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A Discriminant-Function Approach to Ecological Site Classification in Northern New England

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Abstract

Describes one approach to ecologically based classification of upland forest community types of the White and Green Mountain physiographic regions. The classification approach is based on an intensive statistical analysis of the relationship between the communities and soil-site factors. Discriminant functions useful in distinguishing between types based on soil-site factors most strongly correlated with their distribution over the landscape are presented.

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Introduction

Qualitative investigations of the ecological and productive potential of forest land in northern New England from soil, topographic, and vegetative characteristics have a long history (Tuckerman 1860; Bray 1915; Nichols 1918; Adams et al. 1920; Heimberger 1934; Hazard 1937; Stanley 1938; Westveld 1951, 1952, 1954). Only more recently has there been a more quantitative approach to ecological site characterization, primarily in terms of productivity related to suites of site and soil characters (Post and Curtis 1970; Leak 1976, 1978, 1980, 1982).

Leak (1982) discussed the conceptual model upon which classification of communities in northern New England should be based. He enumerated physiographic region, climate (elevation, latitude), mineralogy of the glacial drift, and habitat, defined on the basis of soil substrate, as the hierarchy best able to account for differences in distribution of vegetation in northern New England. In an analysis of the soil- vegetation relationship in the southern White Mountains, Leak demonstrated that habitats distinguished based on land form, soil materials, and vegetation differed in a quantitatively significant manner with respect to stand composition, understory vegetation, biomass, volume, and diameter development by species. These findings indicate that there are distinct relationships between soil-site factors and forest plant communities in northern New England and that further investigation using quantitative methods to determine the strength of this correlation is warranted.

Quantitative analysis of patterns of soil-site factors in relationship to plant communities has proven valuable in the development of ecological classifications in similar ecological regions in the province of New Brunswick, Canada (Zelazny et al. 1989) and in the Lake States (Pregitzer and Barnes 1984; Spies and Barnes 1985; Host et al. 1988). This methodology is being used to help delineate units of land with a unique combination of potential natural community, soil, landscape features, and climate, and which differ from other units in their ability to produce vegetation and respond to management. Such an approach should allow more accurate ecological classification of sites, enhance our understanding of successional pathways of disturbed forest environments, and contribute information that can be used to develop management strategies for forested lands predicated on a site's fullest, most natural potential.

The objectives of this study were to: 1) develop a preliminary classification of forest plant communities found on lithic, basal till, ablation till, and outwash parent materials at similar latitudes across the White and Green Mountains of northern New England; and 2) identify the site and soil-physical factors that best discriminate between communities delimited by this classification across and within these two physiographic regions.

Study Area

Lull's (1968) published physiographic regions (Fig. 1), adapted from Fenneman (1938) for the New England and adjacent states, divide New Hampshire and Vermont into five principal physiographic regions. Sampling was conducted on the Bartlett and Hubbard Brook Experimental Forests and surrounding areas in the White Mountain region and on the Middlebury and Rochester Ranger Districts of the Green Mountain National Forest within the Green Mountain Region (Fig. 2).

Landscapes in both regions reflect the influence of glaciation. The major landforms have been shaped by erosional processes, but the soils of both regions have weathered primarily from a thin mantle of glacial drift of mostly local origin. Glacial till consisting of a mixture of boulders, stones, sand, silt, and clay is the dominant soil parent material located within the study area, though glacial outwash and sediments are common in valleys. The soils on the rolling hilly lower landscapes, near streams, generally are without pan layers, while those at higher elevations and on smooth elliptical landforms usually have compact till layers in the substratum (Driers and Vieira 1977). Although the glacial and soil-forming processes over the study areas are similar, soil mineralogy and characteristics differ. Soils of the Bartlett area are weathered primarily from granitic drift characterized by coarse texture and low fertility. Soils of the Hubbard Brook area are weathered from glacial drift derived from crystalline schist, are somewhat more fertile, and have a more loamy texture. Gneiss, mica schist, and quartzite are the primary components of the bedrock and drift from which soils have weathered in the study area in Vermont. Leak (1978) presented evidence that species composition and site index for a given habitat or type vary among glacial drifts with different mineralogies.

Methods

Field Procedures

A total of 150 upland northern hardwood stands were sampled in 1989. Stands sampled must have met the following criteria: 1) The sample stand must have been located on lithic, basal till, ablation till, or outwash parent material; 2) The site must have been relatively undisturbed and contain predominantly tolerant species. Areas with a recent history of cutting or which appeared to have been cultivated or pastured at any period were omitted. Areas that represented obvious ecotones were avoided; 3) Plot locations ranged in elevation from 215 to 800 m.

One 500-m^2 (12.5-m-radius) circular plot was established in each suitable stand. The absolute cover, the percentage of the ground surface covered by the live foliage area of a plant species, was estimated for all vascular plant species on the sample plot. Cover values were estimated to the nearest 1 percent for species with less than 10 percent total cover, and to the nearest 5 percent when total cover exceeded 10 percent.

