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Association of edaphic factors and vegetation in several isolated Appalachian peat bogs[1]

C. Neal Stewart, Jr.[2] and Erik T. Nilsen

Biology Department, Virginia Polytechnic Institute and State University,
Blacksburg, VA 24061

ABSTRACT

STEWART, C. N., JR. AND E. T. NILSEN (Biology Department, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061). Association of edaphic factors and vegetation in several isolated Appalachian peat bogs. Bull. Torrey Bot. Club 120: 128–135. 1993.—The vegetation of five Appalachian bogs (one site in Tennessee and four in West Virginia) was sampled using a point-quarter method. *Rubus hispidus* had the highest importance value in the Tennessee site and *Vaccinium oxycoccus* in the West Virginia sites. Major differences and similarities in vegetation are summarized, and comparisons are made with northern peat bogs, which are also dominated by dwarf shrubs. The dominant growth form in all the bogs was recumbent shrub, which was two to three times more important than other growth forms. Within the growth form, the importance values of *R. hispidus* (Rosaceae) and the evergreen recumbents (Ericaceae) were inversely related. Among sites, the importance value of *R. hispidus* was positively associated with soil nutrient status ($r^2 = 0.99$), while those of the ericaceous recumbents were negatively associated with nutrients ($r^2 = 0.94$). This relationship was consistent for all macronutrients except nitrate. This relationship is important since eutrophication may exacerbate the decline of Appalachian bogs and indigenous vegetation. As bogs become more minerotrophic, we predict a shift in dominance from evergreen to deciduous species. Specifically, the importance of *R. hispidus* may increase as the importance of bog ericads decreases.

Key words: bog, cranberry, eutrophication, nitrogen, nutrients, phosphorus, *Rubus hispidus, Vaccinium oxycoccus, Vaccinium macrocarpon,* vegetation.

Peatlands are prominent ecosystems in the northern U.S. and Canada, most being located above 41°N latitude (Wieder and Lang 1983). They occupy vast areas, are ecologically important, and have been widely studied. Peatlands are generally characterized by cool wet conditions that encourage peat accumulation. Primary production and decomposition rates are low compared with those reported for other temperate freshwater wetland ecosystems (Schlesinger 1977; Bradbury and Grace 1983).

In the mid- to southern Appalachian Mountains (from Pennsylvania to Georgia), there are relict peatlands that are similar to northern peatlands, which have received little attention from the scientific community. These ecosystems, however, serve as genetic repositories for northern species and also serve vital hydrologic and ecological functions in the Appalachians, since they are a part of the headwaters of many rivers (Smith and Michael 1982).

Most Appalachian peatlands may be classified as small minerotrophic fens, as they are characteristically found in high valleys or synclines subject to cold air drainage and poor water drainage. They have a higher pH and receive significantly greater amounts of ions from surrounding soils than do northern bogs (Wieder *et al.* 1981; Wieder 1985). Ombrotrophic (rain-fed) bogs receive most, if not all, ions from rain water, and have a low pH (<4.1). They also have higher peat accumulation rates and a convex surface profile compared to minerotrophic bogs (Heinselman 1970).

Aside from geochemistry, fens and bogs are differentiated by their vegetational composition. Bogs are generally treeless and are dominated by dwarf shrubs, whereas fens have more variable vegetation including more trees, graminoids, and a higher overall species diversity (Gore 1983). The last is presumably a result of higher nutrient

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[2] Address after June 1, 1993: Agronomy Dept., University of Georgia, Athens, GA 30602.

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availability (Tallis 1983). Both types of wetlands typically are rich in bryophytes, especially Sphagnaceae, but this is especially true in ombrotrophic bogs.

We will use "bog" in a broad sense, to mean any relatively treeless, wet, sphagnous area, including fens. The sites used in this study fit this description and also contain member(s) of the genus *Vaccinium* section *Oxycoccus* (cranberries). Cranberries are dwarf shrub bog endemics that are relatively rare in the Appalachians. For example, *V. macrocarpon* reaches its southern limit in Tennessee and North Carolina, and *V. oxycoccus* in West Virginia (Vander Kloet 1983; Ogle 1984).

The objectives of this study were to conduct a comparative quantitative analysis of the vegetation of dwarf shrub Appalachian bogs containing cranberries as an important plant and to relate the composition of the vegetation to edaphic factors.

