded mulch. Mulch treatment alone caused a slight decrease in growth compared to the no-treatment control. Treatment with inorganic fertilizer doubled growth compared to the control. Treatment with inorganic fertilizer in combination with undegraded, but not highly degraded, mulch nearly tripled growth.

INTRODUCTION

We report here the initial results of experiments designed to investigate the effects on the field performance of Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.), according to the manner in which restoration is conducted.

Our studies have focused on three topics:

1. The effect of geographic origin of the planting stock: it has been often observed in the restoration of other plant species that adaptation to local climate, soil, moisture regimes, and geography can play major roles in the ability of a species to survive in the field. That is, locally-derived planting stock often performs best. To test the degree to which this effect pertains to Atlantic white-cedar, with particular emphasis on restoration within New Jersey, we have compared the growth of rooted cuttings (stecklings) derived from parent trees located at three widely separated sites within the state, along with stecklings produced from cedars grown in North Carolina, in a common garden plot.

2. The effect of type of propagule and type of parent: Atlantic white-cedar can be propagated via the production of stecklings or through the sprouting of seeds to generate seedlings. The former of these methods is relatively quick and economical, and is the method of choice in the industry today. The latter method is slower, more tedious, and more expensive. However, through the use of seedlings, one is more assured of maintaining the full genetic complexity of the species. To test the effects of the propagule-type on the restoration of Atlantic white-cedar we have produced both stecklings and seedlings from a group of parent trees. These were then planted on a common site. Field performance, monitored as height increase, was monitored. In addition, since it is feasible that the vigor of a propagule may be a function of the age of the tree from which it was derived, we have employed as parent trees in this study cedars ranging in age from less than 10 to more than 100 years.

3. The ability of planted Atlantic white-cedars to survive on a barren sand site, and the ability of nutrient amendments to increase their survival and growth: in New Jersey, as elsewhere along the Outer Coastal Plain of the Atlantic seaboard, industrial activities such as sand mining have created extensive bare sand areas that are devoid of vegetation. Subsurface fresh water is often available near the surface at such sites due to the collection water in the mining depressions. However, the nutritional status of these areas is very poor. Since the moisture levels and regional location are favorable to Atlantic white-cedar, we have investigated the ability of the species to survive on this site. In light of the poor nutritional status of these sites, we have also determined the effects of nutrient amendment on the survival and growth at these locations.

METHODS

Biomaterial

Biomaterial for the production of stecklings and seedlings was gathered from healthy Atlantic white-cedar between

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October, 1994 and January, 1995 at High Point State Park and Lebanon and Belleplain State Forests. These sites are located, respectively, in extreme northern, central, and extreme southern New Jersey. The longitudinal distance between the northernmost and southernmost site is approximately 160 miles. The distance between High Point and Lebanon is approximately 105 miles. The Belleplain site sits essentially at sea level, and the Lebanon site is less than 100 feet above sea level. In contrast, the High Point cedar swamp sits approximately 1,500 feet above sea level, the highest reported Atlantic white-cedar site.

Material gathered for steckling production was the terminal 25 to 35 centimeters of cedar boughs. From the current season's new growth on these boughs, the terminal shoots, roughly 10 centimeters in length, were cut. At the cut end of these, the bark and phloem were removed from one side for a length of approximately 2 centimeters. This portion was coated with Hormodin 3 rooting hormone (MSD Agvet Division of Merck & Co., Rahway, NJ, active ingredient: 0.8 percent indole 3-butyric acid) and the cutting was planted in a conical plastic tube, 21 centimeters long X 4 centimeters diameter. (Leach tube, Stuewe Inc., Corvallis, OR) filled with Promix BX (Premier Horticulture, Red Hill, PA) planting medium. Racks of cuttings were placed on heat mats (22 °C) in a greenhouse with a 10-hour minimum day length (350 μEinsteins) and automatically misted with water for 6 seconds every 6 minutes. To acclimate the trees to frost, they were transferred in January 1996 to an open-air chamber with a minimum nighttime temperature of 0 °C. Final outplanting was done in April and May, 1996.

Cedar cones were allowed to open by drying at room temperature for 3 days. The seeds were shaken from the opened cones, placed on top of moist sphagnum moss and stratified by incubation at 4 °C for 6 weeks. Germination was then induced by transferring the seeds to filter papers moistened with distilled water within Petri dishes (papers, water, and dishes were pre-sterilized) and exposing them at 25 °C to 16-hour day length artificial illumination. After 1 month each seed was transferred to the surface of ProMix BX in a Leach tube and exposed to the mist and illumination regime described above for the stecklings.

Stecklings from North Carolina were the gracious gift of the Weyerhauser Corp. and originated from sites approximately 300 miles south of the New Jersey samples. They were produced from a hedge orchard, located in Trenton, NC, whose parent material came from a single site in Craven County, NC (B. Cooney, personal communication).

Experimental Plan and Conduct

All trees were planted on 5-foot centers in May and June, 1996, at sites in central New Jersey. Heights at planting were generally between 10 and 20 centimeters. After planting, vegetation which overtopped the young trees was removed as necessary with a weed whacker during the growing season. The maximum above-ground height of each tree was measured at planting and again in January, 1997 following one season of growth. Net growth for that season was calculated from this data. Data was not collected from trees that had died or been browsed by deer. Statistical analysis of data was conducted with Design Expert 5 software (StatEase Corp., Minneapolis, MN).

Geographic Origins Study

This work was conducted on a small (0.5 ha) Atlantic white-cedar wetland located at the New Jersey Forest Resources Education Center in Jackson, NJ. The site was cleared of trees prior to initiation of the experiment. For each geographic origin (north, central and southern New Jersey, and North Carolina), 12 stecklings prepared from each of five trees were planted, for a total of 60 trees per origin. Stecklings raised by our methods were 10 to 20 centimeters tall at planting. Stecklings from North Carolina were 25 to 35 centimeters tall.

Parent Age / Propagule Type Study

Trees from three age classes were chosen as donors of biomaterial: (1) late-mature trees, with average ages (by increment boring) of 112 to 150 years, (2) relatively young mature trees, with ages between 30 and 50 years, and (3) immature trees less than 6 feet tall and not yet producing cones. Cuttings were gathered from all three groups for the production of stecklings. Seedlings were produced from cones gathered from the first two groups.

The study site is on the edge of an existing Atlantic white-cedar site in Lebanon State Forest, NJ. Atlantic white-cedars were naturally colonizing this site prior to planting, which indicated its suitability for growth of this species. Brush and trees above 8 centimeters in height were removed prior to the experiment. For each age group and type of propagule, 12 trees from each of five parent trees were planted in random order. Deer were effectively excluded by an electric fence.

Establishment of Atlantic White-Cedar on a Sterile Site Study

These studies were conducted on the shore of a freshwater-filled open-pit sand mine at the Lakehurst, NJ facility of the Clayton Sand and Block Co. Two replicate rows of 6-15 x 5.6 meter plots, separated by a 10 meter bare strip, were laid out parallel to one another on the bare, approximately level, sand shore of the lake. Each of the six plots in each row received one of the following treatments, assigned randomly:

1. Osmocote (O.M. Scott, Marysville, OH) time-release fertilizer, 12 month release duration. N:P:K = 17:7:12. Application rate: 1,930 kilograms/acre. Mixed into the soil to a depth of 15 centimeters by roto-tilling.

2. An undecomposed, freshly prepared mulch derived by course shredding of deciduous trees, primarily red maple (*Acer rubrum*). Typical fragment sizes were 1 square centimeter. A layer approximately 5 centimeters deep was applied manually across the plot and incorporated by roto-tilling.

3. A finely ground, highly decomposed mulch derived from municipal yard waste. This material resembled black potting soil, with few pieces as large as 0.5 square centimeters. Rate of application and incorporation by roto-tilling were as described above.

4. A combination of Osmocote and fresh mulch applied as above.

5. A combination of Osmocote and decomposed mulch, applied as above.

6. No treatment, roto-tilled as described above.

Each of these plots was then planted with seedlings (9) from Lebanon State Forest parent trees and stecklings (15) from Lebanon S.F. and from Belleplain State Park.

RESULTS AND DISCUSSION

The steckling survival rate through the greenhouse phase of production was about 90 percent in most cases, although for about 5 percent of the parent trees the rate of steckling establishment was less than 75 percent. The production rate of viable seedlings exceeded 95 percent. Field survival of both stecklings and seedlings exceeded 95 percent in virtually all cases.

The Effects of Geographic Origin on Field Performance

Efficient electric fencing was not installed in time to exclude deer. Approximately 50 percent of the test trees were browsed, removing them from this study. Browse damage was not equally spread across all samples. Particularly hard hit were trees from North Carolina, where the browsing rate was nearly 80 percent.

Table 1 presents the average first year increases in height for trees from each of three New Jersey sites and the North Carolina site. Trees derived from the Lebanon and Belleplain sites grew the best, while those from High Point grew the slowest. Trees from North Carolina, the most distally separated of the sites, performed intermediately between the extremes established by the New Jersey trees. Analysis of variance indicated a significant ($P<0.05$) difference only between the average height of trees derived from High Point and those from the Lebanon and Belleplain sites. Growth of trees from Lebanon, Belleplain, and North Carolina were not statistically different (at $P<0.05$). The slow growth of the High Point trees may represent the consequences of adaptation to the High Point site, which experiences much more severe winters than the other sites studied. It may not be coincidental that the relatively weather-stressed and isolated High Point stand has been shown to be genetically less diverse than other cedar sites (Kuser, in press). The data suggests that there is not a large origin-dependent component to the field performance of Atlantic white-cedar. It must be cautioned, however, that these data are from only one growing season, and that substantial amounts of data were lost due to deer browsing.

The Effects of Parent Age and Type of Propagule on Field Performance

Browsing losses in this experiment were less than 5 percent, and mortality was less than 5 percent. Table 2 presents first-season growth data for 283 trees, stecklings and seedlings, derived from parent materials of three different degrees of maturity. The best growth was by seedlings derived from the most mature trees studied. Their growth was significantly greater than that of any other type of propagule examined ($P<0.01$). The poorest growth was by stecklings produced from this same class of parent. Stecklings from these old trees may exhibit reduced vigor, as their very production was difficult. Their frequency of survival and rooting during the greenhouse phase of the operation was less than 25 percent.

Stecklings from juvenile trees are the commercial source of cedar propagules in many reforestation operations. It is notable that this class of propagule grew almost 40 percent poorer (significant at $P<0.0001$) than the best-growing group (table 2). Intermediate and statistically identical growth was displayed by seedlings and stecklings of relatively young mature trees (table 2). Again, these data represent only the first year of growth and should be taken as only indications of trends, at best. Firm conclusions regarding the fitness of the various types of propagules must await the time when the trees are of sufficient age to form an ecological community or to be harvested for timber. Nonetheless, the apparently superior ability of seedlings from very mature trees to increase their heights, and presumably their biomasses, may put them at a competitive advantage in terms of the capture and utilization of sunlight and nutrients and may also provide them with additional resistance against environmental stress.

Table 1—Mean first year growth of Atlantic white-cedar derived from different geographic locations

Geographic origin	Growth
	cm, +/- mean
High Point	18.9 (1.4)
Lebanon	25.8 (1.5)
Belleplain	23.9 (1.6)
North Carolina	22.0 (2.3)

Table 2—Mean first year growth of Atlantic white-cedar as a function of parent age and type of propagule

Type of propagule	Growth
	cm, +/- mean
Late mature parent	
Steckling	6.1a[a] (0.7)
Seedling	16.3b (0.8)
Young mature parent	
Steckling	12.6c (0.7)
Seedling	13.1c (0.8)
Immature parent	
Steckling	10.2d (0.8)

[a] Means within same column are not statistically different at $P<0.05$.

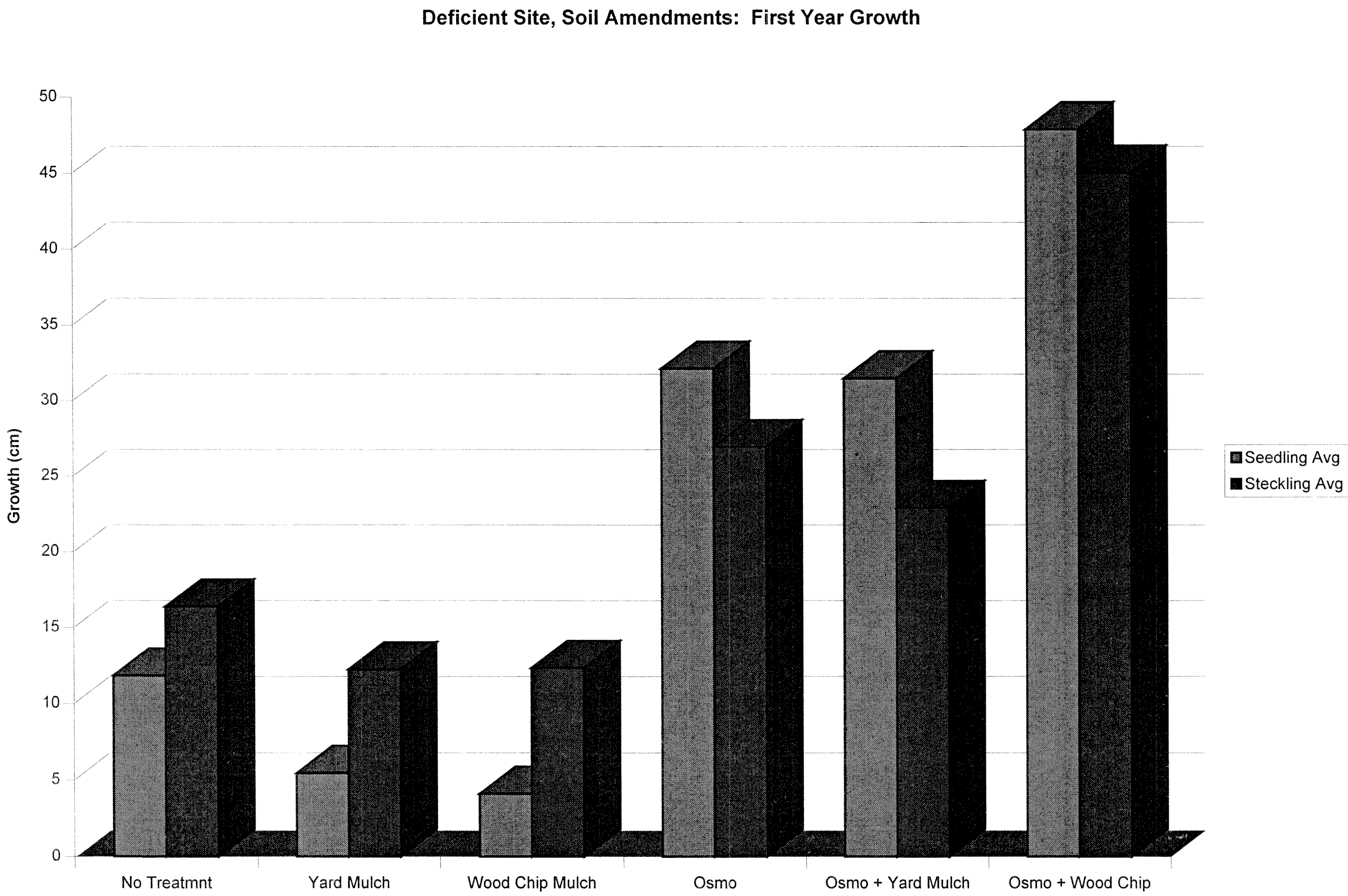

Figure 1—Average first year growth of seedlings and stecklings of Atlantic white-cedar on a barren sand beach as a function of the individual or combined application of organic and inorganic fertilizers (Osmo = Osmocote).

Establishment of Atlantic White-Cedar on a Sterile Site

Excellent survival was obtained, despite the bleakness of this site: mortality through the first season was only 4 percent. Even among trees that were planted in the bare sand with no accompanying mulch or inorganic fertilizer treatment there was virtually complete survival. Water is vital to the survival of cedars, and the fact that the water table at this site was within a foot of the surface throughout the growing season may have fostered their survival. There was no sign of deer and no browsing by deer at this barren, isolated site. Growth data from 276 trees were analyzed. Either stecklings or seedlings would make acceptable biomaterial for introduction of cedar on a site such as this, since there was not a significant difference in the performance of trees in these two groups (fig. 1). The application of organic mulches slightly but significantly ($P<0.01$) reduced growth compared to the no-treatment controls (fig. 1), perhaps due to a sequestering of nutrients by microbial or plant communities introduced with the mulches. The use of inorganic fertilizer was quite beneficial: treatment with Osmocote caused slightly more than a doubling in average height (fig. 1). Treatment with both Osmocote, and highly degraded yard mulch did not significantly increase growth compared to the use of Osmocote alone (fig. 1). This may be due to the fact that this mulch contained a large number of weed seeds, primarily those of crab grass. This led to the growth of a dense mat of grass that may have competed with the cedars for nutrients provided by the Osmocote and the mulch. Freshly prepared course-ground mulch did not lead to the growth of nearly as much competing vegetation. When it was applied along with Osmocote a substantial and significant ($P<0.01$) nearly two-fold stimulation in growth was achieved compared to the use of Osmocote alone (fig. 1). The magnitude of this stimulation was quite impressive, yielding trees that were more than three times taller at the end of the growing season than were the no-treatment controls. The stimulation was not manifested in a height increase alone: substantial increases in overall mass also resulted from fertilizer treatment (data not shown).

CONCLUSIONS

1. There is little effect of geographic origin on the field performance of Atlantic white-cedar stecklings, with the exception that propagules from the isolated site at High Point, NJ may perform slightly poorer than cedars from other locations.

2. The age of the parent tree and the type of propagule may impact the field performance of this species, with seedlings from very old trees growing significantly better, and stecklings from very young and very old trees growing significantly poorer than others tested.

3. It is possible to introduce seedlings and stecklings of Atlantic white-cedar into extremely barren sand locations. Of the treatments tested, fertilization of such a site with a combination of an inorganic time-release fertilizer and a freshly prepared course-ground mulch provided the best (three-fold) stimulation in growth.

4. All these conclusions must be viewed as provisional since they relate only the first year in the life of a species that typically lives in excess of 100 years.

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ATLANTIC WHITE-CEDAR WETLAND RESTORATION PROJECT AT POCOSIN LAKES NATIONAL WILDLIFE REFUGE

Eric Hinesley and Mike Wicker[1]

Abstract—A non-point-source pollution reduction project (Clean Water Act, Section 319) was funded in 1994 by the United States Environmental Protection Agency and administered by the North Carolina Division of Water Quality and North Carolina Division of Forest Resources. The objective was to reduce nitrogen and mercury loading of downstream waters by restoring wetland hydrology and vegetation to a 640-acre research area within an 18,000-acre peat bog that was cleared and drained for farming in the 1970's. The site became part of Pocosin Lakes National Wildlife Refuge in 1991.

In April 1995, an experiment (randomized complete block; five replications and 14 treatments) was established in a block (0.5 x 1.0 mile) near the center of the area targeted for wetland restoration. Four vegetation treatments—Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.), pond pine (*Pinus serotina* Michaux), bald cypress (*Taxodium distichum* (L.) Richard), and control—were combined with two tree spacings (8 x 8 feet and 10 x 10 feet) and two site preparation treatments (none vs. heavy disking). Plots were 2.0 acres in size, and there were 70 plots, totaling 140 acres. Undisturbed border areas separated plots, and riparian strips were maintained along drainage ditches and canals to protect waterways. An electric fence was installed to exclude deer.

Survival of bald cypress, Atlantic white-cedar, and pond pine was 63, 25, and 43 percent, respectively, after 2 years. Site preparation (disking) was most beneficial to bald cypress. Average height of bald cypress, Atlantic white-cedar, and pond pine was 25, 12, and 13 inches, respectively. Deer browsing was severe despite the fence. Achieving survival of Atlantic white-cedar commensurate with that of bald cypress will likely demand additional protection against deer.

Depth to water table averaged 7 to 13 inches. Water samples were collected quarterly from 12 surface water sites in canals surrounding the experimental area. Total Kjeldahl N was 1.8 to 3.5 parts per million (ppm) in surface water, with nitrate and ammonia usually $\leq$ 0.01 and 0.2 ppm, respectively. In 1996, mercury concentrations in unfiltered surface water samples were 5.7 to 22 parts per trillion (ppt). The only samples higher than the State standard of 12 ppt were taken in the winter; others were within the range of values for rainfall.

In the future, higher water levels will hopefully reduce levels of N and mercury in surface and groundwater. In addition to the 640-acre research area, another 1,330 acres have been replanted to primarily bald cypress and Atlantic white-cedar. Plans are underway to restore wetland hydrology on the remaining acreage by installing a total of 14 water-control structures on canals that drain the area.

INTRODUCTION

This report summarizes activities and findings for a non-point source pollution reduction demonstration project funded in 1994 by the U. S. Environmental Protection Agency and administered by the North Carolina Divisions of Water Quality and Forest Resources. The Clean Water Act, section 319, project was designed to reduce nitrogen and mercury loading of downstream waters by restoring wetland hydrology and vegetation to a peat bog that was cleared and drained in the 1970's.

The site is located within Pocosin Lakes National Wildlife Refuge and is currently owned and managed by the U. S. Fish and Wildlife Service (USFWS). Prior to public ownership, the area was cleared, ditched and drained for use in commercial farming and in anticipation of being mined for a peat-methanol plant. In the colonial period the demonstration site was part of the East Dismal Swamp, 20,000 acres of peat and muck swamp (Powell 1987). The proposed peat mining fueled a long-lasting environmental debate based in part on concerns about mercury contamination of surface waters.

Ultimately, proposals for peat mining were abandoned, and the area was transferred to USFWS ownership in 1991. Although the transfer of property to federal ownership ended the likelihood of peat mining in the area, the site remained devoid of a natural community of plants and animals, and the water draining from the site exceeded North Carolina water quality standards for mercury. Further, nitrogen in the runoff was likely contributing to eutrophication downstream. Runoff from the site flows south into Clark-Mill Creek, and eventually Pungo River. These surface waters are classified as nutrient sensitive, as is the whole Tar-Pamlico Basin (Clark 1995). The Tar-Pamlico River Basin-wide Water Quality Management Plan (Clark 1995) indicated that Clark-Mill Creek and the upper end of the Pungo River do not meet their water-use classification standards. Thus, there is a clear need to bring drainage waters into compliance with state standards and to reduce nitrogen loading.

The USFWS intends to gain insights from this 640-acre demonstration project for the restoration of the surrounding area. The restored area should provide downstream water

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quality benefits (i.e., reduced erosion and surface-water discharges with concentrations of total nitrogen and mercury less than or equal to those in rainfall). Other project benefits include wildlife habitat restoration, contributions to the scientific literature on wetland restoration, and the potential for this large demonstration project on restoration of Atlantic white-cedar, bald cypress, and pond pine to serve as a catalyst for the replanting of these wetland trees on private lands with deep organic soils. All these species are valuable for timber and are adapted to grow under wetland hydrologic regimes. Land managed for silviculture of wetland trees would not require ditching, which is considered detrimental to the environment in wetland areas.

Peat in the project site and surrounding area (the old East Dismal Swamp) has developed over the last 9,000 years since the Wisconsin period of glaciation. Dolman and Buol (1967) believed that peat formation in the demonstration area started about the same time as it did in the Dismal Swamp in Virginia, 8,900 $\pm$ 160 years before present (Oaks 1964). Several factors contributed to its formation: low relief, high sea level, and the development of dunes along the Pungo River, which blocked drainage (Dolman and Buol 1967). Under these conditions, vegetation generated organic material faster than it could decompose, and a thick layer of peat was formed slowly over thousands of years. The peat retained nitrogen that had been stored by growing plants, and eventually created a very large bank of nitrogen. The peat also sequestered mercury from the rain cycle, similar to the way an activated charcoal filter cleans water by accumulating contaminants. Historically, mercury was present in the atmosphere at low levels from volcanic activity, but its levels have increased in recent times due to a variety of anthropogenic activities (e.g., combustion of fossil fuels, smelting).

Ditching aerated the peat, causing it to decompose and release mercury. Subsidence from carbon loss after ditching has been estimated at 2.7 centimeters/year for the first two years and 0.4 to 1.2 centimeters/year thereafter (Lilly 1981). Total mercury concentrations in surface water reported for the site have been variable. The highest total mercury concentrations recorded after ditching ranged from 800 to 1,100 parts per thousand in a report prepared for Peat-methanol Associates (Environmental Science and Engineering, Inc. 1982). Concentrations have ranged from less than 2 to over 200 parts per thousand in subsequent reports (N.C. Division of Environmental Management 1983, Evans and others 1984). The surface water-quality standard for mercury is 12 parts per thousand. Total mercury is defined here as the sum of organic and inorganic forms including dissolved and suspended fractions.

MATERIALS AND METHODS

Hydrology Restoration and Monitoring

A water-control structure was installed downstream from the demonstration area in 1996 so that the wetland hydrology could be restored. This structure controls the water regime on 1,500 acres.

Reforestation

About 100,000 trees of Atlantic white-cedar *Chamaecyparis thyoides* (L.) B.S.P.), pond pine (*Pinus serotina* Michaux), bald cypress (*Taxodium distichum* (L.) Richard) were planted by machine and by hand on Block B6 (0.5 mile x 1.0 mile) in April 1995. The tract had 16 columns (20 acres each) separated by small V-ditches (oriented north-south), spaced about 320 feet apart. Ditches drain to the south toward Clark-Mill Creek and the upper Pungo River. Elevation is about 16 feet above sea level, and depth to water table has varied from 7 to 13 inches.

The experimental design is a randomized complete block with five replications and 14 treatments. Four vegetation types (Atlantic white-cedar, pond pine, bald cypress, and control), were combined with two tree-to-tree spacings (8 x 8 feet, and 10 x 10 feet) and two site preparation treatments (none vs. heavy disking). Plots are 2.0 acres, with six plots in each column. There are 70 plots, totaling 140 acres. Undisturbed border areas separate experimental plots, and riparian strips are maintained along v-ditches and canals to protect waterways.

Block B5 (320 acres) was planted in late February 1996, with no site preparation and no protection from deer. Trees were planted directly into the existing vegetation, primarily broom sedge (*Andropogon* spp). A commercial crew hand planted 233 acres (28,000 Atlantic white-cedar, 27,000 bald cypress, and 15,000 pond pine), using a target density of 300 trees/acre. An additional 25,000 trees, consisting of eight hardwood species, were machine planted. About 2,000 acres have been planted since 1995, mostly with bald cypress and Atlantic white-cedar.

Plots in Block B6 were measured for survival and growth in January 1997. Two circular sub-plots (radius of 30 feet) were installed in each 2-acre plot, yielding a 6 percent sampling intensity. Total number of living trees was noted. Heights and diameters were measured on 5 to 10 trees in each sub-plot. If there were fewer than 10 trees, all were measured. Survival counts were converted to trees per acre, and subjected to analysis of variance to determine treatment effects. Average height of plants was also calculated for each species.

Water Sampling

Total mercury, nitrite, nitrate, total ammonia, and pH were sampled at fixed surface-water stations and ground-water wells. Nitrogen samples were analyzed in the Department of Biological and Agricultural Engineering at NC State University. Samples for total mercury analysis were shipped on ice overnight to Frontier Geosciences (414 Pontius Ave. North, Seattle, WA 98109) for analysis. Mercury concentration was determined in nanograms/liter (parts per thousand). Surface-water samples for total mercury were run unfiltered but were preserved with 5 percent BrCl, due to the turbidity of the samples, and allowed to oxidize overnight prior to analysis. Aliquots of the samples were analyzed using $SnCl_2$ reduction, dual gold amalgamation, and cold vapor atomic fluorescence detection (Bloom 1993). Sample analyses, which included quality-control samples and lab performance on precision (repeatability of results based on relative percent deviation of duplicates) and accuracy (based on percent spike recoveries and analyses of standard reference material and blanks), were acceptable.

