National Hierarchical Framework of Ecological Units[1]

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[1] Full citation:
Cleland, D.T.; Avers, P.E.; McNab, W.H.; Jensen, M.E.; Bailey, R.G., King, T.; Russell, W.E. 1997. *National Hierarchical Framework of Ecological Units.* Published in, Boyce, M. S.; Haney, A., ed. 1997. Ecosystem Management Applications for Sustainable Forest and Wildlife Resources. Yale University Press, New Haven, CT. pp. 181-200.

INTRODUCTION

To implement ecosystem management, we need basic information about the nature and distribution of ecosystems. To develop this information, we need working definitions of ecosystems and supporting inventories of the components that comprise ecosystems. We also need to understand ecological patterns and processes and the interrelationships of social, physical, and biological systems. To meet these needs, we must obtain better information about the distribution and interaction of organisms and the environments in which they occur, including the demographics of species, the development and succession of communities, and the effects of humans activities and land use on species and ecosystems (Urban et al. 1987). Research has a critical role in obtaining this information.

This chapter presents a brief background of regional land classifications, describes the hierarchical framework for ecological unit design, examines underlying principles, and shows how the framework can be used in resource planning and management. The basic objective of the hierarchical framework is to provide a systematic method for classifying and mapping areas of the earth based on associations of ecological factors at different geographic scales. The framework is needed to improve our efforts in national, regional, and forest level planning; to achieve consistency in ecosystem management across National Forests and regions; to advance our understanding of the nature and distribution of ecosystems; and to facilitate interagency data sharing and planning. Furthermore, this framework will help us evaluate inherent capabilities of land and water resources and the effects of management on them.

Ecological units delimit areas of different biological and physical potentials. Ecological unit maps can be coupled with inventories of existing vegetation, air quality, aquatic systems, wildlife, and human elements to characterize complexes of life and environment, or ecosystems. This information on ecosystems can be combined with our knowledge of various processes to facilitate a more ecologically sound approach to resource planning, management, and research.

Note that ecological classification and mapping systems are devised by humans to meet human needs and values. Ecosystems and their various components often change gradually, forming continua on the earth's surface which cross administrative and political boundaries. Based on their understanding of ecological systems, humans decide on ecosystems boundaries by using physical, biological, and social considerations.

We recognize that the exact boundaries for each level envisioned in this process and developed in map format may not fit every analysis and management need. Developing boundaries of areas for analysis, however, will not change the boundaries of ecological units. In some cases, an ecological unit may be the analysis area. In other cases, watersheds, existing conditions, management emphasis, proximity to special features (for example natural, wilderness, or urban areas), or other conditions may define an analysis area. In these cases, ecological units can be aggregated or divided if necessary to focus on relevant issues and concerns.

BACKGROUND: REGIONAL LAND CLASSIFICATIONS

Hierarchical systems using ecological principles for classifying land have been developed for geographical scales ranging from global to local. Using a bioclimatic approach at a global scale, several researchers have developed ecological land classifications: Holdridge (1967), Walter and Box (1976), Udvardy (1975), and Bailey (1989a,b). Wertz and Arnold (1972) developed land stratification concepts for regional and land unit scales. Other ecologically based classifications proposed at regional scales include those of Driscoll et al. (1984), Gallant et al. (1989), and Omernik (1987) in the United States and those of Wiken (1986) and the Ecoregions Working Group (1989) in Canada. Concepts have also been presented for ecological classification at subregional to local scales in the United States (Barnes et al. 1982), Canada (Jones et al. 1983, Hills 1952), and Germany (Barnes 1984).
Each of these systems have strong points that contribute to the strength of the national hierarchy. But no single system has the structure and flexibility necessary for developing ecological units at continental to local scales. The concepts and terminology of the national system draw upon this work to devise a consistent framework for application throughout the United States.

ECOLOGICAL UNIT DESIGN

The primary purpose for delineating ecological units is to identify land and water areas at different levels of resolution that have similar capabilities and potentials for management. Depending on scale, ecological units are designed to exhibit similar patterns in: (1) potential natural communities, (2) soils, (3) hydrologic function, (4) landform and topography, (5) lithology, (6) climate, and (7) natural processes such as nutrient cycling, productivity, succession, and natural disturbance regimes associated with flooding, wind, or fire.

