United States
Department of
Agriculture

Forest
Service

Miscellaneous
Publication 1465

Ecogeographic Analysis

A Guide to the Ecological Division of Land for Resource Management

Cover—The semi-arid mountains of the Wallowa National Forest, Oregon contain numerous examples of the landform influences on ecosystem patterns. (USDA Forest Service photo).

United States
Department of
Agriculture

Forest
Service

Miscellaneous
Publication 1465

Ecogeographic Analysis

A Guide to the Ecological Division of Land for Resource Management

Robert G. Bailey[1], Geographer
Land Management Planning Staff
USDA Forest Service
Washington, DC

November 1988

[1]Correspondence address: Land Management Planning Systems, USDA Forest Service, 3825 East Mulberry Street, Fort Collins, CO 80524 (USA)

Bailey, Robert 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. 18 p.

Ecological units of different sizes for predictive modeling of resource productivity and ecological response to management need to be identified and mapped. A set of criteria for subdividing a landscape into ecosystem units of different sizes is presented, based on differences in factors important in differentiating ecosystems at varying scales in a hierarchy. Practical applications of such units are discussed.

Keywords: ecological land classification, landscape ecology, scale, ecosystem mapping, resource planning model

Contents

Introduction

Wildland planning efforts today focus largely on trying to predict or model the behavior of the ecosystem under differing kinds and intensities of management. In order to do this, the land must be divided into component ecosystems that reflect significant differences in response to management and resource production capability.

The question now arises: How much detail is adequate to model the area under analysis?

The answer to this question depends on the complexity of the area and the level of precision needed by the manager. Ecosystems often exist naturally in very different sizes, and can be identified at several geographical scales and levels of detail in a hierarchical manner, ranging from site-specific ecosystems to groups of spatially related systems know as regions. One of the essential frameworks for predictive modeling, therefore, is an identification of ecosystems at different levels of detail that can be linked to different levels of analysis. **Ecogeographic analysis** is the subdivision of a landscape for this purpose.

This approach starts with mapping the ecosystems of various sizes underlying the area for analysis. This requires a union of ecology and geography. In these fields there are numerous textbooks that are lengthy, complete, definitive works. Ecosystem classification has been described by USDA Forest Service (1982) and Driscoll and others (1984). So far ecosystem boundaries have received little systematic treatment. Most textbooks deal with boundary problems superficially, and few special essays are available. One could argue, therefore, that a short accessible monograph that treats the establishment of ecosystem boundaries is needed as a guide for those whose professions involve the analysis and management of land. This monograph is written in an attempt to fulfill this need.

The basic concepts about scale and ecosystems are discussed in textbooks on landscape ecology and geography (Isachenko 1973; Leser 1976; Forman and Godron 1986). A synthesis of these concepts has been presented elsewhere by Bailey (1985). In a brief followup article, Bailey (1987) reviewed the literature to suggest possible criteria to make the concepts operational through mapping. This monograph expands upon these articles to elaborate and illustrate the concepts and criteria. It also provides a discussion of practical applications in planning and management.

Scale of Ecosystem Units

Scale implies a certain level of perceived detail. Suppose, for example, that an area of intermixed grassland and pine forest is examined carefully. At one scale, the grassland and the stand of pine are each spatially homogeneous and look uniform. Yet linkages of energy and material exist between these systems. Having determined these linkages, the locationally separate systems are intellectually combined into a new entity of higher order and greater size. These larger systems represent patterns or associations of linked, smaller ecosystems.

Schemes for recognizing such linkages have been proposed and implemented in a number of countries (for example, Zonneveld 1972). The nomenclature and number of levels in these schemes vary. One scheme, proposed by Miller (1978), recognizes linkages at three scales of perception. While not definitive, it illustrates the nature of these schemes. The smallest, or local, ecosystems (microecosystems) are the homogeneous **sites** commonly recognized by foresters and range scientists. They are of the size of hectares.

Linked sites create a **landscape mosaic** (mesoecosystem) that looks like a patchwork. A landscape mosaic is made up of spatially contiguous sites distinguished by material and energy exchange. They range in size from 10 km^2 to several thousand km^2.

A classic example of a landscape mosaic is a mountain landscape. Between the component systems of a mountain range there is lively exchange of materials: water and products of erosion move down the mountains; updrafts carry dust and pieces of organic matter upward, and downdrafts carry them downward; animals can move from one system into the next; seeds are easily scattered by the wind or propagated by birds.

At broader scales, landscape mosaics are connected to form larger units (macroecosystems). Mountains and plains are a case in point. For example, the lowland plains of the Western United States as a mosaic contrasts with steep landscapes in adjacent mountain ranges. As water from the mountains flows to the valley, and as the mountains affect the climate of the valley through sheltering, two large-scale linkages are evident. Such linkages create real economic and ecologic units. This unit with connected mosaics is called a **region.** Regions are in many scales (Bailey 1983). Like landscapes, they stand in contrast with one another and also are connected through long-distance linkages. Finally this progression reaches the scale of the planet.

Role of Climate in Ecosystem Differentiation

Ecosystems of different climatic areas differ significantly. These differences are the result of factors that control climatic regime defined as the diurnal and seasonal fluxes of energy and moisture. The basic pattern of fluctuation of solar energy is responsible for the largest share of periodicity and spatial variation of the earth's environment. The changing intensity and duration of solar radiation brings about changes in the troposphere, stratosphere, earth temperature and sea temperature; influences migratory and hibernation patterns of animals; and controls the life cycles of much of the biota. Thus, an energy flow that varies systematically through time and space results in an environment that also varies through time and space. The same can be said of the moisture flow. Energy and moisture regimes, in combination, are the dominant controls of all biophysical processes.

Climatic regime, in turn, is channeled, shaped, and transformed by the structural characteristics of ecosystems, that is, by the nature of the earth's surface. In this sense, all ecosystems, macro and micro, are responding to climatic influences at different scales. The primary controls over the climatic effects change with the scale of observation. Latitude, continentality, and mountains all differentiate regional climate, while landforms and local vegetation on them differentiate local climate. Setting ecosystem boundaries involves the understanding of these factors on a scale-related basis.

The factors that are thought to differentiate eco-climatic units, and the scale at which they operate, are described as follows:

Macroscale: Macroclimatic Differentiation

To make comparisons of climates on a macroscale or global level, it is necessary to consider climatic conditions that prevail over large areas. Unfortunately, climate changes within short distances due to variations in local landform features and the vegetation that develops on them. It is necessary, therefore, to postulate a climate that lies just beyond the local modifying irregularities of landform and vegetation. To this climate, the term "macroclimate" is applied. Variations in macroclimate (as determined by the observations of meteorological stations) are related to several factors.

Latitude—The primary control of climate at the global level is latitude, resulting in irregular solar energy at different latitudes. Solar radiation experiences a generally latitudinal decrease from equator to pole due to increases in the angle of incidence of the sun's rays and to the thickness of the atmosphere. The resulting generally east-west belts or **zones** correspond to life zones, plant formations, and biomes commonly recognized by ecologists and biogeographers (Whittaker 1975). The boundaries of zones are determined by thermal and moisture limits for plant growth.

Three major thermally defined zones can be defined: (1) a winterless climatic zone of low latitude, (2) temperate climates of mid latitudes with both a summer and winter, and (3) a summerless climate of high latitude. A winterless climate is commonly defined as one in which no month of the year has a mean monthly temperature lower than 64°F (18°C). This isotherm approximates the position of the boundary of the poleward limit of plants characteristic of the humid tropics. A summerless climate is one in which no month has a mean monthly temperature higher than 50°F (10°C). The 50°F isotherm closely coincides with the northernmost limit of tree growth; hence, it separates the regions of boreal forest from the treeless tundra.

