ABUNDANCE OF RED SPRUCE REGENERATION ACROSS SPRUCE-HARDWOOD ECOTONES AT GAUDINEER KNOB, WEST VIRGINIA

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Abstract.—The abundance of red spruce (*Picea rubens* Sarg.) in the Central Appalachian Mountains has been drastically reduced over the past 100 to 150 years. The purpose of this study was to examine the potential for increases in the relative abundance of overstory red spruce in a Central Appalachian, high-elevation forest by measuring the abundance of red spruce regeneration on transects which crossed transitional spruce hardwood ecotones. Six transects were located in the Gaudineer Knob area of the Monongahela National Forest, WV, in 1996. Ninety-four transect plots were classified into three cover types (red spruce, ecotone, or northern hardwood) using a joining cluster analysis, which grouped plots according to relative basal area of red spruce and northern hardwoods. Forest canopy composition and ecotone abruptness were examined using basal area and stem density data collected at each transect plot. Mean numbers of seedlings (height ≥7.5 cm to <90 cm) and saplings (height ≥90 cm but diameter at breast height <7.5 cm) per hectare for all tree species were computed for each forest cover type.

In this study, red spruce occurred across the entire elevation range sampled (1,090 to 1,350 m). Spruce-hardwood ecotones varied in abruptness and their location was not consistently associated with elevation or aspect. Comparisons using rank-transformed values of mean seedling and sapling densities revealed that red spruce was the most abundant species of regeneration in both the red spruce and ecotone cover types, and was a substantial component of the sapling population in the northern hardwood cover type. The abundance of red spruce regeneration in the ecotone and adjacent hardwood cover types may represent an opportunity, through silvicultural treatments, to increase the relative abundance of overstory red spruce and spruce-dominated stands in the Gaudineer Knob area.

INTRODUCTION

The distribution of red spruce (*Picea rubens*) in eastern North America extends from the mountains of western North Carolina and eastern Tennessee northeastward into central Quebec and New Brunswick (White and Cogbill 1992). Although red spruce can occur at low elevations in the northeastern United States, Canada, and a few disjunct New Jersey populations (Webb et al. 1993), it is restricted to upper elevations in the Central and Southern Appalachian Mountains. Spruce forests were apparently widespread even at low elevations throughout the Appalachian region following the Wisconsin glaciation, but the period of maximum post glacial warmth 8,000 to 4,000 years ago corresponded with a displacement of red spruce to the higher Appalachian peaks and ridges (White and Cogbill 1992). This climate correlated shift in distribution reflects the fact that red spruce is well adapted for growth in a cool climate (Blum 1990) and several studies suggest a physiological basis for the relationship between red spruce growth and temperature (Cook and Zedaker 1992, Vann et al. 1994, Alexander et al. 1995).

In the Central Appalachians of West Virginia, red spruce forests are unique natural areas occurring primarily above an

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elevation of 915 m on the highest ridges, high valleys, and plateaus of the Allegheny Mountain Section (Clarkson 1960). These cool, moist, high-elevation sites likely serve as "climatic islands" suitable for red spruce growth and development. The vegetative composition and structure of both old growth and second growth red spruce and spruce hardwood forests in West Virginia have been documented by several authors (Core 1929, Stephenson and Clovis 1983, Adams and Stephenson 1989, Pauley 1989). In these forests, pure stands of red spruce on the highest knobs and ridges often grade into mixtures, or transitional "ecotones" (Risser 1995), with northern hardwood species at lower elevations. Cogbill and White (1991) analyzed the latitude elevation relationship for Appalachian montane spruce fir forests and described the gradient of vegetation change across these ecotones. In their generalized model, low-elevation deciduous trees and temperate conifers decline in importance as elevation increases and give way to northern hardwood species, dominated by sugar maple (*Acer saccharum* Marsh.), American beech (*Fagus grandifolia* Ehrh.), and yellow birch (*Betula alleghaniensis* Britton). Yellow birch reaches peak importance at higher elevations than do maple and beech, becoming conspicuous in the ecotone as red spruce enters the forest in a mixture of hardwoods. Red spruce then increases in importance as elevation increases (Cogbill and White 1991). Elevations in the Central Appalachians are insufficient to allow for the development of fir-dominated stands above the spruce-dominated zone, as is observed in other parts of the Appalachian spruce-fir range (Cogbill and White 1991).

Spruce-hardwood ecotones in the Central Appalachians may have been sharpened and shifted as a result of anthropogenic disturbances that drastically reduced the abundance of red spruce in the last 100 to 150 years. Conversion of spruce wilderness to agricultural land in the 1800s (Clarkson 1960), followed by widespread logging and associated fires in the late 19th and early 20th centuries, favored the rapid replacement of red spruce with deciduous northern hardwood species and other early successional vegetation (Korstian 1937, Minkler 1945, Clarkson 1964). Thus, while early estimates of the extent of red spruce in the 1700s ranged from approximately 200,000 to 600,000 ha (Hopkins 1891, 1899), more recent estimates indicated that only 17,500 to 44,500 ha of West Virginia forests contain a red spruce component (Mielke et al. 1986, DiGiovanni 1990, Stephenson 1993).