Rainfall

There were two local weather stations from which rainfall data could be compiled for calculations relative to annual rainfall, nutrient inputs, evapo-transpiration, runoff, and nutrient loading. One station was located on the Pungo Unit of the Refuge (approximately 4 miles from the experimental site), the other on Allen Rd (approximately 1 mile from the experimental site). The average of these two stations was used in calculations. Atmospheric inputs of mercury were obtained from data collected as part of the National Atmospheric Deposition Program (NADP) at Pettigrew State Park on the north side of Lake Phelps (approximately 5 miles from the experimental site). Atmospheric inputs of nitrogen were estimated from air-deposition data from the National Acid Deposition/National Trends Network at the Lewiston Station in Bertie County (approximately 60 miles northeast of the experimental site).

RESULTS AND DISCUSSION

Survival and Growth in Block B6 (Planted in 1995)

Target stocking levels were 680 trees/acre at an 8 x 8 foot spacing, and 435 trees/acre at 10 x 10 feet. No inventory was conducted immediately after planting to determine actual plant densities.

The effect of spacing was significant after 2 years in the field (table 1). Bald cypress, Atlantic white-cedar, and pond pine planted at 8 x 8 feet averaged 366, 186, and 265 trees/acre, respectively, which was 11, 68, and 27 percent greater than the stocking at 10 x 10 feet (table 2). A target density of 8 x 8 feet initially has 55 percent more trees than 10 x 10 feet. The number of trees surviving after 2 years also varied significantly among species (table 1). Cypress performed best, averaging 352 trees/acre (table 2). This represented an average survival of 63 percent. Atlantic white-cedar sustained the greatest losses, averaging 148 trees/acre. Only 25 percent of the Atlantic white-cedar seedlings survived the first 2 years. Pond pine averaged 237 trees/acre, indicating that 43 percent of the plants lived through the first 2 years.

The result of site preparation varied by species (significant 'spec x site' interaction, table 1). The difference was primarily with bald cypress; without site preparation, there were 277 trees/acre after 2 years, compared to 427 trees/acre in disked plots (table 2). A stocking of 427 trees/acre equates to an average spacing of slightly more than 10 x 10 feet. Stocking levels of Atlantic white-cedar and pond pine were relatively similar between disked and nondisked plots, with Atlantic white-cedar and pond pine averaging 134 to 162 trees/acre, and 224 to 245 trees/acre, respectively (table 2).

After 2 years in the field, the only variable that significantly influenced tree height was species (table 1). Average total height of bald cypress, Atlantic white-cedar, and pond pine was 24.6, 11.6, and 13.1 inches, respectively. Average

Table 1—Analysis of variance for stocking levels (trees per acre) and height of Atlantic white-cedar, bald cypress, and pond pine in Block B6 after 2 years in the field

		Variable	
Source	*df*	Trees per acre	Height
Replication	4		
Treatments[a]	11		
Species = spec	2	**[b]	**
Site prep = site	1	NS	NS
Spacing = spac	1	**	NS
Spec x site	2	**	NS
Spec x spac	2	NS	NS
Site x spac	1	NS	NS
Spec x site x spac	2	NS	NS
Experimental error	44		
Pure error	60		
Corrected total	119		

[a] Site prep treatments were disking vs. undisturbed; spacings were 8 x 8 ft and 10 x 10 ft.

[b] Significant at P = 0.01(**), 0.05(*), or not significant (NS).

Table 2—Stocking levels of Atlantic white-cedar, bald cypress, and pond pine in Block B6 after two growing seasons, as affected by spacing and site prep treatment

	Species		
Treatment	Bald cypress	Atlantic white-cedar	Pond pine
	----------Trees per acre --------		
Spacing (ft)			
8 x 8	366[a]	186	265
	(25.9)	(21.9)	(18.9)
10 x 10	338	111	208
	(28.2)	(19.6)	(20.4)
Mean	352	148	237
	(19.0)	(15.7)	(14.5)
Site prep			
None	277[a]	162	245
	(22.1)	(23.4)	(19.0)
Disk	427	134	224
	(20.2)	(21.1)	(—)

[a] Mean of 10 plots (5 reps x 2 site prep treatments); s.e. of mean is given in parentheses.

height at planting was not determined, but bald cypress was initially much taller than the other two species. In addition, most trees were browsed during the first and second year despite the presence of a Gallagher electric fence. No stem diameters were measured in the 1996 inventory.

In general, it appeared that bald cypress was less severely browsed than Atlantic white-cedar and will likely outgrow the adverse influence of browsing. Most of the surviving Atlantic white-cedar were heavily browsed, and many plants might eventually succumb or never grow into good trees. On this site, we have concluded that achieving survival of Atlantic white-cedar commensurate with that of bald cypress will demand additional protection against deer, e.g., plastic or metal netting, sleeves, cages, or different types/configurations of electric fencing. Consequently, we are currently carrying out experiments at the site to evaluate various types of deer exclusion.

Nitrogen Analysis

Total Kjeldahl N (TKN), which includes organic N and ammonia, averaged 1.8 to 3.5 milligrams/liter in surface water (table 3). On occasions when NO_2-N was measured, the readings (3 decimal places) were zero milligrams/liter (data not shown). In addition, the concentration of NO_3-N never exceeded 0.02 milligrams/liter, and was usually $\leq$ 0.01 milligram/liter (table 3). NO_3-N was equivalent to approximately 1 percent of the TKN.

Ammonia in surface water ranged from 0.05 to 0.67 milligram/liter, but was mostly $\leq$ 0.2 mg/liter (table 3). The ammonia fraction in surface water was $\leq$10 percent except in July 1996 (22 percent).

TKN in surface water exiting the demonstration plot (1.8 to 3.5 milligrams/liter) is higher than levels recorded at the State downstream ambient water-quality monitoring station, which ranged from 0.5 to 1 milligram/liter in 1996 samples. The current level of TKN is only slightly less than levels reported by Environmental Science and Engineering, Inc. for this area in 1982, of 2 to 4.95 milligrams/liter. In contrast, nitrate/nitrite levels (< 0.01 milligram/liter) in surface water exiting the site were lower than those recorded at the ambient station, which ranged from 0.1 to 1.5 milligrams/liter.

We believe that the level of TKN can be reduced by raising water levels so that the peat is saturated during the winter and part of the growing season. Now that all tree planting and work requiring machinery on site have been completed, the water level can be elevated so that the site is wet enough to be delineated as a jurisdictional wetland, which requires that "the soil is saturated to the surface at some time during the growing season of the prevalent vegetation" (Environmental Laboratory 1987). We intend to maintain a covering of several inches of water over the peat from December through February and to inundate or saturate the site at or near the peat surface between 12.5 and 25 percent (30 to 60 days) of the growing season so that the area meets the hydrologic criteria for seasonably flooded wetlands (Tiner 1994). Our goal is to have water exiting the site no higher in concentration of total nitrogen than rainfall, which was approximately 1 milligram/liter in 1996.

Mercury Analysis

Mercury concentrations in unfiltered surface water at the demonstration site ranged from 5.7 to 255 parts per thousand (table 3). In both years, the only samples higher than the State standard of 12 parts per thousand were

Table 3—Nitrogen and mercury content of surface water, by date, from canals surrounding Block B6 on the Atlantic white-cedar wetlands restoration site

	Sampling date								
Source[a]	Jul 95	Oct 95	Dec 95	Apr 96	Jul 96	Oct 96	Dec 96	May 97	Jul 97
	Mg/liter								
TKN	—	3.5	2.3	1.8	3.3	2.3	2.2	2.2	2.4
NH4	—	0.17	0.09	0.05	0.67	0.16	0.12	0.08	[b]
NO3	[b]	—	—	—	[b]	[b]	0.02	0.01	0.01
	ppt								
Hg	11.5	8.4	255	6.9	9.1	5.7	22	7.6	9.1

[a] For 1995 and 1996, means for N were based on six or more sampling sites; means for Hg were based on duplicates from two sampling sites. In 1997, means for Hg were based on 6 sites.

[b] Content < 0.01 mg/liter.

taken in the winter, and all other samples were within the range of values reported for rainfall (National Atmospheric Deposition Program 1997). The high winter values could be caused by freezing and thawing an exposed layer of peat from December through February. In the future, a layer of several inches of water will be maintained over the peat in the winter to protect it from freezing.

1996 Demonstration site annual inputs and outputs for water, mercury and nitrogen (area = 640 acres or one square mile)

	Water (10^9 liters)	Mercury (grams)	Nitrogen (kilograms)
Inputs (precip.)	3.4	30	3.5 (10^3)
Banked in peat	—	2.25 (10^5)	3.7 (10^7)
Outputs:			
ET	2.0	—	—
Runoff	1.4	37	3.6 (10^3)

In this tabulation, evapo-transipiration (ET) was estimated as 59 percent of precipitation (Charles Daniel, personal communication), bulk density of peat as 0.37 grams/cubic centimeter, and nitrogen content of peat as 1.16 percent (Dolman and Buol 1967).

When peatlands are ditched, the water table is lowered, and the peat is aerated, which improves microbial activity and accelerates decomposition and nutrient release (Havisto and others 1988). To illustrate the magnitude of non-point pollution that could result from the decomposition of the peat layer, consider the following comparison. The City of Raleigh, NC discharges 2.26(10^6) liters/day (60 million gallons) of wastewater with a concentration limit for total nitrogen of 6.0 milligrams/liter resulting in a nitrogen discharge of 1,364 kilograms/day or 4.97(10^5) kilograms/year (1,100,000 pounds). The peat on the 640-acre demonstration plot contains an amount of stored nitrogen equal to 75 years of the City of Raleigh's wastewater discharge.

In 1996, the average concentration of mercury in rainfall at the demonstration area was 8.8 parts per thousand (National Atmospheric Deposition Program 1997). Total mercury occurs in concentrations of 83 parts per billion, approximately 9,000 times the concentration in rain, in the peat (Evans and others 1984). Similar (within one order of magnitude) concentrations of mercury are found in peat from other bogs in North America and Denmark (Casagrande and Erchull 1976, Daniels 1981, Madsen 1981, Glooschenko and Capoblanko 1982, Grigal and Nord 1983). Assuming a constant rate of atmospheric deposition (estimated at 9,677 nanograms/square meter, National Atmospheric Deposition Program 1997) and a peat depth of 2.4 meters (8 feet), about 7,500 years of rainfall would have to be filtered at 100 percent efficiency to produce the amount of mercury currently on the demonstration site. Net accretion of organic material is essential for a peat bog to perform its natural role, which benefits water quality. If ditched bogs are allowed to decompose, they can cause nutrient loading to coastal rivers and estuaries on par with the largest point-source discharges. Wetlands with deep organic soils can be either very good or very bad for surface-water quality depending on their condition. Restoration of hydrology and native plant communities in peat bogs is the catalyst that turns a debilitating environmental liability (drained decomposing peat bog polluting downstream coastal estuary) into a lucrative environmental asset (functional wetland with surface water discharges cleaner than rainwater).

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INFLUENCE OF STRATIFICATION, TEMPERATURE, AND LIGHT ON SEED GERMINATION OF SELECTED PROVENANCES OF ATLANTIC WHITE-CEDAR

Laura G. Jull and Frank A. Blazich[1]

Abstract—Seeds of six provenances (Escambia Co., AL; Santa Rosa Co., FL; Wayne Co., NC; Burlington Co., NJ; New London Co., CN; and Barnstable Co., MA) of Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) were stratified (moist-prechilled) for 0, 30, 60, or 90 days at 4 °C followed by germination at 25 °C or an 8/16 hour thermoperiod of 30 °/20 °C with daily photoperiods of 0 (total darkness), 1 or 24 hours. Alabama and Florida provenances required 30 days stratification, alternating temperatures of 30 °/ 20 °C and photoperiods ≥ 1 hour for maximum germination. In contrast, the North Carolina, New Jersey, Connecticut, and Massachusetts provenances required 30 days stratification, alternating temperatures of 30 °/20 °C and continuous light for maximum germination. However, if photoperiods were < 24 hours, stratification for 60 to 90 days was necessary to maximize germination. When averaged over all treatments, total germination for each provenance was greater at 30 °/20 °C than at 25 °C.

INTRODUCTION

Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) has a wide distribution, occurring in a narrow belt along the northeastern and southeastern coasts of the United States extending west to the Gulf Coast (Korstian and Brush 1931). This evergreen tree with highly prized wood also has the potential for wetlands reclamation, as an ornamental and Christmas tree, and as an understock to graft superior cultivars of other species of *Chamaecyparis* Spach. Throughout its range, natural stands of Atlantic white-cedar are diminishing rapidly. Acreage of white-cedar in North Carolina alone has declined by as much as 90 percent within the last 2 centuries (Frost 1987). White-cedar usually fails to regenerate naturally after logging when no measures are taken to control competing vegetation.

Due to extensive reclamation efforts, there is increasing demand for transplants of Atlantic white-cedar. However, little research has been reported on propagation and culture of the species. Therefore, the objectives of this research were to examine the influence of stratification (moist-prechilling), temperature, and light on seed germination of selected provenances of Atlantic white-cedar.

METHODS

Mature cones of six provenances (Escambia Co., AL; Santa Rosa Co., FL; Wayne Co., NC; Burlington Co., NJ; New London Co., CN; and Barnstable Co., MA) of Atlantic white-cedar were collected fall 1994 (Alabama, North Carolina, New Jersey, and Connecticut), winter 1995 (Massachusetts), or fall 1995 (Florida) from open pollinated trees. Cones were dried for 2 months, followed by seed extraction and storage in sealed glass bottles at 4 °C.

In July 1996, seeds were removed from storage and graded initially with the use of an air column (General Seed Blower-Model ER, Seedburo Intl. Equip. Co., Chicago, IL). Abnormal, damaged, undersized or discolored seeds and other large debris not eliminated by the air column were removed manually. Graded seeds selected for the research were firm with a dark brown color. Graded seeds of each provenance were then stratified for 0, 30, 60, or 90 days at 4 °C. Following stratification, seeds were sown in covered, 9 centimeter glass petri dishes containing two prewashed (rinsed) germination blotters moistened with tap water. Following placement of seeds in the dishes, half were designated for germination at 25 °C and the other half to be germinated at an 8/16 hour thermoperiod of 30 °/ 20 °C. All dishes were placed in double layer, black sateen cloth bags and the seeds allowed to imbibe overnight at 21 °C. The next day, bags were randomized within two growth chambers (C-chambers, Downs and Thomas 1991) set at the appropriate temperatures. Chamber temperatures varied within ± 0.5 °C of the set point.

Within each temperature regime, seeds were subjected daily to the following photoperiods with a photosynthetic photon flux (400-700 nanometers) of 34 μmoles/meter^2/sec provided by cool-white fluorescent lamps: 0 (total darkness), 1, or 24 hours. Light was measured at dish level with a cosine corrected LI-COR LI-185 quantum/ radiometer/photometer (LI-COR, Lincoln, NE). Photoperiod treatments were regulated by removal and placement of the petri dishes in black sateen cloth bags. Regardless of temperature, the 1 hour photoperiod was administered the same time each day, and for the alternating temperature of 30 °/20 °C, it began with the transition to the high temperature portion of the cycle. For the 24 hour photoperiod treatment, the petri dishes remained continuously unbagged in open chamber conditions. Temperatures in the petri dishes never deviated from ambient temperature by more than 1 °C as measured by a thermocouple. The constant darkness treatment was maintained by keeping the petri dishes in the black cloth

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bags throughout the duration of the experiment. Seeds maintained in darkness were examined under darkroom conditions utilizing a green safelight.

For each provenance and temperature, all photoperiod and stratification treatments were replicated four times. A replication for a provenance, with the exception of Massachusetts, consisted of a petri dish containing 100 seeds. A replication for the Massachusetts provenance utilized 40 seeds per dish. Germination counts were recorded every 3 days for 30 days. A seed was considered germinated when radicle emergence was ≥ 1 millimeter. Decayed seeds were removed promptly from the dishes.

Percent germination was calculated as a mean of four replications per treatment. Data were subjected to analysis of variance procedures and regression analysis.

RESULTS AND DISCUSSION

Stratification, temperature, and light had significant effects on seed germination of Atlantic white-cedar. However, responses to these factors varied according to provenance. Averaged over all treatments, the Alabama provenance exhibited the greatest germination (61 percent) followed by the Florida provenance (45 percent), with the remaining provenances ranging from 20-38 percent. However, there were specific treatments for each provenance that resulted in germination > 50 percent. Seed germination of various species of *Chamaecyparis* has been reported to be inherently low, due in part to poor seed quality and also to various degrees of embryo dormancy (Harris 1974).

Regardless of stratification, germination was generally lower at 25 °C than at 30 °/20 °C for each provenance (31 vs. 43 percent, respectively). However, germination was not significantly different between these two temperatures for four of the provenances (Connecticut, Massachusetts, New Jersey, and North Carolina) when germinated in the absence of light. Similarly, Bianchetti and others (1994) reported greater germination of stratified seeds of Atlantic white-cedar at an alternating temperature of 30 °/20 °C versus constant temperatures of 23 °C or 26 °C.

With regard to light, Little (1950) reported "a fair amount of light, probably to provide heat, is desirable for obtaining good seed germination of white-cedar." In the present study, seeds of the Alabama and Florida provenances of white-cedar did not exhibit an obligate light requirement. However, a daily photoperiod of 1 hour and 30 days stratification increased germination greatly in these provenances in comparison to stratified seeds germinated in darkness (48 vs. 76 percent) (fig. 1).

In contrast, the North Carolina, New Jersey, Connecticut, and Massachusetts provenances had an obligate light requirement. When subjected to continuous light, these provenances only required 30 days stratification for maximum germination. When subjected to a 1 hour

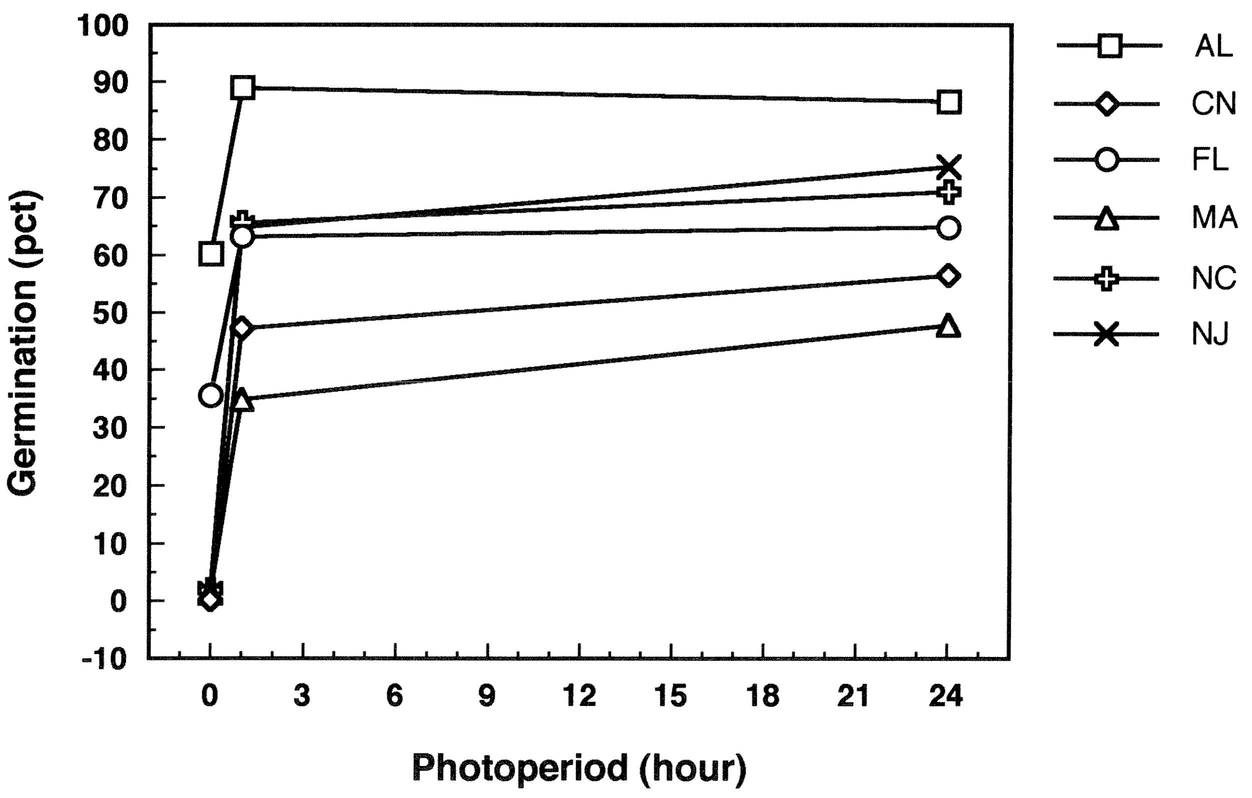

Figure 1—Seed germination of six provenances (listed by state) of Atlantic white cedar as influenced by photoperiod. Seeds were stratified for 30 days followed by germination at 30°/20 °C with daily photoperiods of 0 (total darkness), 1, or 24 hours.

photoperiod, seeds from these provenances required longer stratification times for maximum germination. Regardless of the length of stratification, the New Jersey provenance needed a 24 hour photoperiod to maximize germination (63 percent). This is similar to data reported by Boyle and Kuser (1994) where seeds of white-cedar from New Jersey provenances exhibited greater germination under a 16 hour photoperiod (32 percent) in comparison to negligible germination under a 10 hour photoperiod (0.7 percent).

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ATLANTIC WHITE CEDAR PLANTINGS IN ST. TAMMANY PARISH, LOUISIANA AND THE BOGUE CHITTO NATIONAL WILDLIFE REFUGE, MISSISSIPPI

John W. McCoy, Bobby D. Keeland, and James A. Allen[1]

Abstract—Populations of Atlantic white cedar (*Chamaecyparis thyoides* (L.) B.S.P.) growing at the extreme western range of the species are in danger of being lost, and information on the ecology of these populations is limited. Seeds and seedlings ("wildlings") were collected near Vancleave, MS. The wildlings were transplanted to bay-head sites on Bogue Chitto National Wildlife Refuge where canopy gaps had been created in early 1989. Seeds were germinated, grown in a greenhouse, and transplanted a year later to three locations within a slash pine plantation: a bedded and fertilized site, the margin of a cypress pond, and a wet gap, in St. Tammany Parish, Louisiana. These plantings were established to study survival and growth in different habitat types, to compare seedlings grown from seed versus transplanted wildlings, and to attempt to generate some interest in planting Atlantic white-cedar in the extreme western portion of its natural range.

Overall seedling survival averaged 94 percent after five growing seasons, although significant differences were detected among sites. Mean height per site in 1994 was significantly greater at the bedded and fertilized site (233 centimeters), and lowest at the slash pine site (91 centimeters). Growth at the cypress pond site was intermediate (158 centimeters). Wildlings at the bay-head sites had lower survival rates (75 and 64 percent), but average heights for the two sites were similar to those of the seedlings (265 and 165 centimeters). These results show that plantings involving either local seed or wildlings are viable choices for regenerating Atlantic white-cedar in southern Mississippi and eastern Louisiana.

INTRODUCTION

Atlantic white-cedar (*Chamaecyparis thyoides*(L.) B.S.P.) is a medium sized conifer in the Cupressaceae distributed in swamps and bogs along the Atlantic Coastal plain from Maine to Florida and west along the Gulf Coastal plain to Mississippi (Little 1971). Along the Gulf Coast, the main population consists of *Chamaecyparis thyoides* var. *henryae* and occurs in the panhandle of Florida and southern Alabama (Ward and Clewell 1989). Small scattered populations of *Chamaecyparis thyoides* var. *thyoides* also occur along creeks and in swamps, bay heads, and other wet areas in southern Mississippi. The few stands that remain are in danger of further degradation due to continued cutting, hydrologic modifications, and clearing for agriculture (Ehrenfeld 1990, Boyle and Kuser 1994).

Natural regeneration of Atlantic white-cedar may be limited by deer browsing, competition from hardwoods, and variable seed germination rates (Little 1950, Boyle and Kuser 1994). In addition, this shade-intolerant species needs disturbance to reestablish (Boyle and Kuser 1994). Because of the uncertainties of natural regeneration and concern over the ongoing losses, considerable interest in artificial regeneration of Atlantic white-cedar has developed in recent years, especially in the mid-Atlantic portion of its range. The potential for Atlantic white-cedar reforestation along the western extent of its range, however, has received little attention. This paper examines the potential for establishing Atlantic white-cedar stands in southern Mississippi and adjacent Louisiana. These plantings may produce populations capable of maintaining Atlantic white-cedar in the south-central United States. Specific objectives of this study were to establish stands in different habitat types, compare seedlings grown from seed versus wildlings (wild seedlings) transplanted in the field, and generate interest in planting Atlantic white-cedar in the extreme western portion of its natural range.

METHODS

Description of the Study Sites

The study was conducted in the lower Pearl River watershed at three sites on private land in eastern Louisiana and two gap sites on the Bogue Chitto National Wildlife Refuge (BCNWR) in southern Mississippi (fig. 1).

Three sites in St. Tammany Parish, Louisiana were located in a slash pine (*Pinus elliottii* Engelm.) plantation that included several wet areas supporting cypress stands and pitcher plant bogs. Most of the plantation had been cleared, bedded, and fertilized, and was supporting very young pine trees. Characteristic vegetation of the wetter areas of the plantation included woody species such as baldcypress (*Taxodium distichum* (L.) Rich.), pondcypress (*T. distichum* var. *nutans* (Ait.) Sweet), slash pine, sweetgum (*Liquidambar styraciflua* L.), wax myrtle (*Myrica cerifera* L.), blackberry (*Rubus louisianus* Berger), and catbrier (*Smilax laurifolia* L.), and herbaceous species such as pitcher plants (*Sarricinea* spp.), hatpins (*Eriocaulon* spp.), clubmoss (*Lycopodium* spp.), and sedges (*Carex* spp. and *Cyperus* spp.). Most of these species are

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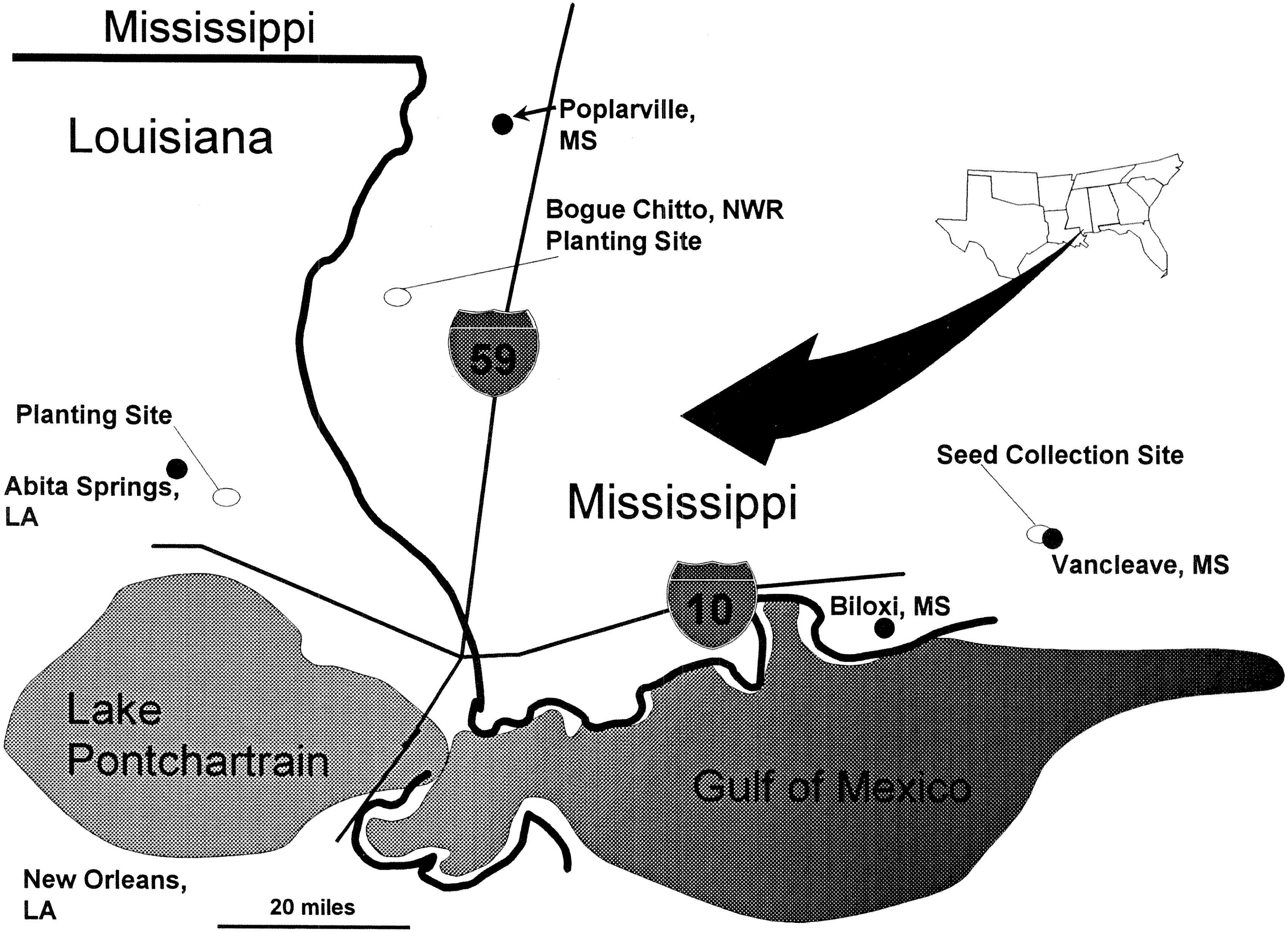

Figure 1—Location of the seed and wildling collection site near Van Cleave, MS and the planting sites near Abita Springs, LA and Poplarville, MS.

common on sites throughout the range of Atlantic white-cedar (Laderman 1989). Two sites were located in open areas too wet to permit slash pine survival. These include a site on the edge of a pond dominated by cypress (POND site) and a wet gap where planted pines did not survive (PINE site). The third site (B&F) was an area adjacent to the POND site that had been freshly cleared, bedded and fertilized for planting slash pine.