The relative amplitudes of the periodicities of annual and diurnal energy cycles vary in each zone. Within the tropics, the diurnal range is of greater magnitude than the annual cycle. Within temperate zones, the annual range exceeds the diurnal range, although the diurnal can be very large. Within the polar zones, the annual range is far greater than the diurnal range.

Precipitation also follows a zonal pattern. The dry zones are controlled by the subtropical high-pressure cells centered on the tropics of Cancer and Capricorn (23½° N and S). These zones are too dry for tree growth.

Continental position—At any given latitude the summers are hotter and the winters colder over the land than over the oceans, giving rise to the distinction between marine and continental climates.

The distribution of land and sea also complicates precipitation patterns. Evaporation is rapid over warm water, and therefore precipitation is generally greater over the margins of the continents bathed by warm water.

By combining the thermally defined zones with the moisture zones, it is possible to delineate four eco-climatic zones: humid tropics, humid temperate, polar, and dry. Within each of these zones, one or several climatic gradients may affect the potential distribution of the dominant vegetation. Within the Humid Tropical zone, for example, rainforests that have year-round precipitation can be distinguished from savannas that receive seasonal precipitation.

The analysis of each zone results in the identification of a number of climatic subzones. These climatic subzones are correlated with actual climatic types, using the system of climatic classification developed by Köppen (1931) and modified by Trewartha (1968). Köppen's system is simple, is based on quantitative criteria, and correlates well with the distribution of many natural phenomena, such as vegetation and soil.

Other bioclimatic methods for mapping zones at global levels exist (for example, Holdridge 1947, Troll 1964, Walter and others 1975). All use selected climatic characteristics that outline zones within which certain general level vegetation homogeneity should be found. They also suggest a strong similarity of vegetation in equivalent bioclimatic zones in different parts of the globe. All of the methods appear to work better in some areas than in others and have gained their own following. Köppen's system has become the most widely used climatic classification for geographical purposes and is, therefore, presented here to illustrate the basis for zone delineation.

By applying Köppen's system, the following thirteen basic climates result:

- Ar Tropical wet: all months above 64°F (18°C) and no dry season.
- Aw Tropical wet-dry: all months above 64°F and 2 months dry in the winter.
- BSh Tropical/subtropical semi-arid: evaporation exceeds precipitation and all months over 32°F (0°C).
- BWh Tropical/subtropical arid: one-half the precipitation of the semi-arid and all months over 32°F.
- BSk Temperate semi-arid: same as BSh but with at least 1 month colder than 32°F.
- BWk Temperate arid: same as BWh but with at least 1 month colder than 32°F .
- Cs Subtropical dry summer (Mediterranean): 8 months 50°F (10°C) or more, summer dry.
- Cf Subtropical humid: 8 months over 50°F.
- Do Temperate oceanic: 8 months over 50°F, warmest month below 72°F (22°C).
- Dc Temperate continental: 4 to 8 months over 50°F.
- E Boreal or subarctic: one warmest month 50°F or above.
- Ft Tundra: all months below 50°F.
- Fi Polar ice cap: all months below 32°F.

The distribution of these climates is shown in figure 1. Each climatic subzone is clearly defined by a particular type of climatic regime, and, with a few exceptions, the subzones largely correspond to zonal soil types and zonal vegetation. Table 1 shows the relations between zonal types and climates as classified by Köppen.

Zonal soil types and vegetation occur on sites supporting climatic climax vegetation. Such sites are uplands, that is, sites with a well-drained surface, moderate surface slope,

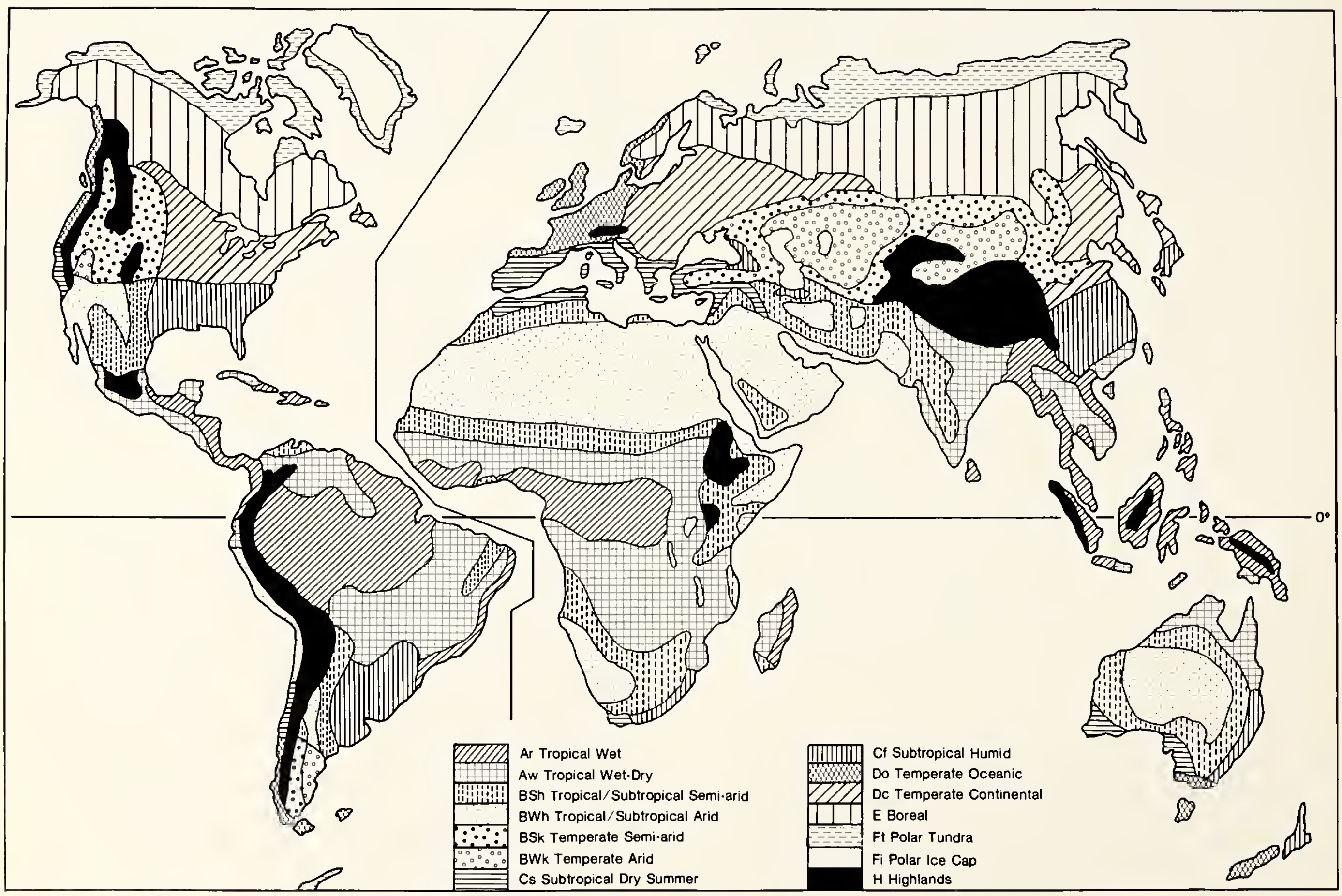


Figure 1—*Eco-climatic zones of the world (after Trewartha 1968).*

Table 1—*Zonal relationships between climate, soil, and vegetation*

Eco-climatic zone	Zonal soil type[1]	Zonal vegetation
Ar	Latisols (Oxisols)	Evergreen tropical rain forest (selva)
Aw	Latisols (Oxisols)	Tropical deciduous forest or savannas
BS	Chestnut, Brown soils and Sierozems (Mollisols Aridisols)	Short grass
BW	Desert (Aridisols)	Shrubs or sparse grasses
Cs	Mediterranean brown earths	Sclerophyllous woodlands
Cf	Red and Yellow Podzolics (Ultisols)	Coniferous and mixed coniferous-deciduous forest
Do	Brown Forest and Gray-brown Podzolic (Alfisols)	Coniferous forest
Dc	Gray-brown Podzolic (Alfisols)	Deciduous and mixed coniferous-deciduous forest
E	Podzolic (Spodosols and associated Histosols)	Boreal coniferous forest (taiga)
Ft	Tundra humus soils with solifluction (Entisols, Inceptisols and associated Histosols)	Tundra vegetation (treeless)
Fi		