Given the dynamic history of red spruce abundance and distribution in the Central Appalachians, the question of whether the red spruce distribution will increase, decrease, or remain stable over the next several decades is one that is both interesting and timely. Red spruce decline in Adirondack and northeastern Appalachian red spruce forests, characterized by mortality, branch dieback, and distinct diameter growth reductions, has been of special concern over the past 20 years, and several biotic, abiotic, and anthropogenic contributing factors have been proposed (Johnson and Siccama 1983, Eagar and Adams 1992, Johnson 1992, Reams and Van Deusen 1993). Although decline in the Central Appalachians has not received as much research attention as the Northeast, Mielke et al. (1986) classified 33 percent of the cubic foot volume in West Virginia as dead or declining, and Adams et al. (1985) provided evidence that Central Appalachian red spruce had experienced radial growth reductions similar to those reported for several northern Appalachian sites. Furthermore, significant shifts in plant species ranges in response to climate change have been proposed, and concern exists that certain high elevation species (perhaps including Central-Appalachian red spruce) may be pushed upslope until local extirpation occurs (Pastor and Post 1988, Peters 1990).

Despite the potential threats to red spruce, other factors could favor an increase in its abundance in the Central Appalachians. The destructive fires and intense logging that characterized the early 1900s have been rare or absent in the last 80-90 years on most upland sites that were converted from red spruce to northern hardwood species. Pielke (1981) suggested that during this period, upland northern hardwoods in the Central Appalachians have matured, improving the soil through nutrient recycling and creating a more favorable microclimate beneath their canopies for successful spruce germination and growth. Hornbeck and Kochenderfer (1998) reported that annual growth rates in three natural red spruce stands and three plantations in West Virginia had stabilized and even shown slight increases following marked declines in the 1960s and 1970s. Their data suggest that there are healthy, productive red spruce forests in West Virginia and that their aerial extent could be enhanced through silviculture, especially in areas where red spruce already exists in the understory. More recent studies simulating future growth in mixed spruce-hardwood forests in West Virginia suggest that silvicultural manipulations could accelerate succession toward stands with a greater red spruce overstory component (Schuler et al. 2002, Rentch et al. 2007). Given that red spruce forests are habitat for rare and endangered plant and animal species, are popular recreation areas, and provide a high-quality wood resource, expansion of red spruce forests in the state could be particularly desirable.

The purpose of this study was to examine the potential for increases in the relative abundance of overstory red spruce in a Central Appalachian, high-elevation forest by measuring the abundance of red spruce regeneration on transects which crossed transitional spruce hardwood ecotones.

DESCRIPTION AND HISTORY OF THE STUDY AREA

Gaudineer Knob (summit elevation 1,355 m) and the surrounding area on Shavers Mountain, Monongahela National Forest, West Virginia (Fig. 1) was chosen for study because it contains a typical mountain top population of red spruce and northern hardwood cover types, as well as transitional ecotones. Average January temperature in this portion of Randolph County is less than -1.1 °C and the area receives more than 132 cm of precipitation annually (Hicks and Mudrick 1994). The geologic substrata in the area surrounding Gaudineer Knob are part of the Hinton formation, consisting of red, green, and medium-gray shales and sandstones. Well drained Inceptisols and Ultisols of the Dekalb Buchanan Association are present, in addition to very sandy Spodosols of the Leetonia series, which typically have a large percentage of coarse fragments (USDA Soil Conservation Service 1978). Adams and Stephenson (1989) found soils at Gaudineer Knob to be predominantly sandy, characterized by high acidity, high levels of organic matter, and low levels of major nutrients.

Between 1824 and 1847 the Parkersburg and Staunton Turnpike (now U.S. Route 250) was constructed from Virginia to the Ohio River, crossing Shavers Fork River at Cheat Bridge (Fig. 1). A small settlement grew here, but as late as 1880 the rest of "Cheat Mountain," as this area is called locally, was essentially wilderness (Deike 1978). In 1884, extensive timber operations commenced along the Shavers Fork River (Hopkins 1899). By 1890, James Dewing and Company began to clear obstructions from the banks of the river north of Cheat Bridge, built a dam, and constructed a railroad 7 km into the woods to extract timber. Timbering in the area progressed for several years until the company folded and sold large tracts of land to the West Virginia Pulp and Paper Company, which logged the