STUDY SITES. Site 1 (Tennessee) is located in the Ridge and Valley physiographic province, 36°30′N, 81°57′W. The treeless area (bog) is about 0.16 ha in area. The site has an elevation of 1010 m and lies at the headwaters of Beaverdam Creek. It is located on Cross Mountain, and lies adjacent to Shady Valley, a onetime large (>4000 ha) boggy area (Killebrew and Safford 1874). The site is bordered by forest on one side and by pasture on the other sides, and is situated on a cattle farm. The bog itself has been fenced for about 9 years to exclude cattle. The surrounding forest is an oak-hickory association. Because site 1 is on a farm, in a watershed impacted by agriculture, we predicted that it would have relatively high soil nutrient status.

Sites 2 and 3 are located on the Allegheny Plateau in West Virginia, 38°5′N, 80°17′W. The bogs are 0.25 ha (site 2) and 0.20 ha (site 3) in area. These sites have an elevation of 920 m and are perched on top of Droop Mountain. The bogs are separated by a 25 m wide strip of forest. The surrounding forest consists mainly of *Tsuga canadensis* and *Picea rubens*. Topography would suggest that these are ombrotrophic bogs, as they receive no mineral nutrients from runoff, and they have a deep peat layer (>1 m).

Sites 4 and 5 are also on the Allegheny Plateau in West Virginia approximately 20 km from sites 2 and 3, 38°12′30″N, 80°15′W. These sites are 3.2 ha (4: Flag Glade) and 11.3 ha (5: Round Glade) in area, and have an elevation of 1030 m. They are part of the Cranberry Glades, a wetland complex comprising about 300 ha. The two bogs are separated by approximately 40 m of scrub and forest. The surrounding forest is similar to that at sites 2 and 3. Because the bogs lie in a hanging valley and receive runoff from surrounding mountains, and the wetland system is dissected by streams, we hypothesized that the soil nutrient status would be intermediate between site 1 and sites 2 and 3. The vegetation at these two sites, unlike the others, has been previously studied (Darlington 1943; Edens 1973).

Methods. Five soil cores of the surface layer (top 20 cm) of the substrate were taken from every second transect in each bog to determine soil nutrient status and pH. Macronutrients were determined by a double acid extraction procedure and measured with an inductively-coupled plasma spectrometer. These, bulk density, and organic matter were determined at the VPI & SU soil laboratory by methods described by Donahue and Gettier (1988). Ammonium was determined by the indophenol blue method, a colorimetric procedure (Keeney and Nelson 1982). Soil nutrients were represented by mass per unit volume of soil to make valid comparisons among the soils, since plants exploit soil nutrients on a volumetric basis.

The point-quarter method (Cottam and Curtis 1956) was used to determine importance values of the species surveyed in each bog. The standard algorithms associated with this technique were employed. However, this method was originally designed for tree surveys, where basal area is a measurement necessary to determine relative dominance, and, in turn, importance values. Since bog plants are of small stature, basal area is not a relevant measurement of size in this case. Instead, we used a relative size index based upon mean ramet volume occupied by each species, and standardized it to the largest species on the sites, *Osmunda cinnamomea*. *Osmunda* occupied ~1 m^3 and had a relative size of 10. *Symplocarpus foetidus* occupied ~0.6 m^3 and therefore had a relative size of 6, and so on (Table 1). Two species (*Drosera rotundifolia* and *Gaultheria procumbens*) that were relatively unimportant in the bogs we surveyed and had extremely small ramet size received an arbitrary relative size of 0.5, the lowest value given. Importance value = relative frequency + relative density + relative dominance. Relative frequency = frequency of each species/frequency of all species. Relative density = density of each species/den-

Table 1. Relative size index of species found in 5 Appalachian peat bogs.