The two BCNWR sites were located in seeps that lie along the sides of gently sloping and wooded bay heads. These sites are characterized by a closed canopy of black gum (*Nyssa sylvatica* Marsh.), sweetbay magnolia (*Magnolia virginiana* L.), and other hardwood tree species similar to the Louisiana sites. At each of the two BCNWR sites, a small canopy gap (less than 200 m^2) was created to provide light and reduce competition for the wildlings. These sites were referred to as Wildling1 and Wildling2.

Field Methods

Source material was collected from a natural Atlantic white-cedar stand near Van Cleave, MS during December, 1988. Seed was collected from mature trees. Thirty wildlings were taken from a nearby site and transplanted onto the BCNWR sites during January 1989, about a month after being removed from their original germination sites. Wildlings were planted irregularly within the created gaps.

The collected seeds were stratified, germinated, and grown in a greenhouse before being transplanted to the field sites during March, 1990. A total of 290 seedlings was transplanted to the three sites in St. Tammany Parish, Louisiana. All seedlings, including those at the bay head sites on BCNWR, were measured for height (to the nearest centimeter) at the time of planting.

Height was remeasured in 1990, 1991, and 1994. The PINE site was also remeasured during the growing season of 1997. Diameters at 140 centimeters were measured to the nearest millimeter with a micrometer.

Statistical Analysis

Differences in the height growth among sites were tested using SAS procedure GLM and the REGWF test (SAS Institute, Inc. 1988).

RESULTS AND DISCUSSION

Survival Rates

Survival was excellent for seedlings planted in Louisiana, with an average of 94 percent survival by the end of the 1994 growing season (fig. 2). Trees at the POND site had the highest survival (98 percent) while the PINE site had the lowest (89 percent). By the middle of the 1997 growing season, survival of trees at the PINE had dropped to 87

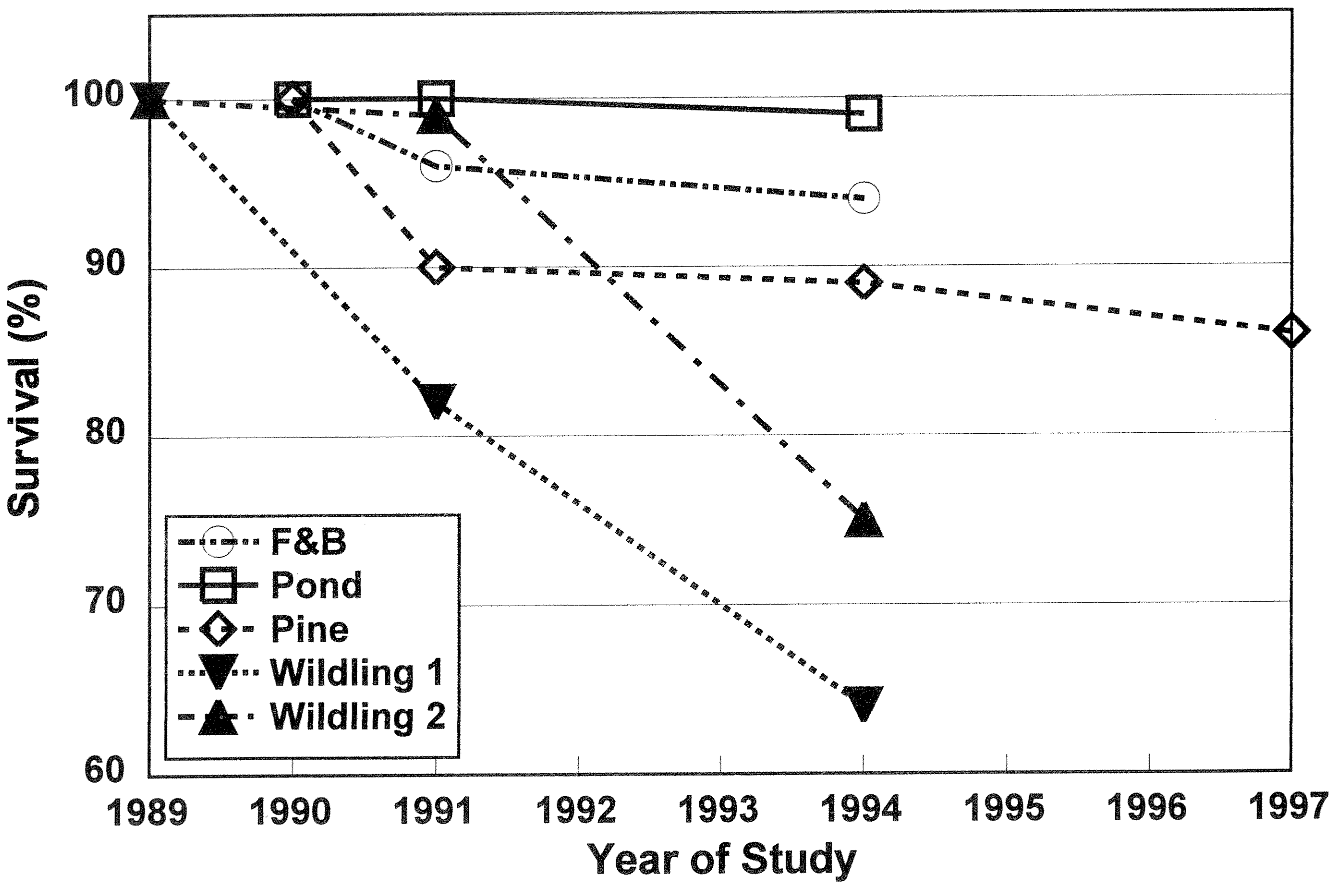

Figure 2—Seedling and wildling survival rates at each of the five study sites. See text for study site designations.

percent. The overall high survival of the trees may have been a result of several factors. The propagules (seed and wildlings) were obtained from a source only about 80 kilometers distant, suggesting adaptations to macro-climate conditions similar to those at the study sites. The openness of the Louisiana study sites, the recent bedding and fertilizing of the B&F site, and the high water table at all sites provided conditions well suited for Atlantic white-cedar survival and growth.

The transplanted wildlings at the Mississippi bay-head sites had lower survival rates when compared with the seedlings planted in Louisiana. Survival at the Wildling1 site began to drop off early and continued dropping to a low of 64 percent by the end of the 1994 growing season. At the Wildling2 site survival was high through 1991 and then dropped off dramatically to a low of 75 percent. Conditions at the wildling sites were less appropriate because of lower light levels caused by the surrounding canopy. Atlantic white-cedar has been shown to be shade intolerant and seedlings require open conditions and intermediate moisture conditions for survival (Laderman 1989). In addition, the transplant shock of removing these seedlings from a natural setting, maintaining them in a greenhouse for approximately one month, then transplanting them into a new site may have resulted in higher mortality than observed at the Louisiana sites where seedlings were transplanted with their complete root systems intact. Direct comparisons of survival or growth between seedlings and wildlings must be taken with caution. Site conditions in Louisiana versus Mississippi may have been different enough to have caused the observed differences, and no sites were planted to both seedlings and wildlings.

Height Growth

In 1994 there were significant differences in height growth among sites (fig. 3) and high variation within sites (table 1). Significantly greater growth was observed at the Wildling2 and B&F sites (average height 265 and 234 centimeters, respectively; $P<0.0001$). Growth at the Wildling1 and POND sites had intermediate growth of 163 and 158 centimeters, respectively. The lowest growth in 1994 was observed at the PINE site where height averaged only 91 centimeters. By the 1997 growing season, however, saplings at the PINE site had grown to an average height of 250 centimeters.

The Louisiana planting sites may have had good growth due to the recent clearing (in preparation for the slash pine plantation) of the site, fertilization, and an abundant supply of water. Although there was little variation in seedling heights at the time of planting, variability increased dramatically by the end of the 1994 growing season (table 1). Part of the variation may have been related to elevated

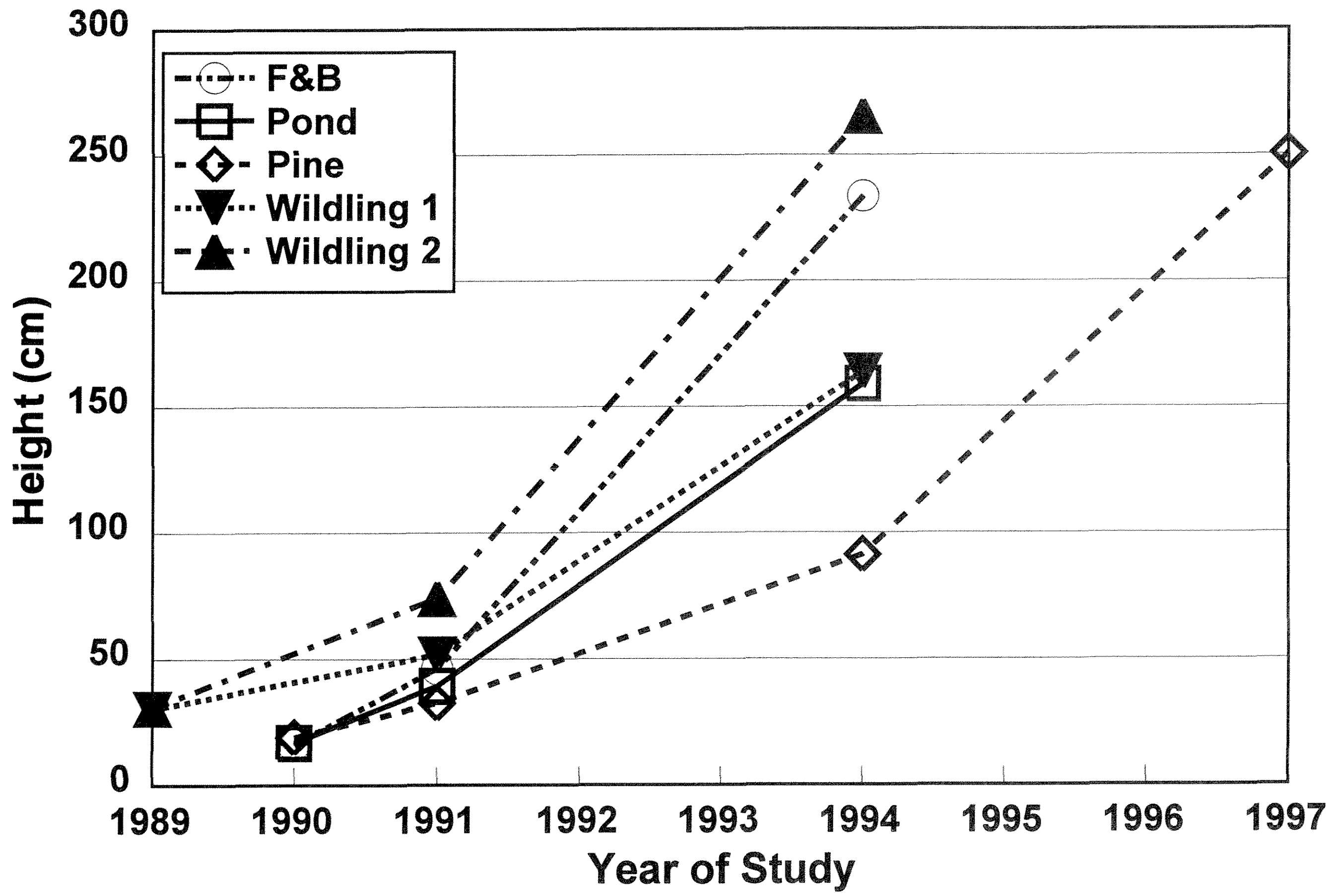

Figure 3—Cumulative height growth of Atlantic white-cedar seedlings and wildlings at each of the five study sites.

Table 1—Heights and diameters of Atlantic white-cedar on the five sites

Site	Year	Height N	Height Mean	Height STD	Diameter N	Diameter Mean	Diameter STD
		- - - - - - - - - - - - -	cm	- - - - - - - - - - - - -			
F & B	1990	156	16.1	3.2	—	—	—
	1991	150	46.2	11.6	—	—	—
	1994	148	233.5	63.4	137	1.58	0.96
PINE	1990	89	19.1	3.4	—	—	—
	1991	81	32.5	5.8	—	—	—
	1994	80	91.2	34.8	—	—	—
	1997	77	250.4	59.2	75	2.02	1.24
POND	1990	44	16.8	3.7	—	—	—
	1991	44	39.2	8.3	—	—	—
	1994	43	158.4	49.2	27	0.70	0.51
Wildling1	1989	11	30.3	17.2	—	—	—
	1991	9	51.7	39.7	—	—	—
	1994	7	163.8	82.5	5	1.70	0.99
Wildling2	1989	16	30.6	11.5	—	—	—
	1991	15	73.9	29.8	—	—	—
	1994	12	265.3	60.8	12	1.55	0.83

areas such as bedding strips that appeared to enhance growth. At the PINE site, where growth was lowest, saplings on the elevated bedding strips achieved 278 centimeters of height growth by the 1997 season, whereas growth on the low ground between bedding strips was only 223 centimeters. Huenneke and Sharitz (1986), Titus (1990), and Ehrenfeld (1995) have shown that microtopographic relief provides safe sites for the establishment and growth of many wetland plant species, including Atlantic white-cedar.

In comparison with other tree species (fig. 4), Atlantic white-cedar was found to be relatively slow growing. Slash pine seedlings, even on sites with a relatively poor site index, can achieve about 6 meters of growth by the eleventh year (USFS 1976). Baldcypress seedlings at Lake Chicot, LA (B.D. Keeland and W.H. Conner, unpublished data) grew to an average height of only 4.75 meters in the same amount of time. Based on the average heights in 1990, 1991 and 1994 for all Atlantic white-cedar seedlings planted in Louisiana, growth by year 11 would be about 4.25 meters (fig. 4).

A potential problem for the Atlantic white-cedar saplings at the Louisiana sites was the heavy growth of catbrier. This

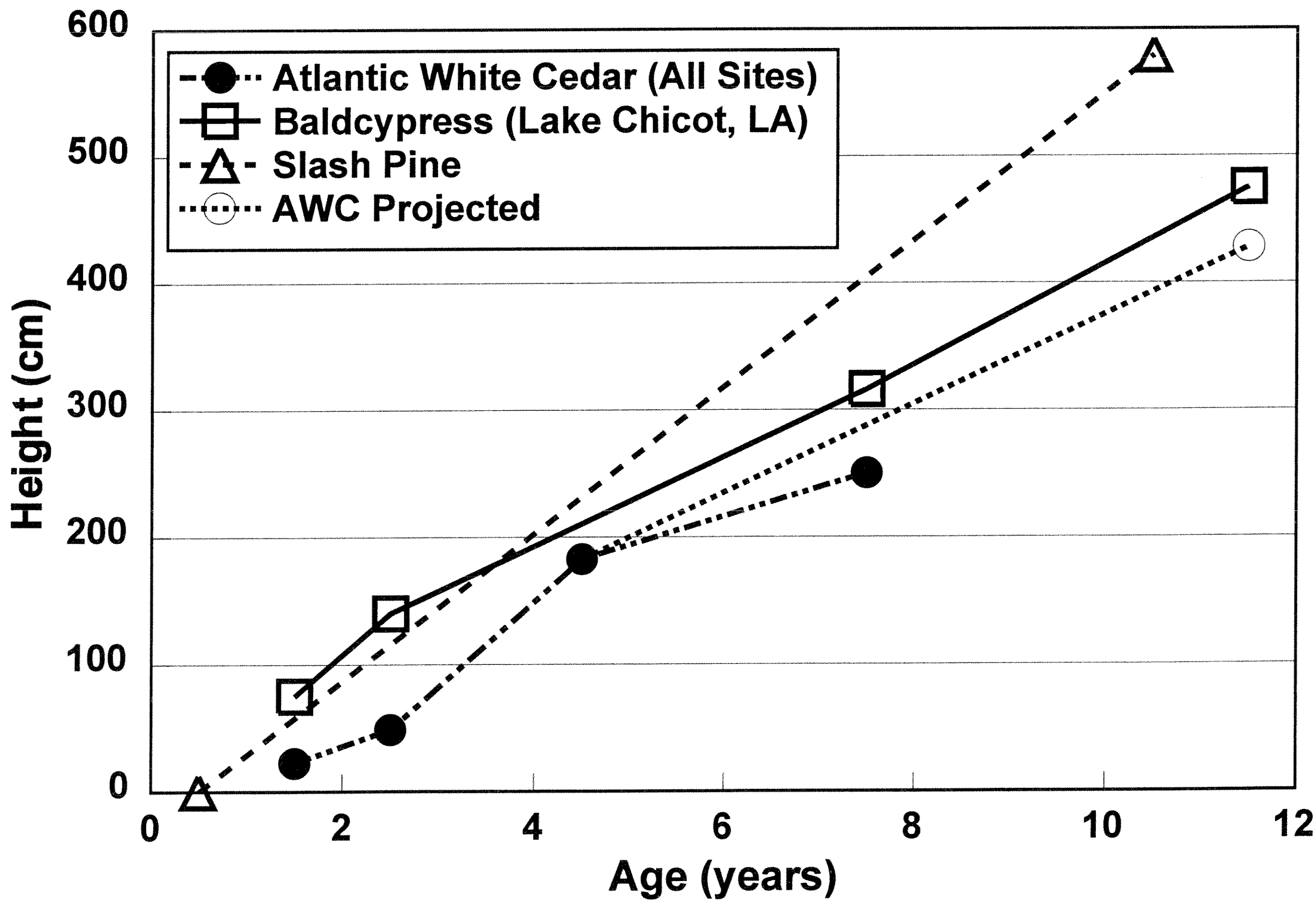

Figure 4—Growth comparison for Atlantic white-cedar, baldcypress, and slash pine. Growth of Atlantic white-cedar was projected through year 11 using regression analysis. The year seven value shown on the figure for saplings measured in this study were not included in the regression as they were from the site that had the lowest growth measured, and therefore were not considered representative of the entire population.

woody vine can compete with saplings by growing over them and shading them. The weight of the vines may also cause the loss of limbs or even the stem during storms. Although we noted the vine climbing onto the Atlantic white-cedar saplings, the vines were not disturbed or removed during measurements. It is of interest in this study to learn how successfully saplings can compete with vines in a semi-natural setting.

Cones were observed on several 8-year-old saplings at the PINE site in 1997. Little (1950) reported the onset of cone-bearing in natural stands of cedar in as little as seven years, and for a nursery grown field transplants in as little as three years after germination. Although the number of cones was small, it is possible that these trees are now providing propagules that could continue or expand the stands originally planted. As the trees mature, the number and quality of seeds will increase. The first seed crops of a tree have a lower average germination rate than later production (Laderman 1989).

Diameter Growth

Diameter measurements were begun in 1994, when a substantial proportion (73 percent) of the trees were greater than 1.4 meters in height. Mean diameters in 1994 were less than 2 centimeters (table 1). Diameters were highly variable, however, and the average for the trees of greater than average height was 1.8 centimeters (for all measured sites combined).

CONCLUSIONS

Atlantic white-cedar is native to southern Mississippi and has been specifically noted in both Jackson and Pearl River counties (Laderman 1989). Although the species has not been noted in natural stands in Louisiana, the proximity of the Mississippi stands suggests that the current or past presence of this species is probable (Brown 1964). The number of individual trees and populations of Atlantic white-cedar are small, adding to the problem of maintaining a viable population. Because most of the cedar stands along the Mississippi Gulf coast are on private lands, they are unprotected and subject to disturbance through land development. Although Atlantic white-cedar is a tree of high commercial value (Ward 1989), the small volume available in Mississippi is generally not sufficient to generate a strong market. As such, the existing stands are largely ignored and occasionally lost through land conversion and hydrologic alterations. Ehrenfeld and Schneider (1991) showed that as the level of urbanization increased, reproduction of cedar decreased significantly.

Due to variable seed viability (Boyle and Kuser 1994), stringent habitat requirements, and limited ability for seed dissemination, Atlantic white-cedar does not easily become established naturally. This study has shown, however, that it is possible to establish viable populations of Atlantic white-cedar in Louisiana and Mississippi through planting of either nursery grown seedlings or wildlings collected in the field. Planted seedlings experience high survival rates and show good growth in this area. Such stands are needed on protected property to insure the long-term viability of Atlantic white-cedar populations along the Gulf Coast of the United States.

ACKNOWLEDGMENTS

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RESTORATION OF AN ATLANTIC WHITE-CEDAR FOREST ECOSYSTEM AT DARE COUNTY AIR FORCE RANGE, NORTH CAROLINA

Scott B. Smith[1]

Abstract—In 1992 the U.S. Department of Defense Legacy Resource Management Program provided initial funding to restore approximately 3,000 acres of Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) ecosystem. Prior to Air Force ownership, the forest had been clearcut during a twenty-year period and left in a severely altered condition. The U.S. Air Force formed a collaborative partnership with the Alligator River National Wildlife Refuge, North Carolina Division of Forest Resources, and North Carolina State University. Representatives from these agencies organized a steering committee and developed a strategic plan to accomplish the following: inventory cutover and remnant forest stands, promote and enhance natural regeneration, develop seed and seedling sources, develop and implement artificial regeneration methods, restore previously high-graded stands, implement a geographic information system and differential global positioning system, and establish water control and management to restore a more natural hydrologic regime.

INTRODUCTION

Dare County Air Force Range was established in northeastern North Carolina in 1964. The Range is situated on a peninsula bordered by the Alligator River, Pamlico Sound, and Croatan Sound. It provides bombing and gunnery training for fighter pilots in the U.S. Air Force, Navy, Marine Corps, and Air National Guard. Ordinance delivery and strafing are restricted to two impact areas; each area is approximately 2,500 acres in size.

The balance of 42,000 acres is managed under ecosystem management principles in conjunction with multiple-use and sustained yield policies. These buffer lands are made up of swamp forests, pocosins, and freshwater and saltwater marshes. The Range is completely surrounded by the Alligator River National Wildlife Refuge which is administered by the U.S. Fish and Wildlife Service. Featured plant communities include Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) and old-growth pond pine *(Pinus serotina)* forests. Protected animal species include the red cockaded woodpecker, red wolf, American alligator, and black bear.

The Dare County peninsula has a long history of timber management. Dare Lumber Company harvested Atlantic white-cedar from 1885 until 1930. West Virginia Pulp and Paper Company managed their forest resources from 1950 to 1975, during which time extensive road and canal systems were established. Mac Millan Bloedell Inc. harvested Atlantic white-cedar from 1975 to 1985. Alligator Timber Company continued harvesting Atlantic white-cedar from 1985 to 1989. The Air Force purchased all available timber rights on Dare County Range in 1981 which included extensive tracts of Atlantic white-cedar forest in cutover condition. The Air Force started a natural resources management program at the Range in 1985.

In 1992 the Department of Defense Legacy Resource Management Program provided the only means available to initiate restoration of the severely altered Atlantic white-cedar ecosystem. Genetic and species preservation, enhanced biological diversity, wetland restoration, and increased aesthetic considerations are far-reaching benefits to be gained from this project. Thus far, the Legacy program has provided more than one million dollars for this effort. The Air Force Air Combat Command provided additional funding from the Conservation and Forestry programs. The U.S. Fish and Wildlife Service and the North Carolina Division of Forest Resources have also contributed substantial funds and expertise towards this project.

The U.S. Air Force formed a collaborative partnership with the Alligator River National Wildlife Refuge, North Carolina Division of Forest Resources, and North Carolina State University. Representatives from these agencies formed a steering committee chaired by the Dare County Range forester, and adopted a strategic plan. A basic premise of the committee was to fund only those activities that would result in Atlantic white-cedar establishment and production. Elements of the strategic plan include:

1. Research the local area's silvicultural history
2. Review available literature on Atlantic white-cedar
3. Inventory cutover areas for natural regeneration
4. Inventory remnant Atlantic white-cedar stands
5. Promote and enhance natural regeneration
6. Develop seed and seedling sources
7. Develop and implement artificial regeneration methods
8. Restore previously high-graded stands
9. Implement a geographic information system
10. Establish a differential global positioning system
11. Establish water control and management to restore hydrology
12. Repair roads for access

Interagency partnerships are dynamic by nature. They require formulating common goals and long-range planning to address inherent differences in policy,

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procedures, and work loads. In the case of Atlantic white-cedar restoration, regularly scheduled meetings have been effective in addressing issues related to contractual procedures, administrative charges, funding procedures, and fiscal schedules between federal and state governments. A continual, open dialogue has helped to avoid problems and formulate solutions.

An initial objective was to contract an inventory of the nearly contiguous 3,000 acres of cutover tracts to determine success or failure of natural regeneration and the level of competing undesirable plant species. The project area is shared by the Dare County Range and Alligator River National Wildlife Refuge and is almost equally divided by their common boundary. Bids received from prospective contractors ranged from 100,000 to 2 million dollars. After reviewing the proposals, the steering committee decided to use Refuge personnel and temporary hires to accomplish the inventory. In addition a forestry consultant firm was contracted to inventory 1,400 acres of remnant mature Atlantic white-cedar stands on the Range. Refuge staff will inventory remnant stands on Alligator River National Wildlife Refuge.

In a preliminary experiment, areas with a sufficient number of Atlantic white-cedar seedlings (600 stems per acre and greater) were treated with herbicide to release the seedlings from overtopping vegetation. Wax myrtle and gallberry shrubs were the most difficult of the competing plant species to control because of the waxy cuticle covering their leaves. The herbicide Arsenal proved to be the most effective on these plants. Working with representatives from American Cyanamid, Dare County Range was one of three test sites in an effort to add release of Atlantic white-cedar to the Arsenal label. The success of the test at the Range led the Environmental Protection Agency to approve the new label in August of 1995.