[1]Names in parentheses are Soil Taxonomy soil orders (USDA Soil Conservation Service 1975).

and well-developed soils. The climax vegetation corresponds to the major plant formation (for example, deciduous forest) that is the presumed result of succession, given enough time.

It is possible to subdivide zones into finer ecological units. For example, the vegetation cover of the savanna zone is highly differentiated. It has heavy forest near its boundary with the equatorial zone and sparse shrubs and grasses near its arid border. Variation in the length and intensity of the rainy season relate to both the variety of vegetation and to soil and hydrologic conditions.

Elevation—The zonal correspondence of climate with latitude and continental position is broken by features that are dependent on differences in elevation, or relief. Because they can occur in any zone they are referred to as **azonal.**

Because of elevation, high mountains are differentiated into vertical zones. Every mountain within a zone has a typical sequence of altitudinal belts that differs according to the zone in which it is located (see fig. 2). Two series of eco-climatic units can, therefore, be established: lowlands and highlands.

The effects of latitude, continental position, and elevation, together with other climatic factors, combine to form the eco-climatic zones of the world. Figure 1 shows the climatic zones within which distinct ecosystem assemblages might be expected to occur. This map shows climatic units that appear to be important to the climatologist and can be used to help determine ecosystem boundaries at the macroscale.

Since meteorological stations are too sparse in many areas, data are simply not available to map more precisely

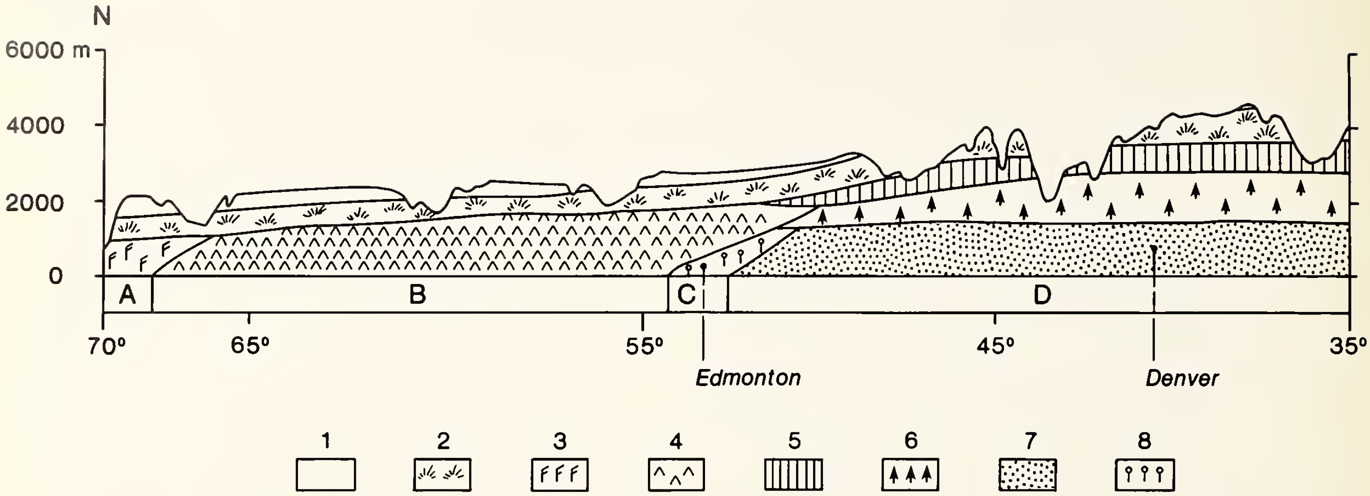


Figure 2—*Vertical zonation in different eco-climatic zones along the eastern slopes of the Rocky Mountains (after Schmithüsen 1976). 1, ice region; 2, mountain vegetation above tree line; 3, boreal and subpolar open coniferous woodland; 4, boreal evergreen coniferous forest; 5, boreal evergreen mountain coniferous forest; 6, coniferous dry forest; 7, short grass dry steppe; 8, boreal evergreen coniferous forest with cold-deciduous broadleaved trees. A, ecotone; B, Boreal; C, ecotone; D, Temperate Semi-arid.*

the distribution of these ecological climates. Thus, we generally substitute other distributions. The composition and distribution of vegetation was used by Köppen in his search for significant climatic boundaries, and vegetation is a major criterion in the ecosystem region maps of Bailey (1983) and Walter and Box (1976).

Climatic differences useful in recognizing units at this level can be reflected in the vegetation in several ways (Damman 1979): (1) changes in forest stand structure, dominant life forms, and topography of organic deposits; (2) changes in dominant species and in the toposequence of plant communities; and (3) displacement of plant communities, changes in the chronosequence of a habitat, and minor changes in the species composition of comparable plant communities. Other differences are given by Küchler (1974) and van der Maarel (1976).

Traditionally, the principal source of such information has been vegetation mapping by ground survey. If large areas are to be surveyed this approach is not very practical, and satellite remote-sensing data with its synoptic overview is used to look for zones where vegetation cover is relatively uniform. These zones are especially apparent in low-resolution remote sensing imagery (Tucker and others 1985).

In some areas, problems resulting from disturbance and the occurrence of an intricate pattern of secondary successional stages make regional boundary placement difficult. In such areas, these problems can be overcome by considering the patterns displayed on soil maps of broad regions, such as the FAO/UNESCO World Soil Map (FAO/UNESCO 1971–78). Because soils tend to be more stable than the vegetation, they provide supplemental basis for recognizing ecosystems regardless of present land use or existing vegetation.

Mesoscale: Landform Differentiation

Macroclimate accounts for the largest share of systematic environmental variation at the macroscale or regional level. At the mesoscale, the broad patterns are broken up by geology and topography (landform). For example, solar energy will be received and processed differently by a field of sand dunes, lacrustrine plain, or an upland hummocky moraine.

Landforms (with their geologic substrate, surface shape, and relief) influence place-to-place variation in ecological factors such as water availability and exposure to radiant solar energy. Through varying height and degree of inclination of the ground surface, landforms interact with climate and directly influence hydrologic and soil-forming processes.

In short, the best correlation of vegetation and soil patterns at meso and microscales is landform because it controls the intensities of key factors important to plants and to the soils that develop with them (Hack and Goodlet 1960; Swanson and others 1988). Realization of the importance of landform is apparent in a number of approaches to classification of forest land (for example, Barnes and others 1982).