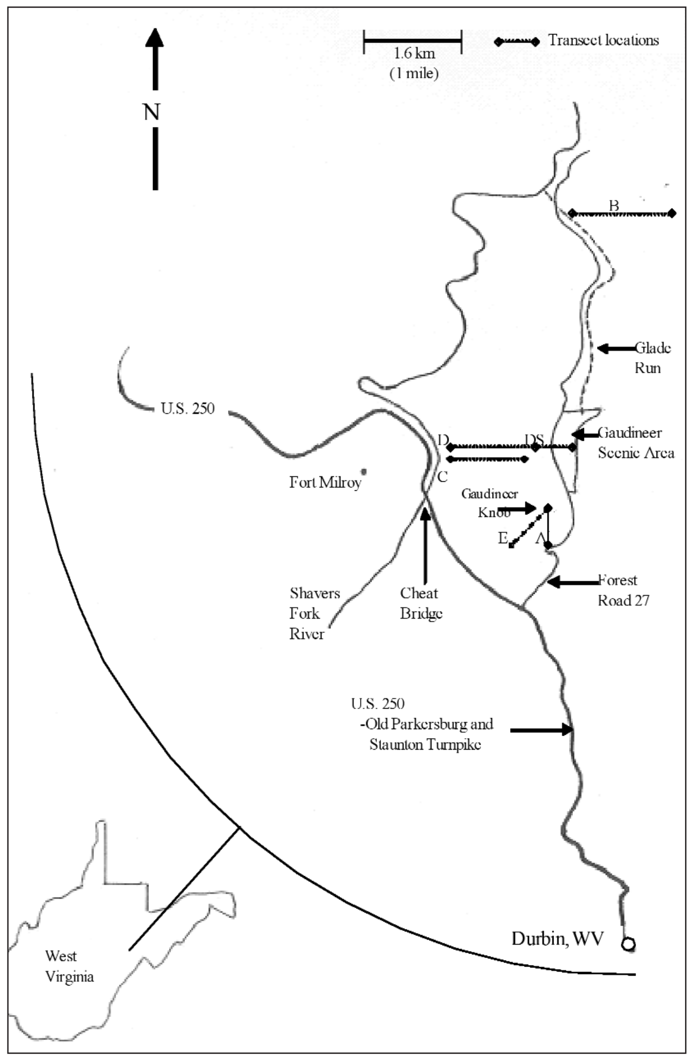

Figure 1.—Map of Gaudineer Knob, WV, and surrounding area. Location of study transects are shown and labeled with capital letters.

area between Cheat Bridge and Glade Run (Fig. 1), continuing as late as the 1930s (Deike 1978). Many areas of the spruce forest also burned over after logging, the fires being fueled by logging slash and deep litter layers. Although most of Cheat Mountain was steadily logged throughout the late 1800s and early 1900s, one 57 ha tract, just 0.4 km east of the Gaudineer Knob summit, was completely spared of any cutting, due to a surveyor's error during pre Civil War times (Brooks 1965).

The late 1800s marked a time of severe mortality and stress in the spruce forests near Gaudineer Knob. Hopkins (1891, 1899) specifically mentions the Cheat Bridge area as having high rates of red spruce mortality. Upon reaching "the battle field of Cheat Mountain" (perhaps the site of Fort Milroy, Fig. 1), where "an extended view was had of the Cheat Mountains extending on all sides," Hopkins (1891) stated that "thousands upon thousands of acres of what must have been a magnificent black green forest of living spruce, was now viewed as an immense waste of dead and decaying trees, presenting a desolate and dreary landscape." Hopkins (1899) implicated bark beetle activity (notably *Polygraphus rufipennis* Kirby and *Dendroctonus frontalis* Zimmerman) in conjunction with severe droughts (notably the drought of 1882) as mortality factors, but the actual contributing factors cannot be stated with certainty.

The summit of Gaudineer Knob had been harvested by 1915 (Mohlenbrock 1990), except for the area mentioned previously. Soils on Gaudineer's summit were spared from fire, permitting successful re-establishment of spruce from seed blown in from the adjacent old-growth stand (Clarkson 1960). Evidence of fire and conversion from spruce forest to hardwood thicket just 0.9 km north of the summit has been documented (Stewart and Aldrich 1949). Since the U.S. Forest Service acquired the land in 1936, partial harvests have been performed in certain parts of the Gaudineer area at various times, which have added to the multi cohort nature of some stands. The tract of old-growth spruce spared from harvest by the survey error has remained uncut and is managed by the U.S. Forest Service as the Gaudineer Scenic Area.

METHODS

Transect and Plot Establishment

Six transects were established in the Gaudineer Knob area of Shavers Mountain (Fig. 1) between June and August 1996. Black and white aerial photographs were used to identify areas in which a gradient of cover types (progressing upslope from hardwoods through mixed spruce-hardwood ecotones and into spruce-dominated stands) appeared to exist, and the six transects were established with a general perpendicular relationship to the contour in these gradient areas, cutting across the ecotone. Transects D and DS both begin at a point near the peak of the Gaudineer Knob ridgeline and run in opposite directions (Fig. 1). A series of 0.04 ha circular plots was established along each transect. To ensure adequate sampling of the ecotone on each transect, the 0.04 ha plots were spaced more closely on transects where an abrupt ecotone was indicated on the aerial photographs than on transects where the transition was expected to be gradual. The elevation in meters of each plot was estimated from U.S. Geological Survey 7.5 minute quadrangle topographic maps. Table 1 provides summary information for each transect, including the number of plots, plot spacings, transect length, aspect, and elevation range of the transects. Ninety-four plots were established.

Measurement of Forest Overstory, Regeneration, and Ground Cover

Within each 0.04 ha plot, the d.b.h. (diameter at 1.37 m above ground) of all live trees 7.5 cm in diameter or greater was measured and recorded in 2.5 cm diameter classes. Regeneration density was measured on five 10.5-m^2 circular subplots established within each 0.04-ha plot. One subplot was established in the center of the 0.04-ha plot, with the other four subplots located in the four cardinal directions at distances of 9.5 m from the center. Numbers of seedlings and saplings for all tree species were counted and recorded within each 10.5-m^2 subplot. A seedling was defined as a live stem at least 7.5 cm tall but less than 90 cm tall. A sapling was defined as a live stem 90 cm tall or greater, but less than 7.5 cm d.b.h. Deciduous hardwood seedlings or saplings were not tallied if they possessed fewer than two mature leaves. Distinction was not made between stems of

Table 1.—Summary information for six transects crossing spruce-hardwood ecotones at Gaudineer Knob, WV.