Species	Relative size
Recumbent shrubs/vines	
Gaultheria procumbens	0.5
Rubus hispidus	0.5
Vaccinium macrocarpon	0.5
V. oxycoccus	0.5
Herbs	
Calopogon pulchellus	1
Drosera rotundifolia	0.5
Galium obtusum	0.5
Hypericum punctatum	1
Impatiens capensis	2
Osmunda cinnamomea	10
Polygonum sagittatum	2
Symplocarpus foetidus	6
Upright woody shrubs	
Acer rubrum	3
Alnus rugosa	3
Amelanchier bartramiana	2
Pyrus melanocarpa	2
Viburnum cassinoides	3
Graminoid	
Agrostis perennans	2
Carex incomperta	1.5
C. lurida	2
C. normalis	3
C. rostrata	3
Eleocharis tenuis	1
Eriophorum virginicum	2
Holcus lanatus	3
Juncus canadensis	3
Panicum dichotomum	2
Rhynchospora alba	1
R. capitellata	2

sity of all species. Relative dominance = size × relative frequency of each species/relative frequency of all species. The point-quarter method has been criticized by Risser and Zedler (1968) as an inappropriate technique for grassland vegetation quantification, because of a tendency to underestimate density of aggregated plant stands. Dwarf shrubs, which are by far the most important group in bogs, do not aggregate to the degree of grass ramets, but are more randomly and evenly distributed throughout a site. In comparing non-destructive techniques, the point-quarter method is probably at least as accurate at estimating vegetation importance as % cover in bog communities. We would contend that it would be superior because it takes into account the three-dimensional structure of the vegetation.

The sampling strategy was thus: 10 parallel, 20 m long transects were established 2 m apart across the bog. From these, 3 were randomly chosen. Every 2 m along the transect was a point, and for every point there were four quarters. A total of 120 quarters were sampled. If a species in the bog was not present within 200 cm of a point, it was not considered present for frequency, but was recorded arbitrarily as 400 cm from the point. Since the most important or dominant species tended to be very close to the point (<50 cm), any value over ~200 cm is negligible in the ultimate importance value computations.

Regression analysis measured the relationships between important recumbent shrub/vine species and also between vegetation, and soil nu-

Table 2. Soil nutrient conditions of 5 Appalachian bogs. Statistical analysis used is ANOVA with multiple comparisons using Fisher's LSD (Zar 1984). Different superscript letters in rows denote significant differences at the 0.05 level.

	Site				
	1	2	3	4	5
Location	Johnson Co., TN	Pocahontas Co, WV: Droop Mtn		Pocahontas Co, WV: Cranberry Glades	
Elevation (m)	1010	920	920	1030	1030
Soil organic matter (%)	42^{a}	91^{b}	94^{b}	94^{b}	95^{b}
Soil bulk density (g/cm³)	0.3^{a}	0.05^{a}	0.05^{b}	0.05^{b}	0.05^{b}
pH	4.7^{a}	4.0^{b}	3.7^{c}	3.6^{c}	3.9^{b}
Soil macronutrients ($\mu g/cm^3$)					
NH_4^+-N	7.16^{a}	1.60^{b}	0.78^{c}	2.52^{d}	5.02^{e}
NO_3^--N	0.90^{a}	0.15^{b}	0.15^{b}	0.15^{b}	0.15^{b}
P	1.20^{a}	0.06^{b}	0.08^{b}	0.17^{c}	0.22^{c}
K	14.3^{a}	0.36^{b}	1.18^{bc}	1.83^{cd}	2.45^{d}
Ca	97.2^{a}	3.45^{b}	5.25^{b}	7.40^{b}	19.0^{c}
Mg	17.7^{a}	1.04^{b}	1.66^{b}	1.35^{b}	3.07^{c}

Table 3. Vegetation importance values of 5 Appalachian peat bogs.

Species	Site 1	2	3	4	5
Recumbent shrubs/vines					
Gaultheria procumbens	—	—	—	—	15
Rubus hispidus	186	10	18	22	46
Vaccinium macrocarpon	17	17	2	—	—
V. oxycoccus	—	190	180	183	118
Totals	203	217	200	205	179
Herbs					
Calopogon pulchellus	—	5	7	—	—
Drosera rotundifolia	—	17	8	4	—
Galium obtusum	4	—	—	—	—
Hypericum punctatum	8	—	—	—	—
Impatiens capensis	6	—	—	—	—
Osmunda cinnamomea	22	2	8	4	—
Polygonum sagittatum	5	—	—	—	—
Symplocarpus foetidus	—	10	18	0.3	—
Totals	45	34	41	8.3	0
Upright woody shrubs					
Acer rubryum	—	1.3	7	—	—
Alnus rugosa	—	—	—	1.4	—
Amelanchier bartramiana	—	—	—	—	2
Pyrus melanocarpa	—	13	28	17	27
Viburnum cassinoides	—	0.8	4	1.9	15
Totals	0	15.1	41	20.3	44
Graminoid					
Agrostis perennans	8	—	—	—	—
Carex incomperta	10	—	—	3	—
C. lurida	6	—	—	—	—
C. normalis	5	—	—	—	—
C. rostrata	—	—	—	3	—
Eleocharis tenuis	7	—	—	—	—
Eriophorum virginicum	—	11	11	16	14
Holcus lanatus	1.1	—	—	—	—
Juncus canadensis	6	—	—	2	—
Panicum dichotomum	4	—	—	—	—
Rhynchospora alba	—	22	11	41	62
R. capitellata	5	—	—	—	—
Totals	52.1	33	22	65	76