It should be noted that climatic regime is an important boundary criterion for ecological units, particularly at broad scales. In fact, climate, as modified by topography, is the dominant criterion at upper levels. Other factors, such as geomorphic process, soils, and potential natural communities, take on equal or greater importance than climate at lower levels.

It follows, then, that ecological units are differentiated and maps designed by multiple components, including climate, physiography, geology, soils, water, and potential natural communities. These components may be analyzed individually, and then combined, or multiple factors may be simultaneously evaluated to classify ecological types, which are then used in ecological unit design. The first option may be increasingly used as geographic information systems (GIS) become more available. The interrelationships among independently defined components, however, will need to be carefully evaluated, and the results of layering component maps may need to be adjusted to identify units that are both ecologically significant and meaningful to management. When various disciplines cooperate in devising integrated ecological units, products from existing resource component maps can be modified, and integrated interpretations can be developed (Avers and Schlatterer, 1991).

Ecological unit inventories are generally designed and conducted in cooperation with the Natural Resource Conservation Service, Agricultural Experiment Stations of Land Grant Universities, Bureau of Land Management, and other appropriate state and federal agencies. Mapping conventions and soil classification meet standards of the National Cooperative Soil Survey.

Table 1. National hierarchy of ecological units

Planning and analysis scale	*Ecological Units*	*Purpose, objectives, and general use*
Ecoregion Global Continental Regional	Domain Division Province	Broad applicability for modeling and sampling. Strategic planning and assessment. International planning.
Subregion	Section Subsection	Strategic, multiforest, statewide, and multiagency analysis and assessment.
Landscape	Landtype association	Forest or areawide planning, and watershed analysis.
Land unit	Landtype Landtype phase	Project and management area planning and analysis.
Hierarchy can be expanded by user to smaller geographical areas and more detailed ecological units if needed.		Very detailed project planning.

CLASSIFICATION FRAMEWORK

The National Ecological Unit Hierarchy is presented in Tables 1, 2, and 3. The hierarchy is based on concepts and terminology developed by numerous scientists and resource managers (Hills 1952, Crowley 1967, Wertz and Arnold 1972, Rowe 1980, Allen and Starr 1982, Barnes et al. 1982, Forman and Godron 1986, Bailey 1987, Meentemeyer and Box 1987, Gallant et al. 1989, Cleland et al. 1992). The following is an overview of the differentiating criteria used in the development of the ecological units. Table 2 summarizes the principal criteria used at each level in the hierarchy.

Table 2. Principal map unit design criteria of ecological units.

Ecological unit	*Principal map unit design criteria*
Domain	Broad climatic zones or groups (e.g., dry, humid, tropical)
Division	Regional climatic types (Koppen 1931, Trewatha 1968) Vegetational affinities (e.g., prairie or forest) Soil order
Province	Dominant potential natural vegetation (Kuchler 1964) Highlands or mountains with complex vertical climate-vegetation-soil zonation
Section	Geomorphic province, geologic age, stratigaphy, lithology Regional climatic data Phases of soil orders, suborders, or great groups Potential natural vegetation Potential natural communities (PNC) (FSH 2090)
Subsection	Geomorphic process, surficial geology, lithology Phases of soil orders, suborders, or great groups Subregional climatic data PNC—formation or series
Landtype association	Geomorphic process, geologic formation, surficial geology, and elevation Phases of soil subgroups, families, or series Local climate PNC—series, subseries, plant associations
Landtype	Landform and topography (elevation, aspect, slope gradient, and position) Phases of soil subgroups, families, or series Rock type, geomorphic process PNC—plant associations
Landtype phase	Phases of soil subfamilies or series Landform and slope position PNC—plant associations or phases

Note: The criteria listed are broad categories of environmental and landscape components. The actual classes of components chosen for designing map units depends on conditions and relative importance of factors within respective geographic areas.

Table 3. Map scale and polygon size of ecological units.

