United States
Department of
Agriculture

Forest Service

Southeastern Forest
Experiment Station

General Technical
Report SE-68

PROCEEDINGS OF A SYMPOSIUM

Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests

CHARLOTTE, NORTH CAROLINA
JANUARY 7-9, 1991

May 1991

Southeastern Forest Experiment Station
P.O. Box 2680
Asheville, North Carolina 28802

PROCEEDINGS
OF A
SYMPOSIUM

Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests

Editors
Dennis L. Mengel
D. Thompson Tew

Charlotte, North Carolina
January 7-9, 1991

Sponsored by:

North Carolina State University
Southeastern Forest Experiment Station
Scott Paper Company
Union Camp Corporation

LIBRARY COPY
ROCKY MT. FOREST & RANGE
EXPERIMENT STATION

CONTENTS

REGIONAL OVERVIEWS

Page

Forests as Landscape Ecosystems: Implications for Their Regionalization and Classification 3
J. Stan Rowe

Land Classification in the Western United States 9
Robert D. Pfister

Ecological Classification System for Classifying Land Capability in Midwestern and Northeastern U.S. National Forests 18
Walter E. Russell and James K. Jordan

History of Forest Site Classification in the South . . . 25
David H. Van Lear

CLASSIFICATION SYSTEM DEVELOPMENT

Land Classification in the Blue Ridge Province: State-of-the-Science Report 37
W. Henry McNab

No More Plots; Go With What You Know: Developing a Forest Land Classification System for the Interior Uplands 48
Glendon W. Smalley

Landscape Ecosystem Classification for South Carolina 59
Steven M. Jones

Delineation and Classification of Wetlands in the Southeast 69
John M. Hefner and Charles G. Storrs

Forest Habitat Regions: Integrating Physiography and Remote Sensing for Forest Site Classification 73
W. Frank Miller and Michael S. Golden

CLASSIFICATION SYSTEM INTERPRETATION

Utilizing a Site Suitability Guide for Site Potential and Species Recommendations on Southern Appalachian National Forests 81
Richard D. Rightmyer and James E. Keys

Use of Land Classification on the Cumberland Plateau 90
John C. Rennie

Page

Forecasting Growth of Pine Hardwood Mixtures From Their Ecological Land Class 93
F. Thomas Lloyd

The Role of Ecological Land Classification Systems in the Silvicultural Decision Process 96
Thomas R. Fox

Site Evaluation for Commercially Important Southern Hardwoods: A Practical Field Method 102
James B. Baker

MAPPING/GIS APPLICATIONS IN CLASSIFICATION SYSTEMS

Dynamic Digital Databases: The Key to Practical Land Classification Systems 105
James L. Smith

Using a Geographic Information System to Classify Forest Productivity in Northwestern California 110
John A. Brockhaus, Lawrence Fox, and Nancy D. Tosta

Classifying Forest Productivity at Different Scales . . 115
Robin Lambert Graham

Landforms, Soils, and Forest Growth: Identification and Integration With Geographic Information Systems 121
R. David Hammer

POSTER PRESENTATIONS

Sampling Map Units to Characterize Forest Site Quality 133
Charles J. Everett and John H. Thorp

Placing "Man" in Regional Landscape Classification: Use of Forest Survey Data to Assess Human Influences for Southern U.S. Forest Ecosystems 135
Victor A. Rudis and John B. Tansey

Timberland Downtown?: Southern Forest Resources Along the Urban-Rural Continuum 137
Christopher E. DeForest, Thomas G. Harris, Jr., Frederick W. Cubbage, and Arthur C. Nelson

Spatial Characteristics of an Appalachian Forest Site . 139
S.J. Tajchman

Page

Classification and Evaluation of the Natchez Trace State Forest, State Resort Park, and Wildlife Management Area for Timber and Wildlife Habitat . . 141
Glendon W. Smalley, Kenderick S. Arney, Lorenda A. Sharber, and Hart W. Applegate

Soil/Site Influences on Forest Growth Within Three Physiographic Regions of Tennessee 142
P. Alan Mays and Elizabeth R. Smith

Page

SCS Forest/Soil Database of North Carolina 144
Albert Coffey

Potential Productivity of Loblolly Pine Plantations in the Southeastern United States 146
S.R. Colbert and H.L. Allen

GIS and Land Classification: Integrated Decision Support for Industrial Forest Management 148
Brent J. Keefer

PREFACE

This volume contains 18 papers and 9 poster abstracts that were presented at a symposium on Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests in Charlotte, North Carolina, on January 7-9, 1991. We appreciate the assistance of all those who contributed to the success of the symposium. The papers are organized into four general categories addressing broad areas related to the classification process.

The symposium was held to assess the current status of site classification in the Southeastern United States. Recurring themes running through all of the papers would seem to indicate that we are speaking the same language and looking at common issues, unlike a decade ago. Ongoing and completed research reports in this volume makes us confident that we will soon have the capability to classify many of the varied sites found in the Southeast.

Papers published in this proceedings were submitted by the authors in camera-ready form, and authors are responsible for the content and accuracy of their individual papers.

STEERING COMMITTEE

Dennis L. Mengel formerly with N.C. State University	CH2M Hill
F. Thomas Lloyd	USDA Forest Service
Steven M. Jones	Clemson University
Glendon W. Smalley retired	USDA Forest Service
Laurie J. Shainsky	USDA Forest Service

REGIONAL OVERVIEWS

FORESTS AS LANDSCAPE ECOSYSTEMS

IMPLICATIONS FOR THEIR REGIONALIZATION AND CLASSIFICATION[1/]

J. Stan Rowe[2/]

Abstract.-- Because organisms cannot exist without environments, the supra-organism reality is the ecosystem that includes both. To understand forests is therefore to understand them as landscape ecosystems whose soil, air and water parts are equally as important as the biological community. Landform, combining surficial materials and surface shape, is an often overlooked key to differentiating dissimilar and similar forest ecosystem sites.

Keywords: Site, multiresource forestry, new forestry

INTRODUCTION

Ideas of what forestry is all about are changing in tune with new understanding of the world around us. The public is demanding not just forest management for sustained timber yield but forest ecosystem management "constrained by the intention of maintaining the forest system as a forest system" (Behan 1990). A "New Forestry" has been defined as taking an ecosystem approach to land management with the aim of maintaining forests as complex ecosystems rather than as tree factories (Gillis 1990). Perhaps the most important task for managers of land and water is figuring out the meaning of "an ecosystem approach" where multiple resources and values are concerned. Clarifying the concept will also illuminate Ecological Land Classification.

LANDSCAPES AS ECOSYSTEMS

Suppose that forested tracts of land are to be managed as ecosystems. What meaning are we to attach to that term? A consensus is lacking. The commonest definition of ecosystem is the textbook "community-plus-environment" that emphasizes the biological component while consigning everything else to a vague milieu, usually represented as a bundle of abstract factors: light, heat, moisture and nutrients. The danger of this simple biological definition is the confusion introduced by the inconstant nature of vegetation and by the wandering proclivities of animals. If an ecosystem is no more than the extension of a community, then an arctic ecosystem vanishes into thin air when its dominant community members take wing and migrate to the southern hemisphere. By the same logic, ecologists have questioned the reality of the visible ecosystem boundary where lake meets land, because amphibians hop across it (McNaughton and Wolf 1973).

A step above the biological definition -- offering deliverance from its dilemmas by tying it down in space -- is the acceptance of soils as bona fide ecosystem parts, granting them as much importance as the biota. Years ago the California Soil-Vegetation Surveys attempted to bring these two components together (Zinke 1960) as have many others since. Berger and Pierpoint (1990) have recently endorsed various forest ecosystem classifications because "they provide proper information for both soil and vegetation components." Yet the conception of forest ecosystems as primarily comprising vegetation and soils is also flawed (Rowe 1984).

The logic that accepts soil as integral to the ecosystem, adding an earth-layer component to the community of any geographic place, suggests the consideration of still other volumetric parts: the air, water, surficial materials and their topography that together make up the supportive matrix of biota and soils. By this reasoning we come to the definition of landscape ecosystems as substantial wholes, as fully functional entities, chunks of the planet's living skin, as "units of nature on the face of the earth," which is what Tansley (1935) the originator of the term "ecosystem" called them when he wrote:

> Though the organisms may claim our primary interest, when we are trying to think fundamentally we cannot separate them from their

---

[1/] Presented at the Symposium Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests, Charlotte, NC, January 7-9, 1991.

[2/] Professor emeritus, University of Saskatchewan, Saskatoon S7N 0W0, Canada. Present address 1012 Josephine St. New Denver, B.C. V0G 1S0

spatial environment with which they form one physical system. It is the systems so formed which, from the point of view of the ecologist, are the basic units of nature on the face of the earth.

Tansley's assertion that basic units of nature exist on the face of the earth and that they are the significant realities rather than organisms per se, shifts attention to dimensional waterscapes and landscapes as themselves more important than the organisms they encapsulate. A forest we know is more than trees, undergrowth plants, animals and micro-organisms in an abstract factored environment. A forest is a landscape, a spatial reality like a large terrarium, consisting of an air stratum over a soil-sediment-water stratum with organisms (including ourselves) the bacon bits in the two-layered sandwich. Wherever we go on the face of the earth -- out on the sea or into a forest -- we immerse ourselves in ecosystems whose importance and reality exceeds our own. The basis for this radical statement is the fact that life is a function of ecosystems, not of organisms. How long would any organisms, Homo sapiens included, be "alive" without the vital supportive matrix of air, water, sediments and received sunshine?

The ecosystem approach, then, is geographically comprehensive; it covers the entire system comprising land, air, water and wildlife.[3/] Such a holistic idea applied to forest landscapes at all sizes, conceiving them as box-like terrariums, implies that a wide range of land characteristics can be drawn on to divide and classify in useful ways. The idea has been expressed in a number of US Forest Service papers such as "Ecoclass" (Corliss and Pfister 1973) and "Land System Inventory" (US Forest Service 1976). It is relevant to this Symposium's purpose which, to quote from the prospectus, "addresses the partitioning of landscapes into logical units based on sound physiography or ecological principles."

REGIONALIZATION AND CLASSIFICATION

Two separate though related steps are involved in the partitioning of landscapes into logical units based on ecological principles. The first is the partitioning and the second is the logical grouping of the resulting units. We begin by searching in the landscape at a chosen scale for forest ecosystems, actual or potential, identifying them at their cores and differentiating them from surrounding ecosystems at their boundaries by criteria relevant to the purpose. Geographers call this process of differentiating and mapping units of the landscape "regionalization" (Bailey 1976). Soil surveys that produce maps are exercises in regionalization. In Canada the countrywide regionalization and evaluation of landscape ecosystems began under the name "Bio-Physical Land Classification," later changed to the more exact "Ecological Land Survey" (Wiken 1980). The methodology has been used to survey the National Parks, and its application in various land inventories of the provinces provides for many of them the base of a Geographic Information System (Holland and Coen 1983, Rubec 1990).

Concurrently with regionalization, though a step behind, a mental aggregating of the results of landscape partitioning develops, evolving into a map legend or a formal classification. Units of the landscape with similar characteristics are placed in the same class while others, judged to be different, are assigned to different classes. Both steps -- regionalization or survey (that differentiates tracts of land) and classification or typing (that differentiates kinds or classes of land) -- interact and co-evolve, each influencing the other. Regionalization is usually "from above," proceeding analytically by division and subdivision, with an eye on differences. Classification is usually "from below," proceeding synthetically by aggregation, with an eye on similarities (Rowe 1979).

The distinction between regionalization and classification is important. The forestry literature frequently confuses the two by calling both "site classification." Remember that classifications are exercises in logic; they can be developed from point or plot data, without dependence on any prior survey-and-mapping exercises and without any particular relevance to them. Many forest site classifications, designed to slot forest stands or deforested areas into appropriate productivity or silvicultural treatment classes, are developed without regionalization, without maps. Some "Field Guides to Forest Ecosystems" (Jones and others 1983, Corns and Annas 1986) are of this type. They are useful for their specific purposes -- which often are to add an ecological dimension to forest cover-type maps -- but they need not be derived from Ecological Land Regionalizations nor tied closely to them. Their classes are more generalized, more abstract, than those that an aggregation of mapped units and complexes of units for a specific region or subregion yields.

MULTIDISCIPLINARY SURVEY

Visualize the continental parts of the world as made up of a mosaic of spatial ecosystems, three-dimensional, each consisting of an atmospheric layer overlying a soil or water layer with organisms concentrated at the solar energized interface. Our job is to sort out the mosaic, differentiating meaningful forest ecosystems and in disturbed places the sites of forest ecosystems. Can it only be done in thematic ways, in single disciplinary ways? We find that most land surveys have been done in this fashion, by phytosociologists, geologists, geomorphologists, pedologists. Each discipline defines its spatial units and draws boundaries on maps according to its own ideas of what is important -- which may not match the disciplinary expectations of others. Years ago Coile (1960) drew attention to the imperfec-

---

[3/] Ecosystems approach to water management. United Nations, Economic Commission for Europe, Economic & Social Council, ENVWA/WP.3/R.7/Rev.1

tions of agricultural soil surveys for forestry purposes in the southeastern States, noting that the soil auger in use at the time was too short to sample deep strata important to tree growth.

If forest land is surveyed from an ecosystem viewpoint rather than from the traditional thematic viewpoints, the result should be a more generalized regionalization and a multi-purpose classification -- which is the definition of a "natural classification." It should help to foster an integrated perception of the entire spectrum of land uses, including with forestry wildlife, agriculture, recreation. It should tell something about sensitivity to acid rain and to traffic, as well as about forest productivity and regeneration silviculture.

By consensus the most useful regionalization is a multi-scale hierarchical system whose nested units, from large to small, are delineated according to visible ecological relationships between climate, landforms, soils and biota (especially the vegetation). Here note that no "correct" hierarchical scaling into domains is waiting to be discovered "objectively" (Bailey 1984). We divide the one big global ecosystem, the ecosphere, into units and at scales that best suit our subjective purposes, which is not to say that all conceptual approaches are equally valuable. If the field is to be advanced different methods should be compared by applying them on the same terrain, as has at least been attempted in Europe (Rowe 1984). Also each new exercise in regionalization and classification should be evaluated as objectively as possible with respect to the ends it purports to serve.

LANDFORM AND ITS GENETIC ROLE

Only one earth exists and there is no substitute for any patch of its surface. This relative uniqueness does not mean that similar parts within any extensive landscape tract cannot be picked out. The question is whether there can be any logic to the exercise.

Hans Jenny analyzed the problem from the viewpoint of a pedologist, identifying five relatively independent "genetic" factors: climate, relief-topography, geological partent material, biota and time. Hold any four steady and let the fifth vary and the result is a sequence of soils: a climosequence if climate is the variable, a chronosequence if time is the variable, and so on. The same logic applies to the patterning of forest ecosystems of which soils are the basal strata (Jenny 1980). As with soils (or vegetation, or local climate), the forms and functions of forest ecosystems express the interactions over time of climate, relief-topography, surficial geological material and available biota.

Jenny's formulation can be simplified from five factors to four by combining relief-topography (surface shape) and geological parent material (sub-surface composition and structure) into <u>landform</u>, at all scales. Examples of local landforms are gravelly terraces, sandy loam levees, sand dunes, lacustrine clay plains. When all the components except landform are invariant -- that is if the regional climate is relatively constant, if the same biota is equally available in all parts of the region and if the time for interaction of ecosystem components within the region is everywhere the same -- then the chief source of within-region variation or pattern in tundra, prairie, savanna or forest landscapes is landform.

Landform -- the slowest changing and most conservative landscape element -- provides the best taxonomic handle for terrestrial ecosystems. It is the stage on which the more changeable players -- surface climate, biotic community and soil -- wax and wane as they act out their successional roles. When <u>they</u> disappear temporarily for one reason or another, the landform remains to provide an identifiable place or "site" where a certain kind of forest ecosystem or successional suite of ecosystems will predictably develop. Landform is the visible means -- clearly or dimly recognized -- by which the boundaries of soils and of potential vegetation communities are extrapolated. If we want to know where resources are and their spatial distribution (Davis 1980), then landform is the stable reference feature to which we must look. Note that at smaller scales, attending to domains and provinces, what we call physiographic divisions are the homologues of landforms.

Another key role of landform, that has not been explored in the ecological literature, is genetic in the sense of exerting initial control over climate near the ground, over the constitution of biotic communities and over the formation of soils. The local fluxes of energy called "topoclimate" are in fact the landform-mediated variations of the overall regional climate. Phrased another way, within large air-mass climatic regions, the suite of landforms (the varying surficial materials and their surface relief/topography expressions) modify the intensity and quality of solar energy input, as well as the reception and retention of precipitation, dust, leaf litter and whatever else is moved around on and in the soil, to form a matching suite of sub-regional climates.

The parallel interacting controls of local climate matched to local landform (for example, the lower slopes of hills as compared to their tops) constitute the mesh of the Darwinian sieve that allows certain plant species and ecotypes to colonize while excluding others. Particularly in the early stages of succession the vegetation communities are aggregated according to specific landform-climate environments. Thus natural vegetation usually appears on aerial photos as repetitive catenary patterns of plant communities matched to particular surficial materials and their slope/exposure facets. Animals follow plants, dependent on them for food and shelter, and the patterns develop as gradients of biotic communities that, with landform-mediated drainage, give rise also to distinctive catenas of soils.

In the eastern USA Nichols (1923) was one of the first ecologists to note what stands out particularly in glaciated terrain: that within reasonably uniform climatic regions the differences in vegetation and in successional patterns after disturbance are primarily associated with differences in surficial materials; that is, with the topography/soil complexes that surface landforms. The same idea was discovered by Hills (1960) whose influence imparted "a strong geomorphic bias" to ecological land classification in Canada (Burger and Pierpoint 1990). Barnes and others (1982) drew attention to a parallel methodology developed in Germany which he and his associates have further illuminated (Simpson and others 1990, Host and others 1987). And of course since 1972 in the National Forests of the Eastern Region the US Forest Service has been using an ecological land classification system that stresses landform and geomorphology based on pioneer work by Dick Alvis and by Wertz and Arnold (1972).

My emphasis on the primary role of landform in shaping forest ecosystem development should not be interpreted as a disparagement of the companion roles of other components such as the soils and the vegetation with its disturbance regimes and successional processes. Superimposed on the characteristics of natural forests entrained by the controls of landform are all the effects of secondary random influences: fire, flood, wind, disease, animal depredation, chance migration, competition that narrows habitat ranges, human land-use practices and other mutualistic or antagonistic biotic interactions.

Nevertheless, the largest part of the repetitive pattern in natural and semi-natural forests can be traced to the repetitive patterns of landforms. Without this consistent match-up the basis for terrain analysis by remote sensing would largely disappear. Here note that the question of scale cannot be neglected because the relative size of pattern-forming influences -- fires, insect infestations, wind storms, freezing belts, land uses -- either enhance or lessen the expected correspondences between landforms and their surface biological patterns.

Landform, then, is an essential component of forest ecosystems at whatever scales they are defined. It merits attention by forest ecologists and forest managers equally with the trees, the undergrowth, the soils, the climate. The classic study "Geomorphology and Forest Ecology of a Mountain Region in the Central Appalachians" by Hack and Goodlett (1960) is worth study by everyone, as are recent contributions such as "Landform effects on ecosystem patterns and processes" Swanson and others 1988) and "Terrain shape index: quantifying effects of minor landforms on tree height" (McNab 1989).

Perhaps past indifference to landform as a key to landscape understanding has been our fascination with classification rather than with regionalization. One can classify forested land in various ways using a range of criteria selected from vegetation and/or soil without any necessary reference to landform, but not so with survey and mapping that force on the observer the importance of surface shape and composition. The Australian land surveys, conducted by interdisciplinary teams, are literally grounded in geomorphology. Their beautifully drawn block-diagrams of terrain, matched with air photos and descriptions in table form, impart ecological understanding with a high degree of artistry (see Bellamy 1986, for example).

CRITERIA FOR ECOLOGICAL LAND CLASSIFICATION

"Ecological regionalizations use various criteria for bounding regions, with the assumption that derived units reflect patterns of systems that differ in response to management and resource production capabilities" (Bailey and others 1985). The adjective "ecological" placed before land regionalization and land classification implies that boundaries between forest ecosystem units will have something more than narrow thematic significance; they will have relational significance. Thus the ELC practitioner does not map soil and vegetation separately, afterwards superimposing one on the other in the vain hope that common boundaries will emerge; s/he seeks rather to differentiate and map land as a unitary thing (Speight 1987), seeking forest ecosystem units suggested by what can be seen and what is known of landform-climate-vegetation-soil parts in interaction, aware of landscape processes, with understanding continually sharpened by field experience.

Not all the important features are equally accessible. The best way to regionalize, to map, is to use visible surface features -- vegetation, landform and its drainage patterns, land use. Their ecological relationships provide the primary stratification to which spot-sampled climate and soils -- more difficult to observe but not less important -- can be linked.

Various methods are used to arrive at ecologically significant boundaries. One method is factorial, searching for clues in the terrain (or on thematic maps of the same terrain) that show changes in the intensity of key factors known to be ecologically important to forests. Thus thermal sensing imagery or climatic maps at appropriate scales may provide isolines of radiation, temperature, soil moisture, and so forth. These can assist in bounding forest units <u>provided that</u> they show some correlation with the natural landscape mosaic. A climatic map by itself is not an ecological map.

A second method searches for terrain features that control the intensity of key factors. Again thematic maps may be useful. Landforms with their control of radiation regime and retention of water and other materials according to slope, aspect and geological substance usually afford good clues to boundary placement. The natural breaks in slope angles, changes from convex-upward to concave-upward surfaces as well as the irregularities that mark changes in surficial materials and soils usually are paralleled by changes in forest vegetation. Nevertheless landform maps are not necessarily ecological maps. Geomorphologists sometimes

discount the importance of the soil skin on their landforms, or map out different tracts according to age rather than to ecological properties. Geomorphological units must be tested by their covariance with other landscape features.

A third method uses biological indicators: vegetation, soils and the residual land-use marks of disturbance and change made by animals and man. But by themselves these too may not be trustworthy for they may reflect unknown past events that have little relevance to current conditions. Validation as good ecological indicators requires that they be checked against variations in physiography. A vegetation pattern that does not make sense in relation to the patterns of landforms, soils and drainage patterns is suspect.

The success of these methods is predicated on mapping areas of sufficient size to reveal repetitive patterns. Boundaries of ecological significance emerge from studies that reveal correlative changes in vegetation, climate, soil, drainage and landforms. Forest ecosystems are discriminated by visible components that go together. This is different from the attempt to synthesize ecosystems by the addition of components initially defined as thing-in-themselves, with no whole ecosystem in mind.

Acknowledgement: The author thanks Ed Wiken for generous assistance in literature survey and for useful comments during the preparation of this paper.

LITERATURE CITED

Bailey, Robert G. 1976. Ecoregions of the United States. U.S. Department of Agriculture, Forest Service, Ogden, Utah 84401

Bailey, Robert G. 1984. Integrating ecosystem components. In: Bockheim, James G., Proceedings symposium on forest land classification: experiences, problems, perspectives; 1984 March 18-20; Madison, WI. NCR-102 The north central forest soils committee, Department of Soil Science, University of Wisconsin, WI 53706 pp. 181-188.

Bailey, Robert G.; Zoltai, Steven C.; Wiken, Ed B. 1985. Ecological regionalization in Canada and the United States. Geoforum 16(3):265-275.

Barnes, B.V.; Pregitzer, K.S.; Spies, T.A.; (and other). 1982. Ecological forest site classification. Journal of Forestry 80:493-498.

Behan, R.W. 1990. Multiresource forest management: a paradigmatic challenge to professional forestry. Journal of Forestry 88(4):12-18.

Bellamy, J.A. 1986. Papua New Guinea: inventory of natural resources, population distribution and land use handbook. CSIRO Division of Water and Land Resources, Natural Resources Series No. 6, Canberra, A.C.T.

Burger, Dys; Pierpoint, Geoffrey. 1990. Trends in forest site and land classification in Canada. Forestry Chronicle 66(2):91-96.

Coile, T.S. 1960. Summary of soil-site evaluation. In: Southern forest soils: eighth annual symposium; 1959; Louisiana State University Press, Baton Rouge, LA. pp. 77-85.

Corliss, John C.; Pfister, Robert D. 1973. Ecoclass -- a method for classifying ecosystems. U.S. Department of Agriculture, Forest Service, Missoula MT. 72 pp.

Corns, I. G. W.; Annas, R. M. 1986. Field guide to forest ecosystems of west-central Alberta. Canadian Forestry Service, Northern Forestry Centre, Edmonton, Alberta T6H 3S5

Davis, L.S. 1980. Strategy for building a location-specific multipurpose information system for wildland management. Journal of Forestry 78:402-408.

Gillis, Anna Maria. 1990. The new forestry: an ecosystem approach to land management. BioScience 40(8):558-562.

Hack, John T.; Goodlett, John C. 1960. Geomorphology and forest ecology of a mountain region in the central Appalachians. Geological Survey Professional Paper 347, United States Government Printing Office, Washington DC.

Hills, G.A. 1960. Regional site research. Forestry Chronicle 36:401-423.

Holland, W.D.; Coen, G.M. 1983. Ecological (biophysical) land classification of Banff and Jasper National Parks; volume 1: summary; Canadian Forestry Service, Northern Forestry Centre, Edmonton, Alberta T6H 3S5

Host, George E.; Pregitzer, Kurt S.; Ramm, Carl W.; (and others). 1987. Landform-mediated differences in successional pathways among upland forest ecosystems in northwestern lower Michigan. Forest Science 33(2):445-457.

Jenny, H. 1980. The soil resource: origin and behaviour. New York: Springer-Verlag.

Jones, R.K.; Pierpoint, G.; Wickware, G.M.; (and others). 1983. Field guide to forest ecosystem classification for the Clay Belt, site region 3E; Ontario Ministry of Natural Resources, Downsview, Ontario, Canada.

McNab, W. Henry. 1989. Terrain shape index: quantifying effects of minor landforms on tree height. Forest Science 35(1):91-104.

McNaughton, S.J.; Wolf, Larry L. 1973. General Ecology. New York: Holt, Rinehart and Winston Inc.

Nichols, G.E. 1923. A working basis for the ecological classification of plant communities. Ecology 4:154-179.

Rowe, J.S. 1979. Revised working paper on methodology/philosophy of ecological land classification in Canada. In: Rubec, C.D.A., Applications of Ecological (biophysical) land classification in Canada; Ecological Land Classification Series No. 7, Lands Directorate, Environment Canada, Ottawa K1A 0H3 pp. 23-30.

Rowe, J.S. 1984. Forestland classification: limitations of the use of vegetation. In: Bockheim, James G., Proceedings symposium on forest land classification: experiences, problems, perspectives; 1984 March 18-20; Madison WI. NCR-102 The North Central Forest Soils Committee, Department of Soil Science, University of Wisconsin, WI 53706 pp. 132-147.

Rubec, C.D.A. 1990. Thirty years of ecological land surveys in Canada. Sustainable Development Branch, Environment Canada, Ottawa K1A 0H3 29 pp.

Simpson, Thomas B.; Stuart, Philip E.; Barnes, Burton. 1990. Landscape ecosystems and cover types of the reserve area and adjacent lands of the Huron Mountain Club. Occasional papers of the Huron Mountain Wildlife Foundation, No.4. Big Bay, MI 49808.

Speight, J.G. 1987. Land classification. In: Gunn, R.H.; (and others), Australian soil and land survey methodology handbook. Inkata Press, Melbourne.

Swanson, F.J.; Kratz, T.K.; Caine, N.;(and others). 1988. Landform effects on ecosystem patterns and processes. BioScience 38:92-98.

Tansley, A.G. 1935. The use and abuse of vegetational concepts and terms. Ecology 16:284-307.

Wertz, W.A.; Arnold, J.F. 1972. Land system inventory. U.S. Department of Agriculture, Forest Service, Intermountain Region, Ogden UT

Wicken, E. 1980. Rationale and methods of ecological land surveys: an overview of Canadian approaches. In: Taylor, D.G., Land/Wildlife integration; Environment Canada, Ottawa K1A 0H3. pp. 11-19.

Zinke, P.J. 1960. The soil-vegetation survey as a means of classifying land for multiple-use forestry. Proceedings Fifth World Forestry Conference, Aug. 29 - Sept. 10, 1960, Seattle WA.

LAND CLASSIFICATION IN THE WESTERN UNITED STATES[1/]

Robert D. Pfister[2/]

Abstract.--Various approaches to classification and mapping of forests, sites and landscapes have been developed during the past few decades. These approaches vary in concepts, objectives, methods, costs, accuracy, scale and application to forest land management. Major systems are reviewed and compared in terms of (1) basic classification concepts, (2) ecological concepts, and (3) primary applications to practical resource management.

Keywords: Site type, habitat type, land system, soils, landform.

INTRODUCTION

My purpose is to provide an overview of land classification activities in the western United States. The period of time I will cover is the last two decades. In reviewing these activities, I hope to show the progress that has been made as well as the problems that have been encountered.

Everyone has one perspective on land classification--their own! Rarely do two people share the same perspective. Land classification sounds very simple--but it is this apparent simplicity that has led to major misunderstandings. You would think that if we all communicate in English, we wouldn't have that problem. However, in the broad field of land classification, it often appears that people are not even using the same language. We are dealing with varied backgrounds in terminology, concepts, experience, environments, and a multitude of scales.

The fact that we hold these symposiums suggests that the subject is broader than one person or discipline can encompass. I suggest that to encompass everyone's interests and activities we would have to define land classification as any map that has been created to show polygons as individual entities within a larger whole. In other words, land classification is clearly tied to the process and products of mapping the landscape for whatever purpose.

With this broad viewpoint, at least three disciplines need to look for common viewpoints.

These include: 1) mostly soil scientists, 2) a few vegetation ecologists, and 3) a very few geographers. Each of these disciplines has made major contributions to the continually developing field of land classification. However, I also submit that the future challenges of land classification will require better communication and cooperation among the different perspectives. I hope this symposium helps meet that need.

Maybe I am a slow student, but as a student of land classification for the past 20 years, I would like to share what I have learned and the basic concepts I use for teaching (so that my students do not have to take the same 20 years I took to gain some understanding). If this approach seems overly simple to some of you folks in the audience, let me explain that we all are conditioned by past experience--what we hear is not necessarily what someone else hears after we each pass it through our own unique filters. Practitioners in the field of land classification can get into loud arguments over very small points because they do not have the same perceptions.

My perception of land classification began with two different classification systems--soils and vegetation. Before you say this is not land classification, let me ask your indulgence. A map of soil series is one kind of land classification. A map of forest cover types is another kind of land classification. A map of potential plant community types is yet another kind of land classification. Some people may prefer to call these "site" classifications, or "vegetation" classifications, but once a map is produced--that map identifies various pieces of land that are charac-

---

[1/]Presented at the Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests Symposium. Charlotte, NC, January 7-9, 1991.

[2/]Research Professor, School of Forestry, University of Montana, Missoula, MT 59812

terized by those specific criteria. The point here is that--no one individual, agency, or discipline has a monopoly on the term "land classification." The same thinking can be applied to the subject of "ecosystem classification." With either land classification or ecosystem classification, no one understands what you are talking about until you specify the criteria, the methods, and the scales you are thinking about.

You may think this lack of common perception and common objectives is a small matter. However, it reaches far beyond one's wildest imagination in the halls of academia, government agencies and even within agencies. It has provided grist for numerous articles, claims and counter claims.

SOIL TAXONOMY AND MAPPING

I was introduced to soil classification as part of forestry training. Soil morphology, description, classification, and development were part of my soils training along with soil physics, fertility,etc. I was a student during the transition from the old 1938 classification, through the "7th Approximation," to the new "Soil Taxonomy." We studied soil maps and the interpretive information that accompanied them.

This country has benefited from a national standardized system. The foundation is in the standard "Soil Taxonomy." Mapping is an attempt to represent that taxonomy across the landscape, although it rarely can be done as representation of pure taxonomic units. With this foundation and availability, soils have been a fundamental part of many (but not all) land classification efforts.

HABITAT TYPE TAXONOMY AND MAPPING

In 1961 I was introduced to another method of classification, the habitat type, that led me to some confusion and curiosity. I was familiar with vegetation classification, but this jump to habitat types as units of land capable of supporting a specific climax plant association caused me some problems. I was used to thinking of land in terms of soils and obvious physical site factors that I could measure easily, such as aspect, elevation, slope and parent material. It was not until I learned to recognize some of the plant species other than the trees that I began to see that potential vegetation or habitat types provided another, at least equally valuable, perspective of the landscape. I first learned to identify habitat types for individual plots, such as during an inventory.

When I first mapped habitat types for a 3,600-acre experimental forest, I realized that the vegetation was reflecting unique differences among sites and landscape patterns. The perspective was different than two previous soil-mapping projects had produced for the same area. When the different maps were overlayed, you could see some degree of correlation, as well as obvious lack of correlation where the plant communities were reflecting site factors differently than previous soil mapping had done.

For me, this was the beginning of an appreciation that more than one perspective can be valuable for understanding and managing forest ecosystems. This was fascinating as a researcher, although managers usually wanted to invest in only one all-purpose land classification and they usually hired soil scientists to provide this input.

LAND SYSTEMS INVENTORY

The U.S.D.A. Forest Service soil scientists faced a difficult task in the early land classification days. Mapping of soil series was an impossibly expensive task considering the large acreages they were charged with. A classification system was needed to get basic resource information efficiently for large areas of land.

The Land Systems Inventory approach was first documented by Wertz and Arnold (1972) in the Intermountain Region and was developed concurrently in the Northern Region. The principal criterion for unit identification and mapping of Landtypes or Landtype Associations was landform as identified on photographs of 1:60,000 to 1:40,000 scale. Once the land units were mapped, a sample of them was visited to identify and describe the soils, vegetation, geology, and topography as a basis for developing management interpretations for the units (Nelson and Jordan 1987).

During the 1970's the Land Type or Land Type Association mapping approach was proceeding in most areas as an attempt to obtain a general land inventory with sufficient characterization to use for multiple-use planning at the resource allocation level. A similar approach, called Soil Resource Inventories, was used in the Rocky Mountain Region and in the Pacific Northwest. In the Pacific Southwest, they called it a Terrestrial Ecosystem approach. In California, many different approaches were being tried including detailed soil-vegetation mapping. Improvements have been made in the system by better integration of vegetation, landform and soils and finer resolution of map units (Nelson and Jordan 1987). A 1984 figure illustrates the different names of similar approaches in the different Forest Service Regions (figure 1).

INTEGRATED CLASSIFICATION SYSTEMS

In 1971, the Washington office of the Forest Service developed tentative guidelines for a national classification of ecosystems. The Chief commissioned an interdisciplinary task force to develop and document a standard ecosystem classification for the greater Pacific Northwest (Washington, Oregon, Idaho, Montana, Wyoming) based upon existing knowledge. The task force produced a document called ECOCLASS (Pfister and others 1973, Corliss 1974) that said a single classification was totally unrealistic, but that two terrestrial classification systems could be linked to define ECOLOGICAL LAND UNITS. The double hierar-

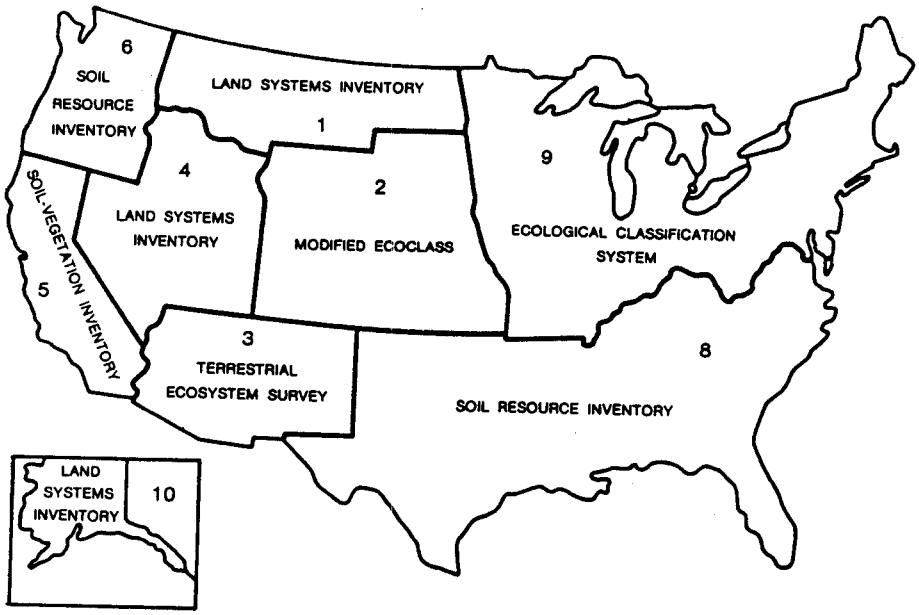


Figure 1.--Forest Service ecological land classification methods, March 1984 (from Bailey 1984).

chy of the ECOCLASS system was used in several areas in the 1970's to identify land units of similar topography, soils, and vegetation potential in conjunction with Unit Planning.

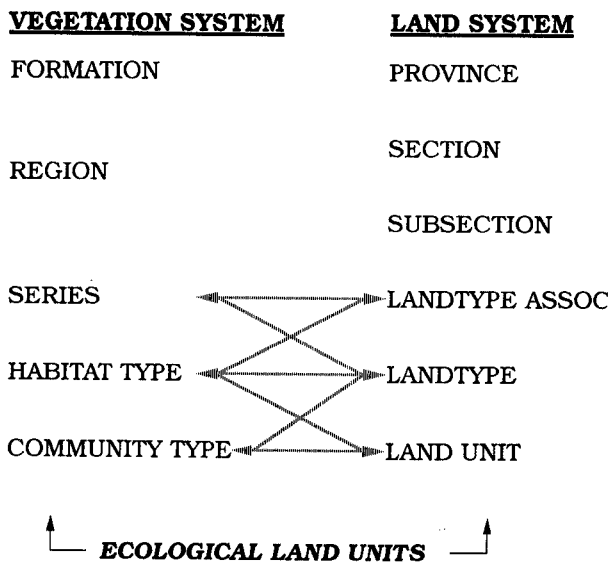


Figure 2.-- Ecoclass vegetation system and land system hierarchies (from Pfister and others 1973).

ECOCLASS was not accepted outside of the regions for which it was developed. In addition, the lack of agreement in basic inventory figures of forest land among agencies at the national level provided impetus for another formal effort. A Rocky Mountain Station research unit was given the task of developing a standard national land classification for five agencies for the entire United States (Driscoll and others 1984). (The Forest Service put it in their manual in 1982, and the Bureau of Land Management published it as a research note in 1983.)

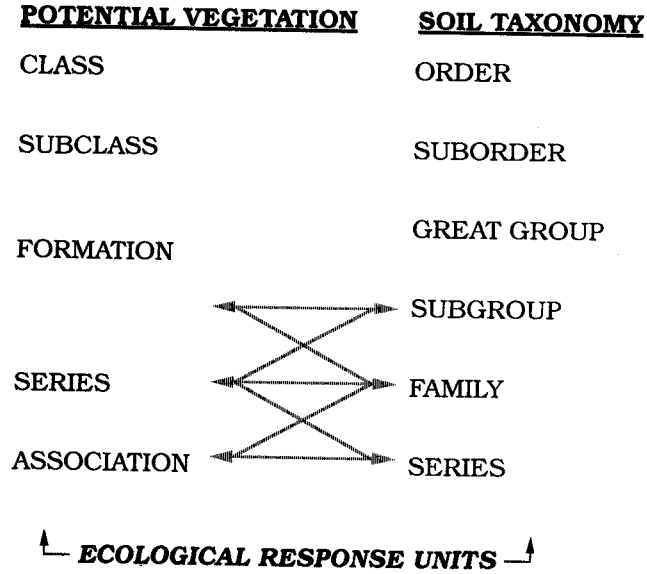


Figure 3.--An ecological land classification system for the United States (from Driscoll and others 1984).

Three independent hierarchies were provided: 1) Potential Vegetation, 2) Soil Taxonomy, and 3) Landform. Taxonomies were available or underway for much of the western United States for Potential Vegetation, and the national Soil Taxonomy was readily available for the entire country. However, a standard taxonomy for landform was not available at that time. Therefore, the application of the system was limited to cross-

classification (identification) of inventory points which then became Ecological Response Units (ERU's), This document went through several reviews and rewrites in an attempt to reach consensus. It was finally pushed to completion, and five agencies signed off on the basic concept. However, there was still considerable resistance by those whose needs were not addressed by the document.

First of all, the system was primarily a taxonomic system and the main intended application was to identify inventory points by their potential vegetation types and soil types (according to standard taxonomies) so that inventory data could be aggregated upward into higher levels of individual or linked hierarchies. Certainly, those people who wanted this information at regional or national levels could see the immediate value of this application. (The Landform hierarchy was also a desired component, but a standard landform hierarchy was not yet available.)

Perhaps basic inventory and aggregation needs were met by this system. However, any of the people who had been working on land classification for planning purposes during the 1970's recognized a basic problem. The National Land Classification could not classify land by simply identifying points in an inventory. It was not designed to produce maps of land units. There was no clear linkage with any of the land system mapping that had been proceeding during the 1970's. What to do?

Most regions simply proceeded with land mapping according to their regional procedures. If the first level of mapping was at the Landtype Association, then the next task was to identify the landtype level in the Land System hierarchy. This was called level III soil mapping in some areas as the Forest Service and the Soil Conservation Service began to rebuild working relationships toward common terminology and increased cooperation.

Two symposiums were scheduled in the 1980's to address the subject of land classification with an emphasis on mapping. The first was in Albuquerque (Moir and Hendzel 1983) and the second was in Madison (Bockheim 1984). This one appears to be the third in the serie,s with a primary focus on mapping approaches to land classification.

The proposed integrated methods have not been widely accepted. Even today, individuals are interpreting the landscape independently by habitat types, soil types, range sites, landforms or remote sensing. Each have unique perspectives and little hope of total communication unless they have the opportunity to work as a team on the same piece of ground.

Why is this? Several reasons can be suggested.

The first system was primarily aimed at mapping systems for application in land use planning. The second system was aimed at identifying inventory points for aggregation of data. A second major difference is the process of classification and the distinction between taxonomy and mapping. If you start with remote sensing, you are searching for ways to subdivide the world into map units that appear to be relatively homogenous. If you start on the ground, you are looking at grouping similar stands or sites. Each group perceives a complete hierarchy, but it is like trying to use a 20-foot extension ladder to paint a 15-foot flagpole when the two ethnic painters haven't figured out how to put the extension ladder together yet!

GAINING BROADER PERSPECTIVES

In order to share my changes in thinking, I need to go back to the late 1960's. My research assignment had shifted from silviculture to the development of forest habitat type classifications (taxonomies) for the Northern Rocky Mountains. In 1970, I had the good fortune to work with the Intermountain Region Land Systems Inventory crew on the Idaho Primitive Area. My role on the team was to help train the soil scientists in habitat type identification, which they were using to help characterize their mapping units. In the process, I gained an appreciation for the immensity of their task--covering over a million acres in a short summer.

In 1971, I had the opportunity to work on a committee of the Northern Region in developing methodology for an Ecological Approach to Unit Planning. (This led naturally to involvement on the ECOCLASS task force.) Habitat type mapping of experimental areas and on entire National Forests was progressing concurrently with independent mapping of landtypes. Obviously, this set the stage for a lot of discussion, to say the least! Landtypes may have been adequate for certain planning needs, but the resolution was unsatisfactory for those managers who wanted to use a more direct classification for interpretation of vegetation potentials and related management information.

A major strength of the habitat type effort was that the taxonomy was available to any field person so they could identify types and make their own maps. Furthermore, the management interpretations were tied to the classes of the taxonomy, not to a specific map unit. Therefore, a foundation was available for building type-specific management information independent of mapping efforts. The habitat type mapping was also relatively efficient.

Both habitat type maps and landtype maps were useful input for planning. The landtypes provided good characterization of landforms and general soils (family level) characteristics important for identifying constraints on management, but were less useful for interpreting vegetation-related potentials. The habitat types provided good information on potentials for multi-resource use related to vegetation potentials, but were much less useful for interpreting constraints related to physical site and landform variables. Planners who had both sources of information at their disposal were more comfortable in their planning efforts.

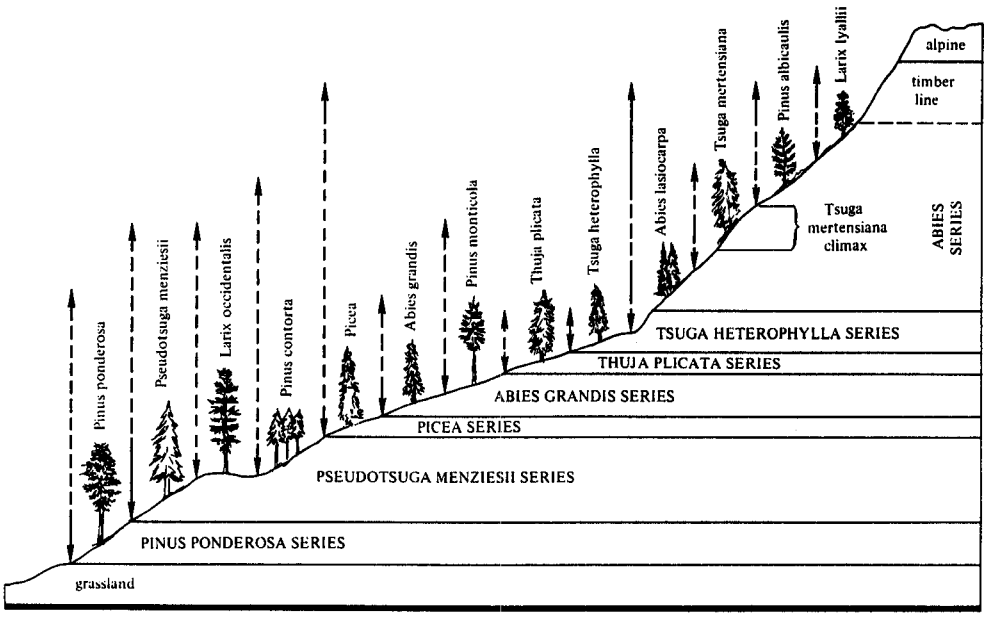


Figure 4. Illustration of the typical distribution of series and species (from Pfister and others 1977).

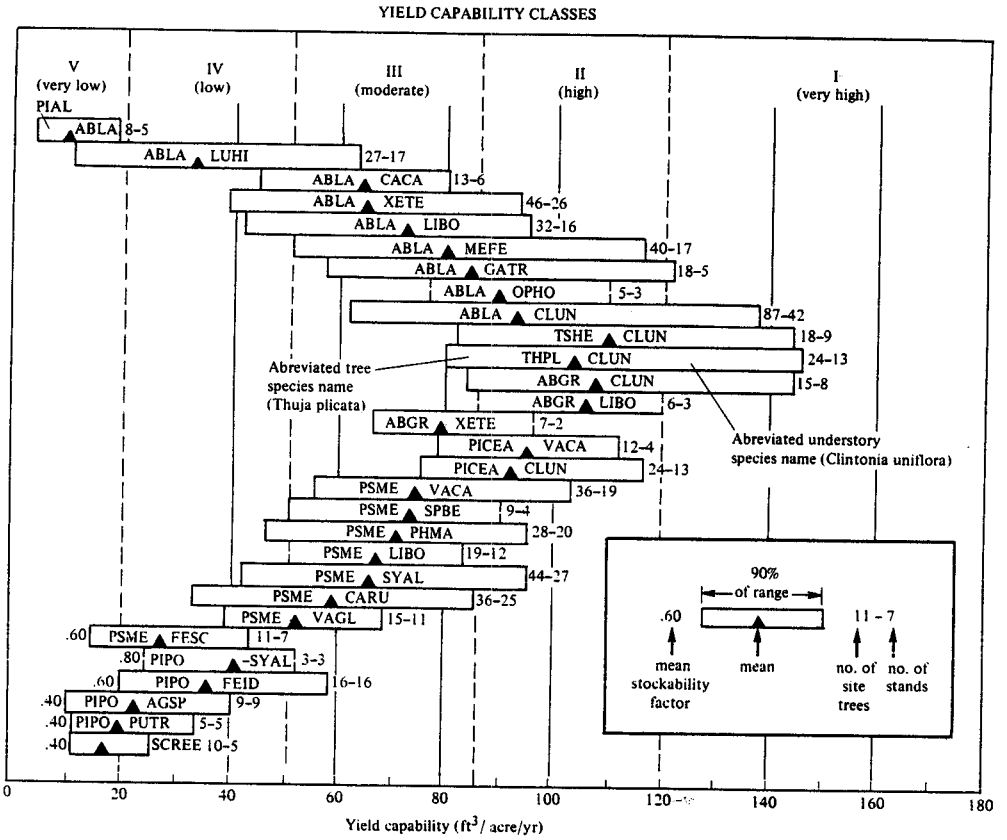


Figure 5. Illustration of the yield capability information for habitat types (from Pfister and others 1977).

CONCEPTS, TERMINOLOGY AND METHODS

In 1977, the Society of American Foresters was also interested in getting a better handle on vegetation, site, and land classification so they invited several authors to develop a special issue for October 1978. Bob Bailey (geographer) and I (plant ecologist) were invited to prepare a joint paper on the basic concepts of land and resource classification. We had little common ground, but were determined to learn from each other and broaden each other's perspectives. In the process, we looked at the basic science of classification to help provide perspective.

Classification embodies the separate approaches of taxonomy and mapping, and we encouraged the use of those terms. Soil taxonomy and habitat type taxonomies are examples where a user often does the identification of points or boundaries on the landscape. Users of taxonomy also usually do the mapping rather than the developers of the taxonomy. Mapping at scales of 15,840 or larger can often be mapped as relatively pure (75 to 90 percent) taxonomic units, with a minimum of complexes or associations. They are a classification system of choice for people working on the ground.

Classification systems that start with identification of relatively homogenous units of landscape are usually done at scales smaller than 1:24,000 and are often termed regionalization. In this process, mapping is usually the first step, followed by sampling, description and interpretation.

The interaction with Bailey opened up a new perspective for me, and helped me interpret some of the integrated efforts. It helped me interpret and characterize the National Classification effort (Driscoll and others 1984) as primarily a "component site taxonomy"--useful for identifying points and providing a means for aggregating data consistently. It bears little relationship to land classification where mapping is the fundamental starting point, except for providing taxonomies that are useful for describing map units.

A PROPOSED REVISION OF ECOCLASS

With much improved hindsight, I now see some problems with the original ECOCLASS as a communication tool for mapping ecosystems. We can improve on the original concept by relating to current mapping efforts and identifying the scale at which the mapping is usually done. We can also make it specific to the Northern Rocky Mountains to avoid regional terminology differences.

For the Potential Vegetation System, we first can remove the term "formation" because it is usually used in a taxonomic hierarchy rather than a mapping hierarchy. At the upper level, Forest Regions have been mapped for Montana (Arno 1978) where distributions of forest species and forest habitat types are used to characterize different effective climatic regions. (Or we can use Bailey's (1976) Ecoregions). Kuchler's (1964) Potential Natural Vegetation map is independent and one level lower. Habitat Type or Habitat Type Phase are the common operational mapping levels, usually requiring a map scale of 1:15,840 or larger. These can be aggregated upward to Groups or Series as they are usually not mapped.

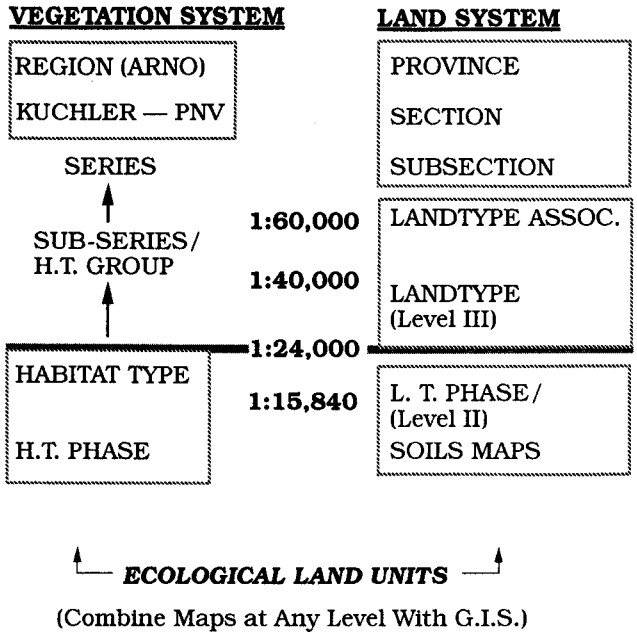


Figure 6,--A proposed revision of ECOCLASS to reflect current mapping efforts in the Northern Rocky Mountains.

Land System mapping is essentially completed for the upper five levels. Landtype Associations and Landtypes have been the focal point of Forest Service mapping, usually at a scale of 1:40,000 to 1:60,000. Maps at scales of 1:15,840 have not been prepared for many areas. However, several private lands have been mapped by the Soil Conservation Service at Level II, at scales ranging from 1:12,000 to 1:24,000.

The lack of maps at the same scale for the Potential Vegetation System and the Land System has seriously hindered our ability to compare and communicate. Defining Ecological Land Units is not easy with maps of greatly different scales. On Forest Service lands we rarely find a map at the landtype Phase level to compare with a habitat type map.

Soil scientists often state that the lowest level of the land system is the same as ecological land unit. Recent maps of habitat types and soil types, both at 1:15,840 clearly illustrate that the polygons have much less correlation than some people care to admit. Both are valuable, but they are different. Each provides a unique perspective and unique interpretations. The principle of compensating factors is well established and cannot be ignored. But look at the power the land manager has when the two are combined to develop ecological land units--areas of similar topography,

soils and potential vegetation. Neither the vegetation system alone, nor the land system alone have yet provided this degree of resolution.

Some plant ecologists are attempting to develop "ecological type" classifications (Allen 1985), which are basically a subdivision of habitat types based on contrasting physical site features and/or productivity. The ecological type appears almost synonymous with the lowest level of the ecological response unit (Driscoll and others 1984) in a taxonomic sense, or with the lowest level of the ecological land unit (Pfister and others 1973) in the mapping sense.

It is interesting to note that the scale of 1:24,000 is about where two major Forest Service operational approaches meet. The foresters mapping habitat types are operating with patterns they can see from the ground. The landtype specialists are mapping patterns that are not visible from the ground. Until these people start operating on the same scale, or appreciate the unique value of each map, or find a way to link mapping efforts, there will be continuing communication problems.

DISCUSSION

Can we avoid the term classification as much as possible when referring to specific efforts? Would it help our terminology, if we generally talked about land classification as primarily a mapping approach--or simply call it land mapping? Can we use the word taxonomy for the classifications that are basically lists of types with keys to help the user identify points or plots.

Could we generally reserve the term land mapping for scales smaller than 1:24,000 and use the term site mapping for scales larger than 1:24,000?

We need pilot demonstrations of the different techniques of land classification done on the same pieces of ground. Experimental forests provide an ideal laboratory for this kind of exercise. Until you independently and objectively demonstrate different techniques, you have little basis for meaningful dialogue. This should include cost and cost effectiveness comparisons for management applications.

The vegetation system will continue to be a major component of any classification system in the western United States because of the status of developing taxonomies. Most of the forest lands now have operational taxonomies that provide the foundation for accumulating management information. However, formal mapping programs have been limited to the Northern Rocky Mountains, perhaps because available mapping dollars have been allocated to completing the landtype mapping. New techniques are being developed to improve the preciseness and utility of the taxonomic systems, and work is also progressing on developing successional pathways relative to various management treatments.

Efficient techniques are also being developed to extend the habitat type concept to areas where few remnants of natural vegetation remain. For example, we are currently completing a habitat type classification of riparian and wetland areas. We call this "habitat typing in the land of no climax!" Existing knowledge of environments and relative species amplitudes (plus minimum field work) can be used to develop a first approximation of the "Series" or "Sub-Series" level of habitat type taxonomy on most landscapes. It illustrates the point that you can still use the concept of developing a useful site classification based on potential vegetation trends without old-growth natural stands.

In evaluating use of different classification systems, I have been impressed with the long term value of taxonomic systems relative to mapping systems. Look for opportunities to provide a taxonomy as a foundation for future work. When you hand a forester a map, all they can do is use the map for the intended purpose. When you provide a taxonomy, other people can use it for identifying points, as criteria for mapping, as description for mapping units, and as a foundation for accumulating management knowledge. One kind of formal taxonomy that would be very useful is a basic, simple topographic or terrain classification. Another useful taxonomy is a local, simplified key to soil types.

I wish you well in your symposium and in your land classification efforts. As a person who believes that classification is a fundamental prerequisite of conceptual thought, I will be interested in your experiences, approaches, and applications to land management

RECOMMENDED READING

Several summaries of ecological land classification have been written in an attempt to provide an overview and an extensive list of references. The following are recommended for their breadth and references:

<u>General overviews, concepts, and terminology:</u>

Description, Classification, and Mapping of Forest Ecosystems, Chapter 16 in the book, Forest Ecology (Kimmins 1987)

Nature of land and resource classification--a re view (Bailey, Pfister and Henderson 1978)

Ecogeographic Analysis: A guide to the Ecological Division of Land for Resource Management (Bailey 1988).

An ecological land classification framework for the United States (Driscoll and others 1984)

<u>Western United States Land Classification:</u>

ECOCLASS--a Method for classifying ecosystems. (Pfister and others 1983; Driscoll 1984)

Ecological Land Classification in Montana and Idaho (Pfister 1977)

Land classification based on vegetation- applications for resource management symposium (Ferguson, Morgan and Johnson 1989)

Forest habitat type classification in western United States (Pfister 1984)

Workshop on southwestern habitat types -- Albuquerque, NM (Moir and Hendzel 1983)

(Copies of my symposium papers are available by writing to me at the School of Forestry, University of Montana, Missoula, MT 59812)

LITERATURE CITED

Allen, B. H. 1985. Ecological type classification for California: the Forest Service approach. Gen. Tech. Rep. PSW-98. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 8 p.

Arno, S. F. 1980. Forest regions of Montana. U.S. Department of Agriculture. Forest Service Research Paper INT-218. Intermountain Forest and Range Experiment Station, Ogden, UT 39 p.

Bailey, R. G. 1976. Ecoregions of the United States. U.S. Department of Agriculture, Intermountain Region, Ogden, UT. Map. Scale 1:7,500.

Bailey, R.G. 1984. Integrating Ecosystem Components (p. 181,188). In: Forest Land classification: Expriences, problems, perspectives. Proceedings of a symposium: March 18-10, 1984. University of Wisconsin, Madison

Bailey, R. G. 1988. Ecogeographic analysis; a guide to the ecological division of land for resource management. Washington, DC: U.S. Department of Agriculture, Forest Service, Miscellaneous Publication 1465. 16 p.

Bailey, R. F.; Pfister, R. D.; and Henderson, J. A. 1978. Nature of land and resource classification -- a review. Journal of Forestry 76: 650-655.

Bockheim, J. G. (ed.) 1984. Forest land classification: Experiences, problems, perspectives. Proceedings of a symposium; 1984 March 18-20; Madison, WI: University of Wisconsin. 276 p.

Corlis, J.C. 1974. EOCCLASS--A method for clas sifying ecosystems. In: Foresters in land-use planning. 1973 National Convention, Society of American Foresters, p. 264-271

Driscoll, R. S.; Minkel, D. L.; Radloff, D. L.; Snyder, D. E.; Hagihara, J. S. 1984. An ecological land classification framework for the United States. Misc. Pub. 1439. Washington, DC: U.S. Department of Agriculture, Forest Service. 56 p.

Ferguson, D. E.; Morgan, P. J.; Johnson, F. D. (compilers). 1989. Proceedings--land classifications based on vegetation: applications for resource management; 1987 November 17-19; Moscow, ID. Gen. Tech. Rep. INT-257. Ogden, UT: U.S.Department of Agriculture, Forest Service, Intermountain Research Station. 515 p.

Kimmins, J. P. 1987. Forest ecology. New York: MacMillan Publ. Co. 531 p.

Kuchler, A.W. 1964. Manual to accompany the map-potential vegetation of the conterminous United States. Am. Geo. Soc. Spec. Publ 36. 116 p. + map (scale 1:1,000,000)

Moir, W.H.; Hendzel,L. 1983. Proceedings of the workshop on southwestern habitat types, April 6-8, 1983, Albuquerque, NM. U.S. Department of Agriculture, Forest Service, Southwest Region. 110 p.

Nelson, D.; Jordan, J.K. 1987. Application of multi-factor land classification on national forests. Economic and Social Development--A role for forests and forestry professionals. Proc. 1987. Soc. Am. For. Nat. Conv. p. 162-165

Pfister, R. D. 1977. Ecological classification of forest land in Idaho and Montana. (p. 329-326) In: 1977 Proc., Ecological Classification of Forest Land in Canada and Northwestern USA, Univ. of British Columbia, Vancouver, CAN.

Pfister, R. D. 1982. Designing successional models to meet management needs. In: Forest Succession and Stand Development Research in the Northwest. Proceedings of the Symposium held 26 March 1981 at Corvallis, OR. Forest Research Laboratory, Oregon State University, p. 44-53. (Joseph E. Means, editor).

Pfister, R. D. 1984. Forest habitat type classification in the western United States. In: Symposium on Site and Productivity of Fast Growing Plantations, Proceedings of a Symposium held in Pretoria and Pietermaritzburg, South Africa, 30 April-11 May 1984. International Union of Forestry Research Organizations. (Editorial Committee: D. C. Grey, A. P. G. Schonau and C. J. Schutz) Volume 1-p.149-162.

Pfister, R. D. 1988. Site classification and productivity in the western United States. (p. 81-91) In: Williams, T. M. and C. A. Gresham, Ed. 1988. Predicting Consequences of Intensive Forest Harvesting on Long-term Productivity by Site Classification. IEA/BE Project A3, Report No. 6. Baruch Science Institute of Clemson University, Georgetown, S. C. USA

Pfister, R. D. 1989. Basic concepts of using vegetation to build a site classification system. In: Symposium, Land Classifications Based on Vegetation: Applications for Resource Management, Moscow, ID, November 17-19, 1987.

Pfister, R. D. and S. F. Arno. 1980. Classifying forest habitat types based on potential climax vegetation. Forest Science 26:52-70.

Pfister, R. D.; Kovalchik, B. L.; Arno, S. F.; Presby, R. C. 1977. Forest habitat types of Montana. USDA For. Serv. Gen. Tech. Rep. INT-34, 174 p. Intermountain Forest and Range Exp. Sta., Ogden, UT.

Pfister, R. D.; Corliss, J. C.: [and others]. 1973. Ecoclass--a method for classifying ecosystems--a task force report to the Chief of the Forest Service. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 52 p.

Wertz, W. A.; Arnold, J. F. 1972. Land system inventory. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 12 p.

ECOLOGICAL CLASSIFICATION SYSTEM FOR CLASSIFYING LAND CAPABILITY IN MIDWESTERN AND NORTHEASTERN U.S. NATIONAL FORESTS [1/]

Walter E. Russell and James K. Jordan [2/]

Abstract.--The Ecological Classification System used by the National Forests in the U.S. Eastern Region is a framework to facilitate integrating appropriate physical and biological factors to stratify forest landscapes into homogeneous resource capability units. The framework provides seven hierarchical levels to accommodate land capability-suitability analyses at different levels of resolution, depending on management information needs.