Legacy funding was also provided to Mr. Lenwood Smith, a graduate student from North Carolina State University, to investigate the interrelationships and effects of soil type, time of year harvest, and subsequent site conditions on natural regeneration of Atlantic white-cedar. Mr. Smith's thesis was completed in 1995 and concluded that overall, regeneration was found to be more probable on Belhaven and Pungo muck soil types logged in the winter. Soil acidity and percent base saturation were also found to be good indicators of Atlantic white-cedar trees or saplings in both soil types. Hydrology appeared to be more critical to Atlantic white-cedar success on Pungo muck soils where different sediment deposits are found beneath the organic layer than on Belhaven soil. General observations indicated that the presence of *Sphagnum* moss could be linked to the success of Atlantic white-cedar and microrelief also appears to play an important role in Atlantic white-cedar success.

Innovative logging methods are being tested in an effort to minimize soil disturbance during harvest operations. Approximately 70 acres of mature (60 years old or older) Atlantic white-cedar has been successfully, naturally regenerated using clearcut harvesting. A seed-tree regeneration harvest of 20 acres is planned for 1997. One harvesting method involves placing the harvester on mats and installing dual wheels with large rubber tires on front and back axles of conventional rubber-tire skidders. An extraction method effective in reducing soil disturbance and rutting involves constructing corduroy skid trails from timber and logging slash. However, some rutting is desirable; it provides microtopography that enhances seed germination and establishment. Merchantable timber from the corduroy skid trails is extracted upon completion of the harvest operation.

In the beginning, the most limiting factor we faced in our efforts to restore previously high-graded timber stands was the lack of available seedlings. Production of Atlantic white-cedar seedlings was last attempted by West Virginia Pulp and Paper Company in the mid-to-late 1950's. Weyerhaeuser Corporation successfully initiated the propagation of containerized rooted cuttings. The North Carolina Division of Forest Resources began producing seedlings from seed in 1994, but not in large quantities due to the limited seed supply. Thus far, 90 acres have been hand planted with survival rates above 95 percent.

The Legacy project funded several U.S. Forest Service projects in 1993. The experiments were conducted at the Southern Forest Experiment Station. Improved techniques were developed for extracting, cleaning, germinating, testing, and storing seeds. Soil seed bank tests indicate that Atlantic white-cedar seed is viable for at least three years. Preliminary results from a tetrazolium test indicate that trees with adequate cross pollination can yield viable seed at 6 years of age.

The Legacy project also funded several North Carolina Division of Forest Resources research projects. In 1993 the North Carolina Division of Forest Resources established a provenance study plot at Dare County Range. This study will determine genetic variation of growth, wood structure, and aromatic oil content of trees within local seed sources and between different soil types across the coastal plain of North Carolina. Seedlings were grown from seed extracted from five high quality trees which exhibited superior growth characteristics on the Range. The containerized seedlings were planted in peat soil. Other soil types included in the concurrent studies are wet mineral and stream floodplain. A solar powered electric fence was required to protect the young seedlings from deer browsing for the first 4 years. Seedlings also experienced browsing by rabbits. On the contrary, little to no browsing was observed in the naturally seeded or hand planted tracts.

The North Carolina Division of Forest Resources is conducting two studies related to nursery production of Atlantic white-cedar. One involves monitoring the effects of soil temperature and sunlight intensity to determine the best cultural practice and soil treatment to enhance seed germination and subsequent growth for bare-root seedling production. The other is a seedling standard evaluation study which will provide information to help guide decisions made by the nursery staff on what is considered to be an acceptable bare root-seedling for distribution.

Several methods of site preparation in organic soils are being evaluated. These include mowing, roller drum chopping, sheering and piling, herbicide applications, and a combination of herbicide and burning. Mowing was determined to be too costly. Physical limitations associated with heavy equipment pulling a roller drum chopper over saturated organic muck soil proved to be too difficult to overcome. The other four methods will be attempted in future years.

A hydrology study scheduled to begin in 1998 is designed to restore a more natural hydrologic regime to the 3,000 acres of wetlands that were altered by past logging practices. The network of roads and canals constructed to access timber resources function like dams. They impede sheet flow and impound water, resulting in water stagnation and conversion of forested wetland habitat. This project will result in improved water circulation, hydrologic regimes, and water quality, thereby improving the growing conditions for Atlantic white-cedar forests.

The Range and Refuge staffs are working together to develop a geographic information system using MapInfo software. A global positioning system base station has been established to provide accurate maps using differential correction software. This element has augmented partnership opportunities through sharing digital databases, equipment, expertise, and volunteer services.

Final analysis shows that the Department of Defense Legacy Resource Management Program project is a public relations success for the Air Force and all partners involved. New information is being discovered that will lead to the recovery and management of the Atlantic white-cedar forest ecosystem.

THE PENN SWAMP EXPERIMENTS: AN OVERVIEW

George Zimmermann, Raymond Mueller, John Brown, Kyle Peer, Sandra Shapiro, Kristin Mylecraine, Christopher Barber, Jeff Cherpika, and Thomas Venafro[1]

Abstract—Penn Swamp is a 55 hectare Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) swamp located in Wharton State Forest in southern New Jersey. Starting in 1989 and ending in 1995, a series of studies were conducted at Penn Swamp, the longest of which was conducted on a clearcut within the swamp. This experiment evaluated deer impact and logging slash effects on Atlantic white-cedar regeneration and vegetation in general. Due to space constraints only a few highlights of the regeneration experiment are presented here. Other studies conducted at Penn Swamp include histosol mapping and sampling, and cover type analysis of aerial photos over a 46-year period.

Results from these studies show a very significant negative impact of white-tailed deer on Atlantic white-cedar regeneration. Maximum histosol depth in the clearcut was 190 centimeters, and mapping revealed an old stream channel. Radiocarbon dating show the deepest histosols formed 9,980 years ago (± 210 YBP). Charcoal layers indicate fire was a force in at least the first few thousand years of histosol genesis. Histosol depositions measured in two of the five cores sampled were 1 centimeter/53.6 years and 1 centimeter/70.6 years. Aerial photo analyses show a dynamic swamp with windthrow events being a significant force on some parts of the swamp.

These data indicate a dynamic forest, which is an amalgam of mixed age groups, influenced by multiple factors including white-tailed deer populations, cutting, logging slash, fire, and windthrow.

INTRODUCTION

Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) forests in the United States have undergone dramatic reductions in acreage since European settlement (Vermeule and Pinchot 1900, Little 1950). Atlantic white-cedar stands that remain in New Jersey are mostly small patches, with few large stands (40 hectares or more) remaining (Zampella 1987). It is important to understand the forces that affect Atlantic white-cedar forest development and composition in order to maintain and enhance the presence of this important wetland community.

Penn Swamp is a 55-hectare stand composed mostly of Atlantic white-cedar and is found in Wharton State Forest in southern New Jersey's Pine Barrens. In the late 1980's a decision was made by state foresters to harvest 3.4 hectares of the swamp (fig. 1). We started a regeneration experiment to study deer and logging slash effects in the clearcut. We also conducted additional studies at Penn Swamp of its history and dynamics.

METHODOLOGY

Histosol Sampling

To map histosol thickness, depths were determined at 10-meter intervals across most of the cleared area. To map the edges of the clearcut's underlying histosols, sampling was done at 5-meter intervals around the margins. Histosol thickness was determined by pushing a steel rod into the histosol and both feeling and hearing a change as the rod entered the mineral layer. Tests of depths next to open soil pits showed this method to be accurate.

In 1994 a transect was surveyed in the clearcut and 5 cores of the histosols taken to the mineral soil at each location (fig. 2). The peat cores were 2 inches in diameter. On two of the cores (numbers 2 and 4), a histosol sample was carefully taken from the bottom and sent to an independent laboratory (Beta Analytical, Inc.) for radiocarbon dating. In addition, the bottom 44 centimeters of core 4, and bottom 16 centimeters of core 3 were divided into consecutive two-centimeter sections and examined for evidence of charcoal. The other cores were too fragmented to reconstruct for this part of the experiment.

Aerial Photographic and GIS Analysis

During 1992 and 1993 an analysis of Penn Swamp aerial photography was done. Aerial photographs from 1940, 1962, 1974, and 1986 were geo-referenced and overlays of cover type delineated. Aerial-photo and wetland specialists at the New Jersey Department of Environmental Protection (NJDEP) helped verify the aerial photo signatures. Ground verification was used when appropriate. All data were input and analyzed using the ARC/INFO (Environmental Systems Research Institute, Inc.) geographic information system (GIS).

Regeneration Experiment

A Latin-square design was used and was replicated inside and outside a 10-foot-high fence designed to protect a part of the clearcut (fig. 1). Vegetation was measured by species and height class each year for 5 years after the clearcut.

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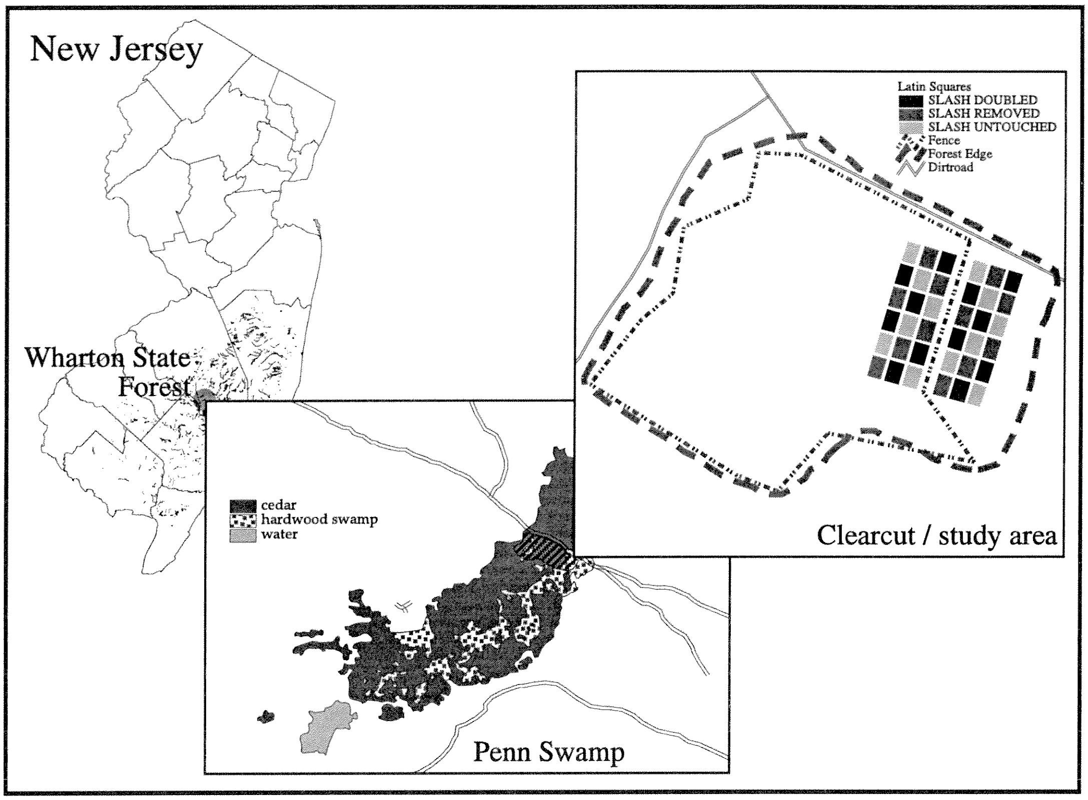

Figure 1—Location of Penn Swamp and the clearcut/study area design.

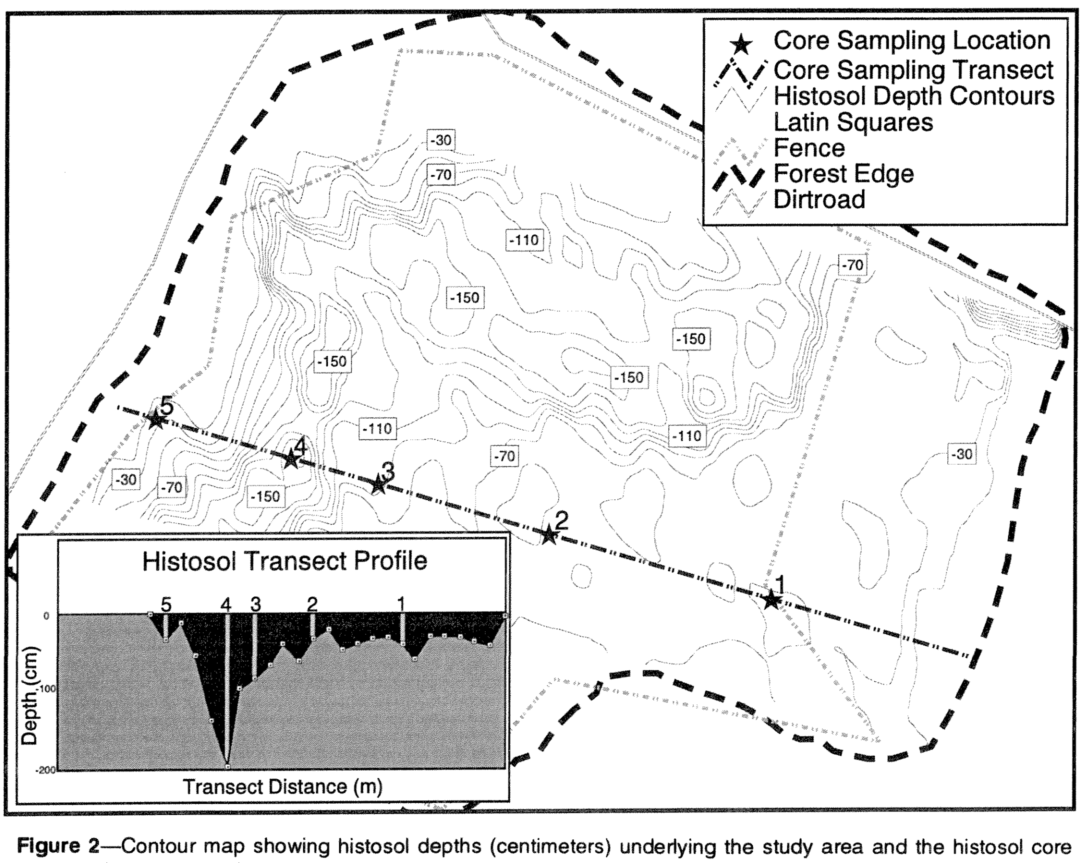

Figure 2—Contour map showing histosol depths (centimeters) underlying the study area and the histosol core transect. Inset shows histosol core locations and depth profile along the sampling transect.

Other parameters measured were percent ground cover and downed debris.

RESULTS AND DISCUSSION

Histosols

Within the Penn Swamp clearcut area the soil characteristics are those of a Typic rather than Terric subgroup of histosols (USDA 1977). The thickness of the histosol varied greatly, ranging from near zero along the margins to a maximum depth of 193 centimeters. Soil pits showed that there was an abrupt contact between organic matter and the underlying mineral substrate.

A map of the histosol thickness (or depth to mineral layer) showed the presence of an infilled stream channel. The channel has a meandering pattern with steeper slopes on the outside of the meanders (fig. 2). The modern stream flows entirely within organic matter and corresponds with the buried channel only in the western part of the research area.

In nearby study areas, Buell (1970) found that conditions favorable to bog formation were not present until approximately 11,000 years before present (YBP). Prior to that, the increased precipitation of the Wisconsin glacial period combined with increased stream gradients produced by lower sea levels led to erosion as well as valley widening and incision. As sea levels rose and precipitation declined, Pine Barren streams flowed slower, and organic matter began to accumulate. Basal organic matter from the Buell study (1970) had radiocarbon dates of 9,125 $\pm$ 195 and 10,485 $\pm$ 240 YBP. Our sample from the old buried channel (core 4, depth = 186 cm) had a radiocarbon date of 9,980 $\pm$ 210 years while our second sample out of the channel (core 2, 40 cm depth) had a date of 3,250 $\pm$ 140 YBP. These correspond to histosol deposition rates of 1 centimeter/53.6 years and 1 centimeter/70.6 years, respectively. These rates are within the deposition rates found by Buell (1970).

Analyses of 2-centimeter segments for charcoal conducted on the intact continuous core pieces showed 18 of the 30 samples to contain charcoal. These samples came from the bottom of two cores (186 cm and 46 cm deep) indicating that fire was a force in the first few thousand years of Penn Swamp's histosol formation. Penn Swamp is in the New Jersey Pine Barrens and thus has a higher fire probability than most if not all Atlantic white-cedar in the East (Forman and Boerner 1981). Little (1979) points out the wide range of effects fire can have on cedar swamps, depending on the parameters of the burn. Even outside the Pine Barrens, researchers have found fire to be the dominant force in pre-settlement Atlantic white-cedar forests (Motzkin and others 1993).

Aerial Photographic and GIS Analysis

Figure 3 shows the vegetation patterns determined from four aerial-photo interpretations of Penn Swamp during a 46-year period. Even in this relatively brief period of time, the dynamics of the swamp are evident. The Penn Swamp seen in 1940 has at least two age classes discernible. We noted that the older cedar were in the more inaccessible (interior) and wetter (southwest) areas where logging would be more difficult. Young cedar comprised 25 percent of the stand area in 1940 and dropped to almost zero as the Atlantic white-cedar matured and reached the upper canopy. Coring of cedar trees at Penn Swamp and aging stumps in the clearcut show Penn Swamp to be a mosaic of multi-aged cedar. The ages found (not including the current cohorts from the recent clearcut) ranged from 28 to 130 years old. By 1962 a number of gaps had formed (since the 1940 photo). Field inspection of some of these gaps in 1993 found numerous intact Atlantic white-cedar blown down from some meteorological event that occurred between 1940 and the 1962 photo. Some of these gaps were regenerating to Atlantic white-cedar, while others were dominated by swamp hardwoods and/or shrubs and other herbaceous species. The 1974 photo shows enlargement and consolidation of some gaps formed before 1962. Emergent meadows decreased in area from 1974 to 1986 (10.4 percent of the swamp area to near 0 percent) while hardwood swamps increased during the same time (0.7 to 7.9 percent).

Regeneration

The regeneration data collected over the five-year study show dramatic effects of white-tailed deer on Atlantic white-cedar, with no cedar growing to 1.3 meters outside the protection of the deer fence. This is consistent with the literature in the Pine Barrens as well as in the East (Little 1958, Marquis 1974). Not all species were negatively impacted by deer (these data to be published elsewhere). The effects of logging slash on Atlantic white-cedar and other species, when analyzed by species and height class, present a complex picture that does not fully agree with published literature (Korstian and Brush 1931, Little 1950). These results, once again, are too complex to present in this limited space.

CONCLUSIONS

It is apparent from this study that Penn Swamp is a very dynamic site in both short- and long-term time scales. Because stands of this size are relatively rare, their management must take into account all forces that influence them and recognize the resulting spatial heterogeneity. The short- and long-term factors that have impacted Penn Swamp include fire, windthrow, cutting, and deer. The white-tailed deer is currently the largest single factor preventing this and many other Atlantic white-cedar stands in New Jersey from regenerating and maintaining their composition.

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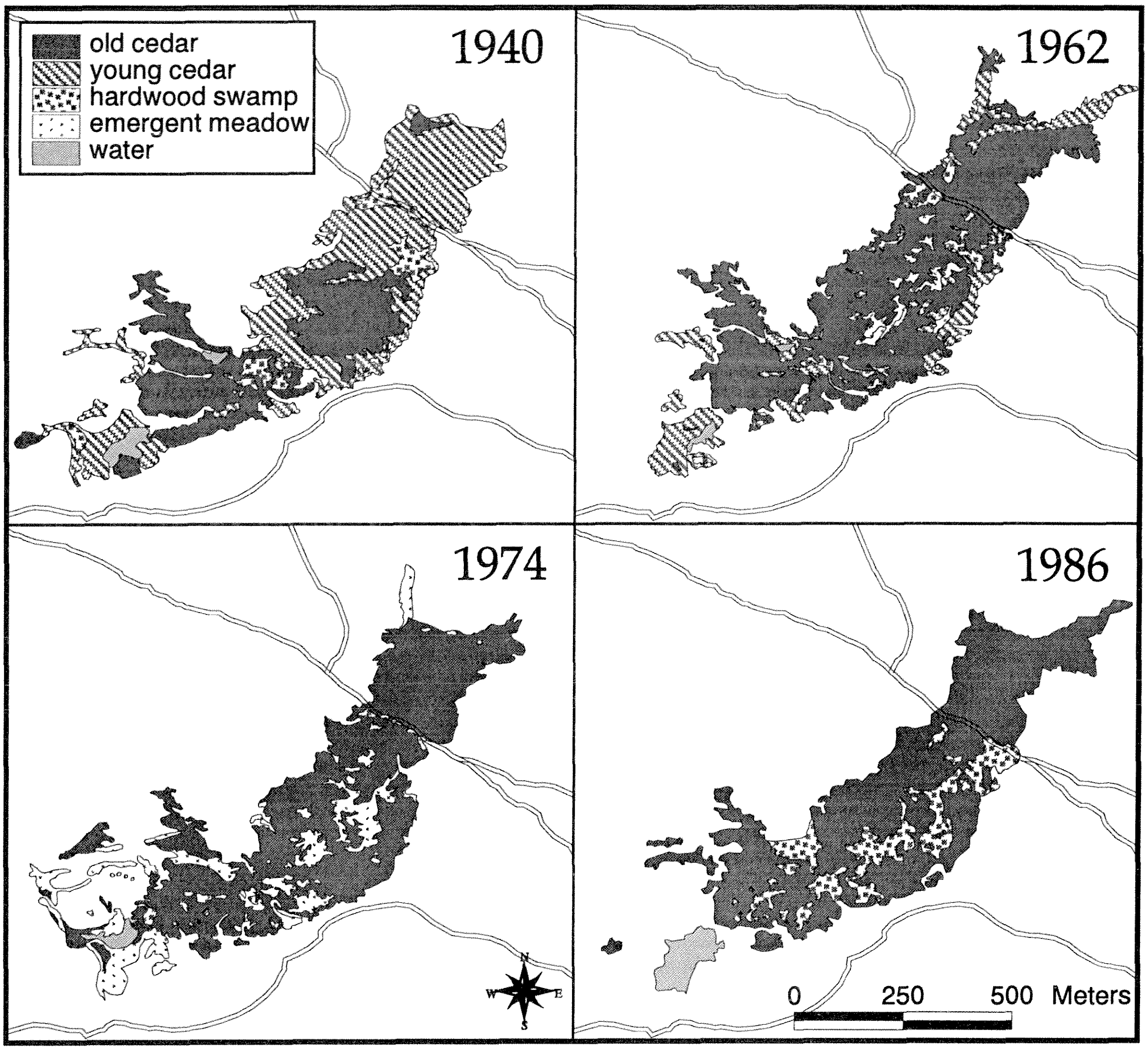

Figure 3—Aerial photo interpretation of cover types at Penn Swamp in 1940, 1962, 1974, and 1986.

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SOME NOTEWORTHY VASCULAR PLANT RECORDS FROM ATLANTIC WHITE-CEDAR, *CHAMAECYPARIS THYOIDES* (L.) B.S.P., HABITATS OF WESTERN GEORGIA

Phil Sheridan, Steve Orzell, and Edwin Bridges[1]

Abstract—Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) is documented for five counties in the western Georgia fall-line sandhills region and from Richmond County in the fall-line sandhills of eastern Georgia. The most extensive stands of Atlantic white-cedar in western Georgia are in the Whitewater Creek watershed, along streams draining the sandhills in Taylor County. At western Georgia stations Atlantic white-cedar occurs along clear-flowing, sand-bottom, seepage/spring streams in stream valleys that dissect Cretaceous/Eocene-age fall-line sandhills. Ten Georgia state rare plants are reported from western Georgia Atlantic white-cedar habitats, including one state threatened, one state endangered, and two state historical species. A total of 48 plant taxa representing Georgia county records were documented. The Atlantic white-cedar habitats of western Georgia are now known to harbor floristic elements of disjunct taxa from the outer Central Gulf Coastal Plain, disjunct taxa from the Appalachian Mountain/Piedmont region, and other local or regionally uncommon obligate seepage plants. The occurrence of a significant number of rare and/or disjunct plant species from Atlantic white-cedar habitats supports protection of these streams as natural areas.

INTRODUCTION

Atlantic white-cedar, *Chamaecyparis thyoides* (L.) B.S.P., was reported for Georgia by Harper (1926) as occurring near the town of Juniper, at the border of Talbot and Marion counties in the fall-line sandhills of western Georgia. James (1961) indicated four Georgia sites in his Florida and Georgia distribution map of this species, of which three are in western Georgia and one is in eastern Georgia, all from within the fall-line sandhills region. Little (1971) maps Atlantic white-cedar for Talbot, Taylor, and perhaps a portion of Marion counties, and also maps a historical record from Richmond County. Wharton (1978) reports Atlantic white-cedar from the area of Whitewater and Cedar Creeks (on the boundary of Taylor and Schley counties) and notes that this appears to be the only Georgia location known for Atlantic white-cedar. Clewell and Ward (1987, 1989) mention the occurrence of Atlantic white-cedar stations in Georgia separated by 30 km, one on a tributary of Upatoi Creek (on the border between Talbot and Marion Counties), and another from Whitewater Creek in Taylor County, presumably based upon Wharton (1978). Mellinger (1984) maps Atlantic white-cedar for nine Georgia counties. Of the counties mapped by Mellinger (1984), three counties (Thomas, Tift and Laurens) may represent questionable records, since Mellinger (1984) includes sight and photographic records, rather than being entirely based upon herbarium vouchers. Jones and Coile (1988) map Atlantic white-cedar from Marion, Talbot and Taylor counties, all within western Georgia. Jones and Coile (1988) is based primarily on herbarium specimens at University of Georgia-Athens with some supplemental records from other sources; therefore, it does not represent a statewide herbaria survey for all Georgia specimens of Atlantic white-cedar. The map in Frost (1987) shows Atlantic white-cedar from the eastern Georgia fall-line sandhills in Richmond County, based upon a historical record in Little (1971) and from Burke County with Michaux (1857) as the source. In 1991 Michael Moore and others collected specimens from three stations along the Sandy Run Creek drainage on Fort Gordon Military Reservation, Richmond County, in the eastern Georgia fall-line sandhills (Tom Patrick, Georgia Department of Natural Resources, personal communication 1997; letter from Michael Moore, University of Georgia-Athens Herbarium, 1991). Atlantic white-cedar is currently documented from five counties (Marion, Peach, Talbot, Taylor and Schley counties) in the western Georgia fall-line sandhills and from Richmond County in the eastern Georgia fall-line sandhills.

