Ecological Forest Site Classification

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ABSTRACT—An ecological method of multi-factor site classification, operational in southwestern Germany for over 30 years, was applied on the Cyrus H. McCormick Experimental Forest in the Upper Peninsula of Michigan. Strong interrelationship was found among physiography, soils, and vegetation, and these factors were used simultaneously in the field to distinguish and map ecosystems that recur in the landscape. Such ecosystem units form the basis for intensive multiple-use management. The method illustrates an alternative to single-factor and component methods and indicates the trend toward integration of the important factors in classifying and mapping ecosystems.

The classification of land and forest sites is a major challenge of the 1980s. Not only is more intensive multiple-use resource management anticipated but enacted legislation (such as the National Environmental Policy Act of 1970, the Federal Land Policy and Management Act of 1976, and the National Forest Management Act of 1976) mandates a structured ecological data base to help in decision-making. Hirsch et al. (1978) stress the need for continuing research, testing of new approaches, and scrutinizing of the classifications used in other countries. We describe here a method of ecological site classification that has been used in West Germany for over 30 years but has not been applied in the United States. This method is the basis for the intensive multiple-use resource management of the German state of Baden-Württemberg. Like similar methods in Canada (Hills and Pierpoint 1960, Jurdant et al. 1975, 1977) it goes beyond an information system or the generation of a data base to integrate major ecosystem factors and provide an ecological classification and map.

Reviews of methods of site classification and site productivity have been provided by Bailey et al. (1978) and Spurr and Barnes (1980). Approaches to forest site classification have stressed either landform (Wertz and Arnold 1972, 1975; Smalley 1979), soil (Soil Survey Staff 1975), or vegetation (Pfister 1976, Pfister and Arno 1980). Increasingly the tendency is to follow the lead of European and Canadian ecologists and employ multiple-factor methods. A method combining soils, topography, and vegetation has been used extensively in California (California Division of Forestry 1969). A component classification (Ecological Classification System) is being developed by the USDA Forest Service for use on national forests in Region 9, and efforts are under way to provide a national site (land) classification system. Such component classifications seek to integrate independent classifications of landform and physiography, soils, vegetation, and hydrologic and aquatic factors that have been or are being developed by specialists in each field.

Our purpose in this article is to present an ecological approach to multi-factor site classification. This approach, which is new to the American scene, is not "quick and dirty" but can be modified to provide a rapid but effective classification suitable for extensive rather than intensive management.

What Is an Ecological Classification?

Ecology is the study of interrelationships between organisms and their environment. An ecological classification is one that expresses the interrelationships (1) between vegetation (overstory, understory, groundcover) and physiography, (2) between vegetation and soils, and (3) between physiography and soils. The modern concept of the ecosystem as the basis for resource management derives from these reciprocal interactions of the biotic community and the physical environment. Physiographic and soil factors (themselves more or less influenced by vegetation) strongly determine the composition, size, and productivity of vegetation. The ecological and silvicultural meaning of physiographic and soil factors becomes apparent only when their relationship to the vegetation is understood. A soil classification or map is not an ecological classification if the relationship of the classes to the vegetation of the area is unknown. Similarly, a vegetation map is not an ecological classification unless the interrelationship between the vegetative types and the environmental factors is known. Classification systems that include climate, soils, landform, and vegetation are being used but are not necessarily ecological (Rowe 1978). Classifications of climate, landform, and soil are helpful, and they become enormously valuable when the specific effects of these factors on plants and animals are known.

In developing the classifications we break the complex gradients of an area into ecosystem units that recur in the landscape—units that can be distinguished by major differences in physiography, soils, and vegetation. Each of these three ecosystem factors provides information for building the classification and mapping the ecosystem units. Physiography often determines microclimate and water movement, certain landforms are highly correlated with soil conditions, and major landforms or features (aspect, slope position) can be identified from aerial photographs. Soil factors, particularly soil moisture, nutrients, and pH, strongly control plant and animal composition, size, and productivity. Vegetation is a phytometer that integrates the physiographic and soil factors and their interactions and reflects by its composition, size, and productivity the ecological and silvicultural meaning of physiography and soil. Thus, the three major factors and their interrelationships most clearly distinguish the local ecosystems.