Transect	No. of 0.04 ha plots on transect	Spacing between plots (m)	Transect length (m)	Aspect	Elevation range (m)
A	13	60, 40[a]	604	S	1,213-1,329
B	15	100	1,408	W	1,116-1,256
C	12	180	1,811	W	1,091-1,299
D	26	60	1,509	W-NW	1,091-1,296
DS	8	60	423	NE	1,220-1,296
E	20	60	1,147	SW-W	1,189-1,290

[a] The ecotone on transect A was more abrupt than anticipated from aerial photos; plot spacing was therefore shortened from 60 m to 40 m during the sampling procedure for seven plots in the middle of the transect in order to adequately sample the ecotone. Otherwise, plot spacings were determined prior to sampling.

seed origin and those of vegetative origin; thus, the term "seedling" in this study was only an indicator of size.

Classification of Plots into Forest Cover Types

A joining q-mode cluster analysis (StatSoft, Inc., Tulsa, OK) was used to group the 0.04-ha plots (n = 94) into three cover type categories: northern hardwood, ecotone, and red spruce. This hierarchical classification technique joined 0.04-ha plots into successively larger clusters, based on the similarity of values for specified variables (Swan and Sandilands 1995). The variables used in this analysis were the relative basal area (BA) of red spruce on a plot (i.e., red spruce BA expressed as a percent of total plot BA) and the relative BA of northern hardwood species on a plot. Euclidean (straight-line) distance was chosen as the measure of similarity between plots, and plots were linked according to the nearest neighbor linkage algorithm (Swan and Sandilands 1995). A dendrogram with three distinctly dissimilar clusters of plots was produced. The cluster of 21 plots with the lowest (<10 percent) relative red spruce BA was classified as the "northern hardwood" cover type, the cluster of 41 plots with intermediate (10-80 percent) relative red spruce BA was classified as the "ecotone" cover type, and the cluster of 32 plots with the greatest (>80 percent) relative red spruce BA was classified as the "red spruce" cover type. The relative BA of red spruce on each 0.04-ha plot was plotted against estimated elevation for each of the six transects, providing a graphical representation of the changes in red spruce abundance with elevation.

Comparison of Mean Regeneration Densities

Mean number of stems per hectare and mean basal area per hectare by species were computed from the 0.04-ha plot data for each of the three forest cover types defined in the cluster analysis (northern hardwood, ecotone, and red spruce). For seedling and sapling densities (stems/ha) and ground-cover variables, the five 10.5-m^2 subplot values were averaged for each 0.04-ha plot, and the larger plot values were used to compute means for each cover type. One way analysis of variance (ANOVA) (Dowdy and Wearden 1991) was used to test the null hypothesis that mean densities for the following four regeneration categories did not differ within cover type: red spruce seedlings, red spruce saplings, northern hardwood seedlings, and northern hardwood saplings. Levene's test for homogeneity of variance revealed heterogeneous class variances that were correlated with means, situations that violate the assumptions of ANOVA. The raw data were therefore transformed using a rank transformation (Conover and Iman 1981) in which all values were replaced with their ranks (assigning the smallest value a rank of 1, the second smallest value a rank of 2, and so on). Average ranks were assigned in the case of ties. ANOVA was then performed on the rank-transformed values (Conover and Iman 1981). Mean ranks were compared using Scheffe's method (Dowdy and Wearden 1991).

RESULTS

Forest Overstory Composition

The total mean BA per hectare and total mean density of stems ≥7.5 cm diameter at breast height (d.b.h.) for each of the three forest cover types is presented by major species in Table 2. Red spruce was a very small component of the plots

Table 2.—Mean (SE) basal area and density of major tree[a] species by forest cover type, on transects crossing spruce-hardwood ecotones at Gaudineer Knob, WV.

Species	Basal area (m^2/ha)			Density (stems/ha)		
	Northern hardwood	Ecotone	Red spruce	Northern hardwood	Ecotone	Red spruce
Acer pensylvanicum	0.2 (0.1)	0.2 (0.1)	0.0 (0)	30 (12.2)	17 (5.6)	0 (0)
Acer rubrum	5.1 (1.4)	5.6 (1.0)	0.2 (0.1)	88 (28.1)	104 (15.4)	12 (4.4)
Acer saccharum	1.7 (0.9)	0.0 (0.02)	0.0 (0)	24 (9.2)	2 (1.8)	0 (0)
Amelanchier arborea	0.3 (0.1)	0.1 (0.1)	0.0 (0)	10 (4.4)	6 (3.2)	0 (0)
Betula alleghaniensis	2.9 (1.1)	5.4 (0.6)	0.7 (0.2)	76 (21.2)	201 (22.1)	76 (16.5)
Fagus grandifolia	4.7 (0.8)	1.4 (0.4)	0.0 (0)	144 (22.3)	48 (12.8)	0 (0)
Fraxinus americana	0.7 (0.6)	0.0 (0.03)	0.0 (0)	6 (3.4)	2 (2.4)	0 (0)
Ilex montana	0.0 (0)	0.0 (0.01)	0.0 (0.01)	0 (0)	5 (2.8)	2 (1.1)
Magnolia acuminata	1.4 (0.6)	0.2 (0.1)	0.0 (0)	16 (6.6)	12 (4.1)	0 (0)
Picea rubens	0.1 (0.03)	8.5 (0.7)	23.2 (1.2)	18 (6.0)	158 (11.1)	609 (68.8)
Prunus serotina	4.2 (1.6)	0.7 (0.3)	0.0 (0)	36 (13.0)	11 (3.3)	0 (0)
Other species[b]	0.0 (0.04)	0.0 (0.04)	0.0 (0)	1 (0.9)	1 (1.1)	0 (0)
ALL SPECIES	21.3 (1.9)	22.3 (1.0)	24.0 (1.2)	450 (36.0)	571 (20.0)	698 (64.0)

[a] Includes stems ≥7.5 cm d.b.h.