trient status (Zar 1984). Nomenclature follows Strausbaugh and Core (1978).

Results and Discussion. Soil Nutrients. Soil bulk density was much higher in site 1 (TN) than in the other sites (WV) (Table 2). This is a result of higher decomposition rates and minerotrophy at site 1, and is reflected by the lower organic matter fraction at site 1. The peat at site 1 was also more highly decomposed than at sites 2–5 (personal observation). All the surveyed bogs except site 1 were very acidic with low concentrations of plant macronutrients. Site 1 was more minerotrophic than the other sites, as is evident by higher soil pH and soil nutrient contents (Table 2). With the exception of site 1, phosphorus was especially low when compared with other wetlands (Schlesinger 1991).

Site 1 is a weakly minerotrophic (poor) fen based upon Heinselman's (1970) widely used criteria of peatland classification which consider pH and cation concentrations. Site 1 is similar to the few bogs that have been studied in the southern Appalachians (Chappell 1972; Ogle 1982; Schafele and Weakley 1990). Based upon the same criteria, sites 2–5 (WV) are weakly ombrotrophic bogs. That is, these mid-Appalachian bogs have slightly higher pH and cation levels than the raised bogs of Minnesota (Heinselman 1970). These bogs seem to represent the maximum ombrotro-

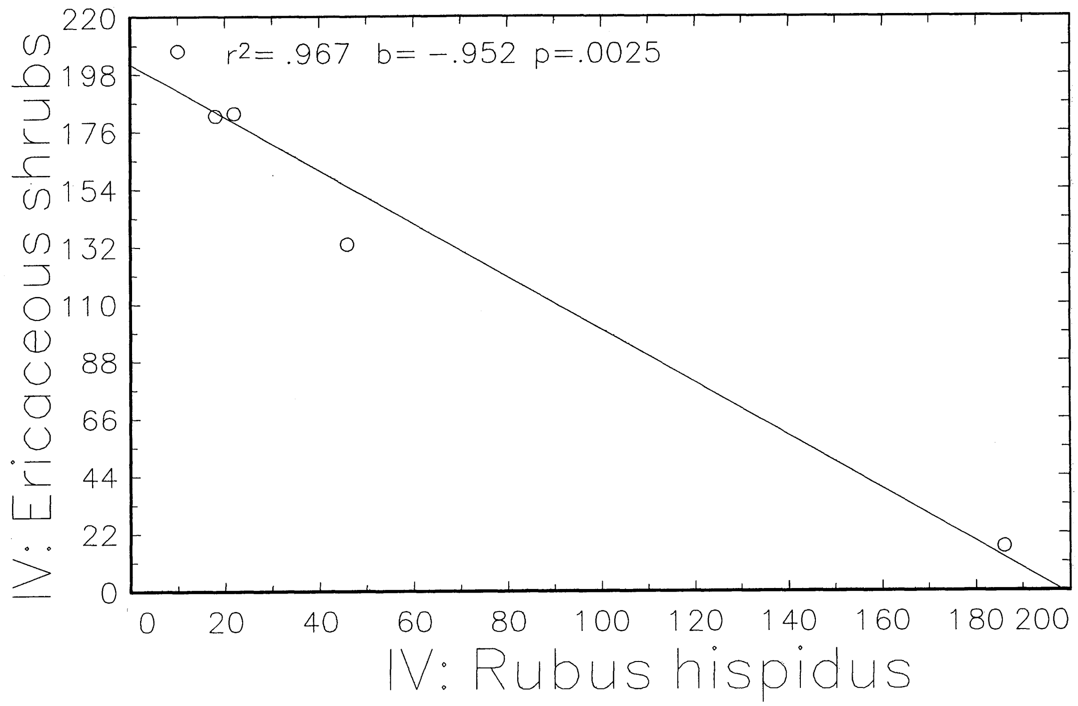

Fig. 1. Regression analysis of importance values between *Rubus hispidus* and the remaining members of recumbent shrubs (all in the family Ericaceae) of 5 Appalachian bogs.

phy found in the mid-Appalachians and are also similar to other WV bogs (Gibson 1982; Wieder 1985) and bogs in northern New Jersey and southern New York (Karlin and Lynn 1988). In general, soil fertility among sites had the relationship: 1 > 5 > 4 > 3 > 2, except for nitrate in which there were no differences among sites 2–5 (Table 2).