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Once the hierarchical classification of ecosystem units is developed, the units of the entire area are mapped. The mapper uses the three factors as a check-and-balance system to distinguish the ecosystem units—the factors reinforce each other in the delineation process.

Baden-Württemberg Method

The model we followed has been used by the Forest Research Station of the southwestern German state of Baden-Württemberg since about 1946 (Schlenker 1964). It is described in detail by Spurr and Barnes (1980, p. 324–329), and a flow chart illustrating its major features is shown in *figure 1*. First, major landscapes, termed growth areas, are identified on the basis of climate, geology, and vegetation. The growth areas are fairly heterogeneous and are, therefore, subdivided into growth districts. Each growth district has a relatively homogeneous macroclimate and a characteristic pattern of landform, soils, and groundcover vegetation.

Within each growth district the different kinds of local ecosystems, termed site units, are classified in a hierarchical system. Interrelationships among physiography, soils, and vegetation are determined, and these factors are used to distinguish and map different site units. A site unit is defined as a collection of individual sites that have (1) similar silvicultural potential (such as choice of species, cultural treatments); (2) similar risks of damage from insects, diseases, or windthrow; and (3) similar growth and yield of forest trees. Once the classification is developed, forest tracts are systematically mapped at a scale of approximately 1:10,000.

A primary feature of the system is that the site units are evaluated on the basis of the growth and productivity of important commercial species. Height-over-age (site index) curves are developed, and total merchantable volume (m^3 ha^{-1}) is determined for the dominant commercial species of the major site units. Site units similar in productivity are combined into groups and managed accordingly (Spurr and Barnes 1980, p. 328). Groundcover species that indicate similar conditions of moisture, nutrients, local climate, or pH are grouped together and named for a characteristic plant (Spurr and Barnes 1980, p. 326–327). Thus, the total vegetative complement is used to distinguish and map site units. Separate maps of vegetation, landform, and soils are not prepared. Integrating all factors and preparing a single classification and site map has proved more reliable and less time-consuming and expensive than making separate maps or overlays of individual factors.

A comprehensive silvicultural guide is prepared to accompany the site map of each state, city, or private forest. Each site unit is described in detail, and the potential productivity of each species or species mixture is given. Prescriptions are also provided for choosing species to regenerate, tending stands, and coping with major insect, disease, and windthrow problems. The system has become the basis for silvicultural planning throughout Baden-Württemberg; standard yield tables are modified as necessary for each growth district, or new yield tables are developed.

In addition to many applications in silviculture, the site classification and map provide basic information for road location and construction, fertilization, planning for forestland consolidation, landscape planning, wildlife habitat improvement, recreation management, waste disposal, hydrological studies of ground-water availability,

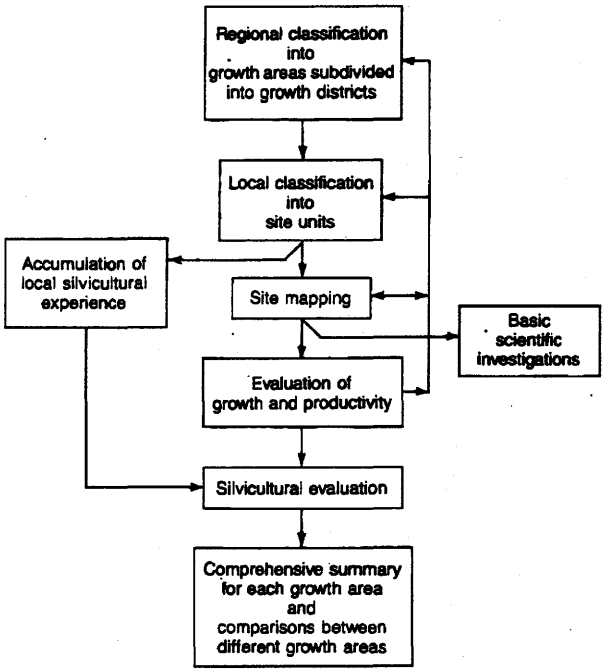

Figure 1. Model of the ecosystem classification system used in Baden-Württemberg, West Germany.

and the terrain accessibility for harvesting equipment. More than 80 percent of the state forests in Baden-Württemberg have been site-mapped. A similar ecological system has long been applied in East Germany (Wagenknecht et al. 1956), and similar ones are well established throughout West Germany and Austria.

