Historical Stem Development of Northern White-Cedar (*Thuja occidentalis* L.) in Maine

Philip V. Hofmeyer, Laura S. Kenefic, and Robert S. Seymour

ABSTRACT

We used stem analysis to quantify early height and diameter growth rates of 80 northern white-cedar trees (17.4–55.0 cm dbh) harvested in 2005 and 2006 in central and northern Maine. It took an average of 42 years (range, 9–86 years) for sampled trees to grow from stump height to sapling size, 96 years to grow to pole size (range, 28–171), 140 years to grow to sawtimber size (range, 54–238), and 170 years to reach shingle-stock size (range, 81–317). Approximately 80% of sampled trees had initial growth suppression followed by release, suggesting they originated as advance regeneration. The mean period of initial suppression exceeded 60 years, and some trees responded to release after nearly 200 years. Although growth rates were generally slow, the variability observed suggests the potential for northern white-cedar both to withstand prolonged periods of suppression and to grow rapidly under favorable conditions. Observed patterns suggest that this species might respond well to uneven-aged or shelterwood silvicultural systems; foresters are recommended to encourage advance regeneration and emphasize protection of the residual northern white-cedar understory during harvest operations.

Keywords: swamp, conifer, arborvitae, Acadian

Northern white-cedar (*Thuja occidentalis* L.) is common in much of southeastern Canada and the northeastern United States (Johnston 1990). In Maine, northern white-cedar is the fourth most abundant conifer in terms of growing stock volume, after red spruce (*Picea rubens* Sarg.), eastern white pine (*Pinus strobus* L.), and balsam fir (*Abies balsamea* [L.] Mill.) (McWilliams et al. 2005). Knowledge of northern white-cedar history, ecology, and silviculture is needed to sustainably manage the region's forests, to provide critical winter habitat for white-tailed deer (*Odocoileus virginianus*), and to provide niche commodity products such as shingles, fence posts, and mulch. Unfortunately, northern white-cedar has historically been underrepresented in the forestry literature (Hofmeyer et al. 2007, 2009), often leading to uninformed management decisions.

US Forest Service Forest Inventory and Analysis data suggest that the area of northern white-cedar forestland in Maine declined by 7% between 1982 and 2003 (McWilliams et al. 2005). Total growing stock volume decreased by 8% over the same period, although sawtimber growing stock volume increased. Ingrowth and accretion were greater than mortality; volume reductions were due to increased cull increment and harvest levels that exceeded growth. From these data, it appears that existing northern white-cedar trees have been getting larger but that recruitment is low.

Slow early height and diameter growth rates have been reported for northern white-cedar in Maine (Curtis 1946), Michigan (Nelson 1951), Minnesota (Cornett et al. 2001), Wisconsin (Rooney et al. 2002), and Quebec (LaRouche 2009). Because northern white-cedar grows slowly and is highly palatable to deer (Nelson 1951, Van Deelen 1999, Cornett et al. 2000), it is often out-competed in the regeneration stratum of mixed stands, leading to species composition shifts (Thornton 1957, Johnston 1972, Scott and Murphy 1987, Cornett et al. 2000). On the Big Reed Forest Preserve in northern Maine, for example, Fraver (2004) noted abundant northern white-cedar regeneration but little sapling and poletimber recruitment after 1900.

Sustainable management of northern white-cedar requires appropriate silvicultural prescriptions. Given the apparent recruitment bottleneck, it is critical that we improve our understanding of the early growth of this species throughout its range. This study describes historical height and diameter growth patterns of sound northern white-cedar trees harvested in central and northern Maine and uses the observed patterns as the basis for management recommendations.

Methods

In 2005, 59 sound northern white-cedar stems were obtained from the shingle mill of Maibec Industries, Inc. (MI), in St-Pamphile, Quebec, Canada. These MI stems were harvested from known stand locations in northern Maine (Figure 1) and had not been bucked to remove sections of decay prior to transport to the mill. Cross-sectional discs were taken from each stem at stump height (SH; 0.3 m), just above breast height (BH; 2.0 m), and mid-height (MH; 4.2 m); samples were taken at these unconventional intervals to allow remaining bole sections to be processed in the shingle mill. An additional 21 sound northern white-cedar trees harvested from central and northern Maine in 2006 for a study of leaf area (LA) (Hofmeyer 2008) were stem-analyzed and included in the present analysis. LA trees were sectioned at 1-m intervals from

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This article uses metric units; the applicable conversion factors are: millimeter (mm): 1 mm = 0.039 in.; centimeters (cm): 1 cm = 0.39 in.; meters (m): 1 m = 3.3 ft.