METHODS

We became interested in Georgia Atlantic white-cedar habitats after easily discovering state rare and disjunct plants during reconnaissance surveys of a few Atlantic white-cedar streamsides in Taylor County. Since 1987 we have conducted several reconnaissance floristic surveys of Atlantic white-cedar stations in western Georgia from Taylor, Peach, and Marion counties. Our study was confined to the Cretaceous/Eocene age fall-line sandhills of western Georgia (fig. 1). Field study sites with potential for Atlantic white-cedar were chosen through literature and limited herbarium surveys and by locating perennial streams draining the sandhill region on U.S. Geologic Survey 7.5-minute series topographic maps. Sites were surveyed by wading into streams lined with Atlantic white-cedar at either road or powerline crossings. Vascular plants found at each site were recorded on species checklists, however, none of these plant lists should be considered comprehensive. At various sites vascular plant collections were prepared to

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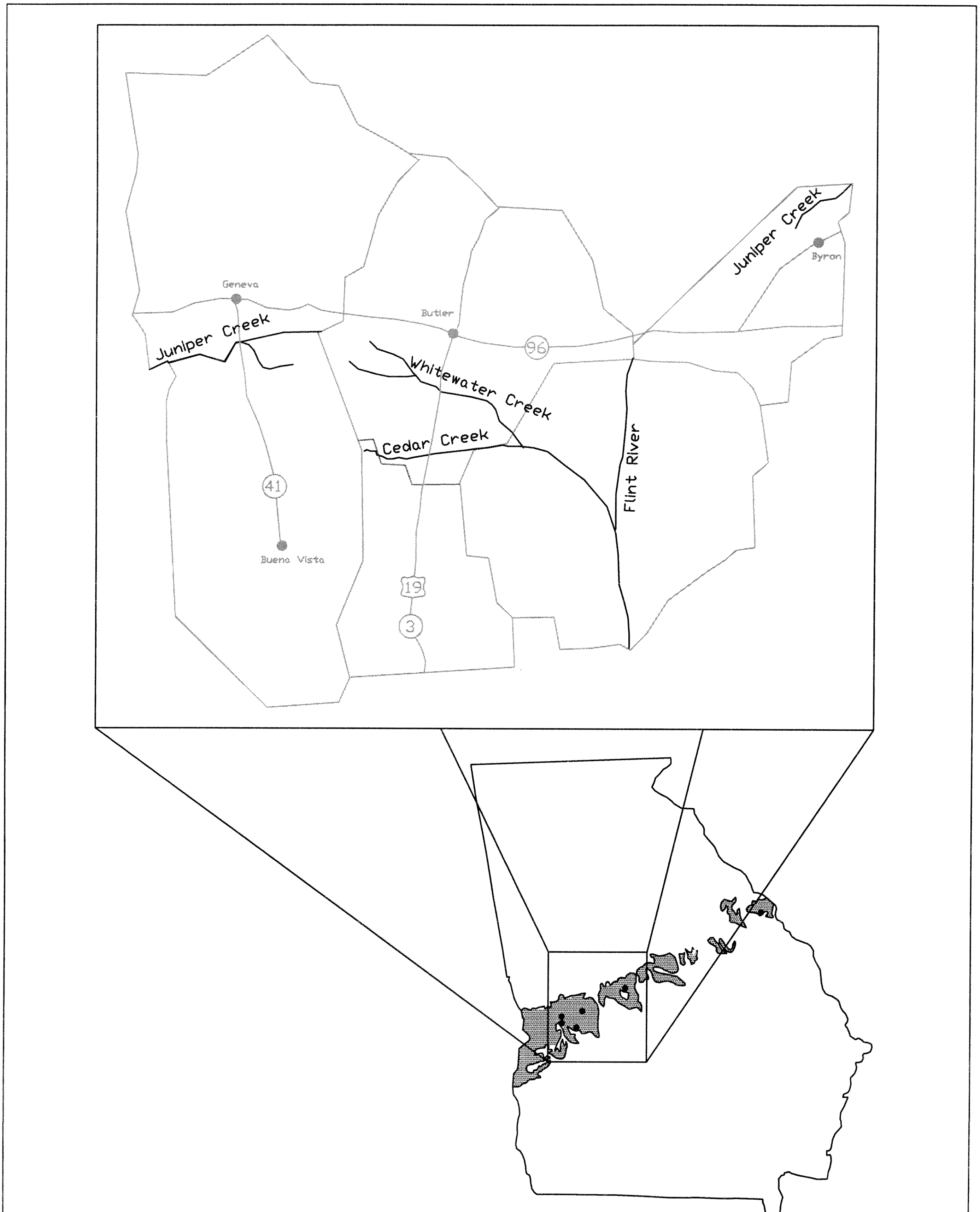

Figure 1—Distribution of white cedar in Georgia. Dots represent general occurrence within the shaded region of sandhills. Detailed section of map delineates specific stream systems in western Georgia where Atlantic white-cedar occurs.

serve as herbarium voucher specimens. Voucher specimens are deposited at the Fairchild Tropical Garden (FTG) and the University of Georgia-Athens (GA). Other standard herbaria acronyms cited in the text are as follows: New York Botanical Garden (NY), Missouri Botanical Garden (MO), Smithsonian Institute (US), and the Gray Herbarium (GH).

Each site surveyed was assigned an alpha-numeric site code that consists of six letters and three numbers. The first two letters are the state abbreviation, followed by the next four letters indicating the county, and lastly, three numbers that serve as a unique site identification number. For example, GATAYLOO3 is in Taylor County, Georgia. Detailed site location information and a topographic map indicating the site location is available from the authors.

Plant taxonomy and nomenclature follows either Kartesz (1994) or Wunderlin and others (1996). Plant determinations were made by the authors. Noteworthy plant collections are defined as those that represent new county records based upon Jones and Coile (1988), or are included on the state list of rare plants (Georgia Natural Heritage Program 1991, 1993). Many of the collections reported here were used in compiling the revised Georgia rare plant list (Patrick and others 1995). Global and state ranking of rare plants follows The Nature Conservancy and the respective state natural heritage ranking scheme (table 1).

RESULTS

Ten Georgia state rare plants, including one state threatened, one state endangered, and two state historical species were found in Georgia Atlantic white-cedar habitats (table 1). No federally endangered or threatened species were found. A total of 48 taxa representing new Georgia county records were discovered in these reconnaissance surveys. There is high potential for discoveries of additional rare plant species and other noteworthy plants (i.e., new state and county records) from western Georgia Atlantic white-cedar habitats, since our field surveys were limited by access, funding and time. Despite our field surveys and those of others (Lane 1976) the floristics of the western Georgia fall-line sandhills region are relatively poorly known. Additional rare plants were observed by the authors, but voucher specimens were not made due to the depauperate condition of the plant material or small population sizes. These are not reported in this paper.

There is a discrepancy between the identification of certain creeks on road signs and that labeled on the U.S. Geologic Survey 7.5-minute topographic maps. There is a transposition between road signs and the topographic maps for Whitewater Creek and Little Whitewater Creek. To avoid confusion we use the topographic map designated names in this paper. Whitewater Creek (Butler West Quad.) is mislabeled on the road signs as Little Whitewater Creek, and is our site GATAYL001, located on Georgia route 137, 5.2 km northeast of Charing and 11.3 km southwest of Butler. On specimen label data we have erroneously referred to Whitewater Creek as Big Whitewater Creek. Little Whitewater Creek (Butler West Quad.) includes sites GATAYL 003, 005, 010, 012 and appears on road signs as Big Whitewater Creek.

Plant collections are listed in alphabetical order in the Appendix.

NOTEWORTHY COLLECTIONS

The *Carex collinsii* (CYPERACEAE) collections reported here from Taylor County represent the first time this species has been seen in the state in over 100 years. Mackenzie (1935) states that *C. collinsii* grows in the dense shade of very wet Atlantic white-cedar and black spruce swamps mostly in the coastal plain, and examined specimens from ten states, including Georgia. Mackenzie (1940) states that *C. collinsii* occurs in shaded swamps from Rhode Island to Pennsylvania, southward to South Carolina and Georgia. Russell and Duncan (1972), in their annotated list of *Carex* in Georgia, list *Carex collinsii* for Georgia based upon literature references to its occurrence in the state (Mohr 1901, Small 1933, Mackenzie 1940, Fernald 1950, Gleason and Cronquist 1963, Eyles and Robertson 1963, Radford and others 1968), but indicate that they had not seen any specimens from Georgia. Bruce Sorrie (Tom Patrick, Georgia Department of Natural Resources, personal communication, 1997) has examined a Georgia specimen at GH with the label data, "pine woods swamps, 2 sites-10

Table 1—Listed rare plants collected in Georgia Atlantic white-cedar habitats

Scientific name	State status	Global rank	State rank
Carex collinsii	N	G4	S2
Carex venusta var. *venusta*	N	G4T?	S1?
Chamaecyparis thyoides	N	G4	S2
Fothergilla gardenii	N	G4	S2
Helenium brevifolium	N	??	SH
Helianthis longifolius	N	G?	S2
Kalmia carolina	N	G5T4	S1
Pinguicula primuliflora	T	G4	S1
Sarracenia rubra	E	G3	S2
Schoenoplectus etuberculatus	N	G3G4	SH

State status: N = none, E = state endangered in Georgia, T = state threatened in Georgia.

Global rank: G2 = globally imperiled, 6-20 populations; G3 = very rare and local throughout its range or found locally in a restricted range, or because of other factors vulnerable to extinction, 21-100 populations; G4 = apparently secure globally although it may be rare in parts of its range, 100-1,000 populations; G5 = demonstrably secure globally, though it may be quite rare in parts of its range, 1,000+ populations.

T# = the rank assigned to a subspecies or variety

? = rank is uncertain

State rank: S1 = critically imperiled in the state, 1-5 populations; S2 = imperiled in the state, 6-20 populations; SH = state historical, indicates that the species has not been observed for 20 or more years in Georgia.

miles apart." The name of the collector was illegible and the listed date is either 1875 or 1878. There is also a Georgia specimen at US collected by Olney s.n., no date, from pine barrens of Georgia, that was annotated as *Carex collinsii* by Hugh T. O'Neill on 20 July 1940. The close association of *Carex collinsii* with Atlantic white-cedar has been noted by many authors (Laderman 1989, Mackenzie 1935, Enser and Caljouw 1989, Naczi 1984). In Georgia, *C. collinsii* grows in the shade of Atlantic white-cedar stands, on elevated sphagnous hummocks above seepage saturated muck in the recesses of the Atlantic white-cedar swamps which adjoin the streams. This very habitat-specific disjunct record is indicative of the significance of Atlantic white-cedar habitats in Georgia as refugia for rare plants.

Carex venusta var. *venusta* (CYPERACEAE) represents a southern extension in Georgia from the only previous Georgia collection, from Hall County in the Piedmont (Jones and Coile 1988). Mackenzie (1935) gives the range of *Carex venusta* as from North Carolina to Florida and indicates that he examined specimens from North Carolina, South Carolina, Georgia and Florida, where it occurs in pine-barren swamps. The illustration of *C. venusta* in Mackenzie (1940) is partially based upon a small collection from the Ocmulgee River swamp in Georgia. Russell and Duncan (1972) list *C. venusta* from Georgia based upon specimens at MO, NY and GA. In Florida, Wunderlin and others (1996) report this sedge from Walton and Wakulla counties in the Florida panhandle. The Wakulla County record is based on a collection by the junior authors, from an acid-seep forest along Black Creek. *Carex venusta* is reported from bogs scattered throughout the Carolinas, and is listed as occurring in Virginia, Georgia, Alabama, Mississippi, and Tennessee in Radford and others (1968). Godfrey and Wooten (1979) report this species from sphagnous bogs, boggy places in woodlands, sphagnous pinelands, evergreen shrub-tree bogs and bays, from eastern New York to the Florida panhandle and Louisiana. This species may be more common in Georgia in seepage-fed forested habitats.

Chamaecyparis thyoides (CUPRESSACEAE). The Peach County collection represents an eastern extension into a region of Eocene-age fall-line sandhills. Despite the fact that local foresters were aware of the Peach County location, botanists were unaware of this station. The state champion Atlantic white-cedar, measuring 50.96 cm diameter at breast height, occurs at the Peach County station on Juniper Creek (Byron Quad.), north of the town of Byron on the edge of the Fort Valley Plateau (Georgia Forestry Commission 1996). Adjacent to Juniper Creek in Crawford County is a tributary known as Whitewater Creek, which drains eastward into Echeconnee Creek. Although the Crawford County drainage of Whitewater Creek was investigated for Atlantic white-cedar at two locations in 1992 by the senior author, none was found. However, additional aerial/field surveys for Atlantic white-cedar are warranted along Whitewater Creek in Crawford County.

We have also observed Atlantic white-cedar on Cedar Creek (Rupert Quad.) within a few meters of the Schley County line, and Tom Patrick (Georgia Department of Natural Resources, personal communication, 1997) reports Atlantic white-cedar from Rogers Mill on Cedar Creek in Schley County. Interestingly, both Juniper and Cedar are used to refer to creeks containing Atlantic white-cedar in western Georgia. Frost (1987) pointed out that "juniper" is a regionally specific term for Atlantic white-cedar in the Carolinas. The term "whitewater" for creeks in the fall-line sandhills of western Georgia probably refers to the generally clear, flowing water characteristic of these seepage/spring-fed streams or represents some local reference to Atlantic white-cedar.

Galax urceolata (=*Galax aphylla*)(DIAPENSIACEAE). This acaulescent rhizomatous evergreen herb represents a monotypic genus (Wood and Channell 1959). *G. urceolata* ranges from the mountains of northern West Virginia and northwestern Maryland to the coastal plain of eastern Virginia and eastern North Carolina, southward and westward to central Georgia, central Alabama and central Tennessee. This species occurs in acid soils, generally in mesophytic associations with *Kalmia*, *Rhododendron* and other Ericaceae (Wood and Channell 1959). Radford and others (1968) report *G. urceolata* from rocky woodlands, and as common in the mountains, but local in the Piedmont and coastal plain of North Carolina. They also report this species from northern South Carolina, Virginia, Georgia, Alabama, Tennessee, Kentucky, and West Virginia. Disjunctions of *G. urceolata* from the Appalachian mountains to isolated locations throughout the Piedmont of North Carolina are well known (Hardin and Cooper 1967), in comparison to the infrequent and lesser-known coastal-plain disjunctions of *G. urceolata*. The Little Whitewater Creek station for *G. urceolata* in Taylor County, Georgia is a southern range extension, and represents one of only a few coastal plain records for *G. urceolata*, a species with definite mountain/piedmont floristic affinities.

Helenium brevifolium (ASTERACEAE) was collected in 1987 during a field survey in Taylor County. This species is noteworthy because it was considered state historical record in Georgia until our collection (Sheridan and others 1997). *Helenium brevifolium* had not been reported for Georgia since the 1940's (Tom Patrick, Georgia Department of Natural Resources, personal communication, 1997). Rock (1957) cites two specimens, one collected from Douglas County and another collected from Meriwether County. Both Rock (1957) and Godfrey and Wooten (1981) indicate that *H. brevifolium* occurs in bogs, shrub-bogs, boggy clearings, boggy stream banks, seepage slopes, wet meadows and wet pine barrens, generally where the soil is saturated or even with standing surface water. Godfrey and Wooten (1981) give the distribution as local in southeast Virginia, the coastal plain, piedmont and mountains of North Carolina, to the western Florida panhandle, Alabama, southern Mississippi, and extreme southeastern Louisiana. Rock (1957) noted that where *H. brevifolium* occurs outside the Gulf Coastal Plain, it inhabits either bogs in the Atlantic coastal plain or coastal-plain-like bogs of the Piedmont. The distribution of *H. brevifolium* is principally in the central Gulf coastal plain region, with inland and northern disjunct stations mostly from boggy habitats. At the Taylor County site, *H. brevifolium* was growing in seepage-saturated, boggy openings in a Atlantic white-cedar bayhead swamp with other seepage-adapted plants.

Pinguicula primuliflora (LENTIBULARIACEAE) is locally abundant along the banks of Whitewater Creek in Taylor County, Georgia. We have also observed this species in Georgia along sandy, spring-fed creeks in Marion County (Sheridan and others, 1997) and predict that it will be found along other seepage/spring streams within the western fall-line sandhills region of Georgia. Both the Marion and Taylor County records represent the first records for *P. primuliflora*, from the fall-line sandhill region of the Coastal Plain. The Taylor County station apparently is the northernmost record. The Marion and Taylor County stations illustrate the floristic affinity of the fall-line Atlantic white-cedar habitats for *P. primuliflora* to habitats found on the outer Gulf coastal plain. Prior to our collections from the fall-line sandhills region in western Georgia, *P. primuliflora* was a central Gulf coastal-plain endemic (fig. 2) and was previously known to occur in the western Florida panhandle, Early County in southwestern Georgia, southern Alabama, and southern Mississippi (Godfrey and Stripling 1961), where it is typically an inhabitant of shallow, flowing spring-fed branches, along boggy creek banks (Godfrey and Wooten 1981), and in mucky seepage-saturated bogs (Orzell and Bridges, field data). Label data from the Early County, Georgia specimen indicates that it was collected from an acid bog, 2 miles south of Hilton (Robert Thorne 2919 and Muenscher, 10 April 1947), and the specimen is deposited at GH (Wood and Godfrey 1957). The Georgia fall-line sandhill habitats for *P. primuliflora* are very similar to sites for *P. primuliflora* in the western Florida panhandle where it also sometimes occurs in association with Atlantic white-cedar. At both locations *P. primuliflora* is locally abundant along Atlantic white-cedar lined streamsides. Commonly associated species from Atlantic white-cedar habitats in the western Florida panhandle and the sandhills region of western Georgia include *Sphagnum* sp., *Sarracenia rubra*, and *Xyris difformis* var. *difformis*.

Sarracenia rubra (SARRACENIACEAE). A 1994 census of plants growing in riparian seepage springs flowing into Little Whitewater Creek by the senior author counted 361 clumps of *S. rubra* over a 1.2-km stretch. *S. rubra* is locally abundant along the Whitewater Creek drainage to Jackson Branch, north of the town of Ideal. Additional discoveries of *S. rubra* in other Atlantic white-cedar habitats and seepage slopes in western Georgia should add considerably to the number of Georgia stations for this state threatened species.

The taxonomic status of the *Sarracenia rubra* complex has been a matter of dispute (Godt and Hamrick 1996, McDaniel 1971, Case and Case 1976, Schnell 1977). Segregates of the *S. rubra* complex have been variously classified as regional variants, forms, subspecies, and distinct species (Godt and Hamrick 1996, McDaniel 1971, Case and Case 1976, Schnell 1977). The most recent treatment (McDaniel 1986) grants species status to some of the taxa, but does not address the taxonomy of subsp. *gulfensis* and that of related subsp. *rubra*. Supporting McDaniel's (1986) treatment of members of the complex (other than subsp. *gulfensis* and subsp. *rubra*) is the disjunct distribution of species in the *rubra* complex, the maintenance of morphological integrity in a standardized culture, and the unique fragrance and color of the species, which suggest adaptation to a different insect fauna (Godt and Hamrick 1996). Collections of *S. rubra* from the fall-line sandhills region of Georgia and the Carolinas, and the outer coastal plain of the Carolinas (McDaniel 1971, Case and Case 1976, Schnell 1977) are referable to subsp. *rubra*. *Sarracenia rubra* subsp. *gulfensis* was described by Schnell (1979) from the western Florida panhandle (Escambia, Santa Rosa, Okaloosa, and Walton counties), and probably also includes a Thorne collection of *S. rubra* from Early County in southwest Georgia (Thorne 1954). *Sarracenia rubra* subsp. *rubra* is locally abundant in Atlantic white-cedar streamside habitats and seepage slopes in western Georgia, as is *S. rubra* subsp. *gulfensis* in the same habitats in the western Florida panhandle (fig. 3). However, the local abundance of *S. rubra* subsp. *rubra* from Atlantic white-cedar habitats and seepage slopes (Sheridan and others 1997, Streich and Kemp 1993) in the fall-line sandhill region of western Georgia was not previously known prior to our 1987 field surveys. Therefore, reevaluation of the infraspecies status of subsp. *rubra* and subsp. *gulfensis* and their taxonomic relationship is warranted, considering the tendency towards subspecies recognition of geographic variants in the *S. rubra* complex.

Schoenoplectus etuberculatus (=*Scirpus etuberculatus*) (CYPERACEAE) was first collected in Georgia by Roland Harper on July 19, 1901 from Alligator Pond, a permanent pond within pine barrens in an outlying Cretaceous-age region, located south of Omaha, in Stewart County (Harper 1903a, 1903b, 1905). Harper also notes having collected several other interesting plants from this pond, including the first collection of *Xyris smalliana*, at that time only reported from the type locality in Florida (Harper 1903b). *Schoenoplectus etuberculatus* is known to occur in ponds, fresh to brackish marshes, and sometimes submerged in streams (Godfrey and Wooten 1981). This species is found primarily along the Atlantic and Gulf coastal plain (Godfrey and Wooten 1981, Smith 1996). Smith (1996) maps this species from Delaware, along the coast of Virginia and Maryland, from the fall-line sandhills of North and South Carolina to the Georgia border, and from north Florida west to extreme southeastern Louisiana. He also maps disjunct stations for *S. etuberculatus* in west-central Georgia (Harper 1903a, 1903b, 1905), in Hardin County, southeastern Texas (Correll 1972), in Washington County, Rhode Island (Enser and Caljouw 1989), and in Oregon County, southern Missouri (Steyermark 1963). *Schoenoplectus etuberculatus* grows partially submerged in the clear-flowing, seepage stream channel of Little Whitewater Creek, in Taylor County. The fidelity of *S. etuberculatus* to Atlantic white-cedar seepage streams in western Georgia and also in the western Florida panhandle further illustrates a floristic affinity of the fall-line Atlantic white-cedar habitats with the outer East Gulf coastal-plain flora.

DISCUSSION

Atlantic white-cedar is recorded for six Georgia counties, five in the Cretaceous/Eocene age western fall-line sandhills region (fig. 1). The most extensive stands of Atlantic white-cedar located thus far in our field surveys in western Georgia occur in the sandhills region south of Butler on the Whitewater Creek drainage in Taylor County. Western Georgia Atlantic white-cedar occurs along clear-flowing, sand-bottom, perennial seepage-stream valleys that dissect the fall-line sandhills.

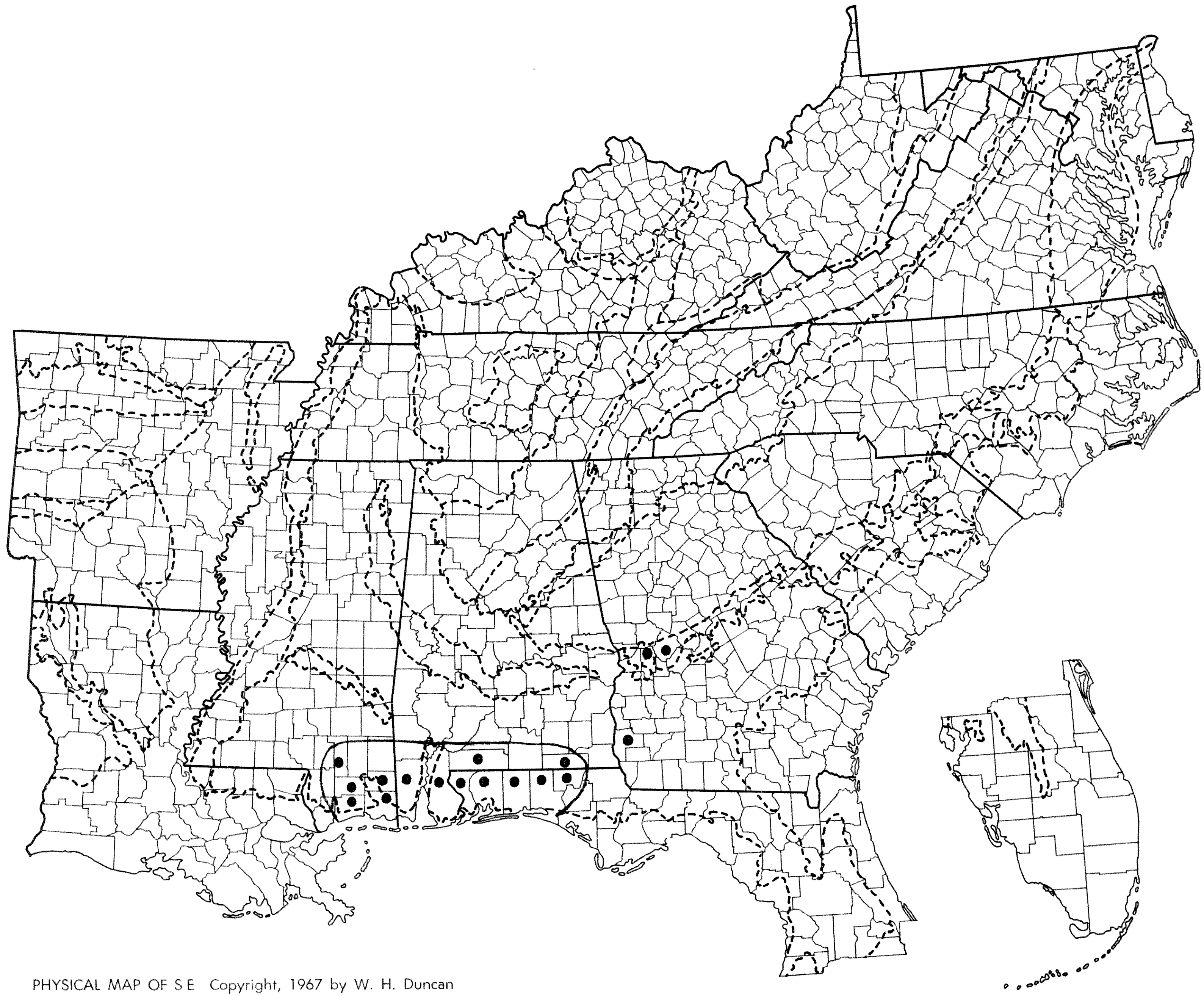

Figure 2—Distribution of *Pinguicula primuliflora*. Solid line outlines center of range.

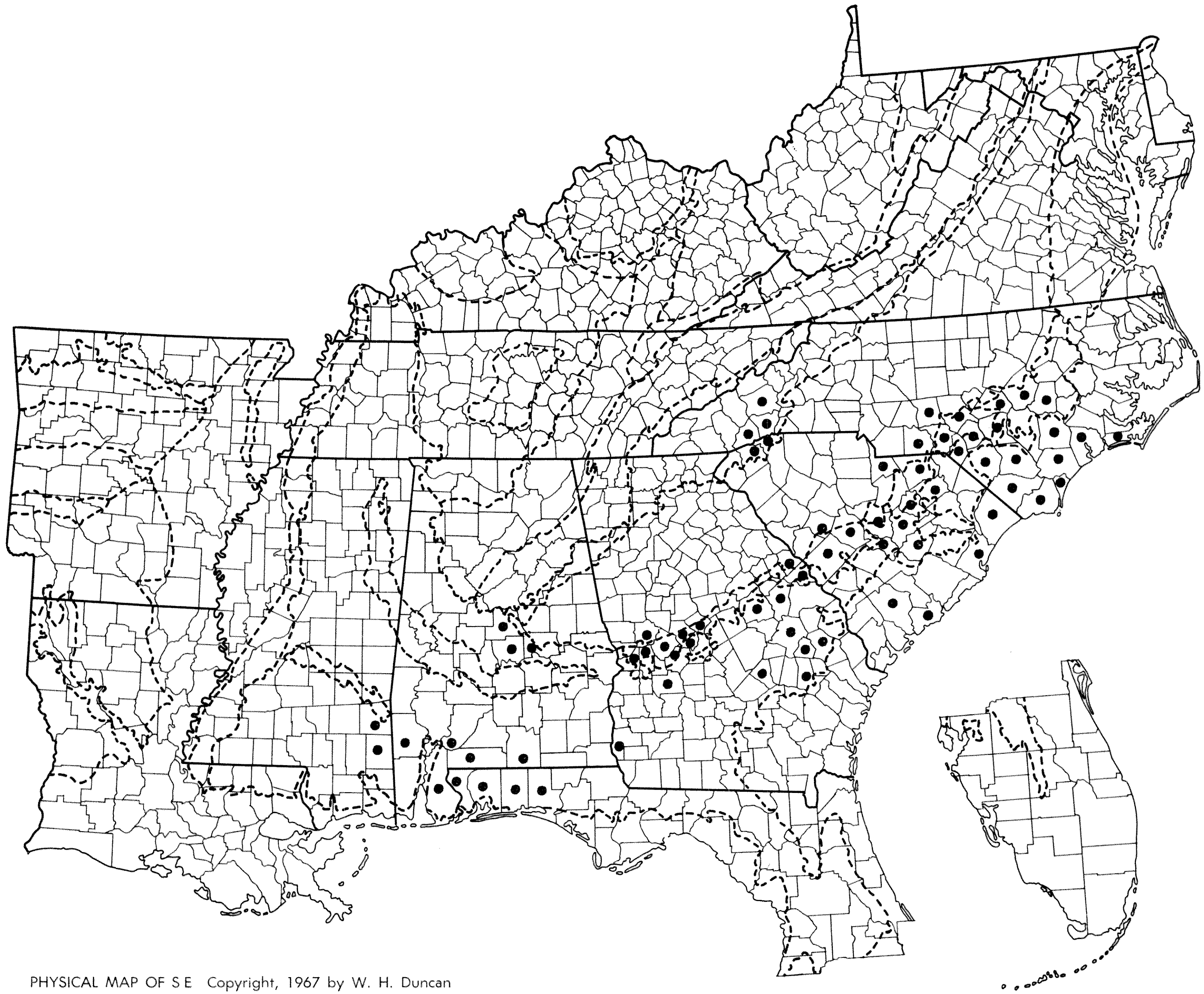

Figure 3—Distribution of the *Sarracenia rubra* complex. Note disjunct distribution of populations, many of which have been identified as discrete taxa.