Keywords: Ecological Type, Ecological Unit, Ecological Land Type, Land Type Association, Ecological Land Type Phase, Opportunity Area.

INTRODUCTION

The National Forest System (NFS), USDA, Forest Service, is responsible for administering and managing the 156 National Forests and 17 National Grasslands in the United States. The Eastern Region (R-9) of the NFS includes nearly 12 million acres of public land in 17 National Forests distributed across 20 midwestern and northeastern states. R-9 contains roughly 6 percent of the total National Forest System land, and approximately half the Nation's human population.

BACKGROUND AND NEED

National Forest management is guided by a number of federal public laws and regulations, beginning with the Organic Act of 1897. Besides the Organic Act, some of the more notable laws include the Multiple Use-Sustained Yield Act (MUSY) of 1960, National Environmental Policy Act (NEPA) of 1969, Resources Planning Act (RPA) of 1974, and the National Forest Management Act (NFMA) of 1976, which amended the RPA. Some of the significant requirements woven through these laws and their implementing regulations are: (1) The National Forests will be managed as ecosystems, (2) productivity of the land will be sustained, and (3) environmental effects will be evaluated.

The Forest Planning process developed pursuant to the National Forest Management Act began to bring to a head the need for more and better spatial information about forest ecosystems, including land capability. The completion and subsequent implementation of Forest Plans brought more focus to this need. The focus is being further sharpened through the evolution of resource management issues, as the public further defines the values and uses for which they want their National Forests managed.

Agency Policy & Guidance

Overall National Forest policy on ecosystem classification and inventory is outlined in Forest Service Manual (FSM) 2060. This policy states in part:

> "1. The Forest Service shall use ecological type classification to coordinate and integrate resource inventories to stratify land and resource production capability and responses to management.
>
> "2. Ecological Units shall be identified in inventory, evaluation, planning, and resource management on National Forest System (NFS) lands."

[1/] Presented at the Symposium on Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests, Charlotte, NC, January 7-9, 1991.

[2/] Regional Soil Scientist, Eastern Region, Milwaukee, WI; and Forest Soil Scientist, Ottawa National Forest, Ironwood, MI, respectively, Forest Service, U.S. Department of Agriculture.

Forest Service Handbook (FSH) 2090.11 provides overall procedural guidance for ecological classification and inventory, and lists the following components, as appropriate for classification and characterization of ecological types:

-Vegetation (Potential Natural Community)
-Soils
-Water (Hydrology)
-Geology (stratigraphy, lithology, landform)
-Climate
-Topography (elevation, slope gradient, aspect)

Definitions (FSM 2060)

Ecological Type is defined as "a category of land having a unique combination of potential natural community, soil, landscape features, climate, and differing from other ecological types in its ability to produce vegetation and respond to management."

Ecological Unit is defined as "a mapped landscape unit designed to meet management objectives, comprised of one or more ecological types."

Thus, Ecological Type is a classification unit, while Ecological Unit is a mapping or inventory unit.

EASTERN REGION (R-9) ECS

Structure

The R-9 Ecological Classification System (ECS) is structured as a hierarchical framework, similar to that of the Land Systems Inventory concept that was developed earlier in the Western United States (Wertz & Arnold, 1972). This nested hierarchy facilitates development of Ecological Units at different levels of resolution, based on management needs (Nelson, Russell, and Stuart, 1984). The hierarchical levels are illustrated in Table 1.

Application of the hierarchical levels

Provinces and Sections are derived from those in Fenneman's Physiography of the Eastern United States (Fenneman, N.M., 1938). The Eastern Region contains all or parts of eight provinces and sixteen sections. These broad, natural physiographic divisions help explain and organize information about natural environmental differences and similarities among the National Forests in the Region. The Provinces and Sections are illustrated in Figure 1.

Subsections have been used on some R-9 National Forests, such as the Green Mountain, White Mountain, and Mark Twain. The Forest Service is involved in a cooperative project with the Upper Great Lakes Biodiversity Committee; The Nature Conservancy; Michigan, Minnesota, and Wisconsin State Heritage Programs; and others, developing subsections in the Upper Great Lakes area, which includes eight National Forests. They are focusing on macroclimatic zones and major glacial physiographic landforms. Present and future applications are expected to include: Regional biodiversity; Landscape Ecology, correlation of Ecological Units among National Forests, beginning of ecological classification of State, County, and privately-owned lands, Forest Plan revisions, etc.

The Land Type Association (LTA), Ecological Land Type (ELT), and Ecological Land Type Phase (ELTP) levels are sometimes referred to as the "working levels" of the ECS, because they have to date received by far the most use. These are the levels that are most useful at the Forest level, for land and resource management planning, and in the implementation of Forest Plans.

The LTA level: Land Type Associations generally number between about 10 and 20 per National Forest. This level was used extensively in the Forest Planning process in the Eastern Region. The primary use was to aid in allocating land to Management Areas, and developing desired future conditions.

The ELT level: A few National Forests used Ecological Land Types for Forest level planning. More commonly, however, the ELT level is used for more detailed planning on subdivisions of National Forests -- Management Areas, or Opportunity Areas. ELTs commonly repeat across the landscape in a predictable pattern within an LTA.

The ELTP level is the most detailed, site-specific level that is normally mapped on an operational basis. It usually provides the level of detail of land capability-suitability information that is needed for project level applications. ELTPs commonly repeat across the landscape in a predictable pattern, within a given ELT. ELTPs can be thought of as mapped representations of sites.

The Site level: The site is the classification unit - the ecological type, as defined earlier; the primary data collection unit. Sites by themselves are not usually delineated on maps, except for special purposes where there is need for extremely site-specific information.

Background

Classification and inventory of ecological units began in R-9 on a limited basis during the early 1970's. The R-9 Ecological Classification System (ECS) was institutionalized in 1979 when the ECS Handbook Chapter was issued. (FSH 1909.21, chapter 30). Subchapter 32, Riparian Area Subsystem, was added to the Regional ECS Handbook in 1981.

The early emphasis of the ECS was to obtain relatively rapid, inexpensive inventories for broad level planning purposes. The broad level inventories, primarily at the LTA level, provided most of the land capability information that was thought to be needed for the first round of Forest Planning under the National Forest Management Act. Forest Plan implementation, however, requires a more detailed level of land and eco-

Table 1.--Hierarchical levels of R-9 Ecological Classification System (ECS) (Forest Service Handbook 1909.21 - Eastern Region Land and Resource Management Planning Handbook, Chapter 30, 1979, working draft revision.)

LEVEL	PRIMARY DIFFERENTIATING CRITERIA	TYPICAL SIZE	APPLICABLE PLANNING LEVEL
Province	Geomorphology, Climate	Multi-State	National-Regional
Section	Geomorphology, Climate, Vegetation	Thousands of square miles	Regional-Subregion
Subsection	Climate, Geomorphology, Vegetation	Tens to Hundreds of square miles	Multi-Forest State
Landtype Association (LTA)	Landforms, Natural Overstory Communities, Soil Associations	Tens to Thousands of acres	Forest
Ecological Landtype (ELT)	Landform, Natural Vegetative Communities, Soils	Tens to Hundreds of Acres	Ranger District, Management Area, Opportunity Area [a]
Ecological Landtype Phase (ELTP)	Soils, Landscape position, Natural Vegetative Communities	Ones to Tens of Acres	Project
Site	Soils, Landscape Position, Natural Veg. Community	Less than one acre	Individual Site

[a] Opportunity Area: A land area identified as providing best opportunities to work toward Forest Plan goals and objectives in an integrated manner. Each National Forest is divided into a number of Opportunity Areas for Forest Plan Implementation (USDA, Forest Service, Eastern Region, 1985, pp. 12-15).

system stratification. Resolution of some of today's public issues call for still more detailed and data-intensive applications of ecological classification. Today's publics are calling for more emphasis on a wider array of values and uses that National Forests can provide; for example, biodiversity, Old Growth forests, threatened and endangered species habitat, etc. These demands call for more detailed, data-intensive applications of the ECS, so that it can provide better information on ecosystem dynamics, as well as land capability to sustain uses and provide goods and services.

Most ECS emphasis to date has been on terrestrial applications. There is growing awareness, however, of the need to devote more attention to developing ecological classification of aquatic ecosystems.

Operational application

The ECS has been applied in R-9 through the Soil Resource Inventory (SRI) activity. Ecological unit inventory operations are coordinated with the National Cooperative Soil Survey (NCSS). The integration of landform, vegetative, and climatic parameters enhance the soil mapping units, particularly from descriptive and interpretive perspectives.

Ecological Units are used to determine land capability for a wide range of resource management prescriptions, evaluate costs and benefits, and predict effects of actions or non-action applied to any given piece of land.

The ECS does not replace timber or other vegetation inventory systems. The ECS identifies the potential natural vegetation community, but not the current vegetative cover. Other inventory systems (Vegetative Management Information System [VMIS] in R-9, for example) identify current vegetative conditions and temporal changes in vegetative cover, but not potential natural vegetation. So the ECS and other established vegetative information systems compliment each other very well.

Examples of Forest Applications

Recognizing that Ecological Type classification and Ecological Unit mapping are evolving sciences and arts, both the National and Regional direction allow for some latitude in approaches on individual National Forests. Following are some examples of ECS development and application on some of the National Forests in the Eastern Region.

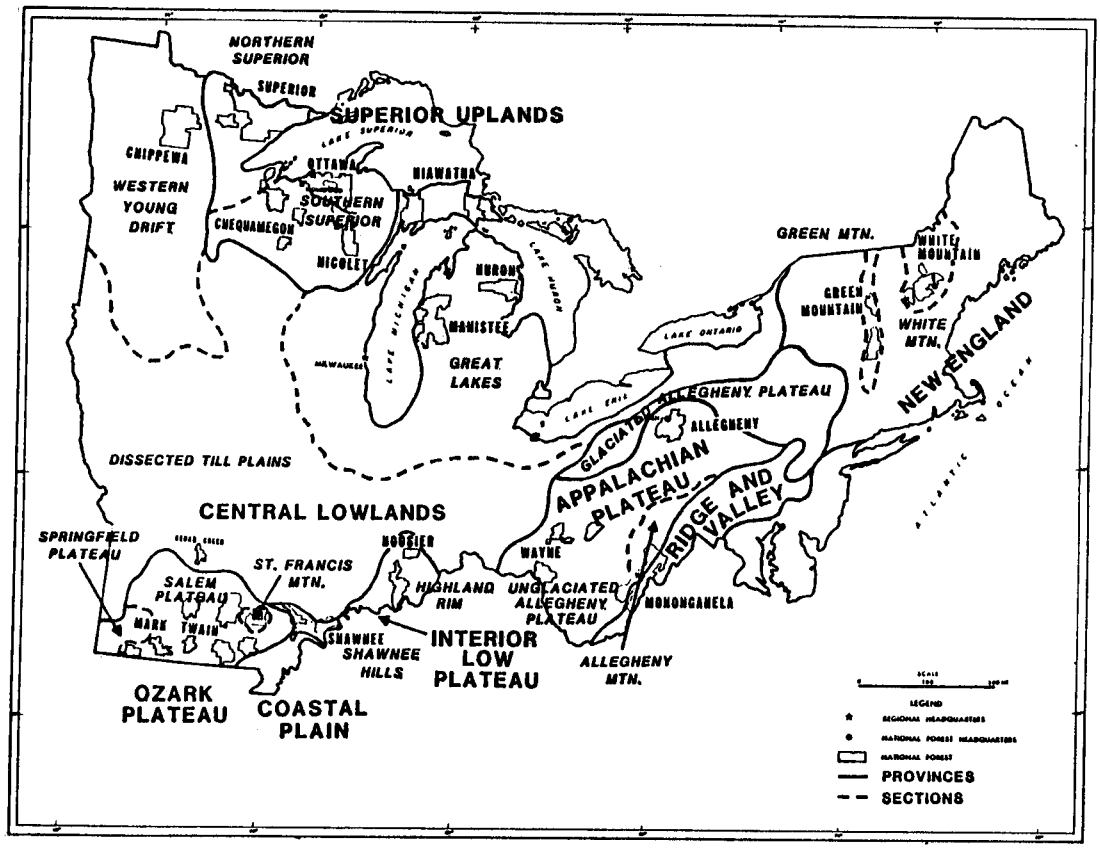


Figure 1.--Provinces and Sections of the Eastern Region

The White Mountain National Forest is in the States of New Hampshire and Maine, in the New England Province, and the White Mountain Section. Richard Alvis began mapping Ecological Land Types (ELTs) on the White Mountain National Forest about 1973. Alvis had had previous experience with Land Systems Inventory on National Forests in the western United States. On the White Mountain, Alvis based the ELT delineations on core differentiating characteristics of geomorphic process, soil substrata, and vegetative potential (climax community). In addition to the core, differentiating characteristics, several associated characteristics were identified, which helped to characterize and describe each ELT. Management interpretations were developed, which indicated suitabilities and predicted responses of each ELT to various management practices and uses. Ecological Land Type mapping was completed on the White Mountain National Forest about 1983, and was heavily used in developing the Forest Plan.

The Land Type Association (LTA) level was not applied on the White Mountain. Four subsections were defined and delineated, to help organize and understand similarities and dissimilarities among certain ELTs.

The Ecological Land Type Phase (ELTP) level is being applied selectively on the White Mountain. Ecological Land Type Phases follow the "Habitats" developed by William Leak, of the Northeast Forest Experiment Station at Durham, NH (Leak, 1982).

The approach on the Green Mountain and Finger Lakes National Forests in the States of Vermont and New York is similar to that on the White Mountain.

The Mark Twain National Forest in southern Missouri, is nearly all in the Ozark Plateau Province, and mostly in the Salem Plateau Section (Miller, 1981). Ecological classification on the Mark Twain began during the mid 70's. The Mark Twain utilized a team approach to develop ecological classification largely from a synthesis of existing data and information on soils and vegetation.

The Forest was initially divided into 5 Subsections, within the 2 Provinces and 3 Sections that the Forest is part of. The 5 subsections were based on differences in land surface form, geology, soils, and natural vegetation. The subsections were subdivided into 18 Land Type Associations (LTAs), based on a finer break-down of land surface form, surface geology, and potential vegetative community. The soils information was from the cooperative soil survey which was ongoing at the time. The vegetative information was from the Natural Communities classification, developed by the Missouri Natural Areas Committee of the MO Dept. of Natural Resources.

The Land Type Associations and Ecological Land Types were used heavily to determine land capability and suitability for the Forest Plan. The

Ecological Land Type information is heavily used in implementing the Forest Plan.

The Mark Twain National Forest ECS is currently being updated, based on re-evaluation of information needs, and "new" data and information that was not available during the first go-round. The "new" data and information includes a completed soil survey, and increased knowledge of the Missouri Natural Plant Communities. The revision will include additional ELTs with more detailed and accurate definitions and descriptions, and may include some application of the Ecological Land Type Phase level.

The Mark Twain and White Mountain are two of the few National Forests in the Eastern Region that have implemented Aquatic Ecological Classification of their surface waters.

The Ottawa National Forest is located in the western part of the Upper Peninsula of Michigan, in the Southern Superior Section of the Superior Uplands Province. Ecological classification began on the Ottawa during the early 70s, in response to a need for land capability information for Forest Planning (USDA, Forest Service, Eastern Region, 1987, pp. 51-67, 131-158). Very little information about basic resources (soils, natural vegetation, glacial geology) was available at that time.

The Forest was first divided into 21 Land Type Associations based on major glacial landforms, areas of bedrock control and outcrop, and major post-glacial erosional landforms. The Forest was also divided into three distinct macroclimatic zones, based on climatic differences caused by proximity to Lake Superior. The Land Type Associations and climatic zones provided the basic land capability-suitability information used in the Forest Planning process.

The Ottawa National Forest Leadership Team recognized the need for more detailed levels of Ecological Classification in 1977. Subsequently, the Forest entered into a cooperative agreement with Michigan Technological University to fully characterize and analyze, stratified, randomly selected sample areas representative of all Land Type Associations, a two percent sample of the Forest. Within each sample area, systematic sampling was completed for soils, landforms, and total vegetation. Through the use of computer ordination models, vegetation relationships were established. Site concepts (Ecological Types) were developed and mapping unit (Ecological Units) concepts were developed based on the observed recorded, and analyzed soil,landform, and vegetation relationships.

From the detailed analysis of soils, vegetation, and landforms, the Ottawa develops Ecological Types, and from the Ecological Types, they build Ecological Land Type Phases (ELTPs) for mapping. Each ELTP is composed of a major site unit (Ecological Type), and usually one or more minor site units (mapping inclusions). A few ELTPs have 2 or even 3 major site units; these are mapping complexes. ELTPs are used to evaluate site potential, predict ecological processes such as successional pathways, and predict environmental effects at the individual project level of detail. ELTPs are aggregated upward into ELTs for more generalized Opportunity Area Analyses and Planning. The process of developing, classifying, and mapping ELTPs continues today, and presently covers approximately 75 percent of the U.S. owned land in the Ottawa National Forest. However, not all of the Forest will be mapped to the ELTP level; areas where management information needs do not require that level of detail have been identified, and are or will be mapped to the ELT level. Concepts, mapping, verification, and development of interpretations continues with involvement of scientists from the North Central Forest Experiment Station, and Universities in Michigan, Minnesota, and Wisconsin. Correlation with adjoining National Forests has begun and will strengthen the use of the Ecological Classification System.

The Huron and Manistee National Forests are located in the northern part of the Lower Peninsula of Michigan, in the Great Lakes Section of the Central Lowlands Province. These 2 National Forests are managed under 1 Forest Supervisor, and are generally referred to as the Huron-Manistee.

Similarly to other National Forests in the Great Lakes States, Land Type Associations on the Huron-Manistee are keyed to glacial landforms. Initiation of a more detailed level of ecological classification was precipitated in the early '80s by a recognition that the "conventional" soil survey was not effectively differentiating some units of landscape that were ecologically significant (USDA, Forest Service, 1987, pp. 15-17, 30-41, 68-97, 186-240).

Since 1984, the Huron-Manistee has been working with Michigan State University and the North Central Forest Experiment Station, developing an Ecological Type classification for the Forests. The Forest Service and University collaborators have taken an analytical approach, emphasizing multiple factors and functional relationships between ecological variables (Cleland, 1982). Plots for sampling multiple factors were located, using a landform-based stratified random sampling design. Detailed observations in each plot were recorded for all vegetation layers, soils, and local landform characteristics. Compositional patterns detected in multivariate analysis of floristic data were used to form ecological species groups, and relate vegetation patterns to environmental factors (Host, 1987). Ecological Types are based on a combination of Ecological Species groups, soils, and landforms, and form the basis for the Ecological Unit inventory, primarily at the Ecological Land Type Phase level.

The ELTP inventory on the Huron-Manistee is being used to implement the Forest Plan, and provide a sound ecological basis for responding to current public issues.

The Allegheny National Forest is located in northwestern Pennsylvania, in the Unglaciated Plateau Section of the Appalachian Plateau Province. The Allegheny is involved in a unique approach to Ecological Classification, in collaboration with Dr. Lew Auchmoody of the Northeastern Forest Experiment Station. The collaborators there are attempting to construct Ecological Units with a Geographic Information System, using plot data to supplement existing data from such sources as soil surveys, contour maps, digital elevation models, geologic mapping, and existing vegetation inventories.

Trends Across the Region

Activities in ecological classification are on the increase on National Forests all across the Eastern Region. On the Hoosier National Forest in Indiana, Ecological Types are being developed in a partnership among Forest resource managers and scientists from Purdue and Indiana Universities, the Indiana Natural Heritage program, and the North Central Forest Experiment Station. A similar cooperative program is about to get underway on the Wayne National Forest in Ohio. The Chippewa National Forest in Minnesota is developing Ecological Land Type Phases in cooperation with the Minnesota Natural Heritage program. The Chippewa has also done some pioneering work on aquatic ecological classification of lakes (USDA, Forest Service, 1987, pp. 159-181).

On the Superior National Forest in northeastern Minnesota, LTAs, ELTs, and ELTPs were developed in the mid 1970's and played a prominent role in developing and implementing the Forest Plan (Prettyman, 1982). The Superior's interdisciplinary (ID) monitoring team made Forest-wide field visits in 1990 to monitor implementation and effectiveness of the Plan; standards and guidelines are ELT dependent and are used in project activity planning (Siderits, 1981). The Ecological Classification System on the Nicolet National Forest in northern Wisconsin is currently being updated, using recent technology developed on the Ottawa and Huron-Manistee National Forests. The Hiawatha National Forest in Michigan's Upper Peninsula recently completed a cooperative project with Michigan State University, developing upland ELTPs, using technology developed earlier on the Huron-Manistee National Forests. The Hiawatha is presently cooperating with Michigan Technological University, to develop wetland Ecological Types. The ELT inventory is about to be completed on the Chequamegon National Forest in Wisconsin (USDA, Forest Service, 1987, pp. 182-184). On the Monongahela National Forest in West Virginia, an effort to develop "provisional" Ecological Land Types, based on existing soils, geology and landform information, is just beginning.

Ecological Classification is both researchable and operational. The Ecological Classification project on the Huron-Manistee National Forests has provided research for 6 Doctoral and 3 Master of Science candidates (Cleland, D.T., Personal communication). However, Ecological Classification is at least as much a research tool as a research topic. Ecological Classification defines differences and similarities between geographic areas, thereby greatly enhancing extrapobility of research results. The researchers at the North Central Forest Experiment Station's Landscape Ecology unit at Rhinelander, Wisconsin, are finding the ECS to be an indispensable tool in defining landscape heterogenity (Crow, T.R., talk at Madison, WI, Nov. 28, 1990).

SUMMARY

The American people, through their elected representatives, have directed that National Forests are to be managed as ecosystems, to provide a sustained yield of a wide array of values, uses, goods, and services. National Forest policy directs that ecological classification and inventory shall be used to help accomplish this. Ecological Types are classified based on a combination of multiple factors of soils, potential vegetation community, geology, topography, hydrology, and climate. Ecological Units are mapped representations of Ecological Types.

The Eastern Region (R-9) of the National Forest System uses a multi-level, hierarchical Ecological Classification System (ECS). The hierarchical framework facilitates mapping of ecological units at different levels of site specificity in order to satisfy different management needs.

The ECS in R-9 has been evolving since the early to mid 70's, in response to changing management needs. The original intent was to provide a relatively rapid method to inventory natural resources and estimate land capability for Forest Planning. Today, the trend is toward more detailed, data-intensive applications, in order to gain better understanding of ecosystems, to respond to today's resource management issues.

ACKNOWLEDGEMENTS

The authors thank their co-workers who have worked diligently over the years to develop, apply, and constantly improve ecological classification and inventory of the National Forests in Region 9, and who have offered suggestions to help develop and improve this paper. Recognizing that when names are named where so many have contributed, some will be omitted, we especially thank: Dave Cleland, Huron-Manistee National Forests; Eunice Padley, Hiawatha National Forest; Barbara Leuelling, Superior National Forest; David Shadis, Chippewa National Forest; Patrick Merchant and Frank Voytas, Wayne-Hoosier National Forests. We also thank our able typist, Eleanor Sczesny, who cheerfully, competently, and professionally, gave extra effort to make this publishable.

LITERATURE CITED

Cleland, David T.; Hart, James B.; Pregitzer, Kurt S.; [and others]. 1985. Classifying Oak Ecosystems for Management. In: Proceedings, Challenges in Oak Management and Utilization; 1985 March; Madison, WI: pp. 120-131. [Available from Cooperative Extension Service, University of Wisconsin, Madison, WI.]

Fenneman, N.M. 1938. Physiography of the Eastern United States, McGraw-Hill Book Co., 714 pp.

Host, George E. 1987. Spatial Patterns of Forest Composition, Successional Pathways, and Biomass Production Among Landscape Ecosystems of Northwestern Lower Michigan. East Lansing: Michigan State University. 180 pp. Dissertation.

Jordan, J.K.; Sommerville, J.L.; Meunier, J.L.; [and others]. 1984. Ecological Classification System, Its Application in Development and Implementation of Forest Planning on the Ottawa National Forest (poster display). In: Proceedings, Forest Land Classification: Experiences, Problems, Perspectives; 1984 March; Madison, WI: p. 251. [Available from University of Wisconsin, Madison, WI.]

Jordan, J.K. 1982. Application of an Integrated Land Classification. In: Proceedings, Artificial Regeneration of Conifers in the Upper Great Lakes Region; 1982 October; Green Bay, WI; pp. 65-82. [Available from Michigan Technological University, Houghton, MI.]

Leak, W.B. 1982. Habitat Mapping and Interpretation in New England. USDA, Forest Service, Northeastern Forest Experiment Station, Research Paper NE-496, 22pp.

Miller, M.F. 1981. Ecological Land Classification, Terrestrial Subsystem, Mark Twain National Forest Missouri. USDA, Forest Service, U.S. Government Printing Office. 56 pp.

Nelson, D.O.; Russell, W.E.; and Stuart, G.W. 1984. The Ecological Classification System in the National Forest System, Eastern Region. In: Proceedings, Forest Land Classification: Experiences, Problems, Perspectives; 1984 March; Madison, WI: pp. 270-276. [Available from University of Wisconsin, Madison, WI.]

Prettyman, Donald H. 1982. Integrated Land Inventory and Conifer Regeneration. In: Proceedings, Artificial Regeneration of Conifers in the Upper Great Lakes Region; 1982 October; Green Bay, WI; pp. 83-110. [Available from Michigan Technological University, Houghton, MI]

Siderits, Karl. 1981. Mammals of the Superior National Forest. Duluth, MN. U.S. Department of Agriculture, Forest Service, Superior National Forest. pp. 44-52.

USDA, Forest Service, Eastern Region. 1985. Working Together for Multiple Use, Integrated Resource Management. U.S. Government Printing Office, 27 pp.

USDA, Forest Service, Eastern Region, 1987. Proceedings, Ecological Classification System Workshop; 1987 May; Traverse City, MI: [Available from USDA, Forest Service, 310 W. Wisconsin Ave., Milwaukee, WI 53203.]

Wertz, W.A.; and Arnold, J.F. 1972. Land Systems Inventory. U.S. Department of Agriculture, Forest Service, Intermountain Region, Ogden, UT. 12 pp.

HISTORY OF FOREST SITE CLASSIFICATION IN THE SOUTH[1]

David H. Van Lear[2]

Abstract.--Potential productivity has been a cornerstone of most land characterization systems used in the South. Soil-site studies identified many variables related to site quality in the exploited southern landscape. Early attempts to use county soil survey maps to delineate site quality were generally unsuccessful, although maps refined to reflect soil and site features important to tree growth have been successfully used for the past 20 years. More recently, landform has been recognized as the primary factor controlling repetitive patterns on the landscape, a realization which has markedly increased understanding of forest-site relationships. Current research focuses on development of landscape ecosystem classification systems which integrate relationships among landform, soil, and vegetation, and which can be linked with modern remote sensing capabilities.

Keywords: landform, landscape ecosystem, GIS, physiography

INTRODUCTION

The evaluation of site quality and development of site classification systems have been among the dominant themes of American forestry for nearly all of the 20th century. Because land is the foundation on which the art and science of forest management must be built, foresters have long appreciated the need to understand the relationships between forests and their physiographic environment. "Students of forestry in the United States are constantly demanding a guide to the topography, drainage, soils, and climatic features of the country." So stated Isaiah Bowman of Yale University in the preface of his book Forest Physiography, published in 1914. We now have many guides, or land classification systems, that enhance our understanding of forest-site relationships.

Most site classification systems used in Southern forestry have been primarily concerned with grouping land units on the basis of productivity. Foresters needed to know what the land could produce. This issue, or subtle variations of it, has been the stimulus of much of the site classification research over the past seven decades. Although certainly an important issue, one can see that there is some historical justification to the criticism that foresters are often too production oriented. We would have saved ourselves much grief if we had been more concerned in the beginning about ecological, as well as economic, values of sites. Unfortunately, the discipline of ecology was still in its formative stages when foresters were first becoming concerned about site classification.

The South is a region of extremely variable physiography (Hunt 1974). Soil, topography, climate, and biotic factors interact to produce a multitude of forest sites in the different physiographic provinces (Ralston 1978; Zahner 1984; Smalley 1986; McNab 1987). In addition, the land has a history of human occupation for thousands of years, during which time it has been exploited to various degrees by all manner of people from the original Indians (Hudson 1976) to the timber barons of the late 19th century (Healy 1985). This long and complex land-use history superimposed on a complex physiography presented a great challenge to foresters seeking to characterize the land.

FOREST SITE CLASSIFICATION IN THE SOUTH

An Appropriate Expression of Site Quality

Early in this century foresters were primarily concerned with forest protection and the productive potential of the land. Productivity is

[1]Presented at the Ecological Site Classification symposium, Charlotte, NC, January 7-9, 1990.

[2]Professor, Department of Forest Resources, Clemson University, Clemson, SC.

a complex concept and difficult to define. It basically deals with the ability of land to produce biomass, not just at the present time but in the future as well. Productivity is a function of both biotic factors and abiotic factors and their interaction (Switzer 1978). Biotic factors which influence productivity include species, stocking, competition, the incidence of disease and insects, and the past history of the stand. Abiotic, or non-living, factors of the environment include soil and site features which control the availability and supply of soil moisture and nutrients for plant use. Site quality was considered immutable by early foresters, but it is now recognized that land has an inherent productivity which can be increased or decreased by management activities.

Productivity was a logical basis for site classification. Early foresters recognized the need for, as well as the difficulty of developing, a standard method of expressing site productivity. Some argued that site quality should be expressed in terms of volume growth (Bates 1918). However, problems in using volume at this time were abundantly apparent (lack of yield tables, difficulty of measurement, differences in units and merchantability limits, periodic vs. final yield, evenage vs. uneven age stands, etc.). Consequently, this concept did not receive wide endorsement.

Another school favored the use of forest site-types, using plant indicators (Zon 1913). This method failed to gain favor in the eastern United States because it was thought that too many factors other than site influence composition and development of understory plant species, especially in the highly disturbed forests of the South.

A third group, which prevailed, favored the use of height at a given age as an index of site quality (Frothingham 1921). Site index was favored because it was directly related to volume growth in normally stocked stands, easily measured, and considered free of the effects of stand density over a rather wide range of stand density. In 1923, the Society of American Foresters recommended that site index, in conjunction with soon to be developed yield tables, be used throughout the country to express the productive potential of forest land.

The theory of using tree height as an index of site quality has been widely criticized (Mader 1963; Grigal 1984; Monserud 1984). Space limitations prevent discussion of these criticisms, many of which are valid. Alternatives have been proposed, but none have gained the wide acceptance of site index. Gale and Grigal (1987) and Henderson et al. (1990) recently proposed a productivity index in which the sufficiency of soils to support root growth is related to forest growth and yield. While this concept is attractive potential, it tacitly assumes that the relationship between above-ground biomass and root biomass of forest trees is the same for all sites. This assumption may or may not be true, but in any event requires further research. Despite the fact that site index has many problems associated with its use, its simplicity, general applica-bility, and long tradition insures that it will continue to be a commmon method of expressing site quality.

Soil-Site Studies

The Society of American Forester's decision to recommend the use of site index as the appropriate expression of site quality initiated a half century of soil-site research. In the South, foresters pondered the question of how could sites be classified into productivity classes in the absence of suitable forest cover? Much of the South's forest had been heavily cut over and cleared for crop production by 1935. Crop land acreage in the South (excluding Texas and Oklahoma) peaked in the mid 1930s at about 65 million acres and between 1900 and 1925 the South led the nation in timber volume cut (Healey 1985). It was against this background of worn-out farmland and cutover forests that the first soil-site studies were conducted in the South.

In 1935, T. S. Coile of Duke University published a paper which concluded that the site index of Piedmont land in North Carolina for shortleaf pine was related to the nature of the subsoil and the thickness of the A horizon. Similar relationships were later found for loblolly pine (Coile 1948). At about the same time, Turner (1938) found that site index of loblolly and shortleaf pines in the Coastal Plain of Arkansas was related to surface soil depth, subsoil texture, and internal drainage. Turner observed that topographic features such as slope position and steepness correlated with site index. Coile also recognized the relationship between topographic position and site index, but did not include it in his regression equations because slope position was correlated to soil depth and did not improve the precision of his equations.

The regression approach used in these studies was apparently addictive, because the pioneering efforts of Coile and Turner were followed by decades of similar studies throughout the southeastern United States and the nation. Numerous investigators (see Carmean 1975) identified many soil and site variables related to site index of different species in various locations and physiographic regions. Variables associated with site quality were those that directly or indirectly influenced availability and supply of water and nutrients for tree growth.

The same soil factors that affect the availability and supply of water and nutrients may also correlate with the quality of the growing space for tree roots. However, topographic features of the landscape may insure a supply of water and nutrients via internal drainage which could compensate for a lack of quality growing space for roots on some sites. Topographic features such as aspect, slope position, and slope shape consistently relate to site index (Carmean 1975).

In mountainous or hilly terrain, topographic features are often equally or more important to site quality than soil factors (Doolittle 1957; Ike and Huppuch 1968; McNab 1987; and Rightmyer 1988). Aspect in steep terrain influences evapotranspiration, which affects development of water stress and subsequent tree growth (Lee and Sypolt 1974). Subsurface flow of water (Hewlett 1982) benefits trees growing on sites located on lower slope positions.

It has been difficult to determine relationships between measured soil/site variables and site quality for hardwoods in the Coastal Plain (Broadfoot 1969), probably because of the complexity of drainage patterns in bottoms. However, Baker and Broadfoot (1977) devised a technique of site evaluation for eight southern hardwoods which combined objective and subjective evaluations of the relative importance of soil physical condition, moisture availability during the growing season, nutrient availability, and aeration. This method is somewhat similar to the concept of a productivity index mentioned earlier (Gayle and Grigal 1987, Henderson et al. 1990), except here the sufficiency of each soil and site factor was related to site index rather than to a soil rooting potential. Baker and Broadfoot developed their method from long years of field experience and found that, when tested, the technique accurately predicted site index of eight southern hardwoods.

Soil-site studies identified many features of the environment that related to tree growth and site quality. However, the relationships are not general for all sites. The essence that one can derive from all these studies is that various combinations of site factors influence the magnitude and timing of supplies of soil moisture and nutrients, the effective properties that control site quality (Stone 1984). Within the confines of necessary assumptions, stone's conception allows one to make some order out of the myriad of physical and chemical site factors shown to be related to site quality, i.e., they all affect the fundamental availability and supply of water or nutrients.

In retrospect, soil-site studies essentially provided a compilation of factors related to site quality, and were not readily applicable to the real management need for spatial delineation of repetitive units of the landscape, i.e., maps. The regression equations produced were often cumbersome and difficult for managers to use. The heterogeneity of forest sites made sampling difficult for practitioners. Researchers themselves ignored the variablility of soil properties within the experimental plots used to develop the equations (Powers 1987). Even if properly sampled, relationships between site quality and any given soil/site parameter were seldom linear (Fisher 1984). For all these reasons, experienced field foresters often had a better intuitive feel for site quality than could be obtained from rather complicated equations.

Use of Soil Surveys

The National Cooperative Soil Survey of the Soil Conservation Service (SCS) had been mapping soils in the South since the 1940s. With so many soil-site studies indicating relationships between soil properties and site quality, foresters naturally tried to utilize soil survey maps when available. However, they were generally disappointed. They found that SCS soil surveys too often pleased soil taxonomists but lacked the user orientation needed by forest managers (Grigal 1984, Smalley 1986).

Most studies found that site quality varied too widely within SCS soil series and mapping units to be of practical use to foresters (Carmean 1965; Van Lear and Hosner 1967; Broerman 1977). Not only was site quality poorly related to soil taxonomic units, response of the land to management was also unrelated. For example, Kushla and Fisher (1980) found that the response of slash pine to fertilization was related to soil drainage class and depth to and nature of the B horizon, but was not related to soil series. The reason for the lack of correlation between soil mapping units and site quality or response to management is obvious--those soil and site factors important to tree growth are often not the same ones considered in soil taxonomy and mapping.

Among the shortcomings of SCS soil surveys was the fact that they failed to incorporate knowledge that productivity is related to land-use history, landform, and climatic conditions, as well as to soil properties. Rowe (1984) suggested that the problem originated when pedologists began perceiving soils as natural bodies and things-in-themselves, rather than associating soils with their ecological significance.

SCS soil surveys are general purpose surveys. Soil surveys for forest management purposes should consider relationships between productivity and landform or moisture gradients (drainage) and soils should be mapped on the basis of properties known to be related to site quality and response to management. There is hope. Soil taxonomists increasingly recognize that the genesis and distribution of soils are best understood when studied in a landscape context, rather than at the level of individual pedons or classification units (Graham and Buol 1990). Arnold (1984) noted that while the recognition of soil individuals is the basis of the soil taxonomy used by SCS, there is a need for a similar type of definition of individual land areas that can be recognized and delineated as ecological response units.

For about the last 20 years, forest industries in the southeastern United States have been mapping their own forest lands. These companies chose either not to use published SCS county soil surveys or to refine them to better meet their special needs. Forest industries need an inventory of their soil resources and a site classification on the basis of productivity and

need for silvicultural treatment (Haines and Haines 1981). Their mapping emphasizes landscape features, such as shape of the landform, its geologic origin, and the position on the landscape. Special attention is given to the relationship between surface and subsurface soil properties and site quality (Everett and Thorp 1990). Industrial experience in the South indicates that foresters and soil mappers can work together to produce maps that better characterize forest land, not only for productivity but also to provide information on potential erosion hazard, regeneration potential, trafficability, and other management considerations for different soils.

Physiographic Classification

Physiographic classification represents an attempt to use physiography, i.e., the physical expression of geologic history, topography, soils, and climate of an area, to define broad land areas within which the local landscape can be subdivided into visually discrete landforms. The concept of physiographic land classification was first developed in Canada (Hills 1961). In 1975, Wertz and Arnold proposed a similar system for the United States to help standardize land classification and facilitate land-use planning, a topic of great public interest in the early 1970s.

In the South, the physiographic land classification concept was first used by Hodgkins et al. (1979) to map (scale of 1:1,000,000) and describe forest habitat regions and subregions of Alabama and Mississippi from landsat imagery. Upper level land classification units of province, region, and subregion were broadly defined by geology, topography, soil, and climate. Habitat regions are primarily useful for national and regional evaluations of forest resource conditions, and are not intended to be the basic units of operational land management where site specific decisions must be made. However, habitat regions do provide the foundation upon which the landscape can be further subdivided. Other southern states with completed habitat maps are Louisiana (Evans et al. 1983), Georgia (Pehl and Brim 1985), and South Carolina (Meyers et al. 1986).

Forest soil scientists often incorporated topographic features into their regression models during the heyday of soil-site studies. However, the practicality of using easily recognizable landforms in site classification systems in the South was slow in coming. Coile (1952), in his review of the relationship of soil and forests, briefly discussed the importance of topographic features to tree growth, but the concept of using landforms as the integrator of the landscape ecosystem (Rowe 1984) was not mentioned.

The term landform did not appear in early soil-site studies in the South, although its surrogate, drainage class, did. Turner (1938) first documented the relation betweeen drainage class and site quality of southern pines in Arkansas where excessively drained upland sands were poor sites and loamy soils in floodplains with good internal drainage were superior sites. In 1956, Beaufait related site quality for willow oak to topographic features such as ridges and flats (he did not call them landforms) and certain soil properties. In the mid 1970s, Weyerhaeuser Corporation developed a site classification system for the Coastal Plain of North Carolina in which soil features were stratified by landform (pocosins, flats, clay uplands) to yield regression equations which adequately predicted site index of loblolly pine (Campbell 1978). Until the data were stratified by landform, accuracy of equations for estimating site index was unacceptable.

The trend toward using landform (or drainage class) as the basic component of site classification systems gained momentum in the 1980s. Fisher (1981) described a site classification scheme for the Coastal Plain based on productivity differences which were related to drainage class, depth to and nature of the B horizon, and character of the A horizon. Drainage classes reflect, in part, subtle differences in elevation between lowlands and the Sandhills of the Coastal Plain. Responses to management activities such as site preparation and fertilization were related to site classes, an important feature in the increasingly domesticated forests (Stone 1975) of the Coastal Plain.

Switzer and Shelton (1984) divided the upland landscape of the Gulf Coastal Plain into five landform components: crest, shoulder, backslope, footslope and toeslope. Productivity was subjectively related to landform with the poorest sites on crests and shoulders and the best sites on the toeslopes. Differences in productivity among landforms were attributed to corresponding differences in nutrient and moisture regimes.

Between 1979-1986, Smalley (1986) developed a comprehensive and practical physiographic site classification system for the Cumberland Plateau and Highlands Rim provinces of the Interior Uplands of the Southeast. His hierarchal system progressively reduces complex landscapes to easily identifiable landforms called landtypes. Landtypes have resulted from similar climatic, geologic, and pedologic processes and are repetitive units of land with distinct potential for growing trees and/or similar management limitations and hazards. For each landtype, the geographic setting, dominant soils, depth to bedrock, soil texture, drainage, relative water supply and fertility, and general vegetation is described, as well as management interpretations.

Smalley's system is practical because it identifies discrete units (landtypes) of the landscape easily visualized by the forest manager and because it has mapping capability at a scale of delineation to meet most management objectives. It provides information concerning species suitability, competition, equipment limitations, erosion hazard, and other factors, as well as productivity. Vegetation is relegated to a position of minor importance because current vegetation was not considered to reflect site

potential and often did not coincide with site boundaries. Sites are further subdivisions of landtypes, but usually not mapped. In mountainous or steep terrain, site conditions often vary dramatically over short distances due to interactions between parent material, depth to bed rock, slope steepness and shape, aspect, terrain stability, vegetation, climate, and drainage and water supply from adjacent sites (Zahner 1984).

McNab (1987) published a first approximation of a site classification system for the Southern Appalachians similar to that of Smalley's for the Interior Uplands. Slope features, such as slope type, slope aspect slope position, slope shape, and gradient are incorporated into the system at different levels to divide the mountainous landscape into increasingly smaller units until landtype phases can be displayed on maps with a scale of 1:20,000 or larger. These landtype phases are the units appropriate for normal forest planning and management. As with Smalley's system, landtype phases are equivalent to an ecological site type if vegetation information is included in the description.

The transition from regression-based soil-site studies to multifactor physiographic site classification greatly increased understanding of forest-site relations and the feasibility of putting this knowledge to work in forest management. As Rowe (1984) pointed out, landform represents the most stable surface component of landscape ecosystems and, over long periods of time, becomes the primary correlate of soils and vegetation in areas of similar regional climate. Landforms are the prime cause of the repetitive patterns of soil and vegetation seen on the landscape. Thus, landforms with their associated soils and biotic communites are the logical basis on which site classification systems should be developed. If site quality varies too widely within landforms, than soil and vegetative features can be used to stratify the landform into units of more narrowly defined site quality.

Ecological Site Classification

Productivity concerns will always be an important part of site classification systems. However, because the forester is a steward of the land and all its resources, the public is increasingly demanding that equal consideration be given to other values of the forest, e.g., wildlife habitat, watershed protection, endangered plants and plant communities, etc. National forests are especially vulnerable to public pressures, but private forests will also come under closer public scrutiny in the future. There is no single site classification system currently in use by the U. S. Forest Service. However, the numerous systems in use by the agency all attempt to delineate and describe units of land that are fairly homogenous with respect to the relationships among vegetation, soil, and landform. The lack of a uniform system of classifying potential natural vegetation has hindered the full incorporation of vegetative components into a nationally standardized system (Larson and Schlatterer 1984).

The concept of ecological site classification was developed in Germany after World War II and has been the basis for their multiple-use management for decades (Barnes 1984). Ecological site classifications are similar to the multifactor physiographic site classification systems just described. However, in an ecological site classification system, the three components of the landscape ecosystem, i.e., landform, soil, and vegetation, are integrated simultaneously in the field. The local climax vegetation is identified and groups of species with narrow ecological amplitude, i.e., site specific, are determined and used to delineate site unit boundaries. Vegetation is given more consideration in delineating site classes than in the physiographic systems described previously.

In the South, ecosystem classification has been applied to a portion of the Coastal Plain in South Carolina (Jones, et al. 1984; Van Lear and Jones 1987). Late successional, near-climax hardwood communities were identified along a landform moisture gradient in the Hilly Coastal Plain province of South Carolina. Site types were identified by these late successional hardwood communities, including both overstory and understory species, that occupied specific landforms. Community identification was based on a relatively small number of character, or diagnostic, species which tend to occur on certain sites in conjunction with common species which have a wider ecological amplitude. In addition to the late successional hardwood communities associated with different landforms, earlier successional communities that precede them were also identified. In this regard, this system is similar to the habitat type approach developed by Daubenmire (1952) for the northern Rockies and now used extensively on national forests in the West (Pfister 1989). Jones (1989) has recently expanded this ecosystem classification system to the Piedmont of South Carolina.

There are numerous reasons why information about plant communities and successional trends should be included along with landform and soil components in land classification systems. By including vegetation, landscape ecosystem classification provides more complete information about ecosystem diversity and functioning. This information is essential if planners and managers are to stabilize and reverse the disturbing trend of landscape fragmentation of the landscape now so common throughout the South. It will be necessary to incorporate the best elements of land use planning and landscape ecology to preserve the landscape mosaic of wildlands (Brown 1989).

Inclusion of information about potential climax or late-successional vegetation and seral communities in a classification system gives insight about the composition and structure of old-growth communities that would prevail in areas protected from timber harvesting. Such areas often exceed 30 percent of the land base in Southern

national forests. In addition, if the seral communities preceeding late-successional communities are known, managers can decide which vegetative stage is desirable on various sites in the landscape. For example, the longleaf pine-wiregrass ecosystem of the Coastal Plain once covered up to 86 million acres, but now occupies no more than 5 million acres (Noss 1989). Accounts of early explorers suggest that much of the PreColumbian landscape of the Coastal Plain was in wet prairies and open savannahs, now rare communities that can only be created and maintained by frequent burning. It is important for ecological reasons to restore a portion of that original ecosystem. A landscape ecosystem classification describing successional sequences of vegetative communities on various site types with and without prescribed fire would aid in delineating those areas where restoration of this endangered ecosystem is best suited.

Forested wetlands commonly found along many coastal streams, rivers, lakes, and bays are among the most extensive types of forest sites in the southern United States. Although development of wetlands has slowed in the South in recent decades, the quality of wetlands continues to decline. To reverse this disturbing trend, wetlands must be delineated and their relationships to surrounding systems identified. Brown (1989) has proposed an landscape ecosystem classification system for wetlands which incorporates landscape position, nutrient availability, and hydrologic regime, in addition to successional trends, as a first step in protecting wetlands.

Riparian zones and streamside management zones throughout the South require similar consideration. Land-use planners and managers must give greater attention to the protection and functions of these sensitive and ecologically important ecosystems and how their management affects associated aquatic ecosystems.

No site or land classification system will satisfy all management needs or resolve all conflicts arising from opposing views on use of specific areas of land. As long as people have opinions and wants, there will be conflicts over land uses. All classification systems are contrivances of man to organize ideas in useful ways (Cline 1963). As such, they will never be perfect. However, classification systems that integrate the major ecosystem components of landforms, soils, and vegetation provide a relatively sound basis upon which individuals, companies, public agencies, and society can make long-term decisions about the land that make sense both ecologically and economically.

New Technologies

Maps have historically depicted the spatial relationships of land, including its characteristics and boundaries, and will continue to be important tools for storing and conveying spatial information. Unfortunately, as forestry became more sophisticated, the rate at which these maps became outmoded also increased. This problem can now be addressed through the use of digital computers and software for handling geographic data. Geographic Information Systems (GIS) and Digital Elevation Models (DEM) are increasingly used to input, store, manipulate, and display geographically referenced data to provide the current information needed by forest managers.

GIS and DEM are commonly used for land-use planning and resource inventory, but researchers are just recently discovering their potential for site classification. Several papers in this proceedings address this new technology, which has exciting possibilities for increasing our ability to map site and landscape features. Hammer (this proceedings) suggests that these new technologies can be used as research tools to generate new data, rather than as just hi-tech ways of producing maps and managing data. Certainly the future is bright for this new technology. Its potential for illustrating relationships between landforms, soils, and vegetation are almost unlimited, as is its potential for expanding our understanding of the values and functioning of these ecosystem components.

CONCLUSIONS

Forest site classification had its origins near the turn of the century shortly after forestry began in this country. The early history of site classification dealt with finding an appropriate expression of site quality, since it was generally recognized that productivity was a basic criterion for delineating sites. Site index, despite its problems, was selected and remains the most commonly used measure of site quality even today. In the South, decades of soil-site studies established the rather obvious fact that site quality was related to those soil and site features that affect the availability and supply of water and nutrients to forest trees. The compilation of factors related to site quality, while a necessary first step in the exploited forests of the South, did little to solve the problem of how to spatially delineate units of land with differing growth potential.

Foresters attempted to use general purpose SCS soil survey maps to delineate sites of different quality. However, these maps were generally not suitable for intensive forest management purposes. Site index varied widely within mapping units and responses to management activities often did not coincide with soil series. Soil and site features important to tree growth were obviously not the properties important to soil taxonomy. However, industrial forestry experience has shown over the past 20 years that foresters and soil mappers can work together to develop soils maps suitable for forest management purposes.

The importance of landform in classifying forest sites was not widely recognized in the South until the late 1970s. Landform naturally integrates climatic, hydrologic, soil, and vegetative variables, and forms the stable

repetitive feature of the landscape. Most importantly, landforms are readily mapped. Multifactor physiographic classification systems which separate landscape components on the basis of geology, topography, and soils into visually identifiable landtypes have greatly increased understanding of forest site relationships.

Ecosystem classification is similar to multifactor physiographic classification except it places greater emphasis on vegetation. Identification of late successional or near climax plant communities that occupy these repetitive landforms and the seral communities that preceed them is an integral part of the system. Such a system provides a broader ecological base upon which the patterns and processes of landscape ecosystems can be interpreted. However, it must be recognized that landscape ecosystem classification, nor any other system, is a panacea that will solve all land classification problems.

In the last decade, great progress has been made in the carteographic expression of geographic data using GIS and similar systems. Integrating site classification systems into these new technologies will improve our ability to manage forest land for maintenance and enhancement of productivity, and at the same time enable us to give due consideration to other values of the forest.

LITERATURE CITED

Arnold, Richard W. 1984. A pedologic view of forest land classification. In: Bockheim, James G., ed. Forest land classification: Experiences, problems, perspectives. 1984 March 18-20, Madison, WI. University of Wisconsin. 18-31.

Baker, James B.; Broadfoot, W. M. 1977. A practical field method of site evaluation for eight important southern hardwoods. Gen. Tech. Rep. SO-14. New Orleans, LA: U. S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 31 pp.

Barnes, Burton V. 1984. Forest ecosystem classification and mapping in Baden-Wurttemberg, West Germany. In: Bockheim, James G., ed. Forest land classification: experiences, problems, perspectives. 1984 March 18-20; Madison, WI. University of Wisconsin. 19-65.

Bates, C. G. 1918. Concerning site. Journal of Forestry 16:383-388.

Beaufait, William R. 1956. Influence of soil and topography on willow oak sites. New Orleans, LA. U. S. Department of Agriculture, Forest Service, Southern Forest Experiment Station Occ. Pap. 148. 12 pp.

Bowman, Isaiah. 1914. Forest Physiography. 1st ed. New York. John Wiley & Sons. 759 pp.

Broerman, F. S. 1978. Site classification-Union Camp Corporation. In: Balmer, William A., ed. Proceedings of a symposium on soil moisture...site productivity. 1977 Nov. 1-3, Myrtle Beach, SC. U. S. Department of Agriculture, Forest Service, Southeastern Area, State and Private Forestry. 64-73.

Brown, Mark T. 1989. Forested wetlands in urbanizing landscapes. In: Hook, Donal D., ed. The forested wetlands of the Southern United States. 1988 July 12-14; Orlando, FL. Asheville, NC. U. S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 19-26.

Broadfoot, W. M. 1969. Problems in relating soil to site index for southern hardwoods. Forest Science 15:354-364.

Campbell, Robert G. 1978. The Weyerhaeuser land classification system. In: Balmer, William A., ed. Proceedings soil moisture...site productivity symposium. 1977 Nov. 1-3, Myrtle Beach, SC; U. S. Department of Agriculture, Forest Service, Southeastern Area, State and Private Forestry. 74-82.

Carmean, Willard H. 1965. Black oak site quality in relation to soil and topography in southeastern Ohio. Soil Science Society America Proceedings 29:308-312.

Carmean, Willard H. 1975. Forest site quality evaluation in the United States. Advances in Agronomy 27:209-269.

Cline, M. G. 1963. Logic of the new system of soil classification. Soil Science 96:17-22.

Coile, T. S. 1935. Relation of site index for shortleaf pine to certain physical properties of the soil. Journal of Forestry 33:726-730.

Coile, T. S. 1948. Relation of soil characteristics to site index of loblolly and shortleaf pines in the lower Piedmont region of North Carolina. Duke University School of Forestry Bulletin 13. 78 pp.

Coile, T. S. 1952. Soil and the growth of Advances in agronomy 4:107-122.

Daubenmire, R. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecological Monographs 22:301-330.

Evans, D. L.; Burns, P. Y.; Linnartz, N. E.; Robinson, C. J. 1983. Forest habitat regions of Louisiana. Louisiana Agricultural Experiment Station Report No. 1. 23 pp., map supplement.

Everett, Charles J.; Thorp, John H. 1990. Forest industries and land characterization: Why develop your own program? In: Use of soil surveys in applying forestry best management practices. 1990 Oct. 17-18, Lynchburg, VA; Virginia cooperative extension service, School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University.

Fisher, R. F. 1981. Soils interpretations for silviculture in the southeastern Coastal Plain. In: Barnett, James P., ed. Proceedings First Biennial Southern Silvicultural Research Conference. 1980 Nov. 6-7, Atlanta, Georgia. U. S. Department of Agriculture, Forest Service, Southern Forest Experiment Station Gen. Tech. Rep. SO-34. 323-330.

Fisher, Richard F. 1984. Predicting tree and stand response to cultural practices. In: E. L. Stone, ed. Forest soils and treatment impacts. Proceeding of the Sixth North American Forest Soils Conference; 1984 June; Knoxville, TN: Department of Forestry, Wildlife and Fisheries, The University of Tennessee: 53-65.

Frothingham, E. H. 1918. Classifying forest sites by height growth. Journal of Forestry 16:760.

Gale, M. R.; Grigal, D. F. 1987. Vertical root distributions of northern tree species in relation to successional status. Canadian Journal of Forest Research 17:829-834.

Graham, R. C.; Buol, S. W. 1990. Soil-geomorphic relations on the Blue Ridge front: II. Soil characteristics and pedogenesis. Soil Science Society of America Journal 54:1367-1376.

Grigal, David F. 1984. Shortcomings of soil surveys for forest management. In: Bockheim, James G., ed. Forest land experiences, problems, perspectives. 1984 March 18-20; Madison, WI. University of Wisconsin. 148-166.

Haines, W. Wayne; Haines, Sharon G. 1981. Application of a land classification to private timber ownerships. In: Proceedings of the 1980 Convention of the Society of American Foresters. Washington, D.C. Society of American Foresters. 175-178.

Hammer, R. David. 1991. Landforms, soils, and forest growth: identification and with geographic information systems. In: Mengal, Dennis, comp. Ecological land classification: Applications to identify the productive potential of southern forests. 1991 January 7-9; Charlotte, NC. (in press)

Healy, Robert G. 1985. Competition for land in the American south. The Conservation Foundation, Washington, D.C. 333 pp.

Henderson, Gray S.; Hammer, R. David; Grigal, David F. 1990. Can measurable soil properties be integrated into a framework for characterizing forest productivity. In: Gessel, S. P.; Lacate, D. S.; Weetman, G. F.; Powers, R. F., eds. Sustained productivity of forest soils. Proceedings of the 7th North American Forest Soils Conference. 1988 July; Vancouver, BC. University of British Columbia. 137-154.

Hewlett, John D. 1982. Principles of Forest Hydrology. The University of Georgia Press, Athens, GA. 183 pp.

Hills, G. A. 1961. The ecological basis for land-use planning. Ontario Department of Lands and Forest Resources Rep. no. 46. 204 pp.

Hodgkins, E. J.; Golden, M. S.; Miller, W. F. 1979. Forest habitat regions and types on a photomorphic-physiographic basis: A guide to forest site classification in Alabama-Mississippi. Alabama Agricultural Experiment Station and Mississippi Agricultural Forestry Experiment Station Southern Coop. Bull. 210. 64 pp.

Hudson, Charles. 1976. The Southeastern Indians. The University of Tennessee Press. Knoxville, TN. 573 pp.

Hunt, Charles B. 1974. Natural regions of the United States and Canada. W. H. Freeman and Co., San Francisco. 725 pp.

Jones, S. M.; Van Lear, D. H.; S. K. Cox. 1984. A vegetation landform classification of forest sites within the upper Coastal Plain of South Carolina. Bulletin of the Torrey Botanical Club 111:349-360.

Jones, Steven M. 1989. Application of landscape ecosystem within the southeastern United States. In: Forestry on the Frontier, Proceedings of the 1989 National Convention, Society of American Foresters; 1989 Sept. 24-27; Spokane, WA. 79-83.

Kushla, J. D.; Fisher, R. F. 1980. Predicting slash pine response to nitrogen and phosphorus fertilization. Soil Science Society Journal 44: 1303-1306.

Lawson, Kermit N.; Schlatterer, Edward F. 1984. Forest land classification--Forest Service perspective. In: Bockheim, James G., ed. Forest land classification: experiences, problems, perspectives. 1984 March 18-20; Madison, WI. University of Wisconsin. 11-17.

Mader, D. L. 1963. Volume growth measurement--an analysis of function and characteristics in site evaluation. Journal of Forestry 61:193-198.

McNab, W. Henry. 1987. Rationale for a multifactor forest site classification system for the Southern Appalachians. In: Hay, Ronald L.; Woods, Frank W.; DeSelm, Hal, eds. Proceedings of the Central Hardwood Forest Conference VI; 1987 February 24-26; Knoxville, TN. Asheville, NC, U. S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 283-294.

Meyers, Richard; Zahner, Robert; Jones, Steven M. 1986. Forest habitat regions of South Carolina from Landsat imagery. Clemson University Department of Forestry, Forest Research Series no. 42. 31 pp., map supplement.

Monserud, Robert A. 1984. Problems with site index: an 21 opinionated review. In: Bockheim, James G., ed. Forest land classification: experiences, problems, perspectives. 1984 March 18-20; Madison, WI. University of Wisconsin. 167-180.

Noss, Reed F. 1989. Longleaf pine and wiregrass: Keystone components of an endangered ecosystem. Natural Areas Journal 9: 211-213.

Pehl, C. E.; Brim, R. L. 1985. Forest habitat regions of Georgia, Landsat 4 imagery. Georgia Agricultural Experiment Station Special Publication 31. 12 pp., map supplement.

Pfister, Robert D. 1989. Ecological site classification in northern Rocky forests: Putting theory to practice. In: Forestry on the frontier. Proceedings Society of American Foresters 1989 National Convention; Sept. 24-27, 1989; Spokane, WA. 74-78.

Powers, R. F. 1987. Predicting growth responses to soil management practices: Avoiding "future shock" in research. In: Future developments in soil science research. Golden Anniversary papers; New Orleans, LA. Soil Science Society of America, Madison, WI. 391-403.

Ralston, C. W. 1978. The Southern pinery: forests, physiography, and soils. In: Tippin, Tom, ed. Proceedings of a symposium on principles of maintaining productivity on prepared sites; 1978 March 21-22; Mississippi State University. 6-13.

Rowe, J. Stan. 1984. Forestland classification: Limitations of the use of vegetation. In: Bockheim, James G., ed. Forest land classification: Experiences, problems, perspectives. 1984 March 18-20, Madison, WI. University of Wisconsin. 132-147.

Society of American Foresters. 1923. Report of committee for classification of forest sites. Journal of Forestry 21:139-147.

Smalley, Glendon W. 1986. Site classification and evaluation for the interior uplands. Tech. Publ. R8-TP 9. New Orleans, LA: U. S. Department of Agriculture, Forest Southern Forest Experiment Station.

Stone, E. L. 1975. Soil and man's use of forest land. In: Bernier, B., Winget, C. H., eds. Forest soils and forest land management. Proceedings Fourth North American Forest Soils Conference; 1973 August, Quebec. Laval University. 1-10.

Stone, E. L. 1984. Site quality and site treatment. In: E. L. Stone, ed. Forest soils and treatment impacts. Proceedings of the Sixth North American Forest Soils Conference; 1984 June; Knoxville, TN: Department of Forestry, Wildlife and Fisheries, The University of Tennessee: 41-52.

Switzer, George L. 1978. Determinants of forest stand productivity. In: Tippin, Tom, ed. Proceedings of a symposium on principles of maintaining productivity on prepared sites; 1978 March 21-22; Mississippi State University. 14-27.

Switzer, G. L.; Shelton, M. G. 1984. Maintenance of productivity: Some observations. In: Karr, Bob L., Baker, James B., Monaghan, Tom, eds. Proceedings of the symposium on the loblolly pine ecosystem (west region); 1984 March 22; Jackson, MS. Mississippi Cooperative Extension Service. 201-216.

Turner, L. M. 1938. Some profile characteristics of the pine-growing soils of the Coastal Plain region of Arkansas. Arkansas Agricultural Experiment Station Bulletin 361. 52 pp.

Van Lear, D. H.; Jones, S. M. 1987. An example of site classification in the southeastern Coastal Plain based on vegetation and landform. Southern Journal of Applied Forestry 11:23-28.

Van Lear, D. H.; Hosner, J. F. 1967. Correlation of site index and soil mapping units--poor for yellow-poplar in Southwest Virginia. Journal of Forestry 65:22-24.

Wertz, W. A.; Arnold, J. F. 1975. Land stratification for land-use planning. In: Bernier, B., Winget, C. H., eds. Forest soils and forest land management. Proceedings 4th North American Forest Soils Conference. 1973 August, Quebec. Laval University. 617-630.

Zahner, Robert. 1984. Soils and climate of the loblolly pine ecosystem, west region. In: Karr, Bob L., Baker, James B., and Monaghan, Tom, eds. Proceedings of the symposium on the loblolly pine ecosystem (west region); 1984 March 20-22; Jackson, MS: Mississippi State University Cooperative Extension Service: 17-32.

Zon, R. 1913. Quality classes and forest types. Proceedings Society of American Foresters 8:100-104.

CLASSIFICATION SYSTEM DEVELOPMENT

LAND CLASSIFICATION IN THE BLUE RIDGE PROVINCE: STATE-OF-THE-SCIENCE REPORT[1]

W. Henry McNab[2]

ABSTRACT.--An ecological land classification system based on vegetation, landform, and soil relationships is being developed for the Blue Ridge Province. The classification overcomes many problems associated with site index, has the potential for a high level of accuracy, and can be used for forest resources other than timber. It can be applied using a range of methods including field mapping, taxonomic classification, and geographic information systems. Results of a test in the Bent Creek Experimental Forest suggest that five major landscape units, consisting of relatively uniform overstory species composition occurring below 3500 feet elevation, can be mapped from recognizable landforms and information on soil maps, and predicted using topographic factors measured on-site.

Keywords: Landscape units, geographic information systems, landforms, soil, site quality, site classification.

