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Vegetation of Linville Gorge Wilderness, North Carolina

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ABSTRACT

Species composition and vegetation-environment relationships are described for Linville Gorge Wilderness, a rugged landscape straddling the Blue Ridge escarpment of the southern Appalachian Mountains. A hierarchical classification is presented for 28 community types, which span eight broad vegetation classes. Vegetation classes associated with infertile conditions are most widespread. THERMIC OAK-PINE FORESTS dominate ridgelines and upper-slopes. ACIDIC COVE AND SLOPE FORESTS are prominent on sheltered, mid- and lower-slopes. MONTANE OAK FORESTS and RICH COVE AND SLOPE FORESTS are present, but are limited in distribution. The atypical concentrations of the latter class on high-elevation ridgelines results from underlying nutrient-rich bedrock. Vegetation composition is most strongly associated with soil nutrients, soil texture, and topographic position. The combination of rugged topography, infertile soils, relatively low annual rainfall levels, and lack of anthropogenic disturbance is responsible for the unusual combination of southern Appalachian vegetation communities that characterize Linville Gorge Wilderness.

INTRODUCTION

Much of our understanding of vegetation of the southern Appalachian Mountains is based on information from a few key research areas. However, the climatic, topographic, and geologic complexity of this region suggests that those areas represent only a small subset of the variation in vegetation and underlying environmental conditions across the region. A unique combination of environmental conditions sets Linville Gorge Wilderness, a low-elevation landscape on the Blue Ridge escarpment, apart from most of the southern Appalachians. This landscape is unusually rugged and topographically complex. Precipitation is low, and soils are particularly infertile for the southern Appalachian region. Finally, this study area escaped the nearly pervasive logging of the early 20th century (see Saunders 1979, Pyle 1988) and is one of only three large areas of old-growth forest remaining in the southern Appalachians.

In this paper we document the variation in composition and structure of the vegetation of Linville Gorge Wilderness. In addition, we (1) document which environmental factors are strongly associated with variation in community composition, and (2) evaluate the extent to which the vegetation communities and their relationships with environmental gradients are similar to those found elsewhere in the southern Appalachian Mountains.

STUDY AREA

Linville Gorge is located in Burke County, North Carolina on the eastern edge of the southern Appalachian Mountains. Geologically, the study area lies within the Grandfather Mountain Window where Late Precambrian rock shows through the ancient Blue Ridge overthrust (Hatcher and Goldberg 1991). The Blue Ridge thrust sheet is represented by Middle Proterozoic Cranberry Gneiss present in the northwest corner of Linville Gorge (D'Agostino et

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al. 1986; Figure 1). Downcutting has exposed three geologic units. In the north, the river has carved a winding gorge through the Late Proterozoic and Early Cambrian Table Rock thrust sheet, before cutting through Late Proterozoic (Grandfather Mountain Formation) meta-arkose and, for the lower two-thirds of Linville Gorge, Precambrian Wilson Creek Gneiss. Steep, highly dissected slopes rise up as cliff-like bluffs at the base of the exposed Table Rock sheet (Figure 2). The shallower and comparatively undissected slopes above the bluffs are underlain by the Table Rock sheet, represented by three units of the Chilhowee Group. Phyllite and Upper Quartzite units occur as a thin band along the western border of Linville Gorge. The most abundant, Lower Quartzite, is exposed as bluffs and underlies the slopes above. This resistant unit also caps the prominent skyline rock massifs of the eastern side of the valley (Figure 2).

No long-term climatic data are available for Linville Gorge (but see Billings and Anderson 1966), but data are available from nearby weather stations at Banner Elk and Boone (northwest of Linville Gorge), Blowing Rock and Grandfather Mountain (north of Linville Gorge), and Ashford (to the south). Precipitation averages 1,250 to 1,625 mm and peaks in the summer. June to August are the hottest months (14 to 17°C average minima, 21 to 27°C average maxima), whereas February is the coolest month (−2 to 0°C average minima, 8 to 12°C average maxima; Earthinfo Inc. 1989).

Slopes above and below the bluffs have Typic or Lithic Dystrochrept soils (in the Ashe, Buladean, Chestnut, Ditney, Soco, Stecoah, and Unicoi soil series). Soils within the bluffs form a complex of coarse, thin, Typic and Lithic Dystrochrepts (Ditney and Unicoi soil series). Some lower-slopes are Typic Hapludults (Brevard series) formed from colluvium and alluvium. River flats have Typic Udifluvent soils (Colvad and Hosting soil series) formed from coarse alluvium (Knight in press).

Only about 5% of Linville has experienced logging, and this was confined to the northeastern section of the study area; the remainder of Linville Gorge contains original vegetation.

Presettlement upland oak, pine and chestnut communities in the southern Appalachian Mountains were subjected to frequent fires (7-to-12 year mean fire interval; Harmon 1982, Frantz and Sutter 1987, Frost 1995). In Linville Gorge, fire scars and tree cores provide evidence of recurrent fires, both catastrophic and noncatastrophic (C. Frost, unpubl. data). On Shortoff Mountain (see Figure 1), the last catastrophic crown fire occurred about 1915 with one preceding in approximately 1860. Those fires were most intense on south-facing slopes and ridgelines with many canopy trees killed, whereas on north-facing slopes fires generally crept across the landscape as ground fires. Low-intensity surface fires occurred in intervals between major crown fires, but their size and frequency remain unknown. The last widespread surface-fire occurred in the early 1950's; fires since that time have been suppressed (C. Frost, pers. comm.). Presettlement fires across the southern Appalachians were ignited by lightning strikes and aboriginal Americans. In Linville Gorge, the three lightning-initiated fires on Shortoff Mountain during the summer of 1993 (C. Frost, pers. comm.) indicate potentially high susceptibility to natural ignitions. Suppression since the mid-part of the twentieth century has reduced the ground-layer flammability of oak and pine communities, and it is unlikely that this important aspect of the natural disturbance system can be restored.

METHODS

Data collection

The limits of this study correspond to the Wilderness boundary; references to Linville Gorge should be taken as references to Linville Gorge Wilderness. Vegetation sampling was stratified so as to capture the major geologic and topographic variation within the Wilderness. Potential plot sites were subjectively selected to include all possible combinations of surficial geology (5 classes; see Figure 1), macro-topography (steep, highly dissected slopes below the bluffs; the bluffs; shallow, undissected slopes above the bluffs), elevation (low- and high-elevations within each macro-topographic unit) and meso-topography (south-facing and north-facing sideslopes, ridgelines, coves, alluvial flats). Sites with comparatively homogeneous vegetation were subjectively chosen for sampling. In total, 181 plots were sampled.

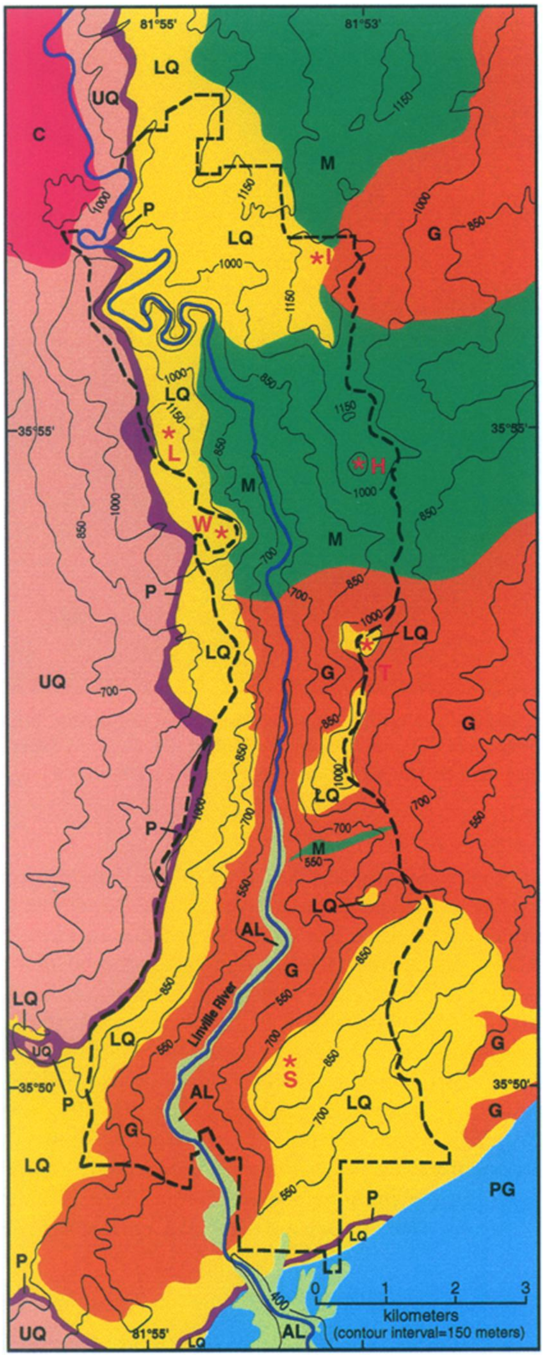


Figure 1. Map of Linville Gorge Wilderness (4,390 hectares, high-point 1,250 m, low-point 400 m) showing topography and surficial geology. Mapping units include: alluvium (**AL**), Cranberry Gneiss (**C**), Wilson Creek Gneiss (**G**), Lower Quartzite (**LQ**), Grandfather Mountain Formation meta-arkose (**M**), phyllite (**P**), Proterozoic Gneiss (**PG**) and Upper Quartzite (**UQ**). Prominent high points include: Hawksbill Mountain (**H**), Gingercake Mountain (**I**), Laurel Knob (**L**), Shortoff Mountain (**S**), Tablerock Mountain (**T**), Wiseman's View (**W**). The Wilderness boundary is indicated by the dashed line. Parent material units follow D'Agostino et al. (1986). Contours shown in meters.

Figure 2. Linville Gorge Wilderness showing complex topography and prominent features on the eastern side of the gorge. From left to right: Tablerock Mountain, exposed Lower Quartzite cliffs below The Chimneys and Shortoff Mountain in the distance (see Figure 1). Photo looking southeast from Wiseman's Knob.

Vegetation was sampled following the North Carolina Vegetation Survey (NCVS) protocol, primarily using the intensive 0.1 ha plot configuration (see Peet, Wentworth, and White 1998). Although an effort was made to include ten 0.01 ha modules in each plot, the highly dissected topography of Linville Gorge sometimes limited aggregated modules to a smaller number. In each sampling unit, presence of all vascular species was recorded for at least five and typically seven spatial scales (0.01, 0.1, 1.0, 10, 100, 400, 1,000 m^2), with the smallest four recorded in two corners of each (of typically four) intensive module. Species cover was estimated in each intensively sampled module using the ten cover classes of the NCVS system (1 = trace, 2 = <1%, 3 = 1–2%, 4 = 2–5%, 5 = 5–10%, 6 = 10–25%, 7 = 25–50%, 8 = 50–75%, 9 = 75–95%, 10 = 95–100%). Diameters of all woody stems (trees, shrubs, lianas) were recorded at breast height (1.4 m) by species within each intensively sampled module, and also collectively across the remaining modules. Botanical nomenclature follows Flora of North America where completed (Volumes 2, 3; Flora of North America Editorial Committee 1993, 1997), and otherwise Kartesz (1994).

Site environmental characterization

Past studies of southern Appalachian vegetation have documented or suggested strong correlations with elevation, topographic characteristics, soil nutrients and underlying geology (e.g., Whittaker 1956, Day and Monk 1974, Callaway et al. 1987, McLeod 1988, Patterson 1994, Wiser et al. 1996, Newell 1997, Newell et al. in press). A wide range of environmental information was used in the present study in an attempt to quantify all factors that might explain variation in vegetation composition.

Soil samples were collected from the top 10 cm of mineral soil (below the litter and humus layer) in the center of each intensively sampled module. Total cation exchange capacity (meq/100g), pH, percent humic matter, estimated nitrogen release, easily extractable P, exchangeable cations (Ca, Mg, K, Na ppm), percent base saturation, extractable micro-nutrients (B, Fe, Mn, Cu, Zn, Al ppm), soluble sulfur and bulk density values were determined for each subsample. Extractions were carried out using the Mehlich III method (Mehlich 1984) and percent humic matter was determined by loss on ignition. Texture analysis employed the Bouyoucos hydrometer method (Patrick 1958) for a composite sample of the four subsamples from each plot. Chemical and textural analyses were conducted by Brookside Laboratories, Inc., New Knoxville, Ohio. All soil values for a plot (typically four) were averaged to obtain a single soil plot value.

Despite our careful removal of litter and humus before collecting soil samples, organic matter (Tables 1, 2) is consistently higher than might be expected for mineral soil. We have collected soils in a similar fashion throughout North Carolina; such high values have not occurred in our Coastal Plain or Piedmont samples, but have occurred consistently in our southern Appalachian samples. There is a conspicuous southern Appalachian latitudinal gradient in soil organic matter from south to north in roughly the following order: Joyce Kilmer Wilderness < Nantahala Mountains < Shining Rock Wilderness < Grandfather and Roan Mountains < Linville Gorge Wilderness (Newell 1997). In some of these studies supplemental soils were collected at a depth of 50 cm; these were significantly lower in organic content, usually in the range of 5–10%. It appears that cool, moist climate and low soil fertility lead to low rates of organic matter decomposition with the result that the upper-most portions of the A horizon (i.e., top 10 cm) routinely contain high levels of organic matter.

Elevation, slope and aspect were measured at the center of the set of intensively sampled modules. Aspect was transformed into a linear variable ranging from 0.00 to 2.00 using the method of Wiser et al. (1996), as modified from Beers et al. (1966): $A' = \cos(A_{max} - A) + 1$, where A = aspect measured in degrees and A' = the transformed aspect. Transformed values between 1° and 75° were tested at increments of 5° to identify $A_{max} = 50°$ as the aspect with the most mesic vegetation. This was derived as the value that maximized the variance in vegetation accounted for using canonical correspondence analysis (CCA; ter Braak 1987) with transformed aspect as the sole environmental determinant. Distance downslope to the nearest stream (DISTSTRM) and distance upslope to the nearest ridge (DISTRIDG) were recorded (mm units on a 1:24,000 map) with measurements made perpendicular to contour lines. These distances were used to calculate relative slope position (RELSLOPE), where relative slope position is distance to nearest stream divided by distance to nearest ridge plus distance to nearest stream (high RELSLOPE corresponds to low slope position). Digital site topographic characteristics were calculated using a USGS 30 m-resolution, digital elevation model. Plot location within the surrounding landscape was quantified using the McNab (1993) Landform Index (LFI) and the McNab (1989) Terrain Shape Index (TSI). TSI was obtained by measuring the plot surface slope angle within a 3×3 pixel window (i.e., 90×90 m area). Profile curvature (PROFCV) and section curvature (SECCV), respectively measuring microtopographic curvature parallel and perpendicular to slope aspect, and topographic complexity (TOPOCOM), were calculated using ARCINFO (Environmental Systems Research Institute 1996). TOPOCOM quantified the complexity or surface roughness of the topography surrounding a plot, calculated as the standard deviation of elevation values for the pixels within a given window size. Values calculated for the 13×13 30 m pixels (i.e., 390×390 m area) were used following preliminary analyses (using values calculated for 8 pixel windows between 3×3 and 17×17 30 m pixels in size) which consistently showed highest correlations between vegetation composition and 13×13 30 m pixel window values. The width of a 13×13 pixel window roughly equals the average slope length of the highly dissected slopes below the bluffs in Linville Gorge.

Potential solar radiation, calculated in ARCINFO using the program SOLARFLUX (Hetrick, Rich, Barnes et al. 1993, Hetrick, Rich and Weiss 1993), was determined using a digital elevation model and latitude, and based on hourly intervals for five hours (10:00 to 15:00 hours) for March 23. This date was chosen as having greatest predictive value based on the findings of a study by Hutchison and Matt (1977) and our unpublished analyses (see Newell 1997).

Site moisture potential was quantified using digital topographic information to develop the Topographic Moisture Index (TMI; see Newell 1997), a modified version of Parker's (1982) topographic relative moisture index. TMI is a scalar that incorporates the influence of topo-

Table 1. Average soil nutrient and textural composition by vegetation class and associated community types. Groups are referenced by their abbreviation code. See Figure 2 for full names. Specific soil variables are as follows: pH, percent base saturation (BS), total cation exchange capacity (CEC; meq/100 g), exchangeable cations (Ca, Mg, K; ppm), easily extractable P, extractable micronutrients (Al, Cu, Fe, Mn, Zn; ppm), organic matter (Orgmat; by loss on ignition), sand, silt and clay (percent)

Vegetation Classes and Types	pH	BS	CEC	Ca	Mg	K	P	Al	Cu	Fe	Mn	Zn	Org-mat	Sand	Silt	Clay
1.1 *Rhododendron minus*	3.7	22	10.2	276	55	85	29	782	0.21	205	3.8	4.4	46.4	8.9	87.1	4.0
1.2 [*Cheilanthes tomentosa*]	3.1	20	11.2	218	49	51	56	1,253	0.67	362	3.7	2.8	21.6	14.3	76.1	9.5
1.3 *Selaginella tortipila*	3.5	15	10.0	296	34	17	18	420	0.10	89	1.0	1.8	9.1	10.0	87.0	3.0
2.1 *Pinus pungens/Gaylussacia*	3.6	22	9.7	220	72	105	20	777	0.17	207	3.0	8.0	40.6	10.4	85.6	4.0
2.2 *Pinus pungens/Kalmia*	3.5	20	10.4	191	81	132	25	575	0.26	120	3.8	5.4	62.6	5.8	91.2	2.9
2.3 *Pinus virginiana-Pinus pungens*	3.5	20	10.3	204	73	108	26	768	0.23	190	3.9	5.4	60.8	8.4	88.3	3.3
2.4 *Pinus rigida-Pinus pungens*	3.5	20	10.9	221	74	118	28	570	0.31	110	2.0	6.5	61.5	7.1	90.0	2.9
2.5 *Quercus alba-Pinus rigida*	3.3	18	17.3	336	120	155	29	509	0.64	128	4.0	9.5	75.5	3.8	92.9	3.3
2.6 *Tsuga caroliniana/Rhododendron*	3.6	20	11.0	211	94	125	35	584	0.27	117	3.9	6.2	63.5	3.3	94.0	2.8
2.7 *Quercus alba-Quercus rubra*	3.7	22	9.3	235	66	87	31	908	0.46	229	6.5	4.4	35.5	12.5	84.3	3.2
2.8 *Quercus montana/Kalmia*	3.7	22	13.6	312	93	151	29	1,098	0.79	213	19.0	6.5	48.9	9.4	86.0	4.6
2.9 *Quercus montana-Quercus coccinea*	3.7	22	10.9	245	82	130	34	516	0.39	114	7.5	5.3	63.6	7.9	88.8	3.3
3.1 *Quercus montana-Acer rubrum*	3.7	22	14.5	357	118	123	42	510	0.41	114	17.6	5.4	54.8	9.2	87.2	3.7
3.2 *Quercus montana/Rhododendron*	3.7	22	11.3	284	89	113	28	652	0.42	141	8.7	4.9	59.9	7.6	89.8	2.6
3.3 *Quercus montana-Pinus strobus*	3.7	22	11.9	274	100	106	26	630	0.36	147	6.3	5.3	50.5	10.3	85.7	4.0
3.4 *Tsuga canadensis-Pinus strobus*	3.6	22	15.9	418	111	131	39	463	0.33	102	7.0	5.6	56.2	5.9	92.3	1.8
3.5 *Tsuga canadensis/Rhododendron*	3.7	22	16.3	459	102	120	28	468	0.40	121	6.2	6.5	69.6	5.1	92.5	2.4
4.1 *Quercus montana-Liriodendron*	4.0	27	15.7	623	155	89	51	941	0.48	256	82.7	4.6	50.8	25.2	70.4	4.3
4.2 *Quercus montana/Cornus florida*	4.1	28	22.3	1,020	116	100	55	1,003	0.90	268	61.7	6.3	44.8	21.3	74.0	4.7
4.3 *Quercus montana-Tilia*	4.0	27	27.4	1,205	123	147	27	966	0.43	336	56.8	7.2	44.0	24.0	69.3	6.8
4.4 *Quercus alba-Acer rubrum*	3.9	24	11.3	383	71	107	31	1,295	0.75	235	92.3	3.8	56.5	15.5	78.5	6.0
5.1 *Carya glabra/Ageratina*	4.2	31	11.0	506	73	66	81	1,449	1.10	149	235.0	4.9	32.1	14.7	76.8	8.5
5.2 [*Liriodendron-Carya glabra*]	4.4	34	18.0	1,003	110	87	86	1,270	0.99	143	237.5	4.2	48.2	29.8	65.2	5.0
5.3 *Tsuga canadensis-Fagus*	4.3	31	19.6	1,022	109	76	47	924	0.68	241	96.7	6.4	61.4	17.9	78.1	4.0
6.1 [*Liquidambar*]	4.8	42	5.8	346	60	28	22	462	0.61	264	111.0	5.9	59.5	93.4	1.6	5.0
6.2 [*Platanus/Asimina*]	4.5	36	15.0	896	90	48	82	842	1.34	255	127.0	4.7	23.5	17.2	71.8	11.0
7.1 [*Alnus/Xanthorhiza*]	4.6	41	5.5	253	51	38	30	540	0.67	382	93.0	4.9	3.9	7.4	88.1	4.5
8.1 [*Scirpus cyperius-Dulichium*]	3.6	21	8.3	162	67	78	94	918	0.10	121	2.0	3.0	71.3	1.4	95.6	3.0