Vegetational Structure. The vegetation of site 1 is dominated by the recumbent *Rubus hispidus,* while sites 2–5 a dominated by the recumbent *Vaccinium oxycoccus* (Table 3). In site 1, *Osmunda cinnamomea* and *V. macrocarpon* are also important. Sites 2–5 have similar co-dominant vegetation (*Pyrus melanocarpa, Rhynchospora alba, R. hispidus, Symplocarpus foetidus*) (Table 3). Notably, *R. alba* was very important at sites 4 and 5, and *R. hispidus* also at site 5. Sampling areas in sites 4 and 5 were located within Darlington's (1943) *Sphagnum*-cranberry-beaked rush association. The sampling was not intended to be a floristic survey, but a vegetational sampling of selected plots. Generally, all sites had one extremely important recumbent, and such species dominated the vegetational structure (Table 3).

Appalachian Bog Vegetation and Northern Bog Vegetation. Anecdotally, Appalachian bogs have been compared to northern peat bogs because both are characteristically dominated by *Sphagnum* and dwarf shrubs and have similar geochemistry (Wieder *et al.* 1981). However, there are differences in species composition, the degree of minerotrophy, and modes of bog formation. The reasons for these differences have not been fully elucidated, but certainly climatic differences, topography, and island biogeographic effects are probably important factors (Wieder *et al.* 1981). Climate in the Appalachians can sometimes be cool enough for peat accumulation, which in turn supports acid-loving bog plants. Cool moist conditions for peat formation exist in hanging valleys and on level mountain tops, and there are few such sites in the mid- to southern Appalachians conducive to bog formation. Therefore, the bogs in the Appalachians are characteristically isolated from one another. These factors contribute to differences in vegetation structures among Appalachian bogs and also to differences from northern bogs of similar geochemistry.

Several important species in the WV sites are absent in the TN site. Some examples are *Vac-*

cinium oxycoccus, which is at its southern limit in WV, *Rhynchospora alba, Eriophorum virginicum, Pyrus melanocarpa, Viburnum cassinoides,* and *Symplocarpus foetidus.* Similarly, the sites in this study are at or near the southern limits of dominant northern bog species. Among Appalachian bogs, however, there are several common dominant species: *Vaccinium oxycoccus, V. macrocarpon, Rhynchospora alba,* and *Eriophorum virginicum.* Likewise, some dominant Appalachian species are not important in northern bogs (*Rubus hispidus, Osmunda cinnamomea, Pyrus melanocarpa,* and *Symplocarpus foetidus*), although all are widely distributed throughout northern areas.

The bogs surveyed in this study had dominant vegetation similar to that of other Appalachian bogs. Cranberries, *R. hispidus, E. virginicum, R. alba,* and *Carex* are common elements in Appalachian bogs (Chappell 1972; Wieder *et al.* 1981; Gibson 1982; Ogle 1982; Schafele and Weakley 1990). However, the vegetational composition is widely divergent among Appalachian bogs for minor species.

Unlike northern ombrotrophic raised bogs, Appalachian bogs are difficult to define precisely by vegetation. Similarly, Appalachian bogs differ in species composition from northern bogs. Nonetheless, both Appalachian and northern bogs are: 1) dominated by dwarf shrubs, 2) acidic, nutrient poor, 3) *Sphagnum* rich, and have a peaty surface layer.