[b] "Other species" were *Acer spicatum, Magnolia fraseri, Ostrya virginiana, Prunus pensylvanica,* and *Sorbus americana.* Species nomenclature follows Gleason and Cronquist (1991).

classified as northern hardwood cover type, occupying on average less than 1 percent (0.1 m^2/ha) of the total BA and only 4 percent (17.9 stems/ha) of the total stem density. Red maple (*Acer rubrum* L.) and American beech were the most abundant trees in terms of BA and stem density. Yellow birch and black cherry (*Prunus serotina* Ehrh.) were also substantial components of the northern hardwood cover type (Table 2). In the plots classed as ecotone cover type, red spruce on average occupied 38 percent (8.5 m^2/ha) of the total BA and 43 percent (157.9 stems/ha) of the total stem density. Compared with the northern hardwood cover type, yellow birch and red maple were more abundant in the ecotone, while American beech and black cherry were less abundant (Table 2). In the red spruce cover type, an average of 96 percent (23.1 m^2/ha) of the total BA and 87 percent (608.6 stems/ha) of the stem density was red spruce. Only yellow birch and red maple shared canopy space with red spruce in the red spruce cover type, while mountain holly [*Ilex montana* (T. & G.) A. Gray] was present as an understory shrub (Table 2).

Ecotone Elevation and Abruptness

Red spruce relative BA versus elevation for each of the six transects is presented in Figure 2. Four transects (A, B, DS, and E) displayed a transition from northern hardwood canopy to red spruce canopy as elevation increased, each passing through a spruce hardwood ecotone phase (Fig. 2a). The elevation at which spruce entered as a canopy component varied among these four transects (from 1,175 m on Transect B to 1,310 m on Transect A), as did abruptness of the ecotone transition zone (e.g., sharp on Transect A, more gradual on Transect B). In contrast, the primarily west facing transects C and D did not display a smooth elevational gradient from hardwood to ecotone to spruce (Fig. 2b). Notably, both pure hardwood stands and pure red spruce stands could be found at the same elevations (between 1,235 and 1,300 m) in the study area.

Regeneration Density

In the red spruce cover type, mean red spruce regeneration densities (19,433 seedlings/ha, 10,189 saplings/ha) were significantly greater than the mean hardwood regeneration densities (Fig. 3, Table 3). Only mountain holly and yellow birch were notable contributors to hardwood regeneration in the red spruce cover type. In the ecotone cover type, mean red spruce regeneration densities (6,350 seedlings/ha, 5,608 saplings/ha) were significantly greater than the mean densities of all northern hardwood species combined (3,663 seedlings/ha, 2,187 saplings/ha), with beech, yellow birch, maple, mountain holly, and black cherry accounting for the greatest hardwood regeneration densities. In the northern hardwood cover type, although the mean densities of all hardwood species combined (13,188 seedlings/ha, 2,936 saplings/ha) were significantly greater than red spruce densities (666 seedlings/ha, 1,196 saplings/ha), red spruce accounted for the second-highest sapling density of all species. Much of the hardwood regeneration in this cover type consisted of black cherry seedlings and vegetative sprouts of American beech (Fig. 3, Table 3).

DISCUSSION

In observing transitional ecotones along several transects on elevation gradients at our study area, we found forest overstory composition to be similar to the hardwood spruce transition described by Cogbill and White (1991). Using a linear regression model based on latitude and elevation, Cogbill and White (1991) predicted the spruce hardwood ecotone on Cheat Mountain, WV (region that includes Gaudineer Knob) to occur at 1,259 m elevation, but documented a possible range from 910 to 1,340 m. At our site, the ecotone transitions varied from very sharp to more diffuse. The effect of elevation on cover type position was

