Relationship of Species and Site Index to Habitat in the White Mountains of New Hampshire

by W. B. Leak

FOREST SERVICE RESEARCH PAPER NE-397
1978
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
370 REED ROAD, BROOMALL, PA. 19008

The Author

WILLIAM B. LEAK joined the Northeastern Forest Experiment Station in 1956, and now is engaged in silvicultural research at the Station's Forestry Sciences Laboratory at Durham, New Hampshire.

MANUSCRIPT RECEIVED FOR PUBLICATION 11 FEBRUARY 1977

Abstract

Eleven forest habitats, representing distinct differences in soil materials or substrate, were defined for areas of granitic drift in the White Mountains of New Hampshire. Beech/sugar maple/yellow birch characterize successional stands on the fine tills and the enriched or cove sites (where white ash also is common). Washed fine till and coarse till are dominated during succession by beech and birch with some red maple. Red maple is the most abundant species on sandy sediments, silty sediments, and dry compact till. Softwoods, especially red spruce and eastern hemlock, characterize successional stands on habitats representing poor drainage, shallow rock, outwash, and wet compact till. Comparative data from a previous study in old stands indicate that coarse till, fine till, and enriched sites are the only habitats where pure hardwoods are the characteristic vegetation in both successional and older stands; most of the other habitats exhibit a trend over time toward softwoods. Site index generally averages highest on habitats where hardwoods predominate and lowest on softwood habitats. Habitat classification should be used in conjunction with gradient analysis to define the relationships of forest vegetation to environmental conditions.

THE RELATIONSHIPS between forest vegetation and natural environmental factors are viewed and analyzed in two distinct ways. Sometimes, continuous changes through space in species populations and community characteristics are related to continuous changes in environmental factors or complexes of factors. This general approach is called gradient analysis (Whittaker 1967). The alternative is an attempt to classify forest vegetation into homogeneous communities associated with homogeneous levels of certain environmental factors. Much of the earliest work on forest vegetation and habitat followed some form of classification analysis, and land classification schemes still are in vogue in Canada (Rowe 1971), Australia (Mabbutt 1968), and elsewhere.

Recent major studies in the White and Green Mountains of New England have successfully employed gradient analysis. Bormann et al. (1970) showed that species and stand characteristics on the Hubbard Brook Experimental Forest in New Hampshire were strongly related to an elevational complex gradient. The only clear zonal boundary was the hardwood-boreal forest transition at about 760 m (2,500 feet) elevation, related to an increased rate of environmental change. Bormann et al. suggest that zonal or community boundaries other than this distinctive hardwood-boreal transition may be arbitrary or poorly defined. Siccama's (1974) work on Camel's Hump and three adjacent mountains in Vermont showed a similar relationship between species distribution and elevation, and provided a detailed explanation for the hardwood-boreal transition in terms of a rapid drop in the length of the frost-free season coupled with moisture and icing conditions associated with the cloud base. Descriptive work on Mt. Whiteface and Mt. Washington in the White Mountains (Leak and Graber 1974) illustrated a relationship between species and elevation similar to that shown in the previous two studies. All three studies showed that tree species exist as a series of overlapping populations similar in pattern to those described by Whittaker (1956) in the Great Smoky Mountains.

Direct gradient analysis and mathematical ordination techniques have been successfully applied to the mixed forests in the Adirondacks (Holway and Scott 1969) and the Lake States (Goff and Cottam 1967).

Clearly, one current trend in the northeastern United States is to view forest species composition as a continuum, and to analyze it by some form of gradient analysis—coupled with a recognition of the most distinct zonal boundaries such as the hardwood-boreal elevational transition. But there are two reasons why classification analysis should be recognized and used—along with gradient analysis—in the mountainous forests of New England and perhaps elsewhere as well. The first reason is utilitarian: the management of forest lands is facilitated by schemes that subdivide the land into fairly large homogeneous units. Then reasonably uniform policies and management techniques can be applied over an entire unit. Of course, we could take a recognized environmental gradient such as elevation, divide it into segments, and use segment limits to define land-unit boundaries. But the resulting units would be gradational rather than homogeneous. A management technique that worked in one part of the unit might not work in another part of the same unit.