INTRODUCTION

The Blue Ridge Physiographic Province extends almost 600 miles from the Susquehanna River in southern Pennsylvania to the vicinity of Mount Oglethorp in northern Georgia (Figure 1). Fenneman (1938) describes the province, including its geomorphic history, and subdivides it into two sections at the Roanoke River Gap in central Virginia. The northern section is a single mountain range averaging about 3000 feet elevation and less than 15 miles wide. The other section, commonly known as the southern Appalachians (Braun 1950) broadens from the Roanoke River into a hilly plateau that gradually changes to rugged mountain ranges and cross ranges, with many summits exceeding 6,000 feet elevation. With an area of over 12 million acres, this province is characterized by igneous and metamorphic rock formations that were intensely folded and faulted during several orogenic periods, then eroded over the past 600 million years into a strongly dissected landscape of mountain ranges with broadly rounded summits. Climate varies with latitude and elevation, which ranges from about 1000 to 6684 feet. Precipitation, which ranges from about 40 to over 80 inches annually, is strongly affected by elevation, local topography, and proximity to the Blue Ridge escarpment. Rock formations are typically acidic in reaction, and can vary in mineral content and resistance to erosion over relatively short distances to form complex landforms[3] consisting of ridges, coves, and connecting sideslopes. Soils formed from these formations are generally low in fertility and have moisture regimes strongly influenced by local topography. Evapotranspiration can exceed precipitation during the late growing season, causing soil moisture deficits (McNab 1991), especially on sites with southerly aspects. This variation in climate, geology, topography, and soils produces a wide range of sites suitable for over 30 commercially valuable timber species, most of which are deciduous. Braun (1950) placed this area in her Oak-Chestnut Forest Region and attributed the great variety of vegetation and large number of species mainly to "the diversity of topography and range of altitude" and partly to variation in soils that formed from a range of geologic formations. Catlin (1984) presents a more detailed description of the rocks, fauna, flora, and past land use along the Blue Ridge Parkway, which extends through much of the province.

[1]Paper presented at the Symposium on Ecological Land Classification: Application to Identify the Productive Potential of Southern Forests, Charlotte, NC, January 7-9, 1991.

[2]Research Forester, USDA Forest Service. Southeastern Forest Experiment Station. Bent Creek Experimental Forest. Rt. 3, Box 1249, Asheville, NC 28806.

[3]Defined as: "Any physical, recognizable form or feature of the earth's surface, having a characteristic shape, and produced by natural causes; it includes major forms such as a plain, plateau, or mountain, and minor forms such as a hill, valley, slope, esker, or dune." (Driscoll and others, 1984)

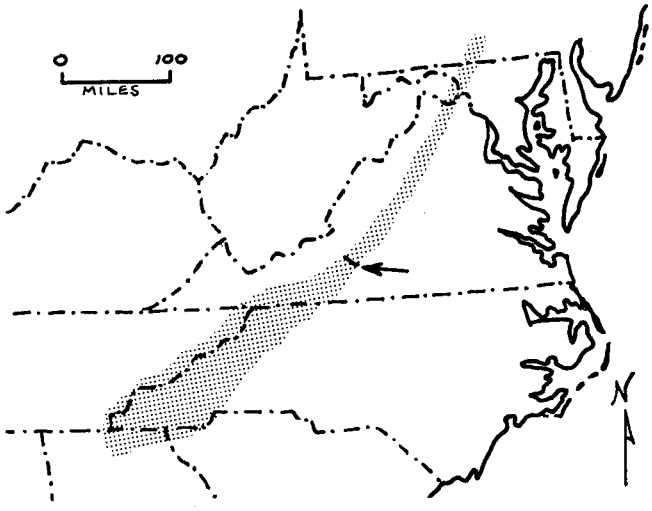


Figure 1.--Location of Blue Ridge Physiographic Province within the southeastern United States (after Braun 1950). Arrow indicates location of Roanoke River, which subdivides the province into northern and southern sections.

Silvicultural prescription and stand management in the Blue Ridge Province require a system for delineating areas with homogeneous species distribution and site productivity. At present, such a system is lacking. Site index is widely used to estimate stand productivity, but it has many limitations (Beck and Trousdell 1973). The most serious is the frequent lack of suitable sample trees. Considerable work has been done to determine soil-site relationships for the commercially important tree species in the Blue Ridge and adjoining provinces (McNab 1988a). Often, however, application of these relationships is risky without a means of classifying sites first for species suitability. Soil surveys often are of doubtful value for forest land classification in mountainous areas. Few counties have been surveyed since 1970, mapping is often inadequate for stand-size areas in complex topography, soil series-site quality data are too generalized, and species recommendations often stress conifers and are misleading for hardwoods. The USDA Forest Service initiated a research program at the Southeastern Forest Experiment Station in 1981 to develop a classification system with the following attributes:

- o Ecological basis for integrating vegetation with climatic, geologic, topographic, and soil environmental factors.
- o Hierarchical structure to allow application at appropriate scales.
- o Quantitative in the lower levels to allow objective application, predictive modeling, and computer-based application.
- o Classification based on recognizable features to facilitate mapping.

The system follows USDA Forest Service guidelines for classifying terrestrial ecological types (U.S. Department of Agriculture, Forest Service 1986) and will be applicable to over 12 million acres of land, 65 percent of which is classed as commercial forest.

Classification of forested landscapes is a two-phase task: (1) establishing classification units based on similarity of environmental attributes, and (2) developing relationships between the classification units and the resources of interest. Briefly summarized in this report are the classification units, which are presented in greater detail elsewhere (McNab 1987a). Also presented are published and preliminary results that illustrate relationships between the classification units and distribution of the vegetation resource in the Bent Creek Experimental Forest. Summarized elsewhere are results of soil-site studies that correlate tree growth with the classification units in and adjacent to the province (McNab 1988a).

METHODS

Land classification terminology and landform definition follow a glossary presented by Driscoll and others (1984). A landform omitted from this glossary but commonly used in the southern Appalachians is "cove": a small, straight valley extending into a mountain or down a mountainside (Bates and Jackson 1980). Hack and Goodlett (1960) use the term "hollow" to describe this landform.

Ecological Basis

Results of numerous studies in the southern Appalachians have indicated that vegetative composition and productivity are highly correlated with a range of broad-scale environmental factors, including climatic zones and geologic formations. For example, Whittaker (1956) and Golden (1974) found that the species composition of tree and shrub vegetation was correlated with environmental gradients associated with elevation, which affects growing-season length and precipitation patterns. Geologic formations influence relief (Fenneman 1938), soil properties (Hack and Goodlett 1960), vegetation distribution (Rohrer 1983), and productivity (McNab 1986, McNab and Merschat 1990). Rowe (1984) suggests that climate, geology, and landform are the principal factors that affect soil formation and development of biotic communities. When evaluated simultaneously, climatic and geologic zones delineate relatively homogeneous areas for application of land classifications.

In mountainous areas of uniform climate and geology, landform strongly influences ecological relationships because of its effects on local climate (Bailey 1988), water relations (Helvey and others 1972) and tree growth (McNab 1984). As early as 1921, broad classes of landform were used to rate productive potential of forested areas (Frothingham 1921). Whittaker (1956) and McLeod (1988) reported that species composition of vegetation was correlated best with topographic variables and next best with soil variables.

Landform is a significant factor affecting ecological relationships (Rowe 1984) and successional pathways of forest ecosystems (Host and others 1987). However, there is no generally accepted method to classify landforms, as there is for soils (Bailey 1981, Driscoll and others 1984).

Soil characteristics generally have a lesser influence on moisture regimes than landform in mountainous areas. Within a landform, soil influences species composition mainly through water storage capacity as expressed by solum depth and texture (Carmean 1975). Mowbray and Oosting (1968) reported strong correlations of vegetative associations with several soil physical characteristics. Braun (1950), and Hack and Goodlett (1960) reported that soil characteristics often account for local variation in species composition and productivity. In areas of reduced relief, such as the Asheville Basin where conditions are similar to the Piedmont Province, soil characteristics likely have a more important effect on vegetation than does landform (Jones 1989).

Ecological forest site classification requires an understanding of the interrelationships among vegetation, landform, and soil. As Barnes and others (1982) explain in greater detail, ecologically similar units of land usually support similar associations of overstory, understory, and ground cover species. Growth and reproduction of these species are responses to specific climate, soil moisture, and soil fertility. A landscape unit is defined as a group of sites with similar species, hazards, and productivity (Barnes and others 1982). Equivalent landscape units can have dissimilar landforms and soils that interact in ways which provide similar site conditions. This concept of equivalent site conditions is essential to the development of a workable and accurate land classification system. A classification system is necessary to reduce the complex array of topographic and soil variables into a few homogeneous landscape units for practical field application.

There are two general approaches to developing a classification: regionalization and aggregation. Regionalization is done by successively dividing large land areas into smaller units of more uniform characteristics. It often is applied to landscapes consisting of perceived units that are difficult to quantify. Aggregation (or taxonomy) combines similar small units into successively larger groups with similar properties. Maps of physiographic provinces are developed by regionalization while soil maps are developed by aggregation. Bailey and others (1978) provide a more complete description and application of each classification method.

Classification Framework

The classification system is a modification of a seven-level hierarchy developed by Wertz and Arnold (1972) for stratifying land units of various scale into homogeneous areas. This general hierarchy has also been used in modified form for ecological classification in Region 9 of the USDA Forest Service (Nelson and others 1984) and in the Interior Uplands (Smalley 1984). The hierarchical framework I am using is:

VII PHYSIOGRAPHIC PROVINCE--A large area of similar geologic structure, geomorphic history, and climate. (Example: Blue Ridge Province).

VI SECTION--Stratifications of provinces that account for variation in climate often associated with elevation and local relief. (Example: zones of precipitation >60 inches).

V SUBSECTION--Subdivisions of sections to account for variation in geologic formations that affect general soil properties. (Example: Anakeesta formation).

IV LANDTYPE ASSOCIATION--Aggregations of landtypes with similar mesoscale landforms, soil properties, and local climate. (Example: mountain upland).

III LANDTYPE--Groupings of landtype phases with similar solar radiation and soil moisture which lead to similar species composition. (Example: steep sideslope with north aspect).

II LANDTYPE PHASE--Clusters of sites with similar microscale landforms which lead to similar vegetative growth. (Example: concave land surface).

I SITE--Smallest, most uniform components of landscapes that Wertz and Arnold (1972) define as "a final integration of all environmental elements that occur together at a specific location" and that affect growth and reproduction of individual trees and shrubs. Sites are classified and clustered to form landtype phases, and are the observations for simulation models.

The upper three levels of the hierarchy represent environmental landscape components that act largely independently and are generally unapparent to the observer. The next three levels represent interrelated landscape components based mostly on recurring topographic features, which can be observed and quantified. Sites vary in size, depending on objectives of the classification, and for this application are about 1-acre in area. The basis of this hierarchy is presented in greater detail elsewhere (McNab 1987a).

This classification scheme has a high degree of compatibility with a system of land classification developed for the Interior Uplands (Smalley 1984). The frameworks have similar overall structure and bases for stratification in the upper three levels. In the next three levels of the hierarchy, however, I use taxonomic methods. Sites of similar species and productivity are grouped into landtype phases, which are then combined into landtypes and landtype associations. Landtypes are equivalent to landscape units and provide ecologically similar conditions that affect species composition of vegetation. Even though methodology differs somewhat between the two classifications, both are based on about the same criteria at the landtype level: landform, aspect, slope position and soil properties. The main difference is that forest communities were associated with landtypes after the classification was developed for the Interior Uplands (Wheat and Dimmick 1987), but I use vegetation to initially identify ecologically similar landscape units.

Landform Quantification

Unlike the topographic variables of aspect and gradient, landform could not be easily defined and measured. Nevertheless, it was an essential variable in prediction models. It therefore was necessary to develop methods for measuring landforms to ensure accurate application in the field, in modeling, and in GIS. Currently, I use two scales to quantify landform: (1) the microscale surface shape of the site, as measured by the terrain shape index (McNab 1989); and (2) the mesoscale shape of the land surface surrounding the site, which is measured by the landform index.[4] These scales of landform are compatible with concepts presented by Bailey (1988) and extend his continental-scale hierarchy down to a localized level. Techniques for quantifying landform were evaluated throughout the Blue Ridge Province using permanent plots established to study growth of yellow-poplar (*Liriodendron tulipifera* L.) (McNab 1987b).

Bent Creek Landscape Model

The classification framework and landform quantification techniques were tested at Bent Creek Experimental Forest, a 6000-acre watershed located in western North Carolina, about 10 miles southwest of Asheville. The watershed, which forms a U-shaped, northeast-facing valley averaging about 5 miles long by 2 miles wide, has a dendritic drainage pattern (Figure 2) and landforms ranging from ravines and coves to ridges and knobs. Summers in the area are long and warm, and winters are short and mild. Annual precipitation averages 45 inches at the headquarters site (elevation 2100 feet) and is evenly distributed, with little occurring as snow. Elevation ranges from 2100 to over 4000 feet. Mean monthly temperature is 36°F for January and 74°F for August, with an annual average of 55°F. The predominant rock formation consists of muscovite-biotite gneiss. Soils are generally deep (>40 inches) and typically consist of Hapludults and Dystrochrepts. Slopes range from almost level to very steep.

Vegetation consists of late successional species in associations that have developed during the past 100 years on sites that once were cultivated, pastured, or selectively logged. The only recent major large-scale disturbance has been the loss of American chestnut (*Castanea dentata* (Marsh.) Borkh.) during the 1930's. The distribution of overstory species is closely related to the soil moisture regime and perhaps ambient temperature. Dry slopes and ridges are dominated by xerophytic species, most of which are drought tolerant oaks: chestnut (*Quercus prinus* L.), scarlet (*Q. coccinea* Muenchh.), black (*Q. velutina* Lam.), and sometimes post oak (*Q. stellata* Wangenh.). Sourwood (*Oxydendrum arboreum* (L.) DC.) is a common associate, along with mockernut hickory (*Carya tomentosa* (Poir.) Nutt.) and pitch pine (*Pinus rigida* Mill.) on some dry sites. Mesophytic species such as yellow-poplar, northern red oak (*Q. rubra* L.) and black locust (*Robinia pseudoacacia* L.) are found on moist slopes and coves. White oak (*Q. alba* L.), red maple (*Acer rubrum* L.), and flowering dogwood (*Cornus florida* L.) are found across a range of site moisture conditions. Alluvial floodplains provide conditions suitable for sycamore (*Platanus occidentalis* L.), river birch (*Betula nigra* L.), boxelder (*Acer negundo* L.) and other species. A host of understory and ground cover species also occur in the Bent Creek drainage. A preliminary inventory of vegetation in a portion of the Bent Creek Valley occupied by The North Carolina Arboretum (Figure 2) revealed 474 vascular plant taxa (Pittillo 1989), including 76 tree and 66 shrub species.

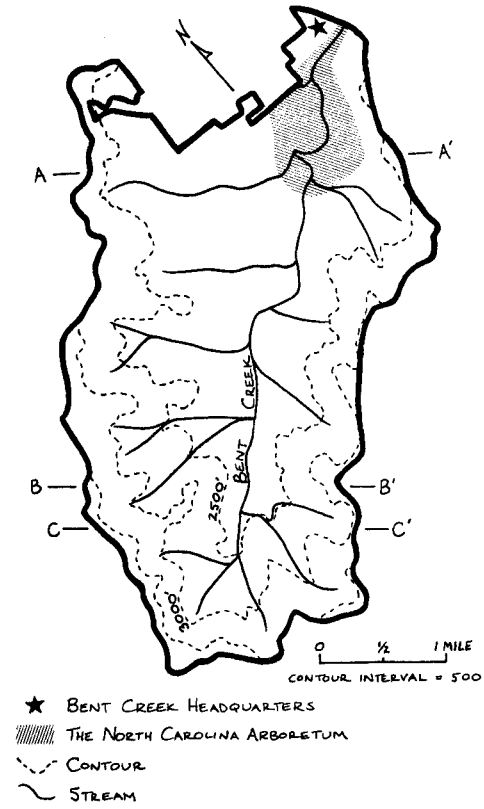


Figure 2.--The drainage pattern of Bent Creek Experimental Forest with locations of The North Carolina Arboretum and section lines (A-A', B-B', C-C').

[4] McNab, W.H. 1991. A field index to quantify the effect of landform on forest site quality. Unpublished draft on file: Asheville, NC: Southeastern Forest Experiment Station.

Mapping Units

Application of the land classification requires definition of mapping units at the landtype association and landtype levels of the hierarchy. In general, physical form of the lower end of the Bent Creek Valley is nearly identical to the intermontane basin model proposed by Gile and others (1981), as presented in Driscoll and others (1984). Based on their findings, and my observations in the field, the following three landtype associations are proposed:

1. MOUNTAIN UPLAND--An elevated land surface more than 1000 feet above surrounding lowlands and generally having steep sides (>25 percent slopes). Soils typically consist of fine-loamy, typic Hapludults and fine-loamy typic Dystrochrepts.

2. PIEDMONT SLOPE--The dominant gentle slope at the foot of a mountain that grades into an alluvial flat. Soils typically consist of clayey, typic Hapludults on slopes that range in gradient from 2 to 25 percent.

3. ALLUVIAL FLAT--A nearly level surface consisting of unconsolidated clastic material deposited by running water including gravel, sand, silt, clay and various mixtures of these. Typically, soils consist of fine-loamy, fluvaquentic Dystrochrepts.

A typical arrangement of these landtype associations in the Bent Creek valley is presented in Figure 3, which illustrates a cross-sectional profile along section line A-A' of Figure 2. The sequence and presence of landtype associations varies with location in the valley. For example, mountain uplands are adjacent to alluvial flats at section line B-B', and only mountain uplands are present at C-C'. These and other arrangements of landtype associations are probably typical of many large valleys in the Blue Ridge Province.

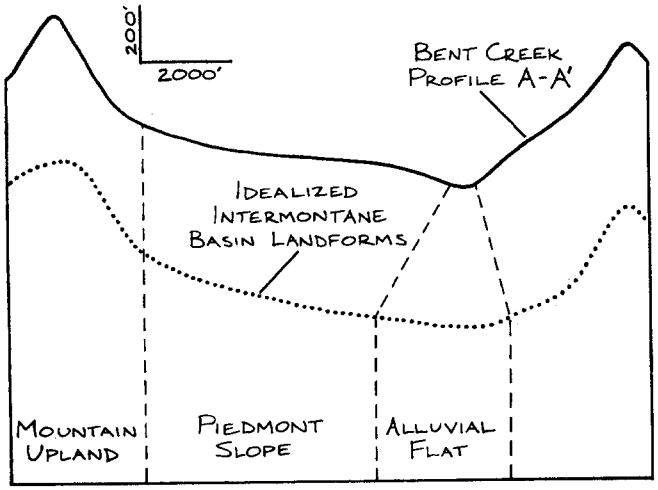


Figure 3.--Profile section A-A' across Bent Creek Valley in comparison to landforms of an intermontane basin described by Gile and others (1981).

Except for alluvial flats, each landtype association consists of three component landforms: ridges, sideslopes, or coves. When combined with aspect, slope position, and soil properties, each component landform becomes a potential mapping unit. Ecologically equivalent mapping units are dominated by vegetation of similar species composition. Alluvial flats have a single landform--sideslopes--which can vary widely in soil properties, depending on drainage.

Field sampling

A tentative landscape classification model based on overstory and understory vegetation was developed in a 3000-acre portion of the Experimental Forest, located mainly on the northern side of Bent Creek and below 3500 feet elevation. Overstory vegetation, landform, and soil were evaluated on 135 permanent, 0.20-acre plots previously randomly established in upland hardwood stands. Basal area was determined by species for trees greater than 4.5 inches d.b.h. To evaluate application of the classification by field mapping, landtype association, landtype, and slope position were determined subjectively, and aspect and gradient were measured on each plot. For application by prediction, the following site variables were measured: elevation, aspect, gradient, landform index, and terrain shape index. Soil characteristics were determined by reference to an unpublished 1:24,000 scale map produced by USDA Soil Conservation Service in 1977.[5] Soils data gathered on sites were ignored because I wanted to classify only from mapped data.

Overstory landscape units were determined from field observations and cluster analysis. Field observations and summary tables were used to determine relationships between landscape units, landform, and soil for use in mapping. Canonical and multivariate discriminant analyses were used to develop a mathematical model for predicting cover types based on topographic variables. The mapping units and the prediction model were tested with data from an independent set of 69 validation plots. Field procedures and analytic methods for the prediction model are explained in greater detail elsewhere.[6]

A preliminary study was made of understory vegetation to determine if its distribution was associated with landform and soils. Field methods were identical to those for the overstory. Landform and soil variables were measured on 81 temporary plots where the understory vegetation was of similar species composition and occupied a

[5] Interim soil survey report for Buncombe County, North Carolina. July 1977. 241 pp.

[6] McNab, W.H. [In press]. Prediction of forest type using topographic variables in Bent Creek Experimental Forest. Proceedings of the sixth biennial southern silvicultural research conference; 1990 October 30-November 3. Memphis, TN. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station.

site of at least 1 acre. Classification of understory landscape units was based primarily on the presence of one or two dominant species. Six prominent landscape units were identified and sampled: (1) a combination of two low-growing (<36 inches) ericaceous species (low ericads), dryland blueberry (Vaccinium vacillans Torrey) and black huckleberry (Gaylussacia baccata (Wang.)K.Koch); (2) mountain laurel (Kalmia latifolia L.); (3) rosebay rhododendron (Rhododendron maximum L.); (4) common alder (Alnus serrulata (Aiton) Willd.); (5) tree seedlings (dbh <1.0 inch) of all species; and (6) miscellaneous fern and herbaceous species, which included species such as New York fern (Thelypteris noveboracensis (L.) Nieuwland) and indian turnip (Arisaema triphyllum (L.) Schott). Deerberry (V. stamineum L.) was often associated with mountain laurel on piedmont slopes, but was not sampled as a landscape unit.

As with the overstory, field reconnaissance was used to associate understory vegetation with landform and soil for use in mapping. Multivariate discriminant analysis was used to develop a prediction model of understory landscale units, but the model was not validated. This preliminary test provides no basis for combining overstory and understory landscape units because field sampling for each was conducted separately. Although ground cover vegetation can be useful in land classification (McNab 1988b), it was omitted from this preliminary evaluation, except for the collective grouping of miscellaneous ferns and herbaceous species.

RESULTS AND DISCUSSION

Landscape Units

Five overstory landscape units of species composition were identified that likely represent a moisture gradient ranging from xeric to subhydric:

Moisture gradient	Landscape unit
Xeric	Scarlet oak (SO)
Subxeric	Chestnut oak (CO)
Intermediate	Mixed oaks (MO)
Mesic	Yellow-poplar (YP)
Subhydric	Sycamore (S)

Landform characteristics account for much of the distribution of landscape units. Mountain uplands provided a range of soil moisture regimes that were correlated with land surface shape, slope position, gradient, and aspect. Chestnut oak, often in association with scarlet and black oaks, occurred mainly on dry sites along ridges and many south-facing slopes. Yellow-poplar occupied coves and lower north facing slopes. Mixed oaks occupied a range of sites considered to be intermediate in soil moisture. Piedmont slopes were dominated by scarlet oak in association with black and white oaks, and sometimes post oak on the most xeric sites. Yellow-poplar, red maple, and white oak often formed stands on mesic lower slope positions of piedmont slopes adjacent to alluvial flats. Alluvial flats were classified as subhydric, but sometimes ranged to mesic depending on soil parent material and properties, gradient, and past land use (such as logging). Crayfish (Cambarus spp) often inhabit the wettest alluvial sites. Location of these over- story landscape units in relation to physiography is shown in Figure 4 and a tentative, generalized classification is presented in Table 1.

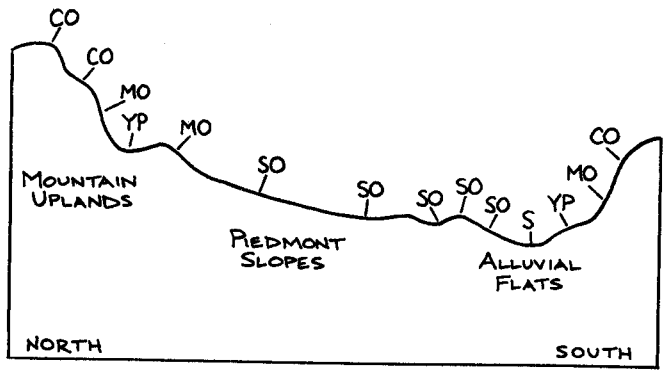


Figure 4.--Idealized overstory landscape units in relation to landtype associations and landtypes in Bent Creek Experimental Forest. (CO=Chestnut oak, MO=Mixed oaks, SO=Scarlet oak, YP=Yellow-poplar, S=Sycamore.)

Table 1.--Tentative classification of selected overstory landscape units.

I. Low elevation landscape units (<3500 feet).
- A. Alluvial flats--Loam to sandy loam soil, nearly level gradients.
  - SYCAMORE-RIVER BIRCH
- B. Piedmont slopes--Gentle to steep gradients, clay loam to sandy clay loam soils.
  - 1. Ridges and upper slopes.
    - SCARLET-WHITE-BLACK-POST OAKS
  - 2. Sideslopes.
    - SCARLET-WHITE-BLACK OAKS
  - 3. Coves and lower slopes.
    - SCARLET-WHITE OAKS, YELLOW-POPLAR
- C. Mountain uplands--steep to very steep gradients, loam to stony loam soils.
  - 1. Ridges and upper slopes.
    - CHESTNUT-SCARLET-BLACK OAKS
  - 2. Mid slopes with southerly aspects.
    - CHESTNUT-BLACK OAKS
    - Mid slopes with northerly aspects.
    - MIXED OAKS
  - 3. Lower slopes with southerly aspects.
    - MIXED OAKS
    - Lower slopes with northerly aspects.
    - YELLOW-POPLAR, N. RED OAK
  - 4. Coves. YELLOW-POPLAR, N. RED OAK

II. Middle elevation landscape units (>3500 feet). Not sampled

Understory vegetation was also associated with specific landscape positions considered to represent a moisture gradient:

Moisture gradient	Understory vegetation
Ultraxeric	Low ericads (LE)
Xeric	Mountain laurel (ML)
Intermediate	Tree seedlings (TS)
Submesic	Rosebay rhododendron (RR)
Mesic	Fern-herbaceous (FH)
Subhydric	Common alder (CA)

Species considered as xerophytic were associated with ridges and slopes with southerly aspects. Coves and slopes with steep north aspects provided conditions suitable for species considered to be mesophytic. Tree seedlings were present on almost all sites, but were most apparent on areas not dominated by one of the other understory units. Rosebay rhododendron dominated some moist sites, especially steep, northerly slopes, and along some streams, but was absent from other similar situations. Typical positions on the landscape occupied by these units are shown in Figure 5, and a tentative classification of understory landscape units was developed (Table 2).

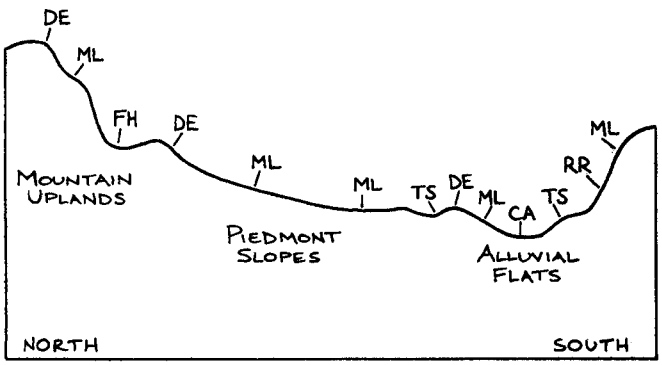


Figure 5.--Idealized understory landscape units in relation to landtype associations and landtypes in Bent Creek Experimental Forest. (TS=Tree seedlings, DE=Low ericads, FH=Fern-herbaceous, ML=Mountain laurel, RR=Rosebay rhododendron, CA=Common alder.)

In general, understory vegetation appears to occupy a narrower range of landscape positions than overstory species, perhaps as a result of shallow rooting depths and greater sensitivity to soil moisture regimes and other conditions including fertility and past land use. Because overstory and understory were sampled separately, a classification including both landscape units could not be developed. However, I observed that certain overstory units tended to be associated with specific understory units. For example, four understory landscape units were found beneath chestnut oak overstories: low ericads, mountain laurel, tree seedlings, and rosebay rhododendron (Table 3).

Groups of species must be defined to apply this classification system. But grouping oversimplifies the distribution of species in relation to environmental conditions. While my overstory landscape units are similar in composition to natural communities of the North Carolina Natural Heritage Program (Schafale and Weakley 1990) and are almost identical to vegetation types described by McLeod (1988), they still differ in relative abundance of each species present. This is because abundance of a species varies continuously from near absence to near complete dominance of stands in response to site conditions, which also vary continuously. For example, yellow-poplar dominated coves but was also present on ridges. Likewise, mountain laurel dominated dry slopes but was also present beside streams. Boundaries drawn between landscape units are therefore likely to be arbitrary and artificial. As Schafale and Weakley (1990) stated "Occurrences near a boundary of a category may be more similar to some occurrences in the adjacent category than they are to members at the opposite end of their own category."

Table 2.--Tentative classification of selected understory landscape units.

I. Low elevation landscape units (<3500 feet).
  A. Alluvial flats. COMMON ALDER
  B. Piedmont slopes.
    1. Ridges, upper slopes with southerly aspects. LOW ERICADS
       Upper slopes with northerly aspects. MOUNTAIN LAUREL
    2. Middle slopes with southerly aspects. LOW ERICADS-MT. LAUREL
       Middle slopes with northerly aspects. MOUNTAIN LAUREL
    3. Coves. TREE SEEDLINGS
  C. Mountain uplands.
    1. Ridges, upper slopes with southerly aspects. LOW ERICADS, MT. LAUREL
       Upper slopes with northerly aspects. MT. LAUREL, TREE SEEDLINGS
    2. Middle slopes with southerly aspects. LOW ERICADS, MOUNTAIN LAUREL
       Middle slopes with northerly aspects. TREE SEEDLINGS, RHODODENDRON
    3. Coves. FERN-HERBACEOUS
II. Middle elevation landscape units (>3500 feet). Not sampled.

Table 3.--Tentative associations of overstory and understory vegetation landscape units.

Understory landscape units	Overstory landscape units				
	SO	CO	MO	YP	S
Low ericads	x	x			
Mountain laurel	x	x	x		
Tree seedlings	x	x	x	x	x
Rosebay rhododendron		x	x	x	
Fern/herb				x	
Common alder					x

(Key to overstory landscape units: SO=Scarlet oak, CO=chestnut oak, MO=mixed oaks, YP=yellow-poplar, S=sycamore.)

Test and Evaluation

The discriminant model correctly predicted about 75 percent of overstory landscape units using topographic and soil factors (Table 4). The most accurate classifications were for scarlet oak and yellow-poplar, which are at opposite ends of the assumed moisture gradient. Accuracy was somewhat better for mapping than for prediction methods.

Results of this preliminary test suggest that understory landscape units also occupy specific sites and can be accurately predicted (Table 5). Overall, prediction accuracy using the discriminant function was 77 percent, about comparable to accuracy obtained for the overstory landscape units. Much of the error resulted from two landscape units. Tree seedlings were found across a range of sites and are likely better associated with disturbance of the overstory than with the soil moisture regime. About a third of the misclassified landscape units were occupied by mountain laurel but were classified as low-ericad sites. Because site conditions for these two landscape units overlapped in the field, the discriminant function was also somewhat inaccurate. If the low ericads and mountain laurel landscape units were combined into a single xeric group, classification success would increase to about 83 percent. It is likely that soils differed beneath these two landscape units, but soils were not mapped at a scale sufficient to indicate different series.

These results suggest that landscape units consisting of overstory and understory species can be identified and mapped using landforms and soils, and that the approach is feasible for land classification in the Blue Ridge Province. Inclusion of vegetation in the mapping process will increase accuracy. However, even if vegetation is not present and the sites have been recently disturbed, use of landform and soils alone should allow reasonably accurate land classification. A reasonable level of accuracy to achieve might be to produce a map that is 80 percent accurate at the 95 percent confidence level.

Geographic Information Systems

Computer application of the classification system was impossible because algorithms for calculation of the landform and terrain shape indexes were not available. When the algorithms are developed, the Bent Creek model may be readily applied by computer methods because all required site variables can be calculated from a single digital elevation data base. Using a raster-type geographic information system, the discriminant model can predict the probable landscape unit for each 1-acre site using stored physiographic and edaphic attributes. Other models also can be applied to determine productivity and hazards associated with each site. The land manager can then delineate stands based on manageable-sized areas and other criteria (Figure 6).

Table 4.--Results of mapping and predicting overstory landscape units on 69 plots.

Actual landscape unit	Classified landscape unit: Scarlet oak	Chestnut oak	Mixed oaks	Yellow-poplar	Sycamore
	- - - - - -Percent- - - - - - - - - -				
	MAPPING METHOD				
Scarlet oak	79	16	5	0	0
Chestnut oak	0	89	11	0	0
Mixed oaks	8	8	84	0	0
Yellow-poplar	0	6	0	94	0
Sycamore	0	0	0	0	100
	PREDICTION METHOD				
Scarlet oak	81	19	0	0	-
Chestnut oak	6	72	16	6	-
Mixed oaks	10	10	70	10	-
Yellow-poplar	0	25	0	75	-
Sycamore	-	-	-	-	-

Sycamore landscape unit was not tested by prediction.

Table 5.--Results of predicting understory landscape units on 81 plots.

Actual understory unit	Predicted understory unit: LE	ML	TS	RR	FH	CA
	- - - - Percent - - - - -					
Low ericads	94	6	0	0	0	0
Mountain laurel	29	53	12	0	0	6
Tree seedlings	0	20	53	20	0	7
Rosebay rhododendron	0	0	0	92	8	0
Fern-herbaceous	0	0	8	0	85	8
Common alder	0	0	0	0	0	100

LE=Low ericads; ML=Mountain laurel; TS=Tree seedlings; RR=Rosebay rhododendron; FH=Fern and herbaceous; CA=Common alder.

YP	YP	YP	YP	YP	YP	S	S	SO	SO	SO	SO	SO	MO	CO	CO	CO
YP	YP	MO	MO	YP	YP	S	S	SO	SO	SO	MO	MO	CO	CO	CO	CO
YP	YP	CO	YP	YP	YP	MO	S	S	SO	SO	SO	YP	CO	YP	CO	CO
YP	MO	YP	YP	YP	MO	MO	MO	S	S	SO	MO	MO	YP	YP	CO	SO
YP	YP	YP	MO	MO	MO	MO	SO	MO	S	SO	MO	YP	YP	YP	CO	CO
MO	YP	MO	MO	MO	SO	MO	MO	S	S	SO	SO	YP	YP	CO	SO	CO
MO	MO	MO	MO	MO	MO	SO	S	S	SO	SO	YP	YP	YP	YP	CO	CO
MO	MO	YP	MO	MO	MO	MO	S	SO	SO	SO	YP	CO	CO	CO	CO	CO

Figure 6.--Example of application of the classification on 1-acre sites using a geographic information system to predict occurrence of five overstory landscape units. Thick line indicates probable stand boundaries. (CO=Chestnut oak, MO=Mixed oaks, S=Sycamore, SO=Scarlet oak, YP=Yellow-poplar.)

Future Work

Although considerable progress has been achieved, several major phases of the classification work remain. Productivity and hazards must be described and evaluated for each landscape unit. Because vegetative composition is influenced by climatic and geologic variables, additional stratifications will be needed to extend the Bent Creek model to other parts of the Blue Ridge Province. Initial success in quantification of micro- and meso-scale landforms suggests that macro-scale relief surrounding the site can also be quantified and could be useful in predicting effects of changing climate on distribution and growth of species. For example, radial growth of yellow-poplar is closely correlated with patterns of growing-season precipitation (Beck 1984), which is likely associated with local relief. Development of a model to predict variation in local rainfall will require a means of quantifying relief. Fractal geometry offers a promising method of doing this (Barenblatt and others 1984). The apparent advantage is that the fractal dimension of a large landscape can be calculated with the same digital data set used by the geographic information system for land classification.

In summary, results of this preliminary evaluation suggest that the integrated, ecological approach is well suited for classifying forest land in the Blue Ridge Province. The proposed system has potential for purposes other than timber management, including classifying habitat suitability for wildlife, estimating water yield from watersheds, and controlling competing vegetation. The classification can be applied by three methods: (1) field mapping landscape units that consist of vegetation, landform, and soil; (2) on-site classification; and (3) computer prediction using digital data bases. Availability of more detailed maps will allow soil information to play a greater role in the classification. Development, evaluation, and modification of this system is a continuous process. Because of the broad range in climate, geology, landform, and soil of the Blue Ridge Province, a final approximation of the classification will likely never be achieved.

ACKNOWLEDGMENTS

The author thanks Director George Briggs and Mr. Ronald W. Lance, The North Carolina Arboretum, for providing information on taxa of the Arboretum and on distribution of understory vegetation in relation to environmental factors.

LITERATURE CITED

Bailey, R.G.; Pfister, R.D.; Henderson, J.A. 1978. Nature of land and resource classification--a review. Journal of Forestry. 76:650-655.

Bailey, R.G. 1981. The landform component in land classification. In: Resource Evaluation Newsletter 8. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. pp. 3-5.

Bailey, R.G. 1988. Ecogeographic analysis: a guide to the ecological division of land for resource management. Misc. Publ. 1465. Washington, DC: U.S. Department of Agriculture, Forest Service. 16 pp.

Barenblatt, G.I.; Zhivago, A.V.; Neprochnov, Yu. P.; Ostrovskiy, A.A. 1984. The fractal dimension: a quantitative characteristic of ocean-bottom relief. Oceanology. 24(6):695-697.

Barnes, Burton V.; Pregitzer, Kurt S.; Spies, Thomas A.; Spooner, Vera H. 1982. Ecological forest site classification. Journal of Forestry. 80(8):493-498.

Bates, R.L.; Jackson, J.L. 1980. Glossary of geology. Falls Church, VA: American Geological Institute. 751 pp.

Beck, Donald E. 1984. Is precipitation a useful variable in modeling diameter growth of yellow-poplar? In: Shoulders, E., ed. Proceedings of the third biennial southern silvicultural research conference; 1984 November 7-8; Atlanta, GA. Gen. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; pp. 555-557.

Beck, Donald E.; Trousdell, Kenneth B. 1973. Site index: accuracy of prediction. Res. Pap. SE-108. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 7 pp.

Braun, E. Lucy. 1950. Deciduous forests of Eastern North America. Philadelphia, PA: The Blakiston Company. 596 pp.

Carmean, W.H. 1975. Forest site quality evaluation in the United States. Advances in agronomy. 27:209-269.

Catlin, D.T. 1984. A naturalist's Blue Ridge Parkway. Knoxville, TN: The University of Tennessee Press. 208 pp.

Driscoll, R.S.; Merkel, D.L.; Radloff, D.L. [and others]. 1984. An ecological land classification framework for the United States. Misc. Publ. 1439. Washington, DC: U.S. Department of Agriculture, Forest Service. 56 pp.

Fenneman, N.M. 1938. Physiography of Eastern United States. New York: McGraw-Hill Book Co., Inc. 714 pp.

Frothingham, E.H. 1921. Site determination and yield forecasts in the southern Appalachians. Journal of Forestry. 19(1):1-14.

Gile, L.H.; Hawley, J.W.; Grossman, R.B. 1981. Soils and geomorphology in the basin and range area of southern New Mexico--guidebook to the desert project. Memoir 39. Socorro, NM: New Mexico Bureau of Mines and Mineral Resources. 225 pp.

Golden, Michael S. 1974. Forest vegetation and site relationships in the central portion of the Great Smoky Mountains National Park. Knoxville, TN: University of Tennessee. 275 pp. Dissertation.

Hack, John T.; Goodlett, John C. 1960. Geomorphology and forest ecology of a mountain region in the central Appalachians. Professional Paper 347. Washington, DC: U.S. Department of Interior, Geological Survey. 66 pp.

Helvey, J.D.; Hewlett, J.D.; Douglass, J.E. 1972. Predicting soil moisture in the southern Appalachians. Soil Science Society of America Proceedings 36(6):954-959.

Host, G.E.; Pregitzer, K.S.; Ramm, C.W. [and others]. 1987. Landform-mediated differences in successional pathways among upland forest ecosystems in northwestern lower Michigan. Forest Science. 33(2):445-457.

Jones, Steven M. 1989. Application of landscape ecosystem classification in identifying productive potential of pine-hardwood stands. In: Waldrop, T.A., ed. Proceedings of pine-hardwood mixtures: a symposium on management and ecology of the type; 1989 April 18-19; Atlanta, GA. Gen. Tech. Rep. SE-58. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. pp. 64-69.

McLeod, Donald E. 1988. Vegetation patterns, floristics, and environmental relationships in the Black and Craggy Mountains of North Carolina. Chapel Hill, NC: University of North Carolina. 222 pp. Dissertation.

McNab, W.H. 1984. Geomorphic factors associated with quality of yellow-poplar sites in the southern Appalachians. In: Shoulders, E., ed. Proceedings of the third biennial southern silvicultural research conference; 1984 November 7-8; Atlanta, GA. Gen. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. pp. 331-336.

McNab, W.H. 1986. Integrated site classification in the southern Appalachians: geologic variables related to yellow-poplar productivity. In: Phillips, Douglas R., ed. Proceedings of the fourth biennial southern silvicultural research conference; 1986 November 4-6; Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. pp. 253-258.

McNab, W.H. 1987a. Rationale for a multifactor forest site classification system for the southern Appalachians. In: Hay, R.L.; Woods, F.W.; DeSelm, H., eds. Proceedings of the 6th central hardwood forest conference; 1987 February 24-26; Knoxville, TN. Knoxville, TN: University of Tennessee, Department of Forestry, Wildlife, and Fisheries. pp. 283-294.

McNab, W.H. 1987b. Yellow-poplar site quality related to slope type in mountainous terrain. Northern Journal of Applied Forestry. 4:189-192.

McNab, W.H. 1988a. Hardwoods and site quality. In: Smith, H. Clay, ed. Proceedings of the workshop on guidelines for regenerating Appalachian hardwood stands; 1988 May 24-26; Morgantown, WV. Morgantown, WV: West Virginia University. pp. 226-240. [SAF Publ. 88-03; available from Office of Publications]

McNab, W.H. 1988b. Microtopography, soil, and vegetation are important factors in a taxonomic site classification system. In: Miller, James H., ed. Proceedings of the fifth biennial southern silvicultural research conference; 1988 November 1-3; Atlanta, GA. Gen. Tech. Rep. SO-74. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. pp. 501-506.

McNab, W.H. 1989. Terrain shape index: quantifying effect of minor landforms on tree height. Forest Science. 35:91-104.

McNab, W.H. 1991. Factors affecting temporal and spatial soil moisture variation in and adjacent to group selection openings. In: McCormick, L.H.; Gottschalk, K.W., eds. Proceedings of the 8th Central Hardwood Forest Conference; 1991 March 4-6; University Park, PA. Gen. Tech. Rep. NE-148. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. pp. 475-488.

McNab, W.H.; Merschat, C. E. 1990. Geologic variables associated with height of yellow-poplar stands in the Bald Mountains of North Carolina. Journal of the Elisha Mitchell Scientific Society. 106(2):25-31.

Mowbray, T.B.; Oosting, H.J. 1968. Vegetation gradients in relation to environment and phenology in a southern Blue Ridge gorge. Ecological Monographs. 38(4):309-344.

Nelson, DeVon O.; Russell, Walter E.; Stuart, Gordon W. 1984. The ecological classification system in the national forest system, Eastern Region. In: Bockheim, J.G., ed. Proceedings of the symposium on forest land classification: experiences, problems, perspectives; 1984 March 18-20; Madison, WI. Publ. NCR-102. Madison, WI: University of Wisconsin, Department of Soil Science. pp. 270-276.

Pittillo, J. Dan. 1989. Botanical resources inventory for the Western North Carolina Arboretum. Asheville, NC: The North Carolina Arboretum. 89 pp.

Rohrer, J.R. 1983. Vegetation pattern and rock type in the flora of the Hanging Rock Area, North Carolina. Castanea. 48:189-205.

Rowe, J.S. 1984. Forest land classification: limitations of the use of vegetation. In: Bockheim, J.G., ed. Proceedings of the symposium on forest land classification: experiences, problems, perspectives; 1984 March 18-20; Madison, WI. Publ. NCR-102. Madison, WI: University of Wisconsin, Department of Soil Science. pp. 132-147.

Schafale, M.P.; Weakley, A.S. 1990. Classification of the natural communities of North Carolina, third approximation. Raleigh, NC: North Carolina Natural Heritage Program. 325 pp.

Smalley, Glendon W. 1984. Landforms: a practical basis for classifying forest sites in the Interior Uplands. Proceedings, 12th annual hardwood symposium of the Hardwood Research Council; 1984 May 8-11; Cashiers, NC. Unnumbered publication. Memphis, TN: Hardwood Research Council. pp. 92-112.

U.S. Department of Agriculture, Forest Service. 1986. Ecosystem classification handbook FSH 2090.11. Washington, DC: U.S. Department of Agriculture, Forest Service. 13 pp.

Wertz, W.A.; Arnold, J.F. 1972. Land systems inventory. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 12 pp.

Wheat, R.M., Jr.; Dimmick, R.W. 1987. Forest communities and their relationships with landtypes on the western Highland Rim of Tennessee. In: Hay, R.L.; Woods, F.W.; DeSelm, H., eds. Proceedings of the 6th central hardwood forest conference; 1987 February 24-26; Knoxville, TN. Knoxville, TN: University of Tennessee, Department of Forestry, Wildlife, and Fisheries. pp. 377-383.

Whittaker, R.H. 1956. Vegetation of the Great Smoky Mountains. Ecological Monographs. 26(1):1-80.

NO MORE PLOTS; GO WITH WHAT YOU KNOW: DEVELOPING A FOREST LAND CLASSIFICATION SYSTEM FOR THE INTERIOR UPLANDS[1/]

Glendon W. Smalley[2/]

Abstract.--A five-level forest site classification system was developed for the 29 million acres of the Cumberland Plateau and Highland Rim physiographic provinces. Six published regional guides that describe the system and how it is used to classify and evaluate forest sites are available. Landtypes, the most detailed level, are described in terms of nine elements, are evaluated in terms of productivity and desirability of selected hardwoods and conifers for timber production, and are rated for five site-related problems. The system permits on-site determinations of site productivity and provides a framework for forest management planning, operations, and research.

Keywords: Cumberland Plateau, Highland Rim/Pennyroyal, landforms, land stratification, site productivity, soils, timber management.

INTRODUCTION

The Keynote Session for this Symposium provided an excellent historical perspective of ecological land classification in Canada and the United States. Suffice it to say that many methods have been employed, but no one system applicable to all the diverse forest sites, forest types, and forest conditions has been developed. In fact, Pierpoint (1984) suggested that "...it is unrealistic idealism to expect to develop a comprehensive so-called universal classification hierarchy that will serve all users, beyond providing a broad regional framework for broad land-use planning."

Professor Rowe (1984) has eloquently submitted that landform is a synthesizing supplement to vegetation and soils and argues that vegetation not be used as the basis for classifying forest land. In his words, "a universal system of forestland classification... will only develop if agreement is reached on concepts as to the nature of forestland, and on purposes to be served in dividing it and classifying it.... The managers of forestland need areal units defined according to criteria that make them relevant to such multi-use aspects of management as silviculture, tree harvesting, wildlife renewal, and watershed protection. Such needs subtly encourage classifiers to take account of climate, soil, and landform in addition to vegetation when devising their typologies. Even more important is the related conceptualizing of spatial ecosystems..., as landscape segments that are not shadowy extensions of vegetation and/or soil but real structure objects-of-interest based on landform. By its modification of the fluxes of solar energy and precipitation, the shape and substance of the land (landform) control the expression of local climate, biota, and soil in site-specific ways. Thus landform provides the integrating framework of other landscape components. Perceived covariances of vegetation and landform in the landscape patterns provide the means for mapping."

Today forest managers are faced with the challenge of producing more wood on diminishing acreage of commercial forest land, and the need for site classification and productivity information continues to be of "high priority"; witness this symposium.

Before the system developed for the Interior Uplands is described here, the title needs to be explained. The "no more plots; go with what you know" was a restriction placed on this author by the then Assistant Director of the USDA Forest Service's Southern Station, James L. Stewart,

---

[1/]Presented at the Symposium--Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests, Charlotte, NC, January 7-9, 1991.

[2/]Principal Soil Scientist (retired), Southern Forest Experiment Station, Forest Service, U.S. Department of Agriculture, Sewanee, TN, and Consultant--Forest Land Classification and Evaluation, Route 1, Box 541, Sewanee, TN 37375.

after it had been determined that development of a forest land classification system was feasible and of high priority, i.e., this author was not to initiate any new plot research, but rather was to base all efforts on personal experience, familiarity with the region, and existing information.

CONDITIONS AND RATIONALE

The Cumberland Plateau and Highland Rim physiographic provinces (fig 1) extend from central and eastern Kentucky and southwest Virginia through middle Tennessee and northwest Georgia into northern and central Alabama (Fenneman . The Plateau is bordered on the east by the Ridge and Valley province. The Highland Rim, called the Pennyroyal in Kentucky, lies west and north of the Cumberland Plateau, surrounds the Nashville Basin in Tennessee, and borders on the Bluegrass and Western Coalfields in Kentucky. On the west, both the Plateau and Rim border on the Upper Coastal Plain.

On the Plateau, soils are derived from thick, mostly horizontal strata of sandstones, siltstones, and shales. Topography, ranging from gentle to rugged and complex, is characterized by

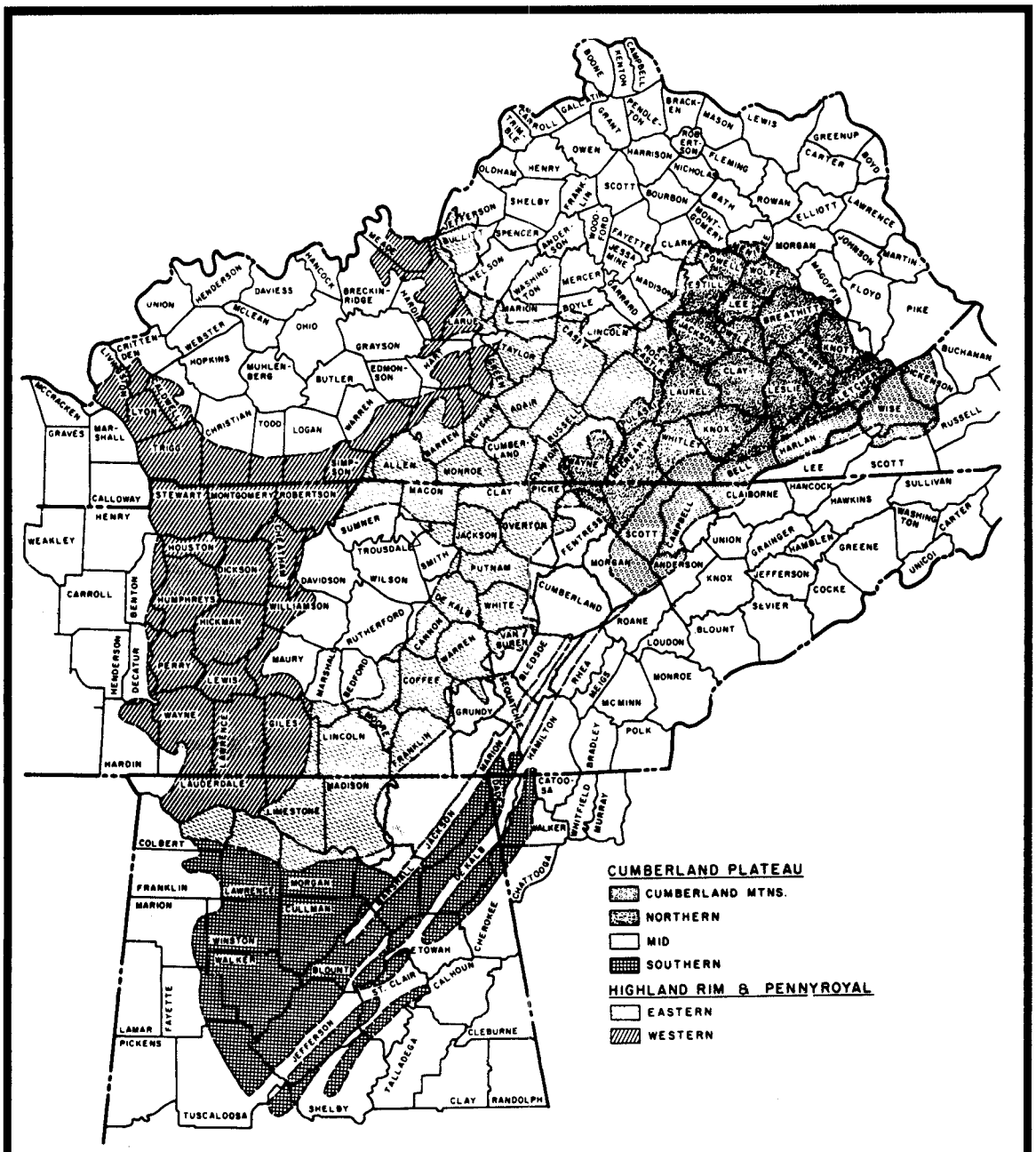


Figure 1. Physiographic provinces and regions of the Interior Uplands.

Ùdendritic drainage patterns with winding, narrow ridges and deep, narrow valleys. In places, the degree of dissection is weaker, and broader interfluves are common. The southern end of the Plateau in Alabama is also well dissected but is less rugged. The Plateau is bounded on the east and west by prominent sandstone escarpments. Elevation ranges from about 1,000 feet in the south to 3,000 feet in the Cumberland Mountains; a few peaks exceed 4,000 feet. Local relief ranges from 100 to 150 feet in the smoother places to 1,000 feet at the Plateau margins and to nearly 2,000 feet in the vicinity of the tallest mountains.

On the Rim, topography ranges from gentle to rugged and complex, and slope gradient ranges from nearly level to very steep. Degree of dissection ranges from young to mature; sinkholes are common in some areas. Elevation ranges from 800 to 1,100 feet over most of the Rim but diminishes to about 500 feet south of the Tennessee River in northern Alabama. Local relief ranges from 200 to 400 feet but is 50 feet or less in the smoothest parts.

Much of the Rim is covered with 2 to 4 feet of loess. Soils are derived from this loess and several strata of limestone of varying purity. Soils with fragipans are common on parts of the Rim. Along the boundary with the Upper Coastal Plain, soils are topographically stratified on the basis of parent material--loess; unconsolidated sands, gravels, and clays; and cherty limestone.

The Interior Uplands have a temperate climate characterized by long, moderately hot summers and short, mild to moderately cold winters. According to Thornthwaite's (1948) classification of climate, it is humid mesothermal. Daily and seasonal weather is controlled largely by alternating cold, dry continental air masses from Canada and warm, moist air from the Gulf of Mexico. During the summer, complete exchanges of air masses are few, and tropical maritime air masses persist for extended periods.

Mean temperature ranges from 55 to 61 °F. The frost-free period is 200 or more days in north-central Alabama and 160 to 180 days in the Cumberland Mountains and on the Northern Cumberland Plateau. Annual precipitation, ranging from 46 to 61 inches with a decreasing trend south to north, is ordinarily well distributed all year, but short periods of very wet or very dry weather are common. Precipitation is highest from December through March and lowest from August through October. Thunderstorms with high-intensity rainfall and occasional hail occur on more than 50 days each year, mostly in late spring and summer. Snowfall seldom exceeds 6 inches and melts in a few days; it is greater and persists for longer periods at the highest elevations.

The Interior Uplands encompass about 29 million acres, and over half is forest land. This area, like much of the eastern hardwood forest region, has a long history of indiscriminate cutting, burning, grazing, and clearing for agriculture. Parts of the Plateau and Rim have been cleared, farmed, and abandoned several times. Some abandoned land now supports forests over 100 years old. Much of the steeper land was never cleared, but it was logged, burned, and grazed. Also, the demise of American Chesnut has drastically altered forest composition and structure. Consequently, the existing forests are a mosaic of stand conditions, with seemingly fortuitous species composition. Productivity is far below potential because of poor stocking, an undesirable mix of species, and the presence of defective and low-vigor trees. Too few suitable stands exist to obtain a direct measure of site potential.

At the onset of this project, very little tree-soil-site information was available, and practically none of that was applicable to the Plateau and Rim. Available information was developed mostly by the factorial approach, which was not always successful. Often, sample selection and statistical manipulation were much less sound than they appeared to be. Also, products of these studies were graphs and equations, but the tools necessary for forest planning and management are maps and inventories.

Less than a quarter of the Plateau and Rim counties had had soil surveys published since 1967, and less than half of these surveys contained "Woodland Suitability" sections. Lack of communication between foresters and soil scientists has resulted in surveys that appeal to soil taxonomists but disappoint forest managers, who find little information or guidance on how to apply soil surveys to their specific and pragmatic goals for managing forest resources.

From a practical standpoint, there is little justification for making the usual medium-intensity soil survey (typical county survey) for most forest management activities associated with "regulated forests" (Stone 1975). Bartelli and DeMent (1970) concluded that low-intensity surveys would provide a reasonable balance between cost and value of the survey for forest management purposes. Boundaries of soil mapping units in low-intensity surveys more often coincide with natural features of the landscape.

Because soils are closely related to landforms and topography, a strong argument can be made for subdividing landscapes instead of mapping soils. Even where soils are to be identified and mapped, the mapping is more meaningful when done by landform. In rugged terrain, landforms may have as many, or even more, recognizable relationships with tree growth than do soil series. Landforms can be easily recognized by foresters and other potential users of land classification systems without formal training in soil science. Rowe (1984) has suggested "...that forest land managers need a scheme that sorts out the patterns of landscapes with which they deal. Climate, soil, vegetation, and landform are all important, but in themselves they are not enough. Forestland managers need defined terrain units or elements of land that comprise all four components in interaction. [Furthermore]...landforms are the spatial synthesizers of site components, and only in the context of landforms can forestland patterns make sense."

Commercial forest land in the five-state area is owned primarily by private individuals. Tract size varies as much as the occupations and/or interests of the owners. Land owned by forest industries and various Federal, State, and local government agencies represents only a small percentage of the total. Considerable acreage of the privately owned land receives no professional forestry input and qualifies as "unmanaged or exploited forests," but some can be classed as "regulated." Most of the forest industry acreage Ùcan be classed as "intensively managed or domesticated" (Stone 1975).

Thus, this author endeavored to devise a forest site classification system that was practical, relatively easy to use, flexible in application, and integrated--not a system consisting of a compilation of site components but rather one composed of discrete units of the landscape with reasonably homogeneous potential for growing trees and/or for management limitations and hazards. The system should be applicable to all sizes and classes of ownership. It should have a mapping capability, and the scale and detail of delineations should be appropriate to meet the management objectives of both "regulated" and "domesticated" forests. Lastly, the system should be hierarchical so the units can be aggregated or disaggregated to meet the needs of land managers as well as regional, State, national, or corporate planners and executives.

DESCRIPTION OF THE SYSTEM

This site classification system was adapted from Wertz and Arnold's (1975) Land System Inventory. The system can best be described as a process of successive stratifications of the landscape. Stratifications were based on the author's knowledge of the interactions and controlling influences of ecosystem components--physiography, climate, geology, soils, topography, and vegetation. Macroclimate does not vary much across both physiographic provinces, but microclimate does vary because of local relief. Vegetation was relegated to a position of minor importance because, generally, existing forests do not indicate site potential, and present stand boundaries may or may not coincide with site boundaries.

The five levels of this system (proceeding from the least detailed to the most detailed) are: physiographic province, region, subregion, landtype association, and landtype. Landtypes are visually identifiable areas that have resulted from similar climatic, geologic, and pedologic processes.

The Cumberland Plateau was divided into four regions--Cumberland Mountains and Northern, Mid- and Southern Plateau (fig.2 and table 1). The Highland Rim was divided into two regions--Eastern and Western. A guide for each of these six regions (Smalley 1979a, 1980, 1982, 1983, 1984b, 1986a) plus a combined edition (Smalley 1986b) have been

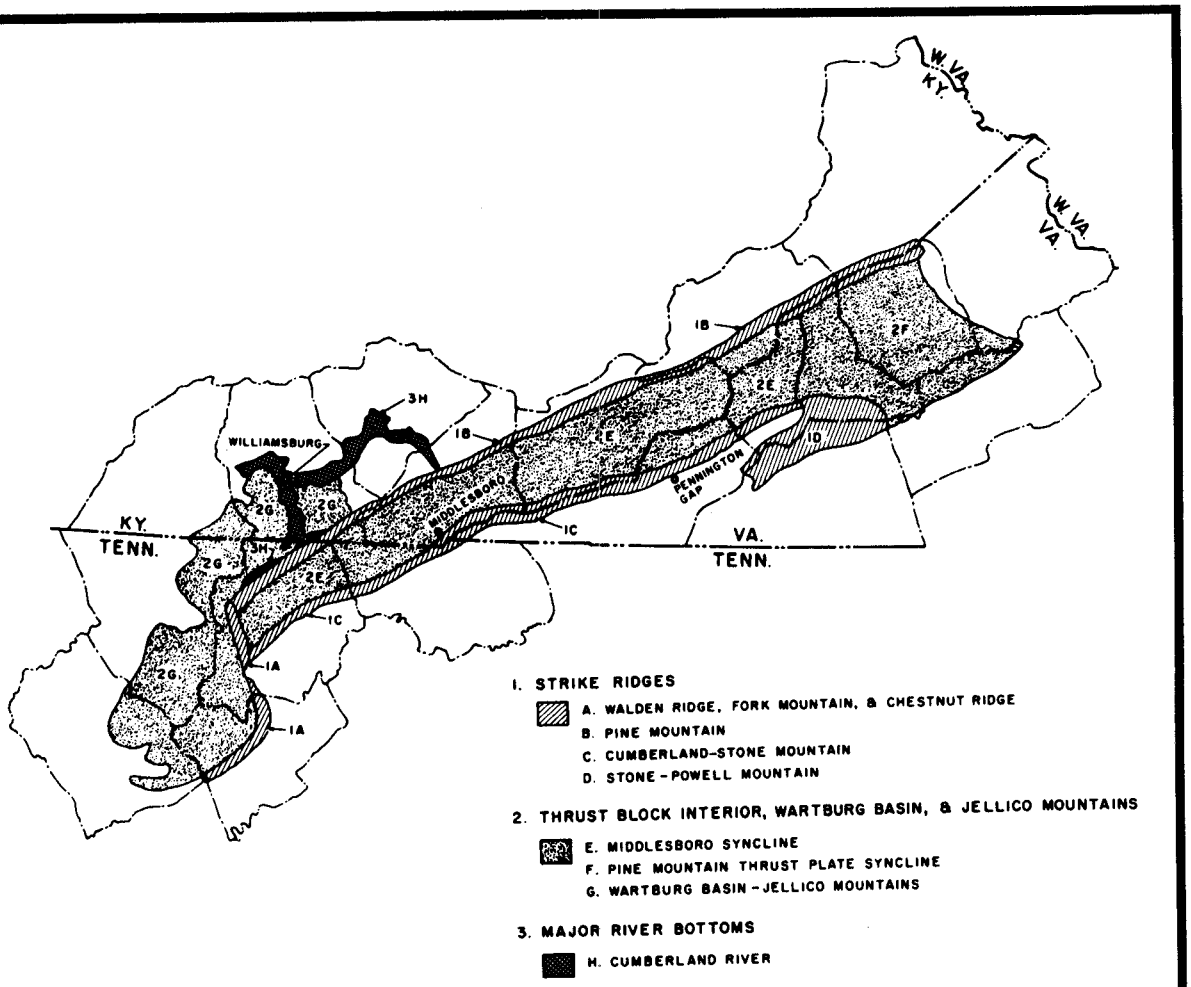


Figure 2.--Subregions and landtype associations of the Cumberland Mountains region.