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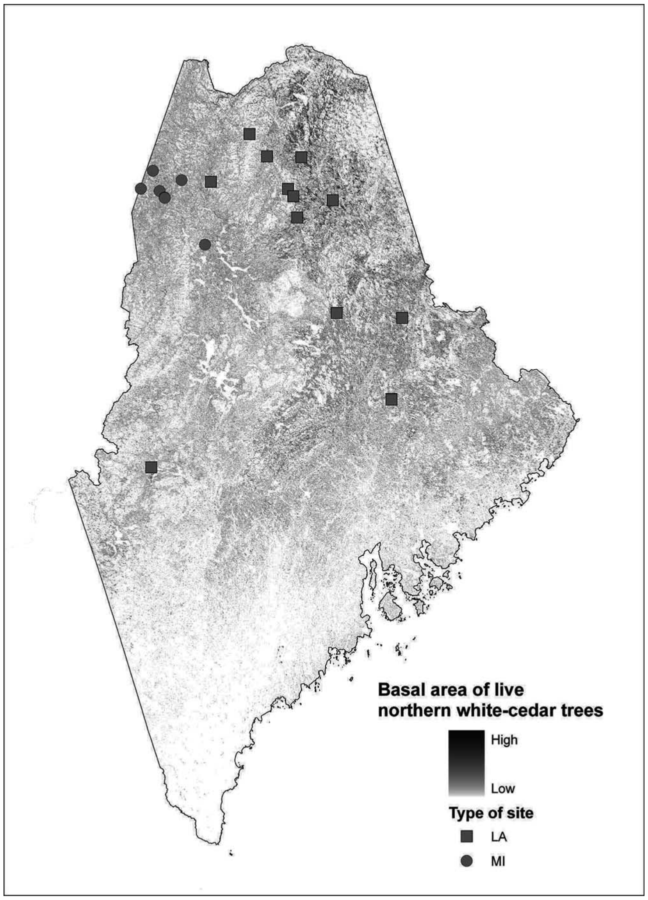

Figure 1. Site locations of the destructively sampled northern white-cedar stems from Maibec Industries (MI; ●) and the leaf area study (LA; ■).

0.3 m to top height. Stand- and tree-level data, though not available for MI trees, were available for LA trees; these trees came from mixed-species stands with varying densities and proportions of northern white-cedar, red spruce, balsam fir, and hardwoods (Hofmeyer 2008).

Cross-sectional discs were dried, sanded, and analyzed in a Regent Instruments WinDendro at a resolution of 1200 dots per inch. A pith locator consisting of a clear transparency with concentric circles of constant radial increment was used to estimate missing growth years in two trees (Applequist 1958); estimated values were within the range observed for all sampled trees. To analyze the MI and LA sample groups concurrently, the number of annual rings per meter of height growth was calculated for all trees. For the remainder of the study, SH referred to 0.3 m, BH to 2.0 m, and MH to 4.2 m. The numbers of years required to reach sapling (2.5 cm at BH), poletimber (12.7 cm at BH), sawtimber (22.9 cm at BH), and shingle-stock (38.1 cm at SH) size were determined for each sampled tree.

A running 10-year radial increment average was used to identify periods of growth release, wherein mean radial growth of ten years after an event is subtracted from the mean radial growth of ten years prior to an event. An absolute increase threshold of 0.41 mm was then applied to mean radial growth patterns (cf. Fraver and White 2005). Using an absolute increase instead of a relative percentage increase (Nowacki and Abrams 1997) reduces the likelihood of identifying false-positive releases arising from low mean growth values. Early sapling growth was evaluated to determine whether sampled stems originated in a gap or in suppression (after Lorimer et al. 1988). Because most stems in this study are from unknown stands, probability measures of origin were not used. A gap-origin threshold of 1 mm/year for the mean of the first 5 years of growth at BH for all trees was used in this study (1 mm is beyond 3 standard errors [SE] of the mean annual growth for the first 5 years of all trees in this study).

