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High Elevation Coniferous Forests in Virginia

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ABSTRACT

Red spruce (*Picea rubens*), the most characteristic species of the subalpine coniferous forests which occupy higher peaks and ridges of the Appalachian system from Maine to Tennessee and North Carolina, has a rather restricted distribution in the mountains of central and southwestern Virginia. The approximate lower limit for red spruce in Virginia is 975 m, although well-developed spruce communities generally do not occur at elevations below 1200 m. Indigenous communities of red spruce exist at no more than about a dozen localities, and at only two of these (Mount Rogers and Whitetop Mountain) is the species relatively abundant. Balsam fir (*Abies balsamea*), commonly present as a codominant species with red spruce in the northern Appalachians, reaches its southernmost limit in the Blue Ridge of northern Virginia, whereas Fraser fir (*A. fraseri*), which has a comparable ecological role in the southern Appalachians, reaches its northernmost limit on Mount Rogers in southwestern Virginia. Values of basal area and density (stems $\geq$ 10 cm DBH) for these communities range from 36 to 56 m^2/ha and from 390 to 1320 stems per ha, respectively.

INTRODUCTION

Red spruce (*Picea rubens*), the most characteristic species of the subalpine coniferous forests which occupy higher peaks and ridges of the Appalachian system from Maine to Tennessee and North Carolina, has a rather restricted distribution in the mountains of central and southwestern Virginia. Presumably, this is because few areas in the region reach the elevations necessary to provide the cool, moist conditions required for the development of this community type. At present, the approximate lower limit for spruce in central and southwestern Virginia is 975 m, although well-developed spruce communities generally do not occur at elevations below 1200 m. Today, indigenous communities of red spruce exist at no more than about a dozen localities in central and southwestern Virginia (Hoffman 1950, Mazzeo 1966, Adams and Stephenson 1984) and at only two of these (Mount Rogers and Whitetop Mountain in extreme southwestern Virginia) is the species relatively abundant. Balsam fir (*Abies balsamea*), commonly present as a codominant species with red spruce in the northern Appalachians, reaches its southernmost limit in the Blue Ridge of northern Virginia (Adams and Stephenson 1985). There it occurs primarily as a minor understory component in a few stands dominated by red oak (*Quercus rubra*). Fraser fir (*A. fraseri*) reaches its northernmost limit on Mount Rogers where it occurs as a dominant overstory component at the highest elevations (Stephenson and Adams 1984).

The isolated spruce communities in the mountains of central and southwestern Virginia have never been studied intensively. The only available quantitative data are provided by Shields (1962), Stephenson and Adams (1984), and Rheinhardt (1984), all of whom focused on the spruce-fir communities of Mount Rogers and adjacent areas, and Bailey and Ware (1990), who studied the spruce forests of Highland County. For the most part, the only published information on the spruce communities that exist at other Virginia localities is found in brief notes (e.g., Chappell 1972).

The objectives of the present study were to obtain quantitative data on the composition and structure of the vegetation at each of the Virginia localities where the red spruce community type occurs and to determine the general characteristics of the soils associated with these communities.

THE GENERAL STUDY AREA

The high-elevation areas in the mountains of central and southwestern Virginia where indigenous communities of red spruce occur include portions of both the Blue Ridge and Ridge and Valley physiographic provinces of the southern Appalachian Mountains (Fenneman 1938). The mountain ridges of the Ridge and Valley Province, which generally run in a southwest-northeast direction, form a relatively narrow belt along the western boundary of Virginia. These ridges are rather level-crested, often with steep slopes, and are usually capped with Clinch (Tuscarora) sandstone of Silurian age. The less resistant (mostly Ordovician) shales and limestones have eroded away, producing the intervening valleys. Elevations in the region generally range from 300 to 1050 m, but many ridgetops exceed 1,200 m and a few reach heights in excess of 1,375 m.

The mountains of the Blue Ridge are located to the east of the Ridge and Valley Province and consist of two rather distinct sections separated by the Roanoke River, the southernmost stream cutting through this ridge system. The northern section, separated from the ridges of the Ridge and Valley by the broad, flat Shenandoah Valley, is an irregular range of relatively rugged, broad-topped mountains which only occasionally exceed 1,200 m. The southern section consists of an elevated plateau which is deeply cut by stream valleys. The highest mountains in Virginia occur in this section of the Blue Ridge, with two peaks (Mount Rogers and Whitetop) exceeding 1,680 m. The Blue Ridge is composed primarily of metamorphosed igneous rocks.