Table 2. Average soil nutrient and textural composition by parent material unit. N represents the number of stands in each parent material type. Specific soil variables are as follows: pH, percent base saturation (BS), total cation exchange capacity (CEC; meq/100 g), exchangeable cations (Ca, Mg, K; ppm), easily extractable P, extractable micronutrients (Al, Cu, Fe, Mn, Zn; ppm), percentage organic matter (Orgmat; by loss on ignition), sand, silt and clay (percent)

	N	pH	BS	CEC	Ca	Mg	K	P	Al	Cu	Fe	Mn	Zn	Orgmat	Sand	Silt	Clay
Alluvium	4	4.4	34	14.6	749	90	50	45	727	0.80	284	107.8	5.4	46.1	38.2	56.1	5.8
Gneiss	47	3.8	24	15.5	535	120	115	36	754	0.42	194	25.0	5.7	51.4	12.9	83.3	3.8
Lower Quartzite	83	3.6	21	11.5	243	82	117	31	670	0.37	157	10.6	5.8	60.9	6.5	90.3	3.2
Meta-arkose	36	3.8	23	12.2	369	71	101	38	697	0.40	118	34.8	4.9	51.1	10.0	85.9	4.1
Phyllite	5	3.9	25	12.3	391	90	107	49	960	1.05	226	154.6	6.3	47.4	9.3	85.9	4.8
Upper Quartzite	5	3.8	24	13.4	432	94	114	50	855	0.51	186	66.6	3.9	45.1	14.9	79.5	5.6

graphic position (digitally derived relative slope position; RSP), curvature and solar radiation; all three are known to have a strong influence on vegetation patterns through evapotranspiration and water runoff (Selby 1985). RSP (Wilds 1996), calculated as the position of a site relative to nearest slope base and nearest ridge, was rescaled from 0 to 20. Overall site curvature was calculated using profile and section curvature (see Wilds 1996) and rescaled between 0 and 10. Spring solar radiation values, derived using SOLARFLUX, were rescaled from 0 to 30. Rescaled curvature, solar radiation and relative slope position values were added to produce a measure of site potential moisture (TMI), with values ranging from 0 to 60, where higher values correspond to greater site moisture.

Classification and characterization

Plot mean cover was calculated for each species by converting cover scores in each 0.01 ha module to mid-point percentage values, averaging these across the entire plot aggregate, and then converting percentages back to cover classes. All soil nutrient values were log-transformed before ordination analyses to make values biologically more interpretable (Palmer 1993). One plot was eliminated from the analyses due to its heterogeneous composition.

Two clustering methods were employed to generate community classifications: Ward's minimum variance method (Ward 1963), which identifies clusters using minimized within-cluster variance, and the Lance and Williams (1967) flexible strategy (see also Lance and Williams 1966, Clifford and Stephenson 1975, Legendre and Legendre 1983). Both methods were implemented in SAS (version 6.11, SAS Institute Inc. 1996) using PROC CLUSTER, with the default beta of −0.25 used for the flexible method. Coefficient of community (Bray and Curtis 1957) was used to calculate a dissimilarity matrix based on species cover relativized by site total (Noy-Meir et al. 1975, van Tongeren 1995). The flexible method was chosen after comparing results from both clustering methods. This method produced clusters similar to those derived using Ward's method, but the identified groups were more interpretable.

Community characterization

The classification was based on 180 stands, which contained a total of 405 species. Groups were accepted at the normalized flexible distance of 1.008. A three-tier hierarchical classification was developed to enable comparisons with vegetation elsewhere in the southern Appalachians. At the highest level, vegetation classes correspond with broad-based vegetation groups present across the southern Appalachians (see Newell 1997 for full list). Each vegetation class includes one or more community type(s), which are the basic vegetation units described and mapped. Distinct, recurring subgroups within a community type are referred to as sub-types. Vegetation classes are typically derived from distinct lineages in the agglomerative hierarchy, except in a few instances in which community types in other closely related branches of the classification were included. Classes are based largely on floristic and environmental similarity within a 1,120-plot southern Appalachian regional classification (Newell 1997).

A standard naming strategy was used for community types, largely consistent with the U.S. National Vegetation Classification under development by The Nature Conservancy. Community type names include species with both high constancy (≥75%) and consistently high cover (≥3 for Rock Outcrops, ≥4 cover class for all other vegetation classes) that characterize and distinguish individual community types. A '−' separates species in the same vertical stratum, whereas a '/' separates species in different strata. Species are listed in descending order of abundance (usually) and vertical strata by descending structural position. Type names enclosed in square brackets are tentative because they are represented by few samples (≤2). Scientific names are used and are referred to by genus only (to save space) unless more than one species in the genus is likely to be present in the study area.

Constancy and prevalence (sensu Curtis 1959) of individual species in each vegetation class and community type were determined. Constancy represents the frequency of occurrence of a species within a specified group of plots. Prevalence is determined by ranking species by constancy and selecting as prevalent the most constant species such that the total number of prevalent species equals the average species richness (per 100 m² module) in the vegetation group. Homoteneity (sensu Curtis 1959), which is the mean constancy of the prevalent species, was calculated to provide an indication of compositional variability among samples within a group.

All plot positions were located on winter-flown color aerial photographs (1:24,000 scale). Field and digitally derived topographic characteristics, aerial photograph color and texture were recorded for each plot and summarized by community type. A detailed vegetation map was then produced showing the distribution of vegetation classes and community types in Linville Gorge. Changes in signature characteristics were used to assign the boundaries between specific community types and vegetation classes.

Relationship of vegetation to the environment

The relationship between species composition and major environmental gradients was explored using nonmetric multidimensional scaling (NMDS; Kruskal 1964) as implemented in the program DECODA (Minchin 1994). NMDS ranks plots based on dissimilarity, in this case calculated using the Bray-Curtis dissimilarity coefficient and relativized cover. NMDS was run using all defaults, except that ordinations were computed using 20 random starting configurations and axes were standardized as species half-changes to correspond with the standard implementations of detrended correspondence analysis. Configurations with the minimum stress levels were used. The 160 stands representing forest vegetation were ordinated using a three dimensional ordination. Variation across compositionally similar groups of stands, identified using cluster analysis, was examined with a series of two-dimensional ordinations.

Multiple regression was used to identify the environmental variables most highly associated with compositional axes. The relationships between individual environmental factors and stand scores were plotted on a vector biplot with the angles indicating direction of highest correlation and the lengths representing the strength of the correlation.

RESULTS

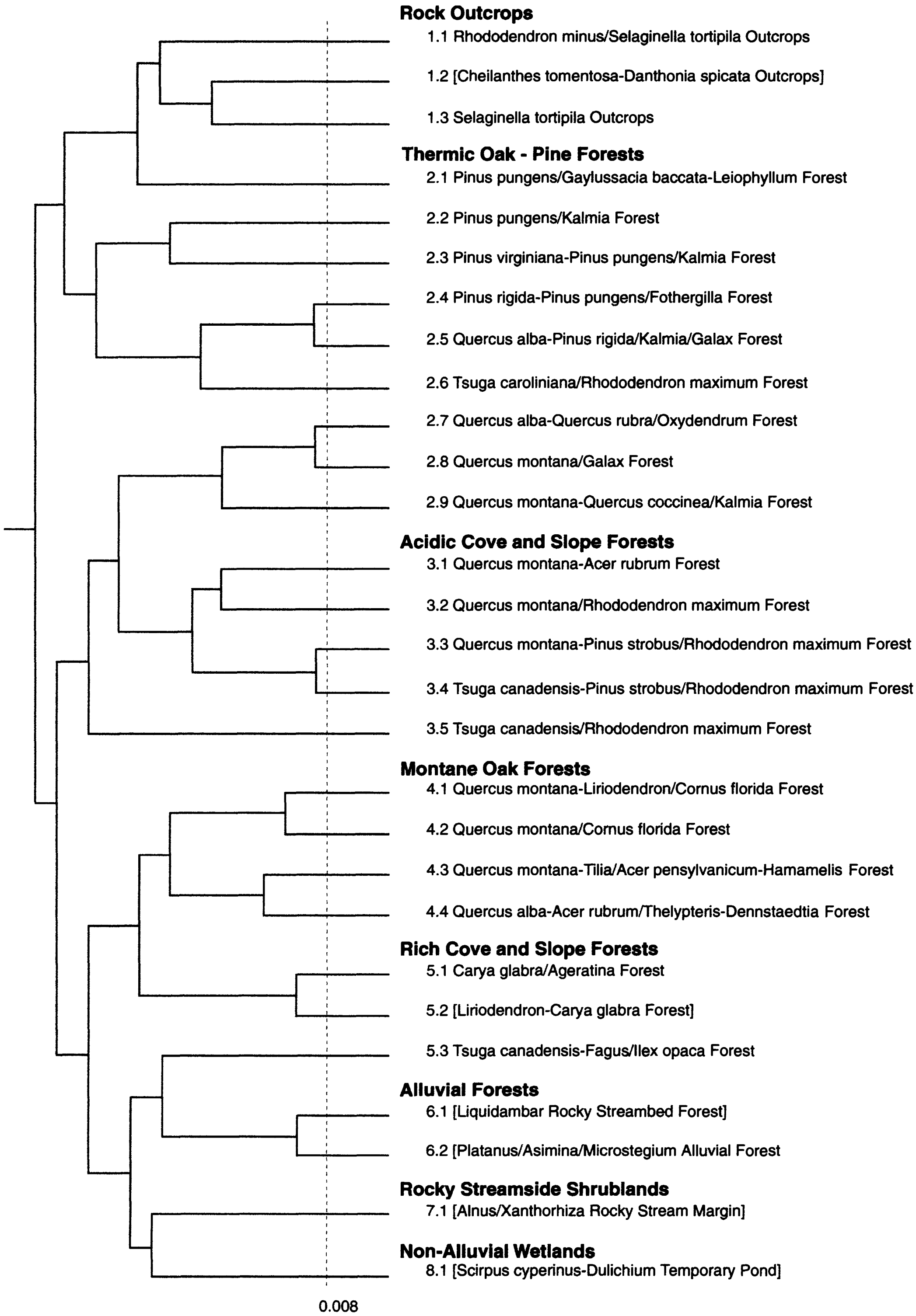
In total, 28 community types spanning eight vegetation classes are recognized in Linville Gorge (Figure 3; note bracketed names are tentative types). The geographic distribution of these types is shown by means of a vegetation map (Figure 4). THERMIC OAK-PINE FORESTS and ACIDIC COVE AND SLOPE FORESTS have the broadest distribution across this landscape, representing respectively 40% and 47% of the vegetation mapped (Figure 4). MONTANE OAK FORESTS are less abundant and RICH COVE AND SLOPE FORESTS, the remaining vegetation class with broad distribution throughout the southern Appalachians, has restricted distribution in Linville Gorge (respectively 8% and 3% of vegetation mapped; Figure 4). ROCK OUTCROPS are closely associated with the steep escarpments that are a prominent feature of this landscape and account for 8% of the vegetation mapped.

Compositional differences among the four major forest vegetation classes are most strongly associated with soil nutrients, soil texture and topographic moisture (Figures 5–6). The two most widespread vegetation classes inhabit infertile sites with silty soils and are separated from one another by topographic differences; THERMIC OAK-PINE FORESTS occur on dry (high solar radiation, low TMI) sites with high slope positions, whereas ACIDIC COVE AND SLOPE FORESTS inhabit moist, sheltered lower slopes. Both MONTANE OAK FORESTS and RICH COVE AND SLOPE FORESTS are dispersed across a broad range of topographic positions; these two are separated by soil nutrients, with the latter class occurring on more fertile soils.

Community characterization

ROCK OUTCROPS

ROCK OUTCROPS are scattered throughout the southern Appalachian Mountains on exposed summits and bluffs (Wiser 1994, Wiser et al. 1996), but are generally of limited extent owing to the antiquity of the landscape. Linville Gorge is an exception in its abundance of rock outcrops associated with the cliffs, bluffs and rocky summits that line both sides of the gorge (Figure 4). Difficulty of access has meant that few studies have been conducted of the rock outcrop vegetation of the southern Appalachians, the work of Wiser on high-elevation rocky


Rock Outcrops
1.1 Rhododendron minus/Selaginella tortipila Outcrops
1.2 [Cheilanthes tomentosa-Danthonia spicata Outcrops]
1.3 Selaginella tortipila Outcrops
Thermic Oak - Pine Forests
2.1 Pinus pungens/Gaylussacia baccata-Leiophyllum Forest
2.2 Pinus pungens/Kalmia Forest
2.3 Pinus virginiana-Pinus pungens/Kalmia Forest
2.4 Pinus rigida-Pinus pungens/Fothergilla Forest
2.5 Quercus alba-Pinus rigida/Kalmia/Galax Forest
2.6 Tsuga caroliniana/Rhododendron maximum Forest
2.7 Quercus alba-Quercus rubra/Oxydendrum Forest
2.8 Quercus montana/Galax Forest
2.9 Quercus montana-Quercus coccinea/Kalmia Forest
Acidic Cove and Slope Forests
3.1 Quercus montana-Acer rubrum Forest
3.2 Quercus montana/Rhododendron maximum Forest
3.3 Quercus montana-Pinus strobus/Rhododendron maximum Forest
3.4 Tsuga canadensis-Pinus strobus/Rhododendron maximum Forest
3.5 Tsuga canadensis/Rhododendron maximum Forest
Montane Oak Forests
4.1 Quercus montana-Liriodendron/Cornus florida Forest
4.2 Quercus montana/Cornus florida Forest
4.3 Quercus montana-Tilia/Acer pensylvanicum-Hamamelis Forest
4.4 Quercus alba-Acer rubrum/Thelypteris-Dennstaedtia Forest
Rich Cove and Slope Forests
5.1 Carya glabra/Ageratina Forest
5.2 [Liriodendron-Carya glabra Forest]
5.3 Tsuga canadensis-Fagus/Ilex opaca Forest
Alluvial Forests
6.1 [Liquidambar Rocky Streambed Forest]
6.2 [Platanus/Asimina/Microstegium Alluvial Forest
Rocky Streamside Shrublands
7.1 [Alnus/Xanthorhiza Rocky Stream Margin]
Non-Alluvial Wetlands
8.1 [Scirpus cyperinus-Dulichium Temporary Pond]
0.008

summits being the conspicuous exception (Wiser 1994, Wiser et al. 1996). Like most previous studies, the present study excludes sites not accessible by foot; no effort was made to formally sample the extremely sparse vegetation that occupies the near vertical cliffs that line the gorge. In effect, sites sampled were mostly those with moderately continuous plant cover and some soil development. Three community types are recognized (Figure 3), but doubtless others could be described if more intensive sampling efforts were undertaken.

Community types of the Linville outcrops differ with parent material, elevation, and aspect (Appendix 1). RHODODENDRON MINUS/SELAGINELLA TORTIPILA OUTCROPS occupy the crests and high ledges of the exposed eastern side of the Gorge, but behind the crests the vegetation grades quickly into PINUS PUNGENS/GAYLUSSACIA BACCATA-LEIOPHYLLUM FOREST. These outcrop sites bear the brunt of the cold, moist west winds and experience considerable winter abrasion from blowing snow and ice.

The [CHEILANTHES TOMENTOSA-DANTHONIA SPICATA OUTCROPS] occur at somewhat lower elevations on the east side of the gorge, particularly on Lower Quartzite as exposed on southern Shortoff Mountain. In contrast, the similar but more woody-plant dominated SELAGINELLA TORTIPILA OUTCROPS constitute the only outcrop type sampled on the western side of Linville Gorge, where they inhabit small, sheltered escarpments and bluff crests near the summit of the dominating Lower Quartzite bluff system. This type inhabits mid-slope sites that are sheltered from exposure to the prevailing west winds. The majority of the bluff faces occur as nearly bare rock. On the western side, stunted forms of PINUS PUNGENS/GAYLUSSACIA BACCATA-LEIOPHYLLUM FOREST and PINUS VIRGINIANA-PINUS PUNGENS/KALMIA FOREST are present in isolated patches of shallow soil accumulation, with TSUGA CAROLINIANA/RHODODENDRON MAXIMUM FOREST occurring in narrow ravines and cool rock crevices. Below the bluff system, *Asplenium montanum* inhabits crevices on sparsely distributed, moist rock faces found as inclusions within other community types such as the TSUGA CANADENSIS/RHODODENDRON MAXIMUM FOREST that dominates much of the valley bottom.