The second reason for using classification approaches in New England forests is that certain environmental conditions tend to be discrete—changing rapidly over a short distance—rather than continuous. The primary discrete factors are those associated with glacial history and soil materials. Billings (1956) and his associates recognized and mapped more than 50 distinct types of bedrock in New Hampshire. Nearly all soils in the New Hampshire mountains are derived from glacial drift deposited about 10,000 years ago; this drift represents a composite sample of many bedrock types. Goldthwaite (1948), however, showed that New Hampshire glacial drift could be mapped with considerable detail into three distinct types representing different mineralogy, material derived from: (1) granite rocks rich in feldspar, (2) slaty schists, and (3) crystalline schists. Within any of these types of drift, Alvis and Lanier[1] have shown, glacial history and mode of deposition result in at least 14 recognized geomorphic classes and associated forest types (the list is still undergoing revision) on the White Mountain National Forest. These classes reflect continental subglaciation (glacial scouring, basal till), superglaciation (open till), alpine glaciation (scouring, deposition), glaciofluvial and fluvial action, and subsurface frost churning. This approach to geomorphic classification is being used to develop a broad system of ecologic land types on the White Mountain

[1]Unpublished report. Region 9 Land Systems Conference, White Mt. Natl. For., Oct. 15-17, 1974.

National Forest based on land form, soil materials, and tree/shrub associations. In many cases, the types of materials associated with geomorphic classes are similar to the physical classes of parent materials locally recognized in soils classification by the Soil Conservation Service (Pilgrim et al. 1968).

Little information is published on the relationships of forest vegetation to geomorphic classes or soil materials in New England. In Ohio, however, Forsyth (1970) found that natural vegetation closely followed geologic boundaries, and the same author had some success in using vegetation to map glacial geology (Forsyth 1968). One of the main problems in relating geologic features to forest vegetation is to account for past stand history or successional stage (Hamilton and Forsyth 1972).

Preliminary work in old, undisturbed stands in the White Mountains indicated a definite relationship between tolerant species and type of soil material within glacial drift of a given mineralogy (Leak 1976). This preliminary work, which will be referred to again later, led to the current study of forest composition and productivity (site index) in successional stands, related to habitat classes based primarily on soil materials.

METHODS

During the summer of 1976, 151 temporary plots were established in the southeastern quarter of the White Mountain National Forest, all within areas of glacial drift derived from granite rich in feldspar (Goldthwaite 1948). All of these plots were located in successional stands that had developed following heavy cutting or clearcutting about 50 to 100 years before. No cultivation or heavy pasturage was evident in the soil profile on these 151 plots; however, a few additional plots were taken on such disturbed sites for comparison. All stands appeared even aged and contained a mixture of tolerant and intolerant species. Species composition and topography surrounding each plot were uniform over at least 2 to 4 hectares, except in the case of enriched sites (defined later) which sometimes were no larger than .5 hectare.

On each plot, basal area by species was estimated for all stems over 6 m (20 feet) tall using a 3-m^2 prism factor. Age at breast height (from increment cores) and total height (from several measurements with a Suunto[2] clinometer) were determined for at least one dominant tree per plot, and later converted to site index (base age 50 years) using curves from Curtis and Post (1962) and Hampf (1965). After cores with questionable age counts and periods of suppression were discarded, 122 samples remained. Aspect and approximate elevation (from topographic maps) were determined for each plot, and observations were taken on species and sizes of tree reproduction.

Toward the center of each plot, I dug at least one pit (sometimes 2 or 3) to a depth of 1 m if possible. Soil auger borings were taken around the perimeter of many plots to check on the uniformity of conditions. Major soil horizons were briefly described and measured. But the major emphasis was placed on classifying the habitat into 1 of 11 types based primarily on soil materials or substrate (B_3, C or D horizons). Most of these habitats were defined and described more fully in an earlier study of old stands (Leak 1976):

(1) **Poorly drained.**—Flat areas with heavy mottling or gray mineral soil throughout the B horizon. Substrate difficult to classify due to standing water or a shallow water table during much of the growing season.

(2) **Rock.**—Smooth tight bedrock, a matrix of sharp-angled or rounded boulders, or nearly pure grus (weathered granite) are found at depths of not more than 65 cm below the top of the mineral soil. This habitat condition often reflects glacial scouring or plucking, sometimes with subsequent frost churning or weathering. Matrices of rounded boulders apparently result from heavy rinsing action along streams or lake shores.

(3) **Outwash.**—Sands or gravels that have been stratified and deposited by moving water. Stones, if any, are without silt caps.

(4) **Wet compact till.**—The compact tills in New Hampshire generally are considered to be of geologic origin—basal till compacted by the glacier. The wet compact tills exhibit a watertight layer at the base of the B horizon with mottling extending upward at least partly into the B horizon. Moving water often is present.

