SPECIES COMPOSITION AND STAND STRUCTURE OF A LARGE RED SPRUCE PLANTING 67 YEARS AFTER ITS ESTABLISHMENT IN WESTERN NORTH CAROLINA

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Abstract.—Red spruce (*Picea rubens* Michx.) is a large and long-lived species that dominated high-elevation forests of the southern Appalachians before most stands were heavily logged in the early 1900s. Restoration of spruce forests by artificial methods has been studied since the 1920s, but little information is available on characteristics of older planted stands. Woody vegetation was inventoried in part of a 50 ha stand of red spruce planted in the Pigeon River watershed of the Pisgah National Forest from 1941 to 1943. The purpose of this study was to determine vegetative composition and structure of the stand, and effects of site variables on growth of red spruce. The spruce component of the stand averaged 1,310 stems ha^{-1} ranging in diameter at breast height from 0.1 cm to 37.5 cm; basal area averaged 29.7 m^2 ha^{-1}. Red spruce basal area was correlated strongly ($r = -0.75$, $p<0.0001$) with an index of site landform and somewhat with aspect ($r = -0.52$, $p<0.01$). This large, even-aged planting of red spruce provides an opportunity for immediate and long-term study of stand dynamics and site relationships associated with restoration of this forest type to a larger part of its former range in the southern Appalachians, as well as investigation of questions related to climate change and growth decline.

INTRODUCTION

Red spruce (*Picea rubens* Sarg.) is a long-lived, shade-tolerant, coniferous tree species that is common in the New England states and Canada; in the southern Appalachian Mountains it occupies an elevation zone between 1,675 m to 1,900 m (Whittaker 1956). Fraser fir (*Abies fraseri* [Pursh] Poir.), a smaller and shorter-lived conifer, is usually associated with red spruce (Korstian 1937) and increases dominance on sites above 1,800 m (Whittaker 1956). Red spruce forests were harvested extensively during the early 1900s and wildfires in logging debris reduced both site quality of the highly organic soils and seed sources for natural regeneration in many areas of the species' former occurrence (Korstian 1937). Forests dominated by red spruce and Fraser fir are estimated to occupy 7,500 ha in the Southern Appalachian Mountains of North Carolina (Dull et al. 1988). Red spruce is a component of high-elevation stands that provide foraging habitat for the endangered northern flying squirrel (*Glaucomys sabrinus coloratus*) (Loeb et al. 2000). Some stands of red spruce show evidence of decline in vigor and increased mortality resulting possibly from changes in air quality and climate (LeBlanc et al. 1992, Busing and Pauley 1994).

Reforestation of cutover and burned high-elevation forests has been investigated since the 1920s (Korstian 1937). Forest managers concluded that artificial means was the most favorable method because of the lack of natural regeneration following burning of heavy logging slash and limited distance of dispersal of spruce and fir seeds (Minckler 1945). Early survival and growth in plantings made for evaluation of non-native species at Mount Mitchell, NC, were studied for 14 years, with the conclusion that the native species of red spruce and Fraser fir were best for reforestation (Minckler 1945). Information is lacking on development of older red spruce stands in the Southern Appalachians.

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One of us (JHH) recently became aware of a stand totaling 50 ha that had been established by planting on a previous spruce site from 1941-1943, in the Pisgah National Forest in western North Carolina (Mead 1942). This planting had been established by the United Daughters of the Confederacy in cooperation with the Pisgah National Forest to memorialize Civil War veterans of North Carolina and is explained more fully elsewhere (Hyatt 2001). Although the planting was mapped by the U.S. Department of Agriculture, Forest Service and records of its establishment had been preserved by one of us (TMO), value of the stand for study of red spruce restoration purposes was realized only recently.

The primary objective of this study was to document the location of the memorial forest and to describe current characteristics of the tree and shrub vegetation. A secondary objective was to investigate environmental factors associated with basal area of the spruce component of the stand. Results reported here are preliminary because only a small part of the stand was sampled.

