RADIAL GROWTH OF PEATLAND ATLANTIC WHITE CEDAR (*CHAMAECYPARIS THYOIDES*) IN GREAT DISMAL SWAMP NATIONAL WILDLIFE REFUGE AND ITS ASSOCIATION WITH LAKE DRUMMOND WATER LEVELS

Craig L. Patterson[1] and Robert B. Atkinson[2]

[1]*Chesapeake Environmental Management, Bel Air, MD 21014*
[2]*Department of Organismal and Environmental Biology, Christopher Newport University,*
1 Avenue of the Arts, Newport News, VA 23606

Abstract: Over 200 years of commercial logging and drainage coupled with recent natural disasters have eliminated mature Atlantic white cedar [*Chamaecyparis thyoides* (L.) B.S.P.] (cedar) stands from Great Dismal Swamp National Wildlife Refuge (GDSNWR). Regeneration of cedar stands will require hydrologic restoration, and findings from tree-ring studies can contribute to restoration success. Analyses were performed on cross-sections of cedar stems to quantify radial growth and determine associations between ring width and climatic and hydrologic variables from 1919 through 2003. A total of 433 radial-growth series and 29,341 annual rings were measured from 105 cedar stem-cuts and were modeled using a 24-month window of Lake Drummond water levels. Growth was most strongly influenced by water levels in Lake Drummond. This study provides evidence that cedar is responsive to water level changes in GDSNWR.

Key Words: hydrologic variables, water level management

INTRODUCTION

Hydrology has been identified as the single most important factor influencing forested wetland processes including primary production and decomposition (Conner et al. 1981, Wharton et al. 1982, Brinson et al. 1984). Day and Megonigal (2000) summarized several years of primary production and decomposition studies in the Dismal Swamp (DS) and reported that hydrology, primarily depth to water table, could be used to distinguish between Atlantic white cedar, *Chamaecyparis thyoides* (L.) B.S.P. (cedar), swamps and three other major forest community types.

Cedar occupies a fairly narrow range of hydrologic conditions, and the life cycle exhibits an interaction with peat. Although it is an obligate wetland species (Reed 1988), cedar is physiologically intolerant of prolonged inundation, at least during the seedling stage (Akerman 1923, Brown and Atkinson 1999). When water tables rise, often as a result of damming by roads (Van Druten and Eagle 2000) or deep peat burns (Akerman 1923, Korstian 1924), cedar stands may revert to high or low pocosin (Schafale and Weakley 1990, Sharitz and Gibbons 1982). Conversely, deeper water tables, which may result from ditching, favor aggressive competitors such as red maple (*Acer rubrum* L.), which is known to invade cedar stands and is the most commonly associated tree in New Jersey (Laderman 1989, Stoltzfus and Good 1990) and Virginia (Kearney 1901, Laderman 1989, Shacochis et al. 2003, Loomis et al. 2003).

The majority of annual primary production by cedar is amassed in bole wood (DeBerry et al. 2003) and one cedar stand in DS has been shown to be sensitive to climate variables (Merry 2005). In addition to meteorological metrics such as temperature, rainfall, and Palmer Drought Severity Index (PDSI), hydrologic variables have been successfully used in tree-ring studies. Hydrology-radial growth relationships derived from analyses of lake level, stream flow, or ground water elevation have allowed for reconstruction of historic water regime conditions in lakes (Stockton and Fritts 1973, Peterson et al. 1999), streams (Cook and Jacoby 1983, Phipps 1983, Cleaveland 2000), and wetlands (Hascall 1997). In many of these studies, relatively recent hydrologic data were used to develop reconstructions spanning hundreds of years. Hydrologic analyses have also provided insight into radial growth habits of peatland species (Jean and Bouchard 1996), including cedar (Golet and Lowry 1987). Similar opportunities may be possible in Great Dismal Swamp National Wildlife Refuge (GDSNWR) with Lake Drummond. Because the shallow Norfolk aquifer supplies Lake Drummond (Lichtler and Walker 1979, USFWS 2006), and because water level changes correspond with climatic conditions and the seasonally flooded hydrologic regime of DS (Marshall 1979, Oaks and Whitehead 1979, Ruffin 1837, USACE 2007), monthly lake level is likely to be a good general measure of ground water variation in GDSNWR. The purpose of this study is to evaluate the relationship between water levels in Lake Drummond and tree ring widths in several former cedar stands.

METHODS

Site Description

Cedar swamps in North Carolina and Virginia are primarily located on the Pamlico Terrace east of the Suffolk Scarp. Drainage from the DS flows from DS to both Chesapeake Bay and to Albemarle Sound via the 3-mile long (5 km) Feeder Ditch which supplies the Dismal Swamp Canal (DSC). Chartered in 1787 by the Commonwealth of Virginia and in 1790 by the State of North Carolina, the 35 km-long DSC was completed in 1805. The US Army Corps of Engineers (USACE) has been in control of DSC since 1925 (Trout 2004) and is responsible for regulating water levels in DSC, Feeder Ditch, and Lake Drummond (Ramsey et al. 1970, USFWS 2006).

The DSC and Lake Drummond appear to be a significant component of DS hydrology. Prior to 1977, the water level in Lake Drummond was allowed to drop to a low level as water was released through a spillway on the Feeder Ditch in order to maintain proper navigable depths in the DSC. The importance of Lake Drummond to DS hydrology was noted in a report by Norfolk District, US Army Corps of Engineers (1986), which stated that the lake is the focal point for management and control of water in the refuge. With federal passage of Public Law 93-402 in August 1974, management of water levels in Lake Drummond was required to place the highest priority on refuge ecology. In order to meet the Congressional mandate, spillway gates were closed whenever the lake level dropped from 5.2 m to 4.8 m.

USACE has recorded daily water level readings of Lake Drummond from a staff gauge just upstream of the Feeder Ditch spillway since 1926 (USACE 2007). In 1935, USACE constructed a new spillway in Feeder Ditch, the same structure still in operation today (Marshall and Robinson 1979, Trout 2004).

Field Methods

Cedar stem-cuts were collected from 11 salvage logging areas in 2006 to 2008 during winter and spring months (figures 1 and 2). Access occurred via Corapeake Ditch, Forest Line Ditch, Cross Canal, and South Ditch roads after logging operations in each area were completed. Trees that survived Hurricane Isabel in 2003 and had not been salvage logged but were subsequently blown down were selected because they, combined with completion dates for each salvage logging area, allowed for accurate dating of the outer growth ring following Yamaguchi (1991). Large trees that were likely canopy dominants or co-dominants were also preferred (Cook et al. 1998, Copenheaver et al. 2005, Pederson et al. 2004, Phipps 1985). Measuring tape was used to determine breast height (137 cm), and a chainsaw was used to extract complete cross-sections perpendicular with the stem. Stem-cuts that exhibited heart rot that would render tree-ring analyses not feasible were discarded. Given that the opportunity to access and collect data from these remote cedar sites in GDSNWR was rare and short-lived and that cedar is a closed canopy species with little history of tree ring research (Cook et al. 1982, Fritts 1976, LaMarche et al. 1982, Stockton 1990), effort was made to collect as many stem-cuts as possible. Each salvage logging area yielded 10 to 12 stem-cuts.