Linville Gorge outcrop vegetation is habitat to a large number of nationally or regionally rare species (see Appendix 1), including southern Appalachian endemics with restricted ranges (e.g., *Hudsonia montana, Liatris helleri*), broad southern Appalachian endemics (e.g., *Asplenium montanum*), and disjuncts from far to the north thought to be relicts of a Pleistocene southern Appalachian tundra habitat (e.g., *Scirpus caespitosa, Sibbaldiopsis tridentata*) (Schafale and Weakley 1990, Wiser 1994). The great majority of these rare species are specialists of stressful but high-light habitats and are excluded from other sites by competition from taller or more densely growing species. The abundance of these local rarities is highest in the RHODODENDRON MINUS/SELAGINELLA TORTIPILA OUTCROPS along the eastern rim where the exposure to cold, moist winds is high, favoring remnant tundra species. Local abundance strongly reflects recent fire frequency; fire in the fringing pine forests reduces competition from lichens and woody plants, letting these light-demanding rare species spread more widely (see Frost 1990, 1993).

1.1 RHODODENDRON MINUS/SELAGINELLA TORTIPILA OUTCROPS.—Small shrubs, including *Rhododendron minus, Kalmia latifolia,* and *Leiophyllum buxifolium,* along with prostrate *Selaginella tortipila,* dominate throughout. There is considerable variation in composition and stature between microsites, with three distinct sub-types recognizable (see Figure 4). Flat ledges are dominated by the RHODODENDRON MINUS-FOTHERGILLA/LEIOPHYLLUM/SELAGINELLA TORTIPILA SUB-TYPE with *Rhododendron minus, Gaylussacia baccata* and *Leiophyllum buxifolium* dominant on summit ledges and *R. minus* and *F. major* dominant on larger ledges. This

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Figure 3. Hierarchical classification of Linville Gorge Wilderness vegetation. The dendrogram shows divisions and final community type groupings identified using the Lance-Williams Flexible-Beta clustering method. Community types are represented by their code and full name; the first number of the code represents the vegetation class. A community type name enclosed by brackets represents a tentative name owing to limited sample size.

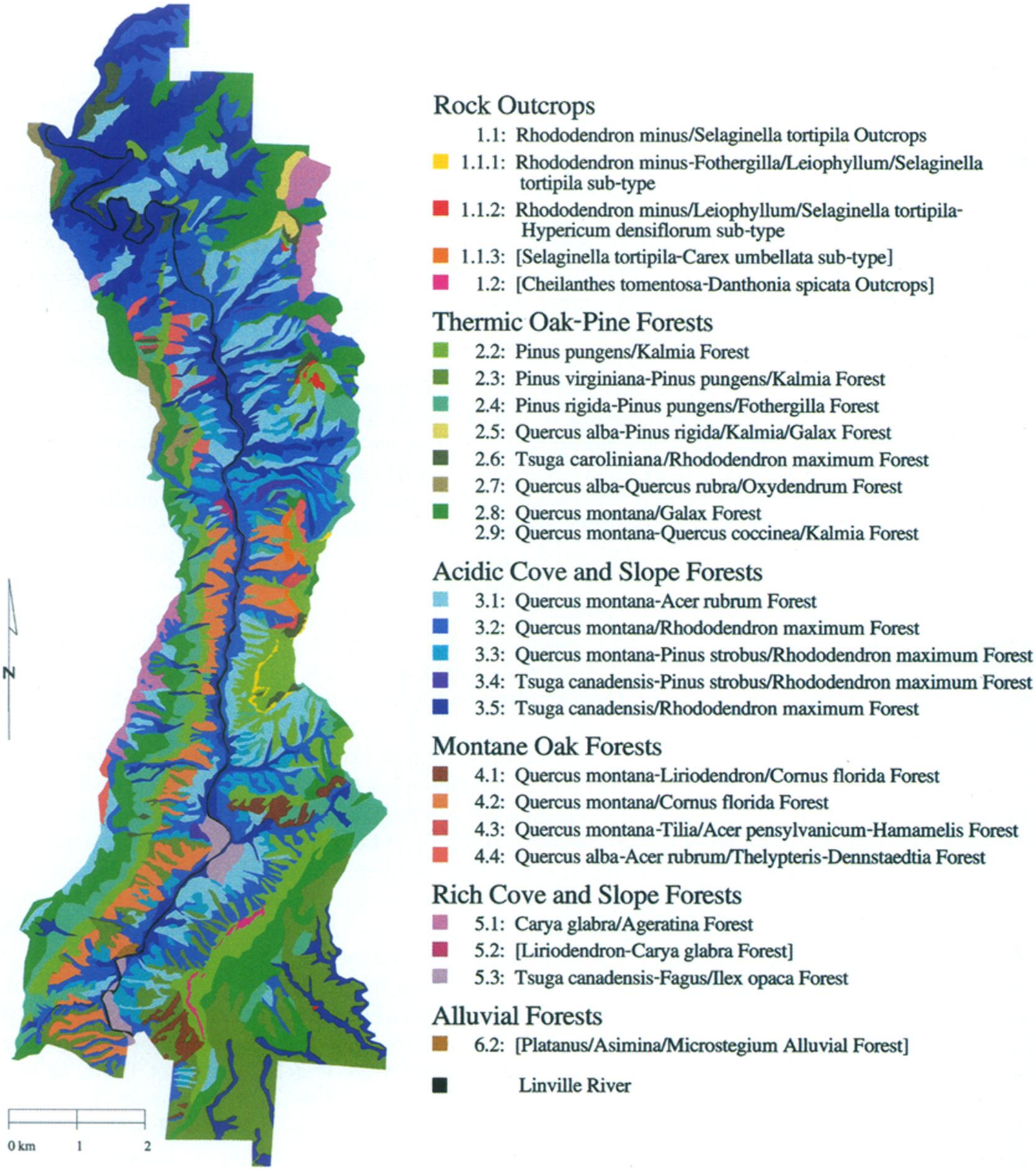

Figure 4. Distribution of vegetation classes and community types in Linville Gorge Wilderness. Topographic information was used in collaboration with winter-flown color aerial photograph (1:24,000 scale) texture and topographic relief to determine group distribution. Spatially restricted types ([ALNUS/XANTHORHIZA ROCKY STREAMSIDE], [SCIRPUS CYPERINUS-DULICHIUM TEMPORARY POND], PINUS PUNGENS/GAYLUSSACIA BACCATA/LEIOPHYLLUM FOREST and SELAGINELLA TORTIPILA OUTCROPS) with smaller distribution than the lowest polygon size (75 × 75 m) were not mapped.

sub-type has moderately tall stature (ca. 2 m). Vegetation on steeper slopes and ledges has less, if any, soil and is often represented by the stunted, patchy RHODODENDRON MINUS/LEIOPHYLLUM/SELAGINELLA TORTIPILA-HYPERICUM DENSIFLORUM SUB-TYPE with *R. minus* and *Hypericum densiflorum* forming low, dense thickets (ca. 0.5 m tall), interspersed with exposed rock. Finally, smooth, exposed rock surfaces are inhabited by the [SELAGINELLA TORTIPILA-

CAREX UMBELLATA SUB-TYPE] which can have a near monoculture of *Selaginella tortipila* with other species concentrated in rock crevices, particularly *Carex umbellata.*

1.2 [CHEILANTHES TOMENTOSA-DANTHONIA SPICATA OUTCROPS].—These sites of somewhat lower elevation than 1.1, contain few woody species, and are floristically closer to the rock outcrops of the nearby Piedmont (Appendix 1; see Schafale and Weakley 1990). There are no species that truly dominate.

1.3 SELAGINELLA TORTIPILA OUTCROPS.—*Selaginella tortipila* forms widespread, dense, prostrate mats (0.1 m tall). Other species are more restricted in their distribution and abundance, with *Danthonia sericea, Pinus virginiana,* and stunted *Rhododendron minus* having consistent cover (Appendix 1). The presence of other species varies with site attributes.

THERMIC OAK-PINE FORESTS

THERMIC OAK-PINE FORESTS inhabit exposed sites with thin soils and are restricted to lower-elevation areas of the southern Appalachian Mountains (Schafale and Weakley 1990). The Linville Gorge Wilderness reaches only 1,250 m in elevation; in effect the entire area is low-elevation, despite its spectacularly rugged topography. In this landscape, the THERMIC OAK-PINE FORESTS class occupies dry, infertile mid- and upper-slopes, dominating slopes above the bluffs, less-extreme areas within the bluffs, and ridges below the bluffs (Figures 4–6). This class is situated at the infertile-end of the soil nutrient gradient (represented by low Ca, Mn and pH values; Figures 5–6; also see Table 1), which is consistent with downslope leaching of nutrients from these sites (Racine 1966) and the low-nutrient status of the underlying Lower Quartzite bedrock. The presence of THERMIC OAK-PINE FORESTS stands on the lower right end of the topographic gradient, which runs from the upper left to lower right of Figure 6, provides evidence for the dry (low RELSLOPE, low TMI, high SOLAR values), mid- and upper-slope position (low RELSLOPE, high DISTSTRM values) of this vegetation class.

Canopy height, stature and composition vary with site exposure, slope and soil depth, but xerophytic conifers (*Pinus pungens, P. rigida, P. virginiana, Tsuga caroliniana*) and oak species (*Quercus montana, Q. coccinea, Q. alba*) dominate, along with a distinctive evergreen shrub stratum of *Kalmia latifolia* and *Rhododendron maximum* or *R. minus*.

The nine community types recognized within the THERMIC OAK-PINE FORESTS (Figure 3) differ variously in site exposure (solar radiation), moisture potential (TMI), nutrient status (especially Mn, Cu), microtopographic shape (section curvature, TSI) and topographic complexity (TOPOCOM) (Figure 7). *Pinus*-dominated types generally occur at lower-elevations on more exposed, dissected sites with thinner, less fertile (lower pH, Cu, Mn) soils (Table 1, Figures 4, 7) than *Quercus* types. Stands dominated by *Tsuga caroliniana* inhabit moister (high TMI, low solar radiation) sites than those dominated by either *Pinus* or *Quercus* (Figure 7), typically sheltered in crevices and ravines along the cliff faces. Individual conifer species form a sequence *P. virginiana-P. pungens-P. rigida-Tsuga caroliniana* along a gradient from hot, dry to cool, moist sites (Figure 7). Concentration of *Pinus virginiana* on lower-elevation (500 to 830 m) sites than other xeric *Pinus*-dominated types is indicative of the typically low-elevation, Piedmont distribution of this species (Whittaker 1956, Racine 1966). Types dominated by the three *Pinus* spp. differ in site exposure and soil depth as well as elevation, consistent with patterns recorded elsewhere in the southern Appalachians (Whittaker 1956, Zobel 1969, Racine and Hardin 1975). Stands dominated by *P. pungens* are most widely distributed and are prominent on the most exposed sites with thinnest soils. PINUS PUNGENS/GAYLUSSACIA BACCATA-LEIOPHYLLUM FOREST forms a stunted, narrow, krummholz-like band along exposed, flat ledges at the summit of the bluffs on both sides of the valley. Shrubbier forms of this type also occur in steep, sheltered crevices within the bluffs. This type grades into PINUS PUNGENS/KALMIA FOREST farther from the bluff edge, on thin-soiled slopes immediately above the bluffs and ridgelines below the bluffs (Figure 7). PINUS RIGIDA-PINUS PUNGENS/FOTHERGILLA FOREST occurs on somewhat moister sites, with greater distance from the bluffs than those inhabited by the previous two types or PINUS VIRGINIANA-PINUS PUNGENS/KALMIA FOREST. This latter type occurs on warm, highly exposed, thin-soiled areas within or immediately above the bluffs, as well as low-elevation sites

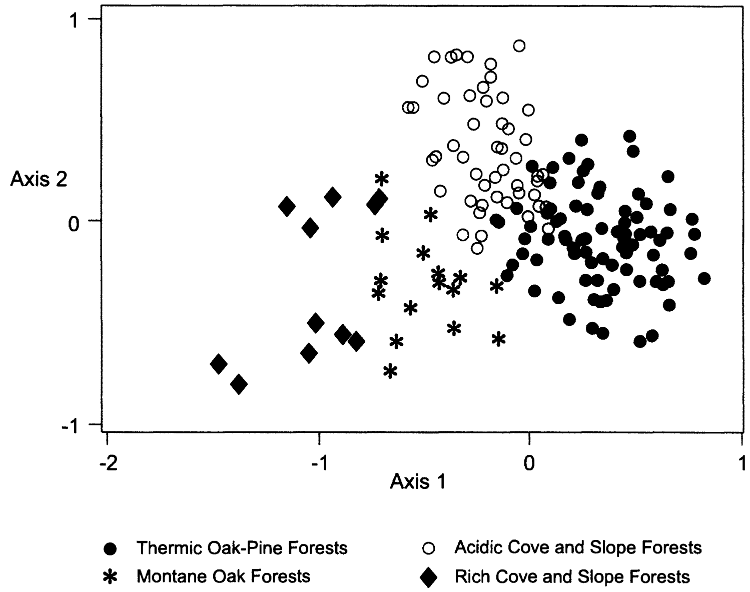

Figure 5. The distribution of THERMIC OAK-PINE FORESTS, ACIDIC COVE AND SLOPE FORESTS, MONTANE OAK FORESTS and RICH COVE AND SLOPE FORESTS vegetation classes on the first two axes of a three-dimensional NMDS ordination (see Figure 6).

on the southeastern slopes of Shortoff Mountain and warmer, southeast-facing ridgelines below the bluffs on the western-side of the main valley.

In contrast to THERMIC OAK-PINE FORESTS types dominated by *Pinus* spp., which typically inhabit dry, convex habitats, TSUGA CAROLINIANA/RHODODENDRON MAXIMUM FOREST sites are moister and usually occur in sheltered, concave gullies within the bluff system (Figures 4, 7, 8). This type also occurs in small, steep creek beds above the bluffs, on upper-slopes in the northern gorge-section of the valley, and, occasionally, with *Tsuga canadensis* on sheltered toeslopes at the base of the bluff system. Sites range from 820 to 1,180 m in elevation.

Community types dominated by oaks generally occur on more fertile and deeper soils than those found in the conifer-dominated forests (Table 1, Figure 7). Sites dominated by *Quercus alba* typically have higher fertility than *Q. montana* and *Q. coccinea* stands and inhabit higher slope positions. The two *Quercus montana*-dominated types are dominant on the moderately steep mid- and upper-slopes above the bluffs. QUERCUS MONTANA/GALAX FOREST, distributed between 900 and 1,145 m elevation, inhabits moister, more fertile sites (higher Ca, Cu, Mn; Table 1) with deeper soils than QUERCUS MONTANA-QUERCUS COCCINEA/KALMIA FOREST, which occurs between 550 and 1,150 m elevation. The latter type grades into PINUS PUNGENS/KALMIA Forest on more exposed sites with thinner soils. QUERCUS MONTANA-QUERCUS COCCINEA/KALMIA FOREST also occurs on slopes below the bluffs.

The two *Quercus alba*-dominated types are restricted to the highest elevation ridgelines and associated off-ridge sites. QUERCUS ALBA-PINUS RIGIDA/KALMIA/GALAX FOREST occurs at higher-elevations (1,075 to 1,260 m), confined to the eastern side of Linville Gorge. QUERCUS ALBA-QUERCUS RUBRA/OXYDENDRUM FOREST, found between 930 and 1,225 m, occurs on both sides of the valley. This type lacks the dense *Galax* groundcover and *Rhododendron catawbiense* shrub layer characteristic of the former type, probably reflecting the less organic, more fertile (higher pH, base saturation; Table 1) character of that type. There is a third *Q. alba*-dominated type present in the MONTANE OAK FORESTS; QUERCUS ALBA-ACER RUBRUM/THELYPTERIS-DENNSTAEDTIA FOREST inhabits more fertile, sheltered upper-slopes than the two THERMIC OAK-PINE FORESTS types, and also lacks the ericaceous shrub stratum prominent in the former types (Table 1, Appendices 2, 4). Differences in the underlying parent material of these three types

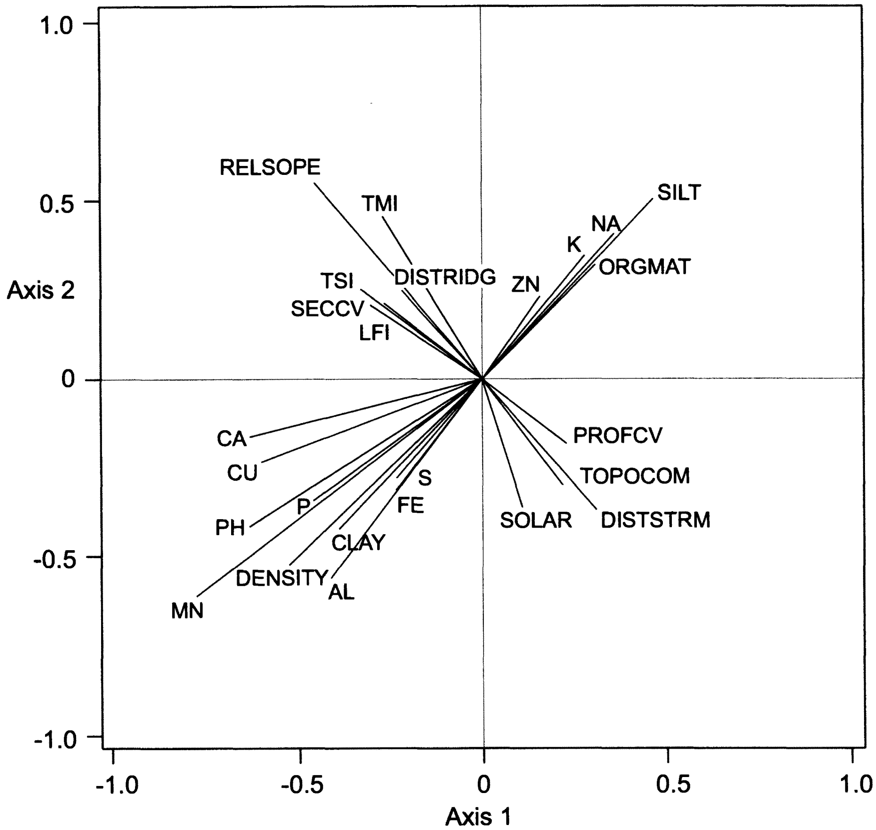

Figure 6. Vector diagram for NMDS ordination of THERMIC OAK-PINE FORESTS, ACIDIC COVE AND SLOPE FORESTS, MONTANE OAK FORESTS and RICH COVE AND SLOPE FORESTS vegetation classes showing association between species composition on the first two ordination axes and major environmental gradients (also see Figure 5). The direction of the vector indicates the direction of maximum correlation, and the length is the strength of the correlation. DISTRIDG indicates distance to nearest ridgeline, DISTSTRM indicates distance to nearest stream, RELSLOPE is a scale for upper-slopes (low) to lower-slopes (high), PROFCV indicates profile curvature, SECCV indicates section curvature, LFI values vary from unprotected upper-slopes (low) to sheltered lower-slopes and coves (high). Increasing TMI values have progressively higher site moisture potential. Increasing TOPOCOM values represent increasing topographic complexity. Low TSI values represent convex upper-slopes and high values represent concave lower-slopes.

may account for variation in soil nutrient status, with QUERCUS ALBA-ACER RUBRUM/THELYPTERIS-DENNSTAEDTIA FOREST associated with the more fertile Upper Quartzite and Wilson Creek Gneiss parent material.