Landforms come in all scales and in a great array of shapes. On a continental scale within the same macroclimate there commonly exist several broad-scale landform patterns that break up the zonal patterns (figure 3). The landform classification of Hammond (1954, 1964), who classified land-surface forms in terms of existing surface geometry, is useful in determining the limits of various mesoecosystems or landscape mosaics. In the Hammond system, summarized in table 2, landforms are identified on the basis of similarity and differences with respect to three major characteristics: relative amount of gently sloping land (less than 8 percent), local relief, and generalized profile (that is, where and how much of the gently sloping land is located in the valley bottoms or in the uplands).

On the basis of these characteristics alone, it is possible to distinguish among (1) plains having a predominance of gently sloping land, coupled with low relief, (2) plains with some feature of considerable relief, (3) hills with gently sloping land and low to moderate relief, and (4) mountains that have little gently sloping land and high local relief.

The second group may be subdivided on the basis of where the gently sloping land occurs in the profile into

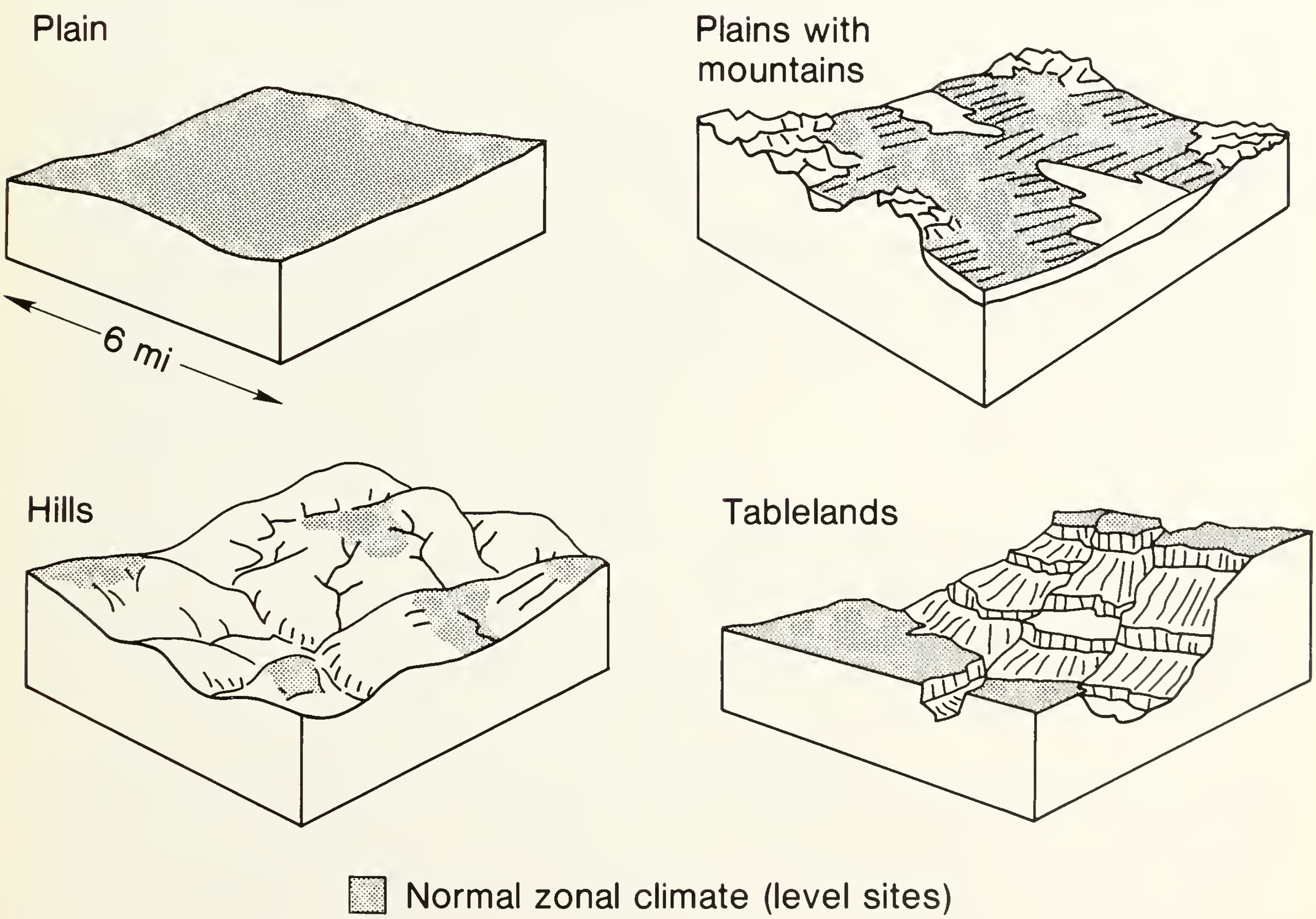


Figure 3—*Land-surface form types and their effect on zonal climate.*

Table 2—*Hammond's scheme of landform classification*

	Symbol	Definition
Slope		
	A	More than 80 percent of area gently sloping.
	B	50–80 percent of area gently sloping.
	C	20–50 percent of area gently sloping.
	D	Less than 20 percent of area gently sloping.
Local Relief		
	1	0–100 feet.
	2	100–300 feet.
	3	300–500 feet.
	4	500–1000 feet.
	5	1000–3000 feet.
	6	Over 3000 feet.
Profile type		
	a	More than 75 percent of gentle slope is in lowland.
	b	50–75 percent of gentle slope is in lowland.
	c	50–75 percent of gentle slope is on upland.
	d	More than 75 percent of gentle slope is on upland.

plains with hills, mountains, or tablelands. Approximate definitions of the grouping or generalized terrain types are as follows:

- Nearly flat plains: A1; any profile
- Rolling and irregular plains: A2 , B1, B2; any profile.
- Plains with widely-spaced hills or mountains: A3a or b, B3a or b to B6a or b.
- Partially dissected tablelands: B3c or d to B6c or d.
- Hills: D3, D4; any profile.
- Low mountains: D5; any profile.
- High mountains: D6; any profile.

Of course, within these classes there exists much variety. Some plains, for instance, are flat and swampy, others rolling and well drained, and still others are simply broad expanses of smooth ice. Similarly, some mountains are low, smoothed-sloped, and arranged in parallel ridges, while others are exceedingly high, with rugged, rocky slopes and glaciers and snowfields.

To account for some of this variability, two additional classes are identified in the plains areas. The two added classes are the following:

- Ice cap: More than 50 percent of the area is covered by permanent ice.
- Poorly drained lands: More than 10 percent of the area is covered by lake or swamp.

Figure 4 shows how some of these classes (landscape mosaics) are distributed in Köppen's Mediterranean (Cs), or Subtropical Dry Summer, zone.

According to its physiographic nature, a landform unit consists of a certain set of sites. A delta has differing types of ecosystems from those of a moraine landscape next to it. Within a landscape mosaic, the sites are arranged in a specific pattern. The tablelands of the west-central part of the North American continent are a case in point (see fig. 5). For example, the Colorado Plateau is made up of various site-specific ecosystems, including valleys of various sizes, smooth uplands, stream channels (mostly dry), individual slopes, terraces, sandbars in the stream channels, and several small and shallow depressions in the uplands.

Units at this level can be most accurately delineated by considering the toposequence (Major 1951), or catena of site types, throughout the unit.

Microscale: Edaphic-topoclimatic Differentiation

Although the distribution of ecological zones is controlled by macroclimate and broad-scale landform patterns, local differences are controlled chiefly by microclimate and ground conditions, especially moisture availability. The latter is the edaphic (related to soil) factor.