Ecological unit	*Map scale range*	*General polygon size*
Domain	1:30,000,000 or smaller	1,000,000s of square miles
Division	1:30,000,000 to 1:7,500,000	100,000s of square miles
Province	1:15,000,000 to 1:5,000,000	10,000s of square miles
Section	1:7,500,000 to 1:3,500,000	1,000s of square miles
Subsection	1:3,500,000 to 1:250,000	10s to low 1,000s of square miles
Landtype association	1:250,000 to 1:60,000	1,000s to 10,000s of acres
Landtype	1:60,000 to 1:24,000	100s to 1,000s of acres
Landtype phase	1:24,000 or larger	<100 acres

Ecoregion Scale
At the Ecoregion scale, ecological units are recognized by differences in global, continental, and regional climatic regimes and gross physiography. The basic assumption is that climate governs energy and

moisture gradients, thereby acting as the primary control over more localized ecosystems. Three levels of ecoregions, adapted from Bailey (1980), are identified in the hierarchy:

1. *Domains,* subcontinental divisions of broad climatic similarity, such as lands that have the dry climates defined by Koppen (1931), which are affected by latitude and global atmospheric conditions. For example, the climate of the Polar Domain is controlled by arctic air masses, which create cold, dry environments where summers are short. In contrast, the climate of the Humid Tropical Domain is influenced by equatorial air masses and there is no winter season. Domains are also characterized by broad differences in annual precipitation, evapotranspiration, potential natural vegetation, and biologically significant drainage systems. The four Domains are named according to the principal climatic descriptive features: Polar, Dry, Humid Temperate, and Humid Tropical.

2. *Divisions,* subdivisions of domains determined by isolating areas of definite vegetational affinities (for example, prairie or forest) that fall within the same regional climate, generally at the level of the basic types of Koppen (1931) as modified by Trewartha (1968). Divisions are delineated according to: (a) the amount of water deficit (which subdivides the Dry Domain into semi-arid, steppe, or arid desert), and (b) the winter temperatures, which have an important influence on biological and physical processes and the duration of any snow cover. This temperature factor is the basis of distinction between temperate and tropical/subtropical dry regions. Divisions are named for the main climatic regions they delineate, such as steppe, savannah, desert, Mediterranean, marine, and tundra.

3. *Provinces,* climatic subzones, controlled primarily by continental weather patterns such as length of dry season and duration of cold temperatures. Provinces are also characterized by similar soil orders. The climatic subzones are evident as extensive areas of similar potential natural vegetation such as those mapped by Kuchler (1964). Provinces are named typically using a binomial system consisting of a geographic location and vegetative type such as Bering
Tundra, California Dry-Steppe and Eastern Broadleaf Forests (Bailey et al. 1985).

Highland areas that exhibit altitudinal vegetation zonation and that have the climatic regime (seasonality of energy and moisture) of adjacent lowlands are classified as provinces (Bailey et al. 1985). The climatic regime of the surrounding lowlands can be used to infer the climate of the highlands. For example, in the Mediterranean division along the Pacific Coast, the seasonal pattern of precipitation is the same for the lowlands and highlands except that the mountains receive about twice the quantity. The provinces are named for the lower-elevation and upper-elevation (subnival) belts, for example, Rocky Mountain forest-alpine meadows.

Subregional Scale

Subregions are characterized by combinations of climate, geomorphic process, topography, and stratigraphy that influence moisture availability and exposure to radiant solar energy, which in turn directly control hydrologic function, soil-forming processes, and potential natural community distributions. Sections and Subsections are the two ecological units mapped at this scale.

*1. Section*s, broad areas of similar sub-regional climate, geomorphic process, stratigraphy, geologic origin, topography, and drainage networks. Such areas are often inferred by relating geologic maps to potential natural vegetation "series" groupings such as those mapped by Kuchler (1964). In recent years, numerical analyses of weather station and remotely sensed climatic information have assisted in determining Section boundaries. Boundaries of some sections approximate geormorphic provinces (for example, Blue Ridge) as recognized by geologists. Section names generally describe the predominant geomorphic type or feature upon which the ecological unit delineation is based, such as Flint Hills, Great Lakes Morainal, Bluegrass Hills, Appalachian Piedmont.