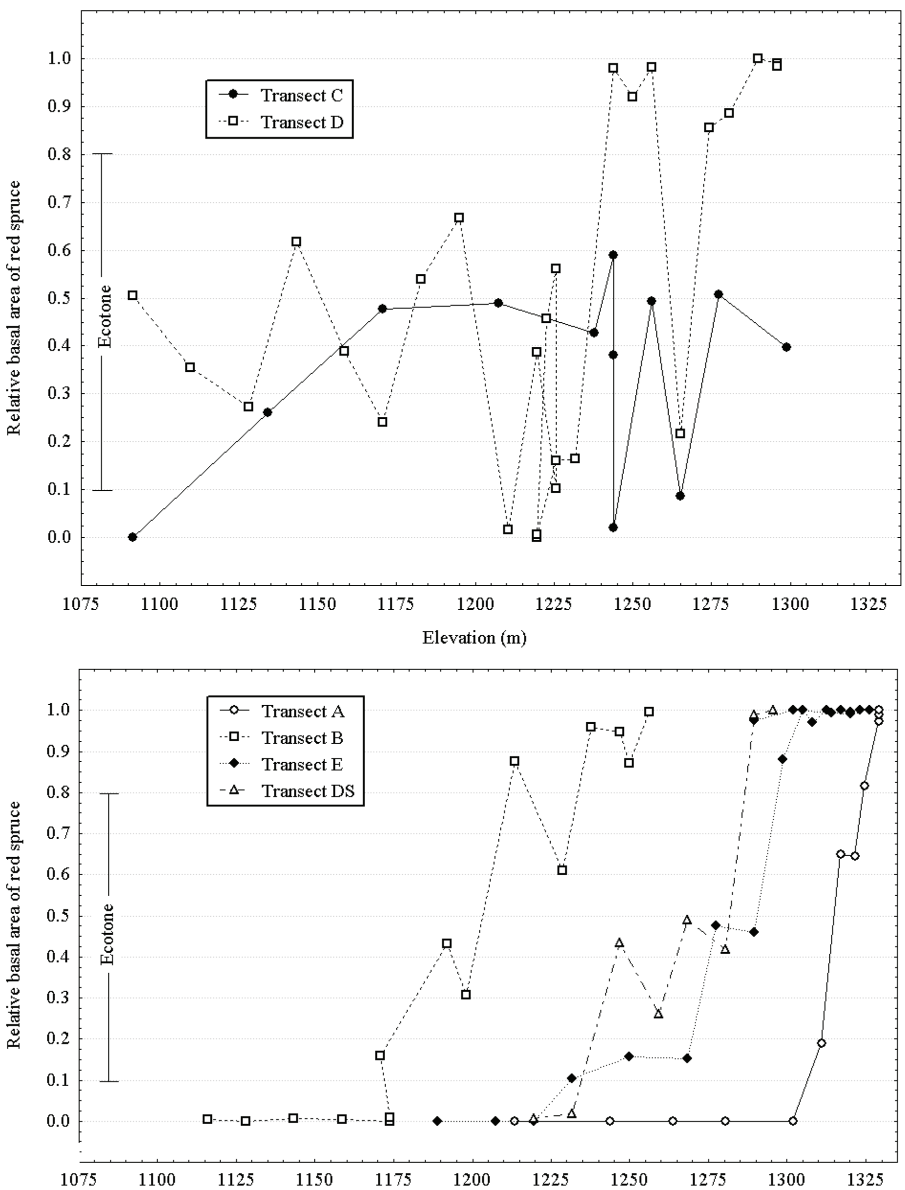

Figure 2.—Relative basal area of red spruce versus elevation for six transects crossing spruce-hardwood ecotones at Gaudineer Knob, WV. A) Transects A, B, E, and DS. B) Transects C and D.

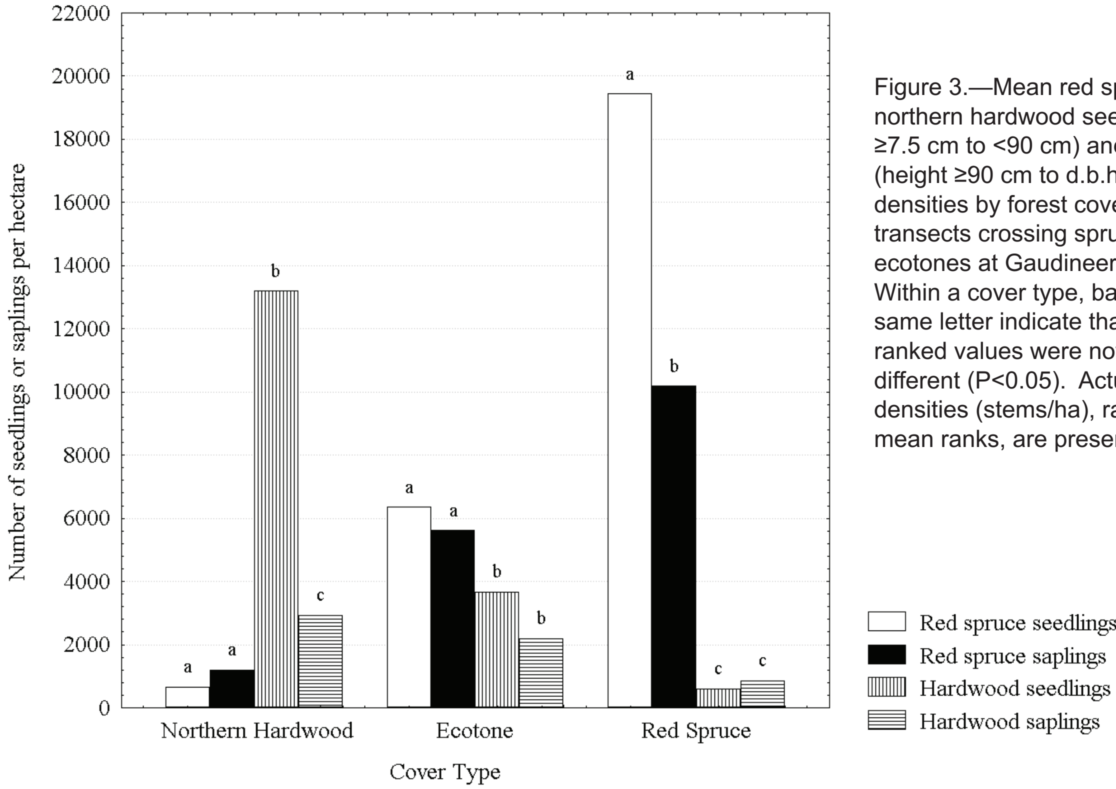

Figure 3.—Mean red spruce and northern hardwood seedling (height ≥7.5 cm to <90 cm) and sapling (height ≥90 cm to d.b.h.<7.5 cm) densities by forest cover type, on transects crossing spruce-hardwood ecotones at Gaudineer Knob, WV. Within a cover type, bars with the same letter indicate that the means of ranked values were not significantly different (P<0.05). Actual mean densities (stems/ha), rather than the mean ranks, are presented.

