LANDSCAPE ECOSYSTEM CLASSIFICATION FOR SOUTH CAROLINA[1]

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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

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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.

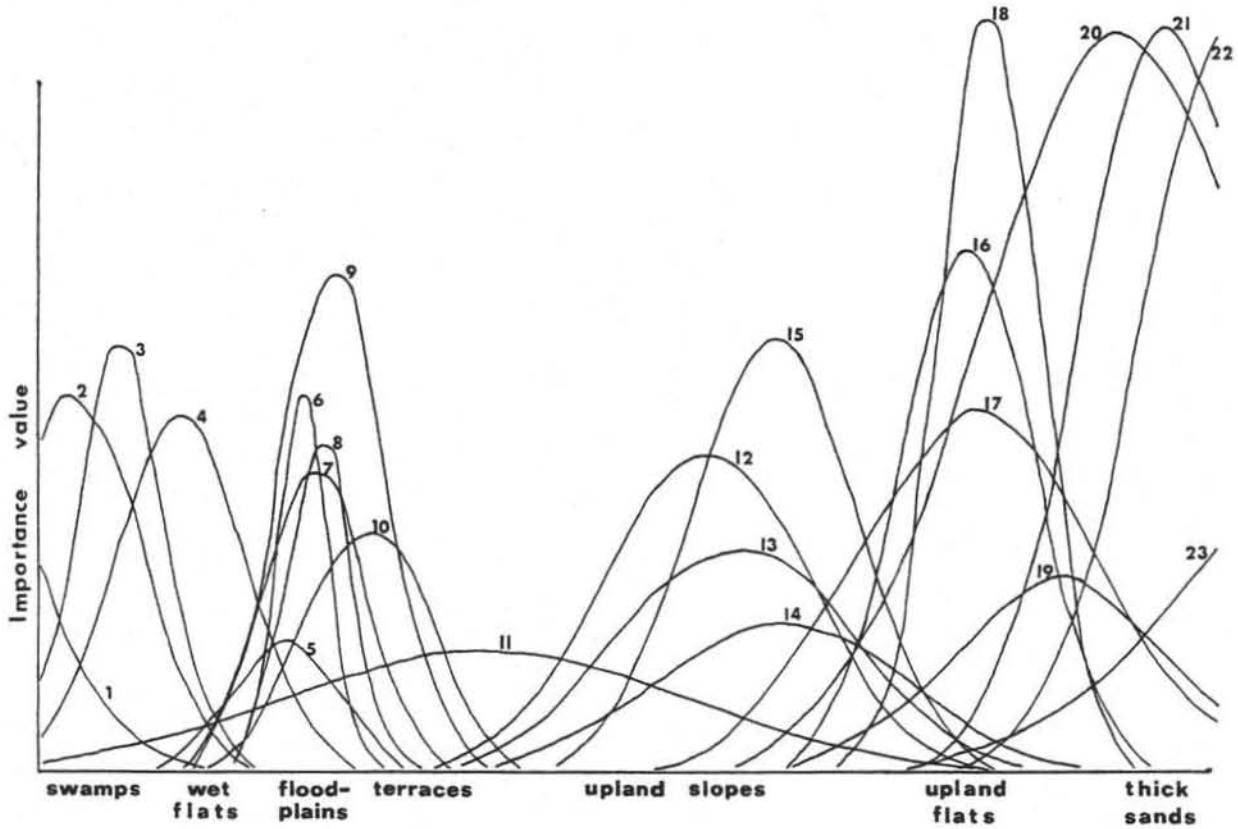
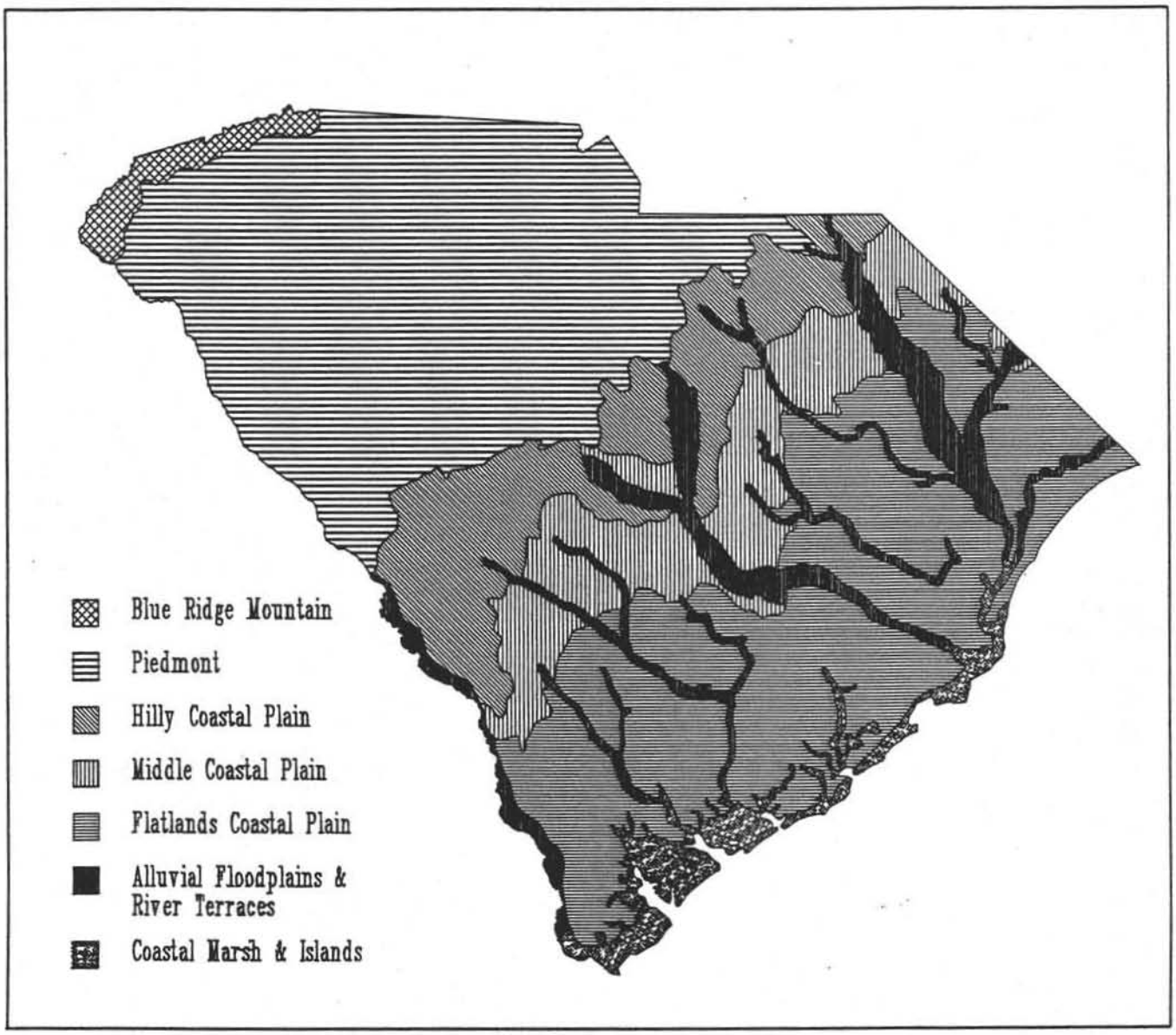