Table 1. Years required to reach a given height from stump height (0.3 m) in 80 stem-analyzed northern white-cedar trees.

Stem height (m)	Minimum age	Mean age	Maximum age	Standard error
	....	.(years)	....	
1.0	4	15.5	36	0.9
2.0	6	26.7	61	1.5
3.0	13	38.4	75	1.7
4.0	19	50.0	103	1.9

Results

Diameter at SH of sampled northern white-cedar trees ranged from 17.4 to 55.0 cm (mean = 40.3; SE = 0.8); age at SH ranged from 87 to 356 years (mean = 184; SE = 6). Mean annual height growth rates (0.08 ± 0.003 m/year over the first 4 m) suggest that it took, on average, 15.5 years to grow from SH to 1 m and 50.0 years to grow from SH to 4 m (Table 1). However, sampled trees took as little as 4 years and as long as 36 years to reach 1 m, and as little as 19 years but as long as 103 years to reach 4 m. A mean of 42 years (range, 9–86 years) was required for northern white-cedar in this study to reach sapling size, 96 years (range, 28–181) to reach poletimber size, 140 years (range, 54–238 years) to reach sawtimber size, and 170 years (range, 81–317) to reach shingle-stock size (Table 2).

Only 16% of sampled trees had early radial increments high enough to be considered gap-origin. In trees that had suppressed origins, the period of initial suppression ranged from 13 to 197 years (mean = 66; SE = 7). A period of initial suppression followed by a growth release was observed at SH in 80%, and at MH in 19%, of sampled trees of suppressed origin (see Figure 2). Twenty-one of the sampled trees showed no signs of release at any point in their ring chronology; that is, no mean annual increment change exceeded the 0.41-mm threshold. Nearly every sampled tree exhibited prominent basal flaring, often extending well above BH, as well as constant or slightly increasing annual radial increment (increasing area increment) over time at BH (see Hofmeyer 2008).

Discussion

Only sound trees were included in this growth assessment. Hofmeyer et al. (2009) found that 80% of 300 outwardly sound northern white-cedar trees studied in Maine were centrally decayed. Early growth rates of northern white-cedar trees with internal decay remain unknown; however, mean annual height increment values found in this study are consistent with findings observed in cedar seedlings and saplings in the Lake States (0.05 m/year in suppression) (Heitzman et al. 1997). These values are less than those observed by Hannah (2004), who found height growth to range from 0.15 to 0.3 m/year depending on site conditions in young even-aged stands in Vermont. Analysis of two sites in Quebec indicated that asexual- and seed-origin northern white-cedar stems required a mean of 6–7 years and 11–13 years, respectively, to reach 0.3 m in

Table 2. Number of years required to reach a given inside-bark diameter at a given height from stump height (0.3 m) for 80 stem-analyzed northern white-cedar trees.

Height[a]	Diameter (cm)	Size class	*N*	Minimum age	Mean age	Maximum age	Standard error
				(years)			
BH	2.5	Sapling	80	9	42.0	86	2.0
BH	12.7	Poletimber	80	28	96.0	171	3.4
BH	22.9	Sawtimber	80	54	139.9	238	4.4
SH	38.1	Shingle stock	66	81	170.1	317	5.7

[a] Stump height (SH) and breast height (BH) refer to 0.3 and 2.0 m, respectively.