Table 3.—Mean (SE) seedling and sapling[a] densities of major tree species by forest cover type, on transects crossing spruce-hardwood ecotones at Gaudineer Knob, WV.

	Seedling Density (stems/ha)			Sapling Density (stems/ha)		
Species	Northern hardwood	Ecotone	Red spruce	Northern hardwood	Ecotone	Red spruce
Picea rubens	666 (176)	6,350 (876)	19,433 (2,478)	1,196 (434)	5,608 (677)	10,189 (2,365)
Total N. Hardwoods	13,188 (2,770)	3,663 (593)	601 (140)	2,936 (522)	2,187 (273)	862 (216)
Acer pensylvanicum	1,015 (324)	353 (110)	0 (0)	625 (186)	121 (36)	0 (0)
Acer rubrum	634 (147)	399 (118)	24 (19)	154 (93)	204 (57)	18 (13)
Acer saccharum	181 (73)	0 (0)	0 (0)	299 (201)	19 (11)	0 (0)
Amelanchier arborea	54 (54)	46 (26)	0 (0)	18 (18)	14 (10)	0 (0)
Betula alleghaniensis	372 (139)	664 (199)	184 (58)	172 (78)	362 (54)	256 (72)
Fagus grandifolia	5,212 (1,212)	840 (243)	0 (0)	1,604 (375)	297 (78)	0 (0)
Ilex montana	227 (124)	650 (142)	375 (129)	18 (18)	1,096 (291)	588 (207)
Magnolia acuminata	100 (52)	65 (34)	0 (0)	0 (0)	14 (8)	0 (0)
Prunus serotina	5,384 (2,280)	622 (221)	0 (0)	45 (45)	23 (12)	0 (0)
Other hardwoods[b]	9 (9)	23 (10)	18 (18)	0 (0)	37 (23)	0 (0)

[a] Seedlings were stems ≥7.5 cm tall, but <90 cm tall. Saplings were stems ≥90 cm tall, but <7.5 cm d.b.h.

[b] Other hardwoods were *Acer spicatum, Magnolia fraseri, Ostrya virginiana, Prunus pensylvanica,* and *Sorbus americana.* Species nomenclature follows Gleason and Cronquist (1991).

not consistent, with almost pure stands of red spruce being scattered over a 200 m range. However, the great majority of plots with over 70 percent relative spruce basal area occurred above 1,225 m elevation. Additionally, no consistent association between aspect and relative red spruce basal area was detected on the six transects we examined. Some transects on west facing aspects had a significant red spruce component at elevations as low as or lower than those on north and east aspects. The latter are generally regarded as "cooler" slopes due to the sun angle, so one might expect lower ecotones on these slopes. However, high precipitation and cloud cover at high elevations can depress the contrasts in temperature and insolation often seen at lower elevations due to slope aspect (White and Cogbill 1992). Furthermore, differences in soils and previous disturbance/land-use history can influence vegetative composition across a landscape, and although our methodology did not address these variables, they are possible factors affecting red spruce distribution at the study site.

After segregating our plots into red spruce, northern hardwood and ecotone cover types (based on relative BA of spruce and hardwoods in the overstory), we found that red spruce was successfully regenerating in all three cover types. Under both red spruce and ecotone cover types, red spruce existed at higher average densities than all hardwood species combined and red spruce was the second most-abundant species in the sapling size class in the northern hardwood cover type. The presence and abundance of sapling sized red spruce indicates that it was not merely a rotating seedling crop, but that plants had become well established and were capable of growing into the overstory.

Projecting the possible composition of these stands requires making some assumptions about the disturbances that could occur and applying some knowledge of the silvical characteristics of the various species involved. First, these stands exist in areas of the Monongahela National Forest that are of recreational value and recognized as habitat for threatened and/or endangered species, such as the Virginia northern flying squirrel (*Glaucomys sabrinus fuscus* Shaw) and the Cheat Mountain salamander (*Plethodon nettingi* Green). Therefore, large clearcuts or prescribed fires in these areas are not likely to be recommended. Red spruce is known to undergo "cohort mortality" as whole even age cohorts simultaneously reach senescence, but red spruce is relatively long lived. Such an occurrence is probably centuries away, especially on the Gaudineer peak, where stands appeared to be 80-90 years old, based on our own increment cores and the harvest time frame reported by Molhenbrock (1990). Anthropogenic impacts of air pollution and acidic deposition, if coupled with climate stresses and/or insects and diseases, could hasten the onset of cohort mortality in red spruce. If these types of impacts are not severe, however, the most common disturbances will probably be individual tree fall gaps that produce relatively small openings. Occasional wind, snow, or glaze storms will create larger gaps.