(5) **Dry compact till.**—The dry compact tills exhibit an abrupt change from friable to firm at the

[2]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U. S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

base of the B horizon. The substrate varies from crisp to extremely hard, and usually is platy in structure. Imbedded stones are difficult to turn or remove. No mottling in the B horizon or moving water are present, possibly because of the porosity of the compact layer or the location of the habitat away from drainage ways.

(6) **Silty sediments.**—Sediments in this paper are defined as very uniform (poorly graded) materials deposited in slack water. The silty sediments are plastic and massive in structure; up to 80 percent by weight consists of silt or finer materials. Sometimes, stones or particles of weathered granite are incorporated into the sediments. Drainage sometimes is impeded.

(7) **Sandy sediments.**—These are poorly-graded materials that are loose and single-grained in structure. These materials resemble fine, well-sorted outwash except that silt caps are present.

(8) **Washed fine till.**—Till is the general name for unsorted glacial drift that has been dumped in place. However, some tills are rinsed or water-worked, probably because they were deposited as the glacier melted. These tills are loosely deposited, usually contain lenses or small blocks of stratified material, and have few surface rocks. The washed fine tills exhibit prominent silt caps. This substrate often occurs in areas containing sediments, which indicates that slack water played some part in their deposition.

(9) **Coarse till.**—These tills apparently were heavily rinsed as they were deposited, removing much of the fine material. The substrate is a loose sand/gravel or loamy sand/gravel. These tills resemble gravelly outwash, except that they have a broader gradation of particle sizes (including stones) and some evidence of silt caps.

(10) **Fine till.**—This is typical till deposited without any evidence of water working. All particle sizes are present; many surface rocks and irregular topography are characteristic. Textures are sandy loam or finer, sometimes with a noticeable silty feeling.

(11) **Enriched.**—These areas usually occur as coves or benches within areas of tills or occasionally compact tills. The distinguishing feature is organic matter or organic-coated fine material incorporated into the mineral horizons. Horizonation is poor. Drainage may be good to moderate or poor. Apparently, these areas are enriched by leaf litter and fine materials continually moving in from surrounding areas.

Table 1.—Numbers of plots, approximate range in plot elevations, and numbers of site-index trees by habitat

Habitat	No. of plots	Approximate range in elevation	No. of site-index trees
		m	
Poorly drained	6	366-427	6
Rock	21	244-671	17
Outwash	11	305-518	13
Wet compact till	22	274-549	13
Dry compact till	18	244-610	16
Silty sediments	12	274-610	11
Sandy sediments	11	244-488	10
Washed fine till	10	274-488	6
Coarse till	18	305-549	12
Fine till	6	335-640	6
Enriched	16	335-610	12
All	151	244-671	122

Elevations, numbers of plots, and numbers of site index trees by habitat are given in Table 1. Note that most habitats were found over a broad range in elevation. All plots were taken below the 760 m elevational mark commonly regarded as the transition point between the hardwood and boreal forest, although some of the rock habitats were found near this limit.