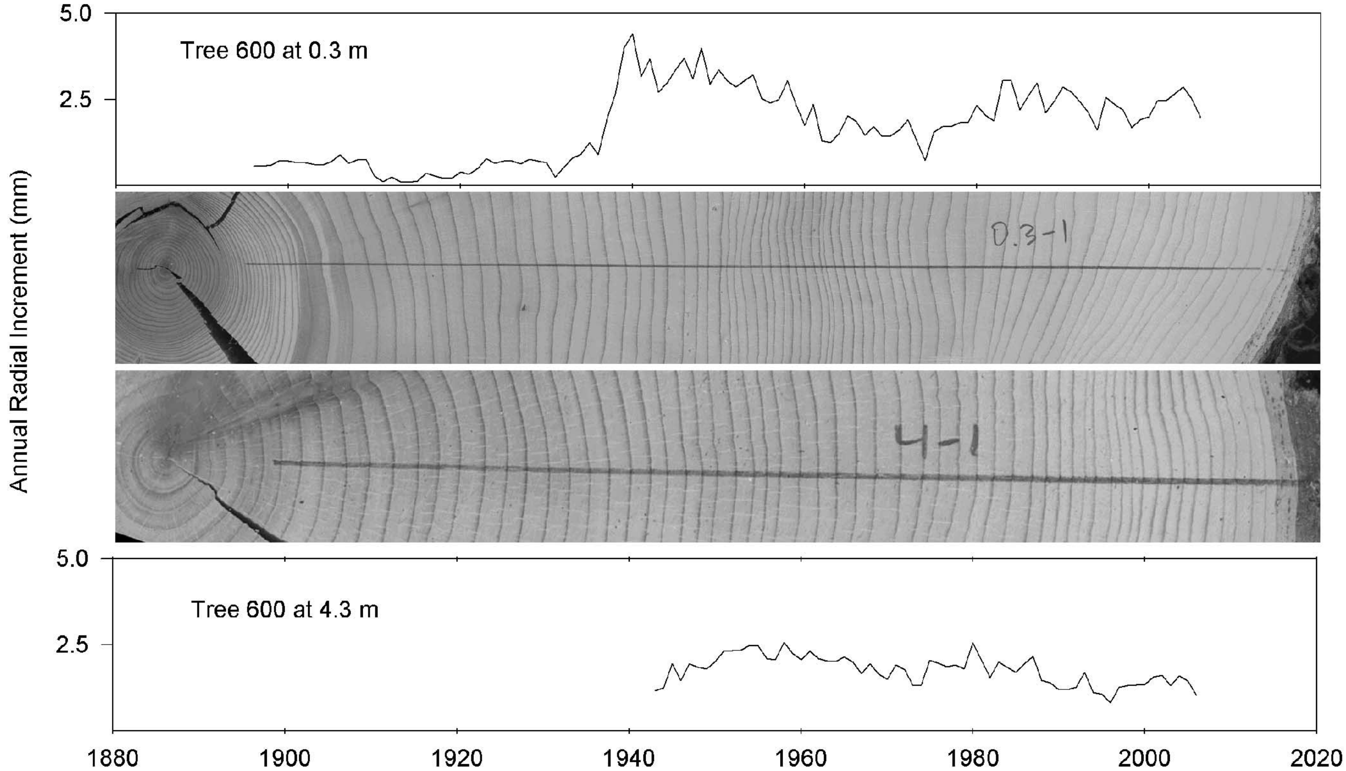

Figure 2. Typical pattern of suppression followed by a release, with relatively constant radial growth in the stump height disc (top) and no signs of a suppressed core at the mid-height disc (bottom).

height (LaRouche 2009). Nonlinear analysis of early growth data predicted that height growth rates of northern white-cedar increase as stems become larger and older (LaRouche 2009).

Slow height growth is often attributed to browse because northern white-cedar is a preferred browse species for white-tailed deer in northern climates (Ullrey et al. 1964, 1967, 1968). Excessive seedling herbivory has been reported as a cause for a lack of northern white-cedar sapling recruitment in the Lake States (Van Deelen 1999, Cornett et al. 2000, Rooney et al. 2002). Herbivory from white-tailed deer is often severe enough in this region to prohibit recruitment of seedlings into the sapling class (Cornett et al. 2000), which has been known to lead to species composition shifts to less palatable or prolific tree species such as balsam fir (Van Deelen et al. 1996, Heitzman et al. 1997). Slow early height development observed in this study suggests that even the fastest growing northern white-cedar seedlings are within deer browsing height (<2 m) for nearly a decade. It is likely that deer browse does not fully explain the initial period of growth suppression observed in this study, because white-tailed deer were not present in northern Maine from European settlement to the 1890s (Stanton 1963), and many of these samples originated during that time. However, deer browse is a concern in newly regenerated northern white-cedar stands, particularly in the Lake States, where deer abundance in dense cedar stands is high during winter months. Even in regions with much lower overwintering deer densities, deer browse can be detrimental to northern white-cedar early development, holding total seedling height to less than 30 cm for decades (Larouche 2009).