STUDY AREA

The red spruce stand was established in the Pisgah District of the Pisgah National Forest, (35.30087°N, 82.90408°W) at an elevation of 1,700 m in the Pigeon River watershed of the Balsam Mountains, in Haywood County, NC. Precipitation likely exceeds approximately 150 cm annually and is uniformly distributed. Temperature averages around -2.8 °C in January and 17.2 °C in July. Bedrock formations consist of metamorphosed gneisses and schists derived largely from granites. Soils are in the Wayah clay loam series, which are classed as Inceptisols. Soils are generally shallow, <100 cm deep, and well drained, but moisture availability is likely high during the growing season as a result of frequent precipitation and high organic content. Natural vegetative communities in the high-elevation ecosystems, below the Fraser fir forests, are dominated by red spruce on exposed ridges and slopes, and hardwoods in valleys and protected slopes (Schafale and Weakley 1990). Much of the original red spruce forests in this area was harvested in the early 1900s. Following harvesting, uncontrolled fires in the heavy logging slash resulted in consumption of the highly organic soil, mortality of natural regeneration, and loss of a seed source for regeneration. In July 1922, 4 years after logging and 2 years after burning, a typical upper slope in the Pigeon River watershed "... had grown up to blackberries, fire cherry, and yellow birch" (Fig. 1). Red spruce and Fraser fir forests of the Balsam Mountains account for about 10 percent of the high-elevation type in North Carolina (Dull et al. 1988).

Administrative records indicate that red spruce seeds from the Monongahela National Forest (lot 14 34) were used to produce seedlings at a Forest Service nursery near Parsons, WV. Four-year-old seedlings (grown 2 yrs from seed, then transplanted and grown another 2 yrs) were field planted using a short-handled mattock at a density averaging about

Figure 1.—Four years after cutting an almost pure stand of red spruce for sawtimber and pulpwood, and 2 years following fire in the dense logging slash, a dense cover of blackberry, pin cherry, and yellow birch dominates the area of a former stand of red spruce in the upper portion of the Pigeon River watershed. (July 1922 photo by C. Korstian, USDA Forest Service).

2,470 seedlings ha^{-1}. Field establishment maps indicated the memorial forest consisted of several tracts. About one-third of the total area was planted during the winter of each year, from 1941 to 1943. In December 1954, administrative records show seedling survival averaged 78 percent and height averaged 0.6 m; most red spruce seedlings were overtopped by a dominant canopy of pin cherry (*Prunus pensylvanica* L. f.). The 1954 field notes state: "Blank spots [with no surviving seedlings] seem to be in open spaces. Spruce seems to do better in the shade of birch, blackberries and laurel bushes."

METHODS

The area used for our study was on a west-facing slope extending down from a ridge crest that bordered the Blue Ridge Parkway, at the Mt. Hardy overlook. Shrub and tree vegetation were inventoried on temporary circular sample plots located at approximately 50-m intervals along five randomly oriented transects that generally paralleled the contours. Plot radii ranged from 5 to 20 m depending on uniformity of site topography and density of vegetation; smaller plots were used where shrub vegetation was dense. Live and dead standing stems ≥0.1-cm diameter at breast height (d.b.h.) were recorded by species and 5-cm diameter class (e.g., 0.1-4.9, 5.0-9.9). Total height and d.b.h. were measured on one dominant or co-dominant red spruce on each odd-numbered plot for estimation of stand site index. Those data were supplemented with total height of a healthy red spruce in the intermediate or suppressed crown classes measured on even-numbered plots to develop a regression model predicting height as a function of d.b.h. Site index (total height at 50 years) was estimated using relationships developed from second-growth red spruce stands in New England (Meyer 1929).

Topographic variables measured at each sample plot consisted of aspect (azimuth from north in degrees), gradient (slope steepness at right angles to contours measured in percent), and terrain shape index (t.s.i.), a quantitative expression of meso-scale landform of the site, as delineated by the plot boundary, that generally ranges between -100 percent (highly convex), through 0 (planar), to +100 percent (highly concave). Briefly, t.s.i. represents the average inclination in percent of the sample plot land surface measured from the center to the boundary in eight equally spaced directions (McNab 1989).

Simple relationships between red spruce basal area and topographic variables were determined through correlation analysis. Regression was used to investigate the individual and combined effects of the three topographic variables on basal area of red spruce at each sample plot. All tests of significance were made at the 0.05 level of probability.