RESULTS

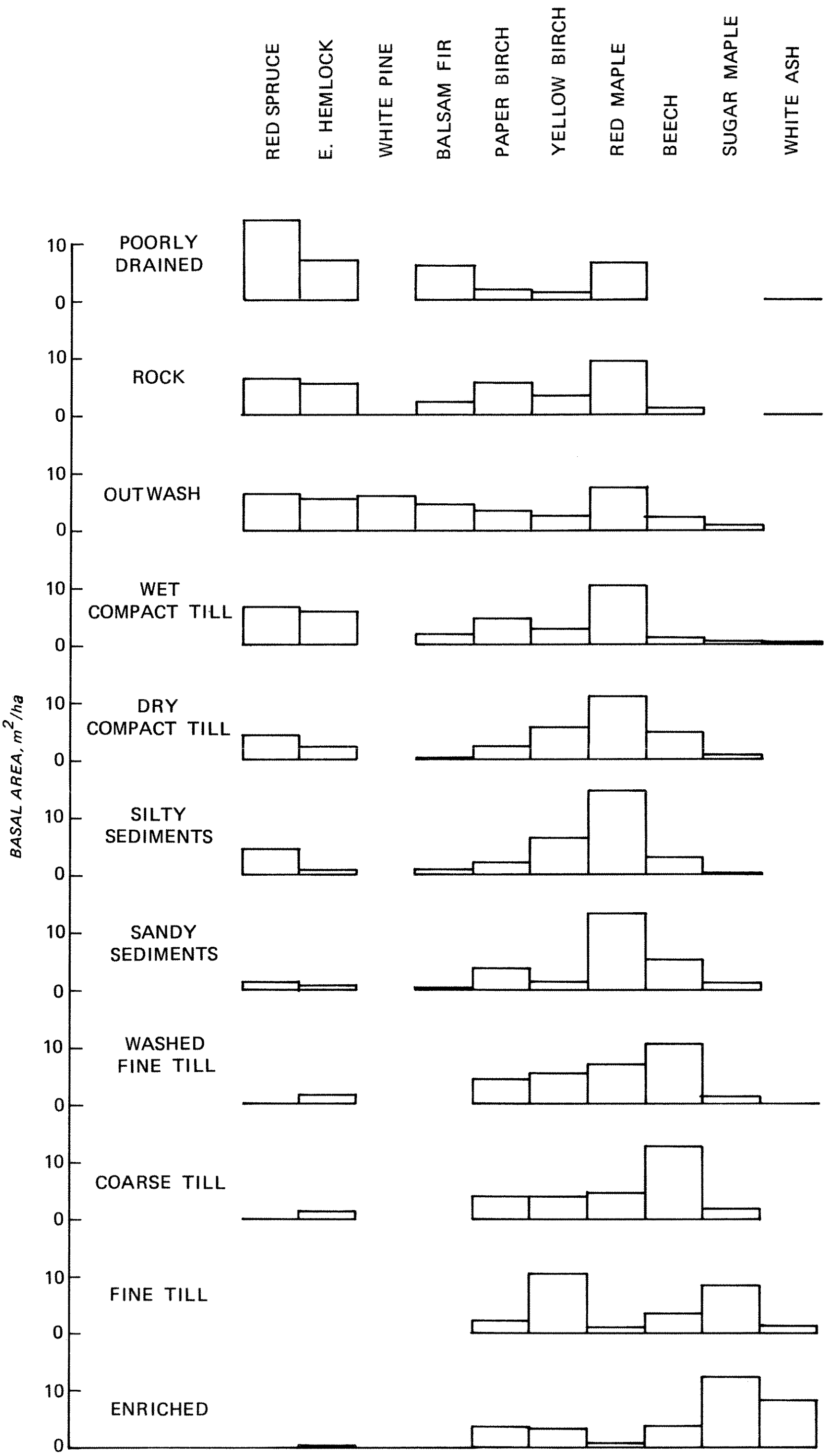
Species Composition

Average species composition of these successional stands in terms of m^2 of basal area per ha differs considerably among the 11 habitats (Fig. 1). To aid in visual comprehension, the habitats in Figure 1 are ordered approximately according to a decreasing component of red spruce and hemlock, with slight deviations to ensure that field-associated types of soil materials (e.g. compact tills or sediments) are adjacent to one another. The ordering of habitats clearly does not represent a simple gradient in moisture or soil texture.

Softwood species, especially red spruce and eastern hemlock, are abundant on habitats characterized by poor drainage, rock, outwash, and wet compact till. On these habitats, red maple is the most abundant hardwood, followed by the birches (yellow and paper). White pine is abundant only on outwash. Oak (*Quercus rubra* L.) sometimes was found on shallow bedrock or outwash.

Softwoods are present, though not abundant, on the dry compact till, on silty sediments, and (to a lesser extent) on sandy sediments. Red maple is

Figure 1.—Basal area in m²/ha by habitat for red spruce (*Picea rubens*), eastern hemlock (*Tsuga canadensis*), white pine (*Pinus strobus*), balsam fir (*Abies balsamea*), paper birch (*Betula papyrifera*), yellow birch (*Betula alleghaniensis*), red maple (*Acer rubrum*), American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), and white ash (*Fraxinus americana*). Other hardwood and softwood species were omitted from the analysis.



the most abundant hardwood; the birches and beech are common associates.

Washed fine till and coarse till contain a preponderance of beech. Red maple and the birches are common associates. Softwoods are in the minority. Some of the largest concentrations of beech in the White Mountains seem to occur on coarse till that is not far removed from gravelly outwash.

Fine till is dominated by sugar maple, birch (especially yellow birch), and beech. This is the first habitat in Figure 1 in which sugar maple is at all abundant. Softwoods are completely absent.

On enriched sites, sugar maple and white ash are most abundant, although beech and the birches also are present. Softwoods are nearly absent. Although present on other sites, white ash is abundant only on the enriched sites.