Under pure or nearly pure stands of red spruce at Gaudineer Knob, healthy red spruce seedlings had been recruited in the low light environment of a closed canopy and released to sapling height where partial disturbances created overstory gaps. Mean seedling density (19,432 stems/ha) and sapling density (10,190 stems/ha) values in the red spruce cover type suggested that dominance by *Picea rubens* would continue on these sites in the years to come. Red spruce seedlings are very tolerant of shade (Hart 1959, Blum 1990) and can persist and develop slowly in the understory (Seymour 1992, Fajvan and Seymour 1993). Partial disturbances can establish a cohort of seedlings, creating enough light in the understory to allow increased sapling growth rates and enabling them to eventually reach canopy status (White et al. 1985, Fajvan and Seymour 1993). Even severely suppressed red spruce saplings that are many decades old can be important contributors to future canopy composition because of their ability to respond with increased growth rates upon release and their initial height advantage over other seedlings (Davis 1991).

In the spruce-hardwood ecotone cover type transected by our plots, red spruce dominated the seedling and sapling populations. Mean red spruce regeneration density was more than double the total mean hardwood density in this cover type (Table 3). This regeneration may represent the potential for increasing the overstory abundance of red spruce, and thus the area occupied by spruce-dominated stands on this mountain. Although diameter distributions in the cover type indicated that hardwoods would be a dominant feature of the main canopy in coming years, the shade-tolerant spruce persisting in the understory could eventually become the canopy dominants following natural or intentional creation of gaps in the overstory. Beech bark disease, which results from attack by the scale insect Cryptococcus fagisuga followed by one of two Nectria fungi (Hicks and Mudrick 1994), appeared to be a significant cause of American beech mortality in the Gaudineer area that could positively influence red spruce recruitment to canopy positions.

The ecotone data in this study may be compared with regeneration densities reported by Nicholas et al. (1992) for spruce-fir stands in the Great Smoky Mountains. Our sapling category (height 90 cm to <7.5 cm d.b.h.) is a size class similar to the combination of their large-seedling and understory categories (height 100 cm to <5.0 cm d.b.h.). For this size class, they reported red spruce densities of 627 stems/ha and 1,053 stems/ha in stands with 42 percent and 58 percent red spruce by density in the overstory (>5.0 cm d.b.h.), respectively. In our ecotone plots, which averaged 43 percent red spruce by density in the overstory (stems ≥7.5 cm d.b.h.), we found higher sapling densities (5,608 stems/ha), which represent a larger proportion of the total understory population. The stands studied by Nicholas et al. (1992) differ from ours in that they are 300-500 m higher in elevation, are slightly more dense in the overstory (610-632 stems/ha versus 570 stems/ha in our stands), and contain a substantial proportion of Fraser fir [*Abies fraseri* (Pursh) Poir.], a species our plots lacked completely.

In the northern hardwood cover type at the Gaudineer Knob area, red spruce seedling and sapling occurrence was scattered, and densities of *Picea rubens* were not as high as total hardwood regeneration densities. However, recruitment of red spruce appeared to be favorable where beech was dying, and spruce saplings were more abundant than any other individual hardwood species except American beech. Although red maple and yellow birch will probably continue to be the dominant species in these stands in the near future, the long lived, shade tolerant spruce could persist in the understory and be released to canopy positions over time, producing mixed spruce hardwood stands. It remains to be seen how red spruce will compete with the more-abundant hardwood regeneration in this cover type. There is a significant component of black cherry mixed with American beech, yellow birch, and maples. Cherry is the shortest lived of these species and will most likely create some small canopy gaps over the next 100 or so years as trees mature and die. Because of the fairly small crowns of mature cherry trees, however, these gaps will be relatively small and quickly sealed by expansion of neighboring tree crowns. In the short term, the most likely scenario to cause a major impact in the understory is the infection of many American beech with beech bark disease and the associated canopy gaps that may result.

The observations from this single-year study alone are insufficient to conclude that the geographic range of red spruce in the Gaudineer Knob area is naturally expanding. Detection of true range expansion or reduction would require monitoring changes in forest composition over time, or possibly by applying the advancing-front theory of forest migration presented by Solomon and Leak (1994), which predicts that species range expansion should be represented by a decrease in maximum tree age over distance from an outpost seed source. However, the abundance of red spruce regeneration in the spruce hardwood ecotone and its presence in adjacent hardwood stands may represent an opportunity, through silvicultural manipulation, to increase the relative overstory abundance of red spruce and restore the presence of more spruce-dominated stands in the Gaudineer area.

If restoration management were to be initiated, as suggested by Hornbeck and Kochenderfer (1998) and Rentch et al. (2007), the possibilities are promising for success in the Gaudineer Knob area. Red spruce enhancement through silvicultural treatments could be achieved in hardwood and ecotone stands where red spruce saplings are already established in the understory. Treatments that remove dominant hardwood species in single tree selection cuts or small patch cuts could be applied. Resulting gaps should be large enough to provide light to release understory red spruce saplings (which often have a height advantage over other less shade-tolerant hardwoods), but small enough to prevent fast growing, early-successional species from dominating gap vegetation. Overstory thinning could be coupled with understory application of a hardwood specific herbicide, which would help prevent vigorous stump sprouting of competitive hardwood species. Treatments of this type in areas with adequate red spruce regeneration have been conducted experimentally at other sites (Rentch et al. 2007) and could accelerate red spruce growth rates and result in stands with a well stocked red spruce overstory.

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