Table 1.--Regions, subregions, and landtype associations of the Cumberland Plateau and Highland Rim/Pennyroyal.

Cumberland Plateau			Highland Rim/Pennyroyal		
Region	Subregion	Landtype association	Region	Subregion	Landtype association
Cumberland Mountains	1. Strike ridges	A. Walden Ridge, Fork Mountain, & Chestnut Ridge B. Pine Mountain C. Cumberland-Stone Mountain D. Stone-Powell Mountain	Eastern Highland Rim-Pennyroyal	1. Highland Rim Plateau	A. Strongly dissected plateau B. Moderate dissected plateau C. Weakly dissected plateau-gray soils (Barrens) D. Weakly dissected plateau-red soils
	2. Thrust block interior, Wartburg Basin, & Jellico Mountains	E. Middlesboro syncline F. Pine Mountain thrust plate syncline G. Wartburg Basin & Jellico Mountains		2. Highland Rim-Nashville Basin transition	E. Tennessee Knobs F. Outer Basin
	3. Major river bottoms	H. Cumberland River & major tributaries		3. Pennyroyal-Bluegrass transition	G. Western Kentucky Knobs H. Eastern Kentucky Knobs
Northern Cumberland Plateau	1. Mountains & coalfields	A. Rugged eastern area B. Low hills belt C. Western escarpment facing the Eastern Highland Rim/Pennyroyal D. Western escarpment facing the Bluegrass		4. Moulton Valley	I. Strongly dissected valley J. Weakly dissected valley-red soils K. Weakly dissected valley-brown soils
	2. Major river bottoms	E. Cumberland & Kentucky Rivers & major tributaries		5. Major river bottoms	L. Tennessee River M. Elk, Duck, & Cumberland Rivers N. Barren, Green, Rolling Fork, Salt, Kentucky, & Red Rivers
Mid-Cumberland Plateau	1. True plateau	A. Weakly dissected plateau surface B. Moderately dissected plateau surface C. Strongly dissected plateau surface D. Crab Orchard Mountains	Western Highland Rim-Pennyroyal	1. Highland Rim plateau	A. Strongly dissected plateau B. Moderately dissected plateau C. Weakly dissected plateau-gray soils D. Weakly dissected plateau-red soils
	2. Walden Ridge	A. Weakly dissected plateau surface B. Moderately dissected plateau surface C. Strongly dissected plateau surface		2. Highlnd Rim-Nashville Basin transition	E. Tennessee Knobs F. Outer Basin
	3. Strongly dissected southern portion	A. Weakly dissected plateau surface C. Strongly dissected plateau surface		3. Karst plain	G. Weakly dissected plain H. Moderately dissected plain I. Slump area
Couthern Cumberland Plateau	1. Table plateaus--Sand & Lookout Mountains	A. Weakly dissected plateau surface-sandstone B. Moderately dissected plateau surface-sandstone C. Strongly dissected plateau surface-sandstone		4. Major river bottoms	J. Tennessee River K. Buffalo River L. Cumberland, Harpeth, Duck, & Elk Rivers M. Green & Barren Rivers
	2. Moderately dissected plateau-Brindley & Little Mountains	A. Weakly dissected plateau surface-sandstone B. Moderately dissected plateau surface-sandstone C. Strongly dissected plateau surface-sandstone			
	3. Strongly dissected western portion	A. Weakly dissected plateau surface-sandstone B. Moderately dissected plateau surface-sandstone			
	4. Shale hills	C. Strongly dissected plateau surface-sandstone D. Moderately dissected plateau surface-shale E. Strongly dissected plaeau surface-shale			

published. Several published papers that describe the overall system and its use (Sims 1987; Smalley 1979b, 1984a, 1985, 1989) are available.

The division of the Cumberland Plateau into regions was mostly arbitrary except for the Cumberland Mountains, which are higher than the adjacent Cumberland Plateau and the Ridge and Valley physiographic provinces. The division of the Highland Rim follows the traditional partition made in Tennessee where the Nashville Basin nearly separates the Rim east and west at the Kentucky and Alabama boundaries. The east-west division extends into Kentucky on the basis of soil parent material--relatively high-grade limestone versus cherty and shaly limestones. In Alabama the division is arbitrary.

Subregions were defined mostly on the basis of well-recognized geographic, physiographic, or geologic areas (table 1). Upland landtype associations were defined mostly on the "degree of dissection" of the landscape and occasionally on broad soil groups. Landtype associations of major river bottoms reflect differences in mineralogy of the sediments. Landtype associations are equivalent to soil associations delineated at the state level by the Soil Conservation Service (SCS)

(Hajek, Gilbert, and Steers 1975; Perkins and Shaffer 1976; Soil Conservation Service 1975, 1979; Springer and Elder 1980.)

Landtype associations were divided into 193 landtypes--95 on the Plateau and 98 on the Rim. Some landtypes are common to more than one region, so the total number of distinct landtypes is probably about 150.

LANDTYPE DESCRIPTIONS

Each landtype is described in terms of nine elements. A sample description (Landtype 24 in the Cumberland Mountains) is shown in table 2. The GEOGRAPHIC SETTING provides an overall description of the landtype, specifying both where it occurs on the landscape and its relation to other landtypes.

The most prevalent soil series are listed under DOMINANT SOILS. These series reflect the most recent designations in soil classification and link this site classification system to county soil surveys published by SCS.

The kind of BEDROCK or PARENT MATERIAL of the soil and DEPTH TO BEDROCK are given next. TEXTURE of the surface soil is described in terms of the 12 conventional classes (Soil Survey Staff 1951).

Internal SOIL DRAINAGE is described in terms of the seven conventional classes (Soil Survey Staff 1951). RELATIVE SOIL WATER SUPPLY of each landtype is rated in five classes: very low, low, medium, high, and very high. This qualitative rating is based on the available water-holding capacity of the dominant soils, but allowances are made for the influence of soil drainage, topographic position, and aspect.

SOIL FERTILITY is described on the basis of seven classes: very low, low, moderately low, moderate, moderately high, high, and very high. Because most soils of the Plateau and Rim are fairly acid and derived from rocks having limited weatherable minerals, soils with high or very high fertility are not common.

The most common woody species in approximate order of abundance are listed under VEGETATION; some distinctive shrub and herbaceous species are included.

FOREST MANAGEMENT INTERPRETATIONS

In the regional guides opposite each landtype description is a table summarizing information on the PRODUCTIVITY of selected tree species, severity ratings for five MANAGEMENT PROBLEMS that can affect forest operations, and SPECIES DESIRABILITY ratings for timber production (e.g., table 3).

Productivity

Productivity of commercially valuable species is expressed as site index and as average annual cubic growth. With few exceptions, site indices for naturally occurring species are the means of values from soil survey interpretations issued by SCS for the dominant soils in each landtype. Curves for most species are based on 50 years, although

Table 2.--A sample landtype description. From Smalley 1984b

Description of Landtype 24: Colluvial mountain slopes, benches, and coves--north aspect

Geographic setting	Deep, loamy, often gravelly, cobbly, or stony soils on sloping to steep lower two-thirds to three-fourths of north slopes in Subregions 1 and 2. The linear to concave slopes range from 15 to 60 percent. Soils formed in loamy colluvium from acid siltstone, shale, and sandstone. Landtype 24 is more common in LTA's E and G than in LTA's D and F, and it occurs below Landtype 22 and above Landtypes 19 and 20. Surface mnes (Landtype 26) occur extensively in association with Landtype 24. In places, this landtype merges with major river bottoms (Landtypes 29 and 30).
Dominant Soils	Jefferson, Grimsley, Shelocta, and Rigley. Zenith and Cutshin occur at higher elevations (above 2,500 ft) on slopes and in coves, particularly in LTA's E and G. Often mapped as soil complexes.
Bedrock	Siltstone, shale, coal, and clay; possibly sandstone and conglomerate.
Depth to Bedrock	Forty to 120 inches or more.
Texture	Loam, fine sandy loan, and silt loam; occasionally sandy clay loam and clay loam. Rock fragment content varies considerably over short distances. Boulders and cobbles are common on the surface, particularly in coves.
Soil drainage	Well-drained.
Relative soil water supply	Medium to high.
Soil fertility	Moderate to moderately high.
Vegetation	Yellow-poplar, northern red oak, white oak, hickories, black oak, red maple, and American beech; occasional sugar maple, cucumbertree, yellow buckeye, eastern hemlock, eastern white pine, white ash, blackgum, white basswood, and black birch. Flowering dogwood, mountain-laurel, American hornbeam, vacciniums, grape, viburnums, hydrangea, alder, and smilax are common understory species.

Table 3.--A sample table of forest management interpretations. From Smalley 1984b

Forest management interpretations for Landtype 24: Colluvial mountain slopes, benches, and coves--north aspect

PRODUCTIVITY

Species	Site index (feet)	Average annual growth (cubic feet per acre)
E. White pine	85	145
Shortleaf pine	75	136
Virginia pine	75	120
White oak	75	57
N. red oak	80	62
Yellow-poplar	100	107

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate to severe	Slight to moderate	Moderate to severe	Moderate to severe	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. white pine	Hickories	E. hemlock
White oak	American beech	Black birch
N. red oak	Cucumbertree	American hornbeam
Black oak	Sugar maple	Serviceberry
Yellow-poplar	Yellow buckeye	Sumac
White ash	White basswood	Red maple
		Blackgum
		Flowering dogwood
		Sourwood

younger base ages are common for fast-growing species grown in short rotations. When site indices were available for one species, estimates for other species were sometimes made using site index comparisons. When necessary, SCS site index values were adjusted for aspect and slope position based on the author's experience and soil-site research. When available, site indices for a specific region or subregion were used instead of averages for the soil series. In a few cases, when no values were available, site indices of important species were estimated. In the tables, these estimated values are enclosed in parentheses.

Average annual cubic growth was calculated from available yield tables. Yield tables represent either normal or fully stocked conditions. Annual growth rates for all naturally occurring species or forest types were averaged over 50 years. Average annual growth for loblolly and shortleaf pine plantations was based on 40 years and for eastern white pine on 35 years, the oldest ages reported in the respective yield tables. Because yields are not expressed in a common merchantability standard, care must be exercised in comparing average annual yields of species, both within and between landtypes.

Management Problems

For the most part, the five management problems --PLANT COMPETITION, SEEDLING MORTALITY, EQUIPMENT LIMITATIONS, EROSION HAZARD, and WINDTHROW HAZARD--and ratings of slight, moderate, and severe follow SCS definitions (Soil Conservation Service 1987).

Species Desirability

Three categories are used to rate species desirability of tree species that commonly occur on each landtype. MOST DESIRABLE species are those that have the potential for fast growth or high value, or both. ACCEPTABLE species are those having moderate growth rate or value. LEAST DESIRABLE species are those having slow growth or low value, or both. These ratings represent the average situation of a region. The presence of local markets could result in a species being assigned to another category.

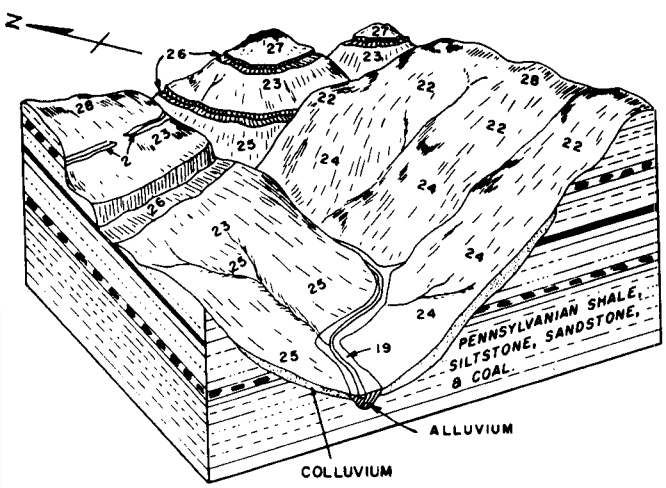
USING THE SYSTEM

The system is designed to allow resource professionals to make on-site determinations of site productivity and provides a site-dependent framework for forest management planning and forest research.

To make on-site determinations on a specific tract of land, users should trace the location of the tract through the classification hierarchy to the level of landtype association, verify the location on the reference map (fig. 2 in each regional guide), (e.g., fig. 2) and ascertain all possible landtypes by referring to the proper table (table 4 in each regional guide, except table 3 in the guide for the Southern Cumberland Plateau). Landscape descriptions (e.g., table 2) and landform drawings (e.g., fig. 3) enable users to identify specific landtypes. Most tracts smaller than 500 acres seldom contain as many as 12 landtypes. Once a landtype has been identified, users should refer to the accompanying table (e.g., table 3) to obtain information about productivity, severity of management problems, and species desirability.

A logical vehicle for converting this site classification system into a valuable forest management tool is a landtype map (fig. 4), which can be used in all phases of management, from day-to-day activities to long-range planning. The number and scale of maps will depend on size of ownership and how intensively one wishes to manage. Landtypes can be mapped at scales of 1:10,000 to 1:60,000, and at these scales, areas as small as 2.5 acres can be recognized on the larger scale maps. Smoothness of the terrain will determine maximum size. In the Interior Uplands, maximum size of landtypes probably will not exceed 50 acres. The U.S. Geological Survey 7.5-minute quadrangle sheets (1:24,000) make excellent base maps on which to delineate landtypes for "regulated" forests. Topographic base maps at a scale of 1:12,000 are more appropriate for "domesticated" forests. Black and white or color aerial photos, particularly stereopairs, can also serve as base maps. A reasonable amount of ground checking should be part of the mapping process. Owners of large tracts should explore the capabilities of mapping, storage, retrieval, and manipulation of this spatial information with a geographic information system.

This site classification system provides a sound ecological basis for forest management planning because it recognizes inherent site differences and soil-related hazards. When the system is



LEGEND

2. Shallow soils and sandstone outcrops
19. Mountain footslopes, fans, terraces, and streambottoms with good drainage.
22. Upper mountain slopes--north aspect.
23. Upper mountain slopes--south aspect.
24. Colluvial mountain slopes, benches, and coves-north aspect.
25. Colluvial mountain slopes, benches, and coves-south aspect.
26. Surface mines.
27. Narrow shale ridges, points, and convex upper slopes.
28. Broad shale ridges and convex upper slopes.

Figure 3.--Landtypes characteristic of Landtype Associations E (Middlesboro syncline) and G (Wartburg Basin-Jellico Mountains) in Subregion 2 of the Cumberland Mountains. From Smalley 1984b

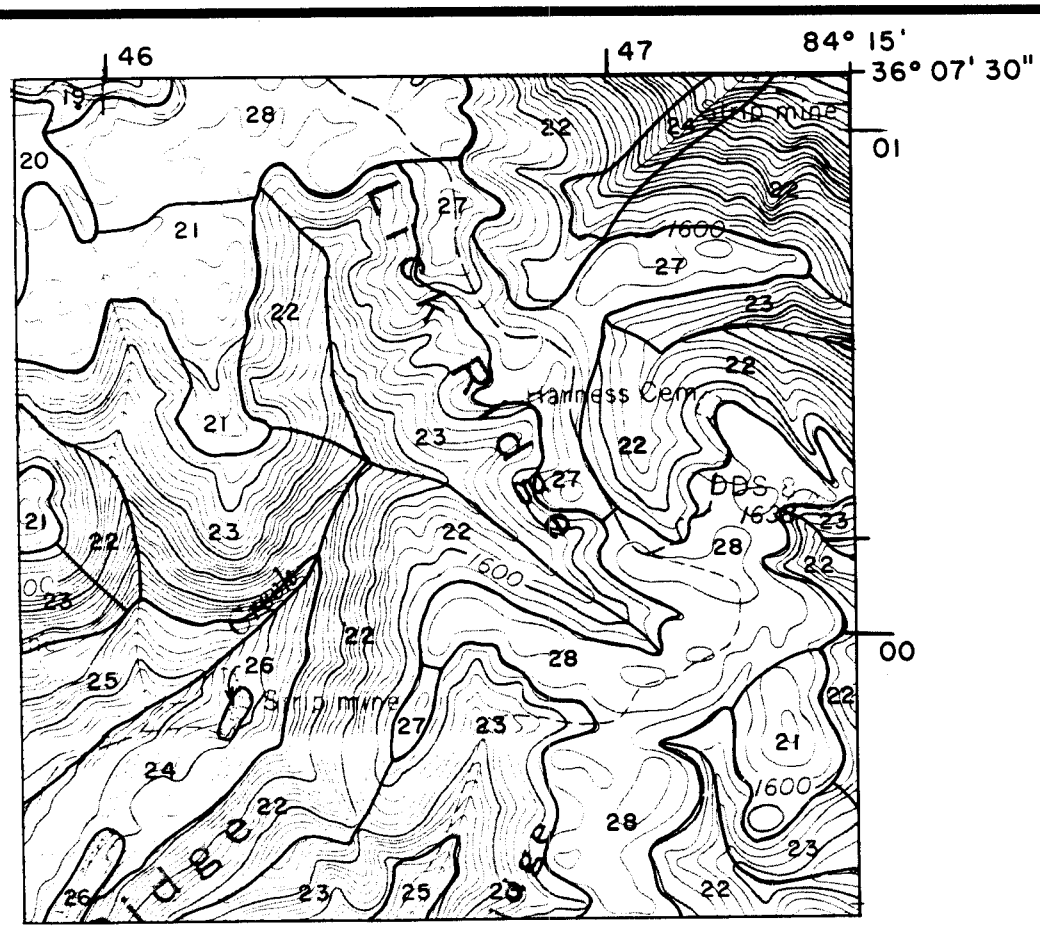


Figure 4.--A sample landtype map showing Landtype Association G (Wartburg Basin and Jellico Mountains) in Subregion 2 of the Cumberland Mountains. Map covers a tract of about 700 acres in the northeast corner of the northwest quarter of the Windrock Quadrangle, Anderson County, TN. The contour interval is 20 feet. Numbers refer to specific landtypes described in Smalley 1984b.

adopted, landtypes become the basic unit of land management rather than existing forest stands whose boundaries are, most likely, artifacts of past land use. Landtypes are landscape units having reasonable homogeneous site potential and a particular set of management constraints and problems. Once landtypes are defined and mapped, existing forest type and inventory information can be merged with the landtypes and forest planning begun. The actual conversion to a landtype system of management can be made gradual as each management unit (e.g., compartment) is entered in the normal sequence of forest operations.

Detailed descriptions of the physical characteristics of each unit of land aid land managers in divising management scenarios that will protect the soil and water, form the basis of silvicultural practices, and promote the maintenance of site productivity.

For forest researchers, this site classification system provides a basis for stratifying study areas (e.g., Cremeans and Kalisz 1988). The system also aids in identifying and isolating problems that need to be researched. Finally, the system provides researchers with a vehicle for quick transfer of research results to the practitioner. Results can be reported on the basis of their applicability to specific landtypes.

Development of the system is a continuing process. Additional research, experience in application, and feedback from users will result in revision of productivity data, refined landtype descriptions, improved interpretations for timber management, and extension of interpretations to other forest resources.

The next step is to study the relationships between plant communities and the landscape units on selected, minimally disturbed areas. The goal of such research is the capability of predicting which community(s) grow on each unit and to ascertain the successional pathways resulting from various disturbances.

APPLICATIONS AND PERIPHERAL STUDIES

This land classification system is gradually being accepted and applied as a basis for the management of timber and wildlife. Several studies have been completed that confirm the efficacy of the system as a sound ecological basis for forest management. Extension of the system to other physiographic provinces is contemplated.

The Tennessee Division of Forestry (TDF) uses the regional guides as a comprehensive training manual to orient new employees and is gradually adopting the system as a basis for the management of the State forests on the Plateau and Rim. The regional guides also provide important baseline information for use in advising and preparing management plans for nonindustrial private landowners. Over 150 public and industrial foresters have had on-the-ground training in the system.

For over a decade, the Tennessee Wildlife Resources Agency (TWRA), in cooperation with Tennessee Valley Authority and Forest Service, has been developing a land classification system for 150,000 acres of wildlife management areas (WMA) as part of a long-term wildlife-forest management program (Hughes 1987). If valid relationships between plant communities and landscape units can be found, TWRA can use the units as a faster, cheaper method to define and map habitat for many wildlife species. The alternative is costly inventories of vegetation on every acre.

Several studies have been conducted to determine these relationships. On the 20,000-acre Cheatham WMA on the Western Highland Rim west of Nashville, vegetation on each of six landtypes was significantly different from that on all other landtypes.[3/] The forest communities (landtypes) can be used in a geographic information system to model wildlife habitat, assess site productivity, and extrapolate from one location to another with similar landtypes and history.

Wheat and Dimmick (1987) studied plant community-landform relationships on two other Western Highland Rim tracts. Three ridge landtypes supported similar communities, and distinctive communities existed on cherty north slopes, cherty south slopes, and in streambottoms having good drainage.

Plant community-landform relationships have also been studied on the 26,000-acre Prentis Cooper State Forest and Wildlife Management Area on the south end of Walden Ridge (Mid-Cumberland Plateau) west of Chattanooga (Arnold 1990). Discriminant analysis of 138 plots located on four extensive landtypes revealed that landtypes had relatively distinct forest cover. Contrariwise, cluster analysis revealed common communities on most landtypes.

During the last periodic survey of forest land in Tennessee by Forest Service's Southern Forest Experiment Station, each survey point on the Mid-Cumberland Plateau was classified as to landtype. Forest type, stand volume, site index, and other stand data were analyzed by landtype in an effort to substantiate the productivity values and description of overstory vegetation on Mid-Plateau landtypes (Rennie 1991).

An intensive study of the soils and vegetation on three major landtypes on the Mid-Cumberland Plateau near Crossville, TN, has been completed (Hammer 1986). Landtypes significantly affected magnitudes of temporal and spatial soil variability (Hammer, O'Brien, and Lewis 1987). The morphological features of soils, when precisely described and interpreted with respect to landtypes, are indicators of patterns of movement and relative amounts of available soil moisture and can be a valuable aid in predicting potential site productivity for Mid-Plateau forest soils. The forest land classification system is apparently a valuable method of grouping Mid-Plateau forest soils into landform units having relatively homogeneous chemical and physical properties.

In Kentucky and Tennessee, WESTVACO is in the process of adapting the land classification system to their Highland Rim lands and expanding the concept to lands in the Upper Coastal Plain. In West Virginia, WESTVACO researchers are developing a similar land classification system for their

---

[3/]Clatterbuck, W.K. 1988. Classification and analysis of forest plant communities on Cheatham Wildlife Management Area in north-central Tennessee. Report submitted to Tennessee Wildlife Resources Agency. Nashville, TN; 110 pp.

Allegheny Plateau and Ridge and Valley woodlands. Evaluations will incorporate existing forest inventory data plus ratings for logging and other intensive forest management activities.

Smalley [4/] has recently completed a land classification of the 45,000-acre Natchez Trace State Forest, State Resort Park, and Wildlife Management Area (NTSF) on the Upper Coastal Plain in west Tennessee for TDF and TWRA. The forest plan for NTSF was roundly criticized by a wide variety of publics. The land classification was developed to form a sound ecological basis on which to revise the plan and eventually to manage the resources of NTSF. Landtype mapping was completed in 1990. The Laurel Hill WMA on the Western Highland Rim in south-central Tennessee is currently being mapped.

For too many years, forest land management decisions have been made without knowledge of the productive capacity and management restrictions of the land. One does not have to look far to see mistakes resulting from this lack of information. With the application of this system, sounder management decisions can be made for forests of the Cumberland Plateau and Highland Rim/Pennyroyal.

LITERATURE CITED

Arnold, David H. 1990. Distinctness of forest communities within landtypes on the Prentice Cooper State Forest, Marion County, TN. 130 pp. Thesis

Bartelli, L.J.; DeMent, J.A. 1970. Soil survey--a guide for forest management decisions in the Southern Appalachians. In: Youngberg, C.T.; Davey, C.B., eds. Tree growth and forest soils. Proceedings, third North American forest soils conference; 1968 August; Raleigh, NC. Corvallis, OR: Oregon State University Press. pp. 427-434.

Cremeans, D.W.; Kalisz, P.J. 1988. Distribution and characteristics of windthrow microtopography on the Cumberland Plateau of Kentucky. Soil Science Society of America Journal 52(3): 816-821.

Fenneman, Nevin M. 1938. Physiography of eastern United States. New York: McGraw-Hill Book Co., Inc. 714 pp.

Hajek, B.F.; Gilbert, F.L.; Steers, C.A. 1975. Soil associations of Alabama. Agronomy and Soils Departmental Series 24. Auburn, AL: Auburn University, Alabama Agricultural Experiment Station and U.S. Department of Agriculture, Soil Conservation Service. 30 pp + map.

[4/]Smalley, Glendon W. Classification and evaluation of forest sites on the Natchez Trace State Forest, State Resort Park, and Wildlife Management Area in West Tennessee.

Hammer, Richard D. 1986. Soil morphology, soil water, and forest tree growth on three Cumberland Plateau landtypes. Knoxville, TN: University of Tennessee. 2 vol. 319 pp. Dissertation.

Hammer, R. David; O'Brien, Ralph G.; Lewis, Russell J. 1987. Temporal and spatial soil variability on three forested landtypes on the Mid-Cumberland Plateau. Soil Science Society of America Journal 51(5): 1320-1326.

Hughes, Thomas, W. 1987. The Tennessee Wildlife Resources Agency wildlife-forest management program. In: Hay, Ronald L.; Woods, Frank W.; DeSelm, H., eds. Proceedings, sixth central hardwood forest conference; 1987 February 24-26; Knoxville, TN. Knoxville, TN: University of Tennessee. pp. 517-518.

Perkins, H.F.; Shaffer, M.E. 1976. Soil associations and land use potential of Georgia soils (map 1:750,000). Athens, GA: Georgia Agricultural Experiment Station and U.S. Department of Agriculture, Soil Conservation Service.

Pierpoint, Geoffrey, 1984. Forest land classification - rationale and overview. In: Bockheim, J.G., ed. Forest land classification: experience, problems, perspectives. Proceedings of a symposium; 1984 March 18-20; Madison, WI. Madison, WI: University of Wisconsin. pp. 6-10.

Rennie, John C. 1991. Use of land classification of the Cumberland Plateau. In this proceedings.

Rowe, J. Stan. 1984. Forestland classification: limitations of the use of vegetation. In: Bockheim, J.G. ed. Forest land classification: experience, problems, perspectives. Proceedings of a symposium; 1984 March 18-20; Madison, WI; Madison, WI. University of Wisconsin. pp. 132-147.

Sims, Daniel H. 1987. How to classify upland forest sites. Forest Farmer 46(3): 8-9.

Smalley, Glendon W. 1979a. Classification and evaluation of forest sites for timber production: Introduction of the new system for classifying forest sites based on the physical features of the landscape. In: Forest Soils and Site Quality Workshop; 1979 May 8-9; Auburn, AL. Auburn, AL: Auburn University. pp 28-47.

Smalley, Glendon W. 1979b. Classification and evaluation of forest sites on the southern Cumberland Plateau. Gen. Tech. Rep. SO-23. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 59 pp.

Smalley, Glendon W. 1980. Classification and evaluation of forest sites on the western Highland Rim and Pennyroyal. Gen. Tech. Rep. SO-30. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 120 pp.

Smalley, Glendon W. 1982. Classification and evaluation of forest sites on the Mid-Cumberland Plateau. Gen. Tech. Rep. SO-38. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 58 pp.

Smalley, Glendon W. 1983. Classification and evaluation of forest sites on the eastern Highland Rim and Pennyroyal. Gen. Tech. Rep. SO-43. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 123 pp.

Smalley, Glendon W. 1984a. Landforms: a practical basis for classifying forest sites in the Interior Uplands. In: Proceedings, 12th annual hardwood symposium; 1984 May 8-11; Cashiers, NC. Asheville, NC: Hardwood Research Council, pp. 92-112.

Smalley, Glendon W. 1984b. Classification and evaluation of forest sites in the Cumberland Mountains. Gen. Tech. Rep. SO-50. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 84 pp.

Smalley, Glendon W. 1985. Landforms: the basis for classifying and evaluating forest sites in the Interior Uplands of the eastern United States. In: Proceedings, IUFRO workshop working party S1.02.06: Forest site classification methods; 1985 October 7-10; Fredericton, New Brunswick, Canada: IUFRO. pp. 114-142.

Smalley, Glendon W. 1986a. Classification and evaluation of forest sites on the northern Cumberland Plateau. Gen. Tech. Rep. SO-60. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 74 pp.

Smalley, Glendon W. 1986b. Site classification and evaluation for the Interior Uplands: forest sites of the Cumberland Plateau and Highland Rim/Pennyroyal. Tech. Publ. R8-TP9. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region. 518 pp.

Smalley, Glendon W. 1989. Site classification and evaluation for the Interior Uplands. In: Clark, F. Bryan, tech. ed.; Hutchinson, Jay G., ed. Central Hardwood Notes, Chapter 4.03. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 5 pp.

Soil Conservation Service. 1975. General soil map, Kentucky (1:750,000). Washington, DC: U.S. Department of Agriculture. In cooperation with: Kentucky Agricultural Experiment Station and Division of Conservation, Department of Natural Resources and Environmental Protection.

Soil Conservation Service. 1979. General soil map, Virginia (1:750,000). Washington, DC: U.S. Department of Agriculture. In cooperation with: Virginia Polytechnic Institute and State University.

Soil Conservation Service. 1987. National forestry manual, subsection 537.11, amendment 4. Washington, DC: U.S. Department of Agriculture.

Soil Survey Staff. 1951. Soil survey manual. Agric. Handb. 188. Washington, DC: U.S. Department of Agriculture. 503 pp.

Springer, M.E.; Elder, J.A. 1980. Soils of Tennessee. Stn. Bull. 596. Knoxville, TN: University of Tennessee Agricultural Experiment Station. 66 pp. + map.

Stone, E.L. 1975. Soil and man's use of forest land. In: Bernier, G.; Winget, C.H., eds. Forest soils and forest land management. Proceedings, fourth North American forest soils conference; 1973 August; Quebec,Canada. Quebec, Canada: les Presses de l'Universite Laval. pp. 1-9.

Thornthwaite, C.W. 1948. An approach toward a rational classification of climate. Geographical Review 38(1):55-94.

Wertz, W.A.; Arnold, J.F. 1975. Land stratification for land-use planning. In: Bernier, G.; Winget, C.H., eds. Forest soils and forest land management. Proceedings, fourth North American forest soils conference; 1973 August; Quebec, Canada. Quebec, Canada: les Presses de l'Universite Laval. pp. 617-629.

Wheat, Robert M., Jr.; Dimmick, Ralph W. 1987. Forest communities and their relationships with landtypes on the western Highland Rim of Tennessee. In: Hay, R.L.; Woods, F.W.; DeSelm, H., eds. Proceedings, sixth central hardwood forest conference; 1987 February 24-26; Knoxville, TN. Knoxville, TN: University of Tennessee. pp. 377-383.

LANDSCAPE ECOSYSTEM CLASSIFICATION FOR SOUTH CAROLINA[1]

Steven M. Jones[2]

Abstract.--Effective and efficient land resource management is dependent upon accurate estimation of site productivity and identification of sites that respond similarly to management practices. The landscape ecosystem classification approach relies on relatively undisturbed vegetation in place of traditional site indices to classify lands into units that are productive equivalents. Variation in landform and soils are then related to the classification units identified by the vegetation. Once the land classification model is developed, classification units can be identified and interpretations made based on landform and soil information. In South Carolina, landscape ecosystem classification models have been developed for lands in the Piedmont and upper coastal plain.

Keywords: landform, soils, vegetation, productive potential, GIS.

INTRODUCTION

The purpose of ecological land classification is to identify units of land distributed across the landscape that are similar relative to type, structure, and productivity of vegetation. Within a classification unit, the similar parcels of land are assumed to be ecological equivalents and have been traditionally referred to as "site types." Historically, productivity of forest site types has been defined in terms of site quality as indicated by the maximum timber crop the land can produce in a given time (Daniel and others 1979). Site index estimates represent an attempt to quantify forest land productivity. It has become so established in our routine for so long that we tend to forget that there is a probability of misclassification associated with the estimate. The shortcomings of using site index as an estimator of site quality are presented at length by Van Lear (1991) and Lloyd (1991) in this proceedings and by Monserud (1984).

The esoteric nature of a classification based on the single land value of timber production has not been of particular concern to forest resource managers of past decades. Obviously, in most situations the value of greatest interest continues to be timber; however, with greater frequency across the south, forest land managers are finding themselves in situations where they must make value judgements for natural resources other than timber. Today's forester is managing lands that society views as a source of quality water, wetland habitats, endangered species habitat, endangered plant communities, wildlife game species, and diversity of landscapes and species.

No single classification can be all things to all people; however, an ecologically based land classification not driven by a single value can be interpreted for many different values.

CLASSIFICATION CONCEPTS

Plants, through their failure or success of establishing viable populations, can be considered as integraters of all possible combinations of environmental factors.

In the absence of disturbance, the distribution of individual species in competition with their associates is a function of environmental conditions. Those species which have a narrow ecological amplitude are considered "diagnostic" and are indicative of their associated environmental conditions. Species with a broad ecological amplitude are considered as "constant" species and are not indicative of a certain set of

[1]Presented at the Ecological Land Classification Symposium, Charlotte, NC, January 7-9, 1991.

[2]Assistant Professor, Department of Forest Resources, Clemson University, Clemson, SC 29634-1003.

environmental conditions (Mueller-Dombois and Ellenberg 1974). Species with similar environmental requirements have overlapping distributions and form associations (Figure 1). It is these associations of diagnostic species under undisturbed conditions that are used in the "site indicator" sense. The presence and absence of diagnostic species are used in place of timber productivity (site index) as a means of determining which land units are equivalent in terms of potential biological productivity.

Under relatively undisturbed, near steady-state or steady-state conditions, the associations of diagnostic species (vegetation types) are related to landform and soils. Landform factors may include slope gradient, slope position, aspect, and slope shape, while the soil component may include drainage, chemistry, and physical properties, such as depth of clay, amount of clay, or thickness of sandy epipedon. Because the interrelationships of vegetation, landform, and soil are known, the resulting land classification is ecologically based. Approaches which overlay single factor classifications to produce a component classifica-tion of climate, soil, landform, and vegetation have been developed and are in use but are not necessarily ecological (Rowe 1978).

This approach for South Carolina parallels the work of Barnes in Michigan (Barnes and others 1982). The Michigan approach developed the terminology of "landscape ecosystem classification" which has been adopted for South Carolina. Landscape ecosystem classification (LEC) expresses the interrelationships (1) between vegetation and landform, (2) between vegetation and soils, and (3) between landform and soils. The term "landscape" is used as a modifier to emphasize that ecosystems are geographic units extending horizontally over the land (Barnes 1989). Landform is the key component because it is permanent and relatively easy to recognize. Soil information is used to refine the classification, while vegetation is used as a check-and-balance.

The approach is hierarchical and adopts the regional classification of South Carolina by Myers and others (1986) for the upper levels of the hierarchy. Broad units were defined from differences in geologic material, topography, soils, and climate which results in variations in species distributions. Within this regional classification, South Carolina is delineated into seven major provinces (Figure 2), 14 regions, and 15 subregions; a total of 23 map units:

Figure 1.--Gaussian species distributions along an environmental gradient interpreted from the first axis of a detrended correspondence analysis. The data are taken from relatively undisturbed, late successional upland, blackwater river and redwater river sites on the Savannah River Site, South Carolina. Species are, by number, (1) bald cypress, (2) water tupelo, (3) lizard's tail, (4) laurel oak, (5) swamp gum, (6) yellow-poplar, (7) dog-hobble, (8) climbing hydrangea, (9) chain fern, (10) red bay, (11) water/laurel oak, (12) dogwood, (13) white oak, (14) black oak, (15) pipsissewa, (16) sand hickory, (17) post oak, (18) deerberry, (19) blackjack oak, (20) broomsedge, (21) dwarf huckleberry, (22) turkey oak, (23) goat's rue.

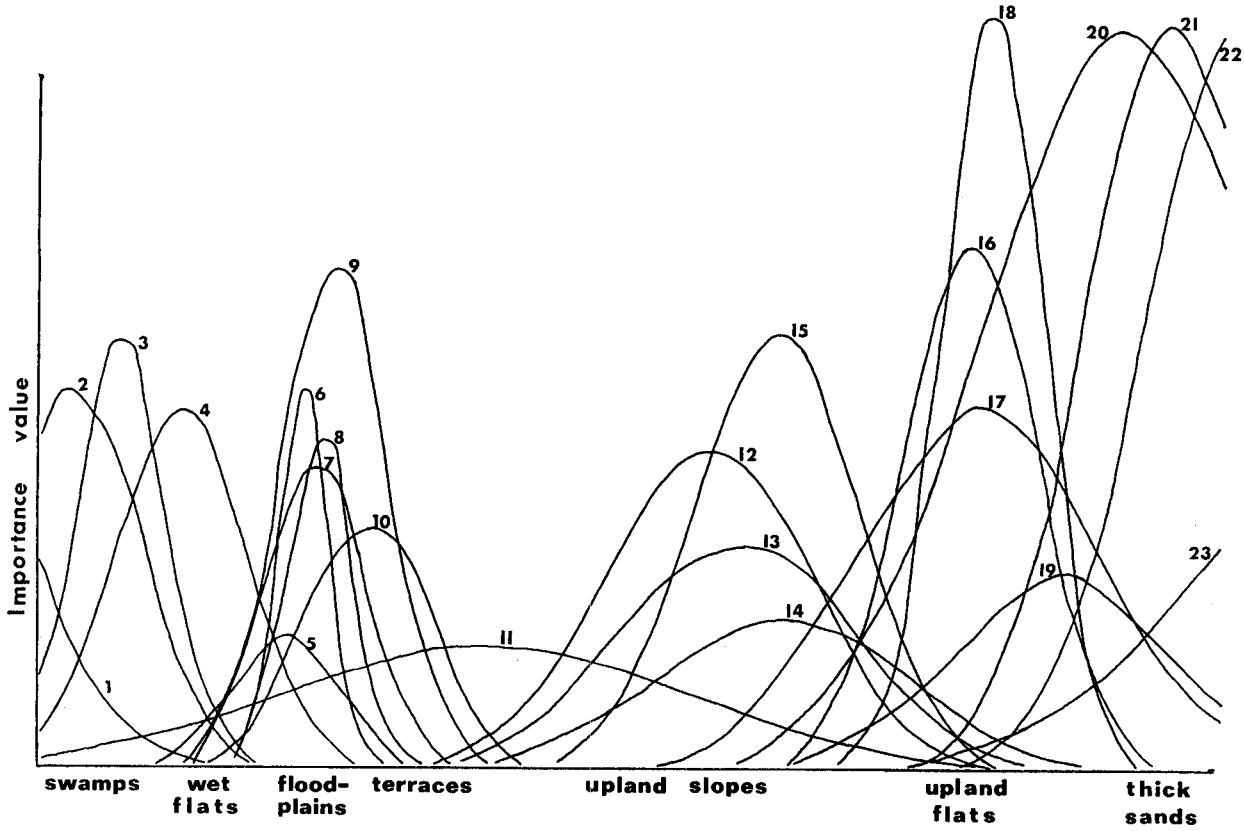
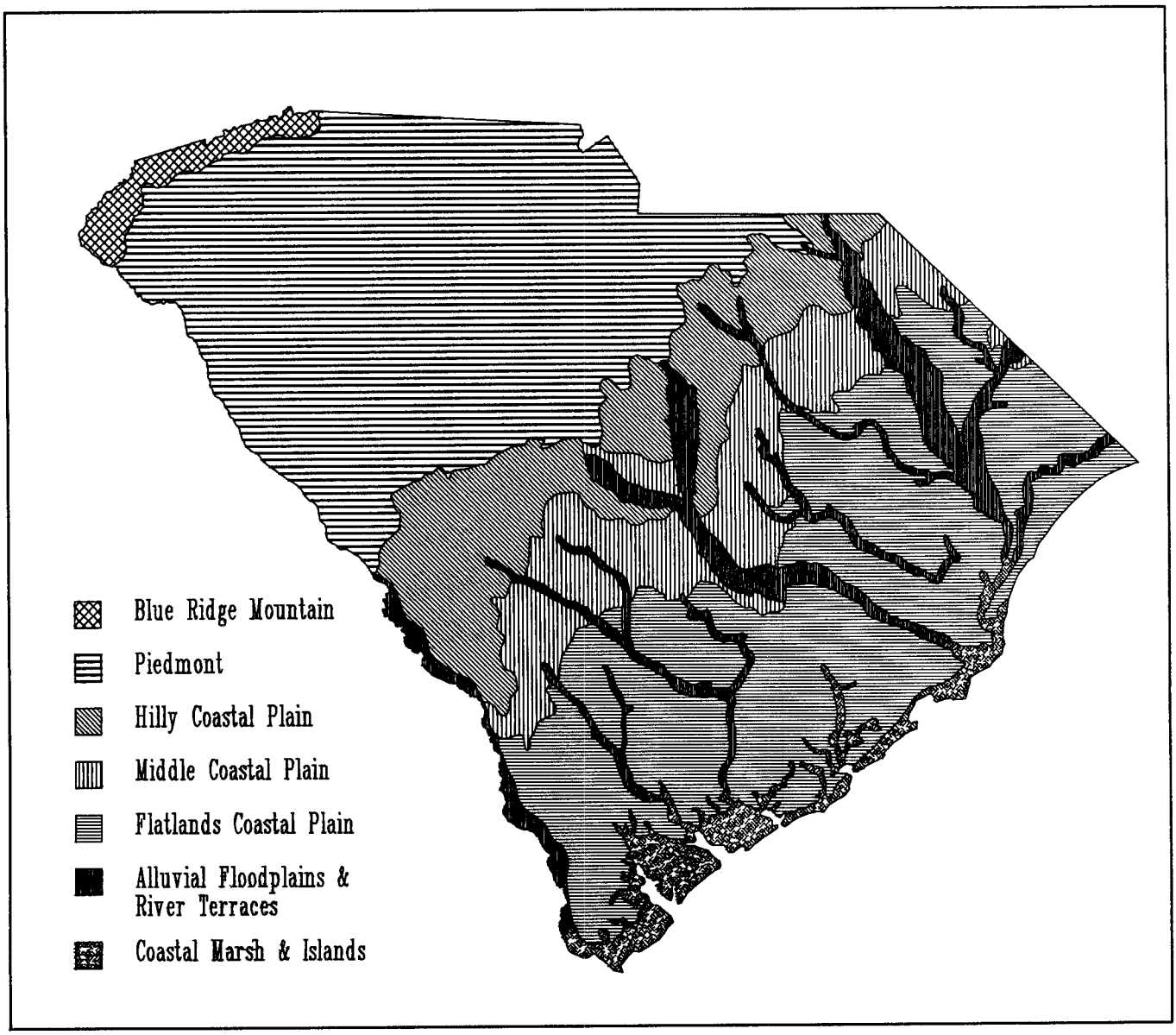


Figure 2.--Physiographic provinces of South Carolina (Myers and others 1986).



Blue Ridge Mountain Province
- Blue Ridge Mountain Region
- Chauga Ridges Region

Piedmont Province
- Piedmont Foothills Region
  - Subregion: Upper Foothills
    Lower Foothills
- Midlands Plateau Region
  - Subregion: Interior Plateau
    Charlotte Belt
    Carolina Slate Belt
    Southern Piedmont Hills
- Kings Mountain Region

Hilly Coastal Plain Province
- Sandhills Region
- Upper Loam Hills Region
  - Subregion: Upper Loam Hills-gentle relief
    Upper Loam Hills-moderate relief
- Redhills Region

Middle Coastal Plain Province
- Southwestern Loam Hills Region
  - Subregion: Southwestern Loam Hills
    Clay Hills
- Northeastern Loam Plains Region

Flatlands Coastal Plain Province
Coastal Flatwoods Region
Subregion: Upper Terraces
Lower Terraces

Alluvial Floodplains and River Terraces Province
Redwater River Floodplains and Terraces Region
Subregion: Alluvial Floodplains
River Terraces
Blackwater River Floodplains Region

Coastal Marsh and Islands Province
Coastal Marsh and Islands Region

Since the vegetation, soil, and landform relationships vary by region, it is necessary to develop a separate landscape ecosystem classification for each region. For some situations, it may be necessary to modify the regional classification to accommodate differences at the subregional level. Each landscape ecosystem model further classifies lands into landform associations and site units. The landform association expresses differences in parent material, topography, and relief. Within each landform association, the site units are identified on the basis of soil physical properties or micro-relief, such as aspect, slope position, slope gradient, or slope shape. The site unit is the level where individual stand management considerations are made.

METHODS

The landscape ecosystem classification approach has been applied within two physiographic provinces of South Carolina. These are the Upper Loam Hills Region and Sandhills Region of the Hilly Coastal Plain Province and the Midlands Plateau Region of the Piedmont Province (Myers and others 1986). Forest stands across the range of upland and bottomland site conditions were sampled within the Hilly Coastal Plain Province. Within the Piedmont Province only the range of upland conditions were sampled. Within the Midlands Plateau Region of the Piedmont Province, the landscape ecosystem modelling was restricted to lands on gneiss-schist derived parent materials. These lands occur primarily within the Interior Plateau and Charlotte Belt subregions. Landscapes associated with Carolina slate are currently under study, and plans are underway to initiate a study on gabbro-diabase derived soils in the near future.

Within both study areas, relatively undisturbed, steady state or near steady state stands were sampled to identify the interrelationships of vegetation with soil and landform variables. Forest stands representing major successional and disturbance conditions, including plantations, were sampled across the range of site conditions. Approximately 350 stands were sampled in developing and verifying the models.

Sampling on 0.1 acre plots included quantitative vegetation measurements of all strata, correlation of soils, description of soil morphology, particle size distribution (in the Piedmont), slope position, aspect, and landform type. Data were analyzed and vegetative classifications developed through multivariate analysis techniques (ordination and cluster analysis). Soil and landform data were related to the vegetative classifications through informal, visual or empirical recognition of pattern in variables and through discriminant analysis procedures. Species associations that are characteristic of a certain set of environmental conditions (diagnostic species) were identified through synthesis table construction. Plot design, measurements, and analytic procedures have been described in detail elsewhere (Jones and others 1984; Jones 1988a and 1988b).

RESULTS

Hilly Coastal Plain

Within the Hilly Coastal Plain Province, seven late successional, hardwood forest types were identified. An association of diagnostic species was described for each hardwood forest type. The distribution of selected diagnostic species for the well drained uplands is given in Table 1. With respect to the four vegetation associations within the uplands landform association, thickness of the sandy epipedon was the major discriminating soil variable. Internal drainage was the major discriminating variable in relation to the three vegetation associations within the alluvial floodplains. Each of the seven site units corresponded with a unique combination of major landform type and soil characteristics which determine the nature of the late successional, hardwood vegetation (Figure 3).

In the absence of vegetation or under disturbed conditions, the site unit can be determined in the uplands by the thickness of the sandy epipedon and in the blackwater alluvial floodplains by the degree of gleying:

I. Upland landform association.
   A. Sandy epipedon >80 inches thick.
      Xeric Site Unit
   B. Sandy epipedon 40-80 inches thick.
      Subxeric Site Unit
   C. Sandy epipedon 20-40 inches thick.
      Submesic Site Unit
   D. Sandy epipedon <20 inches thick.
      Mesic Site Unit
II. Blackwater alluvial floodplain landform association.
   A. Thin, black surfaces.
      1. Gray subsoils at a depth greater than 40 inches or gray mottles at a depth greater than 20 inches.
         Well Drained Site Unit
      2. Underlain with subsoils that are gray throughout.
         Poorly Drained Site Unit

Table 1.--Distribution of selected diagnostic species by site unit for well drained uplands within the Upper Loam Hills, Moderate Relief Subregion of the Hilly Coastal Plain Province

Species	Site Unit			
	Xeric	Subxeric	Submesic	Mesic
Aristida stricta	XXXXXXXXXXXXXXXX			
Gaylussacia dumosa	XXXXXXXXXXXXXXXX			
Quercus laevis	XXXXXXXXXXXXXXXX			
Tephrosia virginia	XXXXXXXXXXXXXXXXXXXXXXXX			
Quercus margaretta		XXXXXXXXXXXXXXXXXXXXXX		
Quercus incana		XXXXXXXXXXXXXXXXXXXXXX		
Quercus marilandica			XXXXXXXX	
Quercus stellata				XXXXXXXX
Quercus alba				XXXXXXXX
Cornus florida				XXXXXXXX
Chimaphila maculata				XXXXXXXX

Detailed descriptions of the vegetation for each site unit are published elsewhere (Jones and others 1981; Jones and others 1984; and Van Lear and Jones 1987).

For each site unit, the vegetative associations of successional or management forests were also described. These are forests with artificially or naturally established overstories. A particular site unit may have more than one management/successional vegetation type associated with it:

Site Unit	Management/Successional Type
B. Thick, black surfaces; underlain with subsoils that are gray throughout.	
3. Very Poorly Drained Site Unit	
Xeric	Longleaf Pine-Turkey Oak-Wiregrasss Longleaf Pine-Turkey Oak-Bracken Fern
Subxeric	Longleaf Pine-Moneywort Longleaf Pine-Sassafras Longleaf Pine-Blackgum-Sand Hickory
Submesic	Loblolly Pine-Black Cherry-Honeysuckle Slash Pine-Black Cherry-Water Oak Slash Pine-Sassafras-Dollarleaf Slash Pine-Blackgum Southern Red Oak-Hickory
(tentative)	
Mesic	Loblolly Pine-Sweetgum-Broomsedge Sweetgum-Water Oak Southern Red Oak-Hickory
Well Drained	Loblolly Pine-Sweetgum-Redbay
Poorly Drained	Loblolly Pine-Redbay-Cane (tentative)
Very Poorly Drained	Loblolly Pine-Swamp Gum-Naked Witherod

Piedmont Province

The upland, hardwood forest stands representing steady state, undisturbed conditions were classified into five forest types, and the associated diagnostic species were identified (Table 2). The five vegetative associations occurred across a range of site conditions extending from xeric upland flats and upper slopes to mesic lower slopes. Thus, the endpoints of an environmental gradient were defined by extremes in landscape position (Figure 4). Detailed descriptions are published elsewhere (Jones 1988a; Jones 1988b). To date, work in the Piedmont bottomlands has not been initiated.

Figure 3.--Landscape ecosystem classification model for the Hilly Coastal Plain Province, South Carolina.

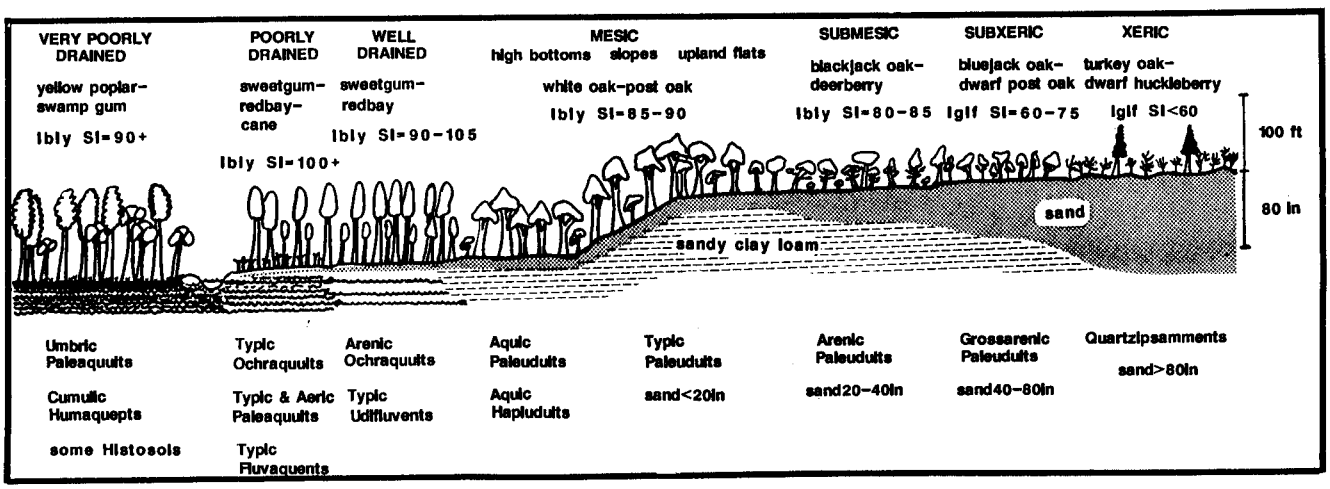


Table 2.--Distribution of selected character species by site unit for the Midlands Plateau Region of the Piedmont Province. Numbers 1, 2, and 3 following the names of woody species represent tree, sapling, and seedling size classes, respectively

Species	Site Unit				
	Mesic	Submesic	Inter.	Subxeric	Xeric
Tiarella cordifolia	XXXXXXXX				
Anemonella thalictroides	XXXXXXXX				
Fagus grandifolia 1	XXXXXXXX				
Asimina triloba 2	XXXXXXXX				
Thelypteris hexagonoptera	XXXXXXXX				
Hepatica acutiloba	XXXXXXXX				
Polystichum acrostichoides	XXXXXXXXXXXXXXXX				
Cercis canadensis 2 & 3	XXXXXXXXXXXXXXXX				
Sanguinaria canadensis	XXXXXXXXXXXXXXXX				
Cimicifuga/Ligusticum		XXXXXXXX			
Geranium maculatum		XXXXXXXX			
Rhus radicans	XXXXXXXXXXXXXXXXXXXXXXXX				
Desmodium nudiflorum	XXXXXXXXXXXXXXXXXXXXXXXX				
Quercus rubra 1	XXXXXXXXXXXXXXXXXXXXXXXX				
Calycanthus floridus 2 & 3	XXXXXXXXXXXXXXXXXXXXXXXX				
Smilacina racemosa	XXXXXXXXXXXXXXXXXXXXXXXX				
Fraxinus americana 2	XXXXXXXXXXXXXXXXXXXXXXXX				
Aristolochia serpentaria		XXXXXXXXXXXXXXXX			
Polygonatum biflorum		XXXXXXXXXXXXXXXX			
Viola hastata		XXXXXXXXXXXXXXXX			
Quercus velutina 1			XXXXXXXXXXXXXXXXXXXXXXXX		
Quercus coccinea 1			XXXXXXXXXXXXXXXXXXXXXXXX		
Vaccinium stamineum				XXXXXXXX	
Quercus stellata 1					XXXXXXXX
Vaccinium vacillans					XXXXXXXX

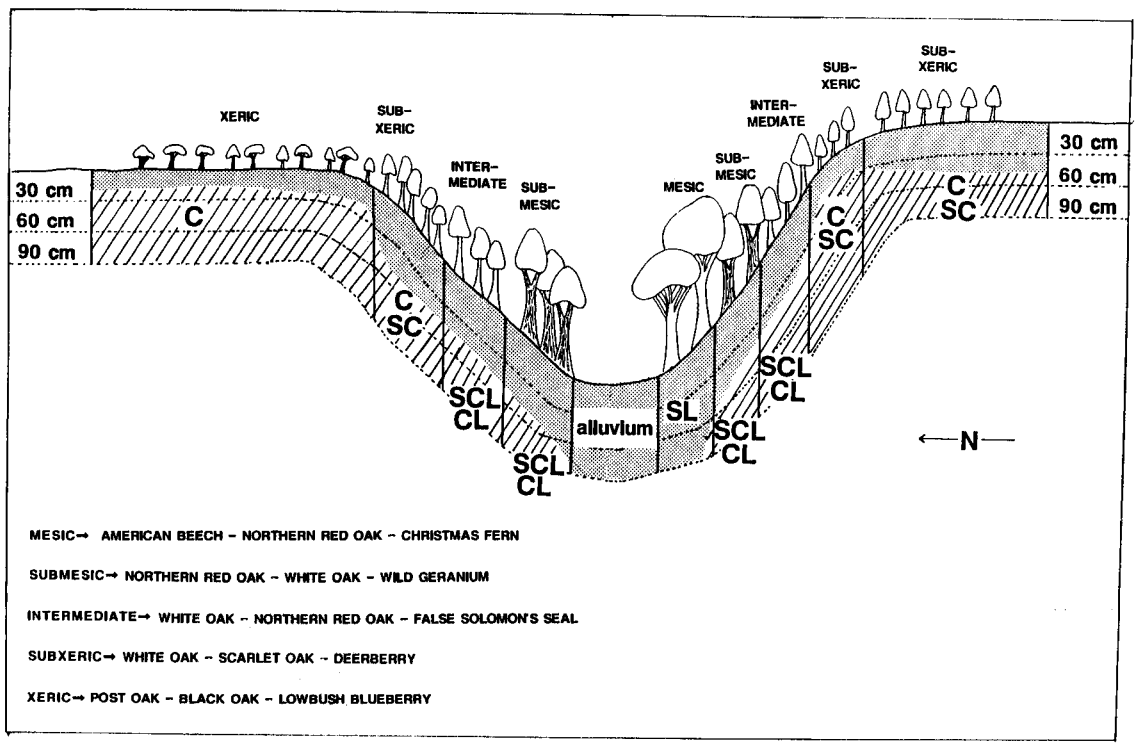


Figure 4.--Landscape ecosystem classification model for the Interior Plateau Subregion of the Midlands Plateau Region of the Piedmont Province, South Carolina.

By combining values of slope position and aspect, a single value rating for landform was developed. The landform rating expresses the degree of exposure of a given site.

The two soil factors found to be related to the distribution of vegetation associations were depth of the horizon where clay percentage was a maximum and the maximum percentage clay. Quantification of these two soil factors were combined into a single value soil rating expressing soil aeration and available water holding capacity within the upper 24 inches of soil.

In relation to the five vegetative associations, the landform and soil indices were nearly equal in their discriminating power with landform being slightly more important in terms of explaining the variation in vegetation. Each of the five site units corresponded with unique combinations of slope position and aspect which interact with soil characteristics (amount and depth of clay) to produce a unique association of plant species. When the vegetation is disturbed or absent, the site unit can be determined quantitatively by calculating a total score from the landform and soil ratings (Jones 1988a) or qualitatively and more generalized through a descriptive key:

I. Ridge flats to slight slopes; or upper (0-20%) slope positions.
   A. Any aspect.
      1. Soils clay to sandy clay (>40% clay);
         a. Maximum clay horizon within 12 inches of surface.
            Xeric Site Unit
         b. Maximum clay horizon within 12 to 24 inches of surface.
            Subxeric Site Unit

II. Mid-upper (60-80%) to mid (40-60%) slope positions.
   A. Southerly to westerly aspects (135° to 315°).
      1. Soils clay to sandy clay (>40% clay);
         a. Maximum clay horizon within 12 inches of surface.
            Xeric Site Unit
         b. Maximum clay horizon within 12 to 24 inches of surface.
            Subxeric Site Unit
      2. Soils clay loam to sandy clay loam (27%-40% clay).
         a. Maximum clay horizon within 12 inches of surface.
            Subxeric Site Unit
         b. Maximum clay horizon within 12 to 24 inches of surface.
            Intermediate Site Unit
   B. Northerly to easterly aspects (316° to 134°).
      1. Soils clay to sandy clay (>40% clay).
         a. Maximum clay horizon within 12 inches of surface.
            Subxeric Site Unit
         b. Maximum clay horizon within 12 to 24 inches of surface.
            Intermediate Site Unit
      2. Soils clay loam to sandy clay loam (27% to 40% clay).
         a. Maximum clay horizon within 24 inches of surface.
            Intermediate Site Unit

III. Mid-lower (20-40%) slope positions.
   A. Southerly to westerly aspects (135° to 315°).
      1. Soils clay to sandy clay (>40% clay).
         a. Maximum clay horizon within 24 inches of surface.
            Subxeric Site Unit
      2. Soils clay loam to sandy clay loam (27% to 40% clay).
         a. Maximum clay horizon within 12 inches of surface.
            Subxeric Site Unit
         b. Maximum clay horizon within 12 to 24 inches of surface.
            Intermediate Site Unit
   B. Northerly to easterly aspects (316° to 134°).
      1. Soils clay to sandy clay (>40% clay).
         a. Maximum clay horizon within 24 inches of surface.
            Intermediate Site Unit
      2. Soils clay loam to sandy clay loam (27% to 40% clay).
         a. Maximum clay horizon within 12 inches of surface.
            Intermediate Site Unit
         b. Maximum clay horizon within 12 to 24 inches of surface.
            Submesic Site Unit
      3. Soils sandy clay loam to sandy loam (<27% clay). Maximum clay horizon at any depth.
            Submesic Site Unit

IV. Lower (<20%) slope positions.
   A. Any aspect.
      1. Soils clay loam to sandy clay loam (27% to 40% clay).
         a. Maximum clay horizon within 24 inches of surface.
            Submesic Site Unit
      2. Soils sandy clay loam to sandy loam (<27% clay). Maximum clay horizon at any depth.
            Mesic Site Unit

Preliminary results of current research indicate that vegetation patterns within the pine management/successional types were not a function of environmental conditions; rather, variation in vegetation was due to conditions of stand establishment or subsequent anthropogenic influences. The pine management/successional types were separated into Virginia (*Pinus virginiana*), shortleaf (*P. echinata*), and loblolly (*P. taeda*) pine types. The Virginia pine type was subdivided into a Virginia pine-hardwood type and a Virginia pine-grass type, while the loblolly pine type was separated into three types: loblolly-sweetgum (*Liquidambar styraciflua*), loblolly-water oak (*Quercus nigra*), and loblolly-partridge pea (*Cassia fasciculata*). In addition, a pine-

hardwood (oak and hickory) mixed type was identified as a later successional stage.

The hardwood forest immediately succeeding the pine management/successional and pine-hardwood types was identified as a successional red oak type. The predominant oaks were southern red (Quercus falcata) and scarlet oak (Q. coccinea), although white oak (Q. alba) and hickory (Carya) are commonly present. The late successional oaks, such as post oak (Q. stellata), white oak (Q. alba) and northern red oak (Q. rubra) succeed the red oak forest depending on site conditions and was described in general as the disturbed white oak forest. As a result of disturbed conditions, yellow-poplar (Liriodendron tulipifera) and white ash (Fraxinus americana) are common associates on moist sites; scarlet oak under drier conditions; and hickories and black gum (Nyssa sylvatica) under all site conditions. Species composition was found to vary across the five site units for both the successional red oak stage and the disturbed white oak stage.

IMPLICATIONS

This approach to land classification on an ecological basis attempts to take into account variation due to major environmental variables by recognizing regions and subregions. For instance, within a given physiographic region or subregion major climatic patterns would not significantly vary. Likewise, when parent material differences are known to affect major soil properties and alter plant species composition and productivity, lands are subdivided into physiographic regions or subregions. As a result, the physiographic classification approach of Myers and others (1986) is implemented in a hierarchical sense, with landscape ecosystem classification modelling the micro-climatic and micro-site variability within a region or subregion. This corresponds to the microscale of Bailey (1988).