Site Classification Of The McCormick Experimental Forest

We decided to test the local-classification methods of the Baden-Württemberg system in the Cyrus H. McCormick Experimental Forest, a tract of 6,950 ha in the Ottawa National Forest about 48 km northwest of Marquette, Michigan. The McCormick tract was selected for its relatively undisturbed forest conditions where the interrelations of physiography, soils, and vegetation could be understood before applying the classification to cutover and otherwise disturbed stands. Our objective was to develop a local classification within a growth district, the Michigamme Highlands. This dominant physiographic feature of north-central Upper Michigan is characterized by a continental climate, short growing season, and heavy snowfall. Acid metamorphic rocks (granite-like gneiss) of early Precambrian Age rise above the surrounding areas and are thinly covered with stratified glacial drift.

Sugar maple (*Acer saccharum*) dominates the relatively coarse-textured, nutrient-poor, glacial-fluvial upland soils.[1] Upland soils are sometimes shallow, and rocky ridges are common. Mixed hardwood-conifer forests characterize the wetlands and occur on deep organic deposits.[2] They are dominated by spruces (*Picea mariana* and *P. glauca*), balsam fir (*Abies balsamea*), north-

[1]*Typic and Entic Haplorthods; Typic and Lithic Dystrochrepts; Dystic Eutrochrepts; and Spodic Udipsamments. Particle size classes range from sandy-skeletal to coarse-loamy; mineralogy is mixed, and soil temperature class is frigid (Soil Survey Staff 1975).*

[2]*Typic Borosaprist to Typic Borohemist, both euic and dysic.*

ern white-cedar (*Thuja occidentalis*), red maple (*Acer rubrum*), and yellow birch (*Betula alleghaniensis*).

Site classification procedure

A systematic method was designed to produce successive approximations of the classification. The steps were (1) reconnaissance, (2) sampling 15- by 30-m plots (data taken on physiography, soils, and vegetation), and (3) mapping. The classification presented in the accompanying box is the fourth approximation developed with data from 108 plots and the mapping of more than 1,800 ha. Examined first were extreme ecosystems such as swamps and sandy outwash plains. The three primary factors—physiography, soils, and vegetation—were studied and their interrelationships observed and recorded in the field.

Detailed information on physiography, soils (including standard soil survey procedures, Soil Survey Staff 1951), and vegetation revealed the holistic nature of each distinctive ecosystem. For example, the soils and vegetation (all layers) of outwash plains were distinct from those of the lower slopes of the high ridges and hills. Acid and neutral swamps were easily differentiated by vegetation, pH, and the degree of decomposition of organic matter.

Tentative ecological species groups, each group indicating a certain set of environmental factors, were developed and refined by inspection of plot data, by field mapping, and multivariate statistical analyses. Further reconnaissance, plot sampling, mapping of more than 1,800 ha of the natural area and adjacent lands, and analysis of soils and physiographic data led to the site unit classification presented in the box. The hierarchy of site units is organized and presented first on the basis of characters of physiography and soils, because they tend to be more stable than the vegetation. The framework of selected physiographic features that recur in the landscape is shown in *figure 2*.

The vegetation of each site unit is named for the dominant overstory species and the most characteristic ecological species group. The ecological species groups are named for a characteristic species and comprise 2 to 14 species. Each site unit typically has a distinctive vegetational complement, characterized by the presence

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Classification of Site Units of the Natural Area of the McCormick Experimental Forest

DRYLAND SITE UNITS

I. Deep soils (bedrock below 100 cm)

A. Level to gently sloping terrain (usually 0–5 percent)

1. Excessively drained sand; jack pine/Vaccinium[1]
2. Somewhat excessively drained sand and gravel; sugar maple/Maianthemum
3. Somewhat poorly drained sand; maple–yellow birch–conifer/Clintonia

B. Moderately to steeply sloping terrain (usually >5 to <30 percent)

4. Well-drained loamy sand; sugar maple/Gymnocarpium
5. Moderately well-drained sandy loam on northerly aspects; sugar maple/Viola
6. Excessively drained sand on steep southerly aspects, white pine–hardwoods/Maianthemum