The canopy was divided into cover layers on the basis of plant form, consisting of dominant / codominant, intermediate, and seedling / sapling tree species, tall and low shrubs, ferns, forbs, grasses, and mosses. Tree species that

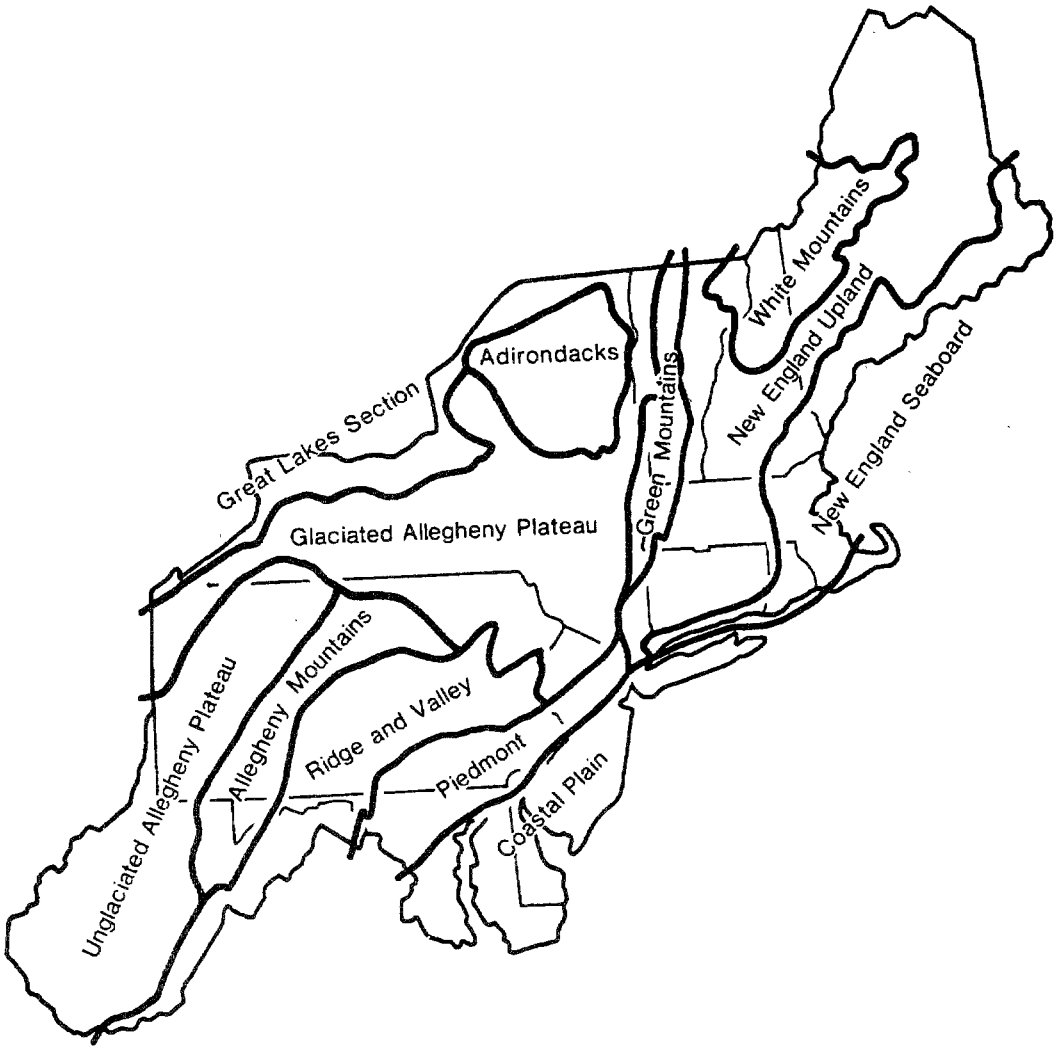

Figure 1.—Major physiographic regions of Vermont and New Hampshire.

were more than 23 cm in diameter at breast height (dbh) were considered as dominants / codominants; those ranging from 3.7 m in height to less than 23 cm dbh were intermediates; and coniferous species between 15 cm and 3.7 m in height were considered as seedlings / saplings, as were deciduous species between 30 cm and 3.7 m in height. Different minimum heights were used because survival rates differ between conifer and deciduous seedlings (Leak et al. 1987; Leak and Wilson 1958).

A soil profile was described and classified using standard soil survey procedures (Soil Survey Staff 1981). Depth of pits generally was to 100 cm unless a restrictive layer was encountered. Samples of the C horizon were collected and analyzed for particle-size distribution using wet-sieving procedures. The samples were sieved into five size classes: very coarse sand (2 to 1 mm), coarse sand (1 to 0.5 mm), medium sand (0.5 to 0.25 mm), fine to very fine sand (0.25 to 0.05 mm), and silt/clay (< 0.05 mm). Table 1 lists the soil-site factors measured at each plot. As the focus of this study was on field-identifiable characteristics of both vegetation and soil, no chemical analyses were performed.

Numerical Analysis

Data analysis was divided into the following procedures:

1) Stands were classified using the two-way indicator-species analysis, TWINSPAN (Hill 1979a), a polythetic divisive technique. TWINSPAN emphasizes differential species and produces an ordered samples X species matrix designed to show sharp relief between groups of species or samples. Ideally, a differential species is one with clear ecological preferences so that it s presence can be used to identify particular environmental conditions.