Our observation of early growth suppression followed by release suggests that northern white-cedar can survive as advance regeneration under shade but may require a significant canopy opening to be recruited into sapling- or pole-size classes. Most of the sampled trees had many years of suppression prior to release, and 5% responded well after over 150 suppressed years. Our data also show that northern white-cedar trees can persist for over 300 years without ever experiencing a growth release. These findings are consistent with those of Heitzman et al. (1997), who reported a tripling of annual height growth in previously established northern white-cedar saplings in Michigan following significant disturbances; they reported growth responses to release after approximately 135 years of suppression. Similarly, Larouche (2009) found that early height development of planted northern white-cedar seedlings was positively correlated with light levels and that growth was faster in canopy gaps

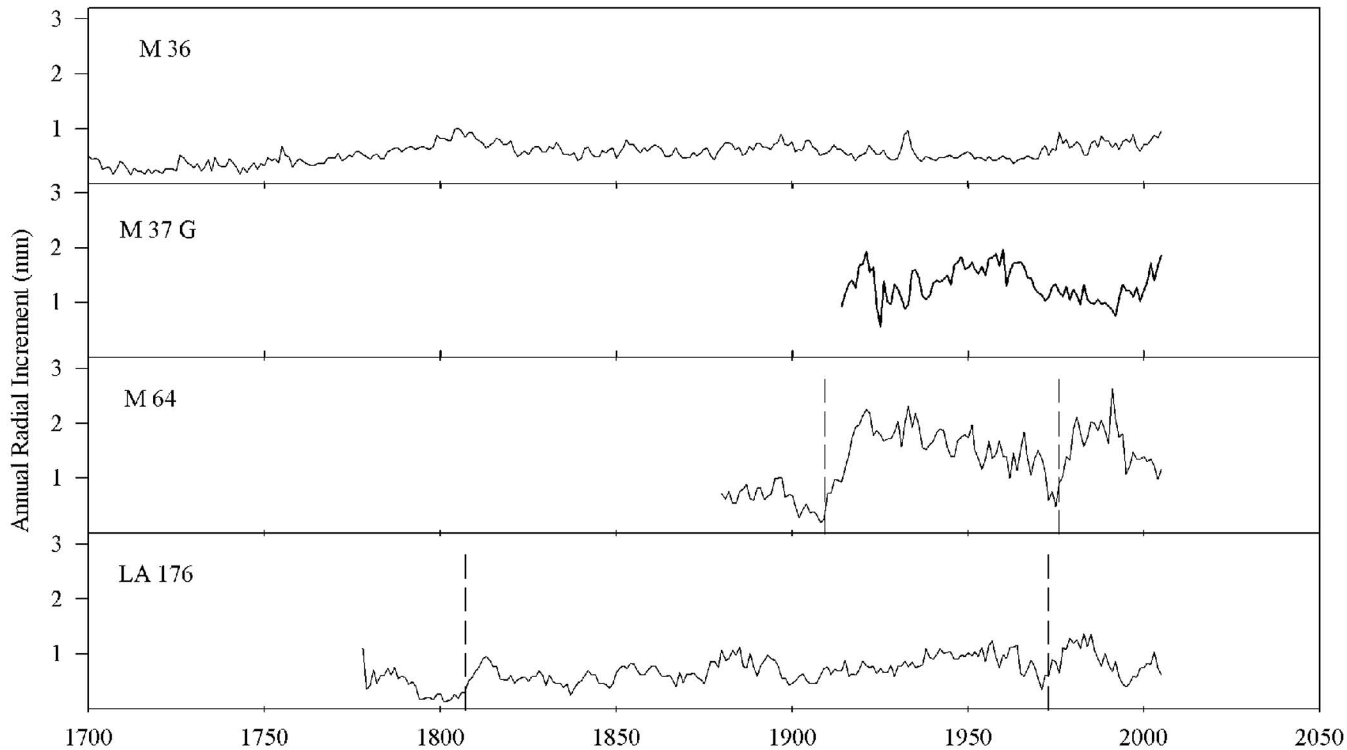

Figure 3. Breast height ring chronologies of four northern white-cedar trees in Maine. M37G was of gap origin; M36 had a suppressed origin and was never released. Vertical dashed lines indicate growth releases in M64 and LA176 coinciding with known spruce budworm outbreaks.

than beneath a partial overstory. Faster height increment was attributed to an increase in indirect light in that study. Data from the Penobscot Experimental Forest in central Maine indicated that radial growth of northern white-cedar saplings (1.3–4.6 cm dbh) in partially cut stands was less than 0.9 cm in 10 years, leading to an estimate of 94 years at BH before becoming merchantable stems (LaRouche 2009).