Climatological data for high-elevation areas in the mountains of central and southwestern Virginia are limited, but data from a U.S. Weather Bureau station established in November 1971 at the University of Virginia Mountain Lake Biological Station (elevation 1,168 m) in Giles County, Virginia, give some indication of the climate of the general study area. The average annual precipitation, based on the period of 1972-1983, is 136.3 cm. The average monthly precipitation ranges from a low of 8.9 cm in August to a high of 14.8 cm in June. The mean annual temperature is 8.1° C. Average monthly temperatures range from a low of -3.7°C in January to a high of 18.5°C in July. The lowest temperature of record is -31.7°C, and the record maximum temperature is 31.1°C. The average frost-free season is about 142 days (U.S. Dept. Commerce 1972-1983).

MATERIALS AND METHODS

Quantitative data on vegetation and topographic variables were collected during the 1982-1984 field seasons for twenty-four spruce stands at fifteen localities in western Virginia (Table 1). Criteria for selection of the unit of vegetation (stand) actually sampled were that: (1) vegetation be relatively homogeneous (with respect to floristics and plant structure) and at least one hectare in size; (2) topography of the area be uniform; (3) there be no obvious evidence that a major disturbance (e.g., logging, fire, windthrow) had occurred during the lifetime of the trees sampled; and (4) red spruce be present in the canopy. Slope inclination and aspect were recorded at several locations within each stand and elevation was estimated using USGS 7.5 minute quadrangle maps, benchmarks, and obvious topographic features.

In each stand, diameters at breast height (1.37 m above ground level and hereafter referred to as DBH) of all live stems of trees ($\geq$ 2.5 cm DBH) were recorded by species in a single 20 m by 50 m (0.1 ha) quadrat. Estimates of percent cover of herbaceous plants, exposed rock, woody debris, and bryophytes were recorded from ten 1 m by 1 m quadrats spaced at 5 m intervals along the tape. All cover values were estimated using a cover class rating scale described by Daubenmire (1968).

Quadrat data were used to calculate relative basal area and relative density values separately for size classes designated as large trees (stems $\geq$ 10 cm DBH) and small trees (stems $<$ 10 cm DBH but $\geq$ 2.5 cm DBH). For each stand, species importance value indices for large trees and small trees were calculated as one-half the sum of relative basal area and relative density. Relative cover was determined for herbaceous plants, bryophytes, woody debris, and exposed rock.

At each locality, cores were extracted at breast height from at least five representative canopy-height red spruce to determine their approximate ages. Heights of these same trees were determined with a clinometer. After cores were air dried, glued in grooved boards, and sanded, growth rings were counted using a binocular microscope.

At least four soil samples were collected from the upper 10 cm in each stand, mixed thoroughly, and sealed in plastic bags to prevent water loss. In the laboratory, these were weighed, oven-dried at 100°C for 48 hours, and reweighed. Samples then were passed through a 2-mm sieve to remove gravel. Soil moisture was calculated as a percentage of the dry weight of the fraction less than 2-mm (Reinhart 1961). Soil pH was determined in a 1:1 soil:water mixture with a glass electrode pH meter; organic matter was determined by loss on ignition (Cox 1990); and soil texture was analyzed with the Bouyoucos hydrometer method (Bouyoucos 1951). Later, analyses of content in parts per million for phosphoric acid, calcium, magnesium, potassium, zinc, nitrate nitrogen, manganese, and total soluble salts were conducted by the Soil Testing Laboratory at Virginia Polytechnic Institute and State University, using procedures outlined by Donohue and Friedericks (1984).

Vascular plant nomenclature follows Radford et al. (1968).

TABLE 1. Locations of 24 red spruce stands sampled in western Virginia.