Frequency of occurrence (percentage of plots containing a species) generally paralleled basal areas by species. If we concentrate upon those species that occur on at least 50 percent of the plots, we can better visualize the forest types or communities that characterize each habitat (Fig. 2). Successional stands on habitats characterized by poor drainage, rock, outwash, or wet compact till are dominated by softwoods, red maple, and birch. Areas of dry compact till, silty sediments, and sandy sediments abound in red maple, beech, and birch. Washed fine till and coarse till support heavy stands of beech with birch and some red maple. Fine till supports typical northern hardwoods—sugar maple, yellow birch, and beech. Enriched sites are similar to the fine tills, but support more sugar maple and ash.

Figure 2 also shows the two predominant tolerant species found on some habitats in old, uneven-aged stands. It is based primarily on an earlier study in the same part of the White Mountains (Leak 1976). Red spruce and eastern hemlock were the predominant tolerants found in old stands on poorly drained habitats down through dry, compact tills and silty sediments. Softwoods are not now abundant in successional stands on the dry compact tills and the silty sediments. However, iron cementation in the B horizon was found on 50 to 60 percent of the plots in these two habitats—an indication that softwoods recently were abundant (Buol et al. 1973). And 55 to 65 percent of the plots in these two habitats contained softwood regeneration judged to be at least as abundant as hardwood regeneration. Old stands of tolerant species on coarse till were dominated by beech, while sugar maple and beech were most common in old stands on fine till and enriched habitats.

Without heavy disturbance due to cutting, windthrow, disease, etc., the species composition of successional stands graphically shown in Figures 1 and 2 should gradually press toward the tolerant species numerically indicated in Figure 2. However, sediment cores from the White Mountains (Likens and Davis 1975) clearly show that major changes in tolerant species—from softwoods toward hardwoods—have taken place over the post-glacial period. So, we might expect that changes in the primary tolerant species will occur over future geologic time in response to climatic change as well as the continuing processes of soil formation; probably, such changes have occurred and will occur at different rates on different habitats.

Influence of Elevation and Disturbance

Although the discussion so far has dealt with habitat classifications, it is important to recognize that continuous environmental gradients may operate within habitat types. The data taken in this study could not be used for a thorough and precise analysis of elevational gradients. However, a comparison of basal areas by species above and below 457 m (1,500 feet) elevation within certain habitats indicates that red spruce is more abundant at higher elevations while hemlock is less abundant (Table 2). A similar pattern was detected in the previous work on habitats of old stands (Leak 1976). Certain hardwoods, such as beech and white ash, tended to decline somewhat incon-

Table 2.—Comparison of basal areas (m^2/ha) of red spruce and eastern hemlock above and below 457 m (1,500 feet) elevation for several habitats

Habitat	Elevation	Red spruce	Eastern hemlock
Rock	244–427	6.4	7.7
	548–671	6.0	1.3
Wet compact till	274–427	4.9	7.1
	488–549	13.2	2.4
Dry compact till	244–396	.8	2.6
	457–610	7.2	1.8
Silty sediments	274–305	—	.8
	457–610	7.1	1.1
Coarse till	305–442	—	1.4
	457–549	.6	.6

Figure 2.—Percentage of plots containing each species in successional stands, including only those species that occur on 50 percent or more of the plots. Numbers 1 and 2 indicate the most common and second most common of the tolerant species found on several habitats in a previous study of old, undisturbed stands (Leak 1976).