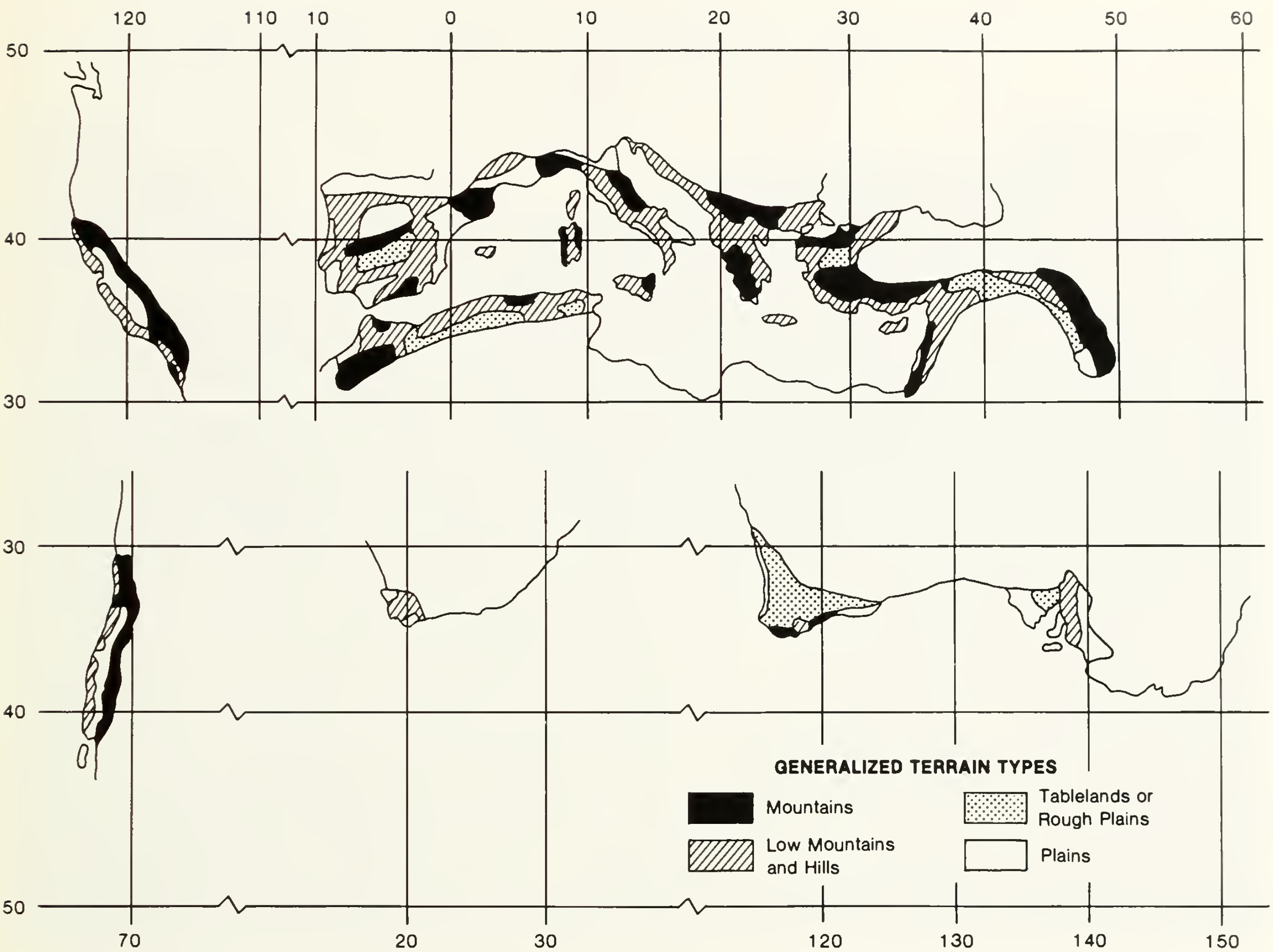


Figure 4—*Landscapes of the Subtropical Dry Summer zone (from Thrower and Bradbury 1973; redrawn with permission from Springer-Verlag, Heidelberg).*

Within a landform there exist slight differences in slope and aspect that modify the macroclimate to topoclimate (Thornthwaite 1953). There are three classes of topoclimate: normal, hotter than normal, and colder than normal (figure 6). The units derived from these classes are referred to as **site classes** (Hills, 1952).

In differentiating local sites within topoclimates, soil moisture regimes have been found to be the feature that provide the most significant segregation of the plant communities. A toposequence of a drainage catena illustrates this phenomenon (figure 7). A common division of the soil moisture gradient is: very dry, dry, fresh, moist and wet.

Deviations from normal topoclimate and mesic soil moisture occur in various combinations within a region, and are referred to as **site types** (Hills 1952). As a result, every regional system—regardless of size or rank—is characterized by the association of three types of local ecosystems or site types:

Zonal site types—These sites are characterized by normal topoclimate and fresh and moist soil moisture.

Azonal site types—These sites are zonal in a neighboring zone but are confined to an extra-zonal environment in a given zone. For instance, in the northern hemisphere, south-facing slopes receive more solar radiation than

Figure 5—*A variety of ecosystems form this mosaic of riparian, grazing, and woodland sites in Unaweep Canyon and vicinity in western Colorado, a well-developed tableland in the Temperate Semi-arid zone. (USDA Forest Service photo.)*

north-facing slopes, and thus south-facing slopes tend to be warmer, drier, less thickly vegetated, and covered by thinner soils than north-facing slopes. In arid mountains, the south-facing slopes are commonly covered by grass, while steeper north-facing slopes are forested. Azonal sites are hotter, colder, wetter, and drier than zonal sites.

Intrazonal site types—These sites occur in exceptional situations within a zone. They are presented by small areas with extreme types of soil and intrazonal vegetation. Vegetation is influenced to a greater extent by soil than by climate, and thus the same vegetation forms may occur on similar soil in a number of zones. They are differentiated into four groups:

First, there are those are that are **unbalanced chemically.** Some examples from the United States are the specialized plant stands on serpentine (magnesium rich) soils in the California Coast Ranges. Other examples are the belts of grassland on the lime-rich black belts of Alabama, Mississippi, and Texas and the low mat saltbush (*Atriplex corrugata*) on shale deserts of the Utah desert, which contrasts with upright shrubs on adjacent sandy ground.

The kind and amount of dissolved matter in groundwater also affect plant distribution. It is especially obvious along coasts and along edges of desert basins where the water is brackish or saline.