2) Stands were ordinated using detrended correspondence analysis, DECORANA (Hill 1979b). TWINSPAN groups were examined in the DECORANA ordination space to evaluate within-group compositional consistency and to facilitate

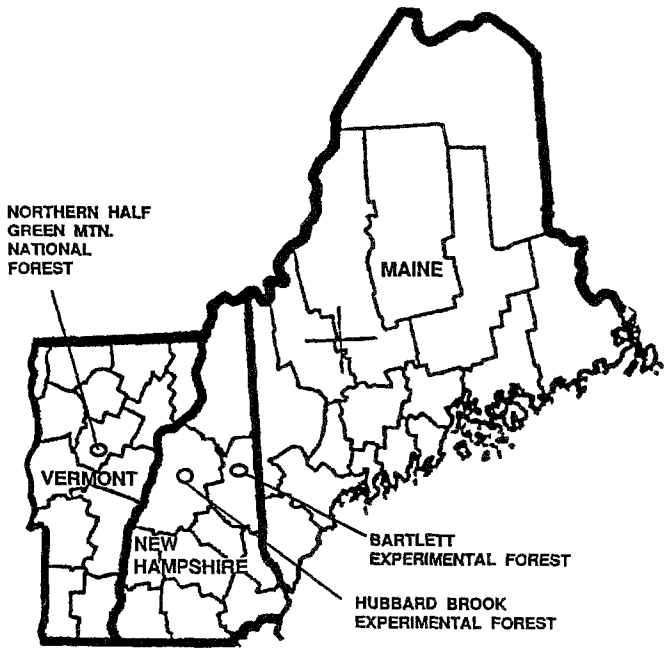

Figure 2.—The study area.

Table 1.—Soil-site factors measured.

Soil-site factor	Unit of measurement
Slope	Percent
Aspect	Degrees—azimuth
Elevation	Meters
Percent bare ground	Percent plot surface area
Percent surface boulders	Percent plot surface area
Parent material	Granite, schist
Texture C horizon	Percent in 2 to 1 mm, 1 to 0.5 mm, 0.5 to 0.25 mm, 0.25 to 0.05 mm, and < 0.05 mm size classes
Soil drainage class	VP=1, P=2, SP=3, MW=4, W=5, EW=6
Depth to impermeable layer	Centimeters
Organic-matter depth	Centimeters
Depth to mottling	Centimeters
Rooting depth	Centimeters from top of mineral soil
Percent coarse fragments	Percent volume, by horizon

determination of environmental gradients that influence the distribution of community types.

3) The relationship of soil-site factors to the community types identified through classification and ordination was analyzed by linear discriminant analysis, a statistical technique in which linear combinations of variables are used to distinguish between two or more categories or cases. The variables "discriminate" between groups of cases and predict into which category or group a case falls based on the values of those variables (Norusis 1985). To some extent, ecological studies violate the assumptions of this predictive procedure. For example, there may be prediction bias if the number of independent variables is large relative to sample size or when multivariate normality cannot be assumed (see Verbyla 1986). However, this limitation does not diminish the descriptive value of the analysis. Discriminant analysis followed the procedures described in Wilkinson (1988).

Results and Discussion

TWINSPAN classification, which is based on the cover attributes of plant species, resulted in the identification of eight forest-community types. Community- type names were derived by denoting the dominant tolerant tree species. Dominant understory species were included in the names of two types because they were found almost exclusively in those two communities. Names and abbreviations for community types are listed in Table 2. TWINSPAN classification was effective in displaying apparent community types among the forest stands sampled. However, it did not indicate whether the samples within the groups and between the groups occupy similar ecological space. DECORANA analysis allows visualization of the similarity of samples and inference of the environmental gradients associated with their distribution. The first and second axes of the detrended correspondence analysis ordination of samples accounted for 61 and 35 percent of the variation in sample DECORANA ordination scores. Rooting depth ($r=0.42$, $P< 0.001$) and elevation ($r=0.59$, $P< 0.001$) had the highest correlations with axes 1 and 2, respectively. A mosaic diagram was constructed by plotting these two axes, showing the general relationship among rooting depth, elevation, and community types (Fig. 3). Rooting depth decreases from the origin of axis 1, with elevation increasing from the origin of axis 2.

Table 2.—Community types and abbreviated codes referred to in the text

Abbreviated code	Community type
FAGR/ACSA/ARTR	*Fagus grandifolia/Acer saccharum/Arisaema triphyllum*
FAGR/ACSA	*F. grandifolia/A. saccharum*
FAGR/ACSA/PIRU	*F. grandifolia/A. saccharum/Picea rubens*
FAGR/TSCA	*F. grandifolia/Tsuga canadensis*
TSCA	*T. canadensis*
TSCA/PIRU	*T. canadensis/P. rubens*
PIRU/ABBA	*P. rubens/Abies balsamea*
PIRU/ABBA/VAAN	*P. rubens/A. balsamea/Vaccinium angustifolium*