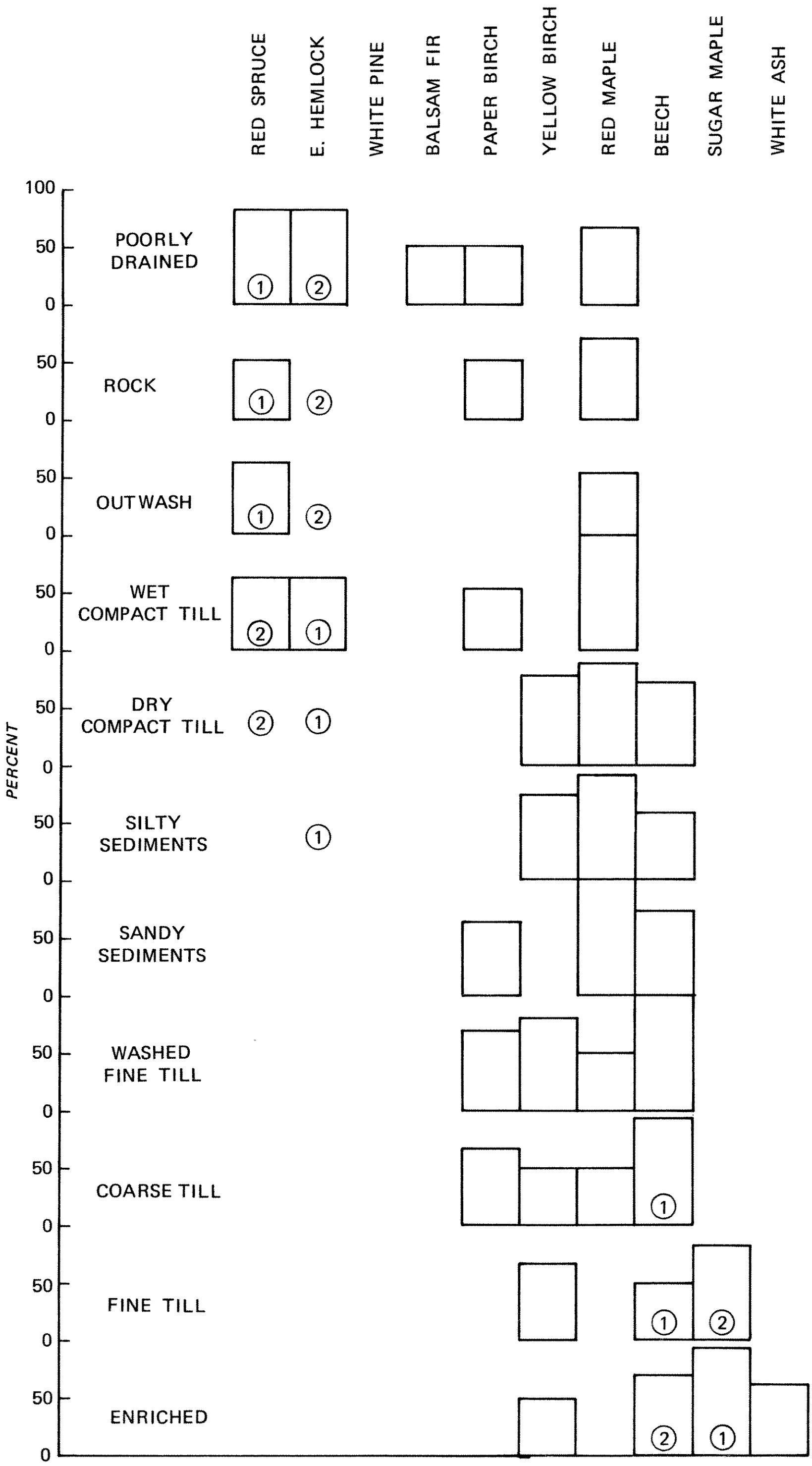


Table 3.—Comparison of basal areas (m²/ha) by species on undisturbed (18 plots) and disturbed (pastured, 3 plots) coarse till

Disturbance	Red spruce	Eastern hemlock	White pine	Balsam fir	Paper birch	Yellow birch	Red maple	Beech	Sugar maple	White ash
Undisturbed	0.2	1.2	—	—	4.0	4.0	4.5	12.7	1.8	—
Disturbed	1.0	7.0	—	—	5.0	—	2.0	8.0	2.0	—

sistently with higher elevation while the birches seem less consistently responsive to increased elevation. Apparently, habitat classification does not eliminate the need for recognizing elevational gradients, but simply provides an added dimension to such work.

Although the study was restricted for the most part to nonfarm sites, three plots were taken on coarse till that had been heavily pastured 60 to 100 years before. These sites had a thin organic layer, a missing or poorly developed A_2 horizon, and poor horizonation elsewhere in the solum; a search nearby revealed old cellar holes and stone walls. In comparison with the undisturbed sites, the pastured areas had more softwoods; hemlock was the second most abundant species (Table 3). Observations elsewhere in the White Mountains indicate that white pine may also be abundant in old pastures on soil materials that usually support hardwoods. Note also that paper birch is the predominant birch on the pastured sites.

Productivity

Productivity was evaluated in terms of site index, the total height of dominant trees at age 50 (either total age or age at breast height depending upon the available site index curves). Site index is a common measure of productivity for timber management purposes.

The relationships between habitat and productivity varied by species (Table 4). The highest site indexes of white ash, sugar maple, paper birch, and possibly yellow birch are found on the fine tills and enriched areas. Site index of these species generally is lower on habitats that support higher proportions of softwoods, the poorly drained and rock habitats for example. Sugar maple apparently has a much lower site index on habitats other than the fine tills and enriched areas. From results with these four species, it seems that habitats dominated by hardwoods generally exhibit a higher site index than those with a softwood influence. However, red spruce and red maple—a common associate of softwoods— showed limited or inconsistent differences in site index among habitats.