Although requiring a greater investment in time and financial resources, the advantage of developing landscape ecosystem models for each region is an increase in accuracy. The models at this scale can be refined to account for minor variations in soil and landform that result in fluctuations in vegetation. These differences can be appreciated at the individual site level.

The landscape ecosystem models are flexible; that is, that can be refined to take into account new information. For a given landscape ecosystem model, this is accomplished by merely subdividing existing site units into one or more new site units. In addition, there is flexibility in the modelling approach to take into account the shift in relative importance of landform to soils across regions. Within the Hilly Coastal Plain, soils are the driving variable in the model. Landform influences are apparent only at a broad level. Landform associations are subdivided into site units based on differences in soil characteristics. In contrast, within the southern Appalachians, landform is the major discriminator of site differences. Landform associations may be subdivided into site units based on landform variables or a combination of soil and landform variables or perhaps soils alone.

The major criterion in measuring the usefulness of a classification approach is its adaptability to mapping procedures and the production of accurate, useful maps from which interpretations of land productivity and other resource values can be made. Obviously, mapping site types based on existing or potential climax vegetation would have limited use in the identification of land productivity in the southern United States. As a result of intensive forestry, including widespread conversion to pine forests, and other widespread anthropogenic impacts, the south's forests are predominately composed of successional species whose presence are a reflection of disturbance conditions rather than environmental conditions.

The use of soil surveys is also perceived as having limited application in delineating site units with similar productive potential. Soil taxonomy is often criticized because soil series are classified based on morphological features often unrelated to site productivity. This problem is overcome by combining soils at the series level into groups that represent ecological equivalents, that is, those soils that produce the same type of late successional vegetation on a given landform.

Early results of efforts to integrate landscape ecosystem classification models into geographic information system data layers are promising (Lloyd and others 1990). Landform is expressed as digital elevation data and soils expressed through digitized soil survey which are grouped and remapped according to their ecological equivalent groups. Predicted site unit boundaries and potential vegetation are mapped through modelling the interaction of landform and soils (Figure 5). Mapped site unit boundaries can be refined in the field by observing the distribution of diagnostic species when they have not been eliminated through land use practices. Since landscape ecosystem classification simplifies all the various combinations of soil variables and landform variables into relatively few site units for a given region, mapping the landscape becomes simplified.

A map of site units derived from landscape ecosystem classification through application of GIS can be used in making multi-value planning decisions. For example, predicting potential habitat for endangered species, wetlands delineation, and ecological restoration projects. In the management of diversity, predictions can be made relative to species diversity at a site level. Perhaps more importantly in terms of managing spatial variability, it is possible to quantify the potential for landscape level diversity. That is, for a given area we can address the number (richness) and relative amounts (evenness) of potential vegetation types directly from maps of site units. Of course, traditional

Figure 5.--Predicted site units map of the Mill Creek Area, Savannah River Site, South Carolina.

Uplands
- Xeric
- Subxeric
- Submesic
- Mesic

Bottomlands
- Well Drained
- Poorly Drained
- Very Poorly Drained

Other
- Altered Soil or Water

N

0 1/2 1 Mi

forestry interpretations (productivity, trafficability, etc.) are possible as well.

LITERATURE CITED

Bailey, R. G. 1988. Ecogeographic Analysis: A guide to the ecological division of land for resource management. USDA Forest Service Misc. Publication 1465, Washington, DC. 18 pp.

Barnes, B. V.; K. S. Pregitzer; T. A. Spies; V. H. Spooner. 1982. Ecological forest site classification. Journal of Forestry 80(8):493-498.

Barnes, B. V. 1989. Old-growth forests of the northern lake states: A landscape ecosystem perspective. Natural Areas Journal 9(1):45-57.

Daniel, T. W.; J. A. Helms; F. S. Baker. 1979. Principles of Silviculture. 2nd ed., McGraw-Hill, New York. 500 pp.

Jones, S. M. 1988a. Old-growth, steady state forests within the Piedmont of South Carolina. Ph.D. Dissertation. Department of Forestry, Clemson University, Clemson, SC. 83 pp.

Jones, S. M. 1988b. Old-growth forests within the Piedmont of South Carolina. Natural Areas Journal 8(1):31-37.

Jones, S. M.; D. H. Van Lear; S. K. Cox. 1981. Major forest community types of the Savannah River Plant: a field guide. Savannah River Plant, National Environmental Research Park Program, U.S. Department of Energy SRO-NERP-9. 79 pp.

Jones, S. M.; D. H. Van Lear; S. K. Cox. 1984. A vegetation-landform classification of forest sites within the upper Coastal Plain of South Carolina. Bulletin of the Torrey Botanical Club 111(3):349-360.

Lloyd, F. T. 1991. Linking a growth and yield model with landscape ecosystem classification for natural pine-hardwood mixtures. [These Proceedings].

Lloyd, F. T.; R. M. Chubb; S. M. Jones. 1990. Using a GIS-implemented ecological land classification model to determine where pine-hardwood regeneration practices work on the Savannah River Site (Abstract). P. 28. In: E. R. Smith (ed.), Proc., First Annual Southern Appalachian Man And The Biosphere Conference. Tennessee Valley Authority. Gatlinburg, TN.

Monserud, R. A. 1984. Problems with site index: An opinionated review. P.167-180. In: J. G. Bockheim (ed.), Proc. Forest Land Classification: Experiences, Problems, Perspectives. NCR-102 North Central Forest Soils Committee, Society of American Foresters, USDA Forest Service, and USDA Soil Conservation Service. Madison, WI.

Mueller-Dombois, D.; H. Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York. 547 pp.

Myers, R. K.; R. Zahner; S. M. Jones. 1986. Forest habitat regions of South Carolina. Clemson University, Department of Forestry Research Series No. 42. 31 p.+map.

Rowe, J. S. 1978. The common denominator of land classification in Canada: an ecological approach to mapping. P.195-198 In: Proc. Ecological Classification of Forest Land in Canada and Northwestern U.S.A. For. Ecol. Working Group, Can. Inst. Forestry and Centre for Continuing Education. Univ. British Columbia, Vancouver.

Van Lear. 1991. History of forest site classification in the south. [These Proceedings].

Van Lear, D. H.; S. M. Jones. 1987. An example of site classification in the southeastern coastal plain based on vegetation and land type. Southern Journal of Applied Forestry 11(1):23-28.

DELINEATION AND CLASSIFICATION OF WETLANDS IN THE SOUTHEAST[1/]

John M. Hefner and Charles G. Storrs[2/]

Abstract--The National Wetlands Inventory of the U.S. Fish and Wildlife Service has prepared large scale wetland maps for over 70 percent of the Southeast. Maps are produced through interpretation of high altitude aerial photographs. Wetlands are identified based on hydrology, soils, and plant species. Classification is in accordance with Cowardin et al. 1979.

Keywords: Classification, inventory, maps, photo interpretation, trends, wetlands.

INTRODUCTION

The National Wetlands Inventory (NWI) of the U.S. Fish and Wildlife Service (Service) has been mapping and classifying wetlands, and analyzing wetland trends since the late 1970's. The data collected and disseminated by the NWI is intended as a tool to foster wise management of this important resource.

The NWI is the fourth wetland inventory carried out by the Federal Government. The first two inventories, conducted in 1906 and 1922 by the Department of Agriculture, were intended to identify lands that could be improved by drainage and converted to productive croplands. The Service's previous wetland inventory was conducted in 1954 to identify important wetland habitat for wildlife, especially waterfowl. The release of the findings in Wetlands of the United States, usually referred to as Circular 39 (Shaw and Fredine 1956), marked a major turning point in wetland conservation.

Since that survey, wetlands have undergone many changes, both natural and man-induced. These changes, coupled with our increased understanding of wetland values, led the Service to establish the NWI. During its 15 year history, the NWI has developed a variety of cartographic and narrative products. However, the project's principal products are detailed large scale wetland maps and periodic reports of the status and trends of the nation's wetlands. Wetland maps are in wide use for impact assessment of site-specific projects including facility and corridor siting, oil spill contingency plans, natural resource inventories, habitat surveys and other studies. National estimates of the current status and trends (i.e., losses and gains) of wetlands have been used to evaluate the effectiveness of existing Federal programs and policies, and to identify national or regional problems. The initial trend study by the NWI increased general public awareness of wetlands and was instrumental in stimulating several pieces of important wetland legislation.

WETLAND CLASSIFICATION

At the inception of the NWI, a variety of regional wetlands classification schemes were in use. However, no single classification fully met the needs of a nationwide project. Therefore, a new classification system (Cowardin et al. 1979) was developed by a team of wetland ecologists, with the assistance of local, State, and Federal agencies, as well as many private groups and individuals. After extensive field testing and four major revisions, the classification was officially adopted by the Service in 1980. Familiarity with the classification is essential to making maximum utility of NWI products.

The Service's wetland classification defines wetlands in the following manner: "Wetlands are

---

1/ Presented at the Symposium on Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests, Charlotte, NC, January 7-9, 1991.

2/ Regional National Wetlands Inventory Coordinator and Assistant Coordinator, respectively, Fish and Wildlife Service, U.S. Department of Interior, Atlanta, Georgia

lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes, (2) the substrate is predominantly undrained hydric soil, and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year" (Cowardin et al. 1979). Lists of wetland plants (Reed 1988), and hydric soils (U.S. Soil Conservation Service 1987), have been developed in support of this definition and are now also an integral part of the Federal methodology for identifying jurisdictional wetlands (Federal Interagency Committee for Wetland Delineation 1989).

The classification is hierarchical. At the most general level, wetlands and deepwater habitats are separated into five systems - Marine, Estuarine, Riverine, Lacustrine, and Palustrine. Each system groups wetlands and deepwater habitats according to hydrologic, geomorphologic, chemical and biological similarities. Estuarine and Palustrine are primarily wetland systems, while Marine, Riverine, and Lacustrine are predominantly deepwater systems. At the next level of the hierarchy, subsystems subdivide the systems on the basis of general hydrologic characteristics. At The taxonomic level below the subsystems are the classes, followed by subclasses. The 11 classes are based on either vegetative life form or substrate and flooding regime. Classes describing vegetated wetlands include Aquatic Bed, Moss-Lichen, Emergent, Scrub-Shrub, and Forested. Classes describing nonvegetated wetlands include Rock Bottom, Unconsolidated Bottom, Unconsolidated Shore, Rocky Shore, Streambed and Reef. Subclasses provide additional life form detail (e.g. needle-leaved evergreen), or substrate information (e.g. sand). The classes and subclasses are easily recognized and can normally be identified by using remote sensing technologies.

At the most precise and detailed level of the classification are dominance types. These are named for the dominant plant species in vegetated wetlands or the predominant sedentary or sessile macroinvertebrate species in nonvegetated wetlands. At this point, the classification is open-ended and dominance types can be identified and named as required. In general, dominance types for forested wetlands can be related to Forest Cover Types as described by the Society of American Foresters (Eyre 1980). For example, Forest Cover Type 98, Pond Pine would be classified: SYSTEM: Palustrine; SUBSYSTEM: none; CLASS: Forested; SUBCLASS: Needle-leaved Evergreen; DOMINANCE Type: Pinus serotina.

To more fully describe wetlands, a series of modifiers have been included in the classification that document hydrology, water chemistry, soil type, and the impact of beavers or man. Modifiers can be applied at the class, subclass, and dominance type levels.

WETLAND MAPPING

Due to the magnitude of this national effort, wetland mapping by the NWI is primarily a remote sensing project. High altitude photography is the basic data source. Since 1980, the NWI has utilized 1:58,000 scale color infrared photography acquired for the U.S. Geological Survey's National High-Altitude Photography Program. Satellite capabilities are regularly investigated and may eventually prove useful for monitoring wetland changes, updating NWI maps, and for producing maps in unmapped areas.

The preparation of NWI maps is a highly structured 11 step process combining photo interpretation, field work, interagency review of draft maps, along with numerous quality control checks (Tiner 1990). Photo interpretation is a manual process in which wetland boundaries and classifications are penned on a clear overlay affixed directly to the photographs. During the interpretation process, careful attention is paid to collateral information, especially county soil surveys and topographic maps. When delineations are complete and have received a satisfactory review by NWI project personnel, the linework and classifications are transferred from 1:58,000 to 1:24,000 scale. Linework is then superimposed onto the corresponding topographic quadrangle to form the wetland map. The maps are then distributed to a variety of Federal and State agencies for review and field checking. Editorial comments are compiled, maps are corrected, and final maps are prepared. This entire process takes from 2 to 3 years from photo acquisition to final map production.

NWI maps can be quite detailed and cartographically complex. The minimum size wetland unit displayed on the maps in Southeastern U.S. is between one and three acres. The level of classification detail is also high. Wetlands are described to the subclass level with modifiers in accordance with Cowardin et al. (1979). Literally hundreds of categories of wetlands are described, some of which infer dominance types. For example, the classification "Estuarine, Intertidal, Forested Wetland, Broad-leaved Evergreen, Regularly Flooded" along the Florida coast, usually is equivalent to the red mangrove (Rhizophora mangle) dominance type. Similarly, the classification "Palustrine, Forested Wetland, Needle-leaved Deciduous, Semipermanently Flooded" in the Southeast describes cypress (Taxodium distichum or T. ascendens) dominated wetlands.

The strict adherence to proven mapping procedures has enabled the NWI to achieve a high level of accuracy. Although only one formal study of NWI map accuracy has been conducted (Swartwout et al. 1981), the maps have successfully passed intense scrutinity during usage. Perhaps the best gauge of overall quality is the willingness of outside agencies to share the cost of map

production and provide field review of the maps. In 1990, over $1.5 million were provided from outside sources.

To date, over 30,000 maps covering over 65 percent of the conterminous United States and 20 percent of Alaska, as well as, Hawaii, Guam, Puerto Rico, and the U.S. Virgin Islands, have been prepared. Over one million map copies have been distributed. Mapping is 70 percent complete for the 10 States comprising the Southeast Region of the Service. Maps are available for all of Kentucky, Tennessee, and Florida.

An important strength of the NWI is the accessibility of its products. Maps are routinely distributed to the U.S. Army of Corps of Engineers, the U.S. Environmental Protection Agency, and the U.S. Soil Conservation Service, as well as, State agencies which have expressed interest in receiving then. Maps are also available for purchase to anyone for a $1.75 each by calling toll free 1-800-USA-MAPS. In addition, they can be obtained from 27 State distribution centers, which in the Southeast are located in South Carolina, North Carolina, Georgia, Florida, Alabama, and Kentucky.

In addition to preparing hard-copy maps, the NWI is constructing a georeferenced database for users of automated geographic information system (GIS) technologies. Copies of the database files, in a variety of formats, can be purchased from the NWI Offices in St. Petersburg, Florida, at (813) 893-3873. The database currently includes digital data for almost 6,000 maps covering 11 percent of the continental United States. The database is complete for Washington, Illinois, Indiana, Maryland, and New Jersey, and is nearing completion for Virginia.

WETLANDS STATUS AND TRENDS REPORTS

Recognizing that maps are a static representation of wetland conditions, the Service conducts periodic studies to determine wetland gains and losses nationwide. The first wetland trend study was completed in the early 1980's and evaluated wetland changes from the mid-1950's to the mid-1970's (Frayer et al. 1983; Tiner 1984). A second study which will be released in early 1991, developed trend information for the mid-1970's to mid-1980's (Frayer In press.).

A stratified random sampling design was used. Aerial photographs taken at the start and the end of each study period were interpreted and wetland acreages measured for 3,629 sample plots, each four-square miles in size. Estimates of wetland acreages were then generated through statistical analysis of the data obtained from the sample plots.

The initial study revealed that over 11 million acres of wetlands were lost from the 1950's to the 1970's, with an average annual net loss rate of 458,000 acres. Agricultural development was responsible for 87 percent of the losses. These and other findings were instrumental in the passage of important wetland legislation, such as the Emergency Wetlands Resources Act of 1986 (P.L. 99-645) and the Swampbuster Provisions of the Food Security Act of 1985 (16 U.S.C. 3801-3845).

Preliminary results from the recently completed trend study indicate that the average annual net loss of wetlands from the 1970's to 1980's has declined by a third, to 290,200 acres. It also appears that the impact of agricultural development had lessened. Estuarine wetlands experienced a relatively small decline, concentrated primarily along the coasts of Texas and Louisiana. Palustrine forested wetlands exhibited greater losses than any other type, a net loss 3.4 million acres. Most of the forested wetland losses were identified in the Lower Mississippi Valley and South Atlantic States.

The design for the national status and trends studies has been utilized for analyzing wetland changes in smaller geographical areas by intensifying the sampling effort. In this manner trend studies have been completed for the Southeastern States (Hefner and Brown 1984), the Mid-Atlantic States (Tiner and Finn 1986; Tiner 1987), Florida (Hefner 1986), and the Central Valley of California (Frayer et al. 1989). Additional localized studies are planned for 1991.

DISCUSSION

Since the early 1980's, the NWI has been single most accurate, accessible and extensive source of cartographic information related exclusively to wetlands. Admittedly, no land cover mapping project based primarily on remote sensing can be without limitations. Aerial photography which is processed poorly or taken under adverse conditions such as periods of severe drought or flooding can affect interpretation accuracy. In addition, some wetland habitats, particularly pine dominated wetlands in the Southeast, are inherently difficult to interpret from aerial photographs. Tiner (1990) describes the special problems related to inventorying a variety of forested wetland types throughout the U.S. Map users need to be aware the delineations of some wetland types are necessarily approximate and detailed on-site study is necessary for accurate boundary determinations.

A deliberate effort has been made by the NWI to make its products available to the greatest number of people possible. However, new NWI map users are sometimes deterred by the seemingly complex classification displayed on the maps. To overcome this, NWI personnel located in each Regional Office of the Service are available to provide assistance in understanding the maps. In addition, formal training sessions in wetland classification and mapping procedures are regularly scheduled.

Maps are now available for over 65 percent of the conterminous U.S. and completion is scheduled for 1998. However, many areas for which maps were produced have changed dramatically. For a few locations, like coastal Georgia, South Carolina, and Louisiana, as well as, southern Florida, updated maps have been prepared with funding from outside sources. Many other areas, like the Lower Mississippi Valley, are in serious need of remapping.

As mapping nears completion, the future scope of NWI is under consideration. The NWI will continue to conduct periodic wetland trend studies as mandated by the Emergency Wetlands Resources Act. Yet many other tasks need doing. A series of reports describing the findings of the NWI in each State needs to be prepared. All NWI maps need to be digitized to NWI standards so that automated analyses can be conducted. Wetland acreages for every State and county need to be determined. In addition, it may be time to expand NWI efforts to evaluate the functional health and value of this important resource.

LITERATURE CITED

Cowardin, L.M.; Carter V.; Golet, F.C.; LaRoe, E.T. 1979. Classification of wetlands and deepwater habitats of the United States. Washington, D.C.: U.S. Fish and Wildlife Service. 103 pp.

Eyre, F.H., ed. 1980. Forest cover types of the United States and Canada. Washington, D.C.: Society of American Foresters. 148 pp.

Federal Interagency Committee for Wetland Delineation. 1989. Federal manual for identifying and delineating jurisdictional wetlands. Washington, D.C.: U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and U.S. Department of Agriculture, Soil Conservation Service. 76 pp.

Frayer, W.E. In press. Status and trends of wetlands and deepwater habitats in the conterminous United States, 1970's to 1980's. Houghton: Michigan Technological University. 32 pp.

Frayer, W.E.; Monahan, T.J; Bowden, D.C.; Graybill, F.A. 1983. Status and trends of wetlands and deepwater habitats in the conterminous United States, 1950's to 1970's. Fort Collins: Colorado State University. 32 pp.

Frayer, W.E.; Peters, Dennis D.; Pywell, H. Ross. 1989. Wetlands of the California Central Valley: status and trends, 1939 to mid-1980's. Portland, OR: U.S. Fish and Wildlife Service. 28 pp.

Hefner, J.M. 1986. Wetlands of Florida, 1950's to 1970's. In: Estevez, E.D., Miller, J.; Morris, J.; Hamman, R. eds., Proceedings, conference on managing cumulative effects in Florida wetlands; 1985 October 17-19; Sarasota, FL. New College Environmental Studies Prog. Publ. No. 37. Madison, WI: Omnipress. pp 23-31.

Hefner, J.M.; Brown, J.D. 1984. Wetland trends in the Southeastern United States. Wetlands 4:1-11.

Reed, P.B., Jr. 1988. National list of plant species that occur in wetlands: national summary. Serv. Biol. Rpt. 88(24). Washington, D.C.: U.S. Fish and Wildlife Service. 244 pp.

Shaw, S.P.; Fredine, C.G. 1956. Wetlands of the United States. Circular 39. Washington, D.C.: U.S. Fish and Wildlife Service. 67 pp.

Swartwout, D.J.; MacConnell, W.P; Finn, J.T. 1981. An evaluation of the National Wetlands Inventory in Massachusetts. In: Proceedings, workshop on in-place resource inventories; 1981 August 9-14; Orono, ME: University of Maine. pp. 685-691.

Tiner, R.W., Jr. 1984. Wetlands of the United States: current status and recent trends. Washington, D.C.: U.S. Fish and Wildlife Service. 59 pp.

Tiner, R.W., Jr. 1987. Mid-Atlantic wetlands: a disappearing natural treasure. Newton Corner, MA: U.S. Fish and Wildlife Service and U.S. Environmental Protection Agency. 28 pp.

Tiner, R.W., Jr. 1990. Use of high-altitude aerial photography for inventorying forested wetlands in the United States. Forest Ecology and Management 33/34:593-604.

Tiner, R.W., Jr.; Finn, J.T. 1986. Status and recent trends of wetlands in five Mid-Atlantic States: Delaware, Maryland, Pennsylvania, Virginia, and West Virginia. Newton Corner, MA: U.S. Fish and Wildlife Service and U.S. Environmental Protection Agency. 40 pp.

U.S. Soil Conservation Service. 1987. Hydric Soils of the United States. Washington, D.C.: U.S. Department of Agriculture. 200 pp.

FOREST HABITAT REGIONS: INTEGRATING PHYSIOGRAPHY AND REMOTE SENSING FOR FOREST SITE CLASSIFICATION[1]

W. Frank Miller and Michael S. Golden[2]

Abstract.--This is a hierarchical system originally developed with the aim of providing a physiographically-based classification with regional consistency throughout the southern U.S. The approach applies remote sensing for delineation of landscape units which are based primarily on physiographic characteristics and relate well to topographic, vegetation, and land-use patterns. The focus is primarily on use of satellite imagery for delineation of "provinces," "forest habitat regions" and "subregions", but information from a variety of sources, including geologic maps, soils maps, and field checking, is applied to the description and refinement of classification units.

Keywords: Site suitability, satellite imagery, southern U.S.

INTRODUCTION

The goal of any forest land classification scheme ultimately should be to provide the information base required for assessment of site suitability. As we are using the term "site suitability" in this paper, we refer to the concept of "attractiveness" and "vulnerability." Attractiveness can be expressed in terms of economics (growth and yield of fiber), aesthetics, or environmental attributes. Vulnerability is used to evaluate the impact of the proposed land use or activity upon the ecosystem; e.g., do we have a fragile soil and an inelastic ecosystem, or do we have an ecosystem with a high degree of elasticity? These concepts were first formulated by McHarg (1969) and developed as a design tool for landscape architects. With slight modification these ideas fit very nicely into the concepts of forest site classification and ecosystem elasticity.

BACKGROUND

The hierarchical classification system presented in this paper provides the information required to evaluate site suitability for a wide range of uses. It was originally developed with the aim of providing a physiographically based system with regional consistency for the 13 southern States. This system has its roots in the early work of the Society of American Foresters Forest Site Classification Committee of the Southeastern Region (Hodgkins, 1965). Soon after the launch of the U.S. s first earth-observing satellite system, Landsat 1, Miller (1973a) utilized the concept of physiographic classification based on satellite imagery for a large area in northern Alabama. The results were presented to the Southern Forest Environmental Research Council and a regional project to develop a unified South-wide land classification methodology was proposed. The project was approved, and researchers in Alabama and Mississippi worked jointly to develop the classification scheme and map these two states (Hodgkins et.al., 1976; 1979).

---

[1]Presented at the symposium, Ecological Land Classification: Applications To Identify The Productive Potential Of Southern Forests. Charlotte, NC, January 7-9, 1991.

[2]Professor of Forestry, Mississippi State University, Mississippi State, MS; Associate Professor of Forestry, Auburn University, Auburn, AL.

The utilization of remotely sensed data for analysis of landforms and landscape units is by no means a new or even a recent concept; geologists, civil engineers and foresters have been interpreting conventional panchromatic photography since it became available in the late 1930 s. However, with the launch of the Landsat series of Earth Observing Satellites (originally Earth Resources Technology Satellites -- ERTS), we gained an entirely new perspective of the surface of the Earth. The repetitive and synoptic characteristics of the satellite data have provided us with a unique tool for interpreting spatial relationships of surface features.

DEVELOPMENT OF THE CLASSIFICATION SYSTEM

Classification levels

I. Physiographic Province

These are major systems of landform-geologic materials. A Province is determined much as Hills (1961) described in his approach--the superimposition of a regional climatic pattern on a given geologic substrate.

II. Habitat Region

These are broad areas identifiable by some uniformity of landform pattern at the 1:500,000 scale of the Landsat imagery.

III. Habitat Subregion

Subregions are delineated when a further subdivision of the broad pattern of landform/geology is discernible on the 1:500,000 scale imagery. Within both this and the previous class there is considerable diversity in topography and soils, but the region or subregion does define narrow the range of local habitat conditions. These units (region or subregion) are the lowest divisions separable on the Landsat imagery.

IV. Land Type

A land type is defined as an area marked by a uniformity in geomorphology; general topography, dominant geologic substrate, and general soil associations.

V. Land Subtype

This classification unit corresponds to Hills (1961) Physiographic Site Type--a more closely defined range of terrain features, dissection, geologic substrates, and soil series.

VI. Habitat Type

Where an observable variability in habitats still exists within a Land Subtype, habitat types can be mapped to further refine productivity and use suitability. For example, within a given Subtype, both Alfisols and Ultisols may occur in mixture. Since there will probably be significant differences in management strategy between the habitats occupying each soil order, a split must be made at the Habitat Type level.

Procedure

A number of different Landsat data products were evaluated for their capability to provide separability of the complex landforms of northern Alabama. Hardcopy products from the various wavelength bands were tested as well as color composites of three channels of data at scales of 1:500,000 and 1:1,000,000. The "best" combination of data products was the Multispectral Scanner (MSS) bands 5 and 7, the red and near infrared bands, respectively. Band 5 gave good differentiation of cultural features versus forested lands; band 7 gave excellent land/water contact, wet soils, and subdued vegetation signatures while enhancing terrain features.

All levels in the hierarchy cannot be interpreted from the same source. The classification unit, the suggested mapping and publication scales, and the data sources are indicated in Table 1. A thorough review of existing geologic maps, soil association maps, and Soil Conservation Service county soil surveys are used extensively in coordination with interpretation of the appropriate imagery.

For all scales of imagery,, the key to analysis of landforms and geologic substrates is the identification of surface drainage patterns. Landform is defined as the type and degree of dissection and the continuity of form. Both local and regional drainage patterns reflect the landforms. The types of drainage patterns have been illustrated by various authors and the nomenclature is standard (Miller and Miller, 1961; Way, 1973). Various formal definitions of drainage pattern have been given, but a common working definition is the spatial arrangement of rivers and streams. A surface drainage pattern consists of two elements, the type of pattern and the density of the pattern. In areas underlain by bedrock these patterns are somewhat related to the depth of developed soil materials, but the major control of pattern is by rock type and geologic structures. In areas of unconsolidated materials, such as the coastal plain provinces, the drainage pattern types more clearly reflect the thickness and nature of the soils and substrates.

The degree of dissection is evaluated by the density or texture of the individual pattern types. The following texture classes were developed by selecting a number of classes in each type and measuring the distances on 1:500,000 scale Landsat Multispectral Scanner (MSS) hardcopy. A coarse-textured pattern is defined as one with approximately 12 mm or more between major tributaries within a river basin, and 3mm between first order streams emptying into the major tributaries. For medium texture, the distances are 8 mm and 1 mm, respectively, for tributaries and first order streams. Both regional and local patterns were studied with particular emphasis on degree of dissection (density) and spatial

arrangement (type), vegetation, and land use. Geologic maps and soil surveys were examined in order to refine boundary delineations at all levels of classification. In a number of cases, traversing suspected boundaries by vehicle was necessary.

Table 1.--A hierarchical land classification system

Division	Scales Mapping	Scales Publication	Sources[a]
Province	1:500,000	1:1,000,000	Landsat MSS bands 5 & 7; geology maps
Region	1:500,000	1:1,000,000	Landsat MSS, bands 5 & 7; geology & soil assoc. maps
Subregion	1:500,000	1:1,000,000	(Same as region)
Land Type	1:120,000	1:250,000	NAP or TM imagery
Land Subtype	1:58,000	1:80,000	NAP color IR & black and white IR
Habitat Type	1:12,000	1:24,000	Low altitude CIR imagery

[a]Abbreviations: MSS = Multispectral scanner; NAP = National Aircraft Program; TM = Thematic Mapper; IR = infrared.

Example

The habitat region map as developed for Alabama and Mississippi is shown in Figure 1, with a small area in east central Mississippi circled for an illustration of potential interpretation. In a closeup view of this area of the map (Figure 2), the area of interest includes Regions 20, 29, and "a", and Subregion 18A. A high altitude aircraft infrared image of the area (Figure 3--the original is in color) allows interpretation of terrain detail to the level of Habitat Type. The description here will proceed from the west to the east side of the area. In the western portion (left) of the area, the open farmland with a medium-textured parallel and subparallel drainage pattern (Region 20, the "Blackbelt Region") indicates a homogeneous, fine-textured substrate, with flat to gently rolling terrain. Moving eastward, there is a distinct ecological break. Although the drainage pattern remains the same, the land cover changes from open farmland to old-field pine and pine/hardwood in the area just west of the highly dissected hills in the center. A field trip and reference to a county soil survey readily established the cause--alkaline clays on the west and acid clays on the east. The highly dissected fine dendritic pattern in the center (Subregion 18A, the "Upper Loam Hills") is a result of gully erosion of a coarse loamy substrate, the Tombigbee Sand Member of the Eutaw Formation. Further east is the alluvial plain of the Tombigbee River and the adjacent low (recent) terraces (Region "a", "Miscellaneous Alluvial Floodplains").

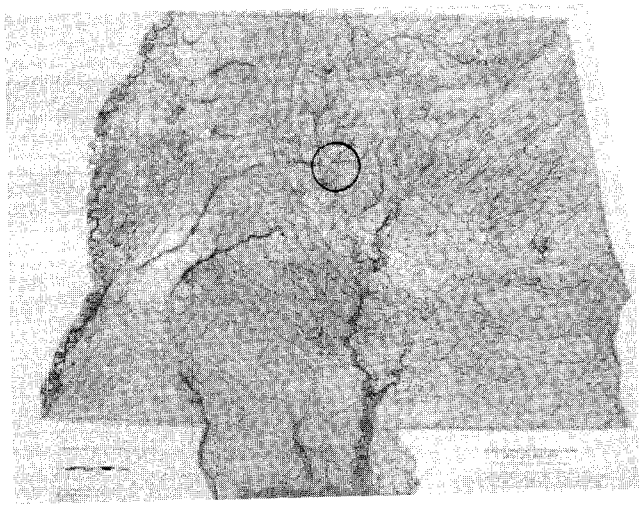


Figure 1.--The physiographic habitat region map of Mississippi and Alabama. The example area described in the text is circled.

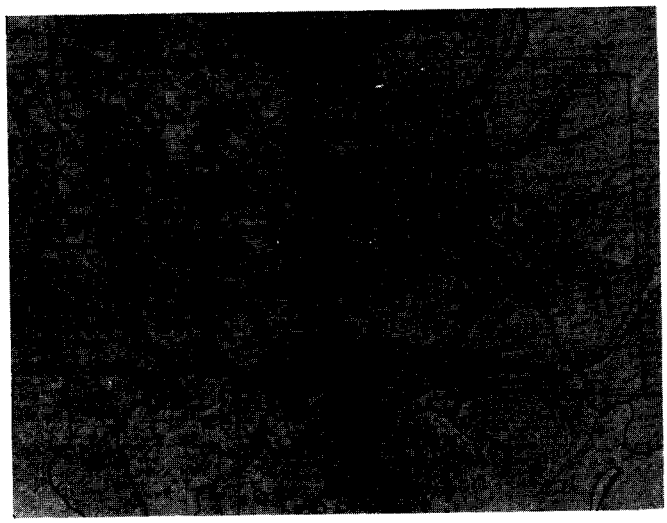


Figure 2.--Closeup of the example area, which involves Region 20, Subregion 18A, and Region 29. The area is bisected by the Tombigbee River (in Region "a").

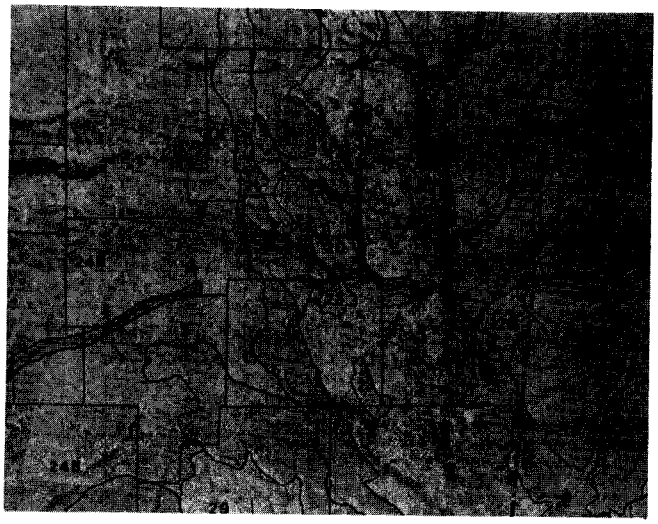


Figure 3.--High altitude aircraft imagery of the example area (original is 1:58,000 scale color IR). The top is north.

The highly reflective area on the eastern (right) side of the frame (Figure 3) represents the Old Terrace Region (Region 29), a series of two distinct terrace levels caused by downcutting of the river and movement to the west. The nature of the drainage pattern on old terrace is unique--a combination of coarse parallel and dendritic, with the drains themselves not deeply entrenched. This indicates flat terrain with a high percentage of soils in the Fragic Great Group.

At this point, we should have amassed sufficient information on soils and terrain to begin our evaluation of site suitability and the resource management decision-making subsequent to data collection.

In addition to the original one for Alabama and Mississippi (Hodgkins et al., 1976; 1979), forest habitat region maps have been published for the States of Louisiana (Evans et al., 1983), Georgia (Pehl and Brim, 1985), and South Carolina (Meyers et al., 1986). One for Tennessee is in preparation.

Refinements

The Subregion level is the point in the classification where the 80 meters resolution of the Landsat MSS data generally ceases to yield additional site-related information. Currently, mapping at the Subregion and Land Type levels may be refined by using Landsat Thematic Mapper (TM) data, which has a resolution of 30 meters, or by using the panchromatic band of the French Spot satellite, which provides a resolution of 10 meters. Also, with the advent of the National Aircraft Program (NAP, formerly NHAP), every state has been covered at least once during leaf-off period with 1:80,000 black and white infrared and 1:58,000 color infrared imagery.

As indicated in Table 1, the Habitat Type is the lowest level in the physiographic delineation of land units of similar properties and use suitability. However, in order to properly evaluate use suitability, an ecological component must be added. The classification has been developed one additional step to include an ecological component comparable to Hills (1961) "Ecological Site Type." A "Forest Habitat Mapping Unit" (Level VII) is defined as a recurring forest community with distinct physiognomic characteristics recognizable on color infrared aerial imagery of scales from 1:6,000 to 1:15,840.

As an example of the differentiation of forest habitat mapping units, a stand of bottomland hardwoods composed of cherrybark and water oak (*Quercus pagoda* Raf. and *Q nigra* L.), hickory (*Carya* spp. Nutt.), and sweetgum (*Liquidambar styraciflua* L.) of sawtimber size and normal density would be mapped as a separate unit from a stand of sugarberry (*Celtis laevigata* Willd.), green ash (*Fraxinus pennsylvanica* Marsh), and boxelder (*Acer negundo* L.) of pole size and normal stocking. This type of mapping has proven to be of value in estimating not only timber volumes, but also upland game (Table 2) and waterfowl habitat (Miller, 1973b).

Table 2.--Habitat quality ratings for four game species as related to selected forest habitat management units--Tombigbee Sand Hills Ecosystem. "Best"= 1 to "worst"= 5.

Forest Type[a]	Density	Habitat Quality Deer	Squirrel	Turkey	Rabbit
MOH	NORMAL	3.0	2.1	3.5	3.0
MOH	SPARSE	2.6	3.6	4.6	3.2
IS	NORMAL	2.6	5.0	5.0	3.5
P	NORMAL	3.5	4.0	4.5	3.5

[a]MOH = mixed bottomland red oaks, hickories, and sweetgum; 12 inches dbh. IS = invader species: sugarberry, green ash, and boxelder; 6-12 inches dbh. P = natural pine (generally loblolly (*Pinus taeda* L.)); 6-10 inches dbh.

CONCLUSION

The development of a uniform hierarchical mapping system that is closely related to interpretation of satellite and aircraft imagery has produced a classification that is constant across the Southern Region. This provides a standard mapping protocol and nomenclature for the divisions of a hierarchical classification scheme. With this technique, it is possible to arrive at a level of classification refinement that permits

the evaluation of use suitability as well as potential productivity estimates.

LITERATURE CITED

Evans, D.L.; Burns, P.Y.; Linnartz, N.E.; Robinson, C.J. 1983. Forest habitat regions of Louisiana. Baton Rouge, LA: Louisiana Agricultural Experiment Station, School of Forestry and Wildlife Management, Research Report no. 1. 23 pp.

Hills, G. Angus. 1961. The ecological basis for land use planning. Ontario Department of Lands and Forests, Research Branch Report no. 46. 204 pp.

Hodgkins, Earl J. 1965. Southeastern forest habitat regions based on physiography. Auburn, AL: Alabama Agricultural Experiment Station, Forestry Department Series no. 2.

Hodgkins, E.J.; Cannon, T.K.; Miller, W. Frank. 1976. Forest habitat regions from satellite imagery: states of Alabama and Mississippi. Map supplement to Southern Cooperative Series Bulletin 210, "Forest habitat regions and types on a photomorphic--physiographic basis." Departments of Forestry, Alabama and Mississippi; Auburn, AL: Alabama Agricultural Experiment Station.

Hodgkins, Earl J.; Golden, Michael S.; Miller, W. Frank. 1979. Forest habitat regions and types on a photomorphic--physiographic basis: a guide to forest site classification in Alabama--Mississippi. Southern Cooperative Series Bulletin no. 210. Auburn, AL: Alabama Agricultural Experiment Station. 64 pp.

McHarg, Ian. 1969. Design with nature. Garden City, N.J.: Natural History Press. 197 pp.

Miller, J.C.; Miller, C.F. 1961. Photogeology. New York: McGraw Hill Book Co., Inc.

Miller, W. Frank. 1973a. The use of ERTS imagery for forestry and agriculture. Final Report, Contract #GSA-73-20. Tuscaloosa, AL: Geological Survey of Alabama, Drawer O.

Miller, W. Frank. 1973b. Interpretation of aerial data for ecological evaluations: the Tennessee-Tombigbee Waterway. In: Sollers, Scott, ed. Remote sensing for environmental analysis. Washington, D.C.: Office of the Chief, U.S. Army Engineers.

Myers, R.K.; Zahner, Robert; Jones, S.M. 1986. Forest habitat regions of South Carolina from Landsat imagery. Clemson, SC: Clemson University Department of Forestry, Forestry Research Series no. 42. 31 pp.

Pehl, C.E.; Brim, Roy L. 1985. Forest habitat regions of Georgia, Landsat 4 imagery. Athens, GA: Georgia Agricultural Experiment Station, Special Publication 33. 12 pp.

Way, D.S. 1973. Terrain analysis: a guide to site selection using aerial photographic interpretation. Stroudsburg, PA: Dowden, Hutchinson and Ross, Inc. 392 pp.

CLASSIFICATION SYSTEM

INTERPRETATION

UTILIZING A SITE SUITABILITY GUIDE FOR SITE POTENTIAL AND SPECIES RECOMMENDATIONS ON SOUTHERN APPALACHIAN NATIONAL FORESTS 1/

Richard D. Rightmyer and James E. Keys 2/

ABSTRACT.--Direct estimates of site productivity are often difficult in stands common to Appalachian forests. A guide has been developed for indirect estimates of productivity using topographic and soil factors allowing recommendations of suitable tree species best suited to the site. A field study of the guide conducted in 1988 indicated site potential is often misclassified without the aid of soil and site data.

KEYWORDS: Land classification, site productivity.

INTRODUCTION

A continuous problem facing forest land managers of the Appalachian forests is the classification of forest lands based on their site potential and making selection of suitable species for management. Direct estimates of productivity is not always practical. High grade harvesting in the early 1900s with little stand management often created stands where accurate prediction of site potential is difficult from the existing stems. A method has been sought to evaluate site potential of such stands on the Chattahoochee National Forest and aid in recommending suitable commercial species for these sites.

Public concerns over conversion of hardwood stands to pine and increasing utilization of natural regeneration methods were identified during the preparation of the Forest Plan (USDA Forest Service 1985). These two issues along with increasing emphasis on natural ecosystem management support the need for accurate site classification. To meet these challenges a guide has been developed on the Chattahoochee National Forest which provides an indirect measure of site productivity using field evaluation of soil and topographic variables providing a recommendation for management types.

1/ Paper presented at the Ecological Land Classification Symposium, Charlotte, NC, January 7-9, 1991.

2/ Forest Soil Scientist, Chattahoochee-Oconee National Forests, USDA-Forest Service, Gainesville, GA 30501, and Regional Soil Specialist, Southern Region, USDA Forest Service, Atlanta, GA 30367

SITE QUALITY STUDIES

In developing the Chattahoochee Guide a review of current literature was done to help decide landform soil and site factors most critical to growth and perhaps those most easy to observe and measure.

Measurement of site quality is an age-old problem of forest management with numerous efforts completed in ways to measure different sites and work with different species. Heiberg and White (1956) defined site as a complex of many factors influencing development of a forest and that a forester must be aware of all the effective factors contributing to this development.

Carmean (1975) produced an exhaustive report on forest site quality evaluation. He states that the first step to intensive forest land management is to determine productive capacity and site quality of the land for alternative tree species. With this knowledge one can compare potential yields to identify the most productive and valued species for the site. The problem arises when deciding to use direct or indirect measures of the site potential.

Direct estimation can be used where age and height can be measured from free to grow, dominant or codominant trees on the site. Where trees are not present or unsuitable due to past management one must use indirect estimates. In stands of this description the relationship of soil and site factors to growth of commercial timber species can be measured to predict growth of a desired species.

Carmean (1970) indicates soil depth, soil texture, soil porosity and parent material are always critical. These characteristics influence the quality and quantity of growing space for roots. In particular his work has shown that changes in the depth of the surface layer; the zone where nutrients and available moisture are most abundant, are the most significant to tree growth.

Soil texture influences the content and movement of moisture; levels of organic matter and the cycling or availability of nutrients (Eigel et al. 1982). Medium textured soils have higher productivity than coarser textured due to higher levels of organic matter, less nutrient leaching and better moisture holding conditions.

Studies by Doolittle (1957), Trimble and Yawney (1968), Trimble and Weitzman (1956), and McNab (1985, 1986, 1988) demonstrate the strong influence of topographic variables on site productivity. Higher productivity for hardwoods is generally found on north facing slopes, lower on south facing slopes. This is generally attributed to increased available soil moisture and deeper rooting depths on the north aspects.

Landform position and landform shape has also been strongly correlated with productivity (McNab 1984). Aspect and landform position affect solar radiation reception which indirectly affects soil moisture losses resulting from evaporation and transpiration. Position on the landform affects soil moisture movement and drainage. For example ridges and upper sideslope positions lose moisture while in contrast lower slope positions are in moisture gaining situations.

DEVELOPMENT OF CHATTAHOOCHEE GUIDE

Guide development focused on three objectives:

-- Define soil and topographic variables influencing site productivity which could be classified in the field setting;

-- Design a format for measuring these variables during standard field examination;

-- Correlate guide recommendations with stand classification data.

During literature review a previous study was found which identified soil and site relationships pertinent to the objectives. Ike and Huppuch (1968) conducted an extensive study on the Chattahoochee National Forest which focused on growth response of seven hardwoods and three pines on sites. They found very strong correlations with several topographic variables and weaker associations with soil variables. The findings of this and other studies in the South along with personal experiences of foresters and soil scientists involved in land classification guided the selection of variables used in the field guide.

Field use of the guide requires measurement of topsoil depth; identification of landform position from a topographic map or on the site; identification of soil texture in the upper 18 inches of soil material and measure of aspect. Solum depth is estimated from field observations or soil survey reports. The guide can be utilized on a stand basis but it is generally desirable to traverse the entire stand; evaluate average site and landform conditions and develop recommendations for the species best suited to the stand. The Chattahoochee National Forest Site Suitability Guide (Rightmyer 1988) is found in Appendix A.

The following definitions describe the variables used in the site classification and species recommendations:

-- Landform Position: position on the landscape or landform

categories evaluated: ridges (ridgetop and upper sideslope), upper sideslope, middle sideslope, lower sideslope

-- Aspect: measure of azimuth from north, exposure, may be described as general direction, i.e. northerly, northeast, southerly

categories evaluated: north to east, south to west

-- Solum Depth: the depth of soil material available for effective root growth, free of restrictive layers and materials, generally the depth of soil material overlying bedrock or parent material

categories evaluated: shallow: 0 to 20 inches, moderately deep: 20 to 40 inches, deep: 40 inches plus

-- Topsoil Horizon Depth: the depth of the surface layer of soil material, area of concentrated soil moisture and available nutrients, zone of feeder (fine) root growth, generally refered to as topsoil

categories evaluated: shallow: less than 2 inches (<2"), moderately deep: 2 to 6 inches, deep: greater than 6 inches (>6")

-- Soil Texture: composition of soil in terms of relative proportions of sand, silt and clay particles; dominant texture in the A and B horizons

categories evaluated: fine: (clays, silty clays, sandy clays), medium: (loams, silt loams, sandy loams), coarse (sands, skeletal-rocky)

Effects of Selected Variables on Site Quality

To completely utilize the Guide one must have a basic understanding of the effects of the soil and topographic variables on site quality and growth potential. The interrelationships between each variable is complex and often difficult to measure, however a basic estimation can be achieved.

The location of a site on a landscape influences growth in terms of the gain or loss of soil moisture due to the effects of gravity on flow and protection from climatic influences. Moisture amounts generally increase as distance from the ridgetop increases due to gravitational flow down the slope. Lower slope positions tend to be gaining, upper slopes are in losing positions.

The amount of solar radiation, sunlight, a given site receives affects growth in terms of evaporation and transpiration controlling the level of available soil moisture. The exposure of a slope controls the temperature of a site which influences the rate of moisture loss, the rate of chemical reaction to breakdown nutrients and protection of the site from adjoining landforms. For example a south facing exposure (south aspect) will receive longer periods of solar radiation resulting in increases in soil temperatures, evaporation and transpiration rates and reduced availability of soil moisture to trees for growth.

Soil depth typically increases in a similar manner, increasing from the ridgetop to the lower slope. The interaction of these two situations is the increased soil depth and moisture available for growth on lower slopes. Additionally lower slope positions may be protected from winds and long periods of solar radiation which allows soil moisture to be retained for longer periods.

The depth of soil material is basic to tree growth, controlling the volume of space available for storage and delivery of soil moisture and nutrients; and for root growth, critical to the amount of intake capacity to acquire these items for growth. The volume of soil material that is available for effective root growth, that allowing unrestricted root movement, will determine the potential of the site to produce vegetation. In general the greater the total depth of soil material the higher the site potential, other factors considered (i.e. stone content, compacted layers, etc.).

Topsoil depth (surface or A1 horizon) also influences the availability of soil nutrients and moisture. Typically this portion of the soil material contains the inflow of nutrients from decomposing organic matter and has a texture allowing soil moisture to be more available. Growth of small feeder roots is generally concentrated in this area. Loss or absence of the surface horizon removes this critical area of nutrient and moisture uptake. Sites with a deeper A1 horizon are more conducive to development of larger and more effective root systems which translates to increased above ground biomass production.

Soil texture describes the proportional makeup of soil particle sizes which directly controls the movement of moisture in the soil material. Soils having a high percentage of clay particles (fine-sized) tend to hold water tightly, therefore unavailable to plant uptake. These soils can also have poor aeration conditions and restricted root growth. Generally soils with medium textures (loamy) have an increased potential for plant growth due to the increased movement and availability of moisture and nutrients.

Coarse textured (sandy or stony) soils tend to allow rapid movement of moisture ouof the soil material therefore losing essential moisture too quickly.

Each tree species found in the southern Appalachians differs in growth requirements; general evaluations cannot be made for broad areas but instead one must analyze specific sites and species.

FIELD STUDY

A field study was undertaken in 1988 and 1989 to validate the Guide and test it's application to site productivity recommendations. Plot data was collected to compare the Guide's recommendations with those of foresters using normal site classification procedures. Secondary objectives included acquainting the foresters with use of a soil/site guide and gaining increased use of soils information.

Study Area Features

The portion of the Chattahoochee National Forest assigned to the Blue Ridge Province of the Appalachian Mountains made up the study area. Rugged mountains and ridges ranging from 1000 to 3400 feet with peaks up to 4000 feet are characteristic of the area. Geology consists of rocks such as granite, schists, quartzite, gneiss, mica-schists and metasedimentary rocks such as metagraywacke and phyllite.

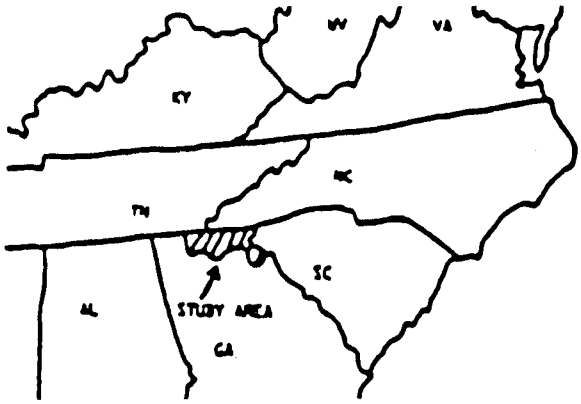


Figure 1.--Study area, Chattahoochee National Forest, northeast Georgia.

Soils range from loamy to clayey in texture and shallow to deep depending on slope, landform position and parent material. Soils are all mesic, classified in the Typic Hapludults and Typic Dystrochrepts families on sideslope and ridgetop positions; in Umbric Dystrochrepts on colluvial positions and Fluventic Dystrochrepts on alluvial positions. Annual precipitation ranges from 52 inches on the west side of the Forest to a high of 80 inches at the northeast corner near Clayton, GA.

Study Procedure

Study data was collected at the sample plot locations selected by the forester during stand examination. A variable plot, defined by a BAF 10 prism, determined the plot size used for the classification of forest and management type.

The Region 8 Silvicultural Examination and Prescription Handbook (USDA-Forest Service 1988) defines forest type as "species of trees that comprise the main crown canopy, i.e. dominants and co-dominants". Management type as defined is what should be produced on the site to best the goals and objectives of the Forest Plan. This differs from a strictly timber oriented management type which is defined as "the forest type that optimizes the productive capability of the site to produce quality material.

The seven foresters participating in the study were directed to use their standard procedures and experience for site classification and in recommending a management type. Because of differences in definition one-to-one correlation was not expected between the Guide and the foresters. The Guide is based on the factors controlling the productive capacity of a site while the forester may be constrained by management direction or bias of direct estimates.

Data was collected at the plots on aspect, landform position, topsoil depth, solum depth, elevation and the forest type. The forester entered their management type recommendation and the guide's recommendation based on the soil and topographic factors in the matrix.

A total of 241 plots were examined arrayed across the entire Forest. Sample plots were taken in the stands being examined as part of the normal entry into areas being considered for treatment.

Data was summarized for each of the guide factors using a SAS program (Statistical Analysis System 1985). Summaries were made for each of the soil/site factors in the guide with comparisons then made between the recommendations of the guide and the foresters.

RESULTS AND DISCUSSION

Landform Position

Landform position was the easiest factor to measure however agreement was variable. Agreement was highest on the ridgetops, both guide and forester recommending pine.

Landform	Agree	Differ
	(percent)	
Ridgetops	71	29
Sideslopes	49	51
Colluvial	48	52
Alluvial	29	71
All Plots	54	46

Moving downslope the level of agreement declines, particularly on the lower sideslopes. On a significant number of plots the guide recommends hardwood due to deeper, loamy and clayey soils and favorable moisture conditions. In contrast the foresters primarily recommended pine; probably influenced by the current stand condition. Although only 7 plots were sampled in alluvial positions the level of agreement was very low; the guide recommending hardwood, the foresters pine.

Aspects

The amount of agreement for aspect did not readily explain differences between the guide and the foresters. On sideslopes the percentage was about the same regardless of aspect.

Aspect	Agree	Differ
	(percent)	
North-East	51	49
South-West	48	52

Again the Guide's consideration of soil and topographic factors favors hardwoods on most north facing positions and lower slopes of south facing aspects. The foresters recommended pine over hardwood or mixed types.

Topsoil Thickness

Data comparison based on surface horizon is inconclusive when comparing recommendations. This was expected due to the minimal experience of the foresters in sampling soil conditions for either soil depth or texture. A 12 inch auger was used for this procedure.

The data collected showed higher agreement for the 0-2 inch and 6 inch+ classes; lower for the 2-6 inch class. This category of data does not provide significant information to support a change in the guide.

Surface (inches)	Agree	Differ
	(percent)	
0 to 2	59	41
2 to 6	39	61
6 +	58	42

Management Type

The level of agreement on hardwood and pines was not significantly different; however for mixed typesthe disagreement level is high. This may be due in part to limited experience in classifying the mixed types and past policy limiting use of such types. This points out an excellent future use of the site suitability guide; identifying soil and site conditions favoring mixed management types.

Managment Type	Plots		Percent	
	Differ	Agree	Differ	Agree
	(number)			
Hardwood	33	44	43	57
Mixed	29	5	85	15
Pine	42	82	34	66

Of the 241 plots examined 124 plots or 52 percent were classified as pine mangement types. Hardwood management types were assigned to 80 plots or 33 percent and mixed types to only 37 plots or 15 percent.

SUMMARY AND CONCLUSIONS

Estimating site potential by use of soil and topographic factors was found to be practical in recommending suitable management types on the Chattahoochee National Forest. In comparing the recommendations of the site suitability guide and foresters levels of agreement were about equal when considering landform position and topsoil depth. Agreement on aspects was not conclusive.

Considering the assignment of management types for the entire sample indicates an emphasis of pine management over hardwood or mixed types. The suspected inaccuracy in using direct estimates of site potential is also evident; a large number of the stands are made up of low quality hardwood stems at present not displaying true site potential.

The evaluation process of the site suitability guide has extended application to a Geographic Information System. The integrated format of the soil and topographic factors should be compatible with the layers typically input in a GIS format.

ACKNOWLEDGEMENTS

The authors thank W. Henry McNab, Research Forester, USDA-Forest Service, Southeastern Forest Experiment Station, for his support to this project. Henry provided analysis of the plot data, advice on the design of the Guide and the field study and a morale boost when the going got tough. A special thanks to Mr. Pat Thomas, Forest Supervisor (now deceased) on the Chattahoochee National Forest who set the process in motion to develop the Guide and emphasized it's use in the management of the multiple resources of the National Forest.

LITERATURE CITED

Carmean, W. H. 1970. Site quality for eastern hardwoods. In: The silviculture of oaks and associated species. Upper Darby, PA: USDA-Forest Service, Northeastern Forest Experiment Station Res. Pap. NE-144. pp. 36-56.

Carmean, W. H. 1975. Forest site quality evaluation in the United States. Advances in Agronomy 27:209-269.

Doolittle, Warren T. 1957. Site index of scarlet and black oak in relation to southern Appalachian soil and topography. Forest Science. 3(2):114-124.

Eigel, R. A., R.L. Blevins, R.F. Wittwer and C.J. Lieu. 1982. Site index of yellow-poplar in relation to soil and topography in eastern Kentucky. In: R.N. Muller, ed. Proceedings of the Fourth central hardwood forest conference; Lexington, KY. pp. 207-219.

Ike, Albert F. and C.D. Huppuch. 1968. Predicting tree height growth from soil and topographic site factors in the Georgia Blue Ridge mountains. Georgia Forest Research Council, Macon, GA.: Georgia For. Res. Pap.54. 11p.

Heiberg, Svend O. and Donald P. White. 1956. A site evaluation concept. Journal of Forestry. 54:7-10.

McNab, W.H. 1984. Geomorphic factors associated with quality of yellow-poplar sites in the southern Appalachians. In: Shoulders, Eugene, ed. Proceedings, 3d biennial southern silvicultural conference, 1984, November 7-8; Atlanta, GA. Gen. Tech. Rep. SO-54. New Orleans, LA: USDA Forest Service, Southern Forest Experiment Station. pp. 331-336.

McNab, W.H. 1986. Integrated site classification in the southern Appalachians: geologic variables related to yellow-poplar productivity. In: Phillips, Douglas, ed. Proceedings 4th biennial southern silvicultural conference, 1986 November 4-6, Atlanta, GA. Gen Tech. Rep. SE-42. Asheville, NC: USDA Forest Service, Southeastern Forest Experiment Station. pp.: 253-258.

McNab, W.H. 1987. Yellow-poplar site quality related to slope type in mountainous terrain. Northern Journal of Applied Forestry. 4(4):189-192.

McNab, W.H. 1988. Hardwoods and Site Quality. In: Smith, Clay, ed. Proceedings-Guidelines for regenerating Appalachian hardwood stands, 1988, May 24-26. SAF Publication 88-03. Society of American Foresters, Washington, D.C. pp. 226-240.

Rightmyer, Richard D. 1988. Site Suitability Guide for Management Type Recommendations on the Chattahoochee National Forest. USDA Forest Service, Gainesville, GA. 10 pp.

SAS Institute Inc. 1985. Statistical Analysis System. Version AOSVS SAS 5.04. SAS Institute, Inc., Cary, N.C.

Trimble, George R. and Sidney Weitzman. 1956. Site index studies of upland oaks in the northern Appalachians. Forest Science. 2(3): 162-173.

Trimble, George R. and H. W. Yawney. 1968. Oak soil-site relationships in the Ridge and Valley region of West Virginia and Maryland. USDA-Forest Service, Northeastern Forest Experiment Station Res. Pap. NE-96.

U.S. Department of Agriculture, Forest Service. 1985. Chattahoochee-Oconee National Forests Land and Resource Management Plan. Gainesville, GA. 320 pp.

U.S. Department of Agriculture, Forest Service. 1988. Region 8 Silvicultural Examination and Prescription Handbook. USDA Forest Service, Southern Region. Atlanta, GA. Forest Service Handbook FSH 2409.26d. 250 pp.

Appendix A.--Site Suitability Guide, Chattahoochee NF, Georgia.

CHATTAHOOCHEE NF SITE SUITABILITY GUIDE (1/88) 1/

LANDFORM POSITION	SOIL DEPTH	SURFACE DEPTH	SOIL TEXTURE	RECOMMENDED MGMT. TYPE*	HARDWOOD POTENTIAL
RIDGETOPS	(Aspect not applicable)				
	<20"	>6"	CLAYEY	HARDWOOD	MEDIUM
			LOAMY	MIXED	MEDIUM
			COARSE	PINE	LOW
		2-6"	CLAYEY	MIXED	MEDIUM
			LOAMY	PINE	LOW
			COARSE	PINE	LOW
		<2"	ALL	PINE	LOW
	>20"	>6"	CLAYEY	HARDWOOD	MEDIUM
			LOAMY	HARDWOOD	MEDIUM
			COARSE	MIXED	MEDIUM
		2-6"	CLAYEY	HARDWOOD	MEDIUM
			LOAMY	MIXED	MEDIUM
			COARSE	PINE	LOW
		<2"	ALL	PINE	LOW
UPPER SIDESLOPES					
ASPECT: N-E					
	0-20"	>6"	CLAYEY	HARDWOOD	MEDIUM
			LOAMY	HARDWOOD	MEDIUM
			COARSE	MIXED	MEDIUM
		2-6"	CLAYEY	HARDWOOD	MEDIUM
			LOAMY	MIXED	MEDIUM
			COARSE	PINE	LOW
		<2"	ALL	PINE	LOW
	20-40"	>6"	ALL	HARDWOOD	MEDIUM
		2-6"	CLAYEY	HARDWOOD	MEDIUM
			LOAMY	HARDWOOD	MEDIUM
			COARSE	MIXED	MEDIUM
		<2"	CLAYEY	MIXED	MEDIUM
			LOAMY	MIXED	MEDIUM
			COARSE	PINE	LOW
	40"+	ALL	ALL	HARDWOOD	HIGH
ASPECT: S-W					
	0-20"	ALL	ALL	PINE	LOW
	20-40"	ALL	ALL	PINE	LOW
	40"+	ALL	CLAYEY	MIXED	MEDIUM
			LOAMY	PINE	MEDIUM
			COARSE	PINE	LOW

LANDFORM POSITION	SOIL DEPTH	SURFACE DEPTH	SOIL TEXTURE	RECOMMENDED MGMT. TYPE*	HARDWOOD POTENTIAL
MIDDLE SIDESLOPES					
ASPECT: N-E					
	0-20"	<2"	CLAYEY	HARDWOOD	MEDIUM
			LOAMY	MIXED	MEDIUM
			COARSE	PINE	LOW
		2-6"	CLAYEY	HARDWOOD	HIGH
			LOAMY	HARDWOOD	HIGH
			COARSE	MIXED	MEDIUM
		>6"	ALL	HARDWOOD	HIGH
	20-40"	<2"	CLAYEY	HARDWOOD	HIGH
			LOAMY	HARDWOOD	HIGH
			COARSE	MIXED	MEDIUM
		2-6"	ALL	HARDWOOD	HIGH
		>6"	ALL	HARDWOOD	HIGH
ASPECT: S-W					
	0-20"	<2"	ALL	PINE	LOW
		2-6"	CLAYEY	MIXED	MEDIUM
			LOAMY	PINE	LOW
			COARSE	PINE	LOW
		>6"	CLAYEY	MIXED	MEDIUM
			LOAMY	MIXED	MEDIUM
			COARSE	PINE	LOW
	20-40"	<2"	CLAYEY	MIXED	MEDIUM
			LOAMY	PINE	LOW
			COARSE	PINE	LOW
		2-6"	CLAYEY	MIXED	MEDIUM
			LOAMY	MIXED	MEDIUM
			COARSE	PINE	LOW
		>6"	ALL	MIXED	MEDIUM
	40"+	ALL	CLAYEY	HARDWOOD	MEDIUM
			LOAMY	MIXED	MEDIUM
			COARSE	PINE	MEDIUM
LOWER SIDESLOPES					
ASPECT: N-E					
	0-20"	<2"	CLAYEY	HARDWOOD	HIGH
			LOAMY	HARDWOOD	HIGH
			COARSE	MIXED	MEDIUM
		2-6"	ALL	HARDWOOD	V.HIGH
		>6"	ALL	HARDWOOD	V.HIGH
	20-40"	ALL	CLAYEY	HARDWOOD	V.HIGH
			LOAMY	HARDWOOD	V.HIGH
			COARSE	MIXED	HIGH
	40"+	ALL	ALL	HARDWOOD	V.HIGH

LANDFORM POSITION	SOIL DEPTH	SURFACE DEPTH	SOIL TEXTURE	RECOMMENDED MGMT. TYPE*	HARDWOOD POTENTIAL
LOWER SIDESLOPES					
ASPECT: S-W					
	0-20"	<2"	CLAYEY	MIXED	MEDIUM
			LOAMY	MIXED	MEDIUM
			COARSE	PINE	LOW
		2-6"	CLAYEY	HARDWOOD	MEDIUM
			LOAMY	MIXED	MEDIUM
			COARSE	MIXED	MEDIUM
		>6"	CLAYEY	HARDWOOD	MEDIUM
			LOAMY	HARDWOOD	MEDIUM
			COARSE	MIXED	MEDIUM
	20-40"	<2"	ALL	MIXED	MEDIUM
		2-6"	CLAYEY	HARDWOOD	MEDIUM
			LOAMY	MIXED	MEDIUM
			COARSE	MIXED	MEDIUM
		>6"	ALL	HARDWOOD	HIGH
	40"+	ALL	CLAYEY	HARDWOOD	HIGH
			LOAMY	HARDWOOD	HIGH
			COARSE	MIXED	MEDIUM

DEFINITIONS OF GUIDE FACTORS

*RECOMMENDED MANAGEMENT TYPE- general category recommendation; specific management types should be based on the forest type in place, site potential and management direction.