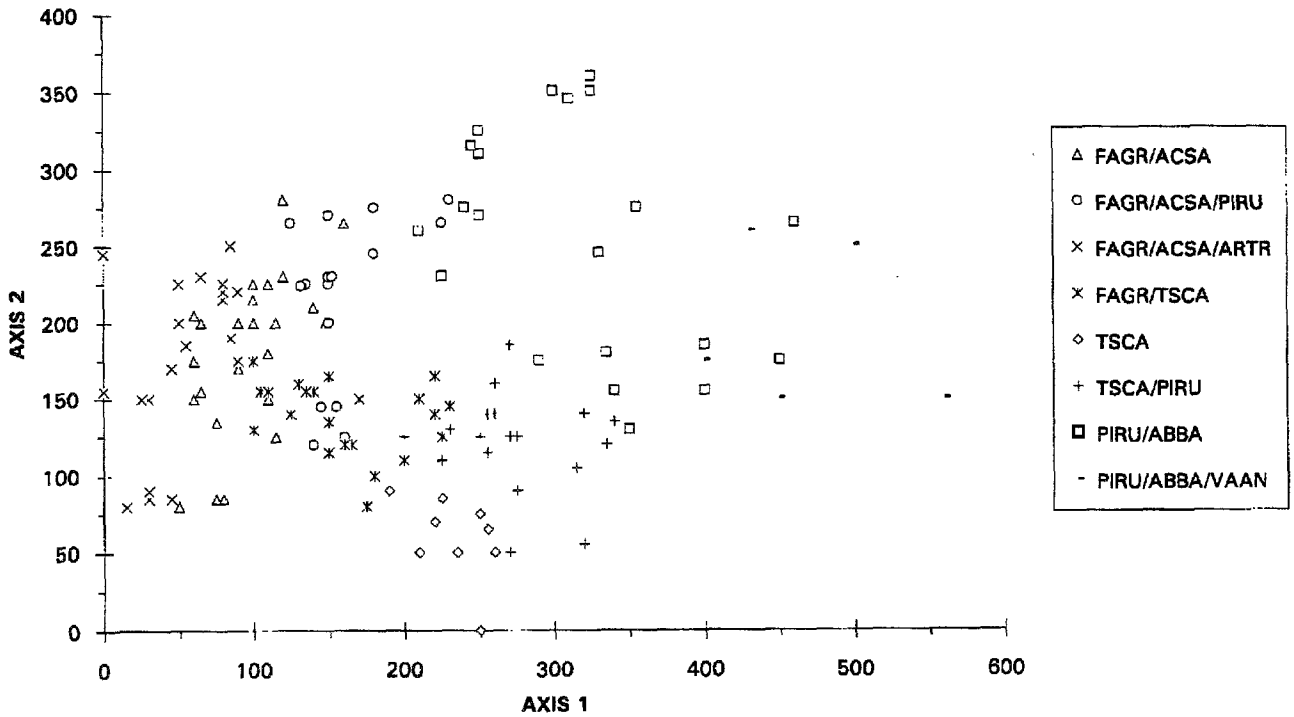

Figure 3.—Location of 147 study plots with respect to DECORANA axes 1 and 2. Axis values are expressed in units of standard deviations of eigenvectors x 100. Symbols represent community type membership identified in TWINSPAN analysis.

Relationship Between Vegetation and Soil-Site Factors

In the field, the transition between conifer-and hardwood-dominated community types was distinct, while the transition between hardwood community types tended to be more gradual. This relationship is illustrated in the graphic of DECORANA scores, which suggest that the species composition of the hardwood community types is more homogeneous than that of the conifer community types.

The relationship between vegetation and soil-site factors was examined using two approaches. The first consisted of a simple comparison of soil taxonomic units and the community types. In the second approach, direct discriminant function analysis was used to determine the relationship between community types and soil-site factors. As stated previously, the focus of this study was on field-identifiable characteristics of both vegetation and site, so physical characteristics were used to analyze soil-site and community-type relationships.

Soil taxonomic units and community types. Tables 3 and 4 show the distribution of sample stands within each community type across the study area by parent material and soil taxonomic group. The pattern of sample stand distribution indicates that communities are responsive to the influence of soil and site characteristics expressed in this manner; however, the variability in the range of distribution suggests that the community types do not respond in a uniform manner to soil-site factors expressed at this scale.

Table 3.—Distribution of community types by parent material

	Till						
Community type	Firm	Loose	Compact	Lithic	Outwash	Other	Total
FAGR/ACSA/ARTR	5	2	12	1	—	3	23
FAGR/ACSA	8	4	11	—	6	—	29
FAGR/ACSA/PIRU	4	2	6	2	1	1	16
FAGR/TSCA	7	3	7	1	3	4	25
TSCA	—	1	2	4	2	—	9
TSCA/PIRU	2	3	5	4	4	1	19
PIRU/ABBA	3	—	2	12	4	—	21
PIRU/ABBA/VAAN	—	—	—	5	—	—	5
Total	31	15	45	29	20	7	147