II. Shallow soils (bedrock within 50 cm)

7. Somewhat excessively drained fine sandy loam on exposed sites; maple–red oak/Maianthemum
8. Well- to moderately well-drained sandy loam on protected sites; red maple–yellow birch–conifer/Clintonia
9. Excessively drained sandy loam on southerly aspects; white pine/Cladonia

III. Other physiographic units

10. Exposed rocky ridges; white pine–red oak–hardwoods/Polygonum
11. Small protected valleys and stream flats; sugar maple–conifer/Circaea
12. Lake and stream borders; conifer–hardwood/Myrica
13. Rocky streamsides; conifer–hardwoods/Aralia
14. Flood plain with alluvial loamy soil; sugar maple/Botrychium
15. Coarse outwash plain; conifer/Cladonia

WETLAND SITE UNITS

16. Open bog; Chamaedaphne/Sphagnum
17. Very infertile swamp on peat (black spruce swamp); black spruce/Ledum
18. Infertile swamp on peat (acid hardwood–confier swamp); hardwood–conifer/Osmunda
19. Fertile swamp on muck (circum-neutral hardwood–conifer swamp); hardwood–conifer/Circaea
20. Open meadow and marsh; sweet gale–sedge
21. Streamside alder on muck; speckled alder/Thalictrum

[1] *Although not occurring in the natural area, this nearby ecosystem of the Yellow Dog Plains was included because it provides the xeric extreme for comparison.*

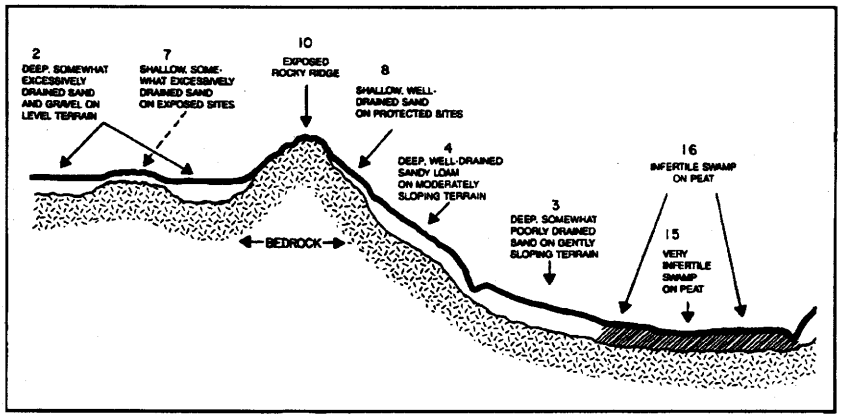

Figure 2. Location of selected site units in relation to physiography, Cyrus H. McCormick Experimental Forest.

Table 1. Occurrence of ecological species groups in selected site units of the McCormick Experimental Forest.

Ecological species group	9—Rocky south slopes WP/Cladonia	10—Rocky ridges WP-RO-Hdwd/ Polygonum	6—Steep south sand WP-hdwd/ Maianthemum	7—Thin dry soils maple-red oak/ Maianthemum	2—Flat sand & gravel sugar maple/ Maianthemum	4—Sloping sandy loam sugar maple/ Gymnocarpium	5—Lower slope loam sugar maple/Viola	8—Thin moist soils red maple-YB-conifer/Clintonia	3—Mottled sand maple-YB-conifer/ Clintonia	17—Black spruce swamp black spruce/Ledum	18—Hdwd-conifer swamp hdwd-conifer/ Osmunda	19—Basic swamp hdwd-conifer/ Circaea
	Site units in order of increasing moisture →											
Cladonia	XX	X	X									
Polygonum	—	X										
Deschampsia	—	—										
Vaccinium	XX	X	—	—								
Maianthemum	—	X	X	XX	XX	X	—	XX	XX	X	X	X
Gymnocarpium					—	XX	XX	—	—			—
Viola							X					
Botrychium							X					
Clintonia			—	—	—	—	—	XX	XX	XX	XX	XX
Osmunda								—	—	—	XX	X
Ledum										XX	—	
Circaea											—	XX
Thalictrum												X

KEY:
— Rare to infrequent
X Common
XX Abundant

NOTE: WP = white pine; RO = red oak; YB = yellow birch; Hdwd = hardwoods

and abundance of various ecological species groups (*table 1*).