Even the oldest trees in the present study had relatively constant radial increment, that is, increasing area increment. This phenomenon was previously reported by Harlow (1927), who noted that trees from two northern white-cedar communities in New York had remarkable "evenness" in their annual growth rings. Trees generally allocate photosynthate hierarchically, first to maintenance respiration of living tissue and then to production of fine roots and leaves, reproductive tissues, primary growth, and finally xylem increment and defensive compounds (Oliver and Larson 1996). As trees age and grow larger, maintenance respiration requirements increase, and stemwood growth often decreases. In addition, trees in subordinate canopy positions may have a lower proportion of photosynthate available for stemwood growth (Assmann 1970, Oliver and Larson 1996). Given that many of the sampled trees were of advanced age and that northern white-cedar commonly occupies subordinate canopy positions, patterns of increasing area increment at SH and BH are difficult to explain. One possibility is that these patterns reflect preferential allocation of resources to lower portions of the stem to tolerate bending stress. Northern white-cedar has a low specific gravity, is weak and brittle in compression (Seeley 2007), and is commonly associated with sites where soil and root stability is poor. Northern white-cedar is a US Fish and Wildlife Service wetland indicator species frequently associated with hydric site adaptations such as hypertrophy, succulent foliage, and elevated root systems (summarized in Kell 2009).

In a detailed reconstruction of the Big Reed Forest Preserve in northern Maine, Fraver (2004) suggested that of all the species sampled, northern white-cedar was the most complacent (i.e., least responsive to local environmental conditions). Although northern white-cedar may be complacent relative to other tree species, findings from this study suggest that northern white-cedar can respond with increased radial increment to favorable changes in the environment. In fact, Heitzman et al. (1997) suggested that most northern white-cedar trees in their study sites were established and/or released in response to stand-level disturbance resulting from historical logging practices. However, LaRouche (2009) found that recruitment and ingrowth of northern white-cedar stems on the Penobscot Experimental Forest was limited by harvesting; partial harvesting operations accounted for as much as 60% of large sapling mortality.

Anecdotally, release periods frequently coincided with historical spruce budworm (SBW; *Choristoneura fumiferana*) epidemics (see Figure 3), although this potential release mechanism was not analyzed in the present study. Nevertheless, breast-height chronologies suggest that 74% of the sampled trees experienced at least one growth release during or shortly after SBW epidemics; known historical SBW outbreaks in northern Maine occurred around 1810–1813, 1913–1919, and 1972–1986 (Krause 1997, Fraver et al. 2007). Because SBW is a defoliating insect that reduces leaf area of its primary hosts (balsam fir and spruce species), growth increases would be expected of nonhost species in mixed-species stands. This dataset was not intended to identify nonhost responses to SBW epidemics; however, it may be an important avenue for future investigations of northern white-cedar responses to release.

Silvicultural Implications

It is clear that suppressed northern white-cedar trees can respond to localized environmental changes with increased growth, even after extended periods of suppression. This finding has important implications for northern white-cedar silviculture. Historical evidence of advance regeneration and subsequent response to release encourages the use of uneven-aged silviculture or variants of the shelterwood system, with options for long-lived reserve trees. Group selection and shelterwood systems were treatments recommended by Hannah (2004) in pure lowlands cedar stands in Vermont. Larouche (2009) recommended partial harvesting for the establishment of northern white-cedar seedlings followed by a group selection release treatment to increase available indirect lighting to established seedlings. Strong responses in height and diameter increment suggest that thinning even-aged cedar stands could be a successful intermediate treatment to increase growth on stems with good form. Foresters are encouraged to promote advance regeneration during partial harvest entries without targeting overtopped suppressed northern white-cedar trees for removal in light of the observed slow early development. In areas with high populations of deer, measures must be taken to reduce the influence of excessive deer browse (for recommendations, see Nelson 1951, Van Deelen 1999, and Rooney et al. 2002). Because of the weak and brittle wood properties of northern white-cedar, caution should be taken to avoid residual stand damage. Protection of understory northern white-cedar saplings, regardless of age, is warranted if this species is desired in the future stand.

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