RESULTS AND DISCUSSION

Study Area

Twenty-one sample plots, ranging in area from 0.0058 ha to 0.0546 ha, were established in the stand in October 2008, resulting in a total area sampled of 0.197 ha. Aspect of the study area averaged 327° (range 270° to 007°) and slope gradient averaged 29.2 percent (range 16 to 50 percent). The t.s.i. averaged -2.25 (range -19.2 to +7.0), which indicates that landform of the sample plots was generally slightly convex, but ranged from highly convex to slightly concave. Arborescent vegetation was present on all plots; shrubs were absent on one plot. Although the red spruce seedlings had been planted, appearance of the stand did not resemble a typical plantation of uniformly spaced trees, because rows were not discernable.

Species Composition and Structure

Woody vegetation consisted of nine arborescent and three shrub species that averaged 4,785 stems ha^{-1} and 49.7 m^2 ha^{-1} of basal area (Table 1). Trees made up 41 percent of stem density and 94 percent of the basal area. Red spruce was the dominant tree species, accounting for more than 60 percent of stem density and basal area, followed by yellow birch (*Betula alleghaniensis* Britton), which made up an additional 25 percent of stand density and basal area. Red spruce and yellow birch trees were present on all plots sampled. Except for mountain ash (*Sorbus americana* Marsh.), species of other trees were sparse, particularly eastern hemlock (*Tsuga canadensis* [L.] Carr.), sugar maple (*Acer saccharum* Marsh.), and black cherry (*Prunus serotina* Ehrh.), which were

Table 1.—Density, stocking, and basal area of species present on 21 plots sampled in a stand of red spruce planted in the Pisgah National Forest in 1941-1943.

Species (Scientific name)	Density (S.D.)[a]		Frequency	Basal area (S.D.)[a]	
	N/ha		*N plots*	*m²/ha*	
Red spruce (*Picea rubens* Sarg.)	1,310.0	(754.8)	21	29.7	(15.5)
Yellow birch (*Betula alleghaniensis* Britton)	520.7	(341.5)	21	11.4	(11.0)
Mountain ash (*Sorbus americana* Marsh.)	48.1	(66.2)	6	1.3	(3.4)
Mountain maple (*Acer spicatum* Lam.)	31.7	(81.8)	4	0.1	(0.2)
Pin cherry (*Prunus pensylvanica* L. f.)	13.6	(38.4)	3	0.3	(0.9)
Northern red oak (*Quercus rubra* L.)	9.8	(34.7)	2	3.3	(13.7)
Eastern hemlock (*Tsuga canadensis* [L.] Carr.)	8.2	(37.4)	1	0.1	(1.0)
Sugar maple (*Acer saccharum* Marsh.)	7.2	(33.2)	1	0.2	(0.8)
Black cherry (*Prunus serotina* Ehrh.)	7.2	(33.2)	1	0.4	(2.0)
All trees	1,954.9	(900.8)	21	46.8	(16.7)
Catawba rhododendron (*R. catawbiense* Michx.)	2,672.4	(3,341.0)	19	2.5	(2.3)
Mountain holly (*Ilex montana* Torr. & Gray)	150.8	(425.0)	4	0.3	(1.1)
Viburnum (*Viburnum lantanoides* Michx.)	6.7	(21.7)	2	0.1	(1.1)
All shrubs	2,829.9	(3,315.0)	20	2.9	(2.4)
All live trees and shrubs	4,784.6	(5,615.4)	21	49.7	(16.9)
All dead standing trees	441.7	(303.8)	20	5.2	(4.0)

[a]Calculated with zero for sample plots where the subject species was absent.

represented by single stems. The shrub layer of most plots was dominated by catawba rhododendron (*Rhododendron catawbiense* Michx.), which accounted for 94 percent of stem density and 86 percent of the shrub basal area. Composition of the major species of this planted stand was similar to that recorded on areas in the same watershed following harvest (Korstian 1937).

Red spruce and yellow birch trees were mostly present in diameter size classes up to 39 cm (Table 2). The largest tree present on the sample plots was a northern red oak (*Quercus rubra* L.) measuring 72 cm d.b.h. Almost all shrubs were less than 9 cm d.b.h. Pooling of both trees and shrubs produces a diameter distribution that resembles the reverse J-curve characteristic of uneven-aged, natural stands of mixed species.