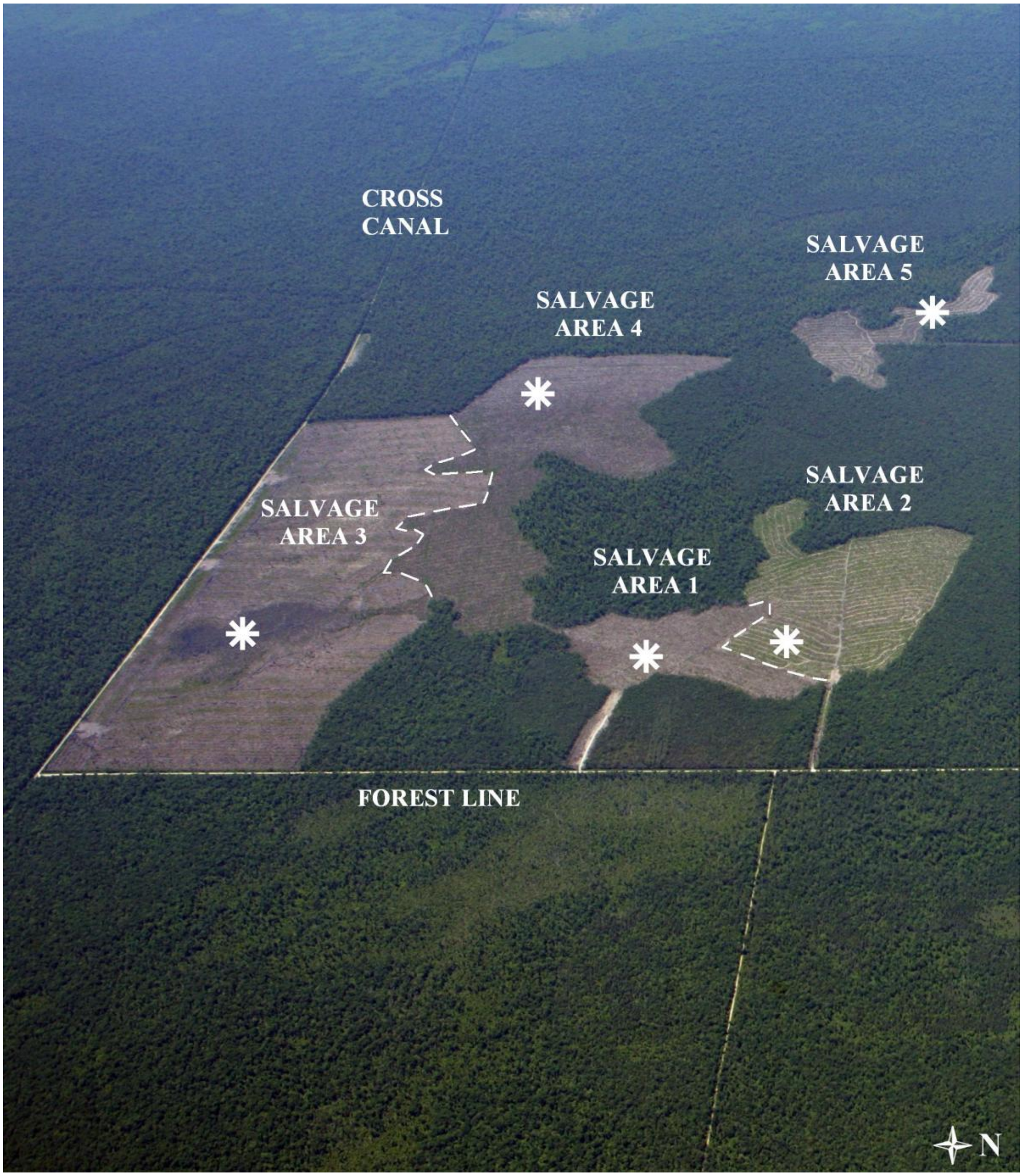

Figure 1. Cedar salvage logging areas 1-5. Asterisks correspond with study-site coordinates listed in table 1 and indicate general locations from which most stem-cuts were collected. Dashed lines delineate boundaries between salvage logging areas, where necessary.