Figure 2.--Physiographic provinces of South Carolina (Myers and others 1986).



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.

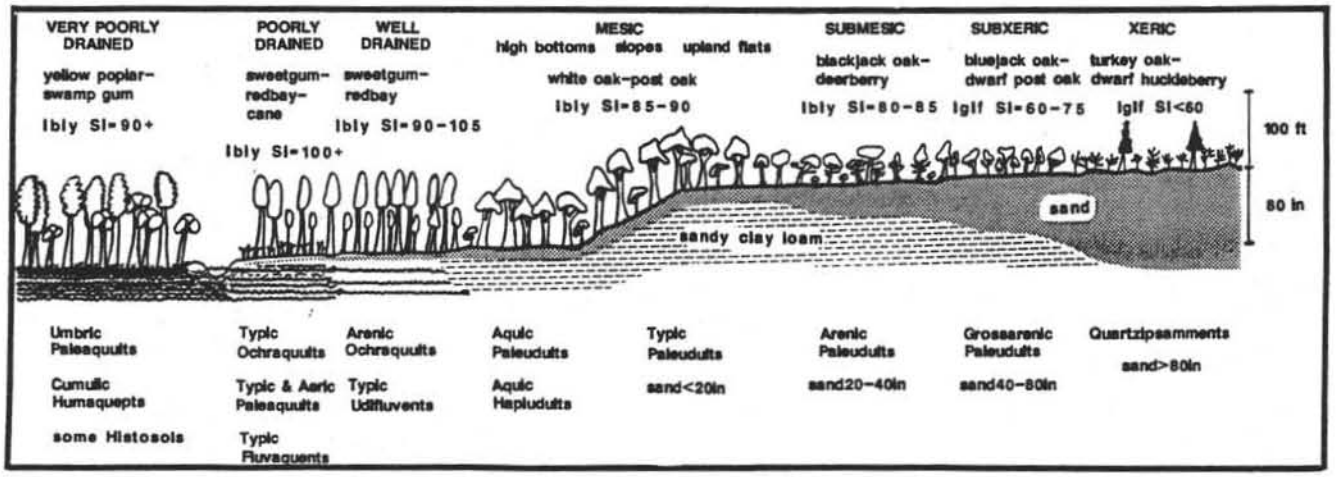


Table 2.--Distribution of selected character species by site unit for the Midlands Plateau Region of the Piedmont Province. Numbers 1, 2, and 3 following the names of woody species represent tree, sapling, and seedling size classes, respectively

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		XXXXXXXXXXXXXXXXX			
Polygonatum biflorum		XXXXXXXXXXXXXXXXX			
Viola hastata		XXXXXXXXXXXXXXXXX			
Quercus velutina 1			XXXXXXXXXXXXXXXXXXXXXXXXXX		
Quercus coccinea 1			XXXXXXXXXXXXXXXXXXXXXXXXXX		
Vaccinium stamineum				XXXXXXXX	
Quercus stellata 1					XXXXXXXX
Vaccinium vacillans					XXXXXXXX

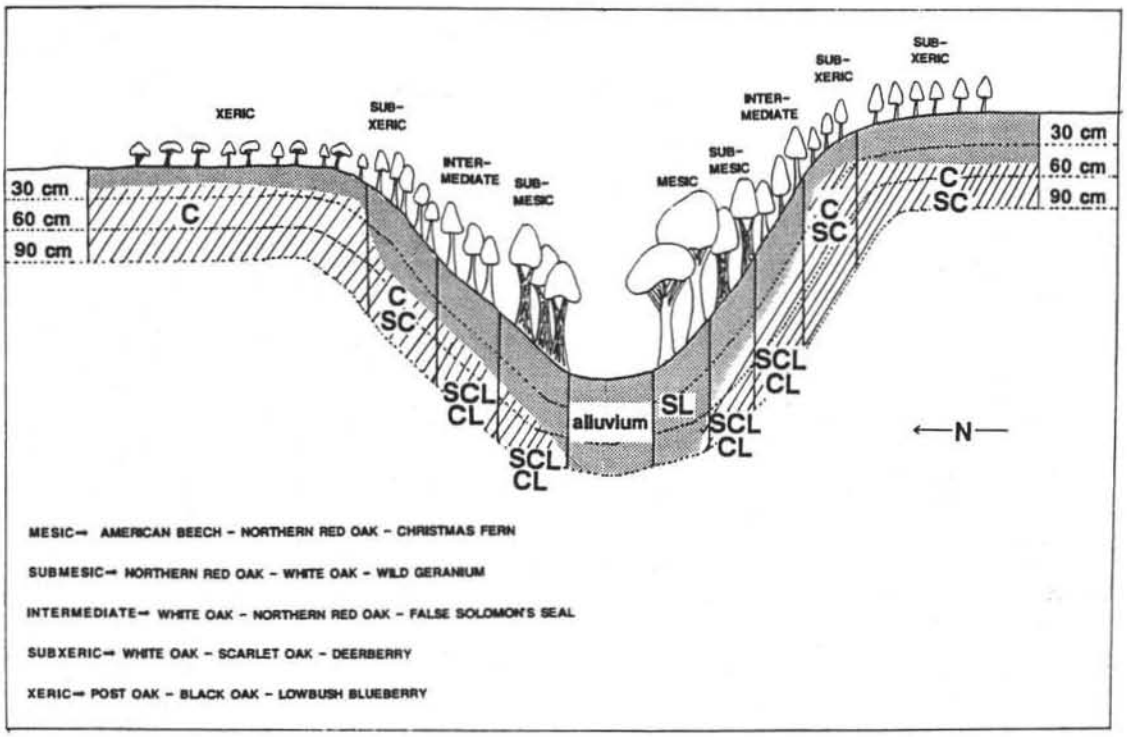


Figure 4.--Landscape ecosystem classification model for the Interior Plateau Subregion of the Midlands Plateau Region of the Piedmont Province, South Carolina.