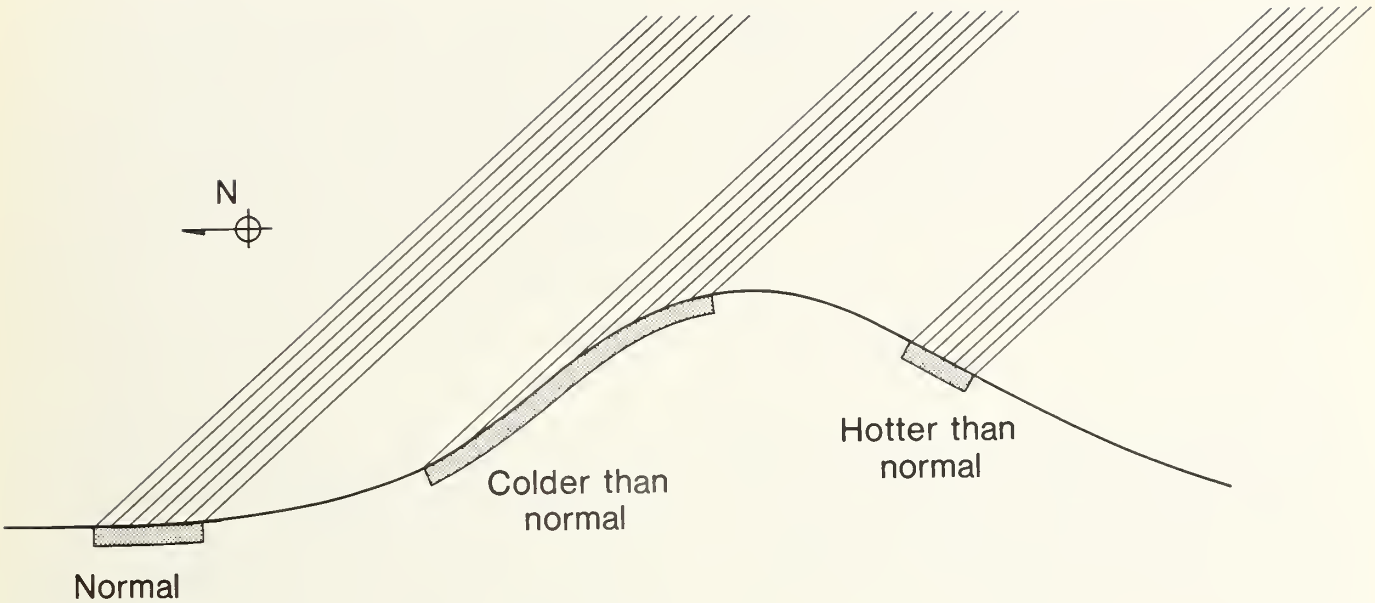


Figure 6—*Topoclimates: effect of slope and aspect on temperature.*

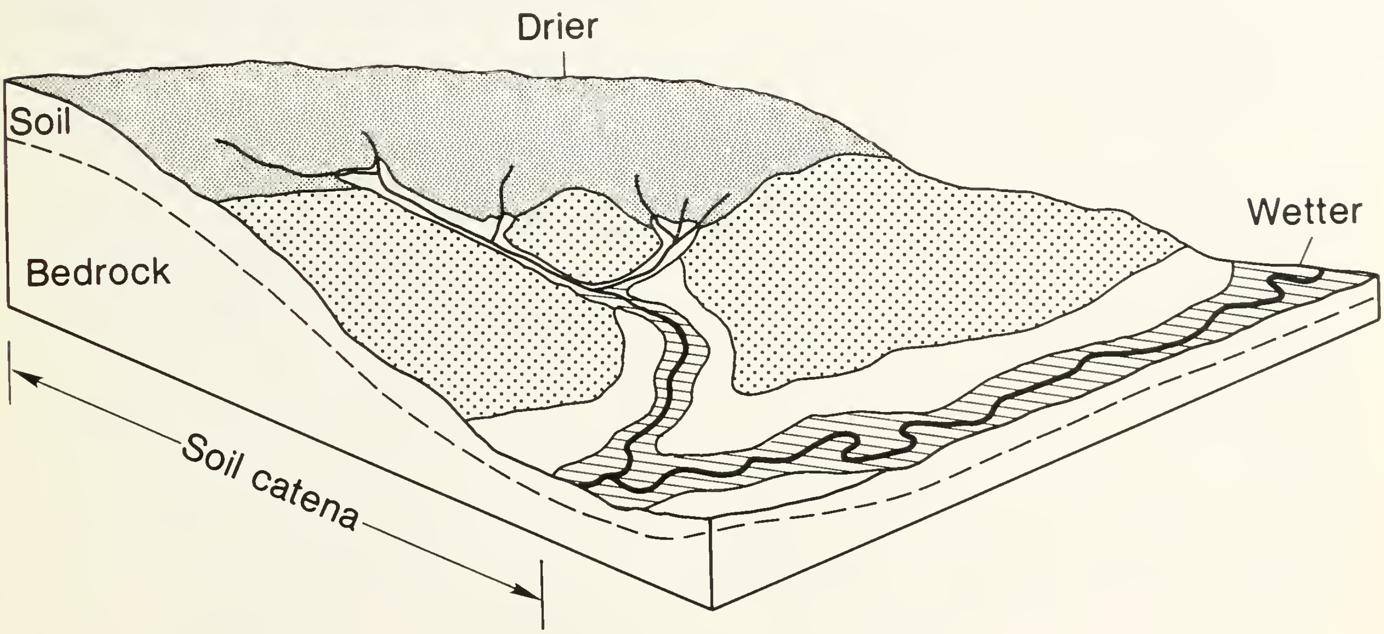


Figure 7—*Block diagram showing a toposequence or catena of soil moisture regimes.*

Second, **very wet** sites are where intrazonal plant distributions are controlled by ground-water table. The plants of these sites are phreatophytes that send roots to the water table. Examples are provided by riparian zones in the deserts of the southwestern United States, such as cottonwood *(Populus deltoides)* floodplain forest, and the cypress *(Taxodium distichum)* and tupelo *(Nyssa aquatica)* forests of the Southeast.

Third, **very dry** sites with sandy soils, because of limited moisture-holding capacity, are drier than the general climate. At the extreme, sand dunes fail to support any vegetation.

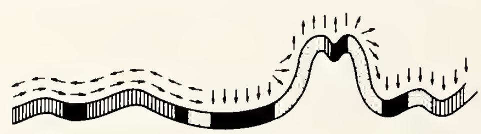
Fourth, there are **very shallow** sites. Soil depth, as a factor in plant distribution, may be controlled by depth to a water table or depth to bedrock. Vegetation growing along a stream or pond differs from that growing some distance away where the depth to the water table is greater. Examples of the influence of depth to bedrock on plant distribution can be seen in mountainous areas where bare rock surfaces that support only lichens are surrounded by distinctive flowering plants growing where thin soil overlaps the rock, and is, in turn, surrounded by forest where the soil deepens.

Figure 8, in a very simplified way, illustrates how topography, even in areas of uniform macroclimate, leads to differences in local climates and soil conditions. The climatic climax theoretically would occur over the entire region but for topography leading to different local climates, which partially determine edaphic or soil conditions. On these areas different edaphic climaxes occur; climatic climaxes occur only on mesic soils.

The units at this scale correspond to units with similar soil particle size, mineralogical classes, soil moisture, and temperature regimes. These are generally the same differentiating criteria used to define families of soils in the System of Soil Taxonomy of the National Cooperative Soil Survey (USDA Soil Conservation Service 1975).

The potential, or climax, vegetation of these units is the plant community with the rank of association, which is the basic unit of phytocenology. Associations (also called habitat types in the Western United States by Pfister and Arno (1980) are named after the dominant species of the overstory and of the understory (Daubenmire 1968).

The use of the word "potential" is critical because it allows a single site to include different kinds of vegetation as long as they represent different stages of biotic succession from weedy pioneers to "climax" forest or grasslands. It is possible to identify another level (provisionally called the **site phase**) to allow the classification to communicate the ages and species composition of existing vegetation. These correspond to forest and range cover types that are commonly mapped by the use of remote sensing imagery.