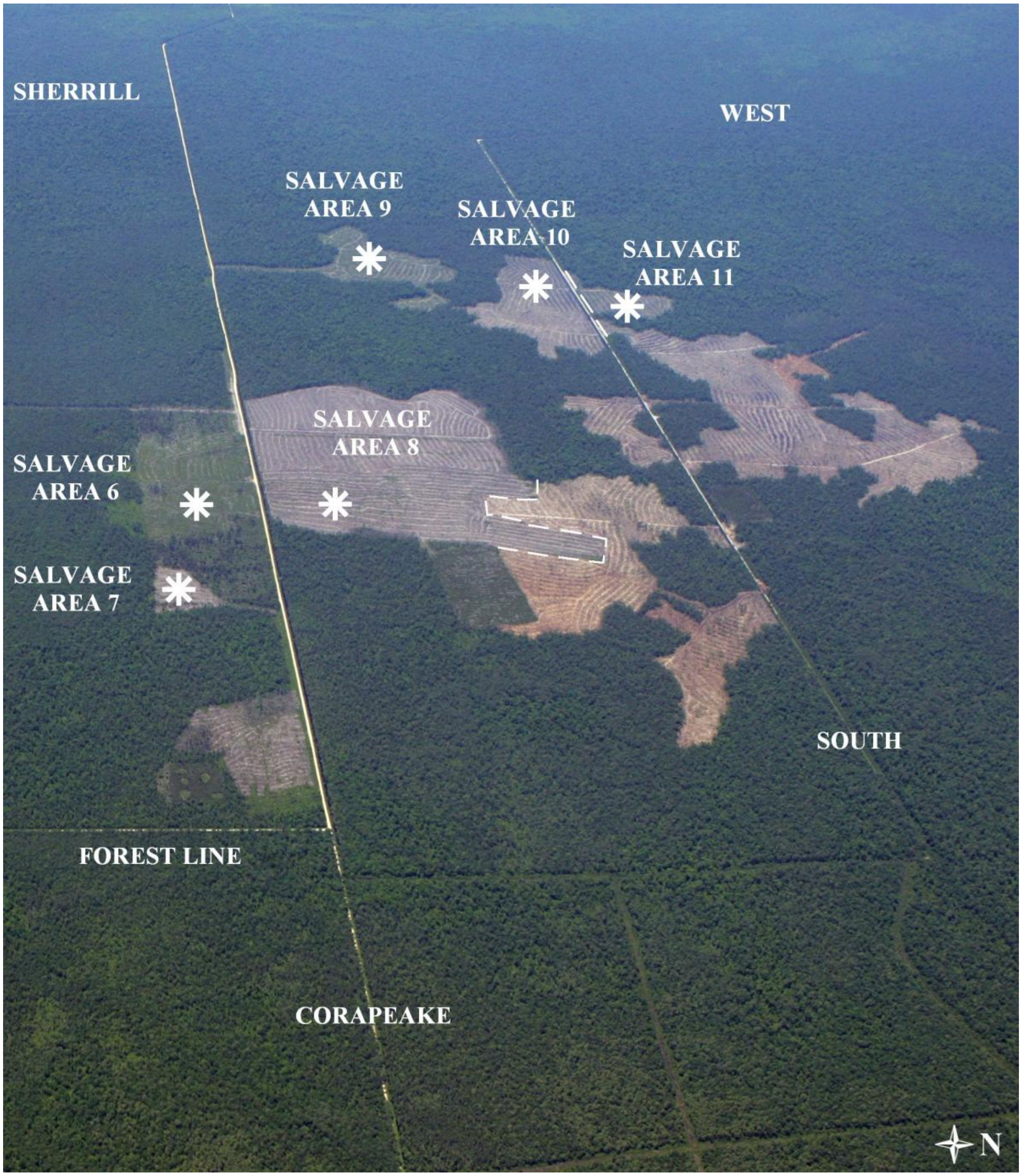

Figure 2. Cedar salvage logging areas 6-11. Asterisks correspond with study-site coordinates listed in table 1 and indicate general locations from which most stem-cuts were collected. Dashed lines delineate boundaries between salvage areas, where necessary.

Table 1. Coordinates of study sites in cedar salvage logging areas. Coordinates refer to the general location in each salvage logging area where most stem-cuts were collected.

Salvage Area	Year Logging Was Completed	Latitude (degrees, minutes, seconds N)	Longitude (degrees minutes, seconds W)
1	2005	36°31’43”	76°28’22”
2	2007	36°31’57”	76°28’23”
3	2007	36°31’02”	76°28’49”
4	2006	36°31’17”	76°29’21”
5	2006	36°32’05”	76°29’43”
6	2004	36°32’42”	76°29’05”
7	2005	36°32’40”	76°28’47”
8	2006	36°32’55”	76°29’05”
9	2007	36°33’09”	76°30’20”
10	2007	36°33’32”	76°30’13”
11	2007	36°33’40”	76°30’07”

Laboratory Methods

After allowing sufficient time for air-drying at room temperature, stem cross sections were smoothed with coarse-grit sand paper via a belt sander and then with progressively finer-grit sand paper via a sanding block until annual ring boundaries were clearly visible (Dang and Lieffers 1989, MacDonald and Yin 1999, Mitsch and Rust 1984, Phipps 1985, Stokes and Smiley 1968). Four or five representative radial-growth series from pith to bark were then delineated on each stem-cut to establish the location along which ring-width measurements would occur and to facilitate crossdating (Dang and Lieffers 1989, Mitsch and Rust 1984). Beginning with stem-cuts in which the year of the outermost ring was undoubtedly known, rings in each radial-growth series were dated (Yamaguchi 1991). Tree rings were traced circumferentially around the cross-section to ensure ring counts were accurate and to identify false rings (Mitsch and Rust 1984). Radial-growth series from each stem-cut was then visually crossdated by comparing ring-width patterns and noting rings of extreme size, particularly narrow rings (Carroll and Jules 2005, Copenheaver et al. 2005, Dang and Lieffers 1989, Larocque and Smith 2005, Pederson et al. 2004, Phipps 1985, Yamaguchi 1991). During this process, stem-cuts that exhibited unusual growth patterns or substantial suppression-release were identified and excluded from further analyses (Bhuta et al. 2009, Pederson et al. 2004).

Ring widths from each radial-growth series were measured to the nearest 0.001 mm with a Velmex TA micrometer system and recorded with Measure J2X software (Bhuta et al. 2009, Copenheaver et al. 2005, Henderson and Grissino-Mayer 2009, Larocque and Smith 2005). The unislide surface and microscope set-up were modified to accommodate stem-cuts. Radial-growth series were then averaged to create one ring-width series for each stem-cut (MacDonald and Yin 1999). Next, measurement and crossdating accuracy was verified using program COFECHA (Bhuta et al. 2009, Carroll and Jules 2005, Cook et al. 1998, Copenheaver et al. 2005, Hopton and Pederson 2005, Henderson and Grissino-Mayer 2009, Larocque and Smith 2005, Pederson et al. 2004). COFECHA generated a master series from all ring-width series and used correlation techniques to test segments of each ring-width series against corresponding segments of the master series.

Segments that did not meet a defined critical correlation coefficient were flagged, and measurements and crossdating within those segments were reviewed (Grissino-Mayer 2001).

Program ARSTAN was used to detrend each ring-width series, calculate mean-value functions, and perform autoregressive modeling. Two detrending iterations were performed on each ring-width series to filter variation attributable to non-climatic factors (Hopton and Pederson 2005, Larocque and Smith 2005, Pederson et al. 2004). For the first detrending, a linear regression line or, in a few cases, a negative exponential curve, was specified to remove the age trend. A linear regression line constrained to a negative or zero slope is a simple, conservative, and biologically reasonable age trend curve (Cook 1985) that is most appropriate when ring-width series are relatively short or exhibit unusual growth patterns (Holmes and Cook 1986). The resulting ring-width indices were then subjected to a second detrending to remove variation due to competition. A cubic smoothing spline with a wavelength equal to two-thirds of each series' length was specified for this purpose. Spline curves have proven very effective in detrending data from closed-canopy forests because they can conform to almost all variation patterns typically observed in these settings (Blasing et al. 1983, Cook 1987, Cook and Peters 1981, Grissino-Mayer 2001, Holmes and Cook 1986). Autoregressive modeling was then performed to remove all autocorrelation and further enhance the climate signal. The resulting ring-width indices were then averaged using biweight means to produce the residual (RESID) chronology for use in subsequent water level-radial growth analyses (Cook 1987, Holmes and Cook 1986). The RESID chronology is recommended when autocorrelation and variation due to competition and disturbance is high (Copenheaver et al. 2005, Henderson and Grissino-Mayer 2009, Pederson et al. 2004).