SOLUM DEPTH	TOPSOIL DEPTH	SOIL TEXTURE
0-20" SHALLOW	<2" SHALLOW	CLAYEY: CLAY, SILTY CLAY
20-40" MODERATELY DEEP	2-6" MODERATELY DEEP	LOAMY: LOAM, SILT LOAM
40"+ DEEP	>6" DEEP	COARSE: SANDY, STONY

ASPECT: N-E: AZIMUTH 330 TO AZIMUTH 120; S-W: AZIMUTH 121 TO AZIMUTH 329
LANDFORM POSITION: FROM ON-SITE OR TOPOGRAPHIC MAP INTREPRETATION
--Toeslopes typically included in lower slopes, coves may be included in both lower and middle slope positions, ridgetops typically include portions of upper sideslopes.

SOURCES OF SOIL INFORMATION: ON-SITE EVALUATION OR SOIL SURVEY REPORTS

HARDWOOD SITE POTENTIAL 2/	RECOMMENDED MANAGEMENT TYPE GROUP
VERY HIGH: SITE INDEX 95+ FOR YELLOW-POPLAR	HARDWOOD
HIGH: SITE INDEX 75-95 FOR OAKS	HARDWOOD
MEDIUM: SITE INDEX 65-75 FOR OAKS	MIXED OR PINE, CK ASPECT
LOW: SITE INDEX <65 FOR OAKS	PINE

1/ Rightmyer, Richard D. 1988. Site Suitability Guide for Management Type Recommendations on the Chattahoochee National Forest, Georgia. USDA Forest Service, Gainesville, GA. 30501

2/BASED ON 50 YEAR CURVES.

USE OF LAND CLASSIFICATION ON THE CUMBERLAND PLATEAU[1/]

John C. Rennie[2/]

ABSTRACT. Smalley (1980, 1982, 1983 & 1984) developed a comprehensive forest site classification system for the Cumberland Plateau, Highland Rim and Pennyroyal regions of Tennessee and adjoining states. Past abuses of forests make the trees in many stands poor indicators of site quality and potential productivity. This paper describes the use of landtype as a descriptor of site quality in a growth and yield predictor on the Cumberland Plateau.

INTRODUCTION

Tennessee has extensive forest resources, with about 50 percent of its land in forests. Three quarters of the forests are hardwoods. Ninety percent of forested lands is in private ownership (May in press) with much of the hardwood forests in small tracts in nonindustrial private ownership. Sound forestry practices are applied to only a small portion of these lands (Birdsey 1983). Increasing the level of forest management on nonindustrial private ownerships is a goal of forestry extension programs, the Tennessee Division of Forestry, consulting foresters, and industrial landowner assistance programs.

Growth and yield predictors are basic tools used in timber management, allowing foresters to predict stand volume and stems per acre, usually by diameter class, at various ages using initial or intermediate stocking, and site quality. Mortality and volume growth for five or ten year periods can also be predicted from the same stand variables.

Currently available growth and yield predictors for hardwood types are not appropriate for Tennessee. They were developed using data from other regions, or from data obtained so long ago so as to be of questionable value. New predictors that are based on current Tennessee data need to be developed.

The work described here uses the Smalley site classification system based upon landtype to quantify site quality in a growth and yield predictor for the Cumberland Plateau of Tennessee. Although a few intensive studies have been conducted using this site classification system, the one reported here is the first with data from a large area.

PAST WORK

Smalley (1980, 1982, 1983 & 1984) presented a system of land classification for the Cumberland Plateau and Highland Rim of Tennessee. Landtypes are defined to include land of about equal productivity. Smalley described the geology, soils, vegetation, productivity and management problems expected on sites within each landtype. This information was drawn from a variety of published material and, in some cases, is based upon extrapolation.

Three studies have examined soil or vegetation within Smalley's landtypes. Hammer (1986) studied relationships among soil morphology, soil water, and forest tree growth on three landtypes at two locations - Catoosa Wildlife Management Area and Fall Creek Falls State Park - both located on the Cumberland Plateau. He concluded that the forest land classification system appeared to be a viable method of grouping soils into units suitable for forest management.

Clatterbuck (in press) used Smalley's site classification to initially stratify vegetation in the six landtypes on the Cheatham Wildlife Management Area in the Western Highland Rim. From this he developed a community classification system that integrated vegetation and landform to serve a basis for multiresource land management decisions.

1/ Invited paper presented at "Ecological Land Classification: applications to Identify the Productive Potential of Southern Forests", 7-9 January 1991, Charlotte, North Carolina.

2/ Associate Professor, Department of Forestry, Wildlife and Fisheries, The University of Tennessee, Knoxville, 37901-1071.

Arnold (1990) studied vegetation communities in four major landtypes that occur in Prentice Cooper State Forest on the Cumberland Plateau. He found that the landtypes examined had relatively distinct forest cover, although some forest types occurred in more than one landtype. He indicated the need for additional variables to distinguish between similar communities that occur on different landtypes.

PRESENT WORK

Much of the Cumberland Plateau and Highland Rim of Tennessee is in mixed hardwoods for which there are no applicable growth and yield predictors. Use of site index as a variable is limited in most of these stands since their history is unknown and many are not even-aged. Landtypes offer an alternative to site index for these mixed stands since they are designed to include areas of similar communities that occur on different landtypes.

This study uses data collected by U.S.D.A. Forest Service, Forest Inventory and Analysis (Forest Survey) field crews. Crews were trained in using Smalley's landtypes on the Cumberland Plateau. At each cluster (sample plot) consisting of ten sample points, landtype (or landtypes) and boundaries were recorded on a special data sheet; disturbance(s) were also recorded where they occurred. Landtype data were keypunched by county, sample plot and sample point.

Standard plot and tree data for the previous and current measurements were provided by the USDA Forest Service. Data were reviewed on a plot by plot basis; plots with significant cutting or other disturbances were removed from the data set.

There were 319 sample plots with useable landtype data, representing 16 counties covering the Cumberland Plateau in Tennessee. Plots occurred in all 20 landtypes described by Smalley (1982). The number of plots ranged from 2 in each of 3 landtypes (upper shale slopes, north; lower shale slopes, south; terraces, streambottoms and depressions with poor drainage)to 54 in the broad undulating sandstone upland landtype.

Nineteen USFS forest types were identified on the sample plots. Eleven forest types were represented by fewer than six plots each. Seven forest types are represented by 12 to 24 plots each. One forest type (white oak, red oak, hickory) was found on 148 plots.

Two hundred and fifty plots had no evidence of harvest activity since the last measurement while 59 showed some signs of partial cut . Nine plots had been clearcut and one plot had a salvage cut. Two hundred and ninety nine plots had no evidence of management since the last measurement, while the remainder had indications of management activities including thinning (1 plot), stand improvement (5), stand conversion (3), site preparation (5) and natural disturbance (6).

Preliminary analyses consisted of contingency tables examining USFS site class by aspect and by parent material. Site classes 1 and 2 were pooled because only one plot was in class 1. Landtypes were pooled into north, south, ridges and drains. A significant difference was found in the distribution of plots by site class over these four categories of aspect. When a fifth category-outcrops - was added, the distribution continued to be significant. The distribution of plots by site class was not significant over parent material.

FUTURE WORK

Development of a growth and yield predictor will be attempted using plots on which there was little or no disturbance. Because most forest types were represented by only a small number of plots, it may be necessary to use only the white oak-red oak-hickory forest type (n=148). However, within this forest type, one landtype is not represented and eleven landtypes are represented by fewer than ten plots. Combining landtypes may be necessary. Possible combination are upper and lower slope or north and south aspect.

Results reported above are for sample plots on which there was a single or dominant landtype. Data were collected on an additional 75 sample plots that did not have a dominant landtype. Within each plot there are ten sample points each with a landtype or disturbance code. If sample points within a sample plot are grouped by landtype, the number of forest types and landtypes in the data set will increase. This may increase the number of landtypes included in the growth and yield predictor and decrease the amount of combining needed to achieve adequate representation in combinations of landtype and forest type.

LITERATURE CITED

Arnold, D.H. 1990. Distinctness of forest communities within landtypes in the Prentice Cooper State Forest, Marion County, Tennessee. Knoxville: University of Tennessee. 130 pp. Thesis.

Birdsey, R.A. 1983. Tennessee Forest Resources. Resource Bulletin SO-90. New Orleans, LA: U.S. Department of Agriculture. Forest Service, Southern Forest Experiment Station. 35 pp.

Clatterbuck, W.K. A community classification system for forest evaluation: development, validation, and extrapolation. Forest Science (in press).

Hammer, R.D. 1986. Soil variability, soil water, and forest tree growth of three forested Cumberland Plateau landtypes. Knoxville: University of Tennessee. 319 pp. Dissertation.

May, D.M. Timber Resources of Tennessee. Resource Bulletin. New Orleans, LA: U.S. Department of Agriculture. Forest Service, Southern Forest Experiment Station (in press).

Smalley, G.W. 1980. Classification and evaluation of forest sites on the Western Highland Rim and Pennyroyal. Gen. Tech. Rep. SO-30. New Orleans, LA: U.S. Department of Agriculture. Forest Service, Southern Forest Experiment Station. 120 pp.

Smalley, G.W. 1982. Classification and evaluation of forest sites on the mid-Cumberland Plateau. Gen. Tech. Rep. SO-38. New Orleans, LA: U.S. Department of Agriculture. Forest Service, Southern Forest Experiment Station. 58 pp.

Smalley, G.W. 1983. Classification and evaluation of forest sites on the Eastern Highland Rim and Pennyroyal. Gen. Tech. Rep. SO-43. New Orleans, LA: U.S. Department of Agriculture. Forest Service, Southern Forest Experiment Station. 123 pp.

Smalley, G.W. 1984. Classification and evaluation of forest sites on the Cumberland Mountains. Gen. Tech. Rep. SO-50. New Orleans, LA: U.S. Department of Agriculture. Forest Service, Southern Forest Experiment Station. 84 pp.

FORECASTING GROWTH OF PINE-HARDWOOD MIXTURES FROM THEIR ECOLOGICAL LAND CLASS[1]

F. Thomas Lloyd[2]

Abstract—A conceptual framework is outlined for an alternative to using site index as a predictor variable in growth and yield models. Site quality differences are captured in ecological land classification units which are predicted from topographic and edaphic data. These units represent a moisture gradient that translates into site quality differences. Separate growth curves are developed for each ecological unit. The resulting growth predictions can be applied directly to particular land areas when the topographic and edaphic factors are registered in a computer-based spatial data system.

Keywords: Stand-level models, site index, growth and yield.

INTRODUCTION

The purpose of this symposium is to share research results and study updates on assessment of the productive potential of southern forests through ecological land classification. Wood volume is a major economic component of productive potential, so linking growth and yield prediction systems to ecological land classification models is of interest. Finding a strong link is the objective of the study described here. More specifically, I hope to use ecological land classification to incorporate site quality into a growth forecasting system for natural pine-hardwood stands in the Piedmont physiographic region. This research is not complete (permanent plots are still being installed), so this progress report describes: 1) the rationale behind using land classification in the place of site index, 2) the model building strategy to be employed, and 3) the permanent plot design.

WHY NOT SITE INDEX?

Model developers and model users have often clashed over the use of site index as a measure of land productivity in growth forecasting systems. The user appreciates the practical difficulties in measuring site index and relating it to a particular landscape. Their dissatisfaction is supported by a large body of literature describing disappointing attempts to relate an assortment of physical site attributes to site index. Model builders are not blind to the problems of users, but they tenaciously cling to the strong relationship between the site index and the stem volume.

It is true that site index describes a major dimension of cumulative stand volume and makes statistically significant contributions to the empirical fit of stand volume expressions to data. In a field where improvements in fits are hard to find, model builders are very reluctant to give up site index as a primary expression of site quality. However, the justification that "it works" is becoming less convincing as evidence of flaws in the site index concept accumulates.

A most disabling flaw is the failure of the foundational assumption that density does not affect height growth across the range of densities encountered in "normal" stand management. Jones (1977) and Lloyd and Jones (1983) showed for loblolly and slash pines (P. taeda L. and P. elliottii Engelm.) that height growth is meaningfully reduced by increasing densities encountered in normal management practice and that the trend becomes increasingly pronounced with increasing stand age. Lloyd and Jones go on to show how volume projections after 20 years are over-estimated by 46 percent in the densest stands (6-feet by 6-feet spacing) when a common site index

[1]Presented at the Symposium on Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests, Charlotte, NC, January 7-9, 1991.

[2]Project Leader, Southeastern Forest Experiment Station, USDA Forest Service, Clemson, SC.

value is used. The site index curves we used accurately described height growth for the widest spacing (15-feet by 15-feet), but increasingly over-estimated height as planting density increased. The conclusion, at least for southern yellow pine, is that density affects height growth and height growth (that is, site index) affects density growth. This feedback mechanism must be addressed in the growth modeling process in a way that site index does not allow.

Research on the precision of the site index estimator (Lloyd and Hafley 1977, Lloyd 1980, and Lloyd et al. 1982) verifies another problem that has been intuitively clear to site index users for a long time. Variance of the site index estimator can be quite large, depending upon sample size and stand age. An imprecise estimate of site index produces estimation bias when it is used as an independent variable in a least-squares model fitting process. Furthermore, this bias is not uniform across the prediction space because of the way variance increases with decreasing stand age. This measurement error can be large, and the resulting bias may help to explain our inability to accurately predict site index from site attributes.

USING LAND CLASSIFICATION FOR SITE QUALITY

Ecological land classification offers an alternative for incorporating site quality into growth and yield prediction. Success will depend on the extent to which the land units defined by the classification model represent site quality and the extent they can be predicted from physical attributes of the land.

The land classification system used in this investigation (Jones 1989) is built on landform, soil, and late successional vegetation interrelationships on Piedmont sites. Its land units represent a moisture gradient that relates well to site quality. Expressions of landform, which describes the attributes of the landscape, include aspect and slope positions. Key soil properties include depth to and percentage of fine textured material in the maximum clay horizons. The modeling approach will use the vegetation-defined ecological land classification units to predict height and density growth.

MODELING APPROACH

Modeling will start with the relatively easy task of projecting changes in closed-canopy stands over relatively short periods (no more than 10 years). The projection interval is restricted because we plan to speed the model-building process by looking backward in time. That is, we will use stem analysis and increment cores from today's trees to reconstruct past conditions on permanent plots. Past mortality can only be inferred for relatively brief periods. Closed-canopy stands will be used in this initial model so as to avoid prediction problems due to rapid composition changes in young stands resulting from death of shade intolerant species that failed to reach an overstory position during early stand development.

The stand-level modeling approach will build on the widely recognized expression:

$$V = kBH \tag{1}$$

where:
k = a constant to be estimated,
B = present stand basal area, and
H = present height of the dominant stand.

Variations of this fundamental, geometrically-based volume construct serves as the underpinning for most stand-level growth and yield models.

This particular application in mixed pine-hardwood stands will partition volume between the pines and the hardwoods, so total stand volume is expressed as:

$$V = V_p + V_h. \tag{2}$$

Equation (1), therefore expands to:

$$V = k_pB_pH_p + k_hB_hH_h. \tag{3}$$

The subscripted terms are the same as k, B, and H defined above for the respective pine and hardwood stand components, and total stand basal area equals the sum of B_p and B_h. Equation (3) simply says that total stand volume is the sum of the component volumes.

The final step in the modeling approach consists of incorporating a growth element. It is easier to envision this process by returning to Equation (1) without the component subscripts. It is assumed for some projection interval that the stand grows dB square feet in basal area and dH feet in height, so future density and dominant height are (B + dB) and (H + dH). The projected volume becomes:

$$V = k(B + dB)(H + dH). \tag{4}$$

It is a straight-forward process to obtain a model for the partitioned stand volume by adding subscripts like those in Equation (3), yielding the model:

$$V = k_p(B_p + dB_p)(H_p + dH_p) + k_h(B_h + dB_h)(H_h + dH_h) \tag{5}$$

where the basal areas and heights B_p, B_h, H_p, and H_h are given conditions in the present stand and the growth increments dB_p, dB_h, dH_p, and dH_h must be predicted. The modeling task of this research will be to develop predictors for these dB and dH increments.

There is much literature on the structure for these growth expressions, but the final forms will be determined from a combination of geometrical, biological, and empirical arguments. Basal area growth (dB) will be related to present basal area (B), stand age, and site quality. The site quality effect will be incorporated by developing separate growth functions for each of the ecological land groups, thus producing a family of growth curves. A similar approach will be used for height growth (dH), which will likely be some expression of present height (H), density (B), and stand age. The growth and yield model is thus linked to the landscape though the parameters associated with ecological units, which are defined by combinations of aspect, slope position, and depth of rooting zone.

PERMANENT PLOT DESIGN

Approximately 125 permanent plots will be distributed uniformly across stands from 15 to 85 years old. They will be installed in natural pine-hardwood stands on National Forests and on the Clemson University Experimental Forest in the Piedmont physiographic region. Presently, 43 plots have been installed.

It was already pointed out that growth will be obtained from increment cores taken at breast height on all merchantable trees (4.6 + inch diameter at breast height) and stem analyses from two trees (one pine and one oak) near each plot, but no closer than 1 chain. The plots are circular in shape and 1/5-acre in size. Diameter at breast height is measured on all tree species (including nonmerchantable trees). All merchantable-sized trees are numbered clockwise on azimuths starting at North and the distance of each from the plot center is recorded. The crown position of each tree is classed as dominant, codominant, intermediate, or suppressed, and total height of every fifth tree in each 1-inch diameter class is measured in both the pine and hardwood components. For diameter classes with less than five trees, height is measured on one randomly selected tree.

The plot center is identified with a metal post. Four large nails are driven into the soil beneath the litter layer to help relocate plot centers if center posts are removed before the next remeasurement. Plots are located on the ground by coordinate readings from global positioning equipment.

We hope to use mortality data from the Forest Inventory and Analysis Unit to adjust initial stocking obtained from the increment cores. Stand density and volume of survivor trees will be adjusted to include basal area and volume estimates of trees that died during the 10 and 20 years periods prior to plot installation. In this manner, net growth (as opposed to survivor growth) will be approximated and the projection interval will be lengthened.

CONCLUSION

The justification for trying something new is strong, and interest among those who use growth and yield models is high. It is no doubt true that the precision of growth predictions will be reduced by the presence of some variation of site quality within an ecological classification unit. However, the traditional site index approach produces an over-confident sense of precision from the fact that families of curves can be constructed arbitrarily close.

The closeness of the site index curves essentially defines the width of the site index class, and Lloyd and Hafley (1977) showed how the probability of misclassification increased with deceasing class size. My assessment is that 3 to 5 productivity classes are probably the best we should expect form either of the above approaches. What is gained by using ecological classification units is the ability to link growth models to the landscape and the ability to more appropriately describe density and height growth as interrelated functions of site quality.

LITERATURE CITED

Jones, Steven M. 1989. Application of landscape ecosystem classification in identifying productive potential of pine-hardwood stands. In: Waldrop, Thomas A., ed. Proceedings, pine-hardwood mixtures: a symposium on management and ecology of the type; 1989 April 18-19; Atlanta, GA. Gen. Tech. Rep. SE-58. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. pp. 64-69.

Jones, Earle P., Jr. 1977. Precommercial thinning of naturally seeded slash pine increases volume and monetary returns. Res. Paper SE-164. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, 12 p.

Lloyd, F. Thomas. 1981. How many tree heights should you measure for natural, Atlantic Coastal Plain loblolly site index? Southern Journal of Applied Forestry 5(4):180-183.

Lloyd, F. Thomas; Jones, Earle P., Jr. 1983. Density effects on height growth and its implications for site index prediction and growth projection. In: Proceedings, Second biennial southern silvicultural research conference; 1982 November 4-5; Atlanta, GA. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. pp. 329-333.

Lloyd, F. Thomas; Hafley, William L. 1977. Precision and the probability of misclassification in site index estimation. Forest Science 23(4):493-499.

Lloyd, F. Thomas; Muse, H. David; Hafley, William L. 1982. A regression application for comparing growth potential of environments at different points in the growth cycle. Biometrics 38:479-484.

THE ROLE OF ECOLOGICAL LAND CLASSIFICATION SYSTEMS IN THE SILVICULTURAL DECISION PROCESS[1/]

Thomas R. Fox[2/]

Abstract.-- An applicable land classification system can provide the type of information required to make site specific silvicultural prescriptions. Since the stand is the basic unit of silviculture, the spatial scale of the land classification system must coincide with that of the stand. An appropriate land classification system must also emphasize the features of a region that most strongly affect productivity and management. Integration of a land classification system with a geographic information system increases the flexibility and accessibility of the information. The development of a silvicultural decision support system ("expert" system) is a potential outgrowth of this integration.

Keywords: Soil Mapping, Geographic Information Systems, Decision Support

INTRODUCTION

Biologically sound silvicultural decisions must be made on a species and site specific basis. Perhaps the two most important factors influencing the silvicultural decision process are the inherent productivity of each site and the potential to affect site productivity through silvicultural manipulations. In todays complex environment, informed silvicultural decisions also require forest managers to synthesize data on a large number of additional factors ranging from the management objectives of the landowner, to the economic climate of the region, to the social and political consequences of a particular decision. It is my contention that some type of land classification system, either implicit or explicit, that takes these factors into consideration is a part of all sound silvicultural decisions.

There are two objectives of this paper. The first is to describe, in a general manner, the attributes I believe are necessary to successfully integrate a land classification system into the silvicultural decision process. Second, by example, I hope to illustrate how silvicultural decisions can be simplified with information derived from an ecological land classification system.

TYPES OF LAND CLASSIFICATION SYSTEMS

An applicable land classification system can provide the type of the detailed information upon which informed silvicultural decisions can be based. It is not my intention to review in detail the numerous land classifications systems that have been developed. However, some brief comments on the process of land classification and the general types of classification systems that exist would be valuable and will help to provide a framework for discussion. Those

1/ Presented at Symposium on Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests, Charlotte, NC, January 7-9, 1991.

2/ Silvicultural Research Coordinator, ITT Rayonier, Inc., Southeast Forest Resources, Forest Research Center, P.O. Box 819, Yulee, FL 32097.

interested in more specific information should refer to the other papers in this volume and several recent reviews and symposia on the subject (Carmean, 1975; Bockheim, 1984; Wickware and Stevens, 1986; Williams and Gresham, 1988).

The Process of Land Classification

Land classification can be a descriptive or a predictive process. Descriptive land classification systems attempt to characterize the biotic and/or abiotic feature of an area and establish unique groups with similar features. This type of classification system often includes a mapping component. Examples of this type of land classification includes the soil mapping done by the USDA Soil Conservation Service and various industrial forest products companies, and the vegetation mapping currently being done by the US Fish and Wildlife Service as part of the National Wetlands Inventory. Predictive land classification systems attempt to relate a property of interest to some measurable feature of the site. The property of interest is usually site index or site quality. These systems may be quantitative and utilize a regression approach, or semi-quantitative and award points for various features. The advantage of these systems is that once the relationship is established, the site quality of any land can be evaluated rapidly with a minimum of effort. Detailed mapping of the land base is usually not done. An example of the regression type of site classification system is the soil-site work of Coile and Schumacher (1964). Examples of the semi-quantitative approach include some of the soil-site work of Zahner (1957) and the site quality rating system developed by International Paper in New England (Saviello, 1979).

In practice, many land classification systems combine predictive features into a descriptive framework. This is usually a normal progression following the implementation of a descriptive system. Correlating properties of the various classification units with forest productivity can lead to an improved understanding of the functional relationships involved. This may in turn lead to an improved classification system.

Types of Descriptive Land Classification Systems

The land classification systems that employ the descriptive approach can be divided into four broad groups: 1) those that utilize general landscape and/or vegetation relationships on a more-or-less regional scale; 2) those that utilize soil-site relationships as the basis for mapping; 3) those that utilize some type of soil grouping procedure; and 4) those that utilize the individual soil series approach.

Landscape Relationships

In the South, the best example of a land classification system that utilizes broad scale landform relationships is the system developed for the Interior Uplands of Kentucky, Tennessee, and Alabama (Smalley, 1980; 1982). This system integrates physiography, geology, soils, topography and vegetation to develop landtypes for the region. These landtypes are evaluated from the standpoint of forest productivity and related management limitations.

Soil-Site Relationships

Soil-site relationships such as those derived by Coile and Schumacher (1964) have been incorporated into a soil mapping system. In the Coile mapping system, soils are grouped into map units based on site index determined from features such as drainage class, texture, and depth of surface horizons. A large amount of forest land in the South has been mapped utilizing this system.

Soil Groups

There have been several attempts to group soils on the basis of similarities in physical properties into relatively narrow classes that respond to management in a like manner. The woodland suitability groups developed by the SCS is one example of this type of classification system (Lemmon, 1970). The CRIFF soil groups (Fisher and Garbett, 1980) are probably the most widely used land classification system in the South based on soil groups. In this system, the forest soils of the southern Coastal Plain are divided into eight groups based on drainage class, the presence of spodic and argillic horizons, and the depth to these subsurface horizons. This system was developed to group soils based on the likelihood of a growth response following forest fertilization. It has proven useful in this capacity. However, it was not intended to be used as a system to classify the inherent productivity of the site.

Soil Series

The most widely used land classification system in the South is the soil mapping approach utilizing the concept of the soil series. A soil series consists of soils that are essentially alike in all major profile characteristics (Brady, 1974). This system is used by the USDA Soil

Conservation Service in the national soil survey. This is a continuing program under which the soils of the entire United States will eventually be mapped. The concept of the soil series has been widely adopted as the basis for mapping forest soils. Many forest products companies have mapped or are mapping their land using this approach (Broerman, 1978; Campbell, 1978). In some cases, standard SCS soil series are employed in the mapping process, while in others "in house" soil series are developed.

SELECTING AN APPROPRIATE LAND CLASSIFICATION SYSTEM

There is no one, single land classification system that is best suited to all situations. What works successfully in one region may be completely inadequate in another region, even within the same company or organization.

The essential unit of silviculture is the stand (Smith, 1986). Therefore, the first requirement of a appropriate land classification system, is that the spatial scale of the land classification system must match the spatial scale of the stand. As Smith (1986) states: "The tendency to treat large groups of dissimilar stands as if they conformed to a uniform, hypothetical average should be studiously avoided." The logical conclusion of this is that land classification systems developed for large-scale, regional applications will probably have very little utility to the silviculturalist in the much smaller world of the stand.

The appropriate land classification system for silvicultural applications depends on both the intensity of silviculture practiced and the specific land base in question.

Intensity of Management

In an intensively managed forest, individual stands as small as one acre may be recognized; whereas under a more extensive management system the same forest may contain stands no smaller than several hundred acres. These two situations will require different land classification systems. An extremely detailed land classification system will be needed if intensive silviculture is to be practiced in a region with a very heterogeneous landscape. However, this same system may be inappropriate and unnecessarily expensive where more extensive silvicultural systems were practiced.

In many areas of the South, industrial forest management is progressing from the idea of the regulated forest to the domesticated forest (Stone, 1975). In the domesticated forest, management inputs are high and technological innovations are incorporated into silvicultural practices. This high input forestry is synonymous with high cost forestry. Economic considerations require that these high input silvicultural systems be extremely site specific in order to obtain the high yields necessary to justify the costs. Therefore, as the transition to the domesticated forest occurs, there is a need for more detailed information from land classification systems.

In the domesticated forest, site quality is no longer a fixed quantity; it may be improved or degraded. Therefore, land classification systems must address not only the inherent productivity of each site, but also the potential to affect site productivity through silvicultural manipulations. Fragile sites must be recognized and treated gently to avoid site degradation. Sites where the inherent productivity can be greatly enhanced must also be delineated so that the appropriate silvicultural treatments can be applied to capture this potential productivity.

Physiographic Region and Landscape Heterogeneity

The physiographic region where the silviculturalist works has a large impact on the selection of an appropriate land classification system. In the mountainous regions of Virginia, North Carolina, Kentucky, West Virginia and Tennessee, factors such as parent material, aspect, slope, and elevation vary tremendously and strongly affect forest productivity and management. Therefore, these features need to be incorporated into a land classification system for this region (Smalley, 1980). In contrast, in the flatwoods of the Coastal Plain in Georgia and Florida, the landscape is flat and the soils are derived from marine deposits. Differences in drainage class, soil texture, and subsurface horizon formation strongly affect productivity and forest management. These features change dramatically with an elevation change of less than two or three feet. In this region, a land classification system must recognize these more subtle features.

INTEGRATING A LAND CLASSIFICATION SYSTEM INTO THE SILVICULTURAL DECISION PROCESS

Nearly every silvicultural decision can benefit from the information provided by a land classification system. In practice, even when a formal land classification system is not in place, most silvicultural decisions probably utilize some implicit

form of land classification. The tract manager who recognizes an area as "A good piece of dirt that really grows trees" or a "Wet spot that gets boggy with just a little rain" has a land classification system that may be as good or better than one generated from a computer. However, this type of personal, implicit land classification system is rapidly overwhelmed by the complexities of silviculture in the domesticated forest. A formal ecological land classification system can provide the framework for sound silvicultural decisions in this complex environment.

The first step in integrating a land classification system into the silvicultural decision process is to involve those who are going to use the system in the development process. There needs to be open, detailed and continuous communication among the field foresters who will utilize the information, those conducting the actual land classification in the field, and the research or technical group who developed the system. This will result in a much improved system. Field foresters are much more likely to utilize a system that they have confidence in because they had input into and helped develop it. Involving the field foresters should also improve and actually speed up the classification process because the field mappers can draw on the accumulated knowledge and experience of those who work day-to-day on the land. Likewise, feedback from both the classifiers and foresters in the field, allows the developers to correct flaws in the system and fine tune it to the needs of a particular area or group.

A successful land classification system also needs to store the data in an accessible manner and present it in a clear and flexible form. Foresters and land managers usually need their information "yesterday". Therefore, they need to have ready access to the data in a form they can use. Unwieldy maps that are hard to work with or difficult to interpret will soon be gathering dust in the back of the closet or relegated to the bottom shelf of the bookcase. The information needs of foresters also change rapidly. One day the land classification data may need to be interpreted relative to forest fertilization decisions. The next, it may be needed to decide on road locations, harvest boundaries or site preparation prescriptions.

Incorporating a land classification system into a geographic information system (GIS) is the best way to meet requirements of accessibility and flexibility. With land classification combined in a GIS, the planning and organization of complex silvicultural and forest management operations in the domesticated forest becomes possible and practical.

Combining a land classification system into GIS also provide a mechanism to retain the accumulated knowledge and experience of land managers. The days when a forester spent the majority of a career on one tract of land are ending. As foresters move from one area to another, a considerable period of time may be spent learning the new area. During this time, productivity and efficiency are reduced. However, incorporating data and observations from previous managers into a GIS based land classification system would allow a forester to learn quickly what has and has not worked in the past. This can serve as an intelligent starting point from which to proceed.

From a silvicultural standpoint, a combined GIS/land classification system should be followed by the development of a silvicultural decision support system. The objective of such an "expert" system would be to provide quantitative information on the silvicultural options available. Ideally, it should permit the evaluation of integrated silvicultural systems rather than just marginal treatment. For example, rather than just determine which is the "best" fertilization treatment, it should evaluate combinations of site preparation, fertilization, thinning, and perhaps competition control to determine what is the "best" overall combination of treatments. The goal is not to replace field foresters with a computer model, but rather to provide them with the information they require to do their job more effectively.

APPLICATIONS OF LAND CLASSIFICATIONS SYSTEMS

Silvicultural decisions can not be based solely on an ecological land classification system. Obviously, other factors such as stand conditions strongly influence silvicultural decisions. However, an appropriate land classification system can be used as a starting point to guide most silvicultural decisions. In this section, a few examples of silvicultural decisions that rely heavily on information that a land classification system can provide will be presented. Numerous other examples exist which could have also been given.

Species Selection

Guiding the selection of the best species to plant on a given site is

perhaps the most common use a land classification system in forestry. The problems resulting from planting a species "off site" have been recognized for decades. In many cases, selection of the appropriate species is relatively straight forward process; i.e. longleaf pine is planted on the sand hills in the Coastal Plain. The problem becomes more complex when several species perform equally well or an exotic species is introduced into a region. However, it is with these less straight forward decisions that a land classification is most needed.

A decision related to species selection, is the deployment of genetically improved material resulting from a tree breeding program. In this case, a land classification system can be used to deploy disease resistant genotypes to high hazard areas, or fast growing genotypes to the best sites. In some companies, family block plantings have been established where specific families are matched to certain sites. This level of refinement requires a very detailed land classification program.

Site Preparation

Because of the strong influence soil type has on the need for certain site preparation treatments, this is another silvicultural decision that is simplified when a land classification system is in place. For example, in the Lower Coastal Plain, bedding on wet sites is required to achieve adequate survival and growth. In other regions, certain sites require subsoiling to break up compacted soil horizons. The productivity of some fragile sites can be severely degraded by intensive mechanical site preparation.

Herbicide Application

Many herbicides used in forestry are soil active compounds. Their efficacy varies with factors such as texture and organic matter content of the soil. Information on these properties from a land classification system can be used to help select which chemical to use and the appropriate application rate. An ecological land classification system can also provide information of the types and densities of competing vegetation that will likely exist on a site.

Fertilization

Forest fertilization is another silvicultural treatment that can be based on soil properties. To maximize the return from fertilization, landowners must be able to locate the most responsive sites. In the Coastal Plain, effective fertilization recommendations can be made using the CRIFF soil groups (Pritchett and Comerford, 1983). In other regions, fertilization recommendations may be based on soil series or even site quality classes (Peterson and Gessel, 1983). All of these systems for identifying sites that will respond to fertilization can be incorporated into a land classification system.

Harvesting Systems

The appropriate system for harvesting timber can usually be determined from a land classification system. Factors such the suitability of a site for dry or wet weather logging, machine or hand felling, ground or aerial skidding can all be evaluated. The best location for logging roads can also be determined. A land classification system used in this manner can ensure that the harvesting system selected will be the most economic and will minimize disturbance of the site.

Numerous examples of the use of a land classification system in the interface between silviculture and forest management also exist. Two examples illustrate some of these applications.

Inventory and Harvest Decisions

Forest stands often include a range of soils and site quality classes. The ability to break larger stands into smaller, more uniform areas will increase the precision of inventory systems. A land classification can be used to stratify stands for this purpose. If sufficient variability exists, large stands can be broken into smaller units, which can then be managed more effectively. A land classification system can also help with harvest scheduling. Area and adjacency constraints in the harvest schedule can be addressed effectively using a land classification system.

Property Taxation

Much of the forest land in the South is appraised for tax purposes on the basis of productivity. An accurate land classification system can be used to support or refute the appraised value of forest land. Site quality evaluations from a detailed land classification system will often be accepted by local tax assessors.

CONCLUSIONS

Ecological land classifications can be extremely useful in the silvicultural decision process. Nearly every silvicultural decision requires the type of information a land classification system can provide.The need for this

information becomes more acute as the intensity of management increases. However, not all land classification systems are appropriate for this purpose. Appropriate land classification systems must match the spatial scale of the stands being managed. The intensity of silviculture and the physiographic region the classification system is to be used in are also critical factors affecting selection of an appropriate land classification system.

LITERATURE CITED

Bockheim, J.D., ed. 1984. Proceedings: Forest land classification: Experiences, problems, perspectives. Madison, WI: University of Wisconsin, Department of Soil Science. 276 pp.

Brady, Nyle, C. 1974. The nature and properties of soils. 8th Edition. New York: Macmillan Publishing Co., Inc. 639 pp.

Broerman, F.S. 1978. Site classification - Union Camp Corporation. In. Balmer, W.E., ed. Proceedings Soil Moisture -- Site Productivity Symposium; November 1-3, 1977; Myrtle Beach, SC: pp. 64-73.

Campbell, Robert, G. 1978. The Weyerhaeuser land classification system. In. Balmer, W.E., ed. Proceedings Soil Moisture -- Site Productivity Symposium; November 1-3, 1977; Myrtle Beach, SC: pp. 74-81.

Carmean, W.H. 1975. Forest site quality evaluation in the United States. Advances in Agronomy 27:209-269.

Coile, T.S.; and Schumacher, F.X. 1964. Soil-site relations, stand structure, and yields of slash and loblolly pine plantations in the southern United States. Durham, NC: T. S. Coile, Inc. 296 pp.

Fisher, R.F.; and Garbett, W.S. 1980. Response of semimature slash and loblolly pine plantations to fertilization with nitrogen and phosphorus. Soil Science Society of America Journal 44:850-854.

Lemmon, Paul E. 1970. Grouping soils on the basis of woodland suitability. In: Youngberg, Chester T.; and Davey, Charles B., eds. Tree Growth and Forest Soils. Corvallis, OR: Oregon State University Press. pp. 413-426.

Perterson, C.E.; and Gessel, S.P. 1983. Forest fertilization in the Pacific Northwest: Results of the regional forest nutrition research project. In: Ballard, Russell; and Gessel, Stanley, P. eds. I.U.F.R.O. Syposium on forest site and continuous productivity; 1982 August 22-28; Seattle, WA. Gen. Tech. Rep. PNW-163. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. pp. 365-369.

Pritchett, W.L.; and Comerford, N.B. 1983. Nutrition and fertilization of slash pine. In: Stone, E.L. ed. The managed slash pine ecosystem. Gainesville, FL: University of Florida, School of Forest Resources and Conservation. pp. 69-90.

Saviello, T. 1979. Northeast soil-based decision model. Research Letter No. 35. Bangor, ME: International Paper Co.

Smalley, Glendon, W. 1980. Classification and evaluation of forest sites on the western Highland Rim and Pennyroyal. General Technical Report SO-30. New Orleans, LA: U. S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 120 pp.

Smalley, Glendon, W. 1982. Classification and evaluation of forest sites on the Mid-Cumberland Plateau. General Technical Report SO-38. New Orleans, LA: U. S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 58 pp.

Smith, D.M. 1986. The practice of Silviculture. 8th Edition. New York: John Wiley & Sons. 527 pp.

Stone, E.L. 1975. Soil and man's use of forest land. In: Bernier, B.; and Winget, C.H. eds. Forest soils and forest land management. Quebec: Les Presses De L'Universite Laval. pp. 1-9.

Wickware, G.M.; and Stevens, W.C., eds. 1986. Proceedings: Site classification in relation to forest management. Joint Forestry Research Committee Publication O-P-14. Sault Ste. Marie, Ontario: Forestry Canada.

Williams, T.M.; and Gresham, C.A., eds. 1988. Predicting consequences of intensive forest harvesting on long term productivity by site classification. Proceeding IEA/BE Project CPC-10 Workshop. Georgetown, SC: Clemson University, Baruch Forest Science Institute.

Zahner, Robert. 1957. Field procedures for soil-site classification of pine land in south Arkansas and north Louisiana. Occasional Paper 155. New Orleans: U. S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 17 pp.

SITE EVALUATION FOR COMMERCIALLY IMPORTANT SOUTHERN HARDWOODS: A PRACTICAL FIELD METHOD[1/]

James B. Baker[2/]

Abstract.--This presentation provides a method of site evaluation for 14 commercially important hardwoods by incorporating the physical, moisture, nutrient, and aeration properties of a soil, as well as soil-site factors that influence these properties, into a site quality rating. The site evaluation technique also (1) identifies soil factors that limit tree growth, (2) provides a basis for possible soil improvement treatments, and (3) allows for comparisons in productivity of hardwoods on a range of sites.

Dr. Baker's presentation was based on two previously published manuscripts. For more information contact Dr. Baker or see:

Baker, James B.; Broadfoot, W. M. 1979. A practical field method of site evaluation for commercially important southern hardwoods. Gen. Tech. Rep. SO-26. New Orleans, LA. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 51 pp.

Harrington, Constance A.; Casson, Bettina M. 1986. SITEQUAL - A user's guide. Computerized site evaluation for 14 southern hardwood species. Gen. Tech. Rep. SO-62. New Orleans, LA. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 13 p.

[1/]Presented at the Ecological Site Classification Symposium, Charlotte, NC, January 7-9, 1991.

[2/]Research Forester, U.S Department of Agriculture, Forest Service, Southern Forest Experiment Station, Monticello, AR.

MAPPING / GIS APPLICATIONS IN CLASSIFICATION SYSTEMS

DYNAMIC DIGITAL DATABASES: THE KEY TO PRACTICAL LAND CLASSIFICATION SYSTEMS[1/]

James L. Smith[2/]

Abstract.--It is clear that strategies for categorizing the ecological landscape will be increasing in importance in the coming years. The temporal and spatial variability of the elements of the landscape make a timely and flexible data base a necessity for developing and implementing these strategies. Remote sensing and geographic information systems are the foundations of such a dynamic, digital data base. Recent developments in these fields will be chronicled, planned activities for the near future described, and some thoughts on the long term situation in these important technical support areas put forth.

Keywords: Geographic information systems, satellite imagery, resource management.

INTRODUCTION

I see the purpose of this, the first presentation of the session, as an introductory one. It is my job to set the table for the speakers who will follow. Thus, I will confine myself to a non-specific discussion of the present state-of-the-art of advanced data gathering technologies (i.e. remote sensing) and information production tools (geographic information systems (GIS)). Although specific application situations may be mentioned from time-to-time, they are not the crux of this particular presentation. I leave that task to the exemplary slate of speakers who come later.

THE CONTEXT

My first task is to set the context for the presentation, and for the major topics of the presentation. We all need to understand on what foundation we are standing. The presentation will deal with remote sensing and geographic information systems. Within remote sensing, the emphasis will be upon digital, remotely sensed imagery acquired by satellite platforms, and within GIS, the capabilities of such systems and how they may be utilized in a land classification situation. While these topics will be discussed separately, and independently to a great degree, they must be thought of as parts of a whole, for neither reaches its greatest potential without the other. We cannot call it a true symbiotic relationship, for remote sensing would survive without GIS, and GIS would survive without remote sensing. However, each improves the other and thus it is a question of prosperity and growth. I will use an analogy to illustrate.

We can regard the development and use of a land classification system as a task, or job, much as we regard the driving of a nail as a task to be performed when building a wall. This task requires the use of the appropriate tool, which in the case of the nail is the hammer. When we examine the tool, we can break it down into its relevant parts and determine the importance of these parts. First, we have the head of the hammer. It is the mass and velocity of the hammer head which actually performs the task of driving the nail. However, the hammer head would be much more difficult to use without a way to give it direction and speed. Thus, the second constituent part, the handle, actually makes the hammer head more efficient at its task, although a nail can be driven in many instances without it depending on the resistance of the material to be nailed. The handle thus is not always required, but makes the use of the hammer head more efficient and more widespread in its potential application. Finally, let's not forget the operator. A hammer without an operator lays on the floor next to the nail and does nothing.

1/ Presented at the Ecological Land Classification Symposium, Charlotte, NC, January 7-9, 1991.

2/ Associate Professor, Department of Forestry, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061-0324.

How is a hammer like remote sensing and GIS? I would argue that they are very much alike, and here is how. Recall that our task is to implement and use a land classification system in the process of natural resource management, rather than drive nails to build a wall. Our tool in this case, like the hammer, is composed of constituent parts. The part of the tool that actually does the work, i.e., the hammer head, is data, for it is this data that actually drives the system and produces the result. One way to obtain data is remote sensing! After the data base has been constructed using remote sensing and other means, we use a GIS to grip that data and produce information. The GIS is used to control and manipulate the data, i.e., give the hammer head speed and direction. However, the GIS itself does no work; its purpose is to make the decision process more efficient, and perhaps through these efficiencies, more complete. Lastly, the natural resource professional uses the GIS to direct the appropriate data in the appropriate form to the task at hand, much as the carpenter must skillfully direct a hammer. The GIS/remote sensing hammer has no value without a trained and competent operator, for it cannot produce the desired result, a decision, by itself.

REMOTE SENSING

Remember the parts of our hammer. Let's talk first about the head; the part that does the work. In our analogy, the head of the mammer is the data. We must have up-to-date data of sufficient quality to achieve our goals, whatever they may be. The question then becomes how we will acquire the necessary data. Data can come from a variety of sources, for instance, field inventory, aerial photography, existing data from other sources, and satellite imagery. It is important to note here that although field work will not be covered explicitly in this presentation, it is an integral part of any natural resource data collection endeavor. Rarely will the remotely sensed data sources stand by themselves without some field verification. Although we will be talking about great advances in technology today, they still require some ground-pounding even in the best situations. Let's briefly talk about aerial photography and existing data sources, and then discuss satellite imagery in more detail.

Aerial photography has become the neglected stepchild of remote sensing in many ways. The advent of digital scanners and satellite platforms has made the study of aerial photography a minor science to funding agencies. I consider this to be a great mistake because we have never utilized aerial photography to its fullest potential. There are a number of different photographic systems available (film type, camera type, filter), and the information they contain at different scales, seasons, etc. has never been fully explored. I urge you to remember aerial photography when you need to obtain resource information. Do not fall into the unnecessary technology trap every time!

Another thing to always remember is that other people and organizations are also in the business of acquiring information about natural resources. The U.S. federal government must be the largest archive of resource information in the world, and all of that information is available to you. The questions you must answer are whether the quality and form of that information meets your requirements. Never assume that it does, or that it does not. In most cases, federally-acquired resource data is extremely inexpensive, and there is no way you could acquire similar information for that price in any other way. However, all data has limitations, and you must match your needs to those limitations. Let's examine one example, digital elevation models, more closely.

I have chosen to discuss digitial elevation models as an example of existing data sources because they seem to be of particular importance to those involved in land classification. In addition, DEM's as they are often called (or DTM's), illustrate the characteristics of existing data sources well. A DEM can be described as a computer-readable (digital) model of surface terrain features, i.e., we have stored the elevations above sea level for a number of known locations on the earth's surface. Values important for land classification can be derived from a DEM, such as slope gradient, aspect, slope position and slope shape. We have even related volume in natural stands to topographic/land form values derived from a DEM with some success. Although not required in theory, the most common form of a DEM is a square or rectangular matrix of elevation values called an altitude matrix. Note here that there are other ways to store elevation data, such as triangulated irregular networks (TIN) which have advantages and disadvantages. However, the altitude matrix is pervasive, and is the structure for DEM data obtained from the U.S. Geological Survey. An individual DEM covers the same area as a USGS 7 1/2 minute topographic quadrangle, and can be referenced by the name of the quad. The resolution of this, the most common DEM, is 30 meters. This can be taken to mean that surface features less than 30 meters in size may be lost, or at least washed out in the data set. Elevations are recorded to the nearest meter, unless the contour interval of the associated quad is less than five feet, in which case the elevations are recorded to the nearest foot. These DEM's are not yet available everywhere, but where they are, they are very inexpensive. The purchase cost is as little as $7 each if more than six are ordered at one time. This data is far from perfect; it is limited in resolution; it is limited in availability; it contains occasional large elevation errors (blunders); it is really of unknown precision. However, I have found the data useful, and cost-effective, but caution is advised. Like all data acquired by someone else, it does not always fulfill my needs. If it is misused, it is not their fault, it is mine!

Remember that we are talking about data base construction, and have previously mentioned field work, aerial photography, and existing data sources. I want to spend a bit more time on satellite imagery, because it seems to be a focus of the papers that follow. Civilian satellite remote sensing has been around since 1972, and much time, effort and money has been spent learning how to acquire it and how to use it. I would say that great progress has been made. There are two major systems available to us, SPOT and Landsat TM. SPOT is a French system, with two modes of operation. The first mode is visible panchromatic, which has a single spectral band with 10 meter resolution. The second mode of operation is multispectral, which has three spectral bands (green, red and near-infrared) at 20 meter resolution. SPOT also is a pointable platform, which gives it the capacity to decrease the number of days which elapse between successive coverages, and to produce stereo satellite images. The cost for a 60km x 60km scene (0.8 million acres) in digital format is approximately $2000 (0.2 cents per acre). Landsat Thematic Mapper (TM) is an American system. The sensor has seven bands (blue, green, red, near-infrared, mid-infrared and thermal), and a resolution of 30 meters. The cost for a 185km x 170km scene (7.7 million acres) in digital form is approximately $4000 (0.05 cents per acre).

All sensor systems are different, and each has its advantages and disadvantages. It is thus difficult to make general statements about satellite imagery and its characteristics. However, I do believe that we can make general observations about the advantages of satellite imagery as a concept. The first advantage is one of synoptic coverage, that is, affordable information for a large area. The costs quoted above are indicative of the situation. If resource information for a large area is needed, satellite imagery may be the only economical choice. Second, satellites provide repetitive coverage of these large area. In most cases, several images of a region can be acquired each year, which can be an important advantage if we need to monitor short term changes in the resource. The third advantage is the ability to select spectral bands for different tasks. Humans can only sense visible light, aerial photography is largely limited to visible light and near-infrared wavelengths, but mechanical scanners can sample from essentially the entire electromagnetic spectrum. We can pick and choose wavelengths as needed, and combine the most important spectral bands for each task. Fourthly, the digital nature of the data allows us to utilize a variety of enhancement algorithms, which can make the basic data much more informative. Finally, the digital nature of the data makes it a natural component of an integrated, dynamic resource data base, which by nature must reside in some sort of computer environment.

Now that we have covered the characteristics of the basic systems, we need to talk a bit about the trends in satellite imagery and digital image processing. First, I see no major changes in the design or operations of SPOT or TM (assuming the American TM program survives the experiment of quasi-commercialization). SPOT 3, scheduled for launch sometime after 1993, will likely add a mid-infrared band to its multispectral mode. Many vegetation "scientists" have been clamoring for this addition to the sensor. In the next year or so (supposedly) the next in the series of Landsat platforms, Number 6, will be launched with the Enhanced Thematic Mapper (ETM). This sensor is basically the same as TM, with a co-registered 15 meter panchromatic band. Also, look for the launch of Canada's RADARSAT, and the European Space Agency's ERS-1, both of which have RADAR sensors on board. Don't forget the 1km resolution Advanced Very High Resolution Radiometer (AVHRR), which will be discussed further in a paper during this session. Japan also has a little known satellite called Marine Observation System which has some terrestrial capabilities. As you can see, there are a variety of platforms and sensors available, not just SPOT and TM. That is one of the trends in satellite imagery -- more specialized platforms and sensors will be available in the future, making the remotely sensed data more useful for a variety of applications. It is also obvious that another trend is improving spatial resolution. While smaller and smaller pixel sizes are not a panacea, most practitioners have stated that an increase in the spatial resolution of satellite image data would make it more useful. The resolution of satellite image data is now similar to high altitude aerial photography, but it still is not comparable to large and medium scale photography used by resource managers on a day-to-day basis for stand level management. A third trend is evident as well, that the number of bands available will increase, and they will be more specifically designed and selected for particular purposes. Fourth, and I believe an important one, the cost of processing digital data will decrease. A good image processing system can now be purchased for a few tens of thousands of dollars, as opposed to a few hundreds of thousands of dollars a decade ago. A fifth trend is that of product flexibility. In years past, satellite data had to be purchased for an entire scene. SPOT and EOSAT (the parent of TM) both offer sub-scene products, which, although more costly per acre, may be more cost-effective. A negative trend is the increasing cost of the raw satellite data. An MSS tape from Landsat used to cost $200, and the same aerial coverage by TM costs $4000. I expect that the rate of increasing data costs will continue at worst, or at best, slow over the coming year. Both of these organizations are profit-making enterprises, and must increase their price as costs increase.

As I combine all these trends together in my mind, the overriding trend is that the cost/benefit ratio for satellite imagery is improving tremendously. It is more costly to acquire, but it is also more useful, and more easily used. Be mindful of my earlier warning about all data sources. Satellite data has a place in resource planning, but it will not do everyting. It has a place in the overall strategy of decision making but it is only one part of the hammer head.

GEOGRAPHIC INFORMATION SYSTEMS

As I stated earlier, GIS and remote sensing are intricately connected. This connection comes from the fact that GIS is predominantly an information manager, and thus there must be information present for it to be useful. Increasing complexity of the decision making situations, and increasing management costs are requiring that we be more clever and efficient in acquiring and utilizing information. Voile', the GIS. If you remember our analogy, the GIS is the handle of the hammer; the part that allows us to use the hammer head more efficiently. GIS is our window to the data base, our data base handle if you will, and it can also add to the data base through built-in spatial analysis functions.

Although no definition of GIS is accepted by everyone, I have my own way of defining it. My definition goes to the purpose of GIS. Note that every feature in the landscape, roads, streams, forests, fields, soils, etc., has both a location and a set of characteristics associated with that location. In other words, there are two kinds of information, spatial (locational), and attribute (characteristics). A GIS is a way of storing and manipulating spatial information and attribute information, and explicitly linking these two disparate data types. Spatial and attribute information can be manipulated individually, or in tandem, depending on the task at hand. Although all GIS's have different ways of accomplishing the job, all are attempting to efficiently tell us where we have what, and what is next to what. Note that there is nothing inherently difficult about what the GIS does. Everything a GIS does could be done by an appropriately trained human given the data and enough time. A human can overlay maps; a human can do neighborhood analyses; a human can look up information in the data base. However, the speed of the computer means it can usually do the job much faster. This speed allows us to either do the same job in less time, or do more things in the same amount of time. That is the advantage of GIS.

When GIS's are discussed, the first argument that usually arises is whether raster or vector data structures are best. I won't pursue that argument in detail, but I will comment. First, raster structures, such as DEM's and satellite images have advantages and disadvantages. Vector structures, which are more similar to traditional looking resource maps, have advantages and disadvantages. Some data is inherently raster, and some is inherently vector. Why can't we have both? Instead of deciding between them, let's have it all. The GIS of the future should use raster when it is appropriate, and vector when it is appropriate. The raster vs vector argument is no argument at all. Let's move on to more important matters.

An important concept to understand when dealing with GIS's is the "theme" or layered data base concept. In a data base, each individual type of spatial information is stored as a separate map. For instance, roads of all types are in one map; roads become a theme in the data base. A set of attributes is attached to the map, giving us the connection between locations and characteristics. There are many other themes, hydrography (streams, lakes, etc.), soils, ownership lines, etc., all stored individually with their associated attributes. A satellite derived land use/land cover map can be a theme. A DEM can be a theme. What I am describing is a dynamic, compartmentalized, integral data base. When a decision needs to be reached, the appropriate themes are selected, and combined if necessary. This theme concept gives the data base more flexibility, and a more dynamic character. Let's use a classification example to illustrate. Suppose we want to classify the area according to aspect, stratigraphy, soil series and current vegetation. Each of these four factors would be captured and stored as a separate theme, and spatially combined (overlayed) to form the classification. If an error is found in one of the themes, or if a map (theme), such as current vegetation, needs to be updated, only the changes are made to those themes. The themes are recombined, and a new up-to-date classification is produced. Think of how remote sensing can be used in theme development. Think of how the timeliness of satellite imagery can help us update certain themes. That is what I mean by a dynamic, digital data base. Dynamic means current. Digital means accessible.

There are many useful analysis functions built into most GIS. These may be very helpful in a land classification system, and provide another justification for GIS in such situations. I will categorize the main spatial analysis functions into two groups, neighborhood analysis and boolean combinations (overlay). In neighborhood analysis, distance to features can be calculated, proximity of buffer zones automatically generated, and such things as viewsheds determined. I believe that the importance of these functions to resource management are fairly obvious. How far is it from a particular point to that structure, or from this road to the stream. Create a new management unit that includes all areas within 500 meters of a lake. If I allow the lessee

to place a well-head at this point, is there any place on the trail above where it could be seen? These are all examples of neighborhood operators. I described boolean combinations (also called map overlay) in the paragraph above when I discussed how individual themes can be merged, or joined to produce new information. There are at least five kinds of map overlay, such as union and intersection, and ways for using map overlay in management situations are too numerous to list.

In summary, suffice it to say that GIS's are powerful tools for resource management. Their greatest power is in integration, whereby various types of data can be combined to produce the information needed for decision-making. Remember, a GIS is only as good as the data that was entered into it. A GIS cannot make the quality of your data better. It cannot give data more precision or resolution. It can make the data more useful, by making it easier to access. A GIS can perform spatial analyses which are becoming more and more important as environmental concerns become prevalent. A GIS can, I believe, make the decision-making process more efficient, and thus, more complete.

SUMMARY

The technologies for acquiring and using resource information have come a long way in the last 10-20 years. We can do things today that were only dreamed of by our predecessors. Remote sensing and GIS can be very helpful, but we must recognize their limitations. Remember that our goal is to make better decisions concerning our important natural resources. Wherever technologies can be used to accomplish that end, they are appropriate. Where technologies do not help accomplish that end, they are not appropriate. It is up to you to decide how and when to utilize technology. Do not blame misuses of technology on inanimate data or computers.

USING A GEOGRAPHIC INFORMATION SYSTEM TO CLASSIFY FOREST PRODUCTIVITY IN NORTHWESTERN CALIFORNIA[1]

John A. Brockhaus
Lawrence Fox III
Nancy D. Tosta[2]

Abstract--Classification of forest vegetation were combined with ecological zone location, elevation, slope and aspect within the framework of a geographic information system to predict forest land productivity over a very large area. Forest vegetation cover classes were provided by Landsat MSS data through computer classification. Ecological zones were compiled from indicator species and local climate data. Elevation, slope and aspect were obtained from DMA digital terrain data. All data layers were registered within a raster based geographical information system. The overall accuracy performance of the model was found to range from 74 percent to 86 percent depending upon the location within the study area.

Keywords: Landsat, GIS, forest productivity, ecozone, terrain.

INTRODUCTION

Federal, state, and local agencies have been mapping prime agricultural lands for several years. Most of this work has focused on the identification of lands for production of cattle and crops. Recently the United States Forest Service has undertaken several projects nationwide to examine techniques for mapping forest land units having various levels of productivity. Three productivity classes were chosen: (1) prime timberland, capable of producing 85 or more cubic feet of wood per acre per year; (2) non-prime timberland, producing between 50 and 85 cubic feet of wood per acre per year; and (3) non-forest land, producing less than 50 cubic feet of wood per acre per year.

The purpose of this project was to evaluate the potential of combining Landsat, topographic, and ecological zone data within the framework of a geographic information system (GIS) for classifying and mapping forest land productivity. Specific objectives were to: (1) Develop a georeferenced data base for mapping timberland productivity; (2) develop and apply linear stepwise discriminant analysis (LSDA) models for classifying prime, non-prime, and non-forest land; (3) assess the accuracy of the models in predicting the three categories of forest land productivity.

BACKGROUND

Forest managers and researchers have used site index as a reliable measure of forest land productivity for many years (Spurr and Barnes, 1973). Site index is an expensive and inconvenient variable to measure when conducting assessments of forest productivity over large land areas.

Aerial photographs have been used to estimate productivity based on vegetation, topography, and soils (Choate, 1961). Photographs have greatly reduced the survey time needed when compared to ground sampling techniques. However, the inventory continues to be labor intensive for large areas.

Previous research indicated that spectral reflectance patterns, developed from Landsat data through computer classification, could provide vegetation cover information over large areas at lower costs than when using aerial photography (Fox et al., 1983). Productivity has been shown to be poorly correlated with unclassified Landsat spectral data (Tom and Miller, 1980). Reliable estimates of forest productivity may be obtained, however, when these data are classified and integrated with digital topographic information. With this in mind, it was decided to use classified Landsat data in order to compress the unclassified spectral data set from approximately 60 digital values in four channels to only 14 to 15 classes of land cover. Previous experience indicated that

[1]Presented at the Ecological Land Classification Conference held in Charlotte, NC on January 7-9,1991.

[2]Research Associate, College of Forestry, North Carolina State University; Professor, Forestry Dept., Humboldt State University; and Director of Geographic Information Systems, Teale Data Center, State of California.

information critical to mapping levels of productivity would probably be contained in the classified data (Fox et al., 1983).

Ecological zone maps had been used previously to incerase the detail of a Landsat classification (Fox and Mayer, 1981). These zones were defined to represent significant climatic and vegetative regions throughout an area. There was interest in the value of eco-zones for predicting productivity, compared to the value of topographic data and Landsat vegetation classes for making predictions.

METHODS

This work was performed in two separate study areas (Figure 1) using slightly diferent data sets for each area. The northern study area (Humblodt County) represents a conifer forest region known to be highly productive, yet containing small regions of non-forest use. The southern area (Mendocino County) contains a greater range of conifer forest productivity and considerable non-forest acreage. both areas are mountainous with elevations ranging from sea level to 7000 feet.

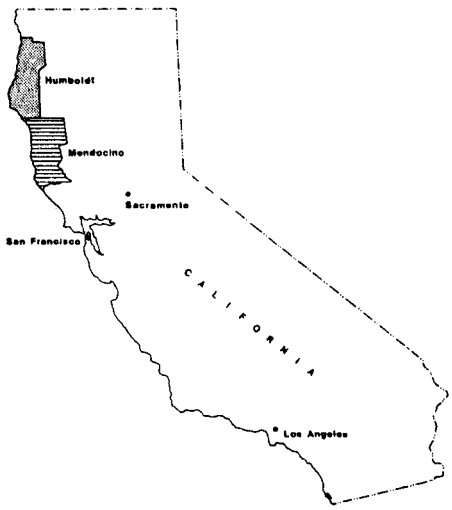


Figure 1--Locational map of the study site.

Classifying the productivity of forest land with LSDA models required the definition of a categorical response variable (productivity classes) and a set of predictor variables (Landsat vegetation classes, ecological zone classes, and topographic variables). The goal of the analysis was to linearly combine the predictor variables so as to best classify timberland into one of the three productivity classes.

The following predictor variables were made available for use by the discriminant analysis models: vegetation cover as determined from classified Landsat data; elevation, percent slope, and apsect class defined by digital elevation data; and ecological zones (eco-zones) in Humboldt County only, as determined from existing map sources (Fox and Mayer, 1981). These variables were selected for this study based on two criteria: (1) that variables selected were probably highly correlated with productivity based on previous studies; and (2) variables could be obtained from satellite image data, digital elevation data, or published maps rather than from sample surveys or airphoto interpretation.