Table 4.—Occurrences of the community types by soil subgroups, in percent

Soil	Community type							
	FAGR ACSA ARTR n=23	FAGR ACSA n=29	FAGR ACSA PIRU n=16	FAGR TSCA n=25	TSCA n=9	TSCA PIRU n=19	PIRU ABBA n=21	PIRU ABBA VAAN n=5
				Spodosols				
Typic Haplorthods	35	42	31	56	33	63	24	—
Typic Fragiorthods	4	29	13	16	23	22	—	—
Typic Fragiaquods	—	—	—	4	—	—	—	—
Aquic Haplorthods	—	7	—	12	—	—	10	—
Aquic Fragiorthods	27	3	6	8	—	—	10	—
Lithic Haplorthods	4	—	6	—	44	5	43	80
				Inceptisols				
Typic Fragiochrept	9	3	13	4	—	—	—	—
Typic Dystrochrept	4	13	18	—	—	—	—	—
Aquic Fragiochrept	9	—	6	—	—	—	—	—
Aquic Dystrochrept	4	—	—	—	—	—	—	—
Fluventic Dystrochrept	4	3	—	—	—	5	—	—
Lithic Dystrochrept	—	—	6	—	—	5	14	20

Correspondence between the various levels of soil taxonomy (Soil Survey Staff 1975) and the eight community types is highly variable. Eight community types identified in this study occurred on 2 soil orders, 3 suborders, 5 great groups, 12 subgroups, and 40 families. Eighty-six of the soils sampled belong to either coarse-loamy, mixed; loamy-skeletal, mixed; or sandy, mixed soil families.

The variability in the occurrence of the community types on soil subgroups reflects the variability displayed in the distribution of community types by parent material. The distribution of hardwood-dominated community types is more broad than for conifer-dominated types. The latter tend to occur primarily on spodosols, but may be found on inceptisols developed from outwash or lithic parent materials. For example, the PIRU / ABBA / VAAN community type was found only on lithic sites. Soil depth to restrictive layer seems the soil-site factor that best accounts for the relationship between soil taxonomic units and conifer community types. Inference could also be made concerning the relationship among elevation, spodic development, and conifer community types. The relationship between soil taxonomic units and hardwood community types is not so obvious. The hardwood community types are broadly distributed, suggesting two possible hypotheses: it may be that hardwood community types occur on a broad continuum not strongly associated with physical soil-site factors, or they are more responsive to soil-site factors not discernible at the soil subgroup level.

These inferences on the relationship between soil subgroups and plant community types are primarily qualitative and reflect the modest utility of soil-subgroup classification to distinguish the vegetation potential of forested sites.

Discriminant functions and community types. Discriminant-function analysis (Wilkinson 1988) identified eight soil-site factors from among those listed in Table 1 (significant at $P < 0.05$), as the most effective predictors of community type membership (Table 5). However, simultaneous comparison of the mean values of the soil-site factors, by community type (Table 6), suggests that there is no simple relationship between community types and soil-site factors.

Using a pooled variance covariance matrix, seven discriminant functions were obtained. Each function represents a dimension along which the community types

Table 5.—Soil-site factors that best discriminate among the eight community types

Soil-site factor	F value	Significance
Lithic	14.448	0.000
Elevation	13.435	0.000
Soil depth to impermeable layer	8.311	0.000
% exposed bedrock	8.189	0.000
% moss-covered bedrock	7.168	0.000
Rooting depth	5.398	0.000
% coarse fragments in rooting zone	2.911	0.007
Organic-matter depth	2.584	0.017

Table 6.—Mean values of soil-site factors by community type

Soil-site factor	Community type							
	FAGR ACSA ARTR	FAGR ACSA	FAGR ACSA PIRU	FAGR TSCA	TSCA	TSCA PIRU	PIRU ABBA	PIRU ABBA VAAN
Lithic (%)	4	0	13	0	4	15	62	100
Elevation (m)	480	490	512	394	308	409	625	585
Depth to impermeable layer (cm)	86	100	85	106	73	89	54	31
Organic-matter depth (cm)	12	14	14	16	11	19	18	13
Rooting depth (cm)	58	62	60	63	47	50	38	32
Coarse fragments rooting zone (%)	24	24	17	25	32	19	14	20
Moss-covered bedrock (%)	0	0	1	0	2	1	3	7
Exposed bedrock (%)	0	0	0	0	4	1	1	9

differ. The first three of these functions account for the majority of discriminating power (see Tabachnick and Fidell 1989), with no additional information forthcoming from the remaining functions. The meaning of the significant functions can be inferred from the pattern of correlation between the soil-site factors and the first three functions (Table 7). Soil-site factors that display the highest correlation with each function can be viewed as representing a gradient important in determining plant-community distribution. Soil-site factors with correlations greater than 0.55 are considered the most important factors in determining this distribution (see Comrey 1973). Function 1 represents a gradient primarily associated with the increasing likelihood of a community type occurring on a lithic site as soil depth decreases with an increase in elevation. Function 2 represents a gradient associated primarily with increasing elevation. Function 3 represents a gradient of decreasing depth of organic matter.