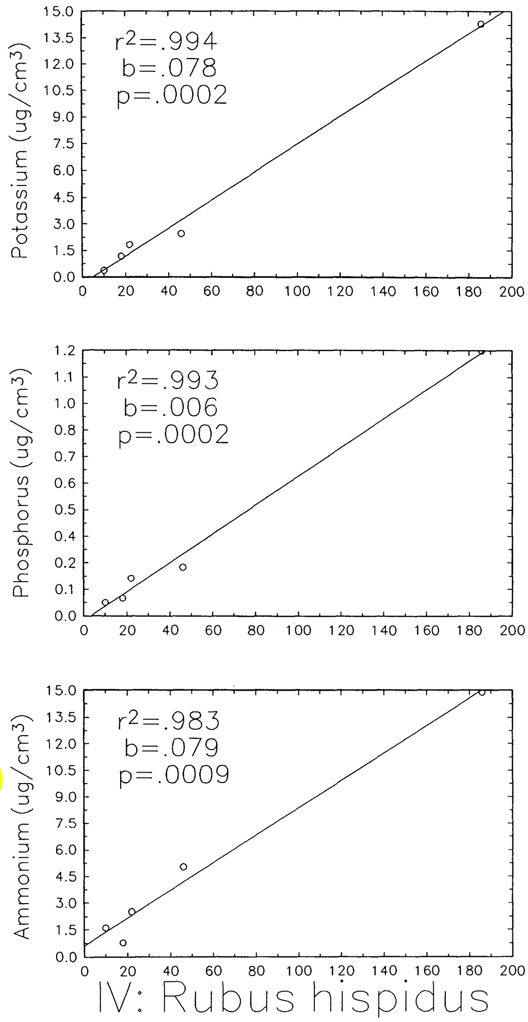

Fig. 2. Regression analysis of importance values and NH_4^+-N, P, K, concentrations in soil with *Rubus hispidus.* Calcium and magnesium show similar r^2 values, slopes and significance.

Edaphic Factors and Bog Vegetation. Sites 2 and 3 are in the same wetland complex, and sites 4 and 5 also are proximate to each other. They were all treated singularly in the regression analysis because of their contrasting vegetation and soil nutrient status. In sites with high nutrient status, *Rubus hispidus* has increased importance as dwarf shrubs (Ericaceae) have decreased importance (Fig. 1). However, the recumbent shrub growth form remains dominant in all sites. There accordingly seems to be a tradeoff between *R. hispidus* and the other members of the growth form (Fig. 1). Importance value of *Rubus hispidus* is positively associated with macronutrients among sites (Fig. 2). Importance values of the remaining recumbent dwarf shrubs are negatively associated with macronutrients (e.g., r^2 = 0.94, K; 0.94, P; 0.97, NH_4^+). Results are statistically significant ($P < 0.05$; H_o: slope (b) = 0), with high r^2 values. Furthermore, even if the regression analysis is performed disregarding site 1, the results are still statistically significant, although the regression lines have slightly flatter slopes.

Substrate cation concentrations and pH are known to be important factors affecting bog vegetational composition (Heinselman 1970; Vitt and Slack 1975; Schwintzer 1978). There is extensive ecophysiological evidence that elevated levels of soil nutrients have profound effects upon alpine and bog plants. Stress-tolerating evergreen species have a higher leaf turnover rate (Shaver 1981) and higher nutrients in litter (Chapin 1980, 1987). Higher nutrient status in leaf litter encourages higher soil nutrient mineralization rates (Schlesinger 1977; Vitousek 1982; Stewart and Nilsen 1992). The resulting fertilization effect, coupled with warmer climate, leads to higher primary productivity, which is observed in Appalachian peatlands compared with their northern counterparts (Wieder and Lang 1983; Wieder *et al.* 1989), and, under global warming scenarios, peat could become a carbon source rather than its current status as a carbon sink (Billings *et al.* 1982).

CONCLUSIONS. Bogs containing dwarf shrubs, such as *Vaccinium oxycoccus,* resemble northern ombrotrophic dwarf shrub bogs but have different species composition and higher minerotrophy. In the bogs we surveyed, recumbent shrubs dominated the vascular vegetation. There was a tradeoff in importance values between *Rubus hispidus* and dwarf ericaceous shrubs. This trend was correlated with soil macronutrient status, with *Rubus hispidus* gaining importance in nutritionally rich sites.

Similar studies of more sites are needed, not only in the Appalachians but in northern bogs as well. Further research is needed to determine if a causal relationship exists between soil nutrients and vegetation structure changes. This may be accomplished by long-term monitoring of bog vegetation structure and also through long-term fertilization studies. If the levels of nutrients are kept chronically high at sites for a long period of time, we will better understand how nutrients induce changes in bog vegetation composition and which nutrients are most important in this role.

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