County	No. of Stands	Locality
Giles	1	Little Spruce Bog near Mountain Lake
Giles	1	Mann's Bog
Giles	1	War Spur Ridge
Grayson	1	Flat below summit of Whitetop Mountain
Grayson	2	Summit of Whitetop Mountain
Highland	1	Bearcamp Knob
Highland	1	Near WV state line south of US Route 250
Highland	1	Sounding Knob Lookout Tower
Highland	1	Tamarack Ridge
Madison	1	Limberlost area of Shenandoah NP
Rockingham	1	Shenandoah Mountain
Russell	3	East end of Beartown Mountain
Russell	2	West end of Beartown Mountain
Smyth/Grayson	5	Summit of Mount Rogers
Tazewell	2	Southwest rim of Burkes Garden

RESULTS AND DISCUSSION

Vegetation and site characteristics of the twenty-four red spruce stands we sampled in western Virginia are summarized in Table 2. Elevation ranged from 983 m at Limberlost in Shenandoah National Park to 1726 m at Mount Rogers. Slopes on which sampled stands occurred varied considerably in aspect, but none were particularly steep. Measured red spruce trees varied in mean height from 32.4 m at War Spur (in Giles County) to 16.3 m at Mount Rogers (the highest elevation). Based on ring counts from cored red spruce trees, most stands presumably are second-growth, although the stand at War Spur apparently has never been cut and thus can be considered as old-growth. Basal area of large trees, which ranged from 35.6 m^2/ha to 55.5 m^2/ha, was relatively high when compared to hardwood stands in the same region (Adams and Stephenson 1983, Rheinhardt and Ware 1984, Stephenson and Adams 1989). Density values (N/ha) (390-1320) were similar to those reported for hardwoods, although the War Spur stand (390) was relatively low (as would be expected since this is an old-growth stand). Bryophyte and herb cover varied considerably, but generally were higher than values for hardwood stands in the mid-Appalachians (Stephenson 1988, Stephenson and Adams, unpublished data). Species richness of vascular plants was lowest (13) at War Spur (the old-growth stand), and highest (43) at Limberlost (the stand located at the lowest elevation).

Twenty-one species were represented in the large tree stratum (Table 3), but only four (red spruce [IV = 59.8], Fraser fir [IV = 16.6], hemlock (*Tsuga canadensis*) [IV = 6.7], and yellow birch (*Betula lutea*) [IV = 6.6]) had average importance values exceeding 5.0. Red spruce is clearly the dominant species. Although Fraser fir was the second leading dominant overall, it occurred only in the five stands sampled at Mount Rogers, where it was the most important species. Hemlock occurred at only seven localities (9 stands), but was very important at four of these

TABLE 2. Summary data for vegetation and site characteristics of 24 red spruce stands sampled in western Virginia.

Parameter	Range	Mean ± SD
Elevation (m)	983-1726	1376 ± 244
Aspect[1]	0.0-2.0	1.1 ± 0.7
Slope (%)	3-38	16 ± 10
Canopy height (m)	16.3-32.4	21.6 ± 4.4
Stand age (yr)	54-215	92 ± 38
Basal area (m^2/ha^2)	35.6-55.5	46.1 ± 6.7
Density (N/ha)[2]	390-1320	834 ± 336
Basal area (m^2/ha)[3]	0.18-4.06	1.34 ± 0.85
Density (N/ha)[3]	50-1740	529 ± 414
Bryophyte cover (%)	1-66	28 ± 23
Herb cover (%)	<1-173	56 ± 56
Exposed rock (%)	0-9	3 ± 4
Dead wood (%)	1-25	12 ± 7
Species richness	13-43	22 ± 8

[1]Cosine transformation of azimuth (Beers et al. 1966), so that 45^{o} = 2.0 and 225^{o} = 0.0
[2]Stems ≥ 10 cm DBH
[3]Stems 2.5 - 9.9 cm DBH

TABLE 3. Composition of the large tree stratum (stems ≥ 10 cm DBH) for all 24 stands.