Community types were ordinated along the environmental gradients determined by the eight soil-site factors by the calculation of canonical discriminant-function group mean scores by community type. Unstandardized group classification coefficients and constants were used to assign community type membership to a sample based on the eight soil-site factors. Classification accuracy of samples ranged from 67 percent correctly classified for the TSCA community type to 20 percent correctly classified for the PIRU/ABBA/VAAN community type, with an average correct classification of 42 percent. The simple numerical probability of guessing the correct community type is 12.5 percent. Discriminant-function analysis computed for a stratified data set, simulating the hierarchical breaks produced in the polythetic divisive groupings delimited by TWINSPAN analysis, increased the average probability of correctly classifying samples at the community type level from 42 to 47 percent (Table 8). One canonical discriminant function, standardized by conditional within-group standard deviations, was computed for each division (Table 9). The interpretation of these functions was inferred from the pattern of pooled within-group correlations between the soil-site factors and each function. Correlation between soil-site factors and each function that was greater than 0.55 (accounting for 30 percent overlapping variance) was interpreted as identifying the most significant factors associated with the hierarchical distribution of the community types.

The function for Division 1 identifies 11 soil-site factors as effective discriminators between the hardwood- and softwood-dominated community types. The likelihood of the community types occurring on a lithic site displayed the highest correlation (r = -0.76) Four percent of hardwood-dominated stands sampled were found on lithic sites compared to 45 percent for softwood-dominated stands. Lithic sites tend to be somewhat nutrient poor and seasonally saturated or droughty depending on slope position. Evergreen foliage, shallow rooting systems, and

Table 7.—Pooled within-group correlation between sil-site factors and canonical discriminant functions

Soil-site factor	Function 1	Function 2	Function 3
Lithic	0.89	0.19	-0.21
Soil depth to impermeable layer	-0.61	0.01	0.04
Elevation	0.57	-0.71	0.18
Percent moss-covered bedrock	0.47	0.22	0.44
Rooting depth	-0.47	0.22	0.44
% exposed bedrock	0.44	0.52	0.36
% coarse fragments rooting zone	-0.23	0.27	0.23
Organic-matter depth	0.08	-0.06	-0.55

Table 8.—Summary and comparison of community classification results using significant soil-site factors as the classification function coefficients on an unstratified data set and on a data set stratified by TWINSPAN divisions

Unstratified		Stratified by TWINSPAN divisions	
Community type	% classified correctly	Community type	% classified correctly
FAGR/ACSA/ARTR	30	FAGR/ACSA/ARTR	57
FAGR/ACSA	41	FAGR/ACSA	43
FAGR/ACSA/PIRU	25	FAGR/ACSA/PIRU	14
FAGR/TSCA	48	FAGR/TSCA	67
TSCA	67	TSCA	50
TSCA/PIRU	42	TSCA/PIRU	50
PIRU/ABBA	57	PIRU/ABBA	43
PIRU/ABBA/VAAN	20	PIRU/ABBA/VAAN	18
Average	42	Average	47

cold-hardiness of conifers give sites a competitive advantage. Rooting depth (r = 0.53), depth to impermeable layer (r = 0.50), and percent exposed bedrock (r = -0.36) are the next highest correlated soil-site factors, and are related to or influenced by soil depth.

Six soil-site factors were identified as effective discriminators between the FAGR/ACSA/ARTR, FAGR/ACSA, and FAGR/ACSA/PIRU community types and the FAGR/TSCA types differentiated at Division 2. The Bartlett area (r = -0.72) and elevation (r = 0.60) had the highest correlations with this function. FAGR/ACSA/ARTR and FAGR/ACSA/PIRU community types were not encountered during sampling in the Bartlett area; FAGR/TSCA was found primarily in the Bartlett area. The relationship between community types and the other four soil-site factors, percentage of 0.25- to 0.05-mm sand (r = -0.40), percentage of 0.50- to 0.25-mm sand (4 = -0.37), the Vermont area, and the percentage of silt/clay suggest why this may be the case. Bartlett soils are weathered primarily from granitic drift and generally are more coarse than soils weathered from the tills derived from metamorphosed mudstones and sandstones found in the Hubbard Brook and Vermont sampling areas. Soils of the TSCA/FAGR community type generally are more coarse than those associated with the other three community types. Texture influences water holding capacity and the percentage of humus and nitrogen present. A coarse textured soil may contain less organic matter and nitrogen than one of a finer texture (Brady 1984). This suggest that the FAGR/TSCA community type occupies sites that are less fertile, and possibly limited by moisture availability, characteristics common in the Bartlett area. The low species diversity in the community types associated primarily with the Bartlett area seems to support this observation. Marchand (1987) noted that hemlock usually occupies the less fertile sites among the hardwood-dominated stands.

Six soil-site factors were identified as effective discriminators between the TSCA and TSCA/PIRU community types and the PIRU/ABBA and PIRU/ABBA/VAAN types at Division 3. Elevation (r = -0.95) had the highest correlation with this function. Conifers segregate themselves distinctly along the elevation gradient (Cogbill and White 1991); this relationship is demonstrated in this function. As a general rule in conifer-dominated communities, hemlock dominates at lower and midslope elevations, while red spruce dominates the shallow, rocky midslope to upperslope positions, eventually giving way to balsam fir at higher elevations. The other five soil-site factors correlated with this function are strongly related to the landforms associated with increasing elevation.