The Georgia fall-line sandhill habitat for Atlantic white-cedar is similar to that noted by Clewell and Ward (1987, 1989) in Florida. Atlantic white-cedar occurs in the Western Highlands and Gulf coastal lowlands in the western Florida panhandle and also at disjunct sites in north-central peninsular Florida (Clewell and Ward 1987, 1989). Atlantic white-cedar streams from the Western Highlands region of the western Florida panhandle (especially in Escambia, Okaloosa, Santa Rosa, and Walton counties) and those found in the north-central peninsular Florida (Marion and Putnam counties) are similar in their overall geomorphic/ landscape setting to the fall-line region in western Georgia. However, stations for Atlantic white-cedar in Apalachicola lowlands of the Gulf coastal lowlands (Bay, Franklin, Gulf and Liberty counties) differ from Atlantic white-cedar stations in Georgia.

The western highlands of the Florida panhandle consist of hills of Plio-Pleistocene Citronelle Formation consisting of non-marine quartz sands that contain discontinuous layers of clay or gravel that have been modified by stream dissection and dissolution of underlying limestones (Schmidt 1984). Erosional relief in the highlands reaches 100 feet in the highly permeable sands that cap the Citronelle formation. These highly permeable sands, with a high infiltration capacity, hold abundant ground water in unconsolidated, surficial sand-and-gravel aquifers. Springs and seepages emerge from these permeable sandhills along the dissected stream valleys forming many small perennial streams.

Florida streamside stations for Atlantic white-cedar (i.e., western highlands and north-central Florida) and the Georgia stations are in regions with extensive, highly permeable, deep sandy soils. These highly permeable sands act as unconsolidated aquifers and when dissected by perennial seepage stream valleys form the environmental conditions ideal for Atlantic white-cedar. Some of the best developed portions of the sandhills of western Georgia are roughly delimited by the Whitewater Creek watershed. Outside of this watershed the sand deposits are much more dissected and narrower in extent.

Atlantic white-cedar in the sand hills of western Georgia grows from 98 to 128 m above sea level. The streams are characterized by swiftly flowing cool tannic water with a sandy bottom. Clear sandy springs emerge along stream banks and are often lined with *Drosera intermedia*, *Pinguicula primuliflora*, and *Sarracenia rubra*. Where seepages saturate the adjoining floodplain, there are mucky-peat filled embayments with quaking, sphagnous flats and peaty hummocks. The stream channel itself may be filled with numerous snags of *Pinus serotina* and Atlantic white-cedar. Sandy and peaty banks up to a meter high direct the stream, and on moist portions of this habitat, individuals or large clumps of *Sarracenia rubra* can be found growing among tree roots or snag edges. *Sarracenia rubra* frequently occurs along bends in the creek lodged in snag roots or peaty deposits.

Floristically, the Atlantic white-cedar habitats of western Georgia are now known to harbor elements of outer Central Gulf coastal plain species (e.g., *Pinguicula primuliflora*), disjuncts from the Appalachian Mountain/piedmont region (e.g., *Galax urceolata*), and other local or regionally uncommon plants requiring the specialized seepage conditions (e.g., *Carex collinsii*) afforded by these habitats. The similarity of western Georgia Atlantic white-cedar streams to those found elsewhere along the Gulf coastal plain in southern Alabama, southern Mississippi, and Florida (the Coldwater drainages) has been superficially noted by others (Kral 1995). In particular, searches by Kral (1995) along Whitewater Creek and its associated drainages have failed to locate *Rhynchospora crinipes*, whereas searches in Atlantic white-cedar habitats along Upatoi Creek have produced specimens of *R. crinipes* (Kral 1995). *R. crinipes* is typically found in rather close association with Atlantic white-cedar streams, where it grows alongside sunlit, or partially shaded, clear, active streams or in streamside seeps (Kral 1995, 1996). The presence of Piedmont species from the Georgia coastal plain has also been previously noted, in particular from the Eocene Red Hills Belt of southwestern Georgia (Thorne 1949). The Eocene Red Hills Belt lies between the fall-line sandhills of western Georgia and the pinelands of the Dougherty Plain to the southeast (Thorne 1949). The primary difference is that the Piedmont elements noted by Thorne (1949) occupy rich deciduous woods of ravine slopes in the Red Hills Belt, in contrast to the acidic sandy soils of the fall-line sandhills.

Some of the highest quality Atlantic white-cedar streamside habitats in western Georgia are in the sandhills south of Butler in the Whitewater Creek watershed of Taylor County. Here, Atlantic white-cedar occurs along clear-flowing, sand-bottom, seepage/spring streams in stream valleys that dissect Cretaceous/Eocene-age fall-line sandhills. The occurrence of a significant number of rare and/or disjunct plant species from this watershed supports protection of these streams as natural areas. Logging practices in the sandhills region of western Georgia and elsewhere in the vicinity of Atlantic white-cedar habitats in the southeastern United States has generally lead to hydrologic alterations, siltation and accelerated erosion that can either wash out or bury Atlantic white-cedar streamside plants (Kral 1996). The protection of such stream systems and the future of Atlantic white-cedar habitats and their associated rare plant assemblages depends upon the proper management of the surrounding forest resources.

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APPENDIX

Alphabetical list of noteworthy plant collections from Atlantic white-cedar habitats in western Georgia. Asterisks before the site code indicate a county record. Following the scientific name and authority is the common name, site code (for example GATAYL003), collection date, collector(s), and acronym of the herbarium where the specimen is deposited.

Aletris farinosa L. - Colicroot.

*GATAYL010: 6 June 1989, *Sheridan and Scholl 124* (FTG).

Bartonia paniculata (Michaux) Muhl. - Screw-stem.

*GATAYL010: 9 September 1990, *Orzell and Bridges 15058* (FTG).

Calopogon tuberosus (L.) Britton and others - Grass-pink orchid.

*GATAYL010: 6 June 1989, *Sheridan and Scholl 132* (GA).

Carex collinsii Nuttall - Collin's sedge.

*GATAYL003: 4 June 1989, *Sheridan and Scholl 106* (FTG).
*GATAYL003: 28 May 1994, *Sheridan and Troup 1581* (FTG).
*GATAYL003: 28 May 1994, *Sheridan and Troup 1587* (FTG).

Carex venusta var. *venusta* Dewey - Dark green sedge.

*GAPEAC001: 18 June 1994, *Sheridan and Patrick 1722* (FTG).

Chamaecyparis thyoides (L.) B.S.P. - Atlantic white-cedar.

*GAPEAC001: 27 Aug 1992, *Sheridan 1330* (FTG).
GATAYL001: 6 May 1987, *Orzell and Bridges 5171* (FTG).
GATAYL001: 17 June 1994, *Sheridan 1709* (FTG).
GATAYL005: 30 May 1994, *Sheridan 1592* (FTG).

Cyrilla racemiflora L. - Titi.

*GATAYL003: 28 May 1994, *Sheridan and Troup 1578* (FTG).

Drosera capillaris Poiret - Pink sundew.

*GATAYL010: 6 June 1989, *Sheridan and Scholl 119* (FTG, GA).

Drosera intermedia Hayne - Water sundew.

*GAPEAC001: 18 June 1994, *Sheridan and Patrick 1718* (FTG).
*GATAYL015: 9 June 1989. *Sheridan and Scholl 212* (GA).

Dulichium arundinaceum (L.) Britton - Three-way sedge.

*GAPEAC001: 27 August 1992, *Sheridan 1331* (FTG).
*GATAYL010: 9 September 1990, *Orzell and Bridges 15052* (FTG).

Eleocharis tuberculosa (Michx) R & S - Tubercled spike-rush.

*GAPEAC001: 18 June 1994, *Sheridan and Patrick 1721* (FTG).

Eleocharis microcarpa Torrey - Small carpel spike-rush.

*GATAYL010: 9 September 1990, *Orzell and Bridges 15053* (FTG).

Epigaea repens L. - Trailing arbutus.

*GATAYL010: 6 June 1989, *Sheridan and Scholl 134* (FTG).

Fothergilla gardenii Murray - Witch-alder.

GATAYL010: 6 June 1989, *Sheridan and Scholl 125* (FTG).

Galax urceolata (Poir.) Brummitt. - Galax.

*GATAYL003: 5 June 1989, *Sheridan and Scholl 116* (FTG).

Helenium brevifolium (Nutt.) Wood - Shortleaf sneezeweed.

*GATAYL001: 6 May 1987, *Orzell and Bridges 5168* (FTG).

Helianthus longifolius Pursh - Longleaf sunflower.

GATAYL001: 9 Sept 1990, *Orzell and Bridges 15036* (FTG).

Hypericum canadense L. - St. John's-wort.

*GATAYL010: 9 September 1990, *Orzell and Bridges 15060* (FTG).

Juncus repens Michx. - Bending rush.

*GAPEAC001: 18 June 1994, *Sheridan and Patrick 1719* (FTG).

Juncus dichotomus Elliott - Split rush.

*GATAYL010: 6 June 1989, *Sheridan and Scholl 137* (FTG).

Juncus scirpoides Lamarck - A rush.

*GATAYL010: 6 June 1989, *Sheridan and Scholl 122 & 136* (FTG).

Kalmia carolina Small - Carolina sheep-laurel.

GATAYL001: 6 May 1987, *Orzell and Bridges 5167* (FTG).
GATAYL003: 5 June 1989, *Sheridan and Scholl 114* (FTG).

Kalmia latifolia L. - Mountain laurel.

*GATAYL010: 6 June 1989, *Sheridan and Scholl 129* (FTG).

Lachnocaulon anceps (Walter) Morong - Bog buttons.

*GATAYL010: 6 June 1989, *Sheridan and Scholl 138* (FTG).

Lachnocaulon minus (Chapm.) Small - Bog buttons.

*GATAYL010: 6 June 1989, *Sheridan and Scholl 139A* (FTG).
*GATAYL010: 9 September 1990, *Orzell and Bridges 15051* (FTG).
*GATAYL012: 4 June 1989, *Sheridan and Scholl 105* (FTG).

Lobelia georgiana McVaugh - Elongate lobelia.

*GATAYL001: 9 September 1990, *Orzell and Bridges 15035* (FTG)

Mayaca aubletii Michx. - Bog moss

*GAPEAC001: 18 June 1994, *Sheridan and Patrick 1720* (FTG).

Mitreola sessilifolia (Walt.) G. Don

*GATAYL001: 9 September 1990, *Orzell and Bridges 15033* (FTG).

Pinguicula primuliflora Wood & Godfrey - Southern butterwort.

*GATAYL003: 28 May 1994, *Sheridan and Troup 1585* (FTG).

Platanthera blephariglottis (Willd.) Lindl. - White-fringed orchid.

*GATAYL001: 9 September 1990, *Orzell and Bridges 15032* (FTG).

Platanthera clavellata (Michx) Luer

*GAPEAC001: 27 August 1992, *Sheridan 1332* (FTG).

Polygala cruciata L. - Crucifex-leaved polygala.

*GATAYL010: 9 September 1990, *Orzell and Bridges 15056* (FTG).

Polygala lutea L. - Orange-sepaled polygala.

*GATAYL010: 6 June 1989, *Sheridan and Scholl 133* (GA).
*GATAYL010: 9 September 1990, *Orzell and Bridges 15057* (FTG).

Polygala nana (Michx) de Candolle - Yellow-sepaled polygala.

*GATAYL003: 5 June 1989, *Sheridan and Scholl 115* (FTG & GA).

Rhynchospora ciliaris (Michx.) C. Mohr - Ciliate beak rush.

*GATAYL012: 30 May 1994, *Sheridan 1591* (FTG).

Rhynchospora glomerata (L.) Vahl - Glomerate beak rush.

*GAPEAC001: 27 August 1992, *Sheridan 1340A* (FTG).

Rhynchospora inexpansa (Michaux) Vahl. - Beak rush.

*GATAYL010: 9 September 1990, *Orzell and Bridges 15049* (FTG).

Rhynchospora rariflora (Michx) Elliott - Beak rush.

*GATAYL012: 30 May 1994, *Sheridan 1589* (FTG).

Sabatia angularis (L.) Pursh - Rose pink or bitter-bloom.

*GATAYL001: 9 September 1990, *Orzell and Bridges 15034* (FTG).

Sarracenia rubra Walt. - Sweet pitcher plant.

GATAYL001: 6 May 1987, *Orzell and Bridges 5169* (FTG).
GATAYL010: 9 September 1990, *Orzell and Bridges 15055* (FTG).
GATAYL015: 9 June 1989, *Sheridan and Scholl 211* (GA).
*GAPEAC001: 27 Aug 1992, *Sheridan 1329* (FTG).

Schoenoplectus etuberculatus (Steudel) J. Sojak - Bulrush.

*GATAYL005: 30 May 1994, *Sheridan 1593* (FTG).

Scleria pauciflora Muhlenberg ex Wildenow - Nut rush.

*GATAYL012: 30 May 1994, *Sheridan 1590* (FTG).

Smilax laurifolia L. - Puncture vine.

*GATAYL010: 6 June 1989, *Sheridan and Scholl 126* (FTG).

Solidago patula Muhl. ex Willd. - Goldenrod.

*GATAYL010: 9 September 1990, *Orzell and Bridges 15050* (FTG).

Utricularia cornuta Michaux - Horned bladderwort.

*GATAYL003: 28 May 1994, *Sheridan and Troup 1588* (FTG).

Utricularia subulata L.- Bladderwort

*GATAYL010: 6 June 1989, *Sheridan and Scholl 121* (GA).
*GATAYL003: 4 June 1989, *Sheridan and Scholl 107* (GA).

Vaccinium elliottii Chapman - Elliott's blueberry.

*GATAYL003: 28 May 1994, *Sheridan and Troup 1582* (FTG).

Vaccinium myrsinites Lamarck - Blueberry.

*GATAYL010: 6 June 1989, *Sheridan and Scholl 130* (FTG).

Xyris baldwiniana Schultes in R. & S. - Baldwin's yellow-eyed grass.

*GATAYL010: 6 June 1989, *Sheridan and Scholl 135* (FTG).

Xyris difformis Chapman var. *difformis* - Yellow-eyed grass.

*GATAYL001: 9 September 1990, *Orzell and Bridges 15037* (FTG).
*GATAYL010: 9 September 1990, *Orzell and Bridges 15054* (FTG).

Zigadenus densus (Desr.) Fernald - Black snakeroot or crow-poison.

*GATAYL010: 6 June 1989, *Sheridan and Scholl 123* (FTG).

A CENSUS OF ATLANTIC WHITE-CEDAR, *CHAMAECYPARIS THYOIDES* (L.) B.S.P., ON THE WESTERN SHORE OF MARYLAND

Phil Sheridan, Keith Underwood, Robert Muller, Judy Broersma-Cole, Robert Cole, and J. Richard Kibby[1]

"Don't stave the boats needlessly, ye harpooners; good white cedar plank is raised full three per cent within the year."

Herman Melville, *Moby Dick*

Abstract—Nine stations are reported for Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) on the western shore of Maryland. Three sites occur on the Magothy River at Cockey and Cypress Creek, while the other six stands are found at Arlington Echo, Carrollton Manor, Evergreen Road (Cypress Creek), East Branch of Forked Creek, Lakeland, and Sullivan Cove on the Severn River. The western-shore Atlantic white-cedar populations consist of 1214 trees over 1.2 m tall, 1895 seedlings and saplings less than 1.2 m, and 827 dead trees. Mean tree diameter ranged from 5.52 cm at Sullivan Cove to 22.46 cm at Arlington Echo. Seedling recruitment was highest at Sullivan Cove with 1475 seedlings. The nine Atlantic white-cedar populations are found on the western shore of Maryland growing in spring freshes along intertidal zones, pond margins, and sandy or mucky creeks. Propagated western-shore Atlantic white-cedar should be used as part of reforestation programs on the Severn and Magothy Rivers due to the attractive and commercial value of the tree, as mitigation for lost historic sites, and to safeguard against population loss at the few remaining sites.

INTRODUCTION

Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) is a rare to uncommon plant in Maryland and has been placed on the state watch list (Maryland Natural Heritage Program, 1994). Steiber (1967, 1971) reported Atlantic white-cedar for a few locations on the western shore of Maryland in Anne Arundel County, while Sipple and Klockner (1984) classified Atlantic white-cedar habitat as uncommon for this region.

The nearest Atlantic white-cedar stands to the western-shore Maryland populations are found 80 km to the east on the Delmarva Peninsula where a total of 58 extant and historic sites are known (Laderman 1989). The closest Virginia populations occur 274 km to the south in the Dismal Swamp and in pine barrens along the Blackwater River (Fernald 1939, 1940, 1947).

We became interested in the exact status of Atlantic white-cedar populations on the western shore of Maryland because of their isolation, local nature, and associated rare plant species. This project was undertaken to provide data for Atlantic white-cedar recovery and restoration on the western shore of Maryland.

MATERIALS AND METHODS

Atlantic white-cedar sites on the western shore of Maryland were determined by consulting Severn River Association (1990), Sipple (1977), Sipple and Klockner (1980, 1984), and field reports (Milt McCarthy, personal communication to DNR, Sipple, field notes 15 August, 1978). Sites were visited in July 1997 to determine the number of living and dead trees as well as seedlings. Additional site visits were made in December 1997 and January and February 1998 to verify some population counts and to inventory new sites. Individuals measuring 1.2 m and over in height were scored as trees while specimens under 1.2 m were recorded as seedlings. Dead individuals were also recorded as part of the census as a separate category. Circumference of all specimens was measured in inches at breast height with a tape measure and then converted to metric diameter. Physical characteristics and plant associates were recorded for each site. Herbarium specimens of Atlantic white-cedar populations were deposited at Towson State University herbarium (herbarium code: BALT).

RESULTS

Three sites for Atlantic white-cedar occur on the Magothy River, while six are found on the Severn River (fig. 1). Two new Severn River Atlantic white-cedar populations were found, one on the east branch of Forked Creek and the other on the south shore near Sunrise Beach off Evergreen Road at a tributary listed as Cypress Creek (Davison and Rucker, 1988).

Tree populations ranged from as few as 9 at one location to as many as 383 individuals at another, with a total of 1214 Atlantic white-cedar trees for the western shore of Maryland (sum of all sites listed in table 1). The largest number of seedlings (1475) was found at Sullivan Cove. Mean living tree diameter was smallest at Suillivan Cove (5.52 cm) and greatest at Cypress Creek Swamp (22.46 cm). No dead trees were found at two sites, while the largest mean dead tree diameter was recorded at Lakeland (48.17 cm). Cypress Creek Savanna had 77 percent of the population in

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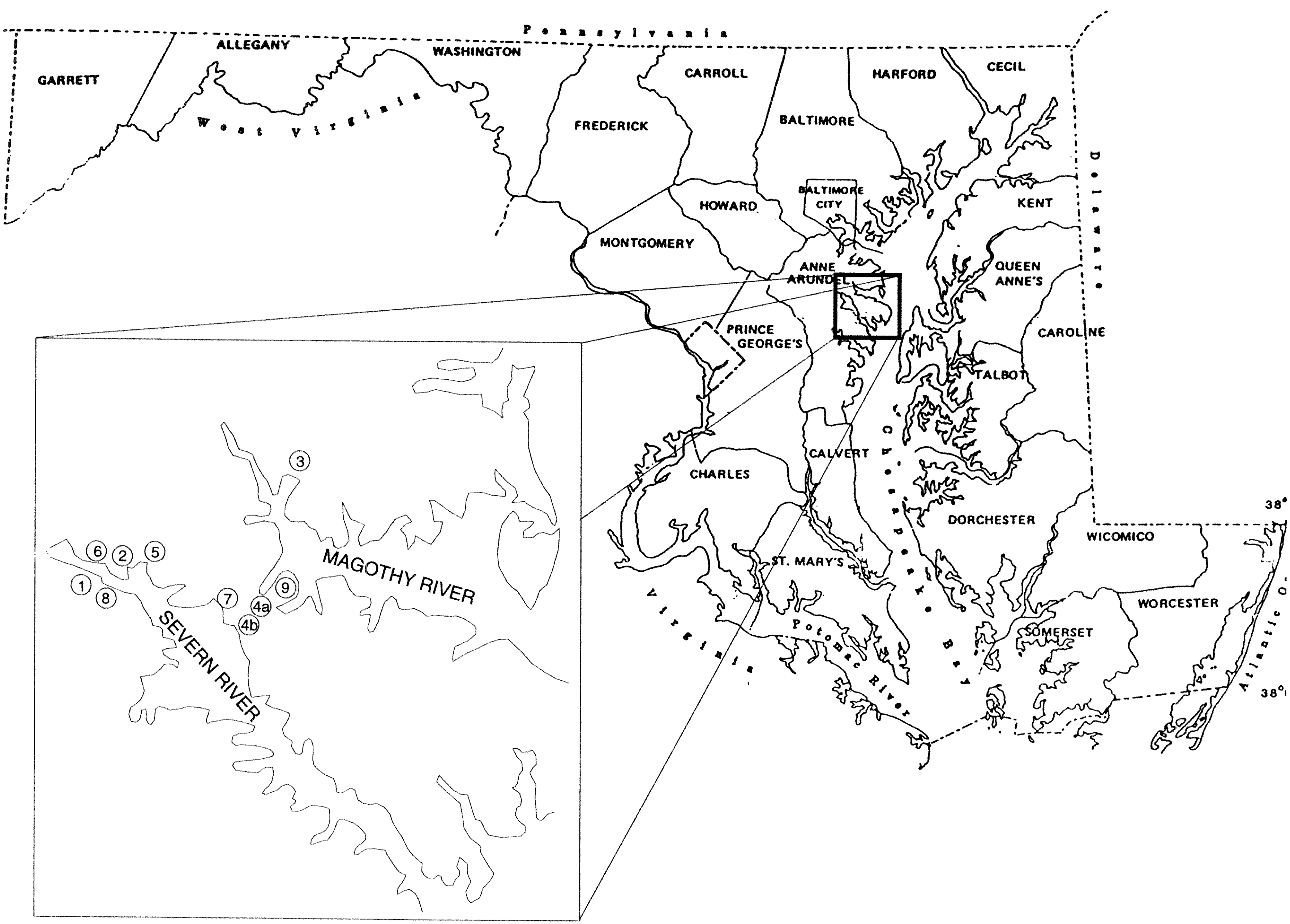

Figure 1—Distribution of Atlantic white-cedar on the western shore of Maryland. Sites are: 1 Arlington Echo; 2 Carrollton Manor; 3 Cockey Creek; 4a Cypress Creek Savanna; 4b Cypress Creek Swamp; 5 Forked Creek; 6 Lakeland; 7 Sullivan Cove; 8 Cypress Creek; 9 Dill Road.

Table 1—Population data for Atlantic white-cedar sites on the Western Shore of Maryland

Parameter	Sites[a]										
	1	2	3	4a	4b	5	6	7	8	9	Total
# Seedlings	40	300	11	24	10	7	9	1,475	—	19	1,885
# Living trees	88	70	49	125	234	9	86	383	11	159	1,214
# Dead trees	25	20	—	501	73	—	11	92	15	90	827
Total	153	390	60	650	317	16	106	1950	26	268	3,936
Mean dia. living (cm)	19.45	7.95	14.47	11.76	22.46	15.64	16.18	5.52	7.36	10.78	
(S.D.)	(17.73)	(8.69)	(11.40)	(8.34)	(11.24)	(14.27)	(15.84)	(7.16)	(2.76)	(7.87)	
Mean dia. dead (cm)	17.36	12.54	—	1.50	14.18	—	48.17	8.29	23.33	13.92	
(S.D.)	(9.82)	(10.41)	—	(0.80)	(9.02)	—	(17.42)	(6.31)	(13.53)	(11.78)	

[a] 1 = Arlington Echo; 2 = Carrollton Manor; 3 = Cockey Creek; 4a = Cypress Creek Savanna; 4b = Cypress Creek Swamp; 5 = Forked Creek; 6 = Lakeland; 7 = Sullivan Cove; 8 = Cypress Creek; 9 = Dill Road

dead trees, while Cypress Creek (Severn River) had a mortality of 58 percent. The champion living Atlantic white-cedar tree on the western shore occurs at Arlington Echo and has a diameter of 69 cm. The largest diameter Atlantic white-cedar found during the census, which had been hit and apparently killed by lightning, is at Lakeland and is 86 cm in diameter.

Interestingly, the Lakeland population seemed to be particularly susceptible to lightning strikes. Lightning scars were found on 50 percent of dead trees and lightning was clearly the cause of death in one tree in 1997. Clewell and Ward (1987, 1989) found that lightning was the cause of mortality for mature Atlantic white-cedar and attributed this to the trees protruding above the canopy and incurring an increased chance of lightning strikes. This seems like a reasonable hypothesis but Clewell and Ward (1987, 1989) did not demonstrate that lightning-struck trees were indeed taller than surrounding trees. Atlantic white-cedar is not the tallest tree at Lakeland and hardwoods intermixed with this tree have not been struck by lightning at anywhere near this rate. The other Atlantic white-cedar populations on the western shore did not have lightning strikes of this magnitude and it is not clear what factor(s) are responsible for this effect. One possible explanation is that some Atlantic white-cedar bogs contain bog iron and are preferentially attracting lightning. Trees in this situation face an increased risk of mortality due to lightning strikes. Lightning mortality on Atlantic white-cedar may be worth investigating in a future study.

Soils on uplands of Atlantic white-cedar habitats on the western shore were either on Collington, Evesboro, Galesboro, or Sassafras fine to loamy sand on slopes ranging from 2 to 40 percent (Kirby and Matthews 1973). Wetlands are composed of mixed alluvial or Bibb silt loam grading to tidal marsh at the outflow from Atlantic white-cedar habitat.

Herbarium vouchers were obtained from all sites and are recorded for Anne Arundel County, Maryland as follows: 16 December 1995, sandy and mucky areas on Cockey Creek feeding Magothy River, Phil Sheridan, Bill Scholl, Keith Underwood, Judy Broersma-Cole, Robert Cole, Robert Muller, Sheridan 1865; 17 December 1995, pond margins and intertidal freshes feeding Severn River at Lakeland, Phil Sheridan and Keith Underwood, Sheridan 1866; 29 July 1997, pond edges and river banks at Carrollton Manor on the Severn River, Phil Sheridan and Robert Muller, Sheridan 1987; 29 July 1997, spring freshes at juncture of deciduous sandy uplands and intertidal marsh as well as sphagnous hummocks at Sullivan Cove on the Severn River, Phil Sheridan and Robert Muller, Sheridan 1989; 29 July 1997, seepage bank at head of eastern branch of Forked Creek on Severn River, Phil Sheridan, Robert Muller, and Keith Underwood, Sheridan 1990; 13 August 1997, edge of *Cladium* marsh at head of Cypress Creek on east side of MD Route 2, 3/4 mile west of Severna Park, Sheridan 1991; 13 August 1997, peaty edge of creek at Arlington Echo Education Center off Indian Landing Road, located at head of Severn River southwest of Lakeland and 1 mile west of Sunrise Beach, Sheridan 1992; 30 January 1998, Atlantic white-cedar bog on branch feeding Cypress Creek at Dill Road, Phil Sheridan, William Sipple, and Keith Underwood, Sheridan 2004; 19 April 1998, sphagnous peat bog at mouth of Cypress Creek on the Severn River east of Evergreen Road and north of Sunrise Beach, Keith Underwood, Sheridan 2007.

DISCUSSION

Carrollton Manor and Sullivan Cove contain more than 94 percent of the Atlantic white-cedar seedlings on the western shore of Maryland. Cypress Creek Swamp and Sullivan Cove contain 51 percent of the mature trees. The skewed nature of the population data on these Atlantic white-cedar populations may reflect both their site history and natural quality.