The size class distribution of red spruce alone suggests an almost normal distribution of diameters with a modal class of 12.5 cm d.b.h. (Fig. 2). Diameter distributions are available for comparison with natural stands of mixed red spruce and Fraser fir (Korstian 1937, Oosting and Billings 1951), but data are lacking for pure stands of red spruce, a species composition that is somewhat unusual for high-elevation forests (Korstian 1937). Fraser fir trees are present in the vicinity of the memorial forest, but did not occur in the area sampled.

The diameter distribution of standing dead trees differed from that of the live trees, with the modal size occurring in the 0 to 9 cm d.b.h. class, followed closely by the 10 to 19 cm class (Table 2). Basal area of the standing dead trees averaged 5.2 m^2 ha^{-1}. The 442 dead trees/ha consisted primarily of yellow birch (44 percent) and red spruce (25 percent). The ratio of dead trees to live trees ranged from 1:2.9 for the smallest d.b.h. class to 1:16.5 for the largest class. Only one tree was windthrown – a red spruce measuring 28 cm d.b.h., which had grown in a layer of organic matter 30 cm thick that had accumulated on solid rock. Past stand dominance by pin cherry was indicated on the forest floor by abundant remnants of stem bark, which was characterized by large, prominent horizontal lenticels. McGill and others (2003) reported that pin cherry can

Table 2.—Diameter distribution for a stand of planted red spruce and mixed tree and shrub species on the Pisgah National Forest at 67 years of age.[a]

Species	Basal area	Diameter class (cm) 0-9	10-19	20-29	30-39	40-49	50+
	m²/ha	*Number of stems/ha*					
Red spruce	29.7	370.5	585.8	300.4	53.7	-	-
Yellow birch	11.4	195.7	180.9	122.9	18.6	2.6	-
Northern red oak	3.3	-	-	-	2.6	-	7.2[b]
Mountain ash	1.3	7.2	16.3	22.6	-	-	-
Black cherry	0.4	-	-	7.2	-	-	-
Pin cherry	0.3	-	9.5	4.1	-	-	-
Sugar maple	0.2	-	7.2	-	-	-	-
Mountain maple	0.1	31.7	-	-	-	-	-
Eastern hemlock	0.1	8.2	-	-	-	-	-
Total trees	46.8	613.3	799.7	457.2	74.9	2.6	7.2
Catawba rhododendron	2.5	2,662.5	9.9	-	-	-	-
Mountain holly	0.3	142.6	8.2	-	-	-	-
Viburnum	0.1	6.7	-	-	-	-	-
Total shrubs	2.9	2,811.8	18.1	-	-	-	-
Total live	49.7	3,425.1	817.8	457.2	74.9	2.6	7.2
Dead standing	5.2	209.0	205.1	27.6	-	-	-

[a] Mean site index for red spruce at 50 years = 11.3 m.

[b] d.b.h. = 72.5 cm.

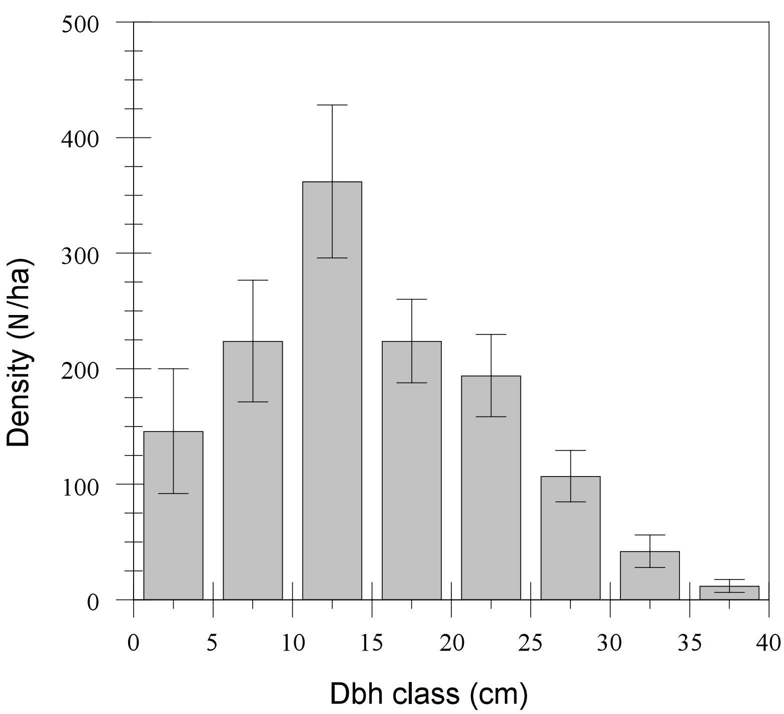

Figure 2.—Density (± SE mean) of the red spruce component of a stand established by planting in the Pisgah National Forest from 1941-1943.

quickly dominate sites severely disturbed by timber harvest or fire, resulting in seedling densities that can exceed 40,000 ha^{-1}. Evidence of fire was not observed in the area sampled.