Mapping

Mappers (who worked in two-person teams) were trained to use physiography, soils, and vegetation simultaneously to map site units. The natural area was systematically mapped on a grid system in which a mapper passed within 2-½ chains (50 m) of any point in the area. On the route the physiography, vegetation, and their interrelationships were constantly observed and interrelationships registered. The information of physiography typically reinforced that of the vegetation and was sufficient to map the site unit boundaries. If there was a question, the soil at one or more points was sampled with an auger. Once trained, a team could map up to 80 ha per eight-hour day in rough and rocky terrain without roads and virtually without trails. A technique combining aerial photographs and ground checking was used in 1980 to map the remainder of the experimental forest.

The west-to-east transect in *figure 3* illustrates the

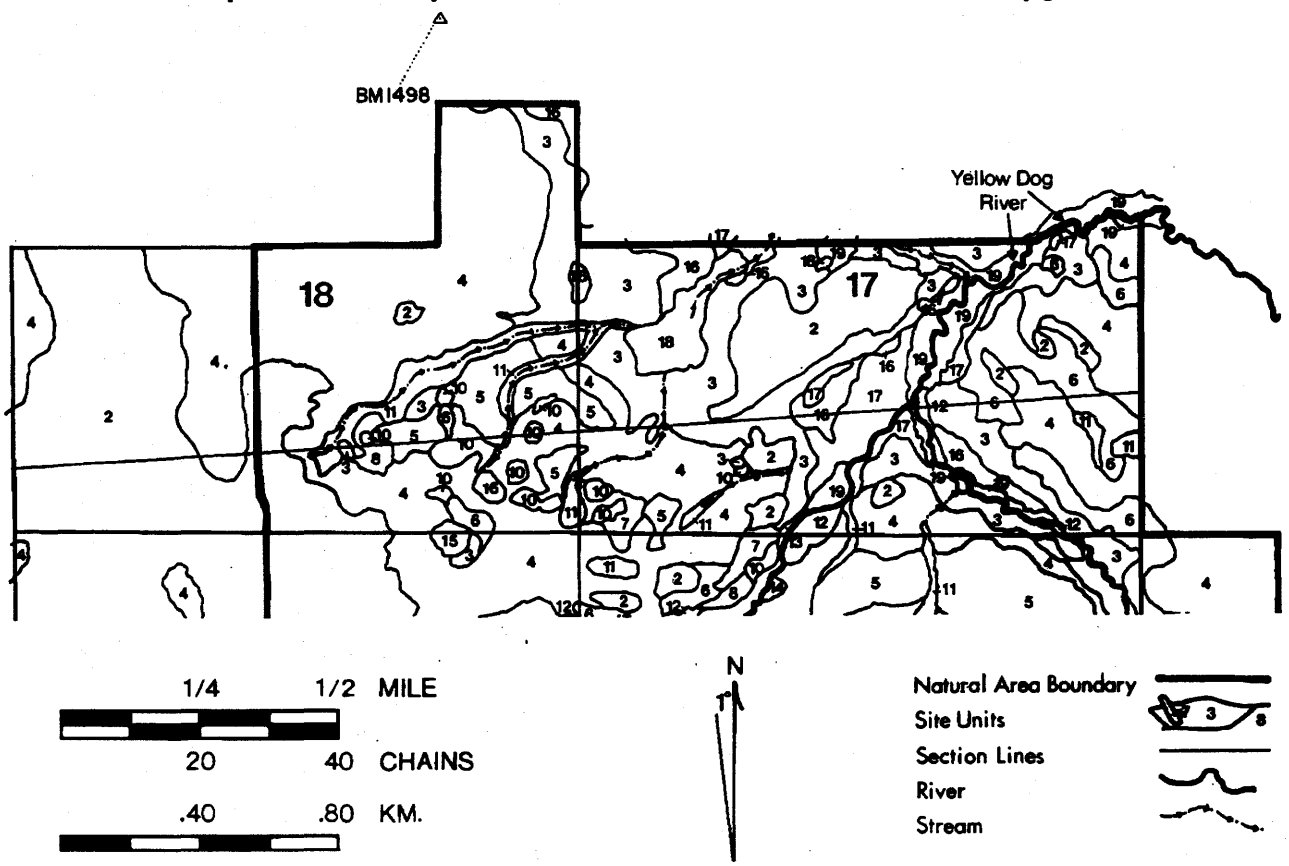

Figure 3. Site unit map of the northern part of the Natural Area of the Cyrus H. McCormick Experimental Forest. Ecosystems along the orange line are discussed in the text.