Sullivan Cove has a large number of both seedlings and mature trees. The number of seedlings and trees at Sullivan Cove may reflect the high natural quality and relatively undisturbed nature of the site. Sullivan Cove is an excellent example of an intact intertidal fresh and sphagnum-bog Atlantic white-cedar habitat (fig. 2) and is only disturbed by a small gravel road bisecting the site. Several state rare plant species such as *Cladium mariscoides* (Muhl.) Torrey and *Platanthera ciliaris* (L.) Lindl. were also found at this site during the census.

The number and mean diameter (22.46 cm) of trees at Cypress Creek Swamp indicate a mature Atlantic white-cedar forest, compared to the early successional state of Sullivan Cove where there are many seedlings but tree diameter averages only 5.52 cm. Cypress Creek Savanna and Sullivan Cove share many floristic and hydrologic affinities. Both sites exhibit a continuum from tidal marsh to open sphagnous hummocks (savanna) to Atlantic white-cedar swamp. Cypress Creek Savanna has an unusually high rate of dead wood (77 percent) with a small mean diameter as well as very few living seedlings, which contrasts with the report of many vigorous Atlantic white-cedar seedlings at this site (Sipple and Klockner 1984). Sipple (personal communication, 1998) reports that much of this mortality occurred around 1988 along with a change in the floristic composition of the site. The most likely explanation for the mortality at Cypress Creek Savanna is some kind of hydrologic disturbance. We found no evidence of pathogens being responsible for this mortality, since dead trees were restricted within a zone, and adjacent trees in Cypress Creek Swamp were unaffected. Atlantic white-cedar is known to be killed by high tidal salinities (Fleming 1978), and tidal levels are known to be increasing along the eastern seaboard. Lowering of ground water levels through surface wells, interdiction of seepage from Cypress Creek Swamp through improvements along an adjacent road, general rise in tidal river levels, and subsequent salt intrusion into Cypress Creek Savanna appear to be the most likely cause of tree mortality.

Sullivan Cove has probably escaped the fate of Cypress Creek Savanna because of its somewhat higher topographic position. We have noted some mortality as well at Arlington Echo where trees formerly grew further out the cove where higher salinities might be expected. An understanding of effects of development on seepage waters, projected rises in tidal levels, and salt intrusion of coastal freshwater wetlands will be an important component of Atlantic white-cedar restoration on the western shore of Maryland.

The Dill Road site on Cypress Creek, also known as Bonnie's Bog, formerly contained *Sarracenia purpurea* L. (Sipple, personal communication, 1998), and a few *Chamaedaphne calyculata* (L.) Moench are still extant. Sedimentation and pollution from an adjacent road has resulted in the destruction of the upper reaches of the bog, and there are many large-diameter Atlantic white-cedar snags of 70-100 years in age. Restoration of the Dill Road site is warranted given the significant elements formerly or currently present at this site.

Carrollton Manor and Lakeland both contain tidal freshes and ponds with Atlantic white-cedar borders. Carrollton Manor has a large number of seedlings in comparison to Lakeland, a difference which we attribute to the effect of beavers browsing woody vegetation and lightly disturbing soils on the pond borders. Removal of plant competition by beavers may provide increased light for germination, or there may be an ancillary beneficial effect from soil

Figure 2—View of Sullivan Cove from Severn River beach at intertidal marsh. Note Atlantic white-cedar at intertidal fresh fracture at base of hillside slope and dramatic change to tidal marsh.

disturbance. Atlantic white-cedar pond habitats, such as Lakeland, which lack beaver disturbance, have a much lower number of seedlings.

Arlington Echo, Cockey Creek, and the Severn River Cypress Creek contain relatively few trees or seedlings despite apparently suitable soils and hydrology. They differ from the other sites in that they are positioned on or at the outflow of meandering creek systems over 2 km in length. The low numbers of Atlantic white-cedar in these three sites may be caused by competition with hardwood species preventing seedling establishment, disease, repeated logging, sterility, or other factors. Part of the population at Cypress Creek was destroyed by slumping of a hillside at a stormwater discharge point and subsequent inundation of the bog. Former abundant populations of Atlantic white-cedar on the Eastern Shore have been reduced to scattered individuals or loose aggregations (Sipple and Klockner, 1984). Similarly these three sites may represent fragments of former larger populations, and present conditions may eventually result in their loss. This would represent a significant reduction in current Atlantic white-cedar stands on the western shore of Maryland.

The Forked Creek population of Atlantic white-cedar is locally restricted by wetland habitat. The site is characterized by peaty soils on a springy hillside along a 20-meter bank of the Severn River. Surrounding banks are dry and limit this population to one cove.

Documentation of the former extent of the western shore populations of Atlantic white-cedar through examination of logging and naval records and peat analysis may help guide recovery efforts on the Severn and Magothy Rivers. The few individuals, low recruitment, and ample habitat or recovery potential at many of these sites warrant a restoration program to prevent the loss of these important populations on the western shore of Maryland.

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WOOD-BARK SPIRALITY CORRELATION IN *CHAMAECYPARIS THYOIDES*

Craig William Stewart and Elisabeth Wheeler

Abstract—The correlation between bark grain pattern and wood grain pattern in ten Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) trees was studied and found to be statistically significant. The trees came from the Jones Lake State Park, Bladen County, NC, and were knocked down by Hurricane Fran. Each tree had two sections removed from it, one at breast height and one at crown height. Each section had a 5- to 10-cm disk removed from it. From each disk a two-inch-wide strip was cut through the pith. Grain angle was measured from these strips. The imaginary longitudinal axis of the tree was used as a reference for measuring grain angle. A measurement of 4° or greater from the longitudinal axis was used to indicate spiral grain. Although this study found a correlation between wood and bark grain patterns, there is a need for further study to confirm the correlation because only ten trees were sampled from one site.

INTRODUCTION

Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) is an important species for the U.S. lumber and pole industries. The species is decay resistant, which makes it effective in the construction of fences and other structures in contact with either the ground or water. Spiral grain is a serious defect of wood and causes uneven shrinkage and an increased amount of warping during the drying process, as well as a reduced resistance to impact bending (Chiu and Lee 1993). It would be beneficial to the lumber industry to be able to predict if a tree contains wood with spiral grain. In other species, such as Taiwan incense-cedar (*Calocedrus formosana* Florin), bark grain angle can be used to predict wood grain angle. This paper presents the results of a pilot study that investigates whether spiral bark pattern would reliably predict spiral wood grain in Atlantic white-cedar.

If a relationship between bark pattern and wood grain angle exists, the information could be valuable to tree improvement programs, and would indicate whether to select only seeds from straight-grained trees. The Atlantic White-cedar Alliance is interested in determining if such a relationship exists. Increased amounts of straight grain should enhance the quality of lumber and poles of Atlantic white-cedar, which would create higher profit. Improved yield and quality would directly result from less warping during drying.

MATERIALS AND METHODS

The trees used in this study grew in a moist area with a soil mixture of wet peat and sand at Jones Lake State Park, NC, and were knocked down by Hurricane Fran in early September 1996. In February, 1997, K.O. Summerville (Griffith Forestry Center, Clayton, North Carolina) provided 10 trees from the stand. Five trees had obvious bark spirality; five had straight bark patterns. Two bolts were removed from each of the ten trees, one bolt from breast height and the other from the crown, yielding a total of 20 samples. The diameters at breast height (d.b.h.) and heights of the trees with spiral bark ranged from 9.8 to 15.4 inches and 69 to 82 feet; d.b.h. and heights of the trees with straight bark ranged from 9.7 to 15.8 inches and 70 to 84 feet.

Five- to ten-centimeter-thick cross-sectional disks were removed from all twenty samples. The disks from the breast-height group were removed 1.5 feet d.b.h. The disks from the crown-height group were removed from the middle section of the region termed the crown. Strips 2.5 to 3 centimeters thick were cut from each disk, cutting the pith in the north to south cardinal direction. The breast-height samples were split along the annual rings at 1 and 3 inches from the outer bark. The crown-height samples were split along the annual rings at 1 and 2 inches from the outer bark. For each tree, the presence of spiral-grained wood was determined for 8 samples, 4 per each height. However, when a knot was present at one of the predetermined splitting dimensions, another location was used so that clear grain could be measured. The grain angle (a) (deviation from the longitudinal axis of the tree) was measured using a protractor. For this study, fiber angles above 4° were scored as spiral grain because angles of this size and larger usually cause warping and shrinkage during drying of the wood.

RESULTS AND DISCUSSION

Results of the study are shown in table 1. Eighty percent of the samples in each group (breast-height and crown-height) had corresponding bark and wood grain patterns. The correlation between the two patterns was found to be 63 percent significant through the use of the dichotomous nominal scale data method (Zar 1984). A study of a larger sample size should increase the percent significance dramatically.

For this study, three correlating measurements per disk were the criterion to conclude that a sample's bark grain pattern (spiral of > 4° vs. straight) predicted its wood grain pattern. At breast height, trees 6 and 9

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Table 1–Proportion of spiral-grained (> 4° inclination) wood samples in trees with spiral-grained bark or straight-grained bark. Measured at breast height and at crown height (4 samples per height)

Tree number	Breast height	Crown height
	--------- *Percent* ---------	
Proportion of trees with spiral-grained bark having spiral-grained wood		
1	100	25
2	100	50
3	75	0
4	50	75
5	75	75
Proportion of trees with straight-grained bark having spiral-grained wood		
6	0	25
7	0	0
8	0	0
9	0	0
10	0	0

did not meet this requirement; for crown-height samples, trees 4 and 5 did not. There are at least three reasons for the lack of correlation: (1) there may have been a knot above or below the disc, thus altering the grain pattern at the measurement point, (2) the grain angle could have been observed incorrectly because a disc was not cut exactly perpendicular to the axis of the tree, so that the reference plane was not truly representative of the vertical axis, and (3) measuring grain angle at a substantial distance from the pith could show no spiral grain, although when measured closer to the pith, spiral grain may be prevalent. Spiral grain is more common in juvenile wood (Harris 1989), which is near the pith. In the future, grain angle in juvenile wood should also be measured.

The relationship between wood grain patterns at breast height and crown height for each tree was also examined. Within-tree samples from trees 2, 3, 4, and 9 did not have matching wood and bark grain patterns. The lack of within-tree correlation could be due to the three reasons given earlier. Also, this nonconformity could be due to grain pattern changing in the upper portion of the tree as the tree grows toward the nearest light source. Seventy percent of the samples taken from crown height exhibited some amount of straight grain.

CONCLUSION

This study indicates wood grain patterns and bark grain patterns may be correlated in Atlantic white-cedar. However, because of the small sample size a strong statistical relationship has not been shown. Further work is needed to verify this study's conclusions. Also, it is recommended that there be a study following the path of both spiral bark trees and straight bark trees through the lumber production process to determine the difference in lumber yield and quality and the economic gains. Further studies on the correlation between bark patterns and wood grain patterns should provide information to develop higher quality lumber from this species, creating higher prices for the material. The rewards for the Atlantic white-cedar lumber industry should be a driving force in the continuation of this study.

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ATLANTIC WHITE-CEDAR PLANT PRODUCTION

K.O. Summerville, William E. Gardner, L. Eric Hinesley, and Robert E. Bardon[1]

Abstract–The North Carolina Division of Forest Resources started production of Atlantic white-cedar, *Chamaecyparis thyoides* (L.) B.S.P., bare-root seedlings in the early 1980's. Problems with seedling quantity and quality led to a series of studies to determine the characteristics of acceptable seedlings, and nursery practices for their consistent production. This paper describes results from three of those studies established between 1989 and 1996: seedling comparison, nursery bed seedling production, and seedling size evaluation.

INTRODUCTION

The North Carolina Division of Forest Resources started production of Atlantic white-cedar, *Chamaecyparis thyoides* (L.) B.S.P., bare-root seedlings in the early 1980's. Seedling yields from these early tree nursery efforts produced disappointing quantities of acceptable plants. Both inconsistent germination of seed over the nursery bed surface and inconsistent size of seedlings at the end of the first growing season were obvious problems.

This paper reports results from three studies initiated between 1989 and 1996 in an effort to refine the definition of an acceptable seedling for out-planting, and to identify those nursery practices that would most consistently produce acceptable seedlings at a reasonable cost. The paper is divided into three sections that deal with those studies: seedling comparison, nursery bed seedling production, and seedling size evaluation.

SEEDLING COMPARISON STUDY

The seedling comparison study was initiated in 1989 to determine what type of planting stock might be necessary for forest restoration of Atlantic white-cedar in eastern North Carolina. Three types of seedlings–bare-root seedlings from the conventional 1-0 nursery bed production, 3.0 cubic inch (small) containerized seedlings, and 5.5 cubic inch (large) containerized seedlings–were out-planted on three sites representing a range of soil and vegetative competition conditions. The seedlings were produced in 1989, and the three sites (Chowan County, mineral soil, light herbaceous vegetation; Pasquotank County, organic soil, medium herbaceous vegetation; Columbus County, mineral soil, heavy herbaceous and shrub vegetation) were planted in March of 1990.

A sample of the three types of seedlings at the time of planting reflected differences in height and root-collar diameter (RCD): the large containerized plants averaged 0.11 inch RCD and 0.99 feet in height; small containerized plants averaged 0.08 inches RCD and 0.54 feet in height; and bare-root 1-0 plants averaged 0.13 inches RCD and 0.51 feet in height.

After out-planting, the seedling mortality, heights and diameters were measured following the first, second, third, and fifth growing seasons. First year results (table 1) and fifth year results (table 2) are reported here.

After the first year's growth (table 1), the large containerized plants and bare-root plants were similar in both height and root-collar diameter. Small containerized plants were somewhat smaller in height and significantly smaller in diameter. First year mortality across all sites was significantly higher for bare-root seedlings (9 percent) than for either size containerized seedlings, but still acceptably low for reforestation. Mortality varied from site to site: none at Chowan County, light mortality which appeared to be browse related on the Pasquotank County site, and more distinct differences between bare-root and containerized plants associated with vigorous vegetative competition on the Columbus County site.

Measurements following the fifth growing season (table 2) indicated that overall mortality had continued to rise on all sites, reaching 21 percent. Mortality of bare-root seedlings was still higher than containerized seedlings (by about 6 percent), but the difference had declined since the first growing season (7.5 percent) and no was longer statistically significant. Mortality has continued to be site specific: little at Chowan County, and about the same at the other two sites. Height differences on individual sites were not significant, though the slight advantage of large over small containerized seedlings over all sites was statistically significant for both height and diameter.

To date, the bare-root seedlings have performed intermediate between the small and large containerized stock in size, but sustained higher initial mortality. The large containerized stock has continued to outperform the small containers with consistent but small differences in height and diameter.

NURSERY BED SEEDLING PRODUCTION STUDY

The objective of this study was to determine nursery bed cultural practices for production of acceptable bare-root 1-0

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Table 1–Field performance of Atlantic white-cedar seedlings after one growing season

Site and soil	Treatment	Root collar diameter	Height	Mortality
		Inches	*Feet*	*Percent*
Overall	Overall	0.17	1.62	4
	Large Container	.18a[a]	1.75a	1a
	Small Container	.14b	1.46b	2a
	Bare-root	.19a	1.64ab	9b
Chowan Co. mineral soil	Large Container	.21a	2.06a	0a
	Small Container	.18b	1.82b	0a
	Bare-root	.22a	1.65c	0a
Pasquotank Co. organic soil	Large Container	.17a	1.51a	4a
	Small Container	.12b	1.18a	4a
	Bare-root	.16a	1.76a	8b
Columbus Co. mineral soil	Large Container	.16a	1.57a	0a
	Small Container	.11b	1.25b	2a
	Bare-root	.19c	1.52a	18b

[a] Means within a column by site (and overall) with the same letter are not statistically different (P < 0.05).

Table 2–Field performance of Atlantic white-cedar seedlings after five growing seasons. Chowan and Pasquotank Counties were measured in June 1995; Columbus County was measured in May 1996

Site and soil	Treatment	Root collar diameter	Height	Mortality
		Inches	*Feet*	*Percent*
Overall	Overall	0.66	8.7	21
	Large Container	.75a[a]	9.1a	19a
	Small Container	.59b	8.4b	19a
	Bare-root	.63ab	8.5ab	25a
Chowan Co. mineral soil	Large Container	.49a	7.9a	4a
	Small Container	.38b	7.4a	2a
	Bare-root	.47ab	17.7a	0a
Pasquotank Co. organic soil	Large Container	1.18a	10.0a	24a
	Small Container	1.07a	9.1a	30a
	Bare-root	1.00a	8.8a	40a
Columbus Co. mineral soil	Large Container	.66a	9.9a	28a
	Small Container	.43b	9.1a	24a
	Bare-root	.54ab	9.5a	34a

[a] Means within a column by site (and overall) with the same letter are not statistically different (P < 0.05).

seedlings for forest restoration. The study was installed in the seedling production beds of the North Carolina Division of Forest Resources, Goldsboro Forestry Center, Claridge Nursery during the 1994 and again during the 1995 seedling crop years.

Field design initially included six replications of five soil treatments on shaded and non-shaded nursery beds. Shade was created by placing 50 percent shade cloth over the seed bed immediately after sowing the seeds. The shade cloth was left in place for 9 weeks until seed germination was completed. The five soil treatments included: 1 = bed without mulch or amendment; 2 = one bushel of loose sphagnum peat moss mixed into the top six inches of soil along a five-foot length of bed (20 square feet); 3 = one-half inch of sphagnum peat moss spread on top of bed; 4 = one-half inch of a 50/50 mixture of peat and vermiculite applied on top of bed; 5 = one-half inch of chopped pine straw mulch applied over the bed following seeding.

Each treatment plot consisted of five linear feet of nursery bed. Atlantic white-cedar seeds were broadcast sown on the top of the beds in experimental soil treatments 1 through 4; they were covered by one-half inch of pine straw in accordance with standard nursery practice in treatment 5. Seeds were sown at a rate calculated to produce an estimated thirty-five seedlings per square foot. A standard nursery fertilizer program was followed. High soil moisture levels (approximately one inch of water per week) were maintained through the first six weeks to enhance seed germination. Then approximately one-half inch of water per week was applied through the growing season. In early fall, irrigation was stopped to facilitate the plant hardening-off process.

Four permanent data collection sub-plots (one square foot each) were established in each treatment. These sub-plots were used to collect data relating to seed germination and germinant survival (tables 3 and 4), and the number of seedlings per square foot (within each height-class) at the time of lifting (tables 5 and 6). Height classes were defined as: 1 = 0 to 5 cm; 2 = 5.1 to 10 cm; 3 = 10.1 to 15 cm; 4 = 15.1 to 20 cm; 5 = 20.1 to 25 cm; and 6 = > 25 cm.

This study was installed in 1994. Seeds were sown the second week of May. The numbers that germinated after three, four, and five weeks, as well as the number that survived, are reported in table 3. Seedling growth during the 1994 season progressed without unusual disturbances, and in January 1995 the crop was lifted, counted, and sorted into the six height classes (table 5).

Table 3—Germination and survival of Atlantic white-cedar by soil treatment and shade treatment in 1994

Shade treatment	Soil treatment[a]	Germination 1 May 30	Germination 2 June 10	Germination 3 June 16	Total germination	Alive June 16
		Number of seedlings per square foot				
Overall	Overall	45.5	12.1	4.16	1.7	44
Shade	Overall	63.0a[b]	14.8a	4.4a	82.2a	61a
No shade	Overall	28.0b	9.5b	3.7a	41.2b	27b
Overall	1	31.7b	7.0c	2.3c	41.0b	30c
	2	50.5a	11.1bc	5.6a	67.2a	53a
	3	38.3b	19.3a	5.0ab	62.6a	45ab
	4	51.3a	14.9ab	4.4ab	70.6a	53a
	5	55.6a	8.4c	3.0bc	67.0a	38bc
Shade	1	61.5[c]	12.5	4.0[c]	78.0[c]	57[c]
	2	77.9[c]	13.5	7.7[c]	99.1[c]	82[c]
	3	53.0[c]	20.5	4.8[c]	78.3[c]	60[c]
	4	71.4[c]	17.5	3.9[c]	92.8[c]	70[c]
	5	51.0[c]	10.4	1.5[c]	62.9[c]	35[c]
No shade	1	1.9[c]	1.5	0.5[c]	3.9[c]	3[c]
	2	23.0[c]	8.8	3.6[c]	35.4[c]	25[c]
	3	23.5[c]	18.0	5.1[c]	46.6[c]	30[c]
	4	31.2[c]	12.3	5.0[c]	48.5[c]	36[c]
	5	60.2[c]	6.7	4.5[c]	71.4[c]	41[c]

[a] Soil treatments: 1 = bed without mulch or amendment; 2 = peat mixed into bed; 3 = peat applied on top of bed; 4 = peat/vermiculite applied on top of bed; 5 = pine straw mulch applied on top of bed.

[b] Means within a column by shade treatment and by soil treatment with the same letter are not statistically different ($P < 0.05$).

[c] Shade-by-soil interaction is significant ($P < 0.01$) with respect to germination 1, germination 3, total germination, and survival.

Table 4—Germination and survival of Atlantic white-cedar by soil treatment and shade treatment in 1995

Shade treatment	Soil treatment[a]	Germination 1 May 4	Germination 2 May 11	Germination 3 May 18	Total germination	Alive July 19
		Number of seedlings per square foot				
Overall	Overall	27.2	14.8	6.8	48.8	14
Shade	Overall	35.5a[b]	15.8a	7.9a	59.2a	16a
No shade	Overall	18.8b	13.8a	5.7b	38.3b	11a
Overall	1	21.8b	8.9c	4.1c	34.8b	6a
	2	43.5a	19.3ab	7.1ab	69.9a	16a
	3	16.5bc	13.4bc	8.4a	38.3b	16a
	4	14.0c	11.5c	5.0bc	30.5b	11a
	5	39.9a	20.8a	9.4a	70.1a	19a
Shade	1	39.6[c]	15.4	7.3[c]	62.3[c]	11
	2	82.7[c]	33.2	13.4[c]	129.3[c]	30
	3	14.3[c]	8.1	6.6[c]	29.0[c]	14
	4	11.2[c]	7.1	4.4[c]	22.7[c]	11
	5	29.8[c]	15.3	7.9[c]	53.0[c]	16
No shade	1	4.1[c]	2.5	0.8[c]	10.4[c]	3
	3	18.7[c]	18.8	10.3[c]	47.8[c]	18
	4	16.9[c]	16.0	5.6[c]	38.5[c]	11
	5	50.0[b]	26.2	10.9[c]	87.1[c]	22

[a] Soil treatments: 1 = bed without mulch or amendment; 2 = peat mixed into bed; 3 = peat applied on top of bed; 4 = peat/vermiculite applied on top of bed; 5 = pine straw mulch applied on top of bed.
[b] Means within a column by shade treatment and by soil treatment with the same letter are not statistically different ($P < 0.05$).
[c] Shade-by-soil interaction is significant ($P < 0.01$) with respect to germination 1, germination 3, total germination, and survival.

Table 5—Number of Atlantic white-cedar seedlings in the nursery bed by soil treatment and shade treatment, with the percent in each size class at the end of the 1994 growing season

Shade treatment	Soil treatment[b]	Height class[a] 1	2	3	4	5	6	Number
		Percent						*Per ft²*
Overall	Overall	4d[c]	26b	34a	25b	10c	1d	37
Shade	Overall	3	25	33	26	11	2	51a
No shade	Overall	4	27	37	23	8	1	23b
Overall	1	14	49	27	9	1	0	23c
	2	1	16	35	32	14	2	47a
	3	1	21	37	26	12	3	37ab
	4	2	20	35	28	13	2	45a
	5	6	35	33	19	6	1	32bc
Shade	1	14	48	27	10	1	0	44
	2	1	15	34	32	16	2	73
	3	1	22	35	26	13	3	48
	4	1	19	34	31	13	2	61
	5	3	32	33	23	8	1	30
No shade	1	10	56	29	5	0	0	2
	2	3	19	40	30	7	1	21
	3	1	20	40	26	12	1	25
	4	3	24	38	23	11	1	30
	5	9	38	33	16	4	0	35

[a] Height classes: 1 = 0 - 5 cm; 2 = 5.1 - 10 cm; 3 = 10.1 - 15 cm; 4 = 15.1 - 20 cm; 5 = 20.1 - 25 cm; 6 = > 25 cm.

[b] Soil treatments: 1 = bed without mulch or amendment; 2 = peat mixed into bed; 3 = peat applied on top of bed; 4 = peat/vermiculite applied on top of bed; 5 = pine straw mulch applied on top of bed.

[c] Overall values for height classes and numbers of seedlings per square foot by shade and soil treatment with the same letter are not statistically different ($P < 0.05$).

Table 6—Number of Atlantic white-cedar seedlings in the nursery bed by soil treatment and shade treatment, with the percent in each size class at the end of the 1995 growing season

Shade treatment	Soil treatment[b]	Height class[a] 1	2	3	4	5	6	Number
		Percent						*Per ft²*
Overall	Overall	5cd	20b	33a	26b	12c	4d	12
Shade	Overall	6	22	32	24	12	4	14a
No shade	Overall	5	18	34	27	11	5	10b
Overall	1	11	36	33	12	6	2	5c
	2	4	11	24	34	19	8	15ab
	3	4	21	29	27	13	6	14ab
	4	3	18	37	27	13	2	11b
	5	9	24	42	20	4	1	16a
Shade	1	11	38	32	13	5	1	10
	2	3	10	24	35	20	8	26
	3	3	33	33	21	7	3	12
	4	2	24	38	23	11	2	10
	5	12	20	45	18	4	1	14
No shade	1	17	33	50	0	0	0	1
	2	0	19	22	33	15	11	3
	3	5	12	26	31	17	9	16
	4	3	12	37	31	15	2	11
	5	7	27	39	22	3	2	19

[a] Soil treatment: 1 = bed without mulch or amendment; 2 = peat mixed into bed; 3 = peat applied on top of bed; 4 = peat/vermiculite applied on top of bed; 5 = pine straw mulch applied on top of bed.

[b] Height classes: 1 = 0 - 5 cm; 2 = 5.1 - 10 cm; 3 = 10.1 - 15 cm; 4 = 15.1 - 20 cm; 5 = 20.1 - 25 cm; 6 = > 25 cm.

[c] Overall values for height classes and numbers of seedlings per square foot by shade and soil treatment with the same letter are not statistically different ($P < 0.05$).

A second installation of similar design was sown in late April 1995. Germination is reported in table 4. The 1995 growing season was subsequently affected by several destructive thunder storms with unusually high winds and heavy rain in three successive weeks of June. Only four replications survived the 1995 growing season and were used in this analysis. The 1995 crop was lifted in March 1996. Results are reported in table 6.

In the 1994 planting, shade treatment significantly improved total germination (table 3). Across the combined shade treatments, soil treatments #2-5 (including the standard production practice #5) all yielded similar germination, while treatment 1 was significantly poorer. However, this overall result masks the fact that, under shade, all experimental soil treatments (#1-4) germinated better than the standard practice, while without shade the standard practice germinated best. The standard practice was the only soil treatment that germinated poorer and had fewer germinants remaining alive with shade than without shade. All other soil treatments germinated better and had higher survival with shade than without shade. Three-fourths of all germination occurred by May 30 (about three weeks from sowing). Three-fourths of the remaining germination had occurred by June 10 (four weeks from sowing). Over the entire study, 71 percent of all germinants (44 of 61.7 per square foot) were still alive after five weeks (June 16); a higher proportion with shade than without shade, and a higher proportion on all experimental treatments (#1-4) than under the standard practice (#5).