Although data were not adequate for analysis, observations suggest the presence of two vegetation associations: 1) a dense red spruce overstory with sparse shrub understory; and 2) sparse red spruce overstory with increased yellow birch and other tree species and a dense shrub understory. The former association tended to occur on convex landforms; the latter on planar and concave landforms.

The largest trees observed in the area studied (outside of the sample plots) were two red spruces in a somewhat inaccessible location: between two shallow drains in a dense patch of catawba rhododendron. Both trees exceeded 75 cm d.b.h. and are believed to be remnants of the original stand. The presence of these trees suggests the possibility for restoration of desirable stand characteristics through management activities, such as thinning (Rentch et al. 2007).

Spruce Component of the Stand

Total height of the dominant and co-dominant red spruce component of the stand averaged 14.6 m and ranged from 11.5 to 17.7 m (Table 3). Site index of the 67-year-old red spruce stand averaged 11.3 m, and ranged from 9.1 to 13.7 m. A regression model was developed for estimation of total height from d.b.h. based on 21 sample trees, one from each plot, which included all crown classes:

$$t.h._m = -4.94 + 5.99*\log(d.b.h.) \qquad (1)$$

where $t.h._m$ is total height (m) of red spruce and log (d.b.h.) is the natural logarithm of tree d.b.h. (cm). Equation (1) has a standard error of 1.9 m and explains 66 percent of the variation of total height (Fig. 3).

Basal area of the red spruce component on each of the 21 sample plots ranged from 4.2 m^2 ha^{-1} to 58.0 m^2 ha^{-1} (Table 3). Scatter plotting suggested a strong negative correlation between basal area of the red spruce stand component and land surface shape quantified by t.s.i. ($r = -0.75$, $p<0.0001$) and a weaker negative relationship of basal area with aspect ($r = -0.52$, $p = 0.01$). Regression analysis indicated that variation in red spruce basal area was significantly associated with only one of the topographic site variables:

$$b.a._{rs} = 25.901 - 1.692*(t.s.i.) \qquad (2)$$

where $b.a._{rs}$ is basal area (m^2 ha^{-1}) of red spruce and t.s.i. is the terrain shape index. Equation (2) has a standard error of estimate of 10.4 m^2 ha^{-1} and r^2 of 0.56. The coefficient of the independent variable in equation (2) indicates that red spruce basal area on a planar site in the stand (i.e., t.s.i. = 0)

Table 3.—Range in size of 11 dominant and co-dominant red spruce trees measured for site index and stand characteristics on 21 sample plots in a 67-year-old planting in the Pisgah National Forest.

Stand characteristic	N	Mean	Range
Total height (m) [a]	11	14.6	11.5-17.7
d.b.h. (cm) [a]	11	26.8	22-38
Site index (m) [a]	11	11.3	9.1-13.7
Density (N/ha) [b]	21	1,310.0	304-2,740
Basal area (m^2/ha) [b]	21	29.7	4.2-58.0

[a] One dominant or co-dominant tree on 11 plots.
[b] All trees on each of 21 sample plots.