pattern of ecosystem units in the area. On the west an extensive flat, infertile outwash plain (site unit 2) is dominated by nearly pure low-quality sugar maple. Conversion to red pine (*Pinus resinosa*)—a topic of considerable management interest—would probably be appropriate for this ecosystem because of the comparatively light competition from hardwoods and greater merchantable productivity of pine than of sugar maple.

To the east a rocky ridge, typical of the Michigamme Highlands, runs approximately northwest to southeast. It is identified by the small patches of site unit 10 and the thin-soil units 7 and 8, which are often adjacent to such rock outcrops. On the northern slope of this ridge site units 4 and 5 predominate. Unit 4 typically occurs on sandy upper and mid-slopes, unit 5 on loamy lower slopes. These ecosystems are dominated by almost pure sugar maple stands of moderate to high productivity; because hardwood competition is vigorous, conversion of the stands of unit 5 to red pine is probably not advisable.

As the terrain levels out just east of the north-flowing stream, site unit 3 prevails on sandy, infertile soil with a high water table. Conifers, especially hemlock (*Tsuga canadensis*) and balsam fir, together with red maple, dominate this gently sloping transition zone to the wetlands of the Yellow Dog River. Adjacent to the river are the wetland ecosystems: acid (site unit 18) or circumneutral (site unit 19) hardwood-conifer swamps and streamside alder (site unit 21).

East of the river, and bordering the transition unit 3, is a characteristic alternation of ecosystems: steep, sandy, southwest slopes dominated by white pine, *Pinus strobus*, (site unit 6), and steep, sandy northeastern slopes dominated by sugar maple (site unit 4). These units occur on a series of ice-contact features. The striking difference in vegetation on the same geologic feature and soil parent material illustrates the strong effect of aspect and microclimate in determining vegetational composition.

Various cutover areas near the tract were examined and presented no problems in mapping. The ecological species groups were present and remained definitive; the physiography and soils remained essentially unaltered after cutting.

An Example of Application

A detailed description was prepared for each site unit. It included physiography, soils (texture, drainage, development, structure, consistence, stone content, pH, rooting), detailed soil profile, vegetation (composition of all layers, ecological species groups, coverage of structural layers), and silvicultural and resource management recommendations. In following the flow chart of the German method (*fig. 1*) we completed the classification and mapping of a local area; our next step would be to undertake productivity studies and a detailed silvicultural and multiple-resource evaluation. In Germany, the evaluation is made in conjunction with the silviculturists and resource managers of the area.

In application, the manager would have an ecosystem map of the area and a book containing detailed descriptions of each site unit, growth and productivity data on each site unit for the major species, prescriptions for silviculture, and recommendations for management of timber, wildlife, pests, and recreation and other appropriate uses. Furthermore, the manager would have participated in this evaluation together with the ecologists when the tracts were classified and mapped.

The following comparison of two ecosystems indicates some of the important ecological and managerial differences.

Site unit 2: Flat, outwash sand plain dominated by low-vigor and low-quality sugar maple: the highest sand content, and greatest susceptibility to fire of any sugar maple ecosystem.

- total height of old-growth sugar maple 21 m (low productivity)
- no erosion hazard
- suitable for mechanized equipment
- low recreation and wildlife values
- moderately high fire hazard
- light competition from hardwoods

Recommendation: convert to red pine for greater productivity; fertilize to improve pine yield.

Site unit 5: Lower slope with moist, relatively fertile sandy loam soil; dominated by high quality, fast-growing sugar maple; significantly less sand, more nitrogen, and higher pH than units 1, 2, and 4.

- total height of old-growth sugar maple 28 m (high productivity)
- moderate erosion hazard
- suitable for mechanized equipment during July through November
- moderate recreation value created by large trees and spring flora
- low fire hazard
- heavy hardwood competition

Recommendation: Manage for high-quality hardwoods.