THERMIC OAK-PINE FORESTS with pine dominance have historically experienced recurrent, stand renewing fire (Zobel 1969, Barden and Woods 1976, Barden 1977, Harmon 1982, Harrod et al. 1998), and charred stumps and stems were observed in more than 50% of the plots. Similarly, fire was important for the maintenance of oak dominance; charred wood and distinctive charcoal deposits occurred in the soil profile of more than 50% of plots in the *Quercus*-dominated types, but limited occurrence of charred stumps and stems points to a longer period of suppression. Stem data indicate that *Pinus pungens* and *P. rigida* are currently regenerating in only the two most exposed xeric *Pinus*-dominated types closely associated with the bluffs (Newell 1997). The present fire regime appears insufficient to maintain the dominance of xeric *Pinus* types in Linville Gorge. Similarly, the limited oak regeneration in all *Quercus*-dominated types in this class (Newell 1997) suggests that the current fire regime is

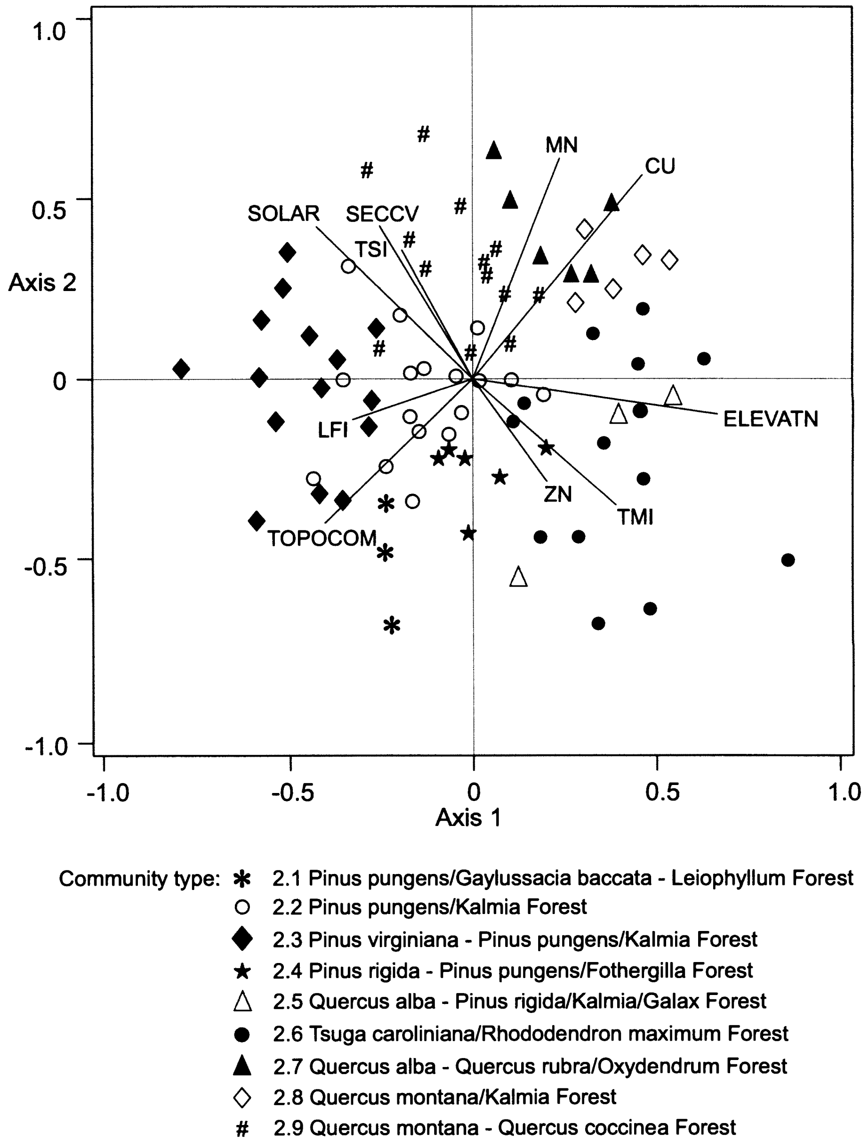

Figure 7. Two-dimensional NMDS ordination showing association between community types in the THERMIC OAK-PINE FORESTS and major environmental gradients. For explanations of environmental variables see Figure 6.

unlikely to sustain the dominance by *Quercus* in the landscape. In contrast, *Tsuga caroliniana,* which does not rely on fire for regeneration, appears relatively stable (Newell 1997). Humphrey (1989) suggests that the long life span and the ability of *T. caroliniana* to tolerate and reproduce in shady conditions enables it to maintain itself and eventually replace other species.

2.1 PINUS PUNGENS/GAYLUSSACIA BACCATA-LEIOPHYLLUM FOREST.—*Pinus pungens* and *P. rigida* dominate the stunted canopy (1.5 m to 9 m height range) (Appendices 2–3). *Gaylussacia baccata* and *Leiophyllum buxifolium* form a dense, low shrub mat, with scattered *Rhododendron minus, Kalmia,* and *Amelanchier laevis* clumps. Shrub stature decreases with increasing exposure and proximity to the bluff rim. *Xerophyllum asphodeloides, Galax urceolata,* and *Gaultheria procumbens* are abundant where shrubs are absent or sparse.

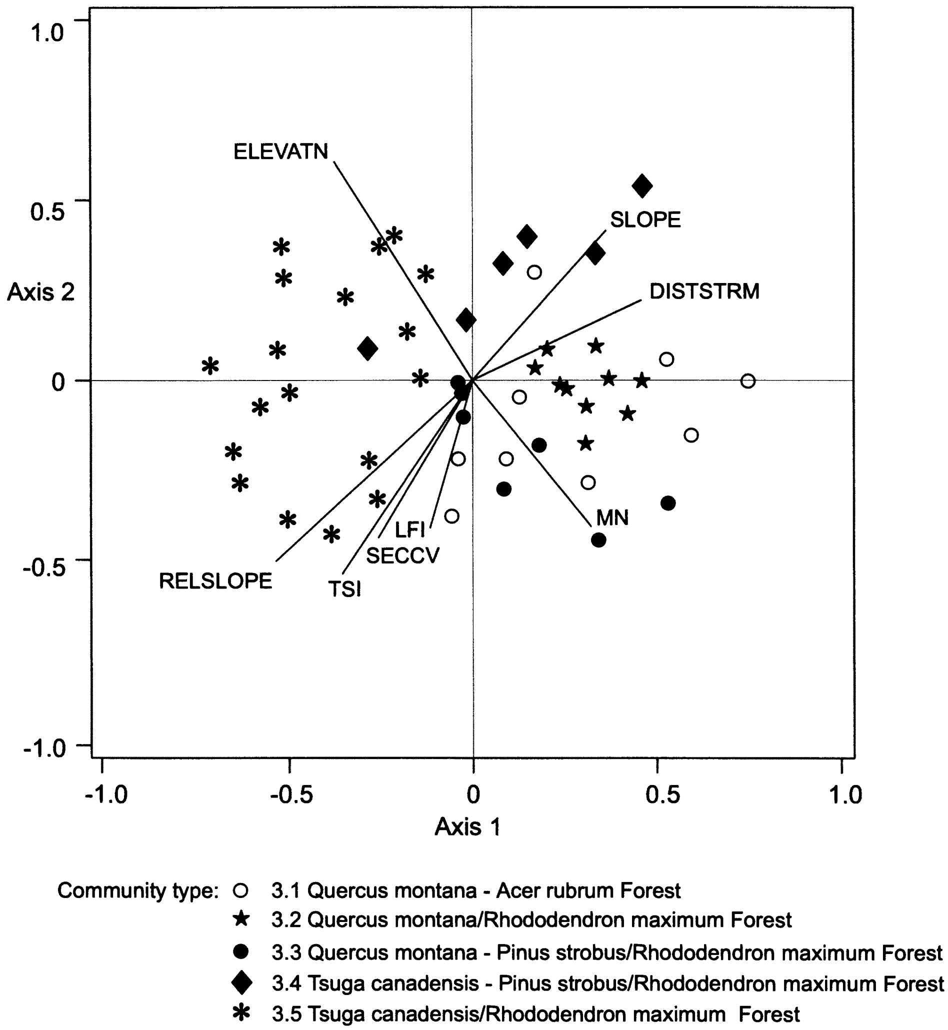

Figure 8. Two-dimensional NMDS ordination showing association between community types in the ACIDIC COVE AND SLOPE FORESTS and major environmental gradients. For explanations of environmental variables see Figure 6.

2.2 PINUS PUNGENS/KALMIA FOREST.—*Pinus pungens* dominates the canopy (ca. 20 m mean height), with *P. rigida, P. strobus, Quercus montana,* and *Q. coccinea* each co-dominating with *P. pungens* on certain sites (Appendices 2–3). *Nyssa sylvatica* and *Acer rubrum* typically dominate the understory. *Kalmia latifolia* dominates the shrub layer association with *Symplocos* and *Hamamelis*. *Galax urceolata* is common on the forest floor, but has greater dominance in sheltered stands. Species diversity is low at all spatial scales (Appendix 2). *Pinus pungens* and *Rhododendron minus* have greater dominance in exposed sites with thin soils. *Pinus strobus* and *Q. coccinea* are canopy codominants on more sheltered stands; *P. strobus* dominance often reflects past crown fires on sites with deeper soils.

2.3 PINUS VIRGINIANA-PINUS PUNGENS/KALMIA FOREST.—*Pinus pungens* and *P. virginiana* are the major canopy dominants, together with varying abundance of *P. rigida* and *Quercus montana* (Appendices 2–3). There is an understory of *Oxydendrum, Nyssa sylvatica,* and *Acer rubrum*. *Kalmia latifolia* is the major shrub species and *Rhododendron minus* has significant cover in the rockier sites. *Vaccinium pallidum* and *Gaylussacia baccata* generally dominate the lowest stratum.

2.4 PINUS RIGIDA-PINUS PUNGENS/FOTHERGILLA FOREST.—*Pinus rigida* and *P. pungens* are the major canopy species in this type, together with *Quercus montana* and less abundant *P. strobus* (Appendices 2–3). *Nyssa sylvatica* forms a distinctive subcanopy stratum. The dense shrub stratum is codominated by *Kalmia latifolia, Fothergilla major,* and *Rhododendron catawbiense* and with less abundant *Symplocos tinctoria.* There is a distinctive low-shrub layer of *Leucothoe recurva* with limited *Gaylussacia baccata. Galax urceolata* is prominent on the forest floor. The uncommon, although locally abundant, *Fothergilla major* is an important shrub component and reaches its highest Linville Gorge abundance in this type (Appendix 2).

2.5 QUERCUS ALBA-PINUS RIGIDA/KALMIA/GALAX FOREST.—*Quercus alba* typically dominates the canopy, in association with *Pinus rigida* (Appendices 2–3). *Acer rubrum* is a major component throughout the canopy and subcanopy and is found in association with *Nyssa* in the latter stratum. *Kalmia latifolia* forms a dense shrub stratum in all stands, whereas *Rhododendron catawbiense* and *Hamamelis virginiana* are present on the highest elevation ridge sites at the northern-end of Linville on Gingercake Mountain (see Figure 1). The forest floor is typically a dense carpet of *Galax urceolata,* often intermixed with *Gaultheria procumbens.*

2.6 TSUGA CAROLINIANA/RHODODENDRON MAXIMUM FOREST.—Although pine and oak are relatively unimportant in this type, it is included in the Thermic Oak-Pine Forests class owing to strong floristic similarities. Canopy height varies considerably (2 to 26 m), influenced by soil depth, site slope and exposure. Large-diameter *T. caroliniana* (mostly 40 to 55 cm) are found in the canopy of tall forest sites in association with emergent *Pinus strobus* and consistent, but smaller, *Nyssa sylvatica* (Appendices 2–3). Stunted *Tsuga caroliniana* and low ericaceous shrub species co-dominate especially exposed sites. *Kalmia latifolia, Rhododendron maximum,* and *R. minus* form a particularly dense shrub stratum in association with *Leucothoe recurva* and *Smilax rotundifolia.* Low fertility coupled with high *Galax* and evergreen shrub density, probably account for the low species richness levels in this type (Appendix 2).

TSUGA CAROLINIANA/RHODODENDRON MAXIMUM FOREST is the only type sampled in Linville Gorge where *Tsuga caroliniana* is the major canopy component. This species is also dominant in a stunted, unsampled Rock Outcrops community type present on the main escarpment faces.

2.7 QUERCUS ALBA-QUERCUS RUBRA/OXYDENDRUM FOREST.—*Quercus alba* and *Q. rubra* dominate the canopy with scattered *Pinus strobus* (Appendices 2–3). *Oxydendrum arboreum* and *Acer rubrum* form a distinctive subcanopy. There is a shrub stratum of *Kalmia latifolia* with *Galax* scattered on the forest floor.

2.8 QUERCUS MONTANA/GALAX FOREST.—Large-diameter *Quercus montana* (43 to 65 [80] cm) dominate the canopy (Appendices 2–3) above a subcanopy of *Acer rubrum* and *Oxydendrum.* The shrub stratum is dominated by *Kalmia latifolia* and *Rhododendron maximum* with less abundant *Tsuga caroliniana. Galax urceolata* provides patchy ground cover.

2.9 QUERCUS MONTANA-QUERCUS COCCINEA/KALMIA FOREST.—*Quercus montana* and *Q. coccinea* dominate the canopy in association with *Acer rubrum* (Appendices 2–3). There is a distinctive *Oxydendrum arboreum* and *Nyssa sylvatica* subcanopy with *Kalmia* the dominant shrub species. Two variants are separated by elevation and slope position. *Quercus alba* is a minor canopy component in the mid-slope variant, *Kalmia* shrub cover is reduced, and there is limited ground vascular cover. The upper-slope variant has a denser *Kalmia* shrub layer with *Leucothoe recurva* and *Sassafras* also present throughout this stratum. *Galax* is prominent in the ground-layer.

ACIDIC COVE AND SLOPE FORESTS

ACIDIC COVE AND SLOPE FORESTS, widespread throughout the southern Appalachians, typically occur on cool, sheltered, infertile sites. A similar distribution is found in Linville Gorge (Figures 4–6), where, owing to the infertility of soils derived from the widespread quartzite, meta-arkose and gneiss, it is one of the two most widespread vegetation classes (Figure 4). Stands are typically low in species diversity and include a dense evergreen shrub layer, either dominated or codominated by *Rhododendron maximum.*

Community types within this class sort reasonably well with respect to gradients of topographic position and soil fertility (Figure 8). In contrast to other ACIDIC COVE AND SLOPE FORESTS types, QUERCUS MONTANA-ACER RUBRUM FOREST dominates dry, moderately steep southeast- to westerly-facing, mid-elevation (460–940 m) sideslopes, although they are on infertile soils (Figure 4). These sites are similar to, but less fertile than those inhabited by QUERCUS MONTANA-LIRIODENDRON/CORNUS FLORIDA FOREST and QUERCUS MONTANA/CORNUS FLORIDA FOREST in the MONTANE OAK FORESTS. TSUGA CANADENSIS/RHODODENDRON MAXIMUM FOREST is the most widespread of the ACIDIC COVE AND SLOPE FORESTS types, dominating a broad range of elevations (540 to 1,085 m) and slope positions on sheltered, moderately steep slopes with infertile soils derived from quartzite. This type dominates slopes in the narrow, northern gorge-portion, lower-slopes of the main valley and adjacent side branches, and small, rocky gullies leading downslope from the bluffs. QUERCUS MONTANA/RHODODENDRON MAXIMUM FOREST is also underlain by quartzite and occurs on moderately steep, mid- to high-elevation (700–1,145 m) mid-slopes, mostly above the bluffs. TSUGA CANADENSIS-PINUS STROBUS/RHODODENDRON MAXIMUM FOREST also inhabits moderately steep sideslopes, but inhabits a broader elevational range (460 to 1,060 m) and is mostly found on sites below the bluffs that are underlain by gneiss. QUERCUS MONTANA-PINUS STROBUS/RHODODENDRON MAXIMUM FOREST inhabits low- to mid-elevation (560 to 990 m), broad ridgelines and off-ridge slopes below the bluffs, mostly on the east side of the valley.

3.1 QUERCUS MONTANA-ACER RUBRUM FOREST.—Large-diameter *Quercus montana* (40 to 91 cm) dominate the canopy, together with *Liriodendron* and *Acer rubrum* (Appendices 4–5). The subcanopy of *Acer rubrum* and *Oxydendrum arboreum,* plus the *Tsuga canadensis* understory, suggests long-term compositional instability. Shrub density and composition vary; *Rhododendron maximum* forms an irregular shrub layer on lower-slope sites, whereas *Kalmia latifolia* has patchy distribution on dry, mid-to-upper-slope sites, and shrubs are virtually absent on the driest upper-slopes. The forest floor contains little more than sparsely scattered *Viola hastata.*

3.2 QUERCUS MONTANA/RHODODENDRON MAXIMUM FOREST.—Large-diameter (40 to 70 cm) *Quercus montana* and *Acer rubrum* dominate the canopy, with less abundant *Betula lenta* and *Magnolia fraseri* (Appendices 4–5). There is a subcanopy of *Oxydendrum* and *Nyssa. Rhododendron maximum* forms a dense shrub layer in association with less abundant *Hamamelis virginiana* and *Kalmia.* The forest floor consists of a thick litter layer, again with few herbs.

3.3 QUERCUS MONTANA-PINUS STROBUS/RHODODENDRON MAXIMUM FOREST.—Large-diameter *Quercus montana* (40–80 cm) and *Pinus strobus* (40–55 cm) codominate the canopy, in conjunction with smaller-diameter *Acer rubrum* (Appendices 4–5). There is a subcanopy of *Oxydendrum* and *Nyssa* and a variably dense *Rhododendron maximum* and *Kalmia latifolia* shrub layer. The forest floor is typically dry with a thick layer of litter and sparse *Galax.*

3.4 TSUGA CANADENSIS-PINUS STROBUS/RHODODENDRON MAXIMUM FOREST.—The canopy consists of *Pinus strobus* and smaller-diameter *Tsuga canadensis* (Appendices 4–5). *Oxydendrum* and *Nyssa* are the major subcanopy species, and *Rhododendron maximum* and *Kalmia latifolia* form a moderately-closed shrub layer. The forest floor is typically a thick litter layer with few herbs.

3.5 TSUGA CANADENSIS/RHODODENDRON MAXIMUM FOREST.—The floristic and structural simplicity of this type is apparent in the low species richness (Appendix 4). Large-diameter (40 to 75 [up to 134] cm) *Tsuga canadensis* form a dense, tall canopy (basal area 66 m^2/ha; mean height 30 m) with scattered *Acer rubrum, Betula lenta, Magnolia fraseri,* and *Nyssa sylvatica* (Appendices 4–5). There is a particularly dense *Rhododendron maximum* layer. The forest floor consists of thick litter and is largely devoid of vascular cover. Subdominant species sort by topographic position: *Acer rubrum, Betula lenta, Nyssa,* and *Oxydendrum* have greater cover in the sideslope variant, whereas *Liriodendron tulipifera* and *Magnolia fraseri* are more prevalent in the cove/stream variant. Low-elevation streamside sites (generally adjacent to the Linville River) have dense tangles of *Leucothoe fontansiana* covering the ground.