Program SYSTAT was used to perform water level-radial growth analyses. Simple linear correlation analysis was used to investigate water level-radial growth associations, calculating the extent to which annual ring-width indices in the RESID chronology varied with monthly water level values. Water level-radial growth analyses were completed over a 24-month water level window from previous-year January through current-year December (Henderson and Grissino-Mayer 2009). Two-tailed hypothesis testing was used (Cook and Pederson 2011), and significance was determined at $\alpha = 0.05$ (Cook and Pederson 2011, Pederson et al. 2004, Zar 1999).

RESULTS

For the period 1927 through 1976, daily lake-level measurements by USACE (2007) revealed that mean annual high water level was 5.37 m above sea level (US coast and geodetic survey mean sea level, 1929 vertical datum), and mean annual low water elevation was 4.54 m (table 2). Mean seasonal drop in water level was 0.83 m during this period. Consistent with USACE data, Berkeley and Berkeley (1976) reported a drawdown of about 1.5 m in 1952, during which large portions of the lake were dry (Henry 1970). A seasonal drawdown of similar magnitude was also recorded in 1941 (USACE 2007). Mean annual lake elevation from 1927 through 1976 was 5.06 m. The highest monthly average of 5.46 m occurred in September 1960, and the lowest monthly average of 3.73 m occurred in November 1952 (USACE 2007). As of 2003, Lake Drummond's highest (5.74 m) and lowest (3.50 m) recorded daily water levels occurred during these 2 months (Ramsey et al. 1970, USACE 2007).

Table 2. Summary of Lake Drummond water-elevation data for each climate period.

Climate Period	Mean Annual Water Level (m)	Mean Annual High Water Level (m)	Mean Annual Low Water Level (m)	Mean Annual Drawdown (m)
1927-1957	5.02	5.35	4.49	0.86
1958-1979	5.11	5.40	4.64	0.76
1980-2003	5.16	5.38	4.85	0.53

USACE considered 5.23 m (17.15 ft) above sea level as the full water level or normal surface elevation for Lake Drummond. This value corresponds with the Norfolk Harbor datum value of 5.68 m (18.65 ft) above zero mean low water (Marshall and Robinson 1979, USFWS 2006) and 5.00 ft on the Feeder Ditch staff gauge. Prior to 1977, USACE operated the Feeder Ditch spillway such that lake level was permitted to drop as low as necessary to support DSC. With the formation of GDSNWR and accompanying federal legislation in 1974, Lake Drummond water level was to be managed with refuge ecology, not DSC navigation, as the principal concern (Atkinson 2001). Starting in 1977, USACE did not release water from the lake during severe droughts (USFWS 2006). It was also determined that elevation 4.80 m (15.75 ft, or 3.60 ft on the staff gauge) was the minimum lake level necessary to support refuge ecology and when lake elevation was below this level, water was not to be released (USACE 2010, USFWS 2006). Excess water was to be released only when the lake surface was above elevation 5.32 m (17.45 ft, or 5.30 ft on the staff gauge) (USACE 2010).

For the period 1977 through 2003, daily lake-level measurements by USACE (2007) indicated that mean annual high water elevation was 5.38 m and mean annual low water elevation was 4.84 m (figure 3). Mean seasonal drop in water level was 0.54 m during this period, nearly 0.30 m less than that observed from 1927 through 1976. Mean annual high water elevation was nearly identical during each time period, but seasonal drawdown greater than 0.60 m rarely occurred after 1976. Greatest gains in water level occurred in November, during which mean monthly water level was 0.16 m higher after 1976. Mean annual water level from 1977 through 2003 was 5.16 m, which was 0.10 m higher than that observed in 1927 through 1976. The highest monthly average of 5.41 m occurred in September 1999, and the lowest monthly average of 4.60 m occurred in October 1980 (figure 3).

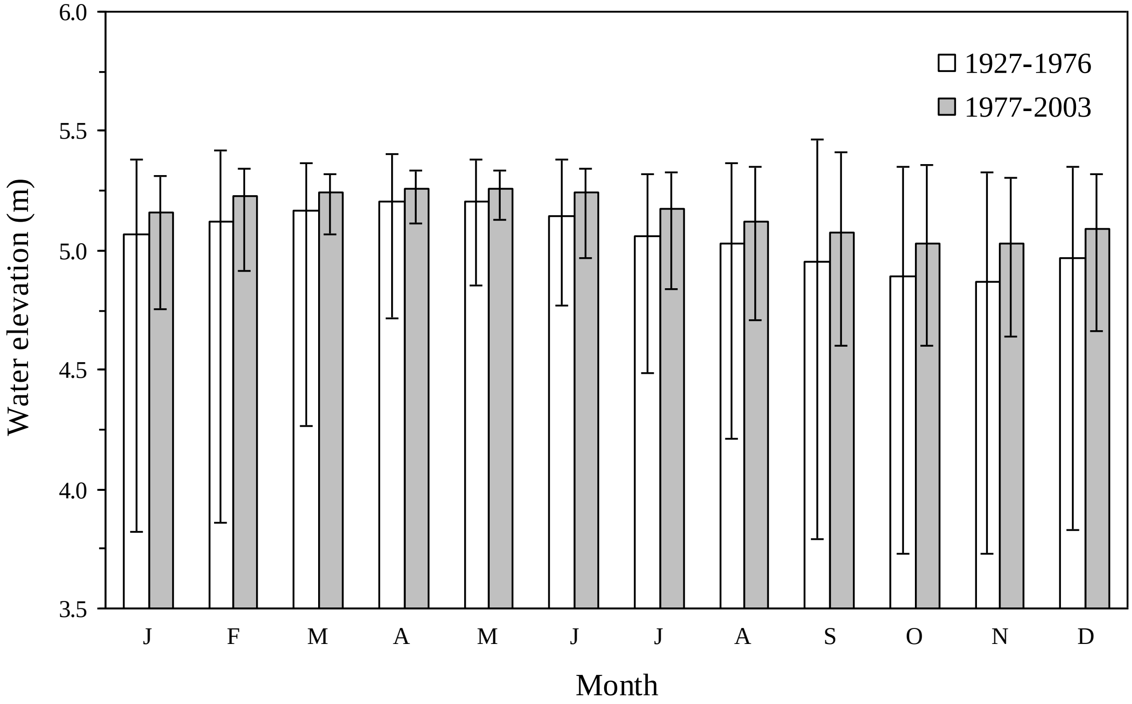

Figure 3. Comparison of mean monthly Lake Drummond water elevation from 1927 through 1976 (white bars) and 1977 through 2003 (shaded bars). Each vertical line indicates the range of monthly lake elevations recorded.