Habitat-Microclimate and soil	*Climax biotic community*	
Normal microclimate over moist soil	Maple-beech	CLIMATIC CLIMAX
Normal microclimate over wet soil	Oak-ash	EDAPHIC CLIMAXES
Normal microclimate over dry soil	Oak-hickory	
Warmer microclimate over moist soil	Tulip-walnut	
Warmer microclimate over wet soil	Sycamore-tulip	
Warmer microclimate over dry soil	Oak-chestnut	
Colder microclimate over moist soil	Elm-ash-oak	
Colder microclimate over wet soil	White spruce-balsam fir	
Colder microclimate over dry soil	Hemlock-yellow birch	

Figure 8—*Different forest climaxes occurring in the Temperate Continental zone of southern Ontario, Canada (simplified from Hills 1952).*

Practical Applications

Ecogeographic analysis may be carried out at different levels (at different scales). The particular rank of the ecosystem in the hierarchy of ecological units depends on the purpose and scale of analysis. We can thus define relationships between the levels of analysis and the rank of the ecological unit subject to investigation:

Regions delimit large areas within which local ecosystems recur more or less throughout the region in a predictable fashion. By observing the behavior of the different kinds of systems within a region, it is possible to predict the behavior of an unvisited one.

Regions have two important functions for management. First, a map of such regions suggests over what area the knowledge about ecosystem behavior derived from experiments and experience can be applied without too much adjustment, for example, silvicultural practices, estimates of forest yields, and seed use. Experience concerning land use, such as terrain sensitivity to acid rain, suitability for agriculture, and effectiveness of best management practices in protecting fisheries, can be applied to similar sites within each region. Second, regions provide a geographical framework in which similar responses may be expected within similarly defined systems. It is thus possible to formulate management policy and apply it on a regionwide basis rather than on a site-by-site basis. This increases the utility of site-specific information and cuts down on the cost of environmental inventories and monitoring.

Landscape mosaics delimit areas that represent different patterns or combinations of sites within a regional ecosystem. The interaction between sites causes processes to emerge that were not present or evident at the site level. The processes of a landscape mosaic are more than those of its separate ecosystems because the mosaic internalizes exchanges among component parts. For example, a snow-forest landscape includes dark pines that convert solar radiation into sensible heat that moves to the snow cover and melts it faster than would happen in either a wholly snow-covered or a wholly forested basin. The pines are the intermediaries that speed up the process and affect the timing of the water runoff. Watershed managers attempt to produce the same effects by strip cutting extensive forests. It is the understanding of landscape process that makes possible the analysis of the effects of management of a site on surrounding site, and thereby the assessment of the cumulative effects that may occur from a proposed management activity.

Furthermore, a map of such mosaics reveals the relative diversity of the landscape. Planning and management of diverse and complex landscapes (for example, mountains) is problematical and difficult, while uniform ones (for example, plains) present problems of relative simplicity. Solving problems related to land use such as erosion and revegetation depend on understanding the complexity of the landscape. By knowing the character of the mosaic and the landscape processes it is possible to analyze and mitigate the problems associated with management activities.

Sites are, for practical purposes, relatively homogeneous with respect to all the biophysical components. Such areal site units are the base for productivity assessments, silvicultural prescription, and forest management.

Site maps are general purpose ecosystem maps. Applied ecosystem maps can be developed by interpreting and grouping the basic ecosystem units shown on the general purpose map. For example, a general purpose map can be interpreted to show units with high arboreal productivity and low potential for slope failure. A further interpretation can be made to place units with such a combination into a category of high suitability for forestry. Different types of applied ecosystem maps will differ only in the interpretation and grouping of the basic ecosystem units.

All natural ecosystems are recognized by differences in climatic regime. The basic idea here is that climate, as a source of energy and moisture, acts as the primary control for the ecosystem. As this component changes, the other components change in response. The primary controls over the climatic effects change with scale. Regional ecosystems are areas of essentially homogeneous macroclimate. Landform is an important criterion for recognizing smaller divisions within macroclimatic units. Landform modifies climatic regime at all scales within macroclimatic zones. It is the cause of the modification of macroclimate to local climate. Thus, landform provides the best means of identifying local ecosystems. At the mesooscale, the landform and landform pattern form a natural ecological unit. At the microscale, such patterns can be divided topographically into slope and aspect units that are relatively consistent as to soil moisture regime, soil temperature regime, and plant association; that is, the homogeneous "site."

Therefore, the answer to the question of boundary criteria is that climate, as modified by landform, offers the logical basis for delineating both large and small ecosystems.

Based on the foregoing analysis, criteria indicative of climatic changes of different magnitude are presented in table 3. Figure 9 illustrates the use of these criteria. They are offered as suggestions to guide the mapping of ecosystems of different size. In broad outline, the criteria for delineation are quite different at each of three scales of analysis. The results of this review are not meant to be definitive, but are an attempt to illustrate criteria that appear to be important and that can be used to establish ecosystem boundaries.

With reference to the general principles involved in assigning prime importance at the different scale levels to different criteria, it should be noted that Rowe (1980) has raised the need for a caveat. Although the levels can be mapped by reference to single physical and biological features, they must always be checked to assure that the boundaries have ecological significance. A climatic map showing such key factors as temperature and precipitation is not necessarily an ecological map, until its boundaries are shown to correspond to significant biologic boundaries. Likewise, maps of landform, vegetation, and soils are not necessarily ecological maps until it has been shown that the types have the same distribution. Before any map is used, it should be thoroughly tested and modified if necessary (Bailey 1984).

It is important to link the ecosystem with management hierarchies. It is not suggested in the foregoing that three levels of ecological partitioning are everywhere desirable; there could be two or nine depending on the kind of question being asked and the scale of the study. However, it is advantageous to have a basic framework consisting of a relatively few units to which all ecological land mappers can relate and between which other units can be defined as required.

Table 3—*Mapping criteria for ecosystem units at different scales with examples*

Scale	Name of unit	Criteria	Examples of units: Lowland series	Examples of units: Highland series
Macro	Region or zone	Eco-climatic zone (Köppen 1931)	Temperate semi-arid (BSk)	Temperate semi-arid regime highlands (H)
Meso	Landscape mosaic	Land-surface form class (Hammond 1954)	Nearly flat plains (A1)	High mountains (D6)
Micro	Site	Microclimate and soil	Normal microclimate over moist soil	Normal microclimate over moist soil