The percentage of moss-covered (r = 0.96) and exposed bedrock (r = 0.72) are the soil site factors that act as effective discriminators between the FAGR/ACSA/ARTR and FAGR/ACSA community types and the FAGR/ACSA/PIRU types at Division 4. Red spruce is characteristically found on sites with shallow, rocky soils. However, overall classification accuracy for the FAGR/ACSA/PIRU samples was poor.

Four soil-site factors discriminate between the TSCA and TSCA/PIRU community types at Division 5: organic matter depth (r = -0.40), percent coarse fragments in the rooting zone (r = 0.39), elevation (r = -0.38), and percent exposed bedrock (r = 0.36). The correlations between these factors and the function are less than the critical value of 0.55; however, 89 percent classification accuracy suggests that the interaction between these factors is significant enough to allow good discrimination between the community types. Comparison of the unstandardized means for these four soil-site factors indicates that the TSCA community type generally occupies sites with a higher percentage of exposed bedrock and coarse fragments in the rooting zone, while the TSCA/PIRU community type is found at higher elevations with a greater depth of organic matter.

The percentage of exposed bedrock (r = 0.89) and moss-covered bedrock (r = 0.71) are effective discriminators between the PIRU/ABBA community types at Division 6. The PIRU/ABBA/VAAN type generally has a higher percentage of exposed and moss-covered bedrock, occupying sites typically found on ridge and mountain summits.

Two soil-site factors, depth to mottles (r = 0.88) and the Bartlett area (r = -0.77), discriminate between the

Table 9.—Soil-site factors that best discriminate between the polythetic divisive groupings produced by TWINSPAN analysis

Soil-site factor	Function 1	Function 2	Pooled within-group correlation	F value	Significance
Division 1: Northern Hardwood vs. Conifers					
Lithic	60.129	62.876	-0.76	58.271	0.000
Rooting depth	0.210	0.179	0.53	28.277	0.000
Depth to impermeable layer	1.664	1.641	0.50	25.410	0.000
% exposed bedrock	-0.043	0.008	-0.36	12.986	0.000
Vermont	3.159	2.115	0.33	10.883	0.001
Compact till	36.619	35.109	0.29	8.497	0.004
Firm till	5.208	3.734	0.29	8.269	0.005
Bartlett	1.267	2.102	-0.27	7.154	0.008
% moss-covered bedrock	0.236	0.209	-0.26	6.952	0.009
Organic-matter depth	1.631	1.795	-0.25	6.594	0.011
% coarse fragments rooting zone	0.019	0.018	0.22	4.830	0.030
Constant	-49.148	-48.780			
Division 2: FAGR/ACSA/ARTR, FAGR/ACSA, and FAGR/ACSA/PIRU vs. FAGR/TSCA					
Bartlett	4.034	8.010	-0.72	29.082	0.000
Elevation	0.015	0.013	0.60	20.082	0.000
% 0.25 mm sand	1.015	1.172	-0.40	8.999	0.004
% 0.5 mm sand	0.922	0.866	-0.37	7.753	0.007
Vermont	4.421	5.244	0.37	7.568	0.007
% silt/clay	0.904	0.898	0.33	6.009	0.016
Constant	-39.035	-38.741			
Division 3: TSCA and TSCA/PIRU vs. PIRU/ABBA and PIRU/ABBA/VAAN					
Elevation	0.010	0.014	-0.95	48.931	0.000
Depth to impermeable layer	1.569	1.407	0.51	14.514	0.000
Lithic	18.483	17.910	-0.51	14.460	0.000
Rooting depth	-0.081	-0.044	0.36	7.007	0.011
No impermeable layer	-29.474	-25.723	0.33	6.041	0.017
% coarse fragments rooting zone	0.135	0.130	0.30	4.917	0.031
Constant	-29.203	-33.306			
Division 4: FAGR/ACSA/ARTR and FAGR/ACSA vs. FAGR/ACSA/PIRU					
% moss-covered bedrock	0.177	-0.413	0.96	8.220	0.006
% exposed bedrock	-0.037	0.386	0.72	4.594	0.036
Constant	0.696	-1.070			
Division 5: TSCA vs. TSCA/PIRU					
Organic-matter depth	0.389	0.552	-0.40	5.254	0.030
% coarse fragments rooting zone	0.285	0.121	0.39	4.836	0.037
Elevation	0.006	0.010	-0.38	4.653	0.040
% exposed bedrock	0.546	0.059	0.36	4.286	0.049
Constant	-10.472	-10.874			

Continued

Table 9.—Continued

Soil-site factor	Function 1	Function 2	Pooled within-group correlation	F value	Significance
Division 6: PIRU/ABBA vs. PIRU/ABBA/VA					
% exposed bedrock	0.023	0.246	0.89	9.546	0.005
% moss-covered bedrock	0.012	0.070	0.71	6.126	0.021
Constant	-0.723	-2.620			
Division 7: FAGR/ACSA/ARTR vs. FAGR/AC					
Mottling depth	0.079	0.127	0.88	11.017	0.002
Bartlett	-1.348	0.215	0.77	8.425	0.005
Constant	-1.295	-2.575			

FAGR/ACSA/ARTR community types and the FAGR/ACSA types at Division 7. Examination of mean depth to mottling indicates that the FAGR/ACSA/ARTR community type is more likely to occur on sites with wetter soil moisture regimes. The FAGR/ARTR/ACSA type was not encountered during sampling in the Bartlett area. This interaction of mottling depth and community distribution along with our knowledge of soils within the study area suggest that the FAGR/ACSA/ARTR community type is strongly related to soil moisture, mineralogy, and/or texture.