Montane Oak Forests

Although Montane Oak Forests are widespread in the southern Appalachian Mountains (Schafale and Weakley 1990) on moderately fertile soils, this class represents only a small portion of the Linville landscape (8% of vegetation mapped; Figure 4) where it is predominantly associated with gneiss parent material. It occupies a broad range of topographic positions on sites with higher nutrient status than Thermic Oak-Pine Forests and Acidic Cove and Slope Forests (Figures 5–6). The change from these latter two classes to Montane Oak Forests with change in substrate is conspicuous in winter aerial photography owing to the absence of an evergreen shrub layer.

Pre-settlement *Quercus*-dominated forests in the eastern United States were largely maintained by infrequent, low-intensity fire (Lorimer 1989, Abrams 1992). Low levels of *Quercus* regeneration (Newell 1997) suggest that the *Quercus* dominance of these types will not be maintained under present conditions of fire suppression.

At Linville Gorge the types within the Montane Oak Forests class separate primarily along axes of topographic-moisture and elevation. Quercus montana-Liriodendron/Cornus florida Forest occurs on dry, south-facing, low-elevation (600–870 m), comparatively undissected mid-slopes in the southern third of the gorge. Quercus montana/Cornus florida Forest has a more restricted elevational range (775–855 m) and inhabits similar, but steeper and more fertile, slopes farther north in the study area (Figure 9). High-elevation (930 to 1,180 m) ridge sites and associated upper-slopes on the western border of Linville Gorge are inhabited by Quercus alba-Acer rubrum/Thelypteris-Dennstaedtia Forest. Small, steep (30 to 44°), high-elevation (900–1,175 m), fertile rocky gullies and seepage slopes, and sites at the base of upper-slope bluffs, are inhabited by Quercus montana-Tilia/Acer pensylvanicum-Hamamelis Forest. The presence of *Tilia* and *Acer pensylvanicum* sets this type apart from other community types, with *Tilia* reflecting the underlying fertile conditions and *Acer* reflecting the cool, moist conditions of these sites.

4.1 Quercus montana-Liriodendron/Cornus florida Forest.—Large-diameter *Quercus montana* (40 to 73 cm) dominate the canopy (mean height 29 m) in conjunction with less abundant *Quercus rubra* (41 to 59 cm) and *Liriodendron tulipifera* (40 to 83 cm) (Appendices 6–7). *Oxydendrum arboreum* and *Acer rubrum* are the major subcanopy species. There is a distinctive, open *Cornus florida* shrub stratum with scattered *Kalmia latifolia*. The dry forest floor is sparsely covered by a variable assemblage of species with limited cover. This type superficially resembles 4.2, but has lower species richness and is inhabited by species associated with drier, less fertile conditions, such as *Oxydendrum arboreum* and *Kalmia latifolia* (Appendix 6).

4.2 Quercus montana/Cornus florida Forest.—Large-diameter *Quercus montana* (40 to 79 cm) dominate the canopy (mean height 26 m) with scattered smaller-diameter *Q. rubra* (Appendices 6–7). *Cornus florida* forms a distinctive shrub stratum with less abundant *Hamamelis virginiana*. The rocky surface (40% rock cover) is inhabited by a high diversity of sparsely distributed species. All herbaceous species have low cover with the exception of *Carex pensylvanica*, which has high cover in two of the three sites.

4.3 Quercus montana-Tilia/Acer pensylvanicum-Hamamelis Forest.—*Quercus montana* is the most consistent canopy dominant (18 m mean height) with variable abundance of *Betula lenta* and *Tilia americana* var. *heterophylla*. *Acer rubrum* is the predominant subcanopy species (Appendices 6–7). Shrub dominance varies; *Rhododendron minus* is more abundant on rocky or shallow soils, *R. maximum* dominates deeper soils and *Hamamelis virginiana* and *A. pensylvanicum* are subdominant throughout. Moss-covered rocks (18%, 39% respectively) are conspicuous on the forest floor. The patchy vascular cover is dominated by *Iris cristata* and *Aster macrophyllus*.

4.4 Quercus alba-Acer rubrum/Thelypteris-Dennstaedtia Forest—*Quercus alba* dominates the canopy (mean height 25 m) of most sites, but with variable amounts of *Betula lenta, Carya glabra,* and *Q. montana* cover (Appendices 6–7). *Acer rubrum* and *Oxydendrum arboreum* are consistent subdominant canopy species, with the latter dominant in the subcanopy. *Hamamelis virginiana* forms an open shrub stratum. Two fern species, *Thelypteris nove-*

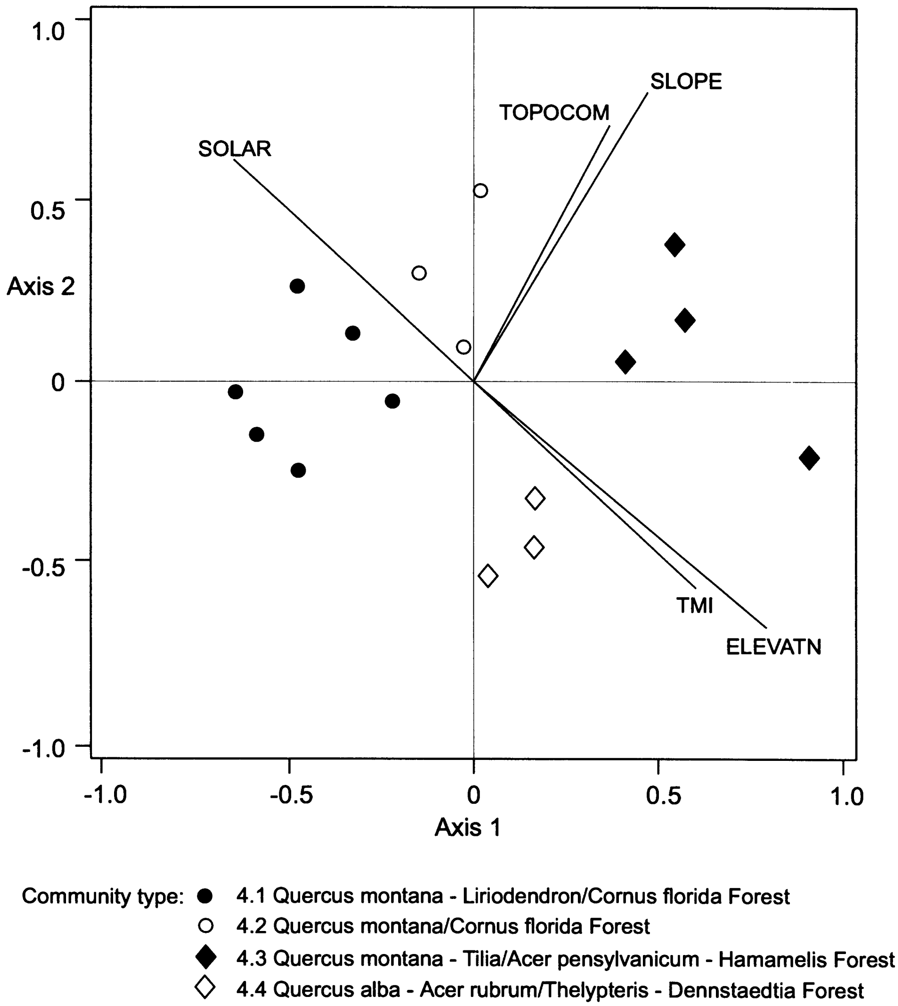

Figure 9. Two-dimensional NMDS ordination showing association between community types in the MONTANE OAK FORESTS and major environmental gradients. For explanations of environmental variables see Figure 6.

boracensis and *Dennstaedtia punctilobula,* carpet the ground, together with a diverse group of low-abundance herbaceous species.

RICH COVE AND SLOPE FORESTS

RICH COVE AND SLOPE FORESTS of the southern Appalachian Mountains are well known for their diverse tree and herb flora (Schafale and Weakley 1990). Similarly, this class contains some of the most species-rich vegetation in Linville Gorge. Although widespread throughout the southern Appalachian Mountains (Schafale and Weakley 1990), in Linville Gorge, where nutrient-rich soils are uncommon, this class occupies a small, but heterogeneous set of nutrient-rich toeslopes and high-elevation ridgelines underlain by atypically nutrient-rich rock (Figures 4–6). Higher fertility is evidenced in the high levels of soil calcium and manganese, both of which tend to be strongly correlated with species diversity in Appalachian forests (Newell and Peet 1996).

The composition of RICH COVE AND SLOPE FORESTS in Linville has only loose resemblance to typical southern Appalachian examples of this class (e.g., Whittaker 1956, Schafale and Weakley 1990, Newell 1997, McLeod 1988). However, [LIRIODENDRON-CARYA GLABRA FOREST] and TSUGA CANADENSIS-FAGUS/ILEX OPACA FOREST have strong similarities with types in the southern escarpment region (Patterson 1994, Wentworth 1980).

In Linville Gorge RICH COVE AND SLOPE FORESTS differ with elevation, slope position and parent material. [LIRIODENDRON-CARYA GLABRA FOREST] occupies shallow, low-elevation (600–745 m) toeslopes on the western side of the valley. The TSUGA CANADENSIS-FAGUS/ILEX OPACA FOREST is confined to somewhat less fertile, upper alluvial terraces and adjacent toeslopes along the bottom of the lower third of Linville Gorge (Figures 1, 4). The unusual high-elevation (1,070–1,190 m), upper-slope position of CARYA GLABRA/AGERATINA FOREST is closely associated with bands of nutrient-rich parent material; one variant is associated with meta-arkose occurring on the east side of Linville Gorge, extending from Gingercake Mountain south to the knob north of Hawksbill, and the second follows a narrow (10–30 m wide) band of phyllite that outcrops along the crest of the western ridgeline (Figures 1, 4).

5.1 CARYA GLABRA/AGERATINA FOREST.—*Carya glabra* dominates the canopy (27 m tall) in conjunction with *Quercus rubra* (Appendices 6–7). Beneath the open mid-stratum is a tall, dense herbaceous stratum dominated by *Ageratina altissima* var. *altissima*, with *Amphicarpaea bracteata, Dennstaedtia punctilobula, Solidago curtisii,* and a diverse assemblage of other herbaceous species.

5.2 [LIRIODENDRON-CARYA GLABRA FOREST].—A tall (38 m mean height), dense canopy of large-diameter *Liriodendron tulipifera* (90 to 148 cm) and *Carya glabra* (41–50 cm) (basal area 61.5 m^2/ha) overtop the open *Tsuga canadensis* subcanopy and *Halesia tetraptera* shrub stratum (Appendices 6–7). The floor is rocky (19% rock), with dense patches of vegetation dominated by *Thelypteris noveboracensis* and *Laportea canadensis.*

5.3 TSUGA CANADENSIS-FAGUS/ILEX OPACA FOREST.—*Tsuga canadensis* dominates the tall (34 m mean height), dense canopy, in association with large-diameter *Fagus grandifolia* (55–79 cm) and scattered *Pinus strobus* (47–62 cm) (Appendices 6–7). Small-diameter *Tsuga* and *Ilex opaca* are predominant in the understory. *Cornus florida* forms an open shrub stratum together with *Asimina triloba* in some sites. A range of sparsely distributed herbaceous species inhabits the forest floor.

ALLUVIAL WETLANDS

ALLUVIAL WETLANDS are distributed along stream and river floodplains throughout the southern Appalachian Mountains (Schafale and Weakley 1990). In Linville Gorge this vegetation class dominates fertile alluvial flats and broad stream margin areas present in the lower third of the valley where the descent of the Linville River flattens and has enabled permanent alluvial surfaces to develop. These areas are subject to recurrent flooding and scour, but also receive frequent nutrient and sediment replenishment.

Flooding frequency and depth varies with elevation and proximity to the Linville River and strongly influence vegetation composition. The [LIQUIDAMBAR ROCKY STREAMBED FOREST] inhabits frequently flooded margins of the Linville River (440 m). The absence of a permanent herbaceous vegetation in this type (Appendix 8) is an indication of the degree of flooding. In contrast, the [PLATANUS/ASIMINA/MICROSTEGIUM ALLUVIAL FOREST] dominates a large, high alluvial flat on the western side of the Linville River (410 m elevation; Figure 4) and is subject to less frequent flooding than the [LIQUIDAMBAR ROCKY STREAMBED FOREST].

6.1 [LIQUIDAMBAR ROCKY STREAMBED FOREST].—*Liquidambar styraciflua* dominates the canopy, together with *Platanus occidentalis* and *Betula lenta* (mean height 12 m) (Appendices 8–9). *Toxicodendron radicans* densely cloaks many tree trunks (all <40 cm in diameter). The ground consists of a bouldery (60% rock) matrix of 10 to 30 cm diameter boulders intermixed with sand and gravel. Vegetation is very sparse and largely restricted to sandy crevices.

6.2 [PLATANUS/ASIMINA/MICROSTEGIUM ALLUVIAL FOREST].—*Liquidambar styraciflua* dominates the tall canopy (39 m height), together with *Liriodendron tulipifera* (40 to 70 cm diameter) and *Platanus occidentalis* (45 to 60 cm). *Asimina triloba* forms a patchy shrub stratum (Appendices 8–9). The ground stratum remains diverse (Appendix 8), although the invasive

Microstegium vimineum densely covers this stratum, and *Ageratina altissima* var. *altissima* is also abundant.

ROCKY STREAMSIDE SHRUBLANDS

ROCKY STREAMSIDE SHRUBLANDS are restricted throughout the southern Appalachian Mountains to open areas adjacent to and often scoured by streams or rivers (Schafale and Weakley 1990). In Linville Gorge this class is patchily distributed on the narrow, open banks along the full length of the Linville River where it is subject to frequent, fast-flowing flood waters.

7.1 [ALNUS/XANTHORHIZA ROCKY STREAMSIDE SHRUBLAND].—Vegetation is patchy, with clumps between large, exposed rock slabs where soil can accumulate, and open sandy areas (Appendices 8–9). *Xanthorhiza simplicissima* is often the dominant species (0.3 m mean height), with *Aster prenanthoides* and *Carex torta* also abundant. Scattered *Alnus serrulata* dominate the shrub cover.

NON-ALLUVIAL WETLANDS

NON-ALLUVIAL WETLANDS are extremely uncommon in the southern Appalachians (Schafale and Weakley 1990) and are represented within Linville Gorge by two small, temporary ponds.

8.1 [SCIRPUS CYPERINUS-DULICHIUM TEMPORARY POND].—The sampled pond (15 × 20 m in size), situated on the shallow upper-slopes on the west side of the valley (995 m) near Conley Cove Trail, is dominated by emergent, monospecific clumps of *Scirpus cyperinus, Dulichium arundinaceum,* and *Osmunda regalis* var. *spectabilis. Juncus effusus, Bartonia virginica,* and *Liquidambar styraciflua* are sparsely distributed around the pond margin (Appendix 8). *Sphagnum* is abundant on the hard pond base. Five of the six vascular species present are restricted to this type in Linville Gorge. The second pond, located on the summit of Shortoff Mountain, was not sampled. Two *Scirpus* spp. and *Isoetes englemanii* dominate the Shortoff pond, with mats of the rare *Sphagnum pylaesii* present around the pond margin. This pond generally contains water between November and June and is dry for the remainder of the year (C. Frost, pers. comm., Weakley 1992).

DISCUSSION

Vegetation-environment relationships

The strong correlations between vegetation and soil nutrients, soil texture and topographic-moisture documented in this study contrast with vegetation-environment patterns described from other southern Appalachian landscapes. Most studies have identified elevation as the key important environmental gradient for interpreting vegetation patterns (e.g., Whittaker 1956, Golden 1981, Callaway et al. 1987, McLeod 1988, Busing et al. 1993, Newell 1997) with topographic moisture and soil characteristics identified as the second and third critical environmental gradients. At Linville Gorge, elevation has only weak associations with vegetation across the full landscape, and is only strongly correlated with vegetation within subsets of compositionally similar stands where differences in soil and topographic characteristics are subtle (Figures 6–9). The strong association of vegetation with soil nutrients and topographic moisture has been documented in other mid- and low-elevation southern Appalachian areas (Wentworth 1980, Patterson 1994, Newell 1997).

Strong correlations between vegetation and soil nutrients have been inferred in past southern Appalachian studies and documented in a few studies (e.g., DeLapp 1978, McLeod 1988, Patterson 1994, Wiser et al. 1996, Newell 1997). The close association between pH and Ca and their representation as predictors of soil fertility follows well-accepted patterns (e.g., Brady 1974). However, the basis for extractable Mn providing consistently the strongest indicator of soil fertility is unclear. High correlations between Mn and vegetation composition have also been documented in other southern Appalachian studies (e.g., Wentworth 1980, Graves and Monk 1985, McLeod 1988, Patterson 1994, Newell and Peet 1996, Newell 1997, Newell et al. in press) and forests elsewhere (e.g., Palmer 1990; R.P. Duncan and R.K. Peet, unpubl.

data). Mn has been shown to be highly positively correlated with pH and soil moisture status in southern Appalachian studies (McLeod 1988, Patterson 1994, Newell and Peet 1996, Newell 1997), although Mn is generally thought to be negatively correlated with pH (see Brady 1974). Further research is needed to determine the specific links between soil fertility, available Mn and vegetation composition.

Topographic moisture index (TMI), relative slope position and solar radiation consistently were strongly associated with vegetation composition. These results contrast with those from less dissected southern Appalachian landscapes, where stands within individual vegetation classes had weak correlations with topography and were consistently strongly correlated with soil fertility (Newell 1997). The consistent association between vegetation and topographic characteristics across the full compositional breadth of vegetation within Linville Gorge and within individual vegetation classes where compositional differences are comparatively subtle highlights the overriding impact of the rugged topography of Linville Gorge on the distribution of vegetation in this landscape.

The strong association between vegetation composition and soil texture observed in this study has been documented previously in only a few southern Appalachian studies (see Mowbray and Oosting 1968, Golden 1981), probably because few studies have quantitatively examined soil texture (but see Newell 1997). In Linville Gorge, textural variation corresponds closely with differences in soil fertility and surficial geology. Soils underlain by Lower Quartzite tend to be less fertile and more silty in comparison to the nutrient-rich soils of gneiss, meta-arkose, phyllite and Upper Quartzite (Table 2). A multiple analysis of variance indicated statistically significant differents in soil chemistry and soil texture among the six surficial geology types (Newell 1997).

Few southern Appalachian studies have examined compositional variation in relation to geologic substrate. This most likely results from the limited availability of detailed geologic information. Strong correlations among compositional variation, soil chemistry and rock type were documented by Wiser et al. (1996) in their study of southern Appalachian Mountain high-elevation Rock Outcrop communities and by Rohrer (1983) in a forest community study in the Hanging Rock area (Stokes County, North Carolina). However, there was little association between geologic type and vegetation composition in either Shining Rock Wilderness or Joyce Kilmer-Slickrock Wilderness (Newell 1997), probably because the degree of textural and nutrient differences between underlying geologic types was limited.