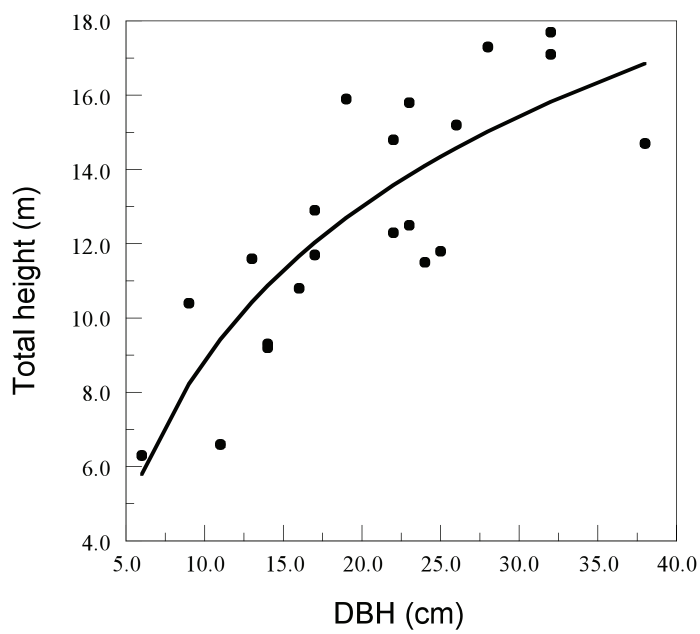

Figure 3.—Relationship of total height to d.b.h. for red spruce ranging in crown class from suppressed to dominant for 21 trees planted in the Pisgah National Forest from 1941-1943.

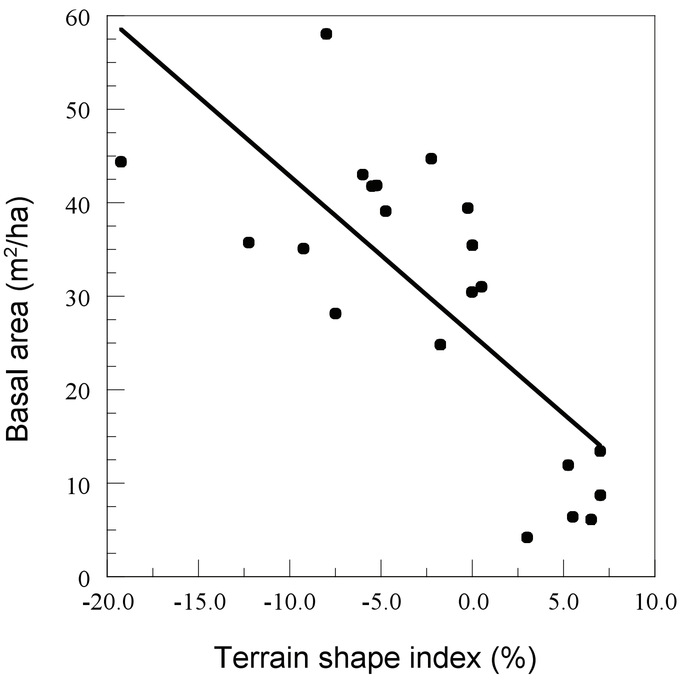

Figure 4.—Relationship of basal area of red spruce to terrain shape index for a planting established in the Pisgah National Forest from 1941-1943.

is estimated as 25.9 m^2 ha^{-1}. Basal area of the red spruce component of sample plots decreased on concave sites and increased on convex sites, as shown in Figure 4. Equation 2 is presented only to suggest a possible relationship of basal area with an environmental variable; the prediction equation should not be used for management decisions until the relationship has been tested elsewhere. Although red spruce basal area was significantly correlated with aspect, that predictor variable was also strongly correlated with terrain shape index ($r = 0.67$, $p = 0.0008$). Multicollinearity between the two predictor variables was likely an artifact of the data set that was collected in a small part of the stand.

Site quality relationships of red spruce have not been reported elsewhere in the Southern Appalachian Mountains, although results from one study suggested that aspect might be important (Minckler 1940). He found that survival of red spruce was slightly higher on south compared to north slopes in test plantings on Mt. Mitchell after 14 years. The effect of aspect on stand basal area of red spruce could not be properly evaluated in this study because data were limited to a single quadrant: northwest. Landform of the sample plot, quantified by t.s.i., had a significant effect on basal area of red spruce, but additional study is needed to confirm that relationship.

In summary, this easily accessible, 50-ha planted stand of red spruce, established from 1941 to 1943, provides a good opportunity for additional study of stand dynamics, particularly for questions associated with restoration of the species on suitable sites in the Southern Appalachian Mountains. The influence of environmental variables on one measure of spruce response to site quality (i.e., stand basal area), should be more fully studied over a broader area of the stand. A series of standard permanent plots, such as those established elsewhere in natural stands (Busing 2004), is recommended for long-term ecological study of the composition, structure, and growth of an uncommon forest type that could be affected by a changing climate.

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