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.

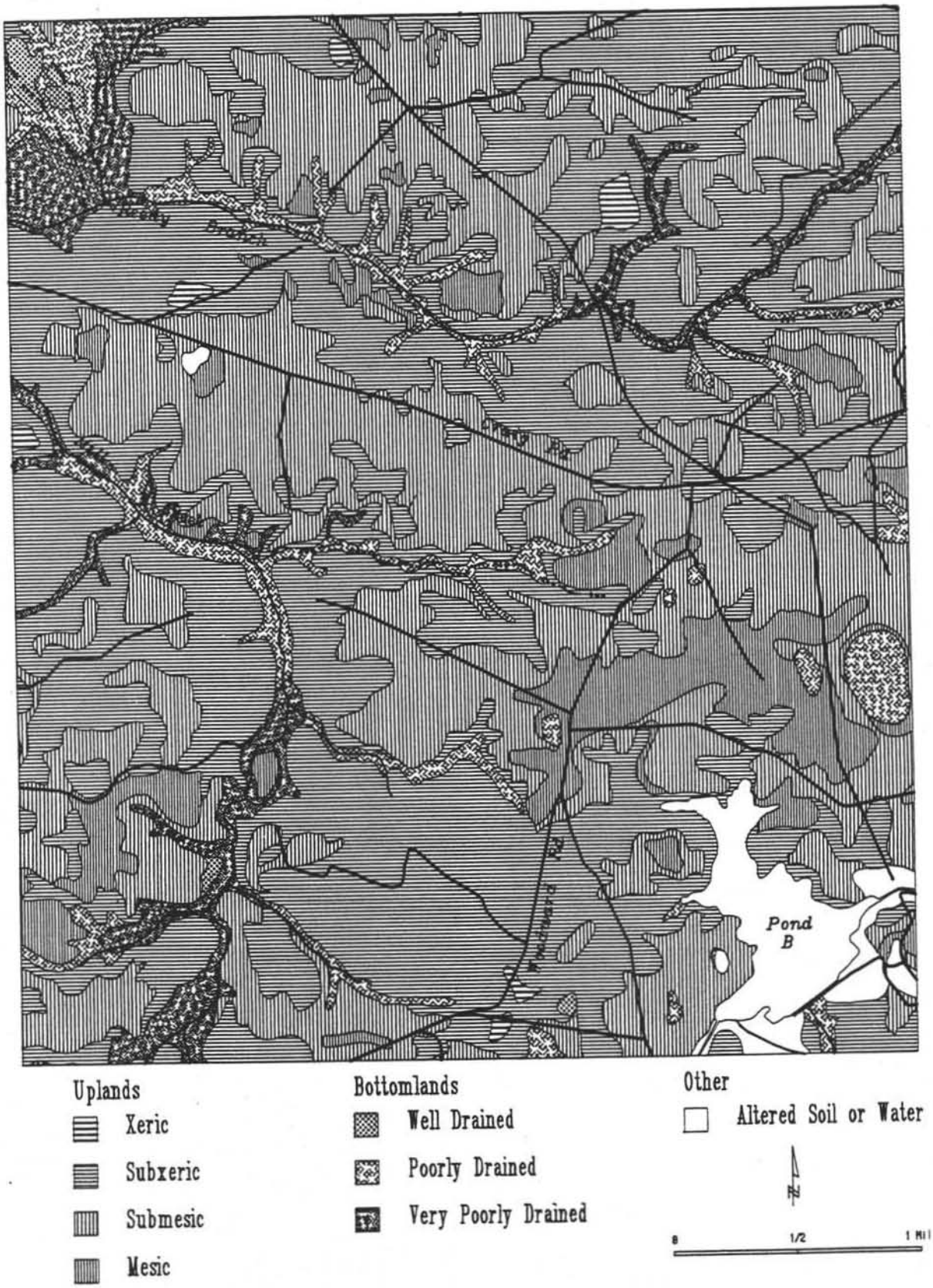
The major criterion in measuring the usefulness of a classification approach is its adaptability to mapping procedures and the production of accurate, useful maps from which interpretations of land productivity and other resource values can be made. Obviously, mapping site types based on existing or 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.



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

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