Mean annual Lake Drummond water elevation from 1927 through 2003 is given in figure 4. In addition to water-level management, annual water elevation responded to 3 distinct climate periods experienced in the GDS region during the study period. Annual lake level was lowest and seasonal drawdown was greatest from 1927 through 1957. Several dry cycles and release of water to DSC appear responsible for the variability of lake levels experienced during this period. Four years with the lowest annual lake level on record (1930, 1941, 1942, and 1952) occurred during this period. Despite continued water release to DSC, cool temperatures and few dry cycles resulted in higher annual water elevation and lower seasonal drawdown from 1958 through 1979. The period 1980 through 2003 experienced the smallest seasonal drawdown due to above-average rainfall and conservation of lake water. Annual water elevation was above average for 15 consecutive years from 1989 through 2003.

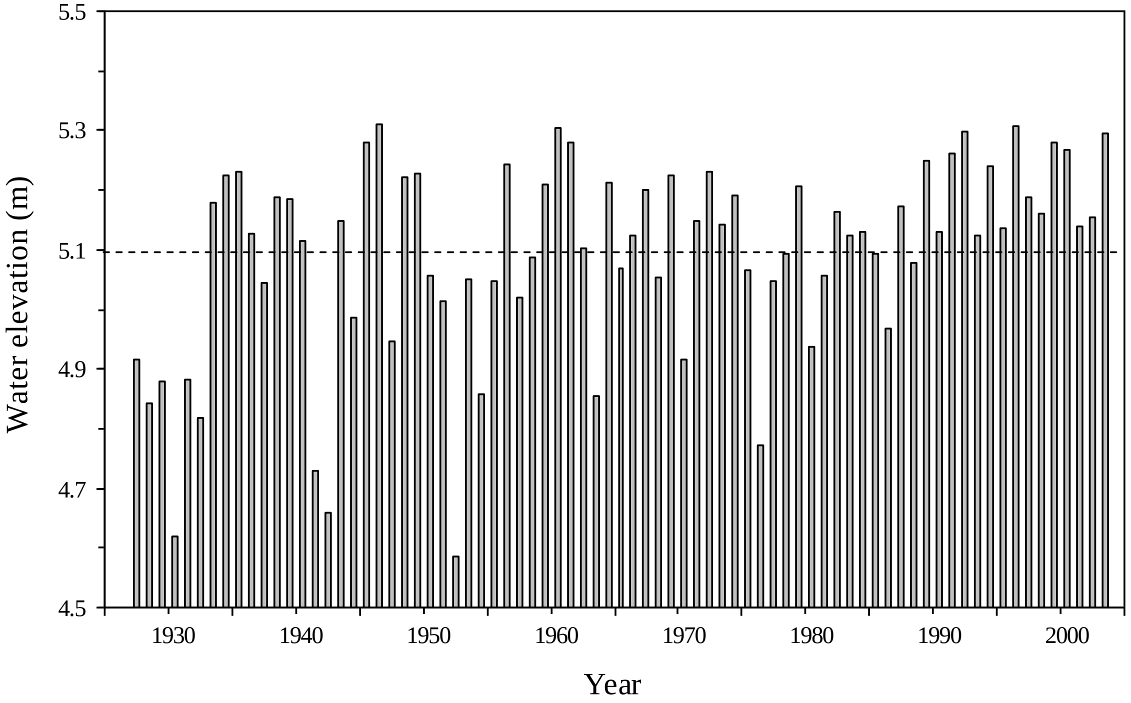

Figure 4. Mean annual Lake Drummond water elevation from 1927 through 2003. Horizontal line indicates the mean lake elevation during this period (5.09 m).

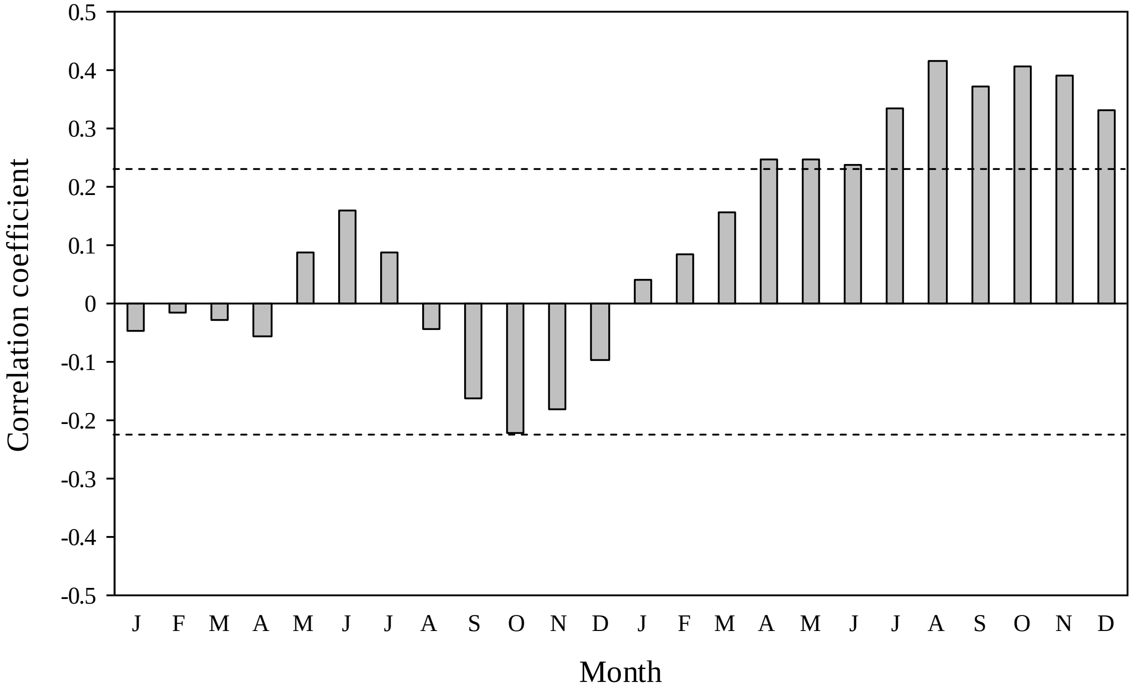

Figure 5. Correlations between mean monthly lake level and RESID chronology (1928-2003) during a 24-month water level window from previous-year January through current-year December. Dashed horizontal lines indicate significance thresholds.

Cedar ring width and Lake Drummond water level were positively correlated from current-year April through December. Highest correlations were detected from July through November, with the strongest correlation occurring in August ($r = 0.42$, $p < 0.001$). A trend of negative associations with previous-year August through December lake level was evident, though none of these correlations were significant. A negative association with previous-year October water elevation was marginally non-significant ($r = -0.22$, $p = 0.055$)(figure 5).

DISCUSSION

Results from this study revealed that Lake Drummond water elevation was a good indicator of wet and dry conditions and can be of value to tree-ring studies in GDSNWR. Reconstruction of lake level via tree rings may be possible, but the lake's history of anthropogenic influences would likely be problematic.