Importance of Integrating Site Factors

The best way to classify and map ecosystems is to use as many of their significant factors and their interrelationships as possible. Single-factor methods employing soils, vegetation, or landform which require separate classifications may not be adequate. Unless modified, soil taxonomy and soil series cannot be used for effective prediction of tree productivity (Carmean 1961, 1975, 1977). In Baden-Württemberg, field tests indicated that single-factor methods and overlays were slower and more expensive than the ecological method.

Alternatively, comprehensive information or data-gathering systems may be developed to classify points or small areas on the earth's surface (Davis 1980). However, it is the ecological integration of factors—the complex factor compensations—that determines differences in species occurrence, succession, and productivity. Although data-gathering systems, single-factor classifications, and component methods are useful in generating information, it remains to be seen whether such methods have sufficient ecological resolution to provide the understanding of ecosystems for multiple-use management or reliable productivity values for intensive timber management.

Because of its generally accepted ability to integrate many site factors simultaneously, vegetation is probably the most popular basis for site classification today. The habitat type method (Daubenmire and Daubenmire 1968, Pfister 1976, Pfister and Arno 1980) is a vegetational approach that is applied extensively in the western United States. Although it is adapted to the large areas

of relatively undisturbed forest and the mountainous landforms of the West (which provide striking aspect and elevational differences), groundcover vegetation could be used effectively even in rather highly disturbed areas and in less mountainous regions.

But vegetation is highly complex, is difficult to sample objectively, and poses formidable problems, especially on burned and severely cutover sites. Species may be absent, distributed in part by chance events, and affected by disturbances in different and unknown ways. Herbs may indicate only upper soil conditions that may be insufficient to predict tree composition and growth. For example, site units 3 and 8 have similar vegetation (*table 2*) but markedly different physiography and substrate; the managerial recommendations for these units are quite different.

While it is easy to say that vegetation integrates many site factors, determining what the factor combination is and what it means is no light task. For the most reliable results, the interrelationships of physiography and soils with each species must be known. Thus we emphasize physiography and soils in addition to vegetation because (1) an understanding of them facilitates efficient and reliable use of the groundcover vegetation; (2) physical environmental factors are relatively stable and are probably better predictors of site productivity than groundcover vegetation; (3) physiography may be used to map large areas on aerial photographs; and (4) knowledge of physiography, soils, and drainage is necessary for sound silvicultural practice (including site preparation, harvesting, fertilization, and thinning), and for wildlife and pest management.

As management for timber and multiple use intensifies, the inevitable trend in forest site classification will be toward ecological systems that integrate the important site factors. Site factors, however, can be combined or integrated in several ways. In the emerging component approach (Bailey et al. 1978, Corliss 1974), existing classifications of the components (landform, soil, vegetation, and hydrologic-aquatic factors) must be integrated at various regional and local levels. Specialists provide the detailed classifications of each component, but ultimately someone must reconcile the hierarchies and divisions of each classification into useful units for the manager. Whether this approach can delineate manageable ecosystem units or just a collection of ill-fitting classes will depend upon the ecological understanding and integrative skill of the people who must reconcile the respective classifications in the field. In contrast, ecologists using the Baden-Württemberg approach simultaneously integrate ecosystem factors as they exist in the field and are not bound to reconcile predetermined classes. Whatever the approach, the need is to develop a system that works. We have demonstrated here one such system that can be applied by students or individuals who have had good training in forest ecology, soils, and biology.

The ecological method does not compete with nor does it replace data-gathering systems or methods that provide taxonomic classifications of landform, soil, or vegetation. Where these are available and reliable, ecological site classification and mapping is faster and better. The ecological approach provides an alternative to component methods and is a model of how diverse ecosystem factors can be effectively synthesized in the field.

A Prediction

Ecological site classification has arrived in Europe and Canada, and its time will come in the United States. Because U.S. foresters will need increasingly detailed understanding of ecosystems and reliable productivity estimates, approaches now based on soils will sooner or later incorporate physiography and vegetation in their classification. And approaches that now use vegetation almost exclusively will sooner or later incorporate landform and soils as integral parts of their classification. As management intensifies, the techniques and outcomes of component methods will come more and more to resemble those of the ecological approach described here. Mapping, which forms the heart of classification, will be universally practiced. Information systems will ultimately have to integrate the data they collect. In this process a great deal can be learned from ecological methods already operational in Europe and Canada. ■

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