Detailed soil analysis and quantitative topographic characterization are needed to fully understand the vegetation patterns in the southern Appalachian Mountains. However, even where such data are available, the complexity of vegetation patterns limits extrapolation from one landscape to another.

Dynamics and disturbance

In Linville Gorge where vegetation patterns have not been altered by logging, the composition and distribution of community types nonetheless reflect historical natural disturbance events, such as fire. Species that typically require fire for regeneration (e.g., *Pinus pungens, P. rigida, Quercus montana, Q. coccinea*; Barden and Woods 1976, Abrams 1992, Harrod et al. 1998) dominate much of Linville Gorge, illustrating the long history of reoccurring fires and the impact of this disturbance in shaping community type distribution. However, the present lack of regeneration by these species (see Newell 1997), resulting from more than 60 years of fire suppression in Linville Gorge, points to future decline of types dominated by these species. Similar trends have been noted in other areas of the southern Appalachians and across the eastern United States (Abrams 1992, Newell 1997, Harrod et al. 1998). Dramatic future changes can be expected in the distribution and composition of the vegetation of in this landscape, with increasing dominance expected for fire-intolerant, shade-tolerant species such as *Acer rubrum* (see Waterman et al. 1995).

The death of chestnut, *Castanea dentata,* had a conspicuous impact on forests throughout most of the southern Appalachians (Keever 1953, Woods and Shanks 1959, Arends 1981). Many forests dominated by *Quercus montana* historically were codominated by chestnut (Braun 1950, Whittaker 1956, Woods and Shanks 1959). However, low chestnut sprout and log abundance, coupled with the preponderance of old (>200 years), large-diameter *Q. montana* in most *Quercus montana*-dominated types, suggests that chestnut was probably only a minor canopy component in Linville Gorge and forests here were not greatly altered by chestnut death. Chestnut forests were documented as dominant on the slopes of Grandfather Mountain, approximately 15 kilometers north of Linville Gorge (Reed 1905), but this area contains significant areas of more base-rich rock than is generally present in Linville Gorge. Much more substantive changes are expected to accompany the arrival of the hemlock adelgid and gypsy moth.

Rare species and community types

The unusual combination of environmental conditions at Linville Gorge enable several regionally rare community types to have widespread distribution. A preponderance of cool, low-elevation ravine sites accounts for the abundance of the TSUGA CAROLINIANA/RHODODENDRON MAXIMUM FOREST. This type has limited distribution throughout the southern Appalachians and occurs almost exclusively in sites similar to those described for it at Linville Gorge (see McLeod 1988, Humphrey 1989, Schafale and Weakley 1990). Similarly, the abundance of well-developed escarpment faces at Linville Gorge accounts for widespread ROCK OUTCROPS distribution.

Factors associated with the presence of QUERCUS MONTANA-PINUS STROBUS/RHODODENDRON MAXIMUM FOREST (documented as White Pine Forest by Schafale and Weakley 1990) are less obvious. In most landscapes *Pinus strobus* is a successional species, often present as the result of clearing or logging (see DeYoung 1979, Wentworth 1980, Patterson 1994). However, fire is the only known disturbance in the comparatively undisturbed old-growth Linville Gorge type.

The majority of nationally and regionally rare species present in Linville Gorge are associated with the ROCK OUTCROPS. These are mostly associated with high-light conditions and are thought to be relicts of Pleistocene tundra (Wiser 1994). Linville Gorge is one of a few landscapes that has a comparative abundance of suitable habitat for these relicts. ROCK OUTCROPS in this landscape have some resemblance to types in the southern escarpment region present on dry habitats on granite domes and outcrops (DuMond 1970, Racine and Hardin 1975, Larson and Batson 1978, Wiser et al. 1996). However, with its low annual rainfall, Linville Gorge lacks the types associated with moist habitats that are a distinctive feature of the southern escarpment region and are habitat to rare and relict vascular and bryophytic species (Billings and Anderson 1966, Anderson and Zander 1973, Farrar and Mickel 1991, Zartman and Pittillo 1998).

Geographic comparisons of vegetation

Complex topography and widespread distribution of thin, infertile soils at Linville Gorge set this landscape apart from the southern Appalachian Mountains in general, and produce unusual patterns of vegetation. THERMIC OAK-PINE FORESTS and ACIDIC COVE AND SLOPE FORESTS dominate the Linville landscape (Figure 4), which is in marked contrast to most southern Appalachian landscapes where MONTANE OAK FORESTS and, to a lesser extent, RICH COVE AND SLOPE FORESTS are typically the most widespread vegetation classes (e.g., Whittaker 1956, Golden 1981, Callaway et al. 1987, McLeod 1988, Newell 1997).

The widespread dominance of THERMIC OAK-PINE FORESTS observed at Linville Gorge has also been documented in the southern escarpment landscapes, the western Great Smoky Mountains and slopes of the escarpment north of Linville Gorge (e.g., Whittaker 1956, Cooper and Hardin 1970, Golden 1974, Wentworth 1980, Callaway et al. 1987, Patterson 1994). Similar vegetation also dominates the monadnocks on the western Piedmont of North Carolina (Williams and Oosting 1944, Taggart 1973, McCurdy 1975). However, the specific THERMIC OAK-PINE FORESTS types occurring in those landscapes differ markedly from those in Linville Gorge (also see Newell 1997).

Community types dominated by *Pinus pungens* and *P. rigida* are widespread across Linville Gorge (Figure 4). These are a distinctive, but less widespread feature on ridges in low-elevation areas in the western Great Smoky Mountains and throughout mid- and low-elevation areas of the southern Appalachians (Whittaker 1956; Golden 1974; McLeod 1988; Peet, unpubl. data) with the exception of the southern escarpment where *P. pungens* and *P. rigida* tend at most to be community type codominants (Wentworth 1980, Patterson 1994; but see Racine 1966). Rugged topography and the widespread distribution of thin, infertile soils probably explains the broader distribution and more widespread abundance of *Pinus* at Linville Gorge in comparison to other southern Appalachian areas of similar elevation (see Losche et al. 1970). Contrasting natural fire regime frequency may also contribute, with the high-rainfall, southern escarpment landscapes probably having had much less frequent fires (>12 year frequency; Frost 1995) than the low-rainfall Linville Gorge (7- to 12-year frequency; Frost 1995) and mid-rainfall areas such as the western Great Smoky Mountains (10-year frequency; Harmon 1982).

The overriding dominance of *Quercus montana* across Linville Gorge sets this area apart from most southern Appalachian landscapes. *Quercus montana* predominates across a broader range of site conditions than the warm south- and southwest-facing slopes and narrow ridges typically associated with this species (e.g., Whittaker 1956, Golden 1974, McLeod 1988). Widespread *Q. montana* canopy dominance may partly reflect an absence of canopy disturbance by logging and chestnut death. Canopies opened by these disturbance types are likely to include fast-growing, shade-tolerant species such as *Betula lenta* and *Acer rubrum*.

The overwhelming dominance of community types with an evergreen shrub layer is another conspicuous feature of Linville Gorge (Figure 4, Appendices 1–9). All community types in the two major vegetation classes have a distinctive shrub stratum dominated by *Kalmia latifolia* and *Rhododendron maximum* or *R. minus*. Evergreen species dominance has been linked to nutrient-poor sites in many ecosystems (e.g., Monk 1966, Small 1972, Goldberg 1982, Monk et al. 1985). The dominance of evergreen species at Linville Gorge illustrates the widespread infertility of soils in this landscape. Winter-flown aerial photographs reveal sharp transitions between evergreen- and deciduous-shrub dominated communities that closely follow soil fertility shifts associated with changes in geologic type.

The combination of rugged topography, low rainfall, predominance of infertile soils and the lack of anthropogenic disturbance in Linville Gorge Wilderness have provided an unusual aggregation of vegetation communities. Vegetation has closest affinities with low-elevation landscapes in the southern Blue Ridge escarpment area near Highlands, the western Great Smoky Mountains, and the monadnocks on the western Piedmont of North Carolina. The overall dominance of *Quercus montana* and vegetation associated with warm or acidic conditions, and the limited distribution of typically widespread vegetation classes such as the RICH COVE AND SLOPE FORESTS, set the Linville Gorge apart as a distinctive landscape in relation to the rest of the southern Appalachian Mountains. Factors controlling the distribution of vegetation in Linville Gorge also differ from the southern Appalachian region in general in that Linville Gorge vegetation is controlled primarily by soil nutrients and topography, rather than elevation, which is the primary environmental gradient in most other landscapes in this region. Moreover, the fact that this Wilderness is one of only three remaining large, intact areas of old-growth forests in North Carolina amplifies the significance of this landscape and the importance of understanding its plant communities and ecological processes.

Appendix 1. Average cover and constancy for species in the ROCK OUTCROPS vegetation class. Values are given for each community type. Each type is represented by its abbreviation code. See Figure 2 for full names. Average cover class is followed by constancy. Only species that are prevalent (see text) in at least one group are shown. + = present in the community, but not prevalent, [a] = prevalence not calculated. * = a regionally or nationally listed species. All listed species are shown. Parent material units represented are Lower Quartzite (LQ), Wilson Creek Gneiss (G) and Grandfather Mountain Meta-arkose (M)

Groups:	1.1		1.2[a]		1.3	
Number of plots:	11		1		3	
Mean elevation (m):	1,043		689		748	
Mean slope (°):	32		80		32	
Dominant aspect (°):	SW		S		SE–S	
Dominant parent material:	LQ, G, M		LQ		LQ	
Homoteneity (see text):	0.54		—		0.65	
Mean species richness/1,000 m^2:	—		—		—	
100 m^2:	18.5		15.7		21.0	
1 m^2:	3.4		1.5			
Species:						
Acer rubrum var. *rubrum*	4	+			1	33
Agrostis perennans			2	100		
Amelanchier laevis	2	36				
Aronia arbutifolia	2	36				
Carex umbellata	2	100	2	100	2	67
Chasmanthium laxum			2	100		
Cheilanthes tomentosa			2	100		
Chionanthus virginicus var. *virginicus*	2	36				
Clethra acuminata	2	36				
Coreopsis major	2	64			2	67
Corydalis sempervirens			2	100	1	33
Danthonia spicata			2	100	3	+
Danthonia sericea	2	55	2	100	2	100
Dichanthelium commutatum					1	33
Dichanthelium depauperatum	1	+			1	33
Dichanthelium dichotomum var. *dichotomum*					1	33
Dichanthelium dichotomum var. (= *Panicum lucidum*)					1	67
Dichanthelium meridionale			2	100		
*Fothergilla major**	4	+				
Galax urceolata	2	55				
*Hudsonia montana**	1	+				
Hypericum densiflorum	5	55	2	100	3	+
Kalmia latifolia	4	55			3	+
Leiophyllum buxifolium	6	82				
Liatris graminifolia	2	45				
*Liatris helleri**	2	+				
Lysimachia quadrifolia	2	36				
*Minuartia groenlandica**			2	100		
Nyssa sylvatica	2	55	2	100	1	+
Pinus pungens	5	45				
Pinus rigida	5	+	2	100		
Pinus strobus	2	36	2	100	3	100
Pinus virginiana					3	100
Rhododendron minus	6	100	2	100	4	100

Appendix 1. Continued

Groups:	1.1		1.2[a]		1.3	
Rhus copallina var. *latifolia*					2	67
Rubus allegheniensis var. *allegheniensis*			2	100	2	67
Schizachyrium scoparium	2	45				
*Scirpus cespitosus**	3	+				
Selaginella tortipila	6	100	2	100	6	100
*Sibbaldiopsis tridentata**	2	+				
Smilax glauca var. *glauca*	2	+	2	100	1	+
Smilax rotundifolia	3	+	2	100	1	67
Tsuga canadensis	4	+			3	33
Tsuga caroliniana	3	45	2	100	2	+
Vaccinium pallidum	3	55				
Vitis rotundifolia			2	100		
Xerophyllum asphodeloides	2	55				
*Zigadenus leimanthoides**	1	+				

Appendix 2. Average cover and constancy for species in the Thermic Oak-Pine Forests vegetation class. See Appendix 1 for details

Groups:	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
Number of plots:	3	17	15	7	3	14	6	5	13
Mean elevation (m):	982	808	690	937	1,193	998	695	802	1,059
Mean slope (°):	10	22	27	12	13	23	13	22	13
Dominant aspect (°):		W–NW	SE	SW–NW	W–NW	N–E, W	SE	SE	SW–NE
Dominant parent material:	LQ	LQ, G	LQ	LQ	LQ	LQ	LQ	LQ, G	LQ, M
Homoteneity (see text):	0.83	0.73	0.67	0.80	0.76	0.64	0.74	0.76	0.88
Mean species richness/1,000 m^2:	—	23.0	—	28.0	—	—	32.8	40.3	27.0
100 m^2:	26.7	17.7	23.0	18.4	22.5	17.8	20.0	23.9	19.7
1 m^2:	5.4	3.5	3.3	4.4	4.3	2.7	3.6	3.4	3.3
Species:									
Acer rubrum var. *rubrum*	3 100	5 100	4 100	5 100	4 100	4 79	6 100	5 100	6 100
Amelanchier laevis	5 100	3 +	2 60	1 +	3 100	2 +	1 +	2 100	1 +
Amianthium muscaetoxicum					1 +	1 +	2 67	2 +	1 +
Andropogon virginicus	2 67	1 +	2 +						1 +
Aronia arbutifolia	2 67								
Betula lenta		1 +	1 +	4 +	2 67	3 +	1 +	2 100	1 +
Castanea dentata		2 +	3 +	3 +	2 100	1 +	3 67	2 +	3 +
Chamaelirium luteum		1 +	2 +		1 +		2 83	1 100	1 62
Clethra acuminata	1 +	1 +			2 +	3 57		1 +	
Coreopsis major		1 +	2 60				1 +		1 +
Danthonia sericea	1 +		2 +						1 +
Dennstaedtia punctilobula								2 80	
*Dichanthelium latifolium**									1 +

Appendix 2. Continued

Groups:	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
*Fothergilla major**	4 67	6 +	3 +	6 100		5 +			1 +
Galax urceolata	5 100	6 88	4 60	7 100	7 100	6 100	6 83	7 100	6 69
Gaultheria procumbens	4 100	2 +	2 60	2 71	3 100	2 +	2 +		3 +
Gaylussacia baccata	6 100	2 76	4 53	4 71	3 +	2 +	2 +	2 +	5 +
Gentiana decora		1 +					2 67	2 80	1 +
Goodyera repens		1 +		1 +	2 100	2 +	1 +		1 +
Hamamelis virginiana	3 +	4 71	2 +	1 +	2 67	3 71	6 +	2 80	3 +
Hexastylis shuttleworthii var. *shuttleworthii*	1 +	2 +		2 +	2 67	2 +	1 +	1 +	2 +
Iris verna	2 100	1 +	1 +			1 +	1 +	1 +	1 +
Kalmia latifolia	6 100	7 100	6 100	6 100	7 100	6 93	7 100	5 100	7 100
Leiophyllum buxifolium	6 100		2 +			1 +			1 +
Leucothoe recurva	4 100	4 59	2 +	5 100	4 100	4 86	2 +	2 +	4 +
Lyonia ligustrina var. *ligustrina*	4 100	2 59	2 60	2 86	2 100	2 +	2 100	2 +	2 62
Magnolia fraseri		2 +	2 +			2 +	1 +	2 80	3 +
Maianthemum racemosum					1 +			1 80	
*Monotropsis odorata**			1 +						
Nyssa sylvatica	5 +	6 100	4 87	6 100	5 100	6 79	4 100	2 100	5 100
Oxydendrum arboreum	2 67	3 59	5 73	4 +	1 +	4 64	5 100	4 100	6 100
Pinus pungens	6 100	7 100	6 100	6 86		6 +			5 +
Pinus rigida	5 100	4 76	5 87	6 100	4 67	5 +	1 +		4 +
Pinus strobus	3 +	6 88	2 93	4 86	1 +	5 79	4 100	3 100	4 92
Pinus virginiana	4 +	4 +	6 100	1 +					1 +

Appendix 2. Continued

Groups:	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
Quercus alba		2 +	2 +		5 67	3 +	7 100	3 +	3 62
Quercus coccinea var. *coccinea*	3 67	5 88	5 60	5 +	3 +	1 +	3 +	1 +	6 92
Quercus montana	3 +	5 88	5 80	5 100		3 64	2 67	6 100	6 100
Quercus rubra		2 +	3 53		2 67	2 +	6 100	4 100	3 +
Rhododendron catawbiense	4 67	1 +		5 86	5 100	6 50	2 +		3 +
Rhododendron maximum	2 +	3 +	2 +	2 +		6 93	5 +	5 100	3 69
Rhododendron minus	5 100	7 +	6 67	7 +	5 +	6 71		2 +	2 +
Robinia pseudoacacia	1 +		2 +			1 +	2 +		2 +
Sassafras albidum	2 67	2 +	4 +	1 +	2 +	3 64	2 83	2 100	4 69
Schizachyrium scoparium		2 +	2 67						1 +
Smilax glauca var. *glauca*	2 67	2 100	2 87	2 100	2 100	2 57	2 100	2 100	2 100
Smilax rotundifolia	4 100	3 71	3 80	2 +	1 +	4 86	2 100	2 100	2 85
Symplocos tinctoria		5 100	5 +	4 100	1 +	2 +	2 83	2 +	3 85
Tsuga canadensis	1 +	2 59	1 +	1 +	1 +	4 +	2 100	3 80	2 +
Tsuga caroliniana	3 100	6 +	2 +	4 +	2 67	6 79	2 83	3 100	2 62
Vaccinium corymbosum	4 67	1 +	3 +		2 67	4 +	1 +	2 +	2 +
Vaccinium pallidum	4 67	3 94	4 80	2 86	1 +	2 +	2 83	2 +	3 100
Vaccinium simulatum		2 +	5 +	2 +	2 67	2 +	2 +	2 100	2 +
Vaccinium stamineum	2 67	2 +	3 60	2 +		3 +	2 +	1 +	2 +
Viola hastata		1 +					3 +	2 +	1 69
Xerophyllum asphodeloides	3 100	3 +	2 +	3 57	2 100	2 +			1 +

Appendix 3. Basal area (m^2/hectare) for woody stems ≥1.4 m in height with Importance Values of >4.00 for community types in the THERMIC OAK-PINE FORESTS vegetation class. The Importance Value of each species was calculated by averaging relative density and relative basal area. For full names see Figure 2

Groups:	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
Acer rubrum var. *rubrum*					6.47		4.86	3.10	3.91
Amelanchier laevis					2.11				
Fothergilla major				0.86					
Hamamelis virginiana							0.59	0.24	
Kalmia latifolia	0.63	4.03	1.15	1.75	3.90	3.47	3.18	2.35	3.43
Leucothoe recurva				0.46		0.33			
Nyssa sylvatica	1.28	2.27		5.96	3.15	3.70			1.27
Oxydendrum arboreum							3.02	2.58	2.84
Pinus pungens	10.73	16.45	8.47	9.92		3.26			
Pinus rigida	10.69	3.44	5.88	8.52	5.58				
Pinus strobus		7.14				5.04	3.96		
Pinus virginiana			8.04						
Quercus alba					5.03		12.44		
Quercus coccinea var. *coccinea*									5.74
Quercus montana			3.28	2.64				13.87	8.08
Quercus rubra							4.58		
Rhododendron catawbiense				0.83	3.54				
Rhododendron maximum						3.42		0.95	
Rhododendron minus	0.06	1.29	0.61	1.39		0.86			
Tsuga caroliniana						10.81			
Total Basal Area:	25.37	46.33	32.27	39.89	34.68	43.48	35.57	30.36	33.75