Significant positive correlations of radial growth were recorded for April through December of the current year. Radial growth of conifers is often positively correlated with soil moisture content (Pallardy et al. 1995). Magnitude and duration of radial growth in conifers that exhibit indeterminate shoot growth, such as cedar (Russell 1998), are especially sensitive to soil moisture content throughout the growing season (Fritts 1976, Kozlowski 1979). A wide annual ring is often attributable to an extended period of earlywood growth due to delay in summer drawdown of soil moisture, while a narrow ring usually results when dry summer conditions terminate earlywood growth and initiate latewood formation (Kozlowski 1979). The relative strength of correlations between ring width and July, August, and September water levels likely corresponded with months during which cedar in GDSNWR was shifting from earlywood to latewood production in most years, as reported for bottomland forests in Illinois by Robertson (1992).

Management of water levels in Lake Drummond prior to refuge establishment may have reduced cedar growth, particularly during dry years. Outflow from Lake Drummond was typically required through much of the year to maintain sufficient water for navigation in DSC (Marshall 1979). From late spring through early autumn, an increased dependence was placed on the lake, not only because of seasonal drawdown of DSC water level, but also due to increased boat traffic and the associated increase in water loss from frequent operation of locks (Lichtler and Walker 1979, Marshall 1979). Operators of the Feeder Ditch spillway released as much water from Lake Drummond as necessary to sustain navigable water depth in DSC (Simpson 1990). During very dry periods, the lake did not provide enough water to maintain normal operations in DSC (Marshall 1979, Trout 2004).

The association between cedar radial growth and Lake Drummond was weak in previous-year summer. This result appears contradictory, but lake-level variation should not be considered equivalent to variation in water table elevation or soil moisture in cedar stands. Furthermore, the link between root-zone soil moisture content and water table elevation is not straightforward, particularly during dry periods (Chason and Siegel 1986, LaRose et al. 1997, Munro 1984, Price 1997, Rothwell et al. 1996). The lack of significant correlations between ring width and lake level in previous-year summer was likely attributable to the effect of evapotranspiration on soil water supply, the rate with which soil moisture can fluctuate relative to lake level, and a general lag in response time of lake level to climate conditions. Also, differences in lake-level management before and after the late 1970s likely weakened the overall hydrology-radial growth model.

ACKNOWLEDGEMENTS

The assistance of Bryan Poovey in locating and retrieving stem cuts is greatly appreciated. Site access was provided by GDSNWR.

LITERATURE CITED

Akerman, A. 1923. The white cedar of the Dismal Swamp. *Virginia Forest Publications* 30:1-21.

Atkinson, R.B. 2001. Atlantic white cedar swamp restoration: Monitoring ecosystem services and self-maintenance. Christopher Newport University, Newport News, VA. Unpublished final report. Sponsored by the US EPA National Center for Environmental Research.

Berkeley, E. and D. Berkeley. 1976. Man and the Great Dismal. *Virginia Journal of Science* 27:141-171.

Bhuta, A.A.R., L.M. Kennedy, and N. Pederson. 2009. Climate-radial growth relationships of northern latitudinal range margin longleaf pine (*Pinus palustris* P. Mill.) in the Atlantic Coastal Plain of southeastern Virginia. *Tree-ring Research* 65:105-115.

Blasing, T.J., D.N. Duvick, and E.R. Cook. 1983. Filtering the effects of competition from ring-width series. *Tree-ring Bulletin* 43:19-30.

Brinson, M.M., H.D. Bradshaw, and E.S. Kane. 1984. Nutrient assimilative capacity of an alluvial floodplain swamp. *Journal of Applied Ecology* 21:1041-1057.

Brown, D.A. and R.B. Atkinson. 1999. Assessing the survivability and growth of Atlantic White Cedar (*Chamaecyparis thyoides* (L.) B.S.P.) in the Great Dismal Swamp National Wildlife Refuge. Pp 1–7 *In* Shear, T. and K.O. Summerville (Eds) Atlantic White Cedar: Ecology and Management Symposium held August 6-7, 1997 at Christopher Newport University, Newport News, VA. USDA Forest Service Southern Research Station, Gen. Tech. Rep. SRS-27.

Carroll, A.L. and E.S. Jules. 2005. Climatic assessment of a 580-year *Chamaecyparis lawsoniana* (Port Orford cedar) tree-ring chronology in the Siskiyou Mountains, USA. *Madrono* 52:114-122.

Chason, D.B. and D.I. Siegel. 1986. Hydraulic conductivity and related physical properties of peat, Lost River Peatland, northern Minnesota. *Soil Science* 142(2):91-99.

Cleaveland, M.K. 2000. A 963-year reconstruction of summer (JJA) streamflow in the White River, Arkansas, USA, from tree-rings. *The Holocene* 10:33-41.

Conner, W.H., J.G. Gosselink, and R.T. Parrondo. 1981. Comparison of the vegetation of three Louisiana swamps sites with different flooding regimes. *American Journal of Botany* 68:320-331.

Cook, E.R. 1985. A time series analysis approach to tree ring standardization [dissertation]. University of Arizona, Tucson, AR.

Cook, E.R. 1987. The decomposition of tree-ring series for environmental studies. *Tree-ring Bulletin* 47:37-59.

Cook, E.R. and G.C. Jacoby. 1983. Potomac River streamflow since 1730 as reconstructed by tree rings. *Journal of Climate and Applied Meteorology* 22:1659-1672.

Cook, E.R. and K. Peters. 1981. The smoothing spline: A new approach to standardizing forest interior tree-ring width series for dendroclimatic studies. *Tree-ring Bulletin* 41:45-53.

Cook, E.R. and N. Pederson. 2011. Uncertainty, emergence, and statistics in dendrochronology. Pp 77-112 *In* Hughes, M.K., T.W. Swetnam, and H.F. Diaz (Eds) Dendroclimatology: Progress and Prospects. Springer Science and Business Media, New York, NY.

Cook, E.R., W.L. Nance, P.J. Krusic, and J. Grissom. 1998. Modeling the differential sensitivity of loblolly pine to climatic change using tree rings. Pp 717-739 *In* Mickler, R.A. and S. Fox (Eds) The Productivity and Sustainability of Southern Forest Ecosystems in a Changing Environment. Springer-Verlag. New York, NY.

Cook, E.R., L.E. Conkey, and R.L. Phipps. 1982. Eastern North America. Pp 126-135 *In* Hughes, M.K., P.M. Kelly, J.R. Pilcher, and V.C. LaMarche Jr. (Eds) Climate from Tree Rings. Cambridge University Press, Cambridge, GB.