DISCUSSION

Species composition and productivity (site index) vary appreciably among 11 habitats defined for areas of granitic drift in the White Mountains of New Hampshire. Successional stands of beech—sugar maple—birch (especially yellow birch) characterize the fine tills and the enriched sites (where white ash also is common). Washed fine till and coarse till support beech and birch with some red maple. Red maple is a predominant species on sandy sediments, silty sediments, and dry compact till, where it occurs with birch and beech; some softwood influence usually is evident on these sites as well. Softwoods (especially red spruce and eastern hemlock), red maple, and birch characterize the habitats representing poor drainage, rock substrates, outwash and wet compact till. Site index generally averages highest on the strong hardwood sites, and lowest on the strong softwood sites. However, species such as red maple maintain fairly high site index even on the strong softwood sites.

Habitat classifications such as this should prove useful in forest land classification, especially when used in conjunction with (1) aerial mapping techniques based on land form and (2) known environmental gradients such as elevation. Since the habitats described in this paper are defined by the physical nature of soil materials, the relationships may differ in areas of different mineralogy, such as drift derived from slaty or crystalline schists (Whittaker 1953).

With the exception of the enriched sites and perhaps the dry compact tills, the habitats described in this paper can be found in units of 20 to 40 hectares or more. However, they may occur in smaller units; and some tracts can only be described as a complex of two or more habitats. The influence of habitat upon vegetation appears to be stronger where the acreage in any given habitat is

Table 4.—Mean site index in feet (and meters) plus and minus one standard error of the mean. Base age 50 years. Based on 122 samples

Habitat	Red spruce[a]	White pine[a]	Balsam fir[a]	Paper birch[b]	Yellow birch[b]	Red maple[a]	Beech[a]	Sugar maple[b]	White ash[b]
Poorly drained	44 ± 4(13.4)	—	—	—	48 (14.6)	—	—	—	48(14.6)
Rock	44 (13.4)	60 (18.3)	—	56 ± (17.1)	48 ± 4(14.6)	60 ± 0(18.3)	—	—	—
Outwash	40 ± 3(12.2)	56 ± 3(17.1)	54 ± 6(16.5)	—	60 ± 6(18.3)	63 ± 3(19.2)	—	—	—
Wet compact till	38 ± 2(11.6)	—	—	54 ± 3(16.5)	57(17.4)	52 ± 6(15.8)	—	—	70 ± 2(21.3)
Dry compact till	44 ± 4(13.4)	—	—	70 (21.3)	56 ± 3(17.1)	60 ± 2(18.3)	57(17.4)	—	—
Silty sediments	51 ± 2(15.5)	—	—	62 ± 0(18.9)	62 ± 7(18.9)	64 ± 4(19.5)	—	—	—
Sandy sediments	—	—	—	68 ± 2(20.7)	61 (18.6)	52 ± 2(15.8)	—	60(18.3)	—
Washed fine till	—	—	—	66 ± 5[c](20.1)	80[c](24.4)	—	57(17.4)	—	—
Coarse till	—	—	—	66 ± 2(20. 1)	55 ± 4(16.8)	—	65 ± 4(19.8)	50 ± 8(15.2)	—
Fine till	—	—	—	77 (23.5)	68 (20.7)	—		68 ± 6(20.7)	76(23.2)
Enriched	—	—	—	74 ± 6(22.6)	63 (19.2)	—	—	72 ± 4(21.9)	81 ± 3(24.7)

[a]Total age 50 years.
[b]Breast-high age 50 years.
[c]Consists of or contains a measurement on a young stand (35 years), which may overestimate site index.

greater. As with any classification scheme, a certain amount of comparative field work is necessary before habitats can be readily identified.

Additional research is needed on the nature of the transition—in soil materials and vegetation—from one habitat to another. Examples of very sharp transitions between till and rock substrates have been noted (Leak 1976), and deposits of outwash and wet compact till often are well defined in terms of vegetational change and habitat boundaries. The chief problems to date have been in making clear boundary distinctions between outwash and coarse till, and between sediments and washed fine till. With additional information on transition patterns, the distinction between gradient analysis and classification analysis may gradually disappear. Landscapes may eventually be described in terms of many gradients varying from gradual to abrupt.