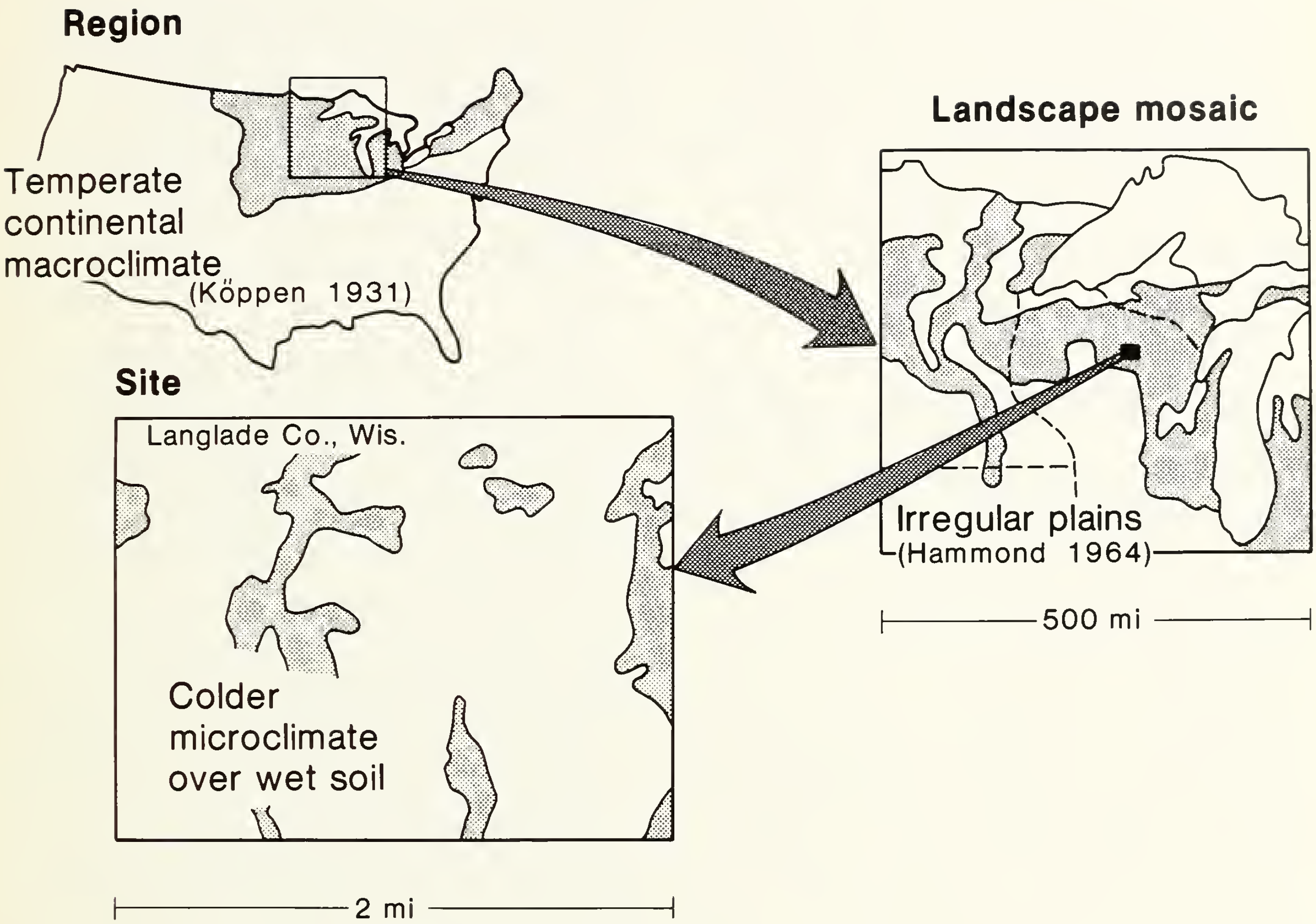


Figure 9—*Ecosystem maps of different scales.*

Literature Cited

Bailey, R.G. 1983. Delineation of ecosystem regions. Environmental Management. 7: 365-373.

Bailey, R.G. 1984. Testing an ecosystem regionalization. Journal of Environmental Management. 19: 239-248.

Bailey, R.G. 1985. The factor of scale in ecosystem mapping. Environmental Management. 9: 271-276.

Bailey, R.G. 1987. Suggested hierarchy of criteria for multi-scale ecosystem mapping. Landscape and Urban Planning. 14: 313-319.

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

Damman, A.W.H. 1979. The role of vegetation analysis in land classification. Forestry Chronicle. 55: 175-182.

Daubenmire, R. 1968. Plant communities: a text book on plant synecology. New York: Harper and Row. 300 p.

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

FAO/UNESCO. 1971-1978. FAO/UNESCO soil map of the world 1:5 million. North America, South America, Mexico and Central America, Europe, Africa, South Asia, North and Central Asia, Australia. Paris: UNESCO.

Forman R.T.T.; Godron, M. 1986. Landscape ecology. New York: John Wiley. 619 p.

Hack, J.T.; Goodlet, J.C. 1960. Geomorphology and forest ecology of a mountain region in the central Appalachians. Prof. Pap. 347. Washington, DC: U.S. Geological Survey. 66 p.

Hammond, E.H. 1954. Small-scale continental landform maps. Annals Association American Geographers. 44: 33-42.

Hammond, E.H. 1964. Classes of land-surface form in the forty eight States. U.S.A. Annals Association American Geographers 54. Map supplement no. 4, scale 1:5 million.

Hills, A. 1952. The classification and evaluation of site for forestry. Res. Rep. 24. Toronto: Ontario Department of Lands and Forest. 41 p.

Holdridge, L.R. 1947. Determination of world plant formations from simple climatic data. Science. 105: 367-368.

Isachenko, A.G. 1973. Principles of landscape science and physical-geographic regionalization (trans. from Russian by J.S. Massey). Carlton, Victoria, Australia: Melbourne University Press. 311 p.

Köppen, W. 1931. Grundriss der klimakunde. Berlin: Walter de Gruyter. 388 p.

Küchler, A.W. 1974. Boundaries on vegetation maps. In: Tüxen, R., editor. Tatsachen und probleme der grenzen in der vegetation. Lehre, FR of Germany: Verlag von J. Cramer. p. 415-427.

Leser, H. 1976. Landscaftsökologie. Stuttgart: Ulmer. 432 p.

Major, J. 1951. A functional, factorial approach to plant ecology. Ecology. 32: 392-412.

Miller, D.H. 1978. The factor of scale: ecosystem, landscape mosaic, and region. In: K.A. Hammond, editor. Sourcebook on the environment. Chicago: University of Chicago Press: p. 63-88.

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

Rowe, J.S. 1980. The common denominator in land classification in Canada: an ecological approach to mapping. Forestry Chronicle. 56: 19-20.

Schmithüsen, J. 1976. Atlas zur biogeographie. Mannheim-Wien-Zurich: Bibliographisches Institut. 88 p.

Swanson, F.J.; Kratz, T.K.; Caine, N.; Woodmansee, R.G. 1988. Landform effects on ecosystem patterns and processes. Bioscience 38: 92-98.

Thornthwaite, C.W. 1953. Topoclimatology. In: Proceedings of the Toronto Meteorological Conference, September 9-15, 1953. Toronto: Royal Meterological Society. p. 227-232.

Thrower, N. J.W.; Bradbury, D.E. 1973. The physiography of the Mediterranean landscape with special emphasis on California and Chile. In: F. di Castri and H.A. Mooney, editors. Mediterranean Type Ecosystems: Origin and Structure. Ecological Studies: Analysis and Synthesis, vol. 7. Heidelberg: Springer-Verlag. p. 37-52.

Trewartha, G.T. 1968. An introduction to climate, 4th ed. New York: McGraw-Hill. 408 p.

Troll, C. 1964. Karte der jahrzeiten-klimate der erde. Erdkunde. 17: 5-28.

Tucker, C.J,; Townshend, J.R.G.; Goff, T.E. 1985. African land-cover classification using satellite data. Science. 227: 369-375.

USDA Forest Service. 1982. Ecosystem classification, interpretation, and application. Forest Service Manual 2061, 2062, 2063. Washington, D.C.

USDA Soil Conservation Service. 1975. Soil taxonomy: a basic system for making and interpreting soil surveys. Agric. Handb. 436. Washington DC: U.S. Department of Agriculture. 754 p.

van der Maarel, E. 1976. On the establishment of plant community boundaries. Bericht der Deutschen botanischen Gesellschaft. 89: 415-433.

Walter, H.; Harnickell, E.; Mueller-Dombois, D. 1975. Climate-diagram maps of the individual continents and the ecological climatic regions of the earth (maps and manual). Heidelberg: Springer-Verlag. 36 p.

Walter, H.; Box, E. 1976. Global classification of natural terrestrial ecosystems. Vegetatio. 32: 75-81.

Whittaker, R.H. 1975. Communities and ecosystems. 2d ed. New York: MacMillan. 387 p.

Zonneveld, I.S. 1972. Land evaluation and land(scape) science. Use of aerial photographs in geography and geomorphology. ITC Textbook of Photointerpretation Vol. VII. Enschede, The Netherlands: International Training Centre for Aerial Survey. 106 p.