Copenheaver, C.A., K.H. Kyle, G.N. Stevens, and M.H. Kamp. 2005. Comparing *Juniperus virginiana* tree-ring chronologies from forest edge vs. forest interior positions in the Cedars Natural Area Preserve in Virginia, USA. *Dendrochronologia* 23:39-45.

Dang, Q.L. and V.J. Lieffers. 1989. Climate and annual ring growth of black spruce in some Alberta peatlands. *Canadian Journal of Botany* 67:1885-1889.

Day, F.P. and J.P. Megonigal. 2000. Plant organic matter dynamics in the Dismal Swamp. Pp 51-57 *In* Rose, R.K. (Ed) The Natural History of the Great Dismal Swamp. Omni Press, Madison, WI.

DeBerry, J.W., R.T. Belcher, D.T. Loomis, and R.B. Atkinson. 2003. Comparison of aboveground structure of four Atlantic white cedar swamps. Pp 67-80 *In* Atkinson, R.B., R.T. Belcher, D.A. Brown, and J.E. Perry (Eds) Restoration and Management of Atlantic White Cedar Swamps: Proceedings of a Symposium at Christopher Newport University, May 31-June 2, 2000, Newport News, VA.

Fritts, H.C. 1976. Tree Rings and Climate. Academic Press, New York, NY.

Golet, F.C. and D.J. Lowry. 1987. Water regimes and tree growth in Rhode Island Atlantic white cedar swamps *In* A.D. Laderman (Ed) Atlantic White Cedar Wetlands. Westview Press, Boulder, CO. (out of press)

Grissino-Mayer, H.D. 2001. Evaluating crossdating accuracy: A manual and tutorial for the computer program COFECHA. *Tree-ring Research* 57(2):205-221.

Hascall, A.P., III. 1997. Reconstruction of wetland hydrology dynamics using tree rings [dissertation]. Western Michigan University, Kalamazoo, MI.

Henderson, J.P. and H.D. Grissino-Mayer. 2009. Climate-tree growth relationships of longleaf pine (*Pinus palustris* Mill.) in the Southeastern Coastal Plain, USA. *Dendrochronologia* 27:31-43.

Henry, E.F. 1970. Soils of the Dismal Swamp of Virginia. *Virginia Journal of Science* 21:41-46.

Holmes, R.L. and E.R. Cook. 1986. Guide for computer program ARSTAN [Internet]. Laboratory of Tree-ring Research, University of Arizona, Tucson, AZ. [cited 2011 Feb 4]. http://www.ltrr.arizona.edu/pub.

Hopton, H.M. and N. Pederson. 2005. Climate sensitivity of Atlantic white cedar at its northern range limit. Pp 22-30 *In* Burke, M.K. and P. Sheridan (Eds) Atlantic White Cedar Ecology, Restoration, and Management: Proceedings of the Arlington Echo Symposium. Jun 2-4, 2003. Millersville, MD. Gen. Tech. Rep. SRS-91. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 74 p.

Jean, M. and A. Bouchard. 1996. Tree-ring analysis of wetlands of the upper St. Lawrence River, Quebec: Response to hydrology and climate. *Canadian Journal of Forest Research* 26:482-491.

Kearney, T.H. 1901. Report on a botanical survey of the Dismal Swamp region. *Contributions U.S. National Herbarium* 5:321-550.

Korstian, C.F. 1924. Natural regeneration of southern white cedar. *Ecology* 5:188-191.

Kozlowski, T.T. 1979. Tree growth and environmental stresses. University of Washington Press, Seattle, WA.

Laderman, A.D. 1989. The ecology of Atlantic white cedar wetlands: A community profile. USFWS Biological Report 85 (7.21).

LaMarche, V.C. Jr., E.R. Cook, and M.G.L. Baillie. 1982. Sampling strategies. Pp 2-8 *In* Hughes, M.K., P.M. Kelly, J.R. Pilcher, and V.C. LaMarche Jr. (Eds) Climate from Tree Rings. Cambridge University Press, Cambridge, GB.

Larocque, S.J. and D.J. Smith. 2005. A dendroclimatological reconstruction of climate since AD 1700 in the Mt. Waddington area, British Columbia Coast Mountains, Canada. *Dendrochronologia* 22:93-106.

LaRose, S., J. Price, and L. Rochefort. 1997. Rewetting of a cutover peatland: Hydrologic assessment. *Wetlands* 17:416-423.

Levy, G.F. and S.W. Walker. 1974. Forest dynamics in the Dismal Swamp of Virginia. Pp 101-126 *In* Kirk, P.W. (Ed) The Great Dismal Swamp. University of Virginia Press, Charlottesville, VA.

Lichtler, W.F. and P.N. Walker. 1979. Hydrology of the Dismal Swamp: Virginia and North Carolina. U.S.G.S. 200 West Grace Street, Richmond, VA.

Loomis, D.T., K.M. Shacochis, J.W. DeBerry, R.T. Belcher, and R.B. Atkinson. 2003. Flora of Atlantic white cedar stands in Great Dismal Swamp and Alligator River National Wildlife Refuges. Pp 91-100 *In* Atkinson, R.B., R.T. Belcher, D.A. Brown, and J.E. Perry (Eds) Restoration and Management of Atlantic White Cedar Swamps: Proceedings of a Symposium at Christopher Newport University, May 31-June 2, 2000, Newport News, VA.

MacDonald, S.E. and F. Yin. 1999. Factors influencing size inequality in peatland black spruce and tamarack: Evidence from post-drainage release growth. *Journal of Ecology* 87(3):404-412.

Marshall, H.G. 1979. Lake Drummond: With a discussion regarding its plankton composition. Pp 169-182 *In* Kirk, P.W. Jr. (Ed) The Great Dismal Swamp. University of Virginia Press, Charlottesville, VA.

Marshall, H.G. and W.W. Robinson. 1979. Notes on the overlying substrate and bottom contours of Lake Drummond. Pp 183-187 *In* Kirk, P.W. Jr. (Ed) The Great Dismal Swamp. University of Virginia Press, Charlottesville, VA.

Merry, S.D. 2005. Factors affecting tree ring width in Atlantic white cedar, *Chamaecyparis thyoides* (L.) B.S.P., within Great Dismal Swamp National Wildlife Refuge and Alligator River National Wildlife Refuge [master's thesis]. Christopher Newport University, Newport News, VA.

Mitsch, W.J. and W.G. Rust. 1984. Tree growth responses to flooding in a bottomland forest in northeastern Illinois. *Forest Science* 30:499-510.

Munro, D.S. 1984. Summer soil moisture content and the water table in a forested wetland peat. *Canadian Journal of Forest Research* 14:331-335.

Oaks, R.Q. Jr. and D.R. Whitehead. 1979. Geologic setting and origin of the Dismal Swamp, southeastern Virginia and northeastern North Carolina. Pp 1-24 *In* Kirk, P.W. Jr. (Ed) The Great Dismal Swamp. University of Virginia Press, Charlottesville, VA.