The reasons why species and site index differ among habitats have not yet been determined. Certainly, nutrition is involved as well as water relations in certain cases (e.g. poorly drained habitats). However, chemical analyses of some of the soils in the White Mountains (Hoyle 1973) have not provided any clear nutritional basis for habitat differentiation.

LITERATURE CITED

Billings, M. P.
1956 **The geology of New Hampshire, Part II: Bedrock geology.** N. H. State Plann. Dev. Comm., 203 p.

Bormann, F. H., T. G. Siccama, G. E. Likens, and R. H. Whittaker.
1970. **The Hubbard Brook ecosystem study: Composition and dynamics of the tree stratum.** Ecol. Monogr. 40:373-388.

Buol, S. W., F. D. Hole, and R. J. McCracken.
1973. **Soil genesis and classification.** Iowa State Univ. Press, Ames, 360 p.

Curtis, R. O., and B. W. Post.
1962. **Site index curves for even-aged northern hardwoods in the Green Mountains of Vermont.** Vt. Agric. Exp. Stn. Bull. 629. 11 p.

Forsyth, J. L.
1968. **The use of vegetation as a tool in the mapping of glacial geology—a challenge to two disciplines, p. 56-60.** *In* The Quaternary of illinois. Spec. Publ. 14. Univ. Ill., Urbana.

Forsyth, J. L.
1970. **A geologist looks at the natural vegetation map of Ohio.** Ohio J. Sci. 70(3):180-191.

Goff, F. G., and G. Cottam.
1967. **Gradient analysis: The use of species and synthetic indices.** Ecology 48(5):793-806.

Goldthwaite, L.
1948. **Glacial till in New Hampshire.** N. H. State Plann. Dev. Comm., Mineral Resour. Surv., Part 10. 11 p.

Hampf, F. E.
1965. **Site index curves for some forest species in the eastern United States.** U.S. Dep. Agric. For. Serv., East. Reg., Upper Darby, Pa. 43 p.

Hamilton, E. S., and J. L. Forsyth.
1972. **Forest communities of South Bass Island, Ohio.** Ohio J. Sci. 72(4):184-210.

Holway, J. G., and J. T. Scott (with contributions by A. R. Breisch, J. G. Droppo, H. L. Hamilton, E. W. Holroyd III, R. F. Kujawski, P. C. Lemon, S. Nicholson, and R. Park).
1969. **Vegetation-environment relations at Whiteface Mountain in the Adirondacks.** Rep. No. 92, Atmos. Sci. Res. Cent., State Univ. N. Y., Albany. 236 p.

Hoyle, M. C.
1973. **Nature and properties of some forest soils in the White Mountains of New Hampshire.** U.S. Dep. Agric. For. Serv. Res. Pap. NE-260. 18 p.

Leak, W. B.
1976. **Relation of tolerant species to habitat in the White Mountains of New Hampshire.** U.S. Dep. Agric. For. Serv. Res. Pap. NE-351. 10 p.

Leak, W. B. and R. E. Graber
1974. **Forest vegetation related to elevation in the White Mountains of New Hampshire.** U.S. Dep. Agric. For. Serv. Res. Pap. NE-299. 7 p.

Likens, G. E., and M. B. Davis.
1975. **Post-glacial history of Mirror Lake and its watershed in New Hampshire, U.S.A.: An initial report.** Verh. Int. Ver. Limnol. 19: 982-993.

Mabbutt, J. A.
1968. **Review of concepts of land classification, p. 11-28.** *In* G. A. Steward (ed.), Land evaluation. MacMillan Co., Toronto.

Pilgrim, S. A., A. B. Prince, and N. K. Peterson.
1968. New Hampshire soils and their interpretations for various uses. Res. Rep. No. 3, N. H. Agric. Exp. Stn. in coop. with U.S. Dep. Agric. Soil Conserv. Serv., 70 p.

Rowe, J. S.
1971. **Why classify land?** For. Chron. 7(3)144-148.

Siccama, T. G.
1974. **Vegetation, soil, and climate on the Green Mountains of Vermont.** Ecol. Monogr. 44:325-349.

Whittaker, R. H.
1953. **A consideration of climax theory: The climax as a population and pattern.** Ecol. Monogr. 23:41-78.

Whittaker, R. H.
1956. **Vegetation of the Great Smoky Mountains.** Ecol. Monogr. 26:1-80.

Whittaker, R. H.
1967. **Gradient analysis of vegetation.** Biol. Rev. 42:207-264.

☆U.S. GOVERNMENT PRINTING OFFICE: 1978—703-112:11