Species	Number stands present	Basal area (m^2/ha)	Relative basal area (%)	Density (N/ha)	Relative density (%)	Importance value
Picea rubens	24	29.2	63.3	470	56.3	59.8
Abies fraseri	5	6.7	14.5	155	18.6	16.6
Tsuga canadensis	9	3.6	7.8	47	5.6	6.7
Betula lutea	19	2.8	6.1	60	7.2	6.6
Acer rubrum	13	1.1	2.4	25	3.0	2.7
Betula lenta	10	0.6	1.3	18	2.2	1.8
Fagus grandifolia	5	0.5	1.1	14	1.7	1.4
Sorbus americana	4	0.3	0.6	18	2.2	1.4
Amelanchier arborea	8	0.4	0.9	10	1.2	1.0
Other species[1]	1-4	0.9	2.0	17	2.0	2.0
Total		46.1	100.0	834	100.0	100.0

[1]Includes *Quercus rubra* (4 stands), *Acer spicatum* (3), *Prunus serotina* (3), *Hamamelis virginiana* (2), *Nyssa sylvatica* (2), *Acer saccharum* (1), *Carya tomentosa* (1), *Fraxinus pennsylvanica* (1), *Liriodendron tulipifera* (1), *Magnolia acuminata* (1), *Pinus strobus* (1), *Sassafras albidum* (1)

(War Spur, Mann's Bog, Little Spruce Bog [all in Giles County], and Limberlost). Yellow birch (12 stands) and red maple (*Acer rubrum*) (13 stands) were each present at 12 of the 15 localities we studied. The lowest importance values for red spruce were recorded at Mann's Bog and Limberlost, where hemlock and yellow birch shared dominance.

TABLE 4. Average importance values for species represented in the large tree stratum (stems ≥ 10 cm DBH) of each red spruce community subtype.

	Red Spruce Community Subtype		
Species	Fraser fir-Spruce[1] (n=5)	Hemlock-Spruce ("Bog")[2] (n=4)	Spruce-dominated[3] (n=15)
Picea rubens	23.2	20.5	80.2
Abies fraseri	71.3	-	-
Tsuga canadensis	-	43.1	1.1
Betula lutea	1.2	19.8	6.1
Acer rubrum	-	3.7	4.0
Betula lenta	-	5.7	1.7
Fagus grandifolia	-	-	2.7
Amelanchier arborea	-	0.2	1.8
Other species	4.3	7.0	2.4
Total	100.0	100.0	100.0

[1]All stands located on Mount Rogers
[2]One stand at SNP; three stands in Giles County
[3]All other stands

Three general subtypes of the red spruce community type can be distinguished on the basis of large tree composition (Table 4). The first of these is the forest community subtype found only at Mount Rogers; this is characterized by the presence of Fraser fir, which is absent from all other localities. The second community subtype is the hemlock-spruce forest in which hemlock typically dominates. This community type may be best described as a "bog" type, since it occupies very moist sites (e.g., Mann's Bog, Limberlost). The final community subtype is dominated by spruce (e.g., Whitetop summit) but may have an admixture of various hardwoods (e.g., Tazewell County); it characteristically occurs on summits or drier side slopes.

Twenty-two taxa of small trees were present in the stands we sampled, including five taxa not recorded as large trees (Table 5). Four are typically considered as understory trees: mountain holly (*Ilex ambigua*), hawthorn (*Crataegus* sp.), mountain maple (*Acer spicatum*), and alder (*Alnus serrulata*). The one potential canopy species was chestnut oak (*Quercus prinus*). Four species (black cherry [*Prunus serotina*], white pine [*Pinus strobus*], sassafras [*Sassafras albidum*], and mockernut hickory [*Carya tomentosa*]) were present in the large tree stratum but not in the small tree stratum. Interestingly, all of the more important large tree species displayed generally similar levels of abundance in the small tree stratum. Red spruce was the most consistently present of the small tree species and was recorded at twelve of the fifteen localities (20 stands); except for hemlock (11 stands) and yellow birch (14 stands), all other taxa occurred at fewer than ten localities. As was the case for large trees, Fraser fir was found only at Mount Rogers, where it was the most important species (Table 6).

TABLE 5. Composition of the small tree stratum (stems 2.5-9.9 cm DBH) for all 24 stands.