Pallardy, S.G., J. Cermak, F.W. Ewers, M.R. Kaufmann, W.C. Parker, and J.S. Sperry. 1995. Water transport dynamics in trees and stands. Pp 301-389 *In* Smith, W.K. and T.M. Hinckley (Eds) Resource Physiology of Conifers: Acquisition, Allocation, and Utilization. Academic Press, San Diego, CA.

Pederson, N, E.R. Cook, G.C. Jacoby, D.M. Peteet, and K.L. Griffin. 2004. The influence of winter temperatures on the annual radial growth of six northern range margin tree species. *Dendrochronologia* 22:7-29.

Peterson, D.L., D.G. Silsbee, and K.T. Redmond. 1999. Detecting long-term hydrological patterns at Crater Lake, Oregon. *Northwest Science* 73:121-130.

Phipps, R.L., D.L. Ierley, and C.P. Baker. 1979. Tree rings as indicators of hydrologic change in the Great Dismal Swamp, Virginia and North Carolina. USGS, Reston, VA.

Phipps, R.L. 1983. Streamflow of the Occoquan River in Virginia as reconstructed from tree-ring series. *Water Resources Bulletin* 19(5):735-743.

Phipps, R.L. 1985. Collecting, preparing, crossdating, and measuring tree increment cores. Water Resources Investigations Report 85-4148. US Geological Survey, Reston, VA.

Price, J. 1997. Soil moisture, water tension, and water table relationships in a managed cutover bog. *Journal of Hydrology* 202:21-32.

Ramsey, E.W., K.R. Hinkle, and L.E. Benander. 1970. Waters of the Dismal Swamp. *Virginia Journal of Science* 21:81-83.

Reed, P.B., Jr. 1988. National List of Plant Species That Occur in Wetlands: National Summary. U.S. Fish and Wildlife Service, Washington, DC, USA. Biological Report 88(24).

Robertson, P.A. 1992. Factors affecting tree growth on three lowland sites in southern Illinois. *American Midland Naturalist* 128:218-236.

Rothwell, R.L., U. Silins, and G.R. Hillman. 1996. The effects of drainage on substrate water content at several forested Alberta peatlands. *Canadian Journal of Forest Research* 26:53-62.

Ruffin, E. 1837. Observations made during an excursion to the Dismal Swamp. *Farmers' Register* 4:513-521.

Russell, J.H. 1998. Genecology of *Chamaecyparis nootkatensis*. Pp 82-92 *In* Laderman, A.D. (Ed) Coastally Restricted Forests. Oxford University Press, New York, NY.

Schafale, M.P. and A.S. Weakley. 1990. Classification of the natural communities of North Carolina; third approximation. N.C. Natural Heritage Program. N.C. Dept. of Environment, Health and Natural Resources, Raleigh, NC. 325 p.

Shacochis, K.M., J.W. DeBerry, D.T. Loomis, R.T. Belcher, and R.B. Atkinson. 2003. Vegetation importance values and weighted averages of Atlantic white cedar stands in Great Dismal Swamp and Alligator River National Wildlife Refuges. Pp 227-234 *In* Atkinson, R.B., R.T. Belcher, D.A. Brown, and J.E. Perry (Eds) Restoration and Management of Atlantic White Cedar Swamps: Proceedings of a Symposium at Christopher Newport University, May 31-June 2, 2000.

Sharitz, R.R. and J.W. Gibbons. 1982. The ecology of southeastern shrub bogs (pocosins) and Carolina bays: A community profile. U.S. Fish and Wildlife Serv. Div. of Biol. Serv. Washington, DC. FWS/OBS-82/04. 93 pp.

Simpson, B. 1990. The Great Dismal: A Carolinian's swamp memoir. University of North Carolina Press, Chapel Hill, NC.

Stockton, C.W. 1990. Climatic, hydrologic and water supply inferences from tree rings. *Civil Engineering Practice* 5:37-52.

Stoltzfus, D.L. and R.E. Good. 1990. Plant community structure in *Chamaecyparis thyoides* swamps in the New Jersey Pinelands Biosphere Reserve, USA. Pp 142-155 *In* A.D. Laderman (Ed) Coastally Restricted Forests. Oxford University Press New York, NY.

Stokes, M.A. and T.L. Smiley. 1968. An Introduction to Tree-ring Dating. University of Chicago Press, Chicago, IL.

Trout, W.E. III. 2004. The Great Dismal atlas. Suffolk, VA. Virginia Canals and Navigations Society.

US Army Corps of Engineers. 1986. Situation Report and Environmental Assessment: Dismal Swamp Canal, Virginia and North Carolina. Norfolk, VA District, US Army Corps of Engineers.

U.S. Army Corps of Engineers. 1993. Installing monitoring wells/piezometers in wetlands. WRP Technical Note. HY-IA-3.1.

US Army Corps of Engineers. 2007. Dismal Swamp Canal navigation project: Lake Drummond daily water-level readings. Norfolk, VA District, US Army Corps of Engineers.

US Army Corps of Engineers. 2010. Lake Drummond / Dismal Swamp Canal daily hydrologic summary [Internet]. Norfolk (VA) District: US Army Corps of Engineers. [cited 2010 Sep 24]. Available from: http://www.nao.usace.army.mil/Technical%20Services/operations%20branch/Water%20Control%20at%20District%20Facilities/dscdaily.htm.

US Fish and Wildlife Service. 2006. Great Dismal Swamp National Wildlife Refuge and Nansemond National Wildlife Refuge final comprehensive conservation plan. Great Dismal Swamp National Wildlife Refuge, Suffolk, VA.

Van Druten, B. and T.R. Eagle. 2000. Comprehensive survey of 3,000 acres of Atlantic white cedar [*Chamaecyparis thyoides* (L.) B.S.P.] clearcut tracts on the Dare County Peninsula, North Carolina. 173 pp *In* Belcher, R.T., D.A. Brown, and R.B. Atkinson (Eds) Restoration of Atlantic White Cedar Ecosystems at Dare County Bombing Range, North Carolina: A Compendium of Research. Tech. Rep.

Wharton, C.H., W.M. Kitchens, E.C. Pendleton, and T.W. Sipe. 1982. The ecology of bottomland hardwood swamps of the southeast: A community profile. Washington, DC, USA, U.S. Fish and Wildlife Service, Biological Services Program.

Yamaguchi, D.K. 1991. A simple method for cross-dating increment cores from living trees. *Canadian Journal of Forest Research* 21:414-416.

Zar, J.H. 1999. Biostatistical Analysis. 4th ed. Prentice Hall, Upper Saddle River, NJ.