Appendix 4. Average cover and constancy for species in the ACIDIC COVE AND SLOPE FORESTS vegetation class. See Appendix 1 for details

Groups:	3.1		3.2		3.3		3.4		3.5	
Number of plots:	9		10		7		6		18	
Mean elevation (m):	759		798		672		945		898	
Mean slope (°):	26		22		12		21		18	
Dominant aspect (°):	SE–W, E		N–E		NW–N		NW		W, N	
Dominant parent material:	G, M		LQ		G, M		G		LQ	
Homoteneity (see text):	0.70		0.77		0.66		0.78		0.55	
Mean species richness/1,000 m^2:	32.3		27.5		29.0		19.0		—	
100 m^2:	13.9		15.2		16.0		14.0		12.0	
1 m^2:	1.5		2.2		2.0		1.4		2.1	
Species:										
Acer pensylvanicum	1	+	5	67	2	+	2	+	2	+
Acer rubrum var. *rubrum*	7	100	6	100	6	100	5	100	5	100
Betula lenta	3	+	6	100	2	+	5	+	5	78
Chimaphila maculata var. *maculata*	1	+	1	+	1	+	2	86	1	+
Cornus florida	2	100	1	+	2	+	2	+	2	+
*Dichanthelium latifolium**									1	+
Galax urceolata	1	+	1	67	3	90	1	86	2	+
Hamamelis virginiana	1	+	4	100	4	60	4	+	3	44
Hexastylis virginica	2	+	1	+	2	70	2	+	2	+
Kalmia latifolia	4	100	4	100	5	100	5	100	4	67
Liriodendron tulipifera	4	78	1	67	1	+	5	100	5	56
Magnolia fraseri	3	+	5	83	3	90	2	+	4	72
Mitchella repens	2	+	1	+	2	+	2	100	2	56
Nyssa sylvatica	2	78	1	67	4	100	5	100	5	78
Oxydendrum arboreum	5	100	4	83	5	100	6	100	5	50
Pinus strobus	4	67	2	+	6	100	6	100	3	+
Quercus montana	7	100	6	100	6	100	3	86	1	+
Quercus rubra	6	100	4	+	2	60	2	+	1	+
Rhododendron maximum	7	100	7	100	6	100	6	100	8	100
Smilax glauca var. *glauca*	2	100	1	83	2	100	1	86	2	+
Smilax rotundifolia	2	100	2	83	2	100	2	100	3	83
Symplocos tinctoria	2	+	2	+	2	100	2	100	1	+
Tsuga canadensis	4	100	6	50	4	100	6	100	7	100
Viola hastata	2	78			2	60	1	+		

Appendix 5. Basal area (m²/hectare) for woody stems ≥1.4 m in height with Importance Values of >4.00 for community types in the Acidic Cove and Slope Forests vegetation class. See Appendix 3 for details

Groups:	3.1	3.2	3.3	3.4	3.5
Acer rubrum var. *rubrum*	5.55	4.34	3.64	3.47	6.47
Betula lenta		4.19			
Kalmia latifolia	0.24	0.64	0.93	1.05	
Liriodendron tulipifera	3.72				
Magnolia fraseri		3.68			
Nyssa sylvatica			3.44	2.25	
Oxydendrum arboreum	1.25		1.61	1.73	
Pinus strobus	0.64		13.21	11.13	
Quercus alba				3.51	
Quercus montana	16.69	15.54	16.11	2.81	
Quercus rubra	5.57				
Rhododendron maximum	5.06	6.94	2.37	4.06	5.81
Rhododendron minus		0.31			
Tsuga canadensis	4.78	3.41		5.44	33.81
Total Basal Area:	51.20	45.41	45.82	44.01	66.10

Appendix 6. Average cover and constancy for species in the MONTANE OAK FORESTS and RICH COVE AND SLOPE FORESTS vegetation classes. See Appendix 1 for details. Parent material units represented are alluvium (AL), Lower Quartzite (LQ), Upper Quartzite (UQ), Wilson Creek Gneiss (G) and Grandfather Mountain Meta-arkose (M)

Groups:	**4.1**	**4.2**	**4.3**	**4.4**	**5.1**	**5.2**	**5.3**
Number of plots:	6	3	4	3	6	2	3
Mean elevation (m):	680	802	1,000	1,040	1,122	671	437
Mean slope (°):	28	38	35	24	24	20	7
Dominant aspect (°):	SE	S–SW	NW	E	E, SE	SE, E	
Dominant parent material:	G	G	G	LQ, UQ, G	M, UQ	M	AL
Homoteneity (see text):	0.68	0.78	0.72	0.78	0.64	0.82	0.76
Mean species richness/1,000 m^2:	52.7	66.0	—	56.3	69.8	61.0	41.0
100 m^2:	24.5	35.5	33.4	33.2	37.3	34.8	21.6
1 m^2:	2.8	4.3	4.7	5.7	8.5	4.7	2.5
Species:							
Acer pensylvanicum	2 +	3 +	4 100	2 100	3 +	3 +	1 +
Acer rubrum var. *rubrum*	4 100	6 100	4 100	6 100	4 83	4 100	2 100
Ageratina altissima var. *altissima*	1 +	2 67	2 +	1 +	6 100	1 +	
Amphicarpaea bracteata		1 +		1 +	4 100	2 +	
Arabis laevigata var. *laevigata*		2 100	1 +		2 +	1 +	
Aralia nudicaulis			1 +	1 +	2 +	1 100	
Arisaema triphyllum	1 +	1 +	1 +	2 100	2 100	2 100	1 +
Arnoglossum atriplicifolium					2 67	1 +	
Asimina triloba							2 67
Asplenium platyneuron var. *platyneuron*	2 +	2 100			2 +	1 +	1 +
Aster divaricatus	1 +	2 67	3 100	1 +	2 +	2 100	2 100
Aster macrophyllus	3 +	1 +	1 +	4 75	2 +	2 +	

Appendix 6. Continued

Groups:	4.1	4.2	4.3	4.4	5.1	5.2	5.3
Aster undulatus	1 +	2 67	1 +	1 +	1 +		
Athyrium asplenioides				3 67	2 +	1 100	1 +
Betula lenta	3 +	1 +	5 +	6 100	2 83	2 100	2 67
Botrychium virginianum					2 +	1 100	
Campanula divaricata	2 67	2 100	2 +		1 +		
Cardamine diphylla			2 75				1 +
Carex communis		2 67		1 +			
Carex digitalis	2 +			2 100	1 +	1 +	2 100
Carex pensylvanica		5 67		1 +			1 +
Carex umbellata	2 67						
Carya tomentosa	2 67	1 +			2 +	3 +	3 67
Carya glabra	3 83	1 +	2 +	5 67	7 100	6 100	3 +
Castanea dentata			1 +	3 100	2 +	1 +	
Chamaelirium luteum	1 +	1 +		2 100			
Chimaphila maculata var. *maculata*	2 83	1 +		1 +	1 +		2 100
Cimicifuga racemosa					2 67	2 100	
Clintonia umbellulata			1 100	2 100	1 +	2 +	
Coreopsis major			2 +	2 +	1 +		
Cornus florida	6 100	5 100	1 +	2 +	1 100	3 100	
Cryptotaenia canadensis					1 +	1 100	

Appendix 6. Continued

Groups:	4.1	4.2	4.3	4.4	5.1	5.2	5.3
Dennstaedtia punctilobula	2 +			6 100	5 83		
Dichanthelium boscii	2 +	2 67	2 +	1 +	2 +		1 +
Dichanthelium commutatum	2 67	1 +			1 +		
Dichanthelium dichotomum var. *dichotomum*	2 83	1 +					
*Dichanthelium latifolium**					2 +		
Dioscorea quaternata	1 +	2 100	2 100	2 100	2 83	1 100	1 +
Dryopteris marginalis		1 +	2 100	1 +	2 67	1 +	
Euonymus americana						2 100	2 100
Eupatorium purpureum var. *purpureum*					2 67	2 100	
Fagus grandifolia							6 100
Galearis spectabilis						1 100	
Galium circaezans var. *circaezans*	1 +	1 +			2 67		1 +
Goodyera pubescens	1 +		1 +	2 100	1 +	1 +	
Halesia tetraptera var. *monticola*	2 +	1 +		3 +	5 +	6 100	1 +
Hamamelis virginiana	1 +	4 100	4 100	6 67	2 +	1 +	
Heuchera americana		2 100					
Huechera villosa var. *villosa*			2 75		2 +		
Hieracium venosum	1 +	1 +					
Houstonia purpurea var. *purpurea*	1 +	2 67	2 75	2 +	1 +		

Appendix 6. Continued

Groups:	4.1	4.2	4.3	4.4	5.1	5.2	5.3
Ilex opaca var. *opaca*	1 +					3 +	5 100
Iris cristata		1 +	4 75	1 +			
Kalmia latifolia	5 100	2 67	2 +	2 100	2 +		1 +
Laportea canadensis			1 +		6 +	3 100	
Leucothoe fontanesiana						1 +	
Liquidambar styraciflua							2 67
Liriodendron tulipifera	5 83	2 100		1 +	5 +	6 100	2 100
Lysimachia quadrifolia			2 100	2 +	2 67	2 100	
Magnolia fraseri	1 +		2 +	3 100	1 +	1 +	2 67
Maianthemum racemosum	1 +		2 75	1 +	2 83	1 100	1 +
Medeola virginiana		1 +	1 +	2 100	1 +	1 100	
Melanthium parviflorum			2 75	2 +	2 +	1 +	
Mitchella repens			1 +			2 100	2 100
Muhlenbergia tenuiflora var. *variabilis*	1 +	2 100	2 +		1 +		
Nyssa sylvatica	3 100	1 +		2 100	1 +	1 +	2 67
Osmorhiza claytonii						1 100	
Oxydendrum arboreum	5 100	2 100		5 100	2 67	2 100	2 67
*Panax quinquefolius**						1 +	
Parthenocissus quinquefolia var. *quinquefolia*	2 100	2 100	3 75	1 +	2 67	2 100	2 100
Penstemon smallii		1 +					
Pinus strobus	3 100	2 67	2 75	2 100	2 +		4 100
Polygonatum biflorum var. *biflorum*	1 +	2 67	2 75	2 100	2 100	1 100	1 +
Polygonum convolvulus var. *convolvulus*		2 67			2 67		
Polypodium virginianum			2 75	1 +	2 +		
Polystichum acrostichoides	2 67	1 +	2 100	2 100	2 83	2 100	2 100

Appendix 6. Continued

Groups:	4.1	4.2	4.3	4.4	5.1	5.2	5.3
Potentilla canadensis var. *canadensis*	1 +	2 67		1 +	2 +		
Prenanthes altissima	1 +	1 +	2 75	2 +	2 83	1 100	
Prosartes lanuginosa			1 +		2 +	2 100	
Prunella vulgaris		2 100					
Pycnanthemum montanum		1 +		1 +	2 83	1 +	
Quercus alba	4 +			7 67	2 +		1 +
Quercus montana	6 100	6 100	6 100	2 +	1 +		1 +
Quercus rubra	6 100	6 100	2 100	3 100	6 100	3 100	3 +
Rhododendron maximum	2 +	1 +	5 100	5 67	1 +	3 100	2 67
Rhododendron minus	1 +	2 100	5 75				
Robinia pseudoacacia	2 +	2 100	2 +	2 100	4 83	2 100	1 +
Rubus allegheniensis var. *allegheniensis*	2 +	2 +	2 75	1 +	3 100		
Sanguinaria canadensis					1 +	2 100	
Sassafras albidum	1 +			2 +	3 67		
Smilax glauca var. *glauca*	2 100	2 100		2 100	2 83	1 100	2 100
Smilax rotundifolia	1 100	2 100	2 100	2 100	2 83	2 100	2 100
Solidago arguta var. *caroliniana*	1 +	1 +	2 75	2 +	2 +		1 +
Solidago curtisii	1 +	2 100	1 +	2 100	3 100	2 100	
Stachys latidens					3 67		
Stellaria pubera	1 +	2 67		1 +	1 +	2 100	1 +
Symplocos tinctoria	2 100			1 +	1 +	1 +	1 +
Thelypteris noveboracensis	1 +			7 67	3 67	4 100	3 +

Appendix 6. Continued

Groups:	4.1	4.2	4.3	4.4	5.1	5.2	5.3
*Thermopsis fraxinifolia**	1 +						
Tilia americana var. *heterophylla*			4 75			2 100	1 +
Tipularia discolor	1 +					1 100	
Toxicodendron radicans		2 67	4 +		3 +	1 +	1 +
Tradescantia subaspera	1 +	1 +			2 67		
Tsuga canadensis	3 83	3 100	2 75	2 100	1 +	6 100	7 100
Uvularia puberula var. *puberula*		2 +	1 +	1 +	2 67	1 +	1 +
Vaccinium stamineum	1 83	2 100	1 +		1 +		
Viburnum acerifolium	1 +	2 67	2 +		2 +	1 100	
Viola affinis	1 +	1 +	2 +	2 +	3 67	2 100	
Viola blanda		2 +	2 +		2 +	2 100	
Viola hastata	2 +			2 +	2 +		2 100
Viola rotundifolia			2 75	2 +		1 +	
Vitis aestivalis	1 +	1 +		1 +	1 +	2 +	1 +
Zizia trifoliata	2 67	2 100	2 75	2 100	2 +	2 +	2 100

Appendix 7. Basal area (m^2/hectare) for woody stems ≥1.4 m in height with Importance Values of >4.00 for community types in the MONTANE OAK FORESTS and RICH COVE AND SLOPE FORESTS vegetation classes. See Appendix 3 for details

Groups:	4.1	4.2	4.3	4.4	5.1	5.2	5.3
Acer pensylvanicum			0.67	0.11			
Acer rubrum var. *rubrum*		1.30	2.43	7.19			
Betula lenta			6.29	2.11			
Carya glabra					8.58	8.58	
Cornus florida	1.14	1.24					
Fagus grandifolia							9.83
Fraxinus americana					0.81		
Halesia tetraptera var. *monticola*					0.23	1.28	
Hamamelis virginiana		0.16	0.68	1.12			
Ilex opaca var. *opaca*							0.71
Kalmia latifolia	0.31						
Liquidambar styraciflua							4.78
Liriodendron tulipifera	5.67				3.29	28.80	
Magnolia fraseri				1.41			
Nyssa sylvatica	0.50						
Oxydendrum arboreum	2.01			5.39			
Pinus strobus							8.08
Quercus alba				5.85			
Quercus montana	17.71	30.00	13.66	2.67			
Quercus rubra	5.09	3.97			7.67	7.62	
Rhododendron maximum			1.57			0.79	0.35
Rhododendron minus			1.54				
Robinia pseudoacacia					2.18		
Sassafras albidum					0.61		
Tilia americana var. *heterophylla*			4.93				
Tsuga canadensis						7.44	17.24
Total Basal Area:	42.52	40.62	37.95	35.20	29.65	61.47	51.99

Appendix 8. Average cover and constancy for species in the ALLUVIAL FORESTS, ROCKY STREAMSIDE SHRUBLANDS and NON-ALLUVIAL WETLANDS. See Appendix 1 for details

Groups:	6.1	6.2	7.1	8.1
Number of plots:	1	1	2	1
Mean elevation (m):	440	409	919	907
Mean slope (°):	1	1	9	flat
Dominant aspect (°):	flat	flat	flat	flat
Dominant parent material:	AL	AL	AL	LQ
Homoteneity (see text):				
Mean species richness/1,000 m^2:	—	54.0	—	—
100 m^2:	26.5	28.0	25.3	6.0
1 m^2:	3.0	8.1	2.2	—
Species:				
Acer rubrum var. *rubrum*	4 100	1 100		
Ageratina altissima var. *altissima*	1 100	5 100		
Agrostis perennans	2 100		2 100	
Agrostis stolonifera			2 50	
Albizia julibrissin		3 100		
Alnus serrulata			2 100	
Amphicarpaea bracteata		2 100		
Anthoxanthum odoratum var. *odoratum*			2 100	
Arabis laevigata var. *laevigata*	1 100			
Arisaema triphyllum		1 100		
Aronia melanocarpa			2 50	
Asimina triloba		6 100		
Aster divaricatus			2 50	
Aster prenanthoides	2 100		2 100	
Athyrium asplenioides		1 100		
Bartonia vriginica				1 100
Betula alleghaniensis	4 100		7 50	
Betula lenta	6 100			
Botrychium biternatum		1 100		
Boykinia aconitifolia			2 100	
Campanula divaricata	2 100			
Carex blanda		1 100		
Carex laxiflora var. *laxiflora*		1 100		
Carex swanii		2 100		
Carex torta	2 100		3 100	
Carpinus caroliniana var. *virginiana*	3 100			
Circaea canadensis		1 100		
Cornus florida	3 100	2 100		
Cryptotaenia canadensis		2 100		
Dichanthelium clandestinum	1 100	2 100		
Dichanthelium dichotomum var. (= *Panicum ramulosum*)	3 100		1 +	
Dryopteris intermedia			2 50	
Dulichium arundinaceum				5 100

Appendix 8. Continued

Groups:	6.1	6.2	7.1	8.1
Elephantopus carolinianus		1 100		
Erigeron pulchellus var. *pulchellus*		1 100		
Euonymus americana		1 100		
Fraxinus americana			2 50	
Galearis spectabilis		1 100		
Galium triflorum		1 100		
Goodyera pubescens		1 100		
Hamamelis virginiana			3 50	
Holcus lanatus			1 100	
Hypericum densiflorum			2 50	
Ilex opaca var. *opaca*		1 100		
Iris verna		1 100		
Juncus coriaceus			2 100	
Juncus effusus var. *solutus*				4 100
Leersia virginica		2 100		
Leucothoe fontanesiana			2 100	
Liquidambar styraciflua	8 100	8 100		1 100
Liriodendron tulipifera		5 100		
Lobelia spicata		1 100		
Lonicera sempervirens	1 100	1 100		
Luzula multiflora var. *congesta*	2 100	1 100	2 100	
Lycopus virginicus		1 100	1 100	
Microstegium vimineum	1 100	8 100		
Muhlenbergia tenuiflora var. *variabilis*	1 100	1 100		
Nyssa sylvatica		1 100	1 +	
Osmunda regalis var. *spectabilis*				5 100
Oxalis stricta	1 100	1 100	1 +	
Parthenocissus quinquefolia var. *quinquefolia*	3 100	2 100		
Phacelia bipinnatifida		1 100		
Pinus strobus	4 100	1 100	2 50	
Platanus occidentalis	6 100	5 100		
Poa cuspidata		1 100		
Polygonum virginianum		1 100		
Potentilla canadensis var. *canadensis*	1 100			
Ranunculus recurvatus	1 100	1 100	1 +	
Rhododendron maximum			2 50	
Robinia pseudoacacia		3 100		
Rosa multiflora	1 100			

Appendix 8. Continued

Groups:	6.1	6.2	7.1	8.1
Rudbeckia laciniata			2 50	
Salix nigra			2 50	
Sanicula canadensis var. *canadensis*		2 100		
Scirpus cyperinus				5 100
Scutellaria species #1			2 50	
Sisyrinchium angustifolium		1 100		
Smilax glauca var. *glauca*		1 100		
Smilax rotundifolia		1 100		
Solanum americanum var. *americanum*		1 100		
Solanum carolinense var. *carolinense*		1 100		
Solidago arguta var. *caroliniana*	1 100			
Solidago curtisii		1 100		
Symplocos tinctoria			2 50	
Tipularia discolor		1 100		
Toxicodendron radicans	6 100	3 100		
Trautvetteria caroliniensis var. *caroliniensis*			2 100	
Trifolium incarnatum	1 100			
Tsuga canadensis	4 100		2 50	
Viola cucullata	2 100	2 100	3 50	
Viola palmata var. *palmata*		1 100		
Vitis aestivalis	1 100	2 100		
Xanthorhiza simplicissima			5 100	

Appendix 9. Basal area (m^2/hectare) for woody stems ≥1.4 m in height with Importance Values of >4.00 for community types in the Alluvial Forests and Rocky Streamside Shrublands vegetation classes. See Appendix 3 for details

Groups:	6.1	6.2	7.1
Acer rubrum var. *rubrum*	0.83		
Alnus serrulata			0.01
Asimina triloba		0.05	
Betula alleghaniensis			0.11
Betula lenta	4.03		
Fraxinus americana			0.99
Liquidambar styraciflua	13.60	15.84	
Liriodendron tulipifera		23.70	
Pinus strobus			0.31
Platanus occidentalis	7.17	10.54	
Rhododendron maximum			0.03
Total Basal Area:	28.57	52.22	1.45

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LITERATURE CITED

ABRAMS, M.D. 1992. Fire and the development of oak forests. BioScience 42:346–353.