Species	Number stands present	Basal area (m^2/ha)	Relative basal area (%)	Density (N/ha)	Relative density (%)	Importance value
Picea rubens	20	0.39	29.1	141	26.7	27.9
Abies fraseri	5	0.26	19.4	155	29.3	24.4
Tsuga canadensis	11	0.15	11.2	48	9.1	10.2
Betula lutea	14	0.15	11.2	42	7.9	9.6
Ilex ambigua	6	0.06	4.5	33	6.2	5.4
Hamamelis virginiana	6	0.05	3.7	26	4.9	4.3
Fagus grandifolia	5	0.04	3.0	18	3.4	3.2
Acer rubrum	9	0.05	3.7	14	2.6	3.2
Amelanchier arborea	7	0.05	3.7	13	2.5	3.1
Betula lenta	8	0.05	3.7	12	2.3	3.0
Sorbus americana	2	0.04	3.0	6	1.1	2.0
Acer pensylvanicum	6	0.01	0.8	8	1.5	1.2
Other species[1]	1-3	0.04	3.0	13	2.5	2.8
Total		1.34	100.0	529	100.0	100.3

[1]Includes *Acer spicatum* (3 stands), *Crataegus* sp. (3), *Magnolia acuminata* (3), *Acer saccharum* (1), *Alnus serrulata* (1), *Fraxinus pennsylvanica* (1), *Liriodendron tulipifera* (1), *Nyssa sylvatica* (1), *Quercus prinus* (1), and *Q. rubra* (1)

TABLE 6. Average importance values for species represented in the small tree stratum (stems 2.5-9.9 cm DBH) of each red spruce community subtype.

	Red Spruce Community Subtype		
Species	Fraser fir-Spruce[1] (n=5)	Hemlock-Spruce ("Bog")[2] (n=4)	Spruce-dominated[3] (n=15)
Picea rubens	13.6	5.0	35.8
Abies fraseri	71.7	-	-
Tsuga canadensis	-	44.1	10.5
Betula lutea	5.5	20.3	6.9
Ilex ambigua	-	8.2	9.3
Hamamelis virginiana	-	11.4	4.5
Fagus grandifolia	-	0.5	5.7
Acer rubrum	-	0.4	6.4
Amelanchier arborea	-	3.4	7.2
Betula lenta	-	2.4	5.4
Sorbus americana	9.1	-	-
Acer pensylvanicum	-	1.9	1.8
Other species	-	2.4	6.6
Total	99.9	100.0	100.1

[1]All stands located on Mount Rogers
[2]One stand at SNP; three stands in Giles County
[3]All other stands

TABLE 7. Soil chemical and physical characteristics for 24 spruce stands sampled in western Virginia (N = 96 for all parameters except sand, silt, and clay separates, where N = 24).

Parameter	Range	Mean ± SD
Gravel (%)	0-51	16 ± 15
Sand (%)	27-83	50 ± 15
Silt (%)	7-51	28 ± 10
Clay (%)	10-46	22 ± 10
Organic matter (%)	13-67	40 ± 39
Soil moisture (% dry wt.)	37-307	144 ± 78
Calcium (ppm)	54-471	160 ± 196
Potassium (ppm)	17-89	40 ± 39
Magnesium (ppm)	10-57	24 ± 20
Phosphorus (ppm)	4-35	16 ± 20
Zinc (ppm)	2.5-6.1	4.4 ± 2.9
Nitrogen (ppm)	3-32	13 ± 20
Soluble salts (ppm)	42-1011	492 ± 637
pH	2.9-4.4	3.4 ± 1.0

In general, soils on which red spruce stands are found in western Virginia are sandy loams, although several other textural classes were represented (Table 7). In comparison to mid-Appalachian hardwood forests we have studied (Stephenson and Adams 1989, unpublished data), the soils of these forests are more strongly acidic and usually have higher levels of organic matter and ambient soil moisture. Otherwise, both forest types are generally characterized by low levels of most soil nutrients.

In summary, the high elevation coniferous forests that occur in the mountains of central and southwestern Virginia constitute a distinctive community type that has a rather limited distribution. This community type is characterized by the presence of red spruce in the large tree stratum, with hemlock and yellow birch as the most consistently important associated species. In fact, hemlock is sometimes the leading dominant on the most mesic (i.e., bog) sites. Fraser fir is present only at Mount Rogers, where it is the overwhelming dominant in stands located at the highest elevations.

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