A supervised Landsat classification of vegetation cover was available for Humboldt County. It was developed for a previous project using guided clustering to select spectral statistics from trianing areas and a maximum likelihood algorithm for final classification (Fox and Mayer, 1981). This supervised classification of portions of two Landsat scenes contained 14 categories tailored to forest communities including, in two cases, classes of species:

Redwood forest
Douglas-fir forest
Dominant Douglas-fir/broadleaf
Dominant broadleaf/Douglas-fir
Mixed conifer forest
Dominant conifer/broadleaf
Broadleaf forest
Broadleaf savannah
Brush land
Dominant brush/conifer regeneration
Agriculture
Grassland
Bare soil
Other

By contrast, an unsupervised classification was available for Mendocino County. The unsupervised analysis was completed as part of a previous statewide land classification project and was based on a resampled mosaic of Landsat scenes (Tosta-Miller and Peterson, 1980). It contained 15 categories of general land cover as well as very generalized forest types such as conifer and broadleaf classes:

Conifer forest
Dominant conifer/broadleaf
Dominant broadleaf/conifer
Broadleaf forest
Open conifer
Open broadleaf
Brushland
Open shrub
Agriculture
Grassland
Bare soil
Rock
Water
Urban
Other

These two methods of classification provided contrasting data sources and represented vastly different levels of technical work.

Topography was described by three variables: elevation, percent slope, and aspect. These variables were derived from Defense Mapping Agency (DMA) digital terrain data provided by the U.S. Geological Survey. Elevation and percent slope were treated as continuous variables while aspect was categorized into eight compass directions; north, northeast, east, southeast, south, southwest, west, and northwest.

Six eco-zones were included in the analysis of Humboldt County only (Figure 2). These zones were defined to stratify significant changes in forest composition and local climate, and yet still be generalized enough to form a manageable number of zones. Coast redwood (Sequoia sempervirens Endl.) is the major timber species in zone one, the moist coastal zone. Zone two, the moist interior, is dominated by Douglas-fir (Pseudotsuga menziesii Carr.), tanoak (Lithocarpus densiflorus Rehd.), and Pacific madrone (Arbutus menziesii Pursh.). Zone three, the dry interior, is dominated by Douglas-fir and California black oak (Quercus kelloggii Newb.). Broadleaf species (tanoak and Pacific Madrone) dominate the forest cover of zone four, the south interior. Zone five, the south coast, is characterized by Douglas-fir. Zone six, coastal spruce, represents a small area dominated by sitka spruce (Picea sitchensis Carr.).

The predictor variables (Landsat class, eco-zone, elevation, slope, aspect) were geographically registered and encoded into a raster based GIS (Smith and Blackwell, 1980). The grid cell size was 100 metres by 100 metres (2.47 acres). A small training data set consisting of 19,382 grid cells was systematically sampled from both study areas. The total population consisted of 1,855,572 grid cells, or 4,583,262 acres. This was determined to be the largest sample obtainable, given constraints of time and cost. The sampled data was used to develop the predictive equations of the LSDA model.

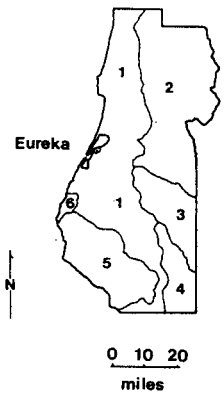


Figure 1--Locator map for the six ecozones used in the Humboldt County study area. The names of the zones are (1) Moist Coastal, (2) Moist Interior, (3) Dry Interior, (4) South Interior, (5) South Coast, and (6) Coastal Spruce.

The training data set contained the values of the predictor variables and the productivity classes. Values for the predictor variables were obtained from the data base containing the training data set. Data characterinzing the productivity classes of the training grid cells were acquired from soil vegetation maps which had been geometrically registered to the data base (U.S. Forest Service, 1961). Forest productivity classes used in this study were not printed on these maps. However, Douglas-fir and Ponderosa Pine (Pinus ponderosa Dougl.) site classes (ranges of site index) were printed for each forest vegetation type identified on these maps. These site index values were transformed into forest productivity classes using U.S. Forest Service conversion tables.

Discriminant functions were developed from the training data with the Statistical Analysis System (SAS) software and BMDP program 7M at the state of California's Teale Data Center. Predictor variables were treated differently depending on whether they were categorical or continuous data. Categorical predictor variables were transformed as the statistical theory used to develop LSDA assumes continuous predictor variables. Landsat class, eco-zone, and aspect class were treated as if each class were a separate variable and coded as zero or one depending on the presence or absence of the class. For example, Landsat class one (redwood forest) was defined as its own variable, having a value of one if the grid cell was in this class and a value of zero if not. This has been shown to be a legitimate method of coding categorical predictor variables in LSDA and regression (Hand, 1981; Brockhaus et al., 1989). Percent slope and elevation were not transformed, as they were already continuous variables.

Predictor variables were selected by the computer program in a stepwise manner to maximize discrimination between productivity classes. Variables which did not provide statistically significant discrimination at the 0.05 level of probability were not included in the final equations. The discriminant functions, developed from the training data, were used to classify the entire geographical data data base into the three productivity classes: prime, non-prime, and non-forest. The VICAR-IBIS image processing and raster based GIS software package was used for this step (Smith and Blackwell, 1980). Finally, thematic maps of each study site were printed from the grid cell data base at a scale of 1:100,000.

RESULTS AND DISCUSSION

Seventeen predictor variables were selected for inclusion into the discriminant model for Humboldt County while 18 were selected for Mendocino County. The selected set of predictor variables in Humboldt County consisted of eight Landsat vegetation classes, four eco-zone classes, four aspect classes, and percent slope. Predictor variables

selected for Mendocino County included twelve Landsat vegetation classes, four aspect classes, percent slope, and elevation.

Landsat vegetation classes were found to be more significant in determining site quality in Mendocino than in Humboldt County. The inclusion of eco-zone boundaries in Humboldt County corresponded to vegetation type boundaries. Aspect class variables were selected first in both counties, reflecting their value in determining these three levels of productivity. The majority of the Landsat classes included in the models were either non-forest or broadleaf forest classes because conifer classes were not closely associated with productivity. The presence of broadleaf and non-forest vegetation influenced the model toward predicting a low productivity class. The species specific conifer classes, provided by the Humboldt Landsat classification, did not contribute significantly to the model.

The final classification maps provided a visual indication of the geographic distribution and extent of each productivity class. These maps also provide a site specific indication of productivity. Area summaries were compiled by county.

Humboldt County was shown to be 74.7 percent prime forest and 24.5 percent non-forest. The non-prime class was shown to occupy 0.8 percent of the the counties land area, sharply lower than that reported by the 1968 U.S. Forest Survey, which indicated that 12 percent of the land area is non-prime (Oswald, 1968). The non-prime area reported here generally agrees with the published site classes of the sample of grid cells taken from the soil vegetation maps to develop the discriminant models (1.6 percent non-prime). The 1968 Forest Survey estimate of prime forest land was 14.9 percent lower than the estimate reported here in terms of land area classified and the non-forest area was 5.2 percent lower than what was estimated in this study.

Area summaries for Mendocino County agreed well with the Forest Survey. The area of prime forest land reported here was 9.3 percent lower than the Forest Survey estimate; non-prime, 13.3 percent higher; and non-forest 3.7 percent higher. These discrepancies are acceptable considering differences in the methods used by the U.S. Forest Service.

Site specific accuracy checks were made in both counties using a sample of the training data in Mendocino County and an independent test data set in Humboldt County. Overall classification accuracy was reduced mainly by errors in the non-forest productivity class. A large number of non-forest grid cells were classified as prime in both counties. Many of these errors probably occurred because grid cells in the rangeland and agricultural areas on the Soil-vegetation maps were defined as non-forest land on those maps (i.e., the ground truth was non-forest). However, these areas did contain small groves of conifer forest, often larger than one grid cell in area. If a forested grid cell was in a highly productive eco-zone and aspect class, it was probably classed as prime, producing a classification error according to the evaluation rules used here. One might argue that many rangeland areas can become productive forest once trees are allowed to invade the site.

The cost of the project was $220,000 or 4.8 cents per acre. The supervised Landsat classification (Humboldt County) was approximately four times more expensive than the unsupervised (Mendocino County). Map production and land area summary costs accounted for a third of the project budget. The project had research objectives which included software development that added to the cost of the inventory. An operational project of this scale could be done for approximately $150,000.

CONCLUSIONS

Merging vegetation-cover classes derived from Landsat data, topographic parameters derived from DMA terrain data, and published eco-zone maps into a statistical model effectively produced three land-cover classes for mapping forest productivity. Eco-zone classes contributed to classification accuracy and reduced the number of vegetation cover classes required for prediction of forest productivity classes. Vegetation cover classes were also shown to be significant to the model. The non-forest classes such as grass or brush were more highly correlated with productivity than were the conifer forest classes. Non-forest classes were provided in equal detail by both the unsupervised Landsat classification and the supervised classification. However, the supervised classification was four times more expensive than the unsupervised. The most valuable contribution from this process is the thematic map. The "in place" information by maps is not available from a sample survey.

ACKNOWLEDGEMENTS

The financial support of the U.S. Forest Service and the California Department of Forestry under Interagency Agreement No. 3-080-078 is gratefully acknowledged. A special thanks is also given to Dynamic Graphics Inc. of Berkeley, California for the in-kind contribution of software development and map production.

LITERATURE CITED

Brockhaus, J. A., M. Campbell, R. Bruck, and S. Khorram. 1989. Analysis of forest decline in the southern Appalachians with TM data. In proceedings of the 1989 ASPRS/ACSM Annual Convention, pp. 227 - 236.

Choate, G. A. 1961. Estimating Douglas-fir site quality from aerial photographs. Research Paper 45. Pac. N.W. Forest and Range Exp. Sta. Portland, Oregon, 26 p.

Fox, L., and K. E. Mayer. 1981. Using ecological zones to increase the detail of Landsat classifications. Proceedings of the Fall Technical Meeting, American Society of Photogrammetry and Remote Sensing. San Francisco. pp. 113-124.

Fox, L., K. E. Mayer, and A. R. Forbes. 1983. Classification of forest resources with Landsat data. J. of Forestry 83:283-287.

Hand, D. J. 1981. Discrimination and Classification. John Wiley, N.Y. pp. 96-97.

Oswald, D. D. 1968. The timber resources of Humboldt county, California. Resource Bulletin PNW-26. Pac. N.W. Forest and Range Exp. Sta. Portland, Oregon. 33 p.

Oswald, D. D. 1972. Timber resources of Mendocino and Sonoma Counties, California. Resource Bulletin PNW-40. Pac. N.W. Forest and Range Exp. Sta. Portland, Oregon. 76 p.

Smith, A. Y., and R. J. Blackwell. 1980. Development of an information data base for watershed monitoring. Photogrammetric Engineering and Remote Sensing 46:1027-1038.

Spurr, S. H., and B. V. Barnes. 1973. Forest Ecology. Ronald Press, N.Y. pp. 247-256.

Tom, C. H., and L. D. Miller. 1980. Forest site mapping and modeling. Photogrammetric Engineering and Remote Sensing. 46:1585-1596.

Tosta-Miller, N., and D. Peterson. 1980. Forest multiple-value assessment and land-cover classification of California. Proceedings of the 14 Int. Symp. on Remote Sensing of Environment. San Jose, Costa Rica. Environmental Research Institute of Michigan. Ann Arbor, Michigan.

U.S. Forest Service. 1961. Soil-vegetation maps of California. Resource Bulletin PSW-13. Pac. S.W. Forest and Range Exp. Sta. Berkeley, California. 6 p.

Zinke, P. J. 1961. Forest site quality as related to soil nitrogen content. Trans. 7th Int. Congress Soil Sci. 3:411-418.

CLASSIFYING FOREST PRODUCTIVITY AT DIFFERENT SCALES[1]

Robin Lambert Graham[2]

Abstract.--Spatial scale is an important consideration in evaluating, using, or creating forest productivity classifications. Scale affects the accuracy of the classification and the data requirements for constructing a classification. These points are illustrated using three classifications at different spatial scales.

Keywords: Spatial scale, spatial variability

INTRODUCTION

Spatial scale is an important consideration when evaluating, using, or constructing forest productivity classifications. First, the factors which dominate spatial variability in forest productivity are scale dependent. For example, within a stand, spatial variability in productivity is dominated by microsite differences; within a national forest such as the Cherokee National Forest, spatial variability is dominated by topography and land-use history (e.g., years since harvest); within a large region such as the Southeast, spatial variability is dominated by climatic patterns. Second, classifications developed at different spatial scales are often used for different purposes. For example, stand-level classifications are often keys or rules used in the field to judge the quality or potential of a site. National-forest classifications are often presented as maps or tables and may be used in forest land planning. Regional classifications may be maps or tables and may be used to quantify or predict resource availability. These scale-related differences in controlling factors and purposes will affect both the methods and the data used to develop classifications. In this paper, I will illustrate these points by describing and comparing three forest productivity classifications, each developed for a specific purpose at a specific scale. My objective is not to argue for or against any of these particular classifications but rather to heighten awareness of the critical role that spatial scale plays in the use and development of forest productivity classifications.

EXAMPLES OF DIFFERENT CLASSIFICATIONS AT DIFFERENT SPATIAL SCALES

Stand Scale (Tens of Hectares)

Existing methods of evaluating future stand productivity at a site generally rely on evidence of past tree growth, for example, site index. Such classification methods, although reliable and conservative, are less useful if (1) the future stand will be a different genotype than existed there formerly, (2) there are no data on past tree growth at the site, or (3) the site has been changed in some fundamental way since the previous stand. These empirical methods also provide little insight into the factors that control productivity. More mechanistic approaches are possible and as an example of a stand-level forest productivity classification, I will describe a classification method designed to explore the factors which control potential stand productivity. The classification relies on a mechanistic model of stand productivity and was developed at Weyerhaeuser Company in the early 1980s (Graham et al. 1985, Graham et al. 1986).

Method

This classification example is a mechanistic model which predicts daily net stand productivity over 1 year. The model is driven by daily climatic data—rainfall, net incoming radiation, average air temperature, average wind speed, and average daytime relative humidity. The site is defined by soil water holding capacity and total amount of nitrogen in the trees and the forest

---

[1]Presented at the Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests Symposium, Charlotte, NC, January 7–9, 1991.

[2]Research Staff, Environmental Sciences Division, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6038.

floor. The stand is characterized by 17 parameters among which are leaf area index, optimal canopy light use efficiency, and ratio of leaf biomass to total living tissue. The model predicts nitrogen concentration in the canopy, water uptake, soil water depletion, gross primary productivity, and net primary productivity. It does not predict stand growth because it does not distribute the stand net productivity among different types of tissue (e.g., wood, bark, or branches). Details about the model can be found in Graham et al. 1985.

The model relates potential site productivity to site environment with ten fundamental equations which:

1. define the effect of climate on net turnover rate of nitrogen,
2. allocate site nitrogen to stand tissue,
3. predict the mass of living tissue in the stand,
4. predict the amount of sunlight absorbed by the canopy,
5. predict the effect of temperature on light use efficiency,
6. predict the maximum gross productivity of the canopy with no water restrictions,
7. predict the effect of temperature on respiration rates,
8. predict the maximum net productivity of the canopy with no water restrictions,
9. calculate the ratio of actual evapotranspiration to potential evapotranspiration, and
10. calculate maximum net productivity with water restrictions.

Results

The model has been used to compare potential productivity of typical sites in the northwest, southeast, and central south; to determine optimal leaf area; and to predict the impact of warmer, drier climates on stand productivity (Graham et al. 1985, Graham et al. 1986). **Figure 1**, generated from multiple model runs, illustrates the comparative effects of different climatic variables at two sites. The model shows how different climatic variables limit productivity at different times in the year and how interactions between different climatic variables can depress productivity more than the most limiting variable could by itself.

The model is useful for making interregional comparisons of potential stand productivity, for comparing soil influences within a region, or for suggesting research directions. The model is not useful for predicting current forest productivity. Furthermore, the intensive climatic data needed to run the model, which are only available at very limited locations, will probably limit its use for mapping potential forest productivity.

Regional Scale (Millions of Hectares)

Existing methods of evaluating or mapping current regional forest productivity generally rely on extensive and intensive forest surveys.

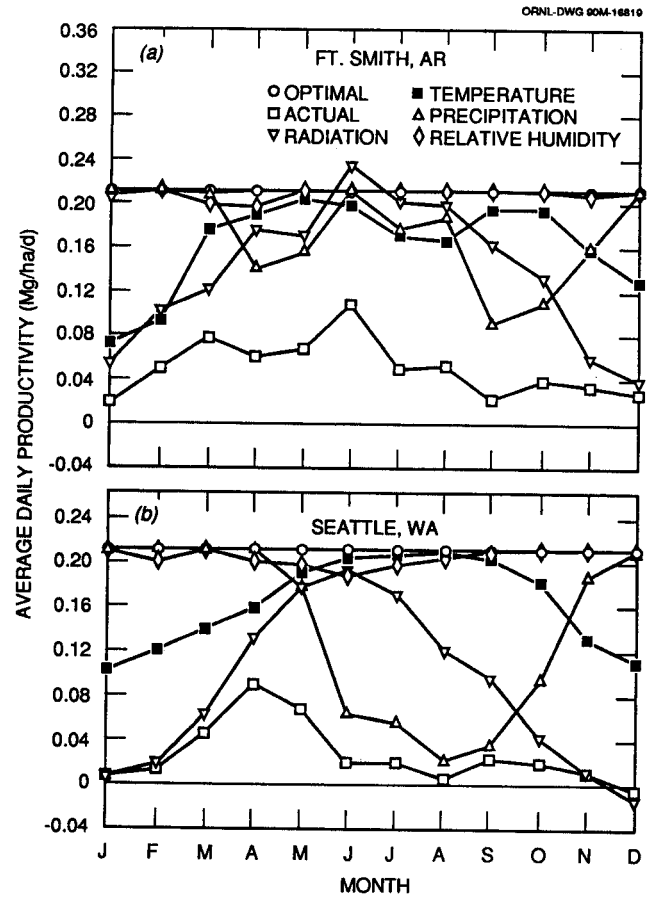


Figure 1.--Model predictions on the effect of site climate on forest productivity. Initially, the climate was set to year-round ideal conditions: Air temperature = 20°C; daily rainfall = 8 mm; Solar radiation = 280 watts/m^2; and relative humidity = 90 percent. Each climatic variable was then relaxed to actual values, while the other variables were kept ideal. Finally all the climatic variables were set to their actual values. The actual variable values came from weather records of a typical year.

This method is extremely valuable, but it is time consuming and expensive. Satellite imagery is extensive, can be acquired at frequent intervals, and is sensitive to canopy characteristics such as greenness and water content—characteristics which are functionally related to productivity (Tucker and Sellers 1986). For these reasons satellite imagery holds promise for classifying forest cover and forest productivity over large regions (Iverson et al. 1989a). As an example of a regional-scale forest-productivity classification, I will use a mapping approach based on satellite imagery. The method relies on Landsat Thematic Mapper (TM) data, NOAA Advanced Very High Resolution Radiometer (AVHRR) data, and limited plot-based, ground truth on forest productivity. The method was developed in the late 1980s with funding from NASA and has been applied to two U.S. regions and evaluated using Tennessee Valley

Authority (TVA) and U.S. Forest Service (USFS) forest inventory data (Iverson et al. 1988, Iverson et al. 1989b).

Methods

The method used is outlined in **Figure 2**. First, a regression model predicting forest productivity on the basis of pixel TM band values is developed using ground-based forest plot productivity values and their corresponding TM band values.[3] The TM band data should be from a phenological period in which there is large contrast between forested pixels and unforested pixels. For hardwood-dominated regions this occurs either in late spring when forests are leafed out and agricultural fields are still largely bare or in early fall when forests are still leafed out but agricultural fields have been harvested and pastures are starting to dry out. A minimum of 30 plots is needed, and more are desirable. The plots should capture the range of productivity rates likely to be seen in the region. Ideally, the plots should be scattered across the entire land area captured in the TM image although practically this is probably not possible. Once the regression model has been developed, it is applied to all the forested pixels within the TM image to create a map of forest productivity. The resolution and extent of this map is of course the same as the TM image, that is pixels 30-meters square, covering an area no greater than 160 km by 160 km (the size of a single TM scene). An entire scene is not needed, but at least a quarter of a scene is desirable.

Once the TM-scale productivity map is generated, it is used as "ground truth" to develop a second regression model predicting forest productivity on the basis of AVHRR band values. (An AVHRR pixel is 1.1 kilometers square and encompasses about 1300 TM-sized pixels.) To do this, an AVHRR image taken during the same phenological period as the TM image is overlaid on the TM-based productivity map. The forest-productivity pixel values falling within a single AVHRR pixel are extracted, and the overall forest productivity value associated with the AVHRR pixel is calculated by summing the productivity values of all forested pixels and dividing by the total number of TM-sized pixels within the AVHRR pixel. Nonforested TM pixels are included in the calculation so that the resultant productivity value is forest production per unit of land as opposed to forest production per unit forested land. About 100 AVHRR pixels are needed and should be scattered over regions on the map with

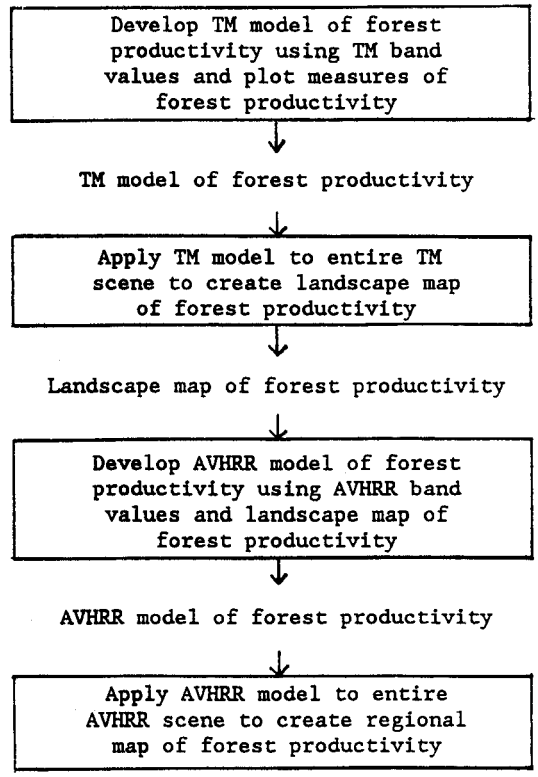


Figure 2.--Outline of regional land classification method using nested TM and AVHRR images.

variable forest cover and forest productivity so that the selected AVHRR pixels encompass all situations observed on the scene. The forest productivity values associated with the AVHRR pixels are regressed against the AVHRR pixel band values to develop the regression model predicting forest production. The final step is to take the full AVHRR image, stratify out pixels that clearly contain no forest (such as water), and apply the AVHRR regression model to all the pixels' band values to create a AVHRR-scale map of forest productivity. Such a map will typically cover an area containing millions of hectares because a single AVHRR scene can be up to 2400 kilometers on a side. A more complete description of the methods are given in Iverson et al. 1989b, Iverson et al. 1988, and Cook et al. 1989.

Results

These methods were applied to an AVHRR and a TM quarter scene centered over the Great Smoky Mountain National Park. About a hundred forest production plots located in mostly mixed hardwood forests within the Park were used for the initial forest-productivity ground truth (Cook et al. 1989b, Iverson et al. 1988). The regression equation relating forest productivity to TM band value had an r^2 of only 0.27 ($n = 111$, $p < 0.0001$). The high significance but low r^2 of the model means that the model can predict the expected median forest productivity over large areas (>100 pixels)

[3]A pixel is a picture element and is the basic land area unit in a satellite image. The size of the pixel will determine the sharpness of the image. The smaller the pixel size, the sharper the image. In satellite imagery, each pixel is associated with one or more band values, reflecting the amount of light given off by the surface area (represented by the pixel) within a given band of wavelengths.

with a high degree of accuracy (+/- ca. 10 percent); however, its ability to predict the forest productivity of any one pixel is poor (Cook et al. 1989). Consequently, the map, while not appropriate for depicting forest productivity at a fine scale, was appropriate for developing the AVHRR forest productivity regression. The equation relating forest productivity to AVHRR band values had an r^2 of 0.51 ($n = 99$, $p < 0.0001$). This equation was applied to the band values of the AVHRR pixels to create a map of forest productivity with a spatial resolution of 1.1 kilometers square. To display the results and compare them with TVA estimates of forest productivity, the AVHRR pixel values were averaged and multiplied by county area to produce county-level estimates of forest productivity. **Table 1** compares TVA county-level estimates of forest productivity with the AVHRR predictions.[4] Because the model was developed initially in terrain dominated by hardwood forest, it predicted productivity better in counties with such conditions. Likewise, the AVHRR productivity estimates correlated much more closely with hardwood annual growth increment than with total annual growth increment.

Table 1.--The correlation and significance of correlation between AVHRR county estimates of forest productivity and TVA county estimates of total forest productivity and of hardwood forest productivity.

County grouping	N	TVA total forest		TVA hardwood forest	
		r	P<	r	P<
All counties					
Total	168	0.52	0.0001	0.62	0.0001
By state					
GA	49	0.72	0.0001	0.80	0.0001
KY	19	0.76	0.0001	0.96	0.0001
NC	32	0.78	0.0001	0.91	0.0001
SC	17	0.55	0.0228	0.62	0.0076
TN	55	0.73	0.0001	0.85	0.0001
VA	13	0.66	0.0134	0.88	0.0001
Counties where >40 percent of the forest is hardwood					
Total	78	0.68	0.0001	0.91	0.0001
By state					
GA	10	0.86	0.0013	0.88	0.0008
KY	12	0.79	0.0021	0.92	0.0001
NC	17	0.82	0.0001	0.93	0.0001
TN	29	0.74	0.0001	0.96	0.0001
VA	10	0.75	0.0119	0.99	0.0001

[4]Because the original productivity data from the ground-based plots were not in the same units as the TVA estimates, the AVHRR results were compared through correlation.

This method is not a substitute for the statistically rigorous forest surveys undertaken by TVA and the USFS. However, such surveys are not possible in all parts of the world, nor is it possible to repeat them at short time intervals. The method does appear to capture the spatial variability of forest productivity over large areas and, therefore, is useful for evaluating large-scale within-region differences in forest productivity. The method would appear to hold promise for monitoring changes in regional or global patterns in forest productivity but probably not for quantifying forest resources. This satellite-classification approach is thus complimentary to traditional forest surveys, which are impractical for global monitoring but very useful for predicting regional resources.

Subcontinental Scale (Billions of Hectares)

The development of new forests can sequester significant amounts of atmospheric CO_2. Consequently, afforestation has been proposed as one means of reducing carbon dioxide buildup in the atmosphere. Because forests have many environmental and economic benefits apart from CO_2 mitigation, afforestation is appealing. The degree to which tree planting can mitigate CO_2 buildup depends in part on the area of land available and suitable for forests. As an example of a very-large-scale forest productivity classification, I will use a forest productivity classification designed to identify the amount and general location of land in Sub-Saharan Africa suitable for afforestation with industrial tree plantations. The classification was developed to assist the African Bureau of the U.S. Agency for International Development in evaluating the impact of different land-use strategies on greenhouse gas emissions (Graham et al. 1990).

Methods

At a continental scale, land availability for afforestation with industrial plantations is defined by climatic conditions, general soil fertility, and current land use. Climatic conditions and soil fertility will control the productivity or viability of plantations, whereas current land use identifies locations without forest cover. (Current land use will also affect the likelihood of adoption of plantation forestry although this was not considered explicitly in this classification.) To gather data on intercontinental variations in these variables, continental maps and a Geographic Information System (GIS) were used. The GIS extracted from the maps at regular 0.4-degree intervals information about soil order, annual rainfall, country identity, and current land use. This information was used to create a data base with about 9000 observations, each observation representing a single point on the continent and containing the map-extracted information. The soil order

information was converted to a fertility index based on the agricultural capability information for each soil order. A simple function was then developed to calculate an index of potential plantation productivity for each point, based on site departures from ideal annual rainfall and on soil conditions. A threshold productivity index value above which plantations were viable was used to identify those points with soil and climate conditions suitable for plantation forestry. The land use at points capable of supporting plantation forestry was then examined to determine how much of the land at each point was not currently in forests. This information was then summed within countries to develop country statistics on land area available for afforestation with industrial plantations. Details on the method are found in Graham et al. 1990.

Results

The approach identified 196 million unforested hectares within Sub-Saharan Africa capable of supporting at least moderately productive plantation forestry. If a more-stringent productivity threshold was used, only 62 million hectares are available. Cameroon, Ethiopia, Madagascar, Mozambique, Nigeria, Tanzania, and Zaire were identified as countries with more than 10 million hectares of land currently not forested but suitable for plantation forestry. Assuming each of the 162 million hectares was planted and managed as an industrial plantation, this land-use conversion would represent a permanent one-time sequestering of about 9.1 billion metric tons of carbon (Graham et al. 1990). Current fossil fuel carbon emissions are about 5.1 billion metric tons per year.

This classification approach is useful for systematically evaluating the continental potential for afforestation. The simplicity of the approach is a function of the paucity of continental data bases and information about this region. The approach could be improved using a more complex productivity index function. The method is appropriate for large-scale analyses of regions for which information on land use and land capability are sketchy. It is not appropriate for actually siting plantations because many other factors need to be considered such as labor pool, nearness of a market, or cost of capital.

DISCUSSION

Spatial scale will constrain the accuracy and information content of a classification. As classifications expand, that is, cover larger and larger areas, accuracy at any one location tends to decrease. However, new information on the spatial patterning of productivity and perhaps the causes of the patterning become available. For example, neither the satellite-based classification nor the continental classification would be appropriate tools for predicting the site productivity of a given hectare. Rather, they provide generalized information about the spatial pattern of forest productivity, something a local classification method could not do.

The scale of the classification will also dictate the type of data needed to develop the classification. Classifications that are specific to a location will often be keyed to the local variables that most affect productivity, such as soil texture or depth and topographic position. Climate is often ignored because it is presumed to be uniform within the area of consideration. Classifications that are extensive or are intended to be applicable to many regions, such as the three classifications presented in this paper, may need to include climate or a surrogate for climate.

Extensive classifications can be developed either bottom-up or top-down; each way has its advantages and disadvantages. Bottom-up classifications created by aggregating the results of many local observations are probably more believable and accurate. However, the bottom-up approach is severely constrained by the need to have uniform information coming from all the local sites. For example, different countries may have different definitions of soils, climate, forest production, vegetation classes, etc., and/or different methods for measuring or evaluating any or all of these variables. Aggregation of the information into a common system may therefore be extremely difficult if not impossible. Top-down classifications, such as the regional and continental classifications presented in this paper, are also constrained by the need for uniform spatially extensive information. Satellite data are valuable in this regard and are often the only data available with such qualities, particularly in remote areas. Unfortunately, satellite data cannot directly measure either productivity or the variables driving productivity such as soil quality, canopy cover, or moisture availability. Satellite data can only be correlated to some of these variables. Thus, any resultant classification is highly dependent on the strength of these correlations.

In summary, spatial scale is an important component of forest productivity classifications. Understanding how spatial scale may constrain the utility of a classification is important for using classifications wisely and for developing useful classifications.

REFERENCES

Cook, Elizabeth A.; Iverson, Louis R.; Graham, Robin L. 1989. Estimating forest productivity with thematic mapper data and biogeographical data. Remote Sensing of the Environment 28:131-141.

Graham, Robin L.; Perlack, Robert D.; Prasad, Anantha M. G.; Ranney, Jack W.; Waddle, Daniel B. 1990. Greenhouse gas emissions in Sub-Saharan Africa. ORNL Technical Report 6640, Oak Ridge National Laboratory, Oak Ridge TN. 135 pp. [Available form Oak Ridge National Laboratory, Oak Ridge, TN]

Graham, R.L.; Fox, T.R.; Dougherty, P.M.. 1986. Multiple stress factors: The potential roles of system models in assessing the impact of multiple stresses on forest productivity. In: Hennessey, Thomas C.: Dougherty, Phillip M.; Kossuth, Susan V.; Johnson, Jon D., eds. Stress physiology and forest productivity. Proceedings of the physiology working group technical session. Society of American Foresters National Convention; 1985 July: Fort Collins, CO: Boston: Martinus Nijhoff Publishers. pp. 151-169.

Graham, Robin L.; Farnum, Peter; Timmis, Roger; Ritchie, Gary A. 1985. Using modeling as a tool to increase forest productivity and value. In: Ballard, R.; Farnum, P.; Ritchie, G. A.; Winjum, J. K., eds. Forest potentials: productivity and value, proceedings of the 4th Weyerhaeuser Science Symposium; 1984 August: Tacoma, WA: pp. 101-130. [Available from Weyerhaeuser Company, Tacoma, WA]

Iverson, Louis R.; Graham, Robin Lambert; Cook, Elizabeth A. 1989a. Applications of remote sensing to forested ecosystems. Landscape Ecology 3(2):131-143.

Iverson, L. R.; Cook, E. A.; Graham, R. L. 1989b. A technique for extrapolating and validating forest cover across large regions: Calibrating AVHRR data with TM data. International Journal of Remote Sensing 10(11):1805-1812.

Iverson, L. R.; Cook, E. A.; Graham, R. L.; Olson, J. S.; Frank, T. D.; Ke, Y. 1988. Interpreting forest biome productivity and cover utilizing nested scales of image resolution and biogeographical analysis. Final report to NASA Thematic Working Group. pp 135. [Available from NASA Headquarters, Washington, DC]

Tucker, C. J.; Sellers, P. J. 1986. Satellite remote sensing of primary production. International Journal of Remote Sensing 7(11):1395-1416.

ACKNOWLEDGEMENTS

The author wishes to thank her co-workers on developing the three classifications (their many names are found in the references), Helga Van Miegrot and Lynn Wright for their thoughtful reviews, and Carole Kappelmann for her careful typing. Oak Ridge National Laboratory is managed by Martin Marietta Energy Systems under contract DE-AC05-84OR214000 with the U.S. Department of Energy. This article is publication no. 3636 of the Environmental Sciences Division, Oak Ridge National Laboratory.

LANDFORMS, SOILS, AND FOREST GROWTH: IDENTIFICATION AND INTEGRATION WITH GEOGRAPHIC INFORMATION SYSTEMS[1/]

R. David Hammer[2/]

Abstract.--A definition of soil system is provided which is suitable for integrating forest productivity, soil, and climatic data using geographic information systems. Users of geographic information systems and digital elevation models are urged to apply these technologies in ways to increase man's knowledge of the structure and function of forest ecosystems.

Keywords: digital elevation models, landforms, soil survey, soil spatial variability, site index

INTRODUCTION

Forest site productivity has received considerable attention in this country for seven decades. That another symposium addresses the topic indicates the persistence of unanswered questions and the interest in obtaining results. Tacitly implied is the human frustration which results when solutions are sought and not found.

Past efforts in forest site productivity will be reviewed with emphasis on the soil resource. The perspective from which the soil has been studied will be examined. Space constraints restrict development of certain themes. For example, tree nutrition will not be discussed. This omission is not from unawareness of the importance of the topic, but is a realization that cursory treatment would serve no useful purpose. Some important concepts will be presented with minimal justification. Key references will be provided so the reader can retrace concepts and past debates.

Finally, a conceptual framework will be presented which could be used in conjunction with digital elevation models (DEM) and geographic information systems (GIS) as research tools for description and study of forest ecosystems. Hopefully the offered approach will foster a more holistic framework for evaluating forest soil systems. The goal is to stimulate thought, to broaden perspectives, to integrate concepts, and to open dialogue.

GEOGRAPHIC INFORMATION SYSTEMS AND DIGITAL ELEVATION MODELS

Defining GIS and DEM

Detailed descriptions of GIS and DEM will not be given, because definitions reflect the perspectives and applications of the definers. The emphasis will be upon potential applications of these technologies to evaluate and inventory forest site productivity. Burrough's (1986) definition of GIS as a ". . .set of tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world for a particular set of purposes." will be used. Digital elevation models are "Any digital representation of the continuous variation of relief over space. . ." (Burrough, 1986). Other recent textbooks describing GIS and DEM include Raper (1989), Estes (1990), and Tomlin (1990).

Current applications of GIS and DEM

Geographic information systems and DEM (usually standard U.S. Geological Survey 30 m DEM) are commonly components in land use planning and resource inventory. Hammer et al., (in press) have reviewed current applications. The most common use of GIS technology has been production of special use maps from existing data bases. This

---

1/ Presented at the symposium "Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests, Charlotte, NC, January 7-9, 1991.

2/ Assistant Professor of Soil Science, 144 Mumford Hall, University of Missouri, Columbia, MO 65211.

is an excellent use of GIS technology, however the potential of GIS as a research tool should not be overlooked. New technology and techniques traditionally have been the avenues to advances in scientific knowledge (Cline, 1961).

An example of producing new maps from existing data is Hendrix and Price's (1986) use of slope, aspect, and soil data in combination with a regionally-developed site index equation in central Vermont. The three layers of information were combined in GIS. A site index regression equation was used to develop potential site index maps from the soil, slope, and aspect information. The Universal Soil Loss Equation (USLE) was used with the slope, aspect and soils data to predict soil erosion. This use of GIS produced potential site index maps and soil erosion maps which would have been difficult to obtain with other methods. The data produced were new data, because they previously did not exist. The GIS technology is well suited for combining data in this way.

However, this application raises important questions. How accurate and precise were the original data layers? How accurate and precise, then, are the final maps? The sources of the slope and aspect data were not provided, so the precision and accuracy are unknown. The heterogeneity of soil survey mapping units will be discussed. Without knowledge of the source and precision of the baseline data, the final results are subject to doubt. The weaknesses of the USLE are widely known.

Placing layers of imprecise or inaccurate data one upon the other will not create more precise or more accurate information. The level of risk in applying such maps is unknown. The potential exists to compound error at a rate not previously possible. When provided to the uninformed, without cautionary warnings regarding possible deficiencies, such information offers the opportunity for enormous error. Failure resulting from application of these data could result in the rejection of a technology with great potential benefits, not because the technology was flawed, but because the data were. Careful, detailed field verification is required for maps produced from multiple layers of data within GIS.

Discussion will now focus upon past forest site productivity and soil research. Following each section, potential ways of using GIS to integrate data and concepts will be presented.

FOREST SITE PRODUCTIVITY

Important factors

The topic is complex. Forest productivity results from the interactions of: 1) the genetic potential of the crop and its competitors; 2) forest management practices -- which run the gamut from planting through stand management and harvest techniques; 3) site properties which affect tree growth -- including soils, stratigraphy, geology, hydrology, geomorphology, and past site history; 4) climate, including seasonal distribution of energy and water; and 5) unplanned perturbations, including man's impact upon global climate.

The variety of site- and crop-specific interactions emerging from this mosaic is bewildering. General truisms are few, and the need for system-specific research is probably greater than acknowledged. Perhaps the poultice lies within perspective, technology, and methodology.

Perspectives

Perspective is an important component in any of man's activities. As Cline (1961) observed in his silver anniversary address to the Soil Science Society of America, "The picture is not the same to all who work in the science, for it is composed of knowledge . . . and different men know, or think they know, different things." Cline's subsequent comments implied that established scientific inertia is only slowly overcome.

The perspective presented herein is strongly influenced by the author's awareness that soils are important components of ecosystems. No component of an ecosystem, physical or biological, can be understood as an individual entity. The system must be studied before the integrated functioning of the parts can be adequately understood.

Soil site investigations

No comprehensive review of site quality and forest productivity has been published since Carmean (1975), although Stone's (1978) discussion of soil moisture regimes is important. Carmean's review supported Coil'e (1952) observation. Site quality is a function of the "quantity and quality" of the rooting volume. The challenge is defining "quantity and quality" in a meaningful way for the selected specie(s).

Henderson et al., (1990) suggested that a soil-based productivity index (PI) offered a conceptual framework meaningful for evaluating soil properties to assess the quantity and quality of the rooting volume. The PI concept has important implications for many forest ecosystems. The concept is discussed in detail elsewhere (Henderson et al., 1990; Huddleston, 1984).

Traditional site index studies have focused upon tree height as a function of landscape features and soil properties. Often a single soil pit was used to obtain soil data subsequently regressed against tree height. Powers (1986) suggested that this approach was naive because the soil variance, temporal and spatial, is unknown. Statistical rigor of many of these studies left much to be desired (Stone, 1978; McQuilkin, 1976). Traditional attempts to correlate yield of plants with soil properties have focused upon identifying a few "key" static soil properties, without regard to processes important in the genesis or maintenance of the soil attributes (Wilding and Drees, 1983).

Such studies often ignored those soil/site attributes affecting water-supplying (author's emphasis) capacity (Henderson et al., 1990).

Rather, the static measurement of soil water-holding capacity has been the focus of attention. Powers (1986) predicted that advances in forest site productivity would be insignificant until soil water relationships have been addressed adequately.

Another major limitation to soil-site studies is in application of results. Graphs and equations resulted from these investigations, whereas maps and inventories are the tools for forest management and planning (Stone, 1978).

The technologies of GIS and DEM have important implications for these approaches in evaluating forest site productivity. For example, Moore and Nieber (1989) used 10 m DEM with GIS to relate non-point sources of pollution to topographic factors. They also predicted times and amounts of relative soil wetness at various locations within the landscape.

With GIS, landform patterns can be identified and representative landforms selected. Forest vegetation can be studied using remotely-sensed data during different times of the year. Periods of stress induced by climate, pests, or pathogens offer ideal times to relate stand vigor (compared with remotely sensed data) to topographic features (identified with GIS).

Soil variance could be correlated to landforms with GIS and used with a PI to assess causal properties affecting tree growth within soils and landscapes. The PI could be used with GIS to develop productivity mapping units independent of soil taxonomic constraints. The integration of soils and landscapes could be very precise using GIS and DEM.

THE SOIL RESOURCE

The dynamic soil

The soil resource, the basis for forest tree growth, is a complex, dynamic body which has received inadequate and shallow (literally) treatment in most forest productivity studies. Too frequently, soil analyses have focused upon the upper fraction of the solum and have ignored the genetic soil horizons. Soil horizons reflect both current and past pedogenic processes and are the key to understanding the chemical, physical, mineralogical, and biological interactions within the soil landscape (Simonson, 1959; Nikiforoof, 1959).

Point locations or infrequent transects are the usual sources of our data. Those who have recognized the dynamic nature of the soil system generally have focused upon the forest floor as the source of most temporal variability in the soil system.

Hammer et al. (1991) used factor analysis to determine the relative proportions of soil variance accounted for by soil chemical and physical properties in the three upper genetic soil horizons within a forested ultisol/inceptisol landscape. The B horizons cation levels and pH extracted 34.7% of the variance. Color and thicknesses of subsurface horizons accounted for another 16.0% of the variance. The A horizon physical and chemical properties (horizon thickness, organic matter content, and cation concentrations) accounted for 27.0% of the extracted variance. Most of the soil variance was associated with subsoil properties.

The importance of the subsoil for forest tree growth generally has been overlooked. Comerford's (1984) review of the role of subsoils in plant nutrition relied heavily upon agronomic research. Subsoil has received the most attention when it has contained physical or chemical limitations to root growth (Loftus, 1971). The importance of lateral subsoil water movement in sloping landscapes requires much more attention before the soil can be understood as a dynamic system.

The soil system is a continuum in which the important variables do not all change at the same rate or in the same direction. Nikiforoff (1959) lamented the tendency of many investigators to regard the soil as a static, innate object rather than a dynamic chemical, physical, and biological system. Further, he predicted that soil research would not regain the impetus enjoyed during the birth of the science until focus shifted from classification to morphology and the causal mechanisms of soil development. Some progress has been made in this arena, but taxonomy continues to receive disproportionate emphasis. Plant root-soil interactions under natural conditions require much study.

Potential applications of GIS are endless for identifying patterns of geomorphic and stratigraphic influences on soil variability. Patterns and distribution of land surface shape could be correlated to geologic and stratigraphic features. Seasonal distribution of soil water could be modeled, then compared to soil distribution. Water distribution with landscapes could be integrated with soils and productivity using GIS and DEM.

Soil survey and soil taxonomy

Soil survey mapping units frequently are components of forest management plans. The inadequacies of the soil series as a predictor of site quality are well documented (Farnsworth and Leaf, 1965; Van Lear and Hosner, 1967; Shetron, 1972; Esu and Grigal, 1979). Jones (1969) concluded that "soil series alone are too heterogeneous ecologically to serve as a basis for evaluating timber productivity. . ." Carmean's classic study (1967) showed that topographic features were more accurate predictors of black oak (*Q. velutina* Lam.) site index than soil series. The inadequacies of the soil series are compounded when uninitiated users assume that delineations upon soil survey sheets represent pure units similar to the model pedon described in the survey.

Grigal (1984) itemized problems with soil survey as: 1) lack of purity in mapping units; 2) lack of coincidence of soil survey boundaries with maps based on non-soil properties; 3) coarse mapping scale; 4) failure to match soil series to landforms;

5) lack of continuity within soil series concepts; and 6) the failure of Soil Taxonomy (Soil Survey Staff, 1975) as a model to construct soil maps. Many of these problems are interrelated. For example, important small landforms frequently cannot be identified at the prevalent mapping scale. The failure of soil survey users to precisely define the needs of the survey to the Soil Conservation Service results in a general product which has limited application for specific needs.

Soil survey field procedures are not well-suited to collecting the kinds of data necessary for quantitative descriptions of the soil, particularly in forested lands. The problem is long-standing. The most extensive mapping unit in older soil surveys probably is the "rough rocky" delineation commonly used to indicate forested uplands in surveys published prior to implementation of the current Soil Taxonomy (Soil Survey Staff, 1975). The agricultural bias in soil classification persists today.

The soil surveyor's primary interest is in naming and delineating soil mapping units. Soil individuals are separated on the basis of taxonomic criteria which may not reflect soil properties important to tree growth. Mapping scale (usually 1:24,000) does not permit separations of units smaller than 2 ha. Landforms and their associated soils often cannot be identified on field sheets at this scale.

Grigal (1984) described a situation in Minnesota in which soils formed in lacustrine materials both in narrow valleys and in broad lakebeds were classified as the same soil series in spite of microclimate differences important to forest tree growth.

The author observed a similar situation in western Washington. The soils were loamy-skeletal, mixed, mesic Andic Xerochrepts moderately deep to compact glacial till. The soils occupied different landforms, but were classified into the same series. Over 8,000 ha of the soils were on undulating till plains in the Puget Trough. Another 12,000 ha of the soil were on colluvial toeslopes of the Cascade Mountains. Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) site index on 50 year curves averaged 7 m higher on the toeslopes. The difference was ultimately attributed to subsurface water movement resulting from summer snowmelt from the summit, over 1700 m above the toeslope. The till plain landforms did not have a source of supplemental soil water. The soils ultimately were taxonomically separated. In retrospect, classifying the toeslope soils as xeric was a mistake.

The soil surveyor does not collect soil variability data in a format suitable for most land users. Field notes and transect information, when collected, are not incorporated into the soil survey. Soil variability information is presented empirically as the "range of characteristics" associated with soil series. This format does not allow extrapolation of soil variability information across the range of the mapping units.

Young et al. (in press) addressed this problem. They recommended that transects be systematically established within representative field sites for all mapping units on the legend. Soil properties important for perceived land use, regardless of their taxonomic significance, would be measured and recorded. Transect data, subsequently presented in tabular format, would include means, ranges, standard deviations, and confidence intervals. In Missouri, procedures are being developed to retain all field notes after a survey is completed. Ultimately, the notes will be transcribed and included with the statewide soil data base.

Site index data in soil surveys is presented as means for individual mapping units. Ranges and standard deviations are lacking. The site index curves used to obtain data are cited infrequently, and the source of the data often are unavailable for the reader. Often the published site index data are from a regional data base and may have been obtained in adjoining states. Problems associated with site index have been well documented (Bull, 1931; Carmean, 1975; Grigal, 1984).

Matching soil properties to landforms with GIS and DEM is an arena deserving much attention. Landform description and distribution of landforms within landscapes are exercises for which GIS and DEM seem ideally suited. Algorithms must be developed for this purpose, but Moore and Nieber (1989) have demonstrated the potential.

Hammer (1986) used stem analysis to examine tree growth within landforms. Height of yellow-poplar (Liriodendron tulipifera L.) and white oak (Quercus alba L.) were shown to increase downslope as soil depth and water-supplying capacity increased (Figure 1). With GIS and DEM, the within-landform variance in soils and tree growth could be integrated and extrapolated across regions, increasing precision of productivity estimates and identifying sites suitable for species or intensive management.

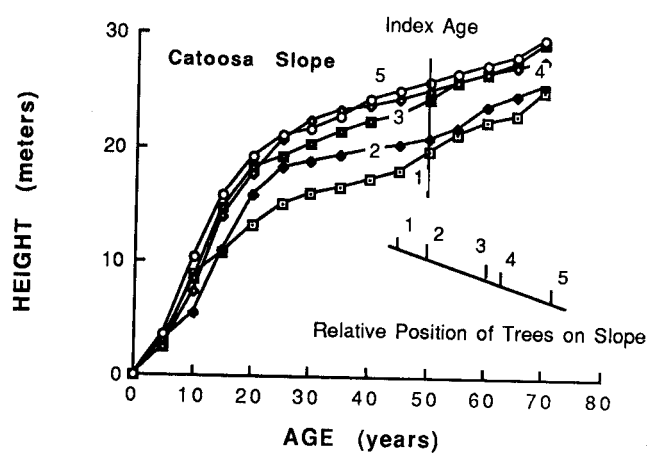


Figure 1. Height of yellow-poplar as a function of landscape position on the mid-Cumberland Plateau. Growth curves were derived from stem analysis (from Hammer, 1986).

RELATIONSHIPS OF LANDFORMS TO SOILS AND TREE GROWTH

The importance for tree growth of landform characteristics such as surface shape, slope length, and aspect are well documented (Carmean, 1965 and 1975; Einspahr and McComb, 1951; Graney, 1977; Smalley, 1967; Hannah, 1968; Ike and Huppuch, 1968). Landforms frequently are components of site classification schemes. Indeed, several papers in this symposium have addressed the topic. Rowe (1984), Smalley (1984), and Grigal (1984) advocated the importance of landforms in forest site assessment.

Soil development involves accumulation of parent materials and horizonation which expresses the dominant soil-forming processes (Simonson, 1959). Landform features influence soil development because landform shape and internal composition are influenced by the forces which deposit the parent materials (Daniels et al., 1971). Landform shape and composition both influence the rate and volume of water movement into and through the soil (Huggett, 1975). The seasonal distribution of water is the driving force of soil genesis (Crowther, 1953). The implications of these interactions for tree growth are obvious. Dan and Yaalon (1968) coined the term "pedomorphic surface" to describe a "landscape in which soils and relief are genetically and evolutionarily interdependent."

Soil series and mapping units must be more closely correlated to geomorphic surfaces. Daniels et al. (1971) and Ruhe (1975) have predicted that future efforts to identify soil units with reduced variability will rely more heavily upon geomorphology.

Typically, soil-landscape studies used line transect sampling (Huddleston and Riecken, 1973); Evans and Franzmeier, 1986, Pregitzer et al., 1983). Patterns of soil distribution related to geomorphic surfaces have been revealed. Variances and rates of change of soil properties within landforms, and the relationships of those changes to geomorphic surfaces, remain unknown.

Crowther (1953) urged a move from taxonomic considerations of soil genesis to a focus on internal relationships of soils with their landforms. He foresaw a search for "general relationships" as distribution of soils in relation to axes representing as many factors, both quantitative and qualitative, as can be observed and tested." Crowther's statement could be regarded as a justification for multivariate statistical analyses of soil-landform relationships.

Hammer (1986) used a 10 m grid on three mid-Cumberland Plateau landtypes to sample soil properties taken with 2.5 cm diameter cores. Discriminant analyses was used to classify individual soil cores using 35 chemical and physical properties representing the three uppermost genetic horizons. Discriminant analysis classified all soil cores into the correct landtypes. Cannonical correlation revealed a distinct clustering of soils into groups by respective landtypes (Figure 2). The cannonical loading scores revealed the soil properties most responsible for the clustering.

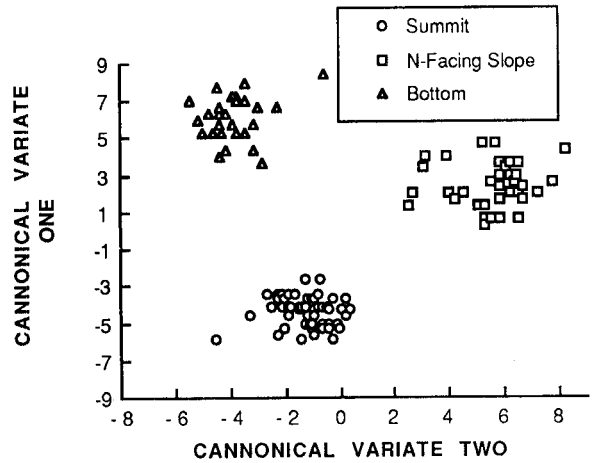


Figure 2. Distribution of soil profiles in three forested mid-Cumberland Plateau landtypes. The data from 35 soil properties representing 132 soil cores were analyzed with cannonical discrimination (from Hammer, 1986).

Three soil variables -- AB horizon color and thickness and extractable acidity of the Bt horizon -- caused separations along cannonical variate 1. The discriminators along cannonical variate 2 were A horizon thickness and Ca, Mg, and K levels from A, AB, and Bt horizons. Results showed that relatively few soil properties can be used to distinguish landforms within a landscape, but that the entire soil profile must be considered. The important soil discriminators probably would change with changes in the soil-landscape environment. More research is needed in this arena.

THE SOIL SYSTEM -- DEFINITIONS AND PERSPECTIVE

Defining the soil system

Soil scientists have approached pedological research from a variety of perspectives. Dijkerman (1974), Yaalon (1975), Huggett (1975) and Smeck (1983) provide important reviews. A major focal point is the definition of soil system. Scientists do not agree upon the boundaries and structure of defined soil systems. Several definitions exist. All are limiting in some way, particularly for use as the conceptual basis for forest site productivity.

Daniels et al. (1984) defined a soil system as ". . .a recurring group of soils that occupies the landscape from the interstream divide to the stream. The soils that make up these systems usually occupy specific landscape positions as a result of the internal soil environment produced by the interaction of stratigraphy, hydrology, geomorphology and climate." This definition provides lateral boundaries, but does not define a lower boundary. Vegetation is omitted, and climate is implied only through its effect on the soils that occupy the landscape and its effect on hydrology. The definition of landscape as it is applied here, is not clear. Ruhe (1969) defined landscape as the portion of the land surface which can be seen in a

single view. Ruhe's experience in prairie ecosystems obviously influenced this definition.

Jenny's (1980) conceptual soil unit, the "tessera", is a "landscape element of arbitrary cross section." When vegetation is included, the system is an "ecotessera." Depth limits are not defined, but climate is included.

A more precisely defined model is Huggett's (1975) "valley basin." This system is bounded by the soil surface, the watershed, and the weathering front at the base. The system is thermodynamically open and can be viewed as a unit cell within a basin network drainage system. Huggett's model was developed from the recognition that the "flux of solids, colloids and solutes within and across the landscape is . . .organized within the framework of. . .system units." Notably absent is the vegetation component. A limitation of this system in soils of the southeastern United States is the lower boundary. The author has observed highly weathered landscapes in which the lower boundary of weathering extends for tens of meters. Saprolite can be extremely deep, particularly in landforms receiving lateral throughflow.

A conceptual soil-landscape model for forest ecosystems

The best elements of the above models can be combined to produce an aesthetically pleasing conceptual soil system. The lateral boundaries would be the watershed divides. The unit cell could be watersheds bounding streams of any order. The "unit cell" could be chosen to represent local first order drainage basins representative of local geologic and stratigraphic conditions (i.e. deep loess adjacent to the Missouri River) or higher order stream basins representative of major land resource areas (Figure 3). The size of Huggett's "unit cell" would be a function of objective. The watershed (unit cell) boundaries could be identified with GIS and DEM.

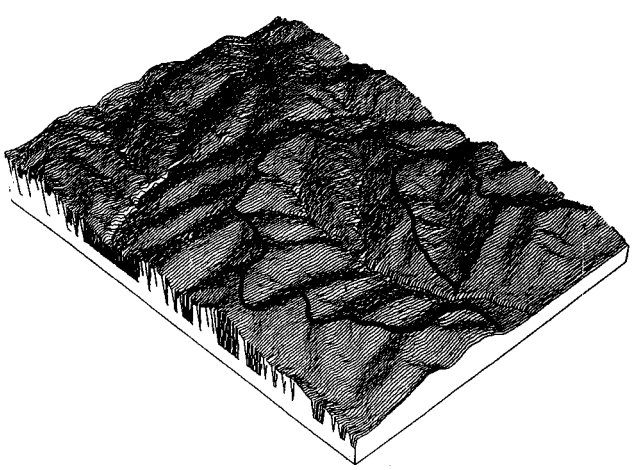


Figure 3. Hypothetical soil system boundaries. The figure is a three-dimensional surface contour generated with GIS from 10 m DEM data. The small unit on the right represents a first order watershed. The larger unit represents a third order watershed.

The lower boundary of the system would be the maximum rooting depth of perennial vegetation. Locating this boundary would require investigating the entire rooting volume of the soil. Stratigraphic discontinuities would be components of the model if plant roots cross the discontinuity.

Vegetation and climate would be components of the system. Climate could be described and defined by objective, but should include seasonal distribution of water, potential evapotranspiration and solar energy input.

Structural elements within the cell would be individual pedomorphic surfaces, stratigraphy, and geology. All of the components of the system could be modeled or monitored as layers within a GIS system.

APPLICATIONS OF GIS AND DEM IN LANDSCAPE ANALYSIS

A field test of slope class maps from DEM and GIS

Hammer et al. (1990) established 10 m test grids in 16 ha fields at two locations in Atchison County, MO. Slope was field-measured with a clinometer for each of the approximately 1400 10 m cells in each field. Slope class maps were produced with ARCINEO® software using standard U.S.G.S. 30 m DEM and 10 m DEM produced from aerial photography. Field-measured slope classes were compared cell-by-cell with slope class maps from the 30 m and 10 m DEM and with the slope classes from the cooperative soil survey.

Filtered 10 m DEM produced the most accurate and precise slope class maps across the range of slopes in the study fields. Within each site, the soil survey correctly classified between 30% and 40% of the area, 30 m DEM correctly classified about 25%, and filtered 10 m DEM correctly classified between 53% and 59% of the area (Figure 4). Filtered 10 m DEM correctly classified at least a

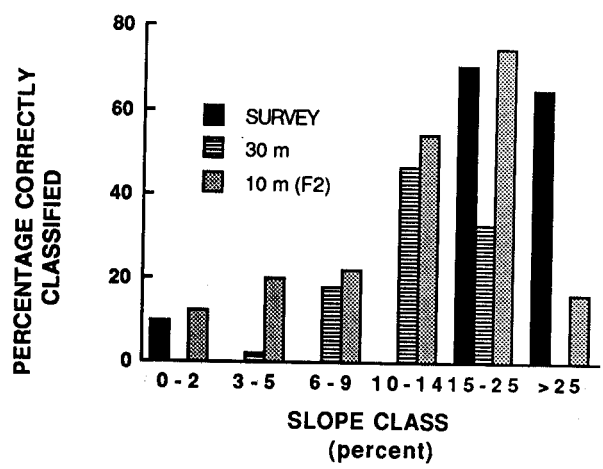


Figure 4. Percentages of area correctly classified into respective slope classes using three methods. Methods are standard soil survey (survey), generated from 30 m DEM with GIS (30 m), and generated from filtered 10 m DEM with GIS (10 m(F2)).

portion of each slope class represented in both fields, while the soil survey represented only dominant slope classes. The 30 m DEM did not identify the 0-2% or >25% slope class in the west area (Figure 5). The patterns of slope class distribution within fields were most accurately represented by 10 m filtered DEM (Figure 5).

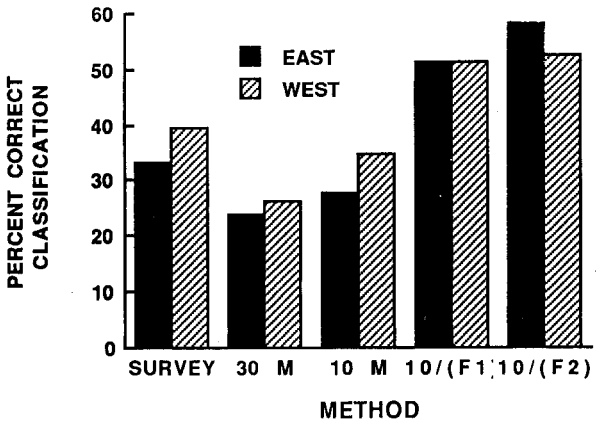
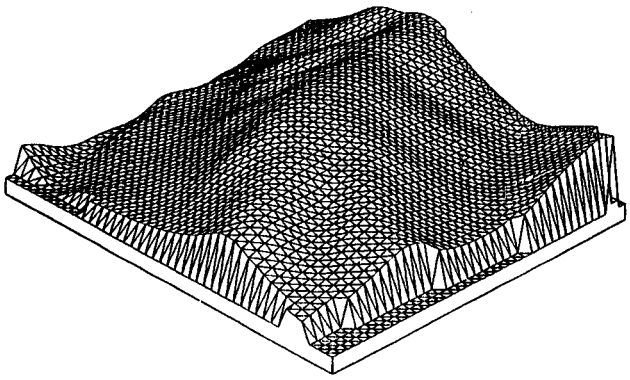


Figure 5. Percentage of total area of two study fields correctly classified into respective slope classes using several methods--soil survey (survey), 30 m DEM (30 M), 10 m DEM (10 M), and 10 m DEM filtered once and filtered twice, respectively (10/F1 and 10/F2).

The precision of GIS produced special use maps cannot be expected to exceed the precision of baseline data. Standard U.S.G.S. 30 m DEM have a vertical accuracy with 7 to 15 m standard deviation (Elassal and Caruso, 1984). Field measurements showed the 10 m DEM used in Atchison County had 1.4 m standard deviation. The finer grid of the 10 m DEM allowed a more detailed protrayal of the subtle relief in the study area. Concavities and convexities on the ridges and backslopes were observed and their slope classes were measured (Figure 6).

Figure 6. Slope class maps produced with several methods. Study site was a 17 ha field in Atchison County, MO.



A. Three-dimensional surface contour of a 16 ha field. Produced from 10 m DEM with GIS. Total relief in the field was 37 m.

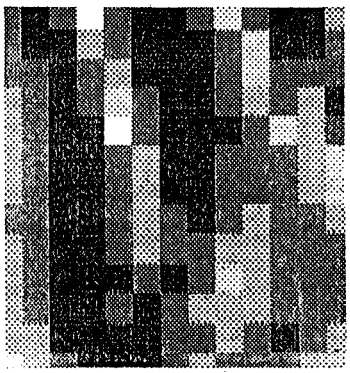
B. Field measured slope classes. Each cell is 10 m square.

Figure 6. (continued)

SLOPE CLASS LEGEND

- 0 - 2 %
- 3 - 5 %
- 6 - 9 %
- 10 - 14 %
- 15 - 25 %
- Greater than 25 %

C. Slope class map produced in soil survey.



D. Slope class map produced with GIS and 30 m DEM.

E. Slope class map produced with GIS and filtered 10 m DEM.

Other applications of GIS and DEM for assessing site quality

A second project in Missouri is being conducted to test the hypothesis that computer-generated slope and aspect maps from 10 m DEM can be used to increase the speed and precision of field soil survey activities. A second hypothesis is that soil variance, once established, can be extrapolated across similar geomorphic surfaces with GIS.