ANDERSON, L.E. and R.H. ZANDER. 1973. The mosses of the Southern Blue Ridge Province and their phytogeographic relationships. J. Elisha Mitchell Sci. Soc. 89:15–60.

ARENDS, E. 1981. Vegetation patterns a half century following the chestnut blight in the Great Smoky Mountains National Park. M.S. thesis. Ecology, University of Tennessee, Knoxville. 79 p.

BARDEN, L.S. 1977. Self-maintaining populations of *Pinus pungens* Lam. in the southern Appalachian Mountains. Castanea 42:316–323.

BARDEN, L.S. and F.W. WOODS. 1976. Effects of fire on pine and pine-hardwood forests in the southern Appalachians. Forest Sci. 22:399–403.

BEERS, T.W., P.E. DRESS, and L.C. WENSEL. 1966. Aspect transformation in site productivity research. J. Forestry 64:691–692.

BILLINGS, W.D. and L.E. ANDERSON. 1966. Some microclimatic characteristics of habitats of endemic and disjunct bryophytes in the southern Blue Ridge. The Bryologist 69:76–95.

BRADY, N.C. 1974. The nature and properties of soils. MacMillan Publishing Co., New York. 639 p.

BRAUN, E.L. 1950. Deciduous forests of eastern North America. The Blakiston Co., New York. 596 p.

BRAY, J.R. and J.T. CURTIS. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr. 27:325–349.

BUSING, R.T., WHITE, P.S., and M.D. MACKENZIE. 1993. Gradient analysis of old spruce-fir forests of the Great Smoky Mountains circa 1935. Can. J. Bot. 71:951–958.

CALLAWAY, R.M., E.E.C. CLEBSCH, and P.S. WHITE. 1987. A multivariate analysis of forest communities in the western Great Smoky Mountains National Park. Amer. Midl. Naturalist 118:107–120.

CLIFFORD, H.T. and W. STEPHENSON. 1975. An introduction to numerical classification. Academic Press. New York. 229 p.

COOPER, A.W. and J.W. HARDIN. 1970. Floristics and vegetation of the gorges on the Southern Blue Ridge Escarpment. p. 291–330. *In*: Holt, P.C. and R.A. Paterson (eds.). The distributional history of the biota of the Southern Appalachians. Part II: Flora. Research Division Monograph 2, Virginia Polytechnic Institute and State University, Blacksburg. 414 p.

CURTIS, J.T. 1959. The vegetation of Wisconsin. An ordination of plant communities. The University of Wisconsin Press, Madison. 657 p.

D'AGOSTINO, J.P., J.W. WHITLOW, and D.F. SIEMS. 1986. Geologic and geochemical maps of the Linville Gorge Wilderness and proposed extension, Burke and McDowell counties, North Carolina. Miscellaneous Field Studies Map MF-1610-A, U.S Geological Survey, Department of the Interior.

DAY, F.P. and C.D. MONK. 1974. Vegetation patterns on a southern Appalachian watershed. Ecology 55: 1064–1074.

DELAPP, J.A. 1978. Gradient analysis and classification of the high elevation red oak community of the southern Appalachians. M.S. thesis. Department of Botany, North Carolina State University, Raleigh. 140 p.

DEYOUNG, H.H. 1979. The White Pine-Hardwood vegetation types of the Great Smoky Mountains National Park. M.S. thesis. The University of Tennessee, Knoxville. 190 p.

DUMOND, D.M. 1970. Floristic and vegetational survey of the Chattooga River gorge. Castanea 35:201–244.

EARTHINFO, INC. 1989. ClimateData. World weather data on CD-ROM. Central Eastern disc. 5541, Central Ave, Boulder, Colorado.

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE. 1996. ARC/INFO 7.0.4. Redlands, California.

FARRAR, D.R. and J.T. MICKEL. 1991. *Vittaria appalachiana*: A name of the "Appalachian Gametophyte". Amer. Fern J. 81:69–75.

FLORA OF NORTH AMERICA EDITORIAL COMMITTEE. 1993. Flora of North America. Volume 2. Oxford University Press. 475 p.

FLORA OF NORTH AMERICA EDITORIAL COMMITTEE. 1997. Flora of North America. Volume 3. Oxford University Press. 590 p.

FRANTZ, V. and R. SUTTER. 1987. *Hudsonia montana,* from discovery to recovery. Plant Conservation Program. Technical Report No. 2. North Carolina Department of Agriculture, Raleigh. 48 p.

FROST, C.C. 1990. *Hudsonia montana* final report: effects of fire, trampling and interspecies competition, 1985–1989. Part I: Report. Department of Biology, University of North Carolina, Chapel Hill. Submitted to the NCDA Plant Conservation Program, 1990.

FROST, C.C. 1993. *Hudsonia montana* monitoring and management for 1992. NCDA Plant Conservation Program, Raleigh, North Carolina. Submitted to the USDA Forest Service and the U.S. Fish and Wildlife Service, 1993.

FROST, C.C. 1995. Presettlement fire regimes in southeastern marshes, peatlands, and swamps. Proc. Tall Timbers Fire Ecol. Conf. 19:39–60.

GOLDBERG, D.E. 1982. The distribution of evergreen and deciduous trees relative to soil type: an example from the Sierra Madre, Mexico, and a general model. Ecology 63:942–951.

GOLDEN, M.S. 1974. Forest vegetation and site relationships in the central portion of the Great Smoky Mountains National Park. Ph.D. dissertation. University of Tennessee, Knoxville. 273 p.

GOLDEN, M.S. 1981. An integrated multivariate analysis of forest communities of the central Great Smoky Mountains. Amer. Midl. Naturalist 106:37–53.

GRAVES, J.H. and C.D. MONK. 1985. A comparison of soils and vegetation over marble and schist along tributaries to Panther Creek, Stephens County, Georgia. Castanea 50:146–163.

HARMON, M.E. 1982. Fire history of the westernmost portion of Great Smoky Mountains National Park. Bull. Torrey Bot. Club 109:74–79.

HARROD, J.C., P.S. WHITE, and M.E. HARMON. 1998. Changes in xeric forests in western Great Smoky Mountains National Park, 1936–1995. Castanea 63:346–360.

HATCHER, R.D. and GOLDBERG, S.A. 1991. The Blue Ridge Geologic Province. p. 11–35. *In*: Horton, J.W. and V.A. Zullo (eds.). The geology of the Carolinas. Carolina Geological Society Fiftieth Anniversary Volume. The University of Tennessee Press, Knoxville. 406 p.

HETRICK, W.A., P.M. RICH, and S.B. WEISS. 1993. Modeling insolation on complex surfaces. Proc. 13th Ann. ESRI User Conf. (Redlands: ESRI) 2:447–458.

HETRICK, W.A., P.M. RICH, F.J. BARNES, and S.B. WEISS. 1993. GIS-based solar radiation flux models. Proc. ASPRS-ACSM Ann. Conv. (Bethesda, MD: ASPRS) 3:132–143.

HUMPHREY, L.D. 1989. Life history traits of *Tsuga caroliniana* Englem. (Carolina Hemlock) and its role in community dynamics. Castanea 54:172–190.

HUTCHISON, B.A. and D.R. MATT. 1977. The distribution of solar radiation within a deciduous forest. Ecol. Monogr. 47:185–207.

KARTESZ, J.A. 1994. A synonymized checklist of the vascular flora of the United States, Canada, and Greenland. Volume 1—Checklist. Timber Press, Portland, Oregon. 622 p.

KEEVER, C. 1953. Present composition of some stands of the former oak-chestnut forest in the southern Blue Ridge Mountains. Ecology 34:44–54.

KNIGHT, D. In press. Soil Survey of Burke County, North Carolina. United States Department of Agriculture, Natural Resources Conservation Service.

KRUSKAL, J.B. 1964. Nonmetric multidimensional scaling: a numerical method. Psychometrika 29:115–129.

LANCE, G.N. and W.T. WILLIAMS. 1966. A generalized sorting strategy for computer classifications. Nature 212:218.

LANCE, G.N. and W.T. WILLIAMS. 1967. A general theory of classification sorting strategies 1. Hierarchical systems. Computer J. 9:373–380.

LARSON, S.S. and W.T. BATSON. 1978. The vegetation of vertical rock faces in Pickens and Greenville Counties, South Carolina. Castanea 48:255–260.

LEGENDRE, L. and P. LEGENDRE. 1983. Numerical ecology. Elsevier Scientific Publishing Company, Amsterdam. 419 p.

LORIMER, C.G. 1989. The oak regeneration problem. New evidence on causes and possible solutions. Forest Resource Analysis 8:1–31.

LOSCHE, C.K., R.J. MCCRACKEN, and C.B. DAVEY. 1970. Soils of steeply sloping landscapes in the southern Appalachian Mountains. Proc. Amer. Soil Sci. Soc. 34:473–478.

MCCURDY, Y. DEB. 1975. An ecosystematic analysis of the vegetation of Hanging Rock State Park, Danbury, North Carolina. M.A. thesis. Curriculum in Ecology, University of North Carolina at Chapel Hill. 107 p.

MCLEOD, D.E. 1988. Vegetation patterns, floristics, and environmental relationships in the Black and Crag-

gy Mountains of North Carolina. Ph.D. dissertation. Department of Biology, University of North Carolina at Chapel Hill. 222 p.
McNAB, W.H. 1989. Terrain Shape Index: quantifying effect of minor landforms on tree height. Forest Sci. 35:91–104.
McNAB, W.H. 1993. A topographic index to quantify the effect of mesoscale landform on site productivity. Can. J. Forest Res. 23:1100–1107.
MEHLICH, A. 1984. Mehlich III soil test extraction modification of Mehlich II extractant. Communications in Soil Science and Plant Analysis 15:1409–1416.
MINCHIN, P.R. 1994. DECODA. Database for Ecological Community Data, Version 2.05. Mainframe release for UNIX systems. Technology Marketing Division, ANUTECH Pty. Ltd. Canberra, Australia.
MONK, C.D. 1966. An ecological significance of evergreenness. Ecology 47:504–505.
MONK, C.D., D.T. McGINTY, and F.P. DAY. 1985. The ecological significance of *Kalmia latifolia* and *Rhododendron maximum* in the deciduous forest of the southern Appalachians. Bull. Torrey Bot. Club 112:187–193.
MOWBRAY, T.B. and H.J. OOSTING. 1968. Vegetation gradients in relation to environment and phenology in a Southern Blue Ridge gorge. Ecol. Monogr. 38:309–344.
NEWELL, C.L. 1997. Local and regional variation in the vegetation of the southern Appalachian Mountains. Ph.D. dissertation. Curriculum in Ecology, University of North Carolina at Chapel Hill. 1,008 p.
NEWELL, C.L. and R.K. PEET. 1996. Plant species richness of Southern Appalachian forests. Bull. Ecol. Soc. Amer. 77 (Supplement):324
NEWELL, C.L., R.K. PEET, C.J. ULREY, T.R. WENTWORTH, K.D. PATTERSON, and D.E. McLEOD. In press. Geographic variation in forest distribution across 5 landscapes in the southern Appalachian Mountains of North and South Carolina. Proc. Appalachian Biogeography Symposium, Blacksburg, Virginia.
NOY-MEIR, I., D. WALKER, and W.T. WILLIAMS. 1975. Data transformations in ecological ordination. II On the meaning of data standardization. J. Ecol. 63:779–800.
PALMER, M.W. 1990. Spatial scale and patterns of species-environment relationships in hardwood forest of the North Carolina Piedmont. Coenoses 5:79–87.
PALMER, M.W. 1993. Putting things in even better order: the advantages of canonical correspondence analysis. Ecology 74:2215–2230.
PARKER, A.J. 1982. The topographic relative moisture index: an approach to soil-moisture assessment in mountain terrain. Phys. Geogr. 3:60–168.
PATRICK, W.H. 1958. Modification of method of particle size analysis. Soil Sci. Soc. Amer. Proc. 22:366–367.
PATTERSON, K.D. 1994. Classification of vegetation in Ellicott Rock Wilderness, southeastern Blue Ridge Escarpment. M.S. thesis. Ecology, North Carolina State University, Raleigh. 91 p.
PEET, R.K., T.R. WENTWORTH, and P.S. WHITE. 1998. A flexible, multipurpose method for recording vegetation composition and structure. Castanea 63:262–274.
PYLE, C. 1988. The type and extent of anthropogenic vegetation disturbance in the Great Smoky Mountains before National Park Service acquisition. Castanea 53:183–196.
RACINE, C.H. 1966. Pine communities and their site characteristics in the Blue Ridge escarpment. J. Elisha Mitchell Sci. Soc. 82:172–181.
RACINE, C.H. and J.W. HARDIN. 1975. The vascular flora and vegetation in the Green River Gorge, North Carolina. Castanea 40:319–345.
REED, F.W. 1905. Report on the examination of a forest tract in western North Carolina. U.S.D.A. Bur. Forestry Bull. 60:1–32.
ROHRER, J.R. 1983. Vegetation pattern and rock type in the flora of the Hanging Rock Area, North Carolina. Castanea 48:189–205.
SAS INSTITUTE INC. 1996. SAS Version 6.11. SAS Institute Inc., Cary, North Carolina.
SAUNDERS, P.R. 1979. The vegetational impact of human disturbance on the spruce-fir forests of the southern Appalachian Mountains. Ph.D. dissertation. Department of Forestry and Environmental Studies, Duke University. 177 p.
SCHAFALE, M.P. and A.S. WEAKLEY. 1990. Classification of the natural communities of North Carolina. Third approximation. North Carolina Natural Heritage Program. Department of Environment, Health, and Natural Resources. 325 p.
SELBY, M.J. 1985. Earth's changing surface. Oxford University Press, Oxford, United Kingdom. 607 p.
SMALL, E. 1972. Photosynthetic rates in relation to nitrogen cycling as an adaptation to nutrient deficiency in peat bog plants. Can. J. Bot. 50:2227–2233.

TAGGART, J.B. 1973. Floristic survey and vegetational analysis of Stone Mountain State Park in North Carolina. M.S. thesis. Department of Botany, North Carolina State University, Raleigh. 51 p.

TER BRAAK, C.J.F. 1987. CANOCO—a FORTRAN program for canonical community ordination by [partial] [detrended] [canonical] correspondence analysis, principal components analysis and redundancy analysis (version 2.1). TNO Institute of Applied Computer Science, Statistics Department, Wageningen, The Netherlands.

VAN TONGEREN, O.F.R. 1995. Cluster analysis. p. 172–212. *In*: Jongman, R.H., C.J.F. ter Braak, and O.F.R. van Tongeren (eds.). Data analysis in community and landscape ecology. Cambridge University Press, Cambridge, United Kingdom. 299 p.

WARD, J.H. 1963. Hierarchical grouping to optimise an objective function. J. Amer. Statistical Assoc. 58: 236–244.

WATERMAN, J.R., A.R. GILLESPIE, J.M. VOSE, and W.T. SWANK. 1995. The influence of mountain laurel on regeneration in pitch pine canopy gaps of the Coweeta Basin, North Carolina, U.S.A. Can. J. Forest Res. 25:1756–1762.

WEAKLEY, A.S. 1992. List of endangered vascular and nonvascular plants present in Linville Gorge Wilderness. North Carolina Natural Heritage Program. Department of Environment, Health, and Natural Resources, Raleigh, North Carolina. Unpublished manuscript.

WENTWORTH, T.R. 1980. Preliminary analysis of vegetation in the Thompson River watershed, North and South Carolina. Veröff.. Geobot. Inst. ETH, Stiftung Rübel. Zürich. 69:145–159.

WHITTAKER, R.H. 1956. Vegetation of the Great Smoky Mountains. Ecol. Monogr. 26:1–80.

WILDS, S.P.-V. 1996. Gradient analysis of the distribution of flowering dogwood (*Cornus florida* L.) and dogwood anthracnose (*Discula destructiva* Redlin.) in western Great Smoky Mountains National Park. M.A. thesis. Curriculum in Ecology, University of North Carolina at Chapel Hill. 151 p.

WILLIAMS, R.M. and H.J. OOSTING. 1944. The vegetation of Pilot Mountain, North Carolina: a community analysis. Bull. Torrey Bot. Club 71:23–45.

WISER, S.K. 1994. High-elevation cliffs and outcrops of the Southern Appalachians: vascular plants and biogeography. Castanea 59:85–116.

WISER, S.K., R.K. PEET, and P.S. WHITE. 1996. High-elevation rock outcrop vegetation of the Southern Appalachian Mountains. J. Veg. Sci. 7:703–722.

WOODS, F.W. and R.E. SHANKS. 1959. Natural replacement of chestnut by other species in the Great Smoky Mountains National Park. Ecology 40:349–361.

ZARTMAN, C.E. and J.D. PITTILLO. 1998. Spray cliff plant communities in the Chattooga Basin. Castanea 63:217–240.

ZOBEL, D.B. 1969. Factors affecting the distribution of *Pinus pungens,* an Appalachian endemic. Ecol. Monogr. 39:303–333.