Table 10.—Schematic of decision rules for assignment of samples to site types

Division 1 Northern Hardwood vs. Conifers

If value of Function 1 > Function 2 then Division 2
If value of Function 2 > Function 1 then Division 3

Division 2 FAGR/ACSA/ARTR
FAGR/ACSA vs. FAGR/TSCA
FAGR/ACSA/PIRU

If value of Function 1 > Function 2 then Division 4
If value of Function 2 >Function 1 then FAGR/TSCA

Division 3 TSCA PIRU/ABBA
TSCA/PIRU vs. PIRU/ABBA/VAAN

If value of Function 1 > Function 2 then Division 5
If value of Function 2 > Function 1 then Division 6

Division 4 FAGR/ACSA/ARTR
FAGR/ACSA vs. FAGR/ACSA/PIRU

If value of Function 1 > Function 2 then Division 7
If value of Function 2 > Function 1 then FAGR/ACSA/PIRU

Division 5 TSCA vs. TSCA/PIRU

If value of Function 1 > Function 2 then TSCA
If value of Function 2 > Function 1 then TSCA/PIRU

Division 6 PIRU/ABBA vs. PIRU/ABBA/VAAN

If value of Function 1 > Function 2 then PIRU/ABBA
If value of Function 2 > Function 1 then PIRU/ABBA/VAAN

Division 7 FAGR/ACSA/ARTR vs. FAGR/ACSA

If value of Function 1 > Function 2 then FACR/ACSA/ARTR
If value of Function 2 > Function 1 then FAGR/ACSA

Use of Discriminant Functions for Delineation of Site Types

Use of the discriminant functions developed to distinguish between community types on the basis of soil-site characters can be expressed as a series of decision rules driven by the function solutions at any given divisional level (Table 10). Sample values of significant soil-site factors (elevation, rooting depth, etc.) identified for a given level are multiplied by the function coefficients for those variables listed in Table 9 and then summed with their constant for that function. The function with the largest value at each level determines the next level to be computed until a classification of that sample into a community type is reached, *i.e.*, there are no more functions to compute.

Summary and Conclusions

Discriminant-function analysis of the eight community types provided a view of the relationship of the community types to each other as a whole. However, simulating the hierarchical breaks produced in the polythetic divisive groups delimited by TWINSPAN analysis not only provided a modest increase in classification accuracy but also the opportunity to account for in greater detail the relationship between community distribution over the landscape and soil-site factors. This is an improvement over more general methods of interpretation of ordination axes which usually involve only simple correlation of soil and site factors with one or two complex axes, as in DECORANA. In TWINSPAN classification, each "break" or division produced is the product of a separate ordination for that data subset or cluster. Consequently, the various divisions at a given level may be focusing on different community gradients that are important for the individual data subsets rather than on a smaller segment of a single complex gradient. Discriminant-function analysis of the stratified data set provided an opportunity to assess the relative contribution of soil-site factors to the composition and distribution of communities defined in this way.

The improvement in the classification accuracy provided by the stratification is associated primarily with the hardwood community types. Accuracy in classification of the conifer community types declined in all cases except one by the same stratification. Discriminant-function analysis of the first TWINSPAN division strongly favored the hardwood community types. Classification accuracy for hardwood types was 87 percent compared to 63 percent for conifer types.

The mosaic diagram of DECORANA scores for axes 1 and 2 allows visualization of the similarity of samples. The transition between hardwood community types is gradual, whereas the transition between conifer types is more distinct. This suggests that the environment occupied by hardwood types is less distinctive than that occupied by conifer types in physical soil-site factors. This within-group similarity would be maximized in discriminant-function analysis. Group assignment is based on the distance of the sample's canonical discriminant score from the canonical discriminant-function group mean scores. Probability of group membership is computed based on these distances and the sample is assigned to the group with the highest probability. Due to the variation in the conifer-dominated samples, it is highly likely that any such sample that overlaps the hardwood-dominated community type's ecological space will be closer to the hardwood group mean than the conifer group mean, leading to misclassification. The resulting modest classification accuracy for the conifer community types at this first division greatly influences the ultimate classification results.

It should be noted that the interpretation of the classification accuracy probably is biased because the plots used to compute the canonical discriminant functions also were used in the determination of classification accuracy. The sample size of several of the community types was too small to conduct a bootstrap method of validation (Verbyla 1986). Therefore, classification of new samples from the study area would greatly enhance our understanding of the effectiveness of the classification function coefficients to predict group membership.

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Describes one approach to ecologically based classification of upland forest community types of the White and Green Mountain physiographic regions. The classification approach is based on an intensive statistical analysis of the relationship between the communities and soil-site factors. Discriminant functions useful in distinguishing between types based on soil-site factors most strongly correlated with their distribution over the landscape are presented.

Keywords: land classification; site; soils; northern hardwoods

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