Representative landforms will be identified with GIS. The representative landforms will be intensively sampled and soil properties important to water retention and movement and to plant root distribution will be measured. The variance of soil properties will be determined for specific geomorphic surfaces. Soil taxonomic units will be determined on the basis of the intensive sampling.

The measured variance will then be extrapolated to similar landscapes using GIS. Randomly selected geomorphic surfaces will be sampled to analyze the goodness of fit of the extrapolated data. Computer cartigraphic techniques will be used to integrate mapping units with geomorphic surfaces. The soil survey will contain soil data in tabular form. Means, variances, standard deviations, and confidence intervals of specific soil properties will be included in the tables. Mapping unit composition will be statistically evaluated on the basis of limiting and non-limiting inclusions.

Should the Boone County exercise be successful, similar techniques will be employed in the soil survey of approximately 20 counties in the Ozark Uplift area of Missouri. These counties contain approximately 5.3 million ha of dissected, mostly forested topography. Plans are underway to eliminate the traditional county-by-county administrative structure and to map by geophysical provinces determined by geology, geomorphology, vegetation, climate, and land use. The objective of the effort would be to use GIS and DEM to enhance the quality of the survey effort, with specific emphasis on evaluating forest site productivity.

Much of this area is remote. The use of GIS to identify representative landscape patterns would be important. Survey crews could intensively sample those areas with easy access, and GIS could be used to extrapolate the information across remote areas. Random field sampling would be used to verify and test the limits of the extrapolated data.

The major land uses in this region are recreation, forestry, and pasture for forage. The soil-landscape information would be collected with these uses in mind. The survey would be enhanced with several watershed studies in which representative geomorphic surfaces within watersheds would be instrumented to measure seasonal distribution of water within landscape elements. A range of watersheds would be selected to represent the major land resources in the region. Watersheds would be selected on the basis of their topographic features, soils and quality and composition of timber stands. Stem analysis would be used to correlate forest productivity to soil-landform units. The plans for this activity are being discussed by state and federal agencies including the Soil Conservation Service (SCS), U.S. Forest Service (USFS), the Missouri Department of Conservation (MDC) and the Missouri Department of Natural Resources (MDNR). The project would involve acquisition of 10 m or 15 m DEM for the entire area.

The DEM would be generated from high resolution satellite imagery. If this effort were successful, the entire survey would be on a digital data base which would include slope-aspect information generated from the DEM. Soil survey users would then have access to only the data they needed, and would be able to obtain custom made special use maps for the area of interest. The MDNR and SCS would jointly administer the data base.

CONCLUSIONS

Soils and forest site productivity are highly correlated with landtype (geomorphic surfaces) and stratigraphy. Traditional efforts to estimate site productivity have suffered from a lack of precision in quantifying the soil resource and relating soil properties to species-specific site requirements. The technologies of GIS and DEM offer the opportunity to more closely weld soil units to landtypes and to construct soil system databases which contain the kinds of data useful for prediction, planning, and management. The potential of GIS and DEM as research tools should not be overlooked in the haste to embrace their cartographic and data base management attributes.

LITERATURE CITED

Bull, H. 1931. The use of polymorphic curves in determining site quality in young red pine plantations. Journal of Agricultural Research 43:1-28.

Burrough, P.A. 1986. Principles of geographical information systems for land resources assessment. Oxford: Clarendon Press. 194 pp.

Carmean, W.H. 1965. Black oak site quality in relation to soil and topography in southeastern Ohio. Soil Science Society of America Proceedings 29:308-312.

Carmean, W.H. 1975. Forest site quality evaluation in the United States. Advances in Agronomy 27:209-258.

Cline, M.G. 1961. The changing model of soil. Soil Science Society of America Proceedings 25:442-446.

Coile, T.S. 1952. Soil and the growth of forests. Advances in Agronomy 4:329-398.

Comerford, N.B.; Kidder, G.; Mollitor, A.V. 1984. Importance of subsoil fertility to forest and non-forest plant nutrition. In: Stone, E.L., ed. Forest Soils and treatment impacts. Proceedings, Sixth North American Forest Soils Conference, Knoxville, TN: pp. 381-404.

Crowther, E.M. 1953. The skeptical soil chemist. Journal of Soil Science 4:107-122.

Dan, J.; Yaalon, D.H. 1968. Pedomorphic forms and pedomorphic surfaces. In: Ninth International Congress of Soil Science Transactions; Vol. 4, Adelaid, Australia: Elsevier Publishing Co. pp 577-584.

Daniels, R.B.; Gamble, E.E.; Cady, J.G. 1971. The relation between geomorphology and soil morphology and genesis. Advances in Agronomy 23:51-88.

Daniels, R.B.; Kleiss, H.J.; Buol, S.W. (and others). 1984. Soil systems in North Carolina. Raleigh, NC: North Carolina Agricultural Research Service Bulletin 467. 77 pp.

Einspahr, D.; McComb, A.L. 1951. Site index of oaks in relation to soil and topography in northeastern Iowa. Journal of Forestry 49:719-723.

Elassal, A.A.; Caruso, V.M. 1984. Digital elevation models. U.S. Geological Survey Circulation 895-B. Washington, DC: U.S. Geological Survey. 39 pp.

Estes, J.S. 1990. Geographic information systems: an introduction. Englewood Cliffs, NJ: Prentice Hall. 303 pp.

Esu, I.E.; Grigal, D.F. 1979. Productivity of quaking aspen. Soil Science Society of America Journal 43:1189-1192.

Evans, C.V.; Franzmeier, D.P. 1986. Saturation, aeration, and color patterns in a toposequence of soils in north-central Indiana. Soil Science Society of America Journal 50:975-980.

Farnsworth, C.E.; Leaf, A.L. 1965. An approach to soil-site problems: Sugar mapel-soil relations in New York. In: Youngerberg, C.T., ed. Forest soil relationships in North America. Proceedings Second North American Forest Soils Conference, Corvalis, OR: University Press.

Graney, D.L. 1977. Site index prediction for red oaks and white oaks in Boston Mountains of Arkansas. Research Paper SO-139. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Grigal, D.F. 1984. Shortcomings of soil surveys for forest management. In: Bockheim, J.G., ed. Proceedings Symposium Forest Land Classification: Experience, Problems, Perspectives: 1984 March, Madison, WI: pp. 148-164.

Hammer, R.D. 1986. Soil variability, soil water, and forest tree growth on three forested Cumberland Plateau landtypes. Knoxville, TN: University of Tennessee. 319 pp. Dissertation.

Hammer, R.D.; Astroth, J.H.; Henderson, G.S.; Young, F.J. (In press) Applications of geographic information systems and digital elevation models for soil survey and land use planning. In: Special Publication, Spatial variability and map units for soil surveys. American Society of Agronomy, Madison, WI.

Hammer, R.D.; Philpot, J.W.; Maatta, J.M. 1991. Applying principal component analysis to soil-landscape research: Quantifying the subjective. In: Proceedings 1990 Kansas State University Conference on Applied Statistics in Agriculture, Manhattan, KS.

Hannah, P.R. 1968. Estimating site index for white and black oaks in Indiana from soil and topographical factors. Journal of Forestry 66:412-417.

Henderson, G.S.; Hammer, R.D.; Grigal, D.F. 1990. Can measurable soil properties be integrated into a framework for characterizing forest productivity? In: Gessel, S.P. (and others) ed. Sustained productivity of forest soils. Proceedings Seventh North American Forest Soils Conference, Vancouver, BC: pp. 137-154.

Hendrix, W.D.; Price, J.W. 1986. Application of geographic information systems for assessment of site index and forest management constraints. In: Proceedings, Geographic Information Systems Workshop. 1986 April; Atlanta, GA: pp. 262-272.

Huddleston, J.H. 1984. Development and use of soil productivity ratings in the United States. Geoderma 32:297-317.

Huddleston, J.H.; Riecken, F.F. 1973. Local soil-landscape relationships in western Iowa: I. Distributions of selected chemical and physical properties. Soil Science Society of America Proceedings 37:264-270.

Huggett, R.J. 1975. Soil landscape systems: A model of soil genesis. Geoderma 13:1-22.

Ike, A.F.; Huppuch, C.D. 1968. Predicting tree height growth from soil and topographic site factors in the Georgia Blue Ridge Mountains. Georgia Forest Research Council Research Paper p. 54.

Jenny, H. 1980. The soil resource origin and behavior. New York, NY: Springer-Verlag. 377 pp.

Jones, J.R. 1969. Review and comparison of site evaluation methods. Research Paper RM-51. U.S. Department of Agriculture Forest Service, Rocky Mountain Forest Experiment Station.

Loftus, N.S. 1971. Yellow-poplar root development on Hartsells subsoils. Research Note SO-131. U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station.

McQuilkin, R.A. 1976. The necessity of independent testing of soil-site equations. Soil Science Society of America Journal 40:783-785.

Moore, I.D.; Nieber, J.L. 1989. Landscape assessment of soil erosion and nonpoint source

pollution. Journal of Minnesota Academic Science 55:18-25.

Nikiforoff, C.C. 1959. Reappraisal of the soil. Science 129:186-196.

Powers, R.F. 1987. Predicting growth responses to soil management practices: Avoiding "future shock" in research. In: Future developments in soil science research. Soil Science Society of America Golden Anniversary Papers, New Orleans, LA: Soil Science Society of America, Madison, WI. pp. 391-403.

Pregitzer, K.S.; Barnes, B.V.; Lemme, G.D. 1983. Relationship of topography to soils and vegetation in an upper Michigan ecosystem. Soil Science Society of America Journal 47:117-123.

Raper, J. (ed). 1989. Three dimensional applications in geographical information systems. New York, NY: Taylor and Francis. 189 pp.

Rowe, J.S. 1984. Forestland classification: Limitations of the use of vegetation. In: Bockheim, J.G., ed. Proceedings Symposium Forest Land Classification: Experience, Problems, Perspectives: 1984 March, Madison, WI: pp. 132-147.

Ruhe, R.V. 1975. Geomorphology. Boston, MA: Houghton Mifflin, Co.

Simonson, R.W. 1959. Outline of a generalized theory of soil genesis. Soil Science Society of America Proceedings 23:152-156.

Smalley, G.W. 1967. Soil-site relations of upland oaks in north Alabama. Research Note SO-64, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Smalley, G.W. 1984. Landforms: A practical basis for classifying forest sites in the interior uplands. In: Proceedings Twelth Annual Hardwood Symposium. Hardwoods Research Council, Cashiers, NC. pp. 92-112.

Soil Survey Staff. 1975. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. Agricultural Handbook 436. Washington, DC; U.S. Department of Agriculture. 754 pp.

Stone, E.L. 1978. A critique of soil moisture-site productivity relationships. In: Balmer, W.E., ed. Proceedings Soil Moisture-Site Productivity, Atlanta, GA: U.S. Department of Agriculture, Forest Service. pp. 377-387.

Tomlin, C.D. 1990. Geographic information systems and cartographic modelling. Englewood Cliffs, NJ: Prentice-Hall. 249 pp.

Van Lear, D.H.; Hosner, J.F. 1967. Correlation of site index and soil mapping units poor for yellow-poplar in southwest Virginia. Journal of Forestry 65:22-24.

Wilding, L.P.; Drees, L.R. 1983. Spatial variability and pedology. In: Wilding, L.P. (and others) ed. Pedogenesis and soil taxonomy: I. Concepts and interactions. New York, NY: Elsevier. pp. 83-113.

Young, F.J.; Maatta, J.M.; Hammer, R.D. (in press) Confidence intervals for important soil properties within mapping units. In: Special Publication, Spatial variability and map units for soil surveys. American Society of Agronomy, Madison, WI.

POSTER PRESENTATIONS

SAMPLING MAP UNITS TO CHARACTERIZE FOREST SITE QUALITY[1]

Charles J. Everett and John H. Thorp[2]

Abstract.--Eleven soil map units which can be identified and delineated using conventional soil survey procedures were characterized as to loblolly pine (Pinus taeda L.) productivity. Four study sites, each 4 hectares in size and containing four permanent 0.04 hectare measurement plots, were established for every map unit studied. For eight of the eleven map units, there is greater than 80% probability that estimated mean site index (age 15) is within ±0.65 meters of the actual population mean. In addition, loblolly pine height growth curves were constructed for six soil map units by destructive stem analysis of 32 plantation-grown trees per map unit. Geologic landform and soil drainage class had significant effects upon curve shape.

INTRODUCTION

Most soils of the South Carolina Lower Coastal Plain are derived from Quaternary age marine and fluvial sediments. Five depositional environments are recognized: deltaic plains, barrier island and bar hills, shelf plains, marsh plains, and valley systems. Soils formed in former marsh plains are the most productive, while soils in old barrier islands and bar hills are generally the least productive.

Post-depositional weathering is also a factor influencing forest site quality. Sediments found further inland at relatively high elevations on the Wicomico and Penholoway terraces are considerably older than the Talbot, Pamlico, and Princess Anne terraces found closer to the coast. Soils derived from older sediments tend to be acid and infertile due to weathering, regardless of the original character of the sediment. Soils derived from young sediments, however, may be fertile.

Where Quaternary deposits are thin, the older sediments of Tertiary age influence soil properties. Deposits of phosphate rock are associated with the base of the Quaternary sediments, particularly where in contact with the top of the Cooper Marl. Morphologically similar soils have been shown to differ greatly with respect to site quality depending on whether or not phosphate rock was present at a shallow depth (Ellerbe and Smith, 1963).

FIELD PROCEDURES

This research project attempts to characterize the site quality of selected soil mapping units in the context of intensive culture of loblolly pine. These soil map units are special integrations of geomorphic landform, depositional environment, landscape position, understory vegetation, and fertility. In relation to the USDA-SCS Soil Taxonomy, many of our soil map units are phases of soil series designed for site-specific intensive forestry.

A total of 218 loblolly pine plantations were identified as candidate study sites that had the following characteristics: planted between 1968 and 1974, bedded, adequately drained if wet, phosphorus fertilized if needed (based on soil test), and neither thinned nor burned hot enough to damage trees.

For each soil map unit studied, four pine plantations were randomly selected. A soil map of each pine stand was drawn, and a four hectare study area was randomly located within the map unit delineation being investigated. Four permanent 0.04 hectare measurement plots were randomly placed within each four hectare study site. Measurement plots were not placed on windrows, within 40 meters of a major ditch, within 20 meters of a road, nor within 10 meters of a map unit boundary.

---

[1] Paper presented at Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests Symposium, Charlotte, NC, January 7-9, 1991.

[2] Research Soil Scientist and Soil Classification Scientist, Westvaco Forest Science Laboratory, Summerville, SC.

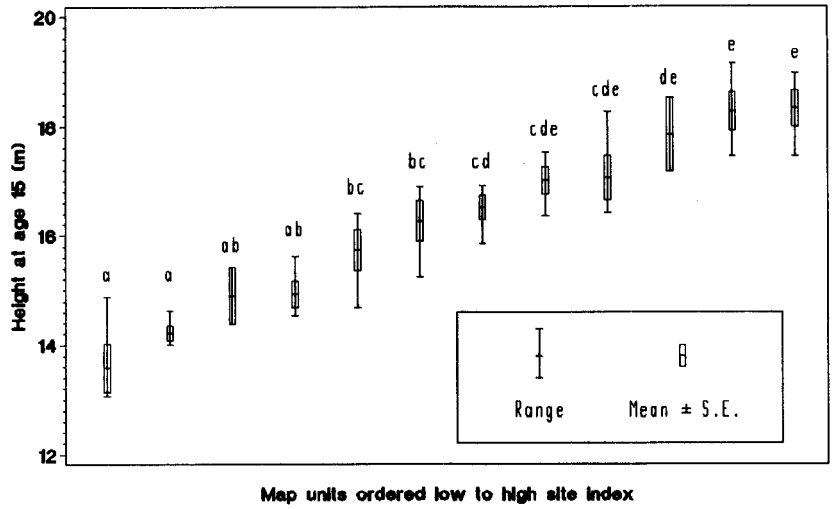


Figure 1. Site quality by map unit. Mean site indices of map units labelled with the same letter are not significantly different (P = 0.05).

Site index at age 15 was calculated for each plot using average height of all dominant and codominant trees, plantation age, and a single set of site index curves.

For six soil map units, stem analysis was performed on 32 trees (four trees per plot; two plots per location). These trees were within four rows of the measurement plot, had a height within one standard deviation of the mean height of all dominant and codominant trees on the measurement plot, and were free of major physical, insect, or fungal damage. Annual height measurements were taken at the end of the summer flush. Disks were cut to verify height-age pairs with a ring count.

RESULTS AND DISCUSSION

Nested analyses of variance were used to identify sources of variation at three levels: (1) map units; (2) locations within map units; and (3) plots within locations. In Figure 1, similar letters indicate no significant difference among map unit mean site indices according to Student-Newman-Keuls multiple range test (P = 0.05). For eight of the eleven map units studied, there is greater than 80% probability that estimated mean site index (age 15) is within ±0.65 meters of the actual population mean. This level of accuracy is considered satisfactory for management decision-making.

To identify polymorphic height growth patterns the stem analysis data were first standardized. All height data for a map unit were multiplied by a constant, which set the map unit's mean height at age 13 equal to 100% relative height. Height growth curves were then described mathematically using a modification of the Chapman-Richards model. Differences in height growth curve shape were evaluated using F-tests comparing full versus reduced regression models for standardized data.

Height growth patterns for Map Units A and I were not significantly different (P = 0.05), nor did growth curve shapes differ significantly for Map Units F and K. The soils of Map Units A and I are similar in texture and drainage class, but occur on different geologic terraces. The soils of Map Units F and K occur adjacent to one another in the same landscape, but differ by one drainage class. All other comparisons indicated significant differences (P < 0.05) in height growth curve shape among map units. If two general families of site index curves are desired, A-I and D-F-J-K would be the best groupings of the map units studied. The two groups of map units differ in that A and I are coarser textured than D, F, J, or K.

CONCLUSIONS

Map unit mean site indices can be estimated with a high degree of accuracy. For eight of the eleven map units studied, there is greater than 80% probability that estimated mean site index (age 15) is within ±0.65 meters of the actual population mean. Significant differences (P < 0.05) in map unit mean site indices were detected.

Height growth patterns for loblolly pine plantations vary significantly by map unit. In this study, six soil map units exhibited four statistically distinct growth curve shapes. Two general groups of height growth patterns were related to the subsoil texture of their underlying soils.

LITERATURE CITED

Ellerbe, C. M. and G. E. Smith, Jr. 1963. Apparent influence of phosphate marl on site index of loblolly pine in the Lower Coastal Plain of South Carolina. Journal of Forestry 61: 284-286.

PLACING "MAN" IN REGIONAL LANDSCAPE CLASSIFICATION: USE OF FOREST SURVEY DATA TO ASSESS HUMAN INFLUENCES FOR SOUTHERN U.S. FOREST ECOSYSTEMS[1]

Victor A. Rudis and John B. Tansey[2]

Abstract.--Information from plots surveyed by U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) units provides a basis for classifying human-dominated ecosystems at the regional scale of resolution. Attributes include forest stand measures, evidence of human influence, and other disturbances. Data from recent FIA surveys suggest that human influences are common to selected forest areas of the Southern United States and that these influences need to be addressed in regional ecological land classification and productivity estimation.

Keywords: disturbances, forest productivity, harvest, management, ownership.

INTRODUCTION

Identifying the best areas to grow trees or to maintain viable forest ecosystems is clearly useful for regional planners, conservation groups, tax assessors, and private landowners. The best forest areas, however, often are defined relative to surveys of limited areas and are not easily discerned from existing vegetation or local stand conditions.

At the stand level, a simple method to classify a forest stand's productive capacity is to estimate the biomass of interest in relation to its age. However, partial disturbances in many forests reduce the use of this technique to undisturbed stands. At the landscape level, stand history of extensive forested areas is rarely known. In addition, periodic disturbances, historic settlement patterns, land use practices, and forest fragmentation vary widely.

In the Southern United States, nearly all forests have been cut at some time. Historic settlement and land-clearing practices have eliminated much of the natural forest vegetation. In forested areas, disturbances such as commercial harvesting, livestock grazing, prescribed fire, noncommercial firewood cutting, and land-clearing activities continue to influence species composition of remaining stands. Adjacent nonforest land uses, operability for timber harvesting, relative access for multiple uses, and relative remoteness all contribute to the mosaic of forest cover at the landscape level.

Data are available to conceptualize the regional importance of these features. Information is derived from the forest survey data base maintained and updated by the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) units. Disturbances and uses are inferred from prevailing land ownership, adjacent land uses, physical features, and evidence of human activities in forested areas. Field observations and calculated attributes are described in FIA field manuals and data base documents.

RESULTS AND CONCLUSIONS

Forest land dominates in selected areas of the southern Coastal Plain, Appalachian Mountains, and Interior Highlands. Forest cover has been eliminated or reduced in major urban counties, and along the lower Mississippi River floodplain and other important agricultural regions (figure 1). More than 30 percent of the forested land has been harvested since the last survey of about a decade earlier. Commercial harvest activity is highest

---

[1]Presented at the Symposium on Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests, Charlotte, NC, January 7-9, 1991.

[2]Research Forester, Forest Service, U.S. Department of Agriculture, Southern Forest Experiment Station, Starkville, MS 39759-0906; and Forester, Forest Service, U.S. Department of Agriculture, Southeastern Forest Experiment Station, Asheville, NC 28802-2680, respectively.

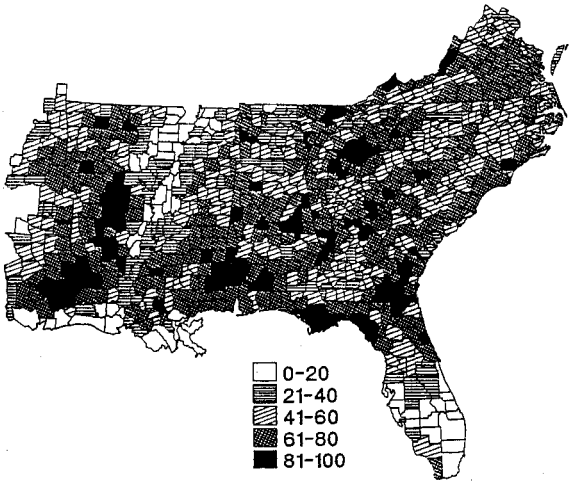


Figure 1.--Percent forest area by county, 1982-1989 surveys, Southern United States.

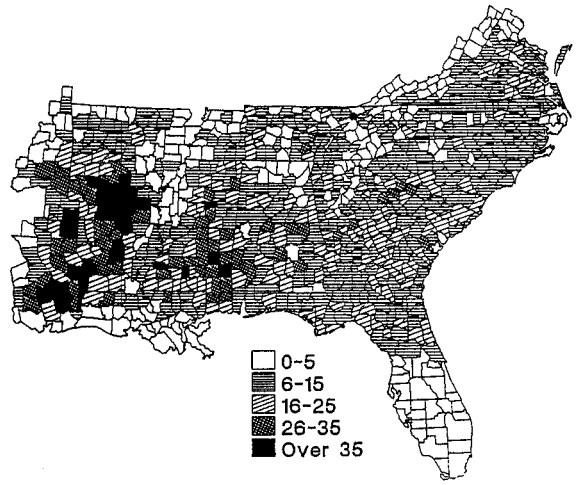


Figure 2.--Percent forest area with recent commercial harvest activity by county, 1982-1989 surveys, Southern United States.

along the southern Coastal Plain and lowest in southern Florida, the lower Atchafalaya River Basin in Louisiana, and western Virginia (figure 2).

In addition to the data illustrated here, related information is available on the regional distribution of ownership (Rosson and Doolittle 1987), fire occurrence (Rudis and Skinner, in press), harvest activities (McWilliams 1989), and remote areas (Rudis 1986). Trends in forest type, ownership, and area are discussed by Alig and others (1986), while numerous State-level forest resource assessments provide additional statistics on timber productivity and disturbance characteristics (e.g., Bechtold and others 1990, Rudis 1988).

The information above summarizes a more extensive presentation depicting the distribution of human influences in Southern United States forests. Only a portion of the data is illustrated in this report. The extent and distribution of forested areas and related disturbances suggest that human influences are important in selected areas of the Southern United States and that these influences need to be incorporated in regional ecological classification and in the estimation of forest productivity.

LITERATURE CITED

Alig, Ralph J.; Knight, Herbert A.; Birdsey, Richard A. 1986. Recent area changes in southern forest ownerships and cover types. Res. Pap. SE-260. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 10 p.

Bechtold, William A.; Brown, Mark J.; Sheffield, Raymond M. 1990. Florida's forests, 1987. Resour. Bull. SE-110. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 83 p.

McWilliams, William H. 1989. Residual pine stocking after harvest on private timberland: a summary for six Southern States. Res. Pap. SO-252. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 12 p.

Rosson, James F., Jr.; Doolittle, Larry. 1987. Profiles of Midsouth nonindustrial private forests and owners. Resour. Bull. SO-125. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 39 p.

Rudis, Victor A. 1986. Emerging patterns in the distribution of roadless forested areas in the Midsouth. In: Kulhavy, David L.; Conner, Richard N., eds. Wilderness and natural areas in the Eastern United States: a management challenge: Symposium proceedings; 1985 May 13-15; Nacogdoches, TX. Nacogdoches, TX: Stephen F. Austin State University, Center for Applied Studies, School of Forestry: 265-270.

Rudis, Victor A. 1988. Nontimber values of east Texas timberland. Resour. Bull. SO-139. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 34 p.

Rudis, Victor A.; Skinner, Thomas V. [In press]. Fire's importance in South Central U.S. forests: distribution of fire evidence. In: Nodvin, Stephen C., ed. Fire and the environment: ecological and cultural perspectives: an international symposium; 1990 March 20-24; Knoxville, TN. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 15 p.

TIMBERLAND DOWNTOWN?:

SOUTHERN FOREST RESOURCES ALONG THE URBAN-RURAL CONTINUUM[1/]

Christopher E. DeForest, Thomas G. Harris, Jr., Frederick W. Cubbage, and Arthur C. Nelson[2/]

Abstract.--An Urban-Rural Continuum provides a simple, practical way to classify forest resources and estimate the size and extent of the urban forest. Metropolitan counties contain over 26 percent of the Southeast's timberland acreage--about 28 million acres--and over 26 percent of its standing sawtimber and softwood and hardwood growing stocks. A ten-point Urban-Rural Continuum which codes counties from most highly urbanized to most rural allows even more precise stratification of timber resources.

Keywords: Continuum codes, urban forest, timberland, timber availability, land-use planning.

INTRODUCTION

We used forest inventory data and Urban-Rural Continuum Codes to calculate what portion of the Southeast's forest resources lie within the "urban forest," narrowly and expansively defined. Assigning "timber management" probabilities to zones of the urban forest would enable foresters to estimate how much of the inventoried forest will actually be harvested and retained as timberland. Similarly, urban foresters and rural planners can use the codes to identify, assess, and manage the "urban forest," writ small or large.

DATA

County Classification

We used the USDA Economic Research Service's Urban-Rural Continuum Codes (Butler 1990) for counties in the southeastern US. The Census Bureau has divided all US counties into metropolitan and non-metropolitan counties; metropolitan counties make up Metropolitan Statistical Areas (MSAs). The Urban-Rural Continuum further divides metro counties into four codes (0 to 3), and non-metro counties into six codes (4 to 9), as defined below.

Forest Statistics

We used the most current forest survey Resource Bulletins from the USDA's Southeastern and Southern Forest Experiment Stations. Alabama data is from 1990; Florida from 1987/88; Georgia from 1989; South Carolina from 1986/87; North Carolina from 1984 and 1990; and Virginia from 1985/86. The Resource Bulletins include data on the number of acres of timberland in each county; the standing sawtimber volume; and the softwood and hardwood growing stock volumes. The same Bulletins provided data on timber growth and removals.

1/Presented at the Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests symposium, Charlotte, NC, January 7-9, 1991.

2/Research Coordinator, Professor, and Associate Professor, School of Forest Resources, University of Georgia, Athens GA; and Associate Professor, Graduate City Planning Program,College of Architecture, Georgia Institute of Technology, Atlanta GA.

URBAN-RURAL CONTINUUM CODES (from Butler 1990)

Code	
	Metro counties:
0	Central counties of metro areas of 1 million population or more
1	Fringe counties of metro areas of 1 million or more
2	Counties in metro areas of 250,000 to 1 million
3	Counties in metro areas of fewer than 250,000
	Nonmetro counties:
4	Urban population of 20,000+, adjacent to a metro area
5	Urban population of 20,000+, not adjacent
6	Urban population of 2,500-19,999, adjacent to a metro area
7	Urban population of 2,500-19,999, not adjacent
8	Completely rural or <2,500 urban population, adjacent to a metro area
9	Completely rural or <2,500 urban population, not adjacent to a metro area

METHODS

County Codes

We used MapMaker software to display counties according to their Urban-Rural Continuum Codes, as displayed in this symposium's poster session. MapMaker allowed us to lump different county codes together, to show the cumulative effects of broadening the "urban" areas beyond the central urban counties. Counties coded 0 through 3 comprise the Metropolitan Statistical Areas (MSAs).

Forest Statistics

We set up Quattro spreadsheets for each southeastern state and entered the county-level data on timberland acreage, standing sawtimber volume, and softwood and growing stock volumes. (We combined hardwood and softwood species to arrive at standing sawtimber volume). Another column had each county's Urban-Rural Continuum code.

Sorting Forest Data on the Urban-Rural Continuum

We then sorted the forest statistics spreadsheets by Urban-Rural county code, to calculate the percent of the Southeast's forest resources in each code, and in groups of codes encompassing broader notions of "urban". We also compared timber growth to timber removals in all southeastern counties, focusing on counties within MSAs.

RESULTS

Highly urban counties account for little of the Southeast's forest resources; but the "urban forest" becomes a significant component as one broadens the definition of urban. Table 1 presents the portion of the Southeast's forest resources within the single most urban counties (coded 0), the two most urban groupings (coded 0 or 1), the three most urban, and so on. Recall that counties coded 0 to 3 comprise Metropolitan Statistical Areas; the MSAs contain 28 million acres of the Southeast's timberland, or about 26%. The MSAs also have approximately 26% of the Southeast's standing sawtimber volume (softwood and hardwood combined), and approximately 26% of the Southeast's softwood growing stock and hardwood growing stock volume.

We also found that timber growth exceeded timber removals in 116 of the 153 metro counties in the Southeast, or 76% (four Florida counties and one Virginia county lacked timber growth and removal data). In the other 37 counties, timber removals exceeded net annual growth.

CONCLUSIONS

Is the Urban-Rural Continuum a useful way to classify the productive potential of forests? YES, especially as a quick first cut on where to--and not to--put effort into evaluating the biological productive potential.

Foresters should note that timber availability probably parallels the Urban-Rural Continuum. Timberland in the urban core probably won't be harvested; timberland in the suburbs or exurbs may or may not be. Timber removals there may result from land clearing and conversion of timberland to "higher and better" uses. Foresters relying on forest survey statistics may choose to reduce their own estimates of current and future forest resources accordingly.

Urban foresters and planners can classify and manage the urban forest along the Urban-Rural Continuum. It may help them anticipate public demands on urban--and sprawling suburban--forests, where amenity preferences may outweigh commodity production. The Continuum--and a suitably expansive vision of the urban forest--could guide land-use planning by state and local governments.

DIRECTIONS FOR RESEARCH

1) Test the hypothesis that actual timber availability parallels the Urban-Rural Continuum:

Analyze timberland values along the Continuum

Analyze changes in land-use and cover type in urban areas

Locate counties with tree protection ordinances or local logging regulations

Add "management objectives" query to forest survey data form, focusing on small forest landowners

2) Based on timber removal and timberland conversion trends along the Continuum, estimate correction factors for true availability of forest resources for harvest.

3) Integrate Continuum method with other classification schemes. To identify possible timberland purchases or mill sites, perhaps first winnow out land in counties considered "too urban", then apply an ecologically-based method for identifying biological productivity potential.

4) Arrange Conservation Reserve Program (tree planting) data along the Urban-Rural Continuum and predict future timber supplies.

Acknowledgements: The authors wish to thank research assistants Charles O. Bailey, Jr., Samuel C. Carlton, and Xiaowen Tao of the School of Forest Resources for their help. This study was funded in part by the Georgia Forestry Commission and the School of Forest Resources.

LITERATURE CITED

Butler, Margaret A. April 1990. Rural-urban continuum codes for metro and nonmetro counties. Washington DC: U.S. Department of Agriculture Economic Research Service, Agriculture and Rural Economy Division. Staff Report No. 9028. 38 pp.

Table 1.--Percentage of Southeastern US[a/] timberland acreage, standing sawtimber volume, and softwood and hardwood growing stock within each Urban-Rural Continuum Code[b/] and groups of codes. Percentages are listed singly for each county code, and cumulatively beginning with counties coded 0 (the most highly urbanized counties). Counties coded 0 through 3 comprise Metropolitan Statistical Areas (MSAs).

	URBAN-RURAL CONTINUUM CODE										
	Metro Counties				Nonmetro Counties						
	0	1	2	3	4	5	6	7	8	9	Total
Timberland area											
Percent	0.6	2.4	13.9	9.2	4.7	4.1	24.4	19.5	11.4	9.8	100%
Cumulative %	0.6	3.0	17.0	26.2	30.9	35.0	59.4	78.9	90.2	100%	
Sawtimber Volume											
Percent	1.0	3.1	14.2	8.2	4.6	4.8	23.9	18.9	11.0	10.3	100%
Cumulative %	1.0	4.1	18.3	26.5	31.1	35.9	59.8	78.7	89.7	100%	
Softwood Growing Stock											
Percent	1.0	2.6	14.6	8.3	4.2	4.8	24.5	19.2	11.3	9.5	100%
Cumulative %	1.0	3.6	18.2	26.5	30.7	35.5	60.0	79.2	90.5	100%	
Hardwood Growing Stock											
Percent	0.8	3.6	13.7	8.8	4.9	4.5	23.9	16.9	11.3	11.6	100%
Cumulative %	0.8	4.4	18.1	26.9	31.9	36.4	60.2	77.1	88.4	100%	

a/ Alabama, Florida, Georgia, South Carolina, North Carolina, and Virginia

b/ adapted from Butler (1990)

SPATIAL CHARACTERISTICS OF AN APPALACHIAN FOREST SITE

S. J. Tajchman[1/]

Abstract.--Spatial variation of site factors in a forested Appalachian watershed is considered. Within forest types, specific site parameters can be defined for partial areas of irregular shape randomly distributed in the watershed. A three-dimensional analysis of landscapes and statistical approach to forest land classification are proposed.

Keywords: Topography, site factors, spatial variation.

Foresters attempt to relate the productive capacity of forest land to site factors such as topography, soil, climate, and others. In the central Appalachians the best sites are usually found on lower slopes, north and east aspects, and on gentle concave-shaped slopes; poorer sites usually are found on narrow ridges and upper slopes, on south and west aspects, and on steep convex-shaped slopes.

Site evaluations can be regarded as point observations and their extrapolation into characteristic landscape units was considered by Carmean (1970). With this in mind, spatial distributions of important site factors in the forested Appalachian watershed were obtained (Boyles, 1983; Minton and Tajchman, 1990; Tajchman and Wiant, 1983; Tajchman et al., 1988). A detailed description of the study area is given by Tajchman (1981).

The results suggest, that traditional evaluations and classifications of forest land may appear as idealized models missing the actual conditions. They show that within forest types, specific site parameters, e.g., thickness of soil horizons, stoniness, soil moisture, above ground biomass, can be defined for partial areas of irregular shape randomly distributed in the watershed. This can be seen in Fig. 1 based on data for the A-horizon thickness.

A detailed description of all forest lands does not seem to be feasible, however statistical characterstics of site factors based on a detailed analysis of selected landscapes could be obtained for defined geographic regions. "Partitioning of

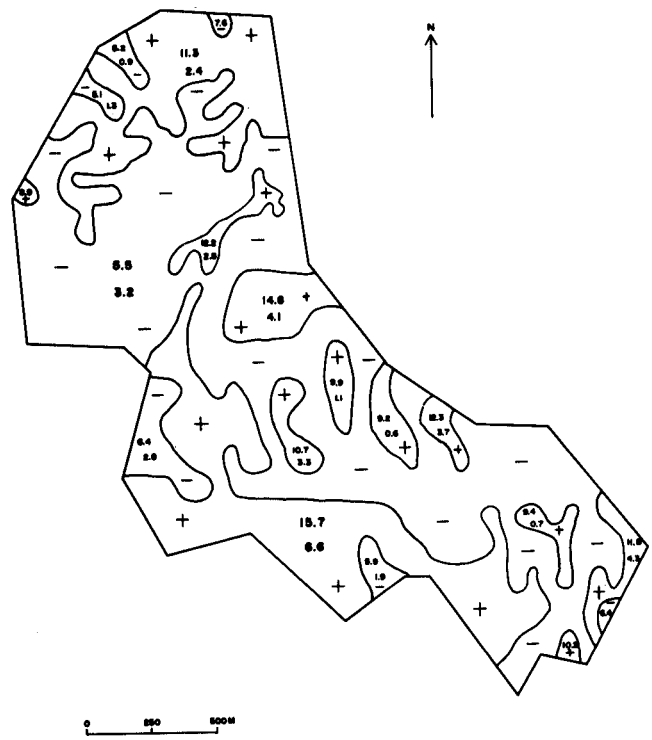


Figure 1.--The distribution of the actual differences between plot values and the average value of A-horizon thickness for the entire watershed. Partial areas characterized by positive or negative signs are separated by isolines representing the average for the whole catchment (X = 8.8 cm). The numbers represent average values and standard deviations of A-horizon thickness in centimeters for partial areas of the catchment. Adopted from Boyles (1983).

[1/]Professor of Forest Meteorology, Division of Forestry, West Virginia University, Morgantown, WV 26506.

landscapes into logical units based on sound physiographic or ecological principles" (Symposium Objective) should be based on a quantitative analysis.

Topography and other site factors can be defined in the X, Y, Z - coordinate system (Tajchman, 1975, Fig. 2).

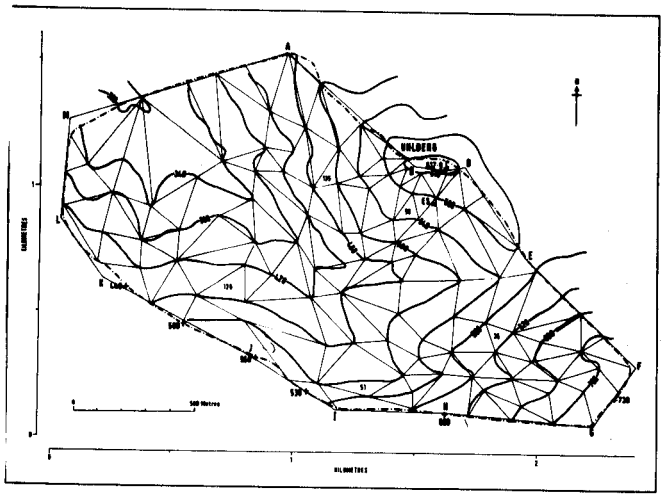


Figure 2.--Forest lands can be analysed in the X, Y, Z - coordinate system. They can be subdivided into triangular segments regarded as elements of planes. Computed topographic parameters, and other properties and processes, for each triangle can be assigned to the coordinates of its gravity center. This permits spatial, temporal, and multidimensional analysis of forest lands, and delineation of sites showing specific properties. The above diagram is after Tajchman (1975).

The next stage should involve the corresponding analysis of the processes of forest growth, including a wide spectrum of mass and energy exchanges. Economic value, susceptibility to disease and weather hazards, insect manifestation, position of roads and logging areas could be also considered. Since forests cover a part of the landscape, classification of forest lands should be linked to the classifications of remaining areas.

LITERATURE CITED

Boyles, R.L. 1983. Analysis of stoniness and rockiness in a forested catchment in north central West Virginia. Morgantown: West Virginia University. 142 pp. Thesis.

Carmean, W.H. 1970. Site quality for eastern hardwoods. In: The silviculture of oaks and associated species. U.S.F.S. Res. Pap. NE-434, 27 pp.

Minton, C.M. and S.J. Tajchman. 1990. Soil moisture characteristics of forested slopes in the central Appalachians. Forestry Notes, W.V. Univ. Agric. For. Exp. Stn., Vol. 14. In press.

Tajchman, S.J. 1975. On calculating the horizon limitation and the short wave radiation income for a mountainous area. Rivista Italiana di Geofisica, Vol. 1 (Speciale): 174-180.

Tajchman, S.J. 1981. On computing topographic characteristics of a mountainous catchment. Can. J. For. Res., 11(4): 768-774.

Tajchman, S.J. and H.V. Wiant, Jr. 1983. Topography and biomass characteristics of a forested catchment in northern Appalachians. For. Ecol. Manage., 5: 55-69.

Tajchman, S.J., Harris, M.H. and Townsend, E.C. 1988. Variability of the radiative index of dryness in an Appalachian watershed. Agric. For. Meteorol., 42: 199-207.

CLASSIFICATION AND EVALUATION OF THE NATCHEZ TRACE STATE FOREST, STATE RESORT PARK, AND WILDLIFE MANAGEMENT AREA FOR TIMBER AND WILDLIFE HABITAT[1]

Glendon W. Smalley[2], Kenderick S. Arney[3],

Lorenda A. Sharber[3], and Hart W. Applegate[4]

ABSTRACT

The 45,000-acre Natchez Trace State Forest, Park, and Wildlife Management Area (NTSF) began as a land reclamation project of the Resettlement Administration in 1935. The State of Tennessee acquired ownership in 1955. Smoother ridges, moist bottoms, and some slopes were cleared, row-cropped, and pastured resulting in extensive sheet and gully erosion of the fragile soils. Mixed oak forest dominate the uplands that were not cleared; loblolly pine plantations occupy the former gullied cropland. Bottomland hardwoods occur in the wet bottoms; some ponded areas support alder thickets. Most of the erosion has been controlled. Upland soils are derived from a 2 to 3-foot cap of loess and/or the underlying loamy and clayey unconsolidated Coastal Plain sediments.

A land classification system has been developed as part of the overall land management planning process. The landscape was divided into 25 landtypes based on differences in geology, topography, soils, vegetation, and stream order. Landtypes are described in terms of nine elements (geographic setting, dominant soils, parent material, solum thickness, surface soil texture, internal soil drainage, relative soil water supply, soil fertility, and vegetation). Each landtype is evaluated in terms of productivity (site index and mean annual cubic growth) and desirability (most desirable, acceptable, and least desirable) of selected hardwoods and conifers for timber production, and for suitability as wildlife habitat. Also, each landtype is rated for five problems (plant competition, seedling mortality, equipment limitations, erosion hazard, and windthrow hazard), that can affect forest management operations. The resulting landtype map is one element of the physical and biological information about NTSF that is stored on an ESRI (Environmental Systems Research Institute) Geographic Information System.

The land classification system permits the intensive study of the relationships between forest plant communities and the landscape units. The ultimate goal of such a study is the capability of predicting which community(s) grow on each unit and to ascertain the successional pathways resulting from various forest cuttings. Once plant-landscape relationships are known, land managers can easily and economically determine wildlife habitat parameters.

Although the land classification was developed just for NTSF, it is applicable to an estimated 1 to 2 million acres in West Tennessee, northeast Mississippi, and northwest Alabama.

Key words: forest land classification, site productivity, erosion, timber management, wildlife habitat, Upper East Gulf Coastal Plain, West Tennessee.

[1]Poster presented at the Symposium on Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests, Charlotte, NC, January 7-9, 1991.

[2]Principal Soil Scientist (retired), USDA-Forest Service, Southern Forest Experiment Station and Consultant--Forest Land Classification and Evaluation, Rt. 1, Box 541, Sewanee, TN 37375.

[3]Staff Forester and Wildlife Biologist respectively, Tennessee Wildlife Resources Agency, Ellington Agricultural Center, P. O. Box 40747, Nashville, TN 37204.

[4]Assistant State Forester, Tennessee Division of Forestry, 701 Broadway, Nashville, TN 37203.

SOIL/SITE INFLUENCES ON FOREST GROWTH WITHIN THREE PHYSIOGRAPHIC REGIONS OF TENNESSEE.[1/]

P. Alan Mays and Elizabeth R. Smith[2/]

Abstract.--Most often, landform classification systems attempt to rate forest productivity based on data that are not site specific. Remeasurement data from permanent forestry plots were used to evaluate one system developed by the U.S. Forest Service. Considerable agreement exists between the observed and reported annual growth rates for selected hardwood species on most landtypes within the study areas.

Keywords: annual growth rate, landtype, hardwoods

INTRODUCTION

Many attempts have been made to rate forest productivity and site limitations based on landform classification systems. Most often, the development of these systems depended on data which were not site specific. In this study, data collected from 282 Continuous Forestry Inventory (CFI) plots within three physiographic regions of Tennessee were used to evaluate one such system developed by the U.S. Forest Service (Smalley 1980, 1984) for the classification and evaluation of sites in the interior uplands.

Three study sites were selected to represent the forests of the Tennessee Valley Region based on availability of remeasurement data and physiographic location. The sites selected include:

(a) Emory River Land Company (ERLC) is a private landholding located in the Cumberland Mountains of eastern Tennessee. Soils have formed in interbedded sandstone, siltstone and shale. ERLC has the greatest relief with elevations ranging from 323 m to 957 m above sea level. Rainfall averages 148 cm annually. Disturbance at this site has been primarily due to fire and logging (Smith 1990).

(b) Land Between the Lakes (LBL) is a national demonstration area managed by TVA and is located at the interface of the Western Highland Rim and Coastal Plain Provinces in Tennessee and Kentucky. Soils have formed in cherty limestone and both gravelly and clayey Coastal Plain sediments. Many upland areas have been covered with a blanket of loess. Annual precipitation totals 131.5 cm. The greatest amount of disturbance at LBL is due to logging.

(c) Wayne County (WC) is also located in the Western Highland Rim and Coastal Plain Provinces in southwest Tennessee and is comprised of mostly private landholdings. Soil parent materials are similar to those of LBL but include the thick beds of cherty limestone of the Fort Payne Formation. Climate and past site disturbance is also comparable to that of LBL.

Within each site, plots were chosen for reinventory and collection of additional data based on species composition, tree size, topography, soils, and the absence of significant recent disturbance. Plots were natural, second-growth stands of mixed hardwood species with diameter distributions that consisted of primarily large trees (greater than or equal to 28 cm dbh). Soils were described from opened pits in each plot. Annual basal increment was estimated using remeasurement data. Species' productivity was compared with the expected productivity from Smalley's system using paired t-tests.

RESULTS

The majority of all CFI plots were easily adapted to the landtype classification scheme established by the U.S. Forest Service for these regions. A limited number of plots at LBL and WC were placed into landtypes that are more commonly found in other subregions of the Western Highland

[1/] Presented at the Ecological Land Classification Symposium, Charlotte, NC, January 7-9, 1991.

[2/] Environmental Scientist and Forest Biometrician/Ecologist, respectively, Tennessee Valley Authority, Norris, TN.

Rim. Over sixty percent of all plots within each site were concentrated on four distinct landtypes - narrow ridges, colluvial sideslopes (both north and south aspect), and concave footslopes/stream bottoms.

Agreement between the observed and reported annual growth rates for selected hardwood species was greatest at the ERLC plots in the Cumberland Mountains, where only yellow-poplar growth rates were significantly less on the colluvial north sideslopes and stream bottom landtypes. Disagreements in annual growth rates at LBL were confined to upland oaks in essentially the same landtypes. The WC plots exhibited the greatest differences between growth rates of the three sites. Upland oaks and yellow-poplars on the three most dominant landtypes had significantly different annual growth rates. It should be noted that the WC site had fewer plots per landtype and appeared to have experienced more recent disturbance than the ERLC and LBL sites.

Total mean annual growth rates were much higher at the ERLC site due to higher moisture availability and a greater proportion of pines, which exhibited higher growth than associated hardwood species. Total mean annual growth increased along a moisture gradient that extended from narrow ridges into the footslope/stream bottom landtypes. Total annual growth rates for the WC site ranged from 16.4 cubic feet per acre for the narrow ridges to 53.4 cubic feet per acre for the stream bottom plots. By comparison, the annual growth rates at the Cumberland Mountains plots were 35.6 cubic feet per acre on narrow shale ridges and 57.9 cubic feet per acre in the stream bottoms. Total annual growth rates on those plots at the ERLC site which had a significant number of pines could exceed 80.0 cubic feet per acre.

SUMMARY

Smalley's land classification system appears to be a suitable method for estimating potential productivity for forest stands within the regions of our study. Such a system may be useful for assessing trends in current growth, as well as providing a gauge with which to measure future changes in growth and species composition.

LITERATURE CITED

Smalley, Glendon W. 1980. Classification and evaluation of forest sites on the Western Highland Rim and Pennyroyal. U.S. Dep. Agric. For. Serv. Gen. Techn. Rep. SO-30, 120 p. South For. Exp. Stn., New Orleans, LA.

Smalley, Glendon W. 1984. Classification and evaluation of forest sites in the Cumberland Mountains. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. SO-50, 84 p. South. For. Exp. Stn., New Orleans, LA.

Smith, Elizabeth R. 1990. Temporal and spatial variability in tree growth response to climate. Knoxville, TN: The University of Tennessee. 363 p. Ph.D. Dissertation.

SCS FOREST/SOIL DATABASE OF NORTH CAROLINA[1/]

Albert Coffey[2/]

Keywords: Site index, soil map units, soil profile description.

Utilization of soil map units is a logical way to classify forest lands based on their potential productivity. The USDA Soil Conservation Service (SCS) uses soil as the base element for determining site index. Other macro-elements that influence site index include climate, slope, slope position, aspect, drainage, and elevation. Micro environmental factors, not always easily identified, also play a role in forest productivity. Micro environmental factors are not recorded for determining SCS site index.

SCS maintains a National Forest/Soil Database. It is a collection of site index plots collected on specific soil series throughout the nation. This database enables the user to analyze different macro-elements using soil as the base. On some sites, soil is the most identifiable and important element. On these sites, site index based just on the soil is uniform and closely defined. On other sites, soil, used with a combination of other macro-elements, more closely defines the site. This database is used to assign site indices in published soil surveys, soil interpretations for the SCS Technical Guide, and for establishing new soil series. Soil surveys and the Technical Guide are used by SCS conservationists, foresters, and landowners for conservation planning, land use decisions, and species selection. Information from the Forest/Soil Database is available from SCS staff foresters within each state.

Recent refinements in soil mapping, particularly in the mountains, will make soil map units better indicators of site productivity. These improvements include expanded recognition of parent material, aspect, elevation, soil temperature, and rainfall. In addition, the use of 1 inch = 1000 feet photography allows for delineation of more detailed map units than can be done with conventional scale photographs such as 1 inch = 2000 feet.

In North Carolina site index data collection by SCS was begun in 1956 when a plot of shortleaf pine (*Pinus echinata* Mill.) was collected on Pacolet soil in Wilkes County. Since then 1,790 plots have been collected across the state on 203 soil series. Foresters and soil scientists from SCS, North Carolina Forest Service, U.S. Forest Service, and North Carolina Division of Soil and Water Conservation have collected plot data.

Data is collected on form SCS-ECS-005 and includes plot location in state plane coordinates which are digitized from 7.5 minute United States Geological Survey (USGS) topographic maps. Elevation is also determined from USGS maps. Precipitation at each plot is determined from rainfall charts for North Carolina, or more site-specific data is used if it is available. Slope, slope length, and aspect (azimuth) are recorded. Upper, middle, and lower slope positions are also shown.

A detailed soil profile description is prepared by a soil scientist for each site index plot. Having a profile description allows the plot data to be placed in the correct soil series if the series names are changed during subsequent field reviews or during correlation. The profile description includes identification and depth of horizons and any of the features described for horizons listed in the National Soils Handbook.

Site index is collected on five trees of the same species in each plot if suitable trees are found. Trees that exhibit tight rings or abnormal growth patterns are not used. Only dominant and co-dominant trees are measured since the objective is to determine potential soil productivity. Other data recorded includes diameter, height, inches of radial growth in the last 10 years, understory abundance, canopy density, and a listing of as many as 12 understory and ground plants. Scientific plant name symbols are used in data recording.

Standard deviation can be calculated from the SCS Forest/Soil Database from soil and any combination of data collected when enough plots are available. The SCS standard for statistical accuracy is a coefficient of variation (C.V.) of eight or less.

[1/]Poster paper presented at the symposium on Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests, Charlotte, NC, January 7-9, 1991.

[2/]Albert Coffey is Forester, Soil Conservation Service, U.S. Department of Agriculture, Raleigh, NC.

After the data is collected, it is checked, edited, and entered by computer into the National Forest/Soil Database. Information can be retrieved by any of the fields or combinations of fields on form SCS-ECS-005. Tables of data by county, state, or major land resource area are available.

Acknowledgments: The author thanks Sara A. Browning, Forest Service, U.S. Department of Agriculture; and James L. Robinson, Soil Conservation Service, U.S. Department of Agriculture, for contributing data and suggestions.

LITERATURE CITED:

USDA Soil Conservation Service. 1980. National Forestry Manual.

POTENTIAL PRODUCTIVITY OF LOBLOLLY PINE PLANTATIONS IN THE SOUTHEASTERN UNITED STATES[1/]

S.R. Colbert and H.L. Allen[2/]

Realized levels of productivity (stemwood production per unit area per year) for pine plantations in the Southeastern United States are substantially lower than potential. Even in fully stocked stands, existing growth rates rarely represent a site's productive cacacity; growth is typically reduced to a level at which an adequate supply of the limiting resource can be maintained to assure proper physiological function.

Classification of forest lands based on potential productivity requires knowledge of the ecophysiological processes (e.g., the amount of solar radiation intercepted, the photosynthetic efficiency of the canopy, the consumption of fixed carbon to stemwood), as well as the climatic and site factors (e.g., availability of light, water, and nutrients, and inherent levels of heat, CO_2, and O_2), affecting these processes.

Over the past 25 years, productivity of southern pines has been significantly increased through application of silvicultural treatments such as drainage, fertilization, weed control, cultivation, thinning, pest management, and genetic improvement. The North Carolina State Forest Nutrition Cooperative (NCSFNC) has 15 regionwide studies comprising over 375 installations designed to examine silvicultural options to improve loblolly pine productivity during stand regeneration and in established stands. The goal of this research effort is to increase the production efficiency of southern pine stands through the silvicultural manipulations of site resources.

Results from a poorly drained clay soil in South Carolina illustrate the potential response from cultural treatments at time of stand establishment. Ten-year height and stand volume responses of loblolly pine to bedding, fertilization, and weed control averaged 14 ft and 875 ft^3 ac^{-1}, respectively, over the control. Treatment effects on annual height growth were most pronounced during the first four years of growth, although incremental gains continued through 10 years. The largest response was due to bedding, followed by fertilization, and weed control. Annual height growth for the bedding+fertilizer+weed control treatment culminated at approximately 4.0 ft yr^{-1} after 8 years.

Six-year volume responses to N+P fertilization over a wide range of existing growing conditions ranged from 569 to 911 ft^3 ac^{-1} and averaged 687 ft^3 ac^{-1}. Strong incremental gains were observed during the fifth and sixth years following fertilization; additional incremental gains appear probable for future years on these sites. Of a host of initial stand, site, foliage, and climatic variables screened, analyses indicate that stand leaf area, fascicle weight, and foliar N concentrations were the most highly correlated with response. In contrast, there was no correlation between response and stand basal area.

Seven years after treatment, net volume growth response to thinning for a 21-year-old loblolly pine stand on the Cumberland Plateau was 370 ft^3 ac^{-1} for all trees and 338 ft^3 ac^{-1} for crop trees. The combination of fertilization and thinning increased net volume growth 632 and 586 ft^3 ac^{-1} over the control for all trees and crop trees, respectively. Crop tree diameter growth response for this study increased to a maximum at age 7 of 0.65 inches for the fertilization+thinning treatment, 0.35 inches for thinning alone, and 0.21 inches for fertilization alone.

These data demonstrate that southern pine productivity is not fixed--silvicultural treatments can dramatically affect the availability and allocation of soil water and nutrient resources to enhance growth and yield. Forest managers have two strategies for improving pine productivity: 1) accelerate individual tree growth to shorten the time it takes for crop trees to achieve or regain full site occupancy and/or 2) increase the maximum leaf area attained at full site occupancy.

The amount, display, and duration of leaf area or foliage biomass largely determines the quantity of radiation intercepted by forest

---

1/ Presented at Ecological Land Classification: Applications to Identify the Productive Capacity of Southern Forests, Charlotte, NC, January 7-9, 1991.

2/ The authors are Associate Director, and Associate Professor of Forestry and Director, respectively, North Carolina State Forest Nutrition Cooperative, NC State University, Raleigh, NC 27695-8008.

canopies. In addition, patterns of carbon fixation, transpiration, and aboveground respiration within forest stands are closely associated with foliage mass or surface area. A strong, positive, and linear relationship existed between stemwood growth and leaf area index in an analysis of three of the Regionwide 13 installations. The ability to intercept radiation has been hypothesized as a major determinant of productivity in forest stands.

Theoretical analyses indicate that maximum aboveground productivity of southern pine stands should be achieved at projected leaf areas of 5.0 m^2 m^{-2}. Leaf areas of all but the most productive southern pine stands are far below this maximum--values of 1.5 to 3.0 are commonly measured. Low nutrient availability, water stress, high temperatures, and elevated ozone levels have been implicated as factors causing suboptimal leaf area index and reduced light interception, resulting in diminished productivity.

Traditional stocking measures based on basal area and number of stems are measures of past performance and may not always provide an adequated measure of current or potential productivity. Leaf area represents a measure of site occupancy that integrates tree size, stand density, and site resource supply. While foliage surface area is strongly related to stocking in young stands, we hypothesize that leaf area is independent of basal area in fully stocked stands after canopy closure. Under these conditions, leaf area can have a wide range of values depending on site quality and climatic limitations. The relationship between 1987 cohort leaf surface area and basal area supports this hypothesis.

Effective stand management requires knowledge of the factors limiting leaf area and whether these limitations can be ameliorated. Maximum site occupancy should be redefined as the leaf area index sustainable given fixed site resources (i.e., those that cannot be manipulated silviculturally). By calculating the difference between a stand's current and maximum potential leaf area, forest managers should be able to predict the magnitude and duration of response to fertilization and other silvicultural practices.

Clearly, the productivity potential of the southern pine region is not presently being realized. Application of state of the art silvicultural treatments from plantation establishment could increase site index (dominant height at age 25) and mean annual increment (MAI) by as much as 10 to 15 ft and 150 to 200 ft^3 ac^{-1} yr^{-1}, respectively, on most sites. These gains are possible while maintaining or actually decreasing regeneration costs. For established stands, MAI could be increased by over 100 ft^3 ac^{-1} yr^{-1}.

Major limitations impeding the application of existing technology are: 1) uncertainty concerning the magnitude, probability, and economic value of response; 2) lack of knowledge necessary to develop the appropriate fertilizer prescription; 3) inadequate capital for silvicultural treatments due to uncertainty of the long-term supply and value of wood; and 4) infrastructure barriers that slow the acceptance or implementation of new tehcnologies. To overcome these limitations we must better inform forest managers of the opportunities and provide sufficient evidence to increase their confidence that these potentials can be realized.

GIS AND LAND CLASSIFICATION: INTEGRATED DECISION SUPPORT FOR INDUSTRIAL FOREST MANAGEMENT[1]

Brent J. Keefer[2]

Abstract: This poster presentation examines several practical examples of applying land classification to industrial forest management problems. These application areas include environmental regulation, timber inventory, fertilization and herbicide recommendations, and harvest size planning. Our experiences overwhelming conclude that GIS is essential to using land classification information.

Keywords: wetlands, fertilization, clearcut, inventory

The only way to effectively and fully use land classification information is to input this information into a geographic information system thereby providing the capabilities to organize, manipulate, analyze, display and create information in such a way that responsible and accurate decisions can be made. ITT Rayonier Inc., Southeast Forest Resources launched the development of a GIS 2 years ago using pc-based ARC/INFO and then moved to SUN workstation ARC/INFO 8 months ago. The displayed maps represent several practical applications that involve analyzing or interpreting land classification information.

Potential Wetlands Classification:

As forest industry continues to come under fire from environmental regulation, GIS provides an invaluable tool to assess the impact of potential environmental regulations. It also permits us to develop management plans which consider multiple objectives including environmental concerns. One poster presented demonstrated three different wetlands interpretations based on the Clean Water Act, U.S. Fish and Wildlife Service, and the Interagency Federal Manual on wetlands. Each definition of wetlands resulted in more acreage of managed pine plantations being classed as wetlands. This particular map was used to show the need for a more narrow and more reasonable definition of wetlands. We are also able to map areas where endangered or environmentally sensitive plant and wildlife species occur on our lands. We can then monitor the impacts of our activities and develop appropriate management plans.

Timber Inventory:

An application currently being evaluated is to use the differences in soil types to assist in creating sampling strata for timber cruising. Although a stand of timber has been managed over it's rotation as a homogeneous unit, in actuality it may not be homogeneous due in part to site quality differences. When the stand is cruised for volume estimates at harvest, these in-stand differences must be recognized and the statistical sample adjusted to account for them. Currently, our foresters often divide a stand into strata based upon observation of timber differences from the field or aerial photography.

This GIS and soil mapping project may allow us to stratify the stand by using changes in soil type under the stand.

Clearcut Size Reduction:

ITT Rayonier has recognized the impact that large, contiguous acreages of clearcut forestland have on the public's image of industrial forestry. Consequently, we are attempting to reduce clearcut size and implement a 2-3 year period of "green-up" between adjacent clearcuts. Soil types can often be used as a logical method for breaking up a large stand into several smaller cutting groups that can then be scheduled for harvest 2-3 years apart.

---

[1]Presented at the Ecological Land Classification Application To Identify The Productive Potential Of Southern Forests, Charlotte, NC, January 7-9, 1991

[2]GIS Coordinator, ITT Rayonier Inc., Southeast Forest Resources, Fernandina Beach, FL

Fertilization Recommendations:

ITT Rayonier is involved in a very active fertilization program, but often selection of the stands which will benefit most from fertilization is a difficult and time consuming task. Currently the decision process involves field observations of each potential fertilization site. With the GIS, we are able to overlay the soil classification layer with the timber stand layer and then query the resulting unioned layer to select stands for fertilization. The criteria for fertilization include stand age, soil type, site quality and past fertilization history.

In conclusion, GIS provides the means necessary to integrate multiple sources of land classification information. A decision support system is thereby created which supplies many alternatives to the decision maker. The system is not the decision maker, but rather the synthesizer of hundreds of alternatives into several of the best alternatives from which the decision maker can choose.

☆U.S. GOVERNMENT PRINTING OFFICE: 1991-534-675

Mengel, Dennis L.; Tew, D. Thompson, eds. 1991. Proceedings of a symposium: Ecological land classification: applications to identify the productive potential of southern forests. Gen. Tech. Rep. SE-68. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 149 pp.

Eighteen papers representing four categories–Regional Overviews; Classification System Development; Classification System Interpretation; Mapping/GIS Applications in Classification Systems–present the state of the art in forest-land classification and evaluation in the South. In addition, nine poster papers are presented.