In the 1995 planting, the shade treatment again significantly improved total germination (table 4). Across the combined shade treatments, soil treatment #2 again performed about as well as treatment #5 (the routine production practice), in terms of total germination; however, treatments 3 and 4, in addition to treatment 1, were significantly poorer. Germination results with shade and without shade were more variable than the previous year. Without shade, the standard production practice (#5) again outperformed all other soil treatments in germination and survival. Under shade, only soil treatments #1 and 2 outperformed the standard production practice in germination, and only soil treatment #2 had more seedlings surviving by July 19. Slightly more than half of all germination (27.2 of 48.8 per square foot) occurred by May 4 (about two weeks from sowing). Two-thirds of the remaining germination had occurred by May 11 (three weeks from sowing). Over the entire study, only 27 percent of all germinants (14 of 48.8 per square foot) were still alive by July 19; the number varied by soil treatment and was heavily influenced by severe weather.

At the end of the 1994 growing season, when seedlings were lifted, counted, and separated into six height classes, the number of seedlings per square foot was significantly higher on plots that had been under shade (table 5). Two soil treatments (#2 and 4) had significantly more seedlings per square foot than the standard nursery practice (#5) or the other treatments. Under shade, all experimental soil treatments produced more seedlings per square foot than the standard production practice, whereas the standard practice produced the most seedlings per square foot where there was no shade. Overall, one-fourth of the lifted seedlings were categorized as in class 2, one-third as class 3, and one fourth as class 4. The high bed densities observed in this study (approximately 45 to 70 per square foot) did not adversely affect the distribution of seedlings among size classes: shaded plots had the same distribution across classes 2, 3 and 4 as the overall average, and soil treatments #2 and 4 had higher than average numbers of seedlings in classes 4 and 5, especially under shade.

At the end of the 1995 growing season, when seedlings were lifted, counted, and separated into the six height classes, the number of seedlings per square foot was again significantly higher on plots that had been under shade than on plots without shade (table 6); however, bed densities (averaging 12 per square foot) were much lower than in 1994. Also differing from the earlier year, two soil treatments (#1 and 4) had significantly fewer seedlings per square foot than the standard nursery practice or the other treatments. Soil treatment #2 was still the best among the experimental treatments (#1 through 4). Though it did not produce more seedlings per square foot than the standard production practice overall, it clearly out-produced all other soil treatments under shade, while the standard practice was again best without shade. Overall, one-fifth of the lifted seedlings were categorized as class 2, one-third as class 3, and one fourth as class 4, fairly consistent with the previous year's results. Once again, soil treatment #2 produced a higher than average proportion of class 4 and 5 seedlings.

SEEDLING SIZE EVALUATION STUDY

The seedling size evaluation study was a direct continuation of the nursery bed study reported above. Its objective was to determine the minimum size bare-root seedling acceptable for transplanting to a reforested site.

The seedlings from the nursery bed studies of 1994 and 1995, sorted by the six height classes, were planted in February 1995 and April 1996. The four sites (in two years) included two plantings on organic soils in 1995: Bladen Lakes State Forest and Washington County (Pocosin Lakes National Wildlife Refuge), and in 1996 a wet, mineral-soil site on Bladen Lakes State Forest, and an organic-soil site in Pamlico County. The planting design utilized the six height classes as treatments, with five-tree row plots of each treatment randomized within each of eight replications on each site. Seedling height, animal browse damage, and mortality were recorded after one growing season (table 7).

The 1995 Bladen Lakes site was prepared by bedding, but fairly strong shrub competition emerged during the growing season. The Washington County site was flat-planted and developed a moderate herbaceous competition. Both 1996 sites were flat-planted; Bladen Lakes developed moderate, and Pamlico County had heavy, herbaceous competition. Plant spacing on all sites was five feet within rows and eight feet between rows. The Washington County site received unusually high rainfall, remaining flooded for much of the 1995 growing season, so heights were not recorded.

Table 7—Height, mortality and browse damage following one growing season on Atlantic white-cedar seedlings planted on four sites in 1995 and 1996

		Seedling height class[a] from nursery					
Site	Mean	1	2	3	4	5	6
Overall							
Height (ft)	0.84	0.45a[b]	0.64b	0.87c	0.96cd	0.99cd	1.04d
Mortality (%)	17	28a	16bc	9c	16bc	19b	14bc
Browse (%)	7	1a	5abc	5ab	9bc	11c	8bc
1. Bladen Lakes 1995							
Height (ft)	.84	.51a	.70b	.86c	.87c	1.05d	1.05d
Mortality (%)	2	3a	0a	3a	5a	0a	0a
Browse (%)	8	3a	3a	3a	21c	8ab	15bc
2. Washington Co. 1995							
Mortality (%)	22	33a	25abc	13bc	28ab	25abc	10c
3. Bladen Lakes 1996							
Height (ft)	1.48	.82a	1.13b	1.67c	1.69c	1.73c	1.96d
Mortality (%)	19	20bc	10cd	3d	8cd	35ab	40a
Browse (%)	7	0a	3a	10ab	8ab	15b	4ab
4. Pamlico Co. 1996							
Height (ft)	1.01	.38a	.61b	.87c	1.08d	1.22d	1.46e
Mortality (%)	25	58a	30b	18bc	23bc	15bc	8c
Browse (%)	11	0a	18ab	6ab	3a	21b	11ab

[a] Height classes: 1 = 0 - 5 cm; 2 = 5.1 - 10 cm; 3 = 10.1 - 15 cm; 4 = 15.1 - 20 cm; 5 = 20.1 - 25 cm; 6 = > 25 cm.

[b] Overall values within rows with the same letter are not statistically different ($P < 0.05$).

Following the first growing season, the mean height across all four plantings was 0.84 feet (table 7). Seedlings of the largest height-class consistently produced larger average height values at the end of the first growing season. Mean mortality was 17 percent across all plantings. The smallest height class (#1) developed significantly higher mortality than the other height classes. On the unusually wet Washington County site, class 3 and 6 seedlings had significantly lower mortality than class 1; however, the other categories had intermediate results. Under the heavy herbaceous competition on the Pamlico County site, mortality was unacceptably high in class 1 seedlings, and was consistently lower within the larger height classes. Height class #1 also had less browse damage than the others, but browse damage has remained relatively low on all sites during the first year (averaging 7 percent).

Additional years' observations on these and other plantings may help refine the minimum acceptable seedling size for specific conditions of soil type, site preparation, and weed competition. These early observations have only shown the class 1 seedlings to be inferior in terms of mortality, though height correlates positively and fairly consistently across the range of size classes.

PRODUCTION AND QUALITY OF ATLANTIC WHITE-CEDAR SEED IN COASTAL NORTH CAROLINA

Franklin T. Bonner and K.O. Summerville[1]

Abstract–A 3-year study of Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) seed production and quality in North Carolina revealed that: (1) drying cones at 35 or 40 °C combined with 1 or 2 wet/re-dry cycles extracted 90 percent or more of the viable seeds without damage; (2) on the average there were about 10 seeds per cone, with only 1 or 2 of those filled; (3) seed lots may be cleaned to a high degree of purity and fullness with air-screen cleaners and small seed blowers, although some filled seeds must be sacrificed to achieve the latter; (4) stratification for 4 weeks produced near-maximum germination at the fastest rates for most seed lots, although geographic and seed-year variations still occurred; (5) yields and germination of seeds from trees less than 10 years of age were equal to that of seeds from older trees (45+ years); (6) natural seedfall in two well-stocked stands placed some 800 to 1,500 viable seeds per m^2 in the top 5 cm of the litter, and buried seed tests showed that as many as half of these could survive for 1 year in the litter, and some for 2 years.

INTRODUCTION

Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) is a valuable tree of coastal wetlands that occurs in a narrow belt from southern Maine to southern Mississippi (Little 1979). Its wood is highly prized for boats, posts, and utility poles (Kuser and Zimmerman 1995). An intermediate tolerance to shade and rather exacting seedbed moisture requirements (Little and Garrett 1990) combine to make natural regeneration of Atlantic white-cedar problematic on many sites. The recent widespread interest in preserving and restoring forested wetland ecosystems has brought increased attention to artificial regeneration of this species and to a number of the problems associated with seedling production.

Seed production by Atlantic white-cedar is prolific, but as for many such species, there seems to be a large proportion of the seeds that are empty. Because seed production begins at the early ages of 3 to 5 years (Little and Garrett 1990), and cone collection from young trees is very easy, questions are frequently raised about the quality of seeds from very young trees. Varying degrees of dormancy also contribute to the difficulties of seedling production (Boyle and Kuser 1994). A desire for better stand establishment of Atlantic white-cedar on the Alligator River National Wildlife Refuge, North Carolina, (ARNWR) by the U.S.Department of the Interior Fish and Wildlife Service, and the U.S. Department of Defense prompted the studies on seed production and quality described in this paper.

MATERIAL AND METHODS

General

The majority of seeds used in these studies were collected by personnel of the U.S. Fish and Wildlife Service, U.S. Air Force, and North Carolina Division of Forest Resources on or near the ARNWR from 1992 to 1994. Cones were partially dried, bagged, and shipped to the U.S. Forest Service Seed Research Laboratory in Starkville, Mississippi, for seed extraction and testing. Upon receipt, the bags were opened for additional drying. No evidence of damage to cones or seeds during shipment was observed. Some samples were extracted in North Carolina, and the seeds were shipped to Starkville. Cone collections in Jackson County, Mississippi, were made by the senior author.

For evaluation of the soil seed bank potential, blocks of litter/soil were collected on the ARNWR and sent immediately to Starkville. For tests of seed longevity in the soil, samples of cleaned seeds were placed in mesh bags in Starkville and flown to the Refuge for burial on forest sites. Bags were retrieved each year and shipped to Starkville for analysis of the quality of the remaining seeds.

Extraction and Yield

Cones collected in 1992 from mature trees (45+ years) at two Dare County, NC, stands: Milltail Creek (within the ARNWR) and Sycamore Road (within the U.S. Air Force Dare County Range). Cones were dried in petri dishes for 24 hours at temperatures of 30, 35, or 40 °C (±1°) maintained in forced-draft laboratory ovens. The cones were then uniformly shaken by hand in a box for 1 minute to extract the seeds. In one treatment group, the cones were then dissected by hand to recover all seeds. Other cone samples were subjected to wet/re-dry cycles. They were sprayed with a water mist and enclosed in plastic bags for 10 to 12 hours to ensure cone closure, re-dried at the same temperatures, and re-shaken. There were four treatments: 0, 1, 2, and 4 wet/re-dry cycles. After the last shaking, each cone was dissected by hand to recover all seeds. There were 4 replications of 25 cones each for

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each temperature and wet/re-dry cycle combination. Extraction efficiency was calculated by dividing number of seeds shaken from the cones by total number of seeds in the cones (shaken + hand-extracted).

Another test was carried out with 1993 cones from mature trees from both stands. All drying was on a table in the laboratory (23 °C, 50 percent RH), and all cones went through 3 wet/re-dry cycles. It took about 5 days for cones to open completely under these conditions. Each seed fraction was weighed and x-rayed to determine the number of filled seeds. Samples of these seeds were cleaned and upgraded (empty seeds removed) with a seed blower, then germinated without any pretreatment in cabinet germinators under official test conditions (ISTA 1993). The seeds were placed on moist germination blotters under an alternating temperature regime of 8 hours (light) at 30 °C, then 16 hours (dark) at 20 °C.

Individual tree collections were also made in 1992 from 60 trees in young plantations and natural stands, ages 8 to 10 years, from 15 counties in North Carolina. Four bags of 100 cones each were collected from each tree. These cones were dried indoors, shaken to remove seeds, then crushed to ensure that all seeds were removed. After cleaning, the seeds were x-rayed to determine how many seeds were filled, then germinated as described above. Average yields per cone were calculated from the bulked lots, and not from individual cone data.

Seed Cleaning

Different methods for cleaning and upgrading (removing empty seeds) were tested on the bulk collections of several years and various stands. No planned experiments were carried out; methods were worked out by trial and error.

Table 1—Extraction efficiencies for various cone-opening treatments on 1992 cones from mature trees at Milltail Creek, Alligator River National Wildlife Refuge, North Carolina. Results from the nearby Sycamore Road stand (not shown) were similar

Temp.	Wet / redry cycles	Extraction efficiency
	Number	*Percent*
30 °C	0	53
	1	75
	2	93
	4	96
35 °C	0	69
	1	81
	2	97
	4	100
40 °C	0	76
	1	93
	2	100
	4	100

Stratification Trials

Several stratification trials were carried out to assess the degree of dormancy encountered in different seed lots. Samples of 50 or 100 seeds were imbibed overnight in polyethylene bags of tap water at room temperature. The excess water was poured off, and the bags were placed in a refrigerator at 2-3 °C for periods ranging from 2 to 12 weeks. Seeds were then germinated as described previously, except that test periods were sometimes extended to make sure that all viable seeds germinated. Light requirement for germination was tested with a paired test of light and dark germination with foil-covered petri dishes in the same germinators.

Soil Seed Bank

Soil and litter blocks 10 x 10 x 5 cm (4 x 4 x 2 in.) were removed from the surface in two stands in the ARNWR. These blocks were carefully cut into 3 layers approximately 2.5 cm (1 in.) thick and placed in germinators set at the conditions described previously. When germination was apparently complete, the blocks were removed, dried, crushed, and sifted through a screen mesh to recover the remaining seeds. These seeds were examined and classified as "good" or "bad." "Good" seeds were full-sized and apparently fully developed; "bad" seeds were undersized or broken.

Longevity was tested by burying plastic mesh pouches with 100 seeds each at 12 plots in each of two stands: Sycamore Road in l993 and Milltail Creek in 1994. The pouches were covered with about 1 in. of litter. One pouch was retrieved from each plot annually, and the surviving seeds were counted and germinated in the Starkville laboratory as described previously.

RESULTS AND DISCUSSION

Extraction and Yield

Extraction efficiency exceeded 90 percent at all temperatures when used in combination with wet/re-dry cycles (table 1). Drying at 30 °C required 3 cycles to achieve this level; 35 °C required 2 cycles; and 40 °C required only 1 cycle. Results were similar for both collections. This technique is used on other conifer species and is sometimes referred to as "teasing" the seeds from the cones. In extraction of the 1993 bulk collection from Milltail Creek, each cycle yielded fewer seeds and slightly lower proportions of filled seeds (table 2). When samples from the fractions were tested, however, fraction #1 germinated 55.0 percent, and a bulked sample from fractions #2 and 3 germinated 62.8 percent. Fewer filled seeds were recovered in repeated wet/re-dry cycles, but their quality equaled that of seeds recovered in the first drying.

Average total seed yields per cone from mature trees in 1992 were 9.4 ± 0.4 for the Sycamore Road lot and 7.6 ± 0.3 for the Milltail Creek lot. Average number of filled seeds, however, was only 1.0 for the Sycamore Road lot and 0.6 for the Milltail Creek lot. Yields from the young trees in 1992 were similar. They averaged from 2.1 to 10.2 total seeds per cone and <0.1 to 1.4 filed seeds per cone.

Table 2—Seed yield from bulk collections in 1993 from mature trees at Milltail Creek, Alligator River National Wildlife Refuge, North Carolina

Wet/redry cycles	Weight	Percent of total	Filled seeds
	g		*Percent*
1	119.2	67	51
2	33.9	19	38
3	24.3	14	32
Total	177.4	100	

Yields from mature trees in 1993 from Milltail Creek and Sycamore Road averaged 4.9 and 2.5 seeds per cone and 2.0 and 0.3 filled seeds per cone. Collections from young trees in 1993 from many of the same areas used in 1992 produced comparable counts: 5.2 to 8.6 total seeds per cone and 0.2 to 1.7 filled seeds per cone. These results confirm the widely-held belief that there are typically very few filled seeds in Atlantic white-cedar cones. Bianchetti and others (1993) report approximately 20 percent filled seeds in a bulked sample of North Carolina sources. Yield differences among locations and stands are likely due to variation in pollen supply or weather during pollination. The results also clearly show that there were no differences between mature and very young trees in yield and quality of seeds.

Seed Cleaning

Preliminary cleaning of seed lots was successfully carried out with small air-screen cleaners or hand screens of the same type. Cones and large debris were removed with a #10 1/2 (4.2 mm) round-hole screen, and smaller debris, primarily needle fragments, was removed with a #7 (2.8 mm) round-hole screen. Two or three passes over the #7 screen were required to remove most of the small debris. Other screen sizes may be required for other collections, as seed size can vary among sources and years.

Very fine debris and a significant amount of empty seeds were removed from the small lots with the Stults and General ER® laboratory blowers. For larger lots, the same thing could probably be accomplished with a fractionating aspirator, but we were unable to test such a machine in this study because of the small lot sizes. With the 1992 collections, cleaning and upgrading as described above produced final purities of 81 and 94 percent for the Sycamore Road and Milltail Creek lots respectively. Average seed weights were 1,136 ± 18 and 1,1421 ± 19 seeds per gram for these lots. To reach purities of this level, however, seed managers must be prepared to lose some filled seeds in the process. We upgraded one lot from Croatan National Forest in North Carolina to 60 percent filled seeds, and higher levels are possible. The amount of losses will vary by seed lot, but the cost seems small to pay for lots of high purity and fullness.

Stratification Trials

The first stratification test compared periods of 0, 4, 8, and 12 weeks with an older seed lot stored by the North Carolina Division of Forest Resources. These seeds were apparently quite weak, as it took 140 days to get complete germination (table 3). The results suggest that stratification certainly stimulated germination, but that even 12 weeks might not be enough for maximum germination. The second test, with seeds from the bulk collections in 1992 from Milltail Creek and Sycamore Road stands compared only 0, 2, and 4 weeks. It confirmed the benefits of stratification, but 4 weeks did not appear to be long enough, even though the test was allowed to run for 48 days (table 3). Light slightly increased germination of unstratified seeds of these lots: 9 percent for Milltail Creek and 3 percent for Sycamore Road. A third test with 1992 bulk collections from Brunswick and Jones Counties, North Carolina, suggested that 4 weeks was optimum in terms of germination rate and also for total germination for one of the lots (table 4). In the fourth stratification test, there were

Table 3—Results of stratification tests on old stored seeds from the NC Division of Forest Resources and the 1992 bulk collections from Milltail Creek and Sycamore Road stands in Dare County, N.C. Percentages are based on total seeds. Test periods were NC Division of Forest Resources = 240 days, and 1992 Alligator River National Wildlife Refuge bulk lots = 48 days

Stratification period	Source: NC Div. of For.	Source: Milltail Creek	Source: Sycamore Road
Weeks	*Germination (pct.)*		
0	3.0	5.7	9.7
2	—	11.3	11.0
4	34.6	17.0	19.3
8	25.6	—	—
12	46.6	—	—

Table 4—Results of stratification tests on 1992 bulk lots from Brunswick and Jones Counties, N. C. The seed lots were extensively cleaned, and percentages are based on filled seeds only. Test period was 28 days

Stratification period	Brunswick Co. Germ.	Brunswick Co. Peak value	Jones Co. Germ.	Jones Co. Peak Value
Weeks	*Pct.*	*Pct./day*	*Pct.*	*Pct./day*
0	67.4	3.4	75.4	3.5
2	77.1	3.3	75.0	3.6
4	94.3	5.6	77.6	4.4
8	96.7	4.8	64.4	3.6

Table 5—Germination rate expressed as mean germination time (MGT) and peak value for four different stratification periods. Data represent mean values from 12 different seed sources collected in 1992, 1993, and 1994

Stratification period	MGT	Peak value
Weeks	*Days*	*Pct./day*
0	14.24	3.8
2	13.22	4.5
4	12.36	5.5
8	13.29	5.3

Table 6—Germination of seeds buried in litter at two sites in Dare County, N.C. Values are means of 12 plots. (ARNWR = Alligator River National Wildlife Refuge)

Site	Original germination	Germination after 1 year	2 years
	- - - - - - - - - *Percent*	- - - - - - - -	
Sycamore Road (Air Force Range)	17.0	7.1	6.6
Milltail Creek (ARNWR)	59.0	30.8	—

12 seed lots, 11 from eastern North Carolina, and 1 from Jackson County, Mississippi. The combined results (table 5) show germination rate only, expressed both as mean germination time (MGT) and peak value (PV) after Czabator's (1962) method. Germination rate was definitely greater with 4 weeks of stratification. Some of these lots were from very young trees (< 10 years) in natural stands, and their performance was equal to that of seeds from mature trees.

Bianchetti and others (1993) reported that 14 days of stratification was enough to produce maximum germination in 28 days in the laboratory, but they did not report any germination rate data. In nursery production, however, rate of emergence is often the key to success, and the treatment that gives the greatest rate of germination should be favored in seedling production systems. Atlantic white-cedar is notorious for variable dormancy, so 4 weeks may not be the optimum period for all seed lots. In our last test with 12 different lots, 4 weeks was not the optimum for all of them, but it was for most. Boyle and Kuser (1994) found that 30 days of stratification was enough for seeds from eight swamp sites in New Jersey. Four weeks appears to be a good general recommendation for the species unless preliminary tests show a different optimum for particular geographic sources or years.

Soil Seed Bank

It was difficult to separate the layers without some mixing occurring, but there were viable seeds in each layer. Total viable seeds (all depths) were 585 per m^2 for the Sycamore Road stand and 325 per m^2 for the Milltail Creek stand. The ungerminated seeds were too numerous to cut, but if only 10 percent of them were viable (based on the earlier tests), there were another 1,000 viable seeds per m^2 at the Sycamore Road stand and 500 per m^2 at the Milltail Creek stand. Fowells (1965) reports that from 64 to 2,718 viable seeds per m^2 were found in the surface inch of litter in New Jersey stands of Atlantic white-cedar. These data suggest that there were plenty of viable seeds present in the litter in these stands for natural regeneration to occur when the overstory is removed. About half of the seeds buried in pouches survived the first year, and some survived the second year (table 6). Although the loss of 50 percent of the viable seeds after one year seems serious, the large numbers found present would seem to be enough to produce some natural regeneration as long as two years after seedfall. In fact, field observations in New Jersey have suggested that seeds can remain viable in sphagnum moss on the forest floor for as long as 14 years (Kuser and Zimmerman 1995).

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INVENTORY OF REMNANT ATLANTIC WHITE-CEDAR STANDS IN NORTH CAROLINA

Kelly N. Davis and Stephen M. Daniels[1]

Abstract—A State-wide inventory of remnant Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) stands was conducted during 1996 and 1997. All known pure and mixed stands greater than four acres were cataloged; numerous sites were included that contained smaller stands and groves. Ground accessible sites were visited, and stand data were collected, including size, age, species composition, diameter at breast height, height, and basal area. Inaccessible sites, mainly in northeastern counties, were aerially inspected. Soil type, ownership, and natural community type were recorded for all sites. Stands were located based on information provided by the NC Natural Heritage Program, The Nature Conservancy of NC, NC Department of Agriculture, botanist Cecil Frost, NC Department of Forest Resources Staff Forester K.O. Summerville, NC Department of Forest Resources County Rangers, Weyerhaeuser Senior Forest Scientist Joe Hughes, public land managers, and others, as well as county-by-county observations.

Nearly 200 sites were inspected on which Atlantic white-cedar presence was confirmed. Sites were located in 27 counties in the coastal plain and piedmont. Counties with the greatest number of total sites included Dare, Tyrrell, Hyde, Washington, Hoke, and Brunswick. Counties with the largest site sizes included Dare, Tyrrell, Hyde, Washington, and Camden. Counties with relatively high numbers of small acreage sites included Hoke, Cumberland, and Sampson. Other counties with remnant stands or groves included Bladen, Lee, Harnett, Wilson, Nash, Richmond, Currituck, Hertford, Gates, Pasquotank, Beaufort, Craven, Wayne, Jones, Onslow, New Hanover, Fender, Pamlico, and Columbus.

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THE ANALYSIS OF WHITE-CEDAR REGENERATION AT THE BELLEPLAIN FOOD PATCH SITE IN CAPE MAY COUNTY, NEW JERSEY

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Abstract—The Belleplain Food Patch site was one of seven study areas begun in 1989 throughout central and southern New Jersey to study factors affecting Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) regeneration.

The site had been converted from hardwoods and was one of a pair of such sites in Belleplain State Forest. In the fall of 1992, the Atlantic white-cedar regeneration was inventoried by height class, and measurements were taken in each experimental plot of litter depth, elevation, number and diameter of stumps, and distance to the edge of the remaining cedar/swamp hardwood stand. Twenty-four wells were spread across the site to measure and monitor hydrologic and soil features. Various silvicultural treatments were applied to the study area.

Analysis of Atlantic white-cedar regeneration showed advanced regeneration before the hardwood stand was cut and chipped in 1989. These trees belonged to the two larger height classes (0.9 to 1.3 m, > 1.3 m). The other three height classes (< 0.3 m, 0.3 to 0.6 m, 0.6 to 0.9 m) represent individuals that became established after the site was cut.

Regeneration occurred more often in the southern control treatment where no Atlantic white-cedar seed was applied. Preliminary regression analysis of each height-class density versus all of the variables showed some statistically significant (though low) relationships.

The smaller height-class Atlantic white-cedar were correlated to distance from the residual forest edge, clay presence and depth, and water table depth. The two largest height classes did not significantly correlate to any variable measured.

Although only parts of the site achieved adequate stocking levels, much was learned about the regeneration requirements of hardwood sites that are on the xeric end of Atlantic white-cedar's niche.

Further analyses on the Belleplain Food Patch site will use more complex multiple regression and geostatistical techniques in an attempt to uncover the limiting factor in Atlantic white-cedar regeneration at this site.

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PRELIMINARY STUDY OF PHOTOSYNTHETIC RATES OF ATLANTIC WHITE-CEDAR SOURCES FROM NEW JERSEY

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Abstract—This is a preliminary study that measures the photosynthetic rate and its variation for Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) rooted cuttings from three sites in New Jersey. The cuttings are being grown under four different light treatments: full sunlight, 40 percent shade, 55 percent shade, and 70 percent shade. This study attempts to quantify the photosynthetic rate of Atlantic white-cedar, to create response curves for each source, and to identify variability components to help design a larger outdoor experiment.

This experiment was conducted in a greenhouse between October 1996 and July 1997. The rooted cuttings used were taken from eight individual trees from three Atlantic white-cedar swamps in New Jersey. Three cuttings from each source were placed in each of the light treatments, for a total of 24 cuttings per treatment. All photosynthetic measurements were made using the Ciras-1 Portable Photosynthesis System with a Parkinson Conifer Leaf Cuvette. For each measurement, several factors were recorded, including net photosynthetic rate, temperature, photosynthetically active radiation, date, time of day, and weather condition.

Photosynthetic rates for all sources combined ranged from -0.2 to 13.7 μmol CO_2 m^{-2} s^{-1}, and averaged 4.20 μmol CO_2 m^{-2} s^{1}. These rates compare with rates previously reported for other conifer species. Initial analysis of variance models show that there is significant photosynthetic variation between individual cuttings from the same source, as well as between sources. Other factors found to significantly influence photosynthetic rate are light treatment, source-by-light-treatment interaction, date, and date-by-light interaction. Further statistical analysis will include fitting photosynthetic response curves to light for each source.

This study will also measure the growth of Atlantic white-cedar cuttings under each shade treatment. Heights were measured at the beginning of the experiment and will be measured again after approximately one year. The biomass and shoot/root ratios of the cuttings will also be measured at the end of the experiment to analyze Atlantic white-cedar growth and success under each treatment.

This study has identified several variability components that affect the photosynthetic rate of Atlantic white-cedar. To determine differences between sources, an experimental design should eliminate or partition these components. In the future, we will include sources from throughout the natural range of Atlantic white-cedar to identify any geographical variation over a larger area. We will also be comparing Atlantic white-cedar photosynthetic rates with rates of some of its vegetative competitors in New Jersey.

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As the past decade has seen a resurgence of interest in Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.), a conference was convened in August 1997 to present the latest information in the research and management of the species. New information included, among other things: natural and artificial regeneration and growth after harvesting; genetics and seedling production; management on public lands; development of new taper equations for predicting wood volume; and distribution and composition of plant communities dominated by Atlantic white-cedar. These were reported in 16 oral presentations and 3 abstracts.

Keywords: Atlantic white-cedar, *Chamaecyparis thyoides*, coastally restricted forests, ecosystem restoration.