2. Subsections, smaller areas within Sections with similar surficial geology, lithology, geomorphic process, soil groups, subregional climate, and potential natural communities. Subsection boundaries usually correspond with discrete changes in geomorphology. Names of Subsections are usually derived from geologic features, such as Plainfield sand dune, Tipton till plain, and granite hills.

Landscape Scale
At the landscape scale, ecological units are defined by general topography, geomorphic process, surficial geology, associations of soil families, and potential natural communities, patterns, and local climates (Forman and Godron 1986). These factors affect biotic distributions, hydrologic function, natural disturbance regimes, and general land use. Local landform patterns become apparent at this level in the hierarchy, and differences among units are usually obvious to on-the-ground observers. At this level, terrestrial features and processes may also have a strong influence on ecological characteristics of aquatic habitats (Platts 1979, Ebert et al. 1991).

Landtype association ecological units represent this scale in the hierarchy. These are groupings of landtypes or subdivisions of subsections based on similarities in geomorphic process, geologic rock types, soil complexes, stream types, lakes, wetlands, subseries or plant association vegetation communities. Repeatable patterns of soil complexes and plant communities are useful in delineating map units at this level. Names of Landtype Associations are often derived from geomorphic history and vegetation community.

Land Unit Scale
At the basic land unit scale, ecological units are designed and mapped in the field based on properties of local topography, rock types, soils, and potential natural vegetation. These factors influence the structure and composition of plant communities, hydrologic function, and basic land capability. Landtypes and landtype phases are the ecological units mapped at this scale.

1. Landtypes, subdivisions of landtype associations or groupings of landtype phases based on similarities in soils, landform, rock type, geomorphic process, and plant associations. Land surface form that influences hydrologic function (for example, drainage density, dissection, and relief) is often used to delineate different landtypes in mountainous terrain. Valley bottom characteristics (for example, confinement) are commonly used in establishing riparian landtype map units. Names of landtypes include an abiotic and biotic component (USDA Forest Service Handbook 2090.11).

2. Landtype Phase, subdivisions of Landtypes based on topographic criteria (for example, slope-shape, steepness, aspect, position), hydrologic characteristics, associations and consociations of soil taxa, and plant associations and phases that influence or reflect the microclimate and productivity of a site. Landtype phases are often established based on interrelationships between soil characteristics and potential natural communities.In riparian mapping, landtype phases may be established to delineate different stream-type environments (Herrington and Dunham, 1967). Naming is similar to landtypes.

The Landtype Phase is the smallest ecological unit recognized in the hierarchy. However, even smaller units may need to be delineated for very detailed project planning at large scales (Table 1). Map design criteria depend on project objectives.

Plot Data
Point or plot sampling units are used to gather ecological data for inventory, monitoring, and quality control, and for developing classifications of vegetation, soils or ecological types. This plot data feeds into databases for analysis, description, and interpretation of ecological units (Keane et al. 1990). Plots, while not mappable, can be shown on maps as point data.

UNDERLYING PRINCIPLES

Ecosystem Concept
Ecosystems are places where life forms and environment interact; they are three-dimensional segments of the Earth (Rowe 1980). Tansley introduced the term *ecosystem* in 1935, first articulating the explicit

idea of ecological systems composed of multiple abiotic and biotic factors (Major 1969). The ecosystem concept brings the biological and physical worlds together into a holistic framework within which ecological systems can be described, evaluated, and managed (Rowe 1992). The structure and function of ecosystems are largely regulated along energy, moisture, nutrient, and disturbance gradients. These gradients are affected by numerous environmental and biological factors including climate, geology, soils, flora, fire, and wind, and these factors vary at different spatial and temporal scales (Barnes at al. 1982, Jordan 1982, Spies and Barnes 1985). Ecological systems therefore exist at many spatial scales, from the global ecosphere down to regions of microbial activity. Using multiple biotic and abiotic factors, the National Hierarchy of Ecological Units organizes the environmental components of ecosystems into an orderly set of spatial scales based on measurable features and processes. The National Hierarchy thus takes the infinite variety of ecosystems and places them into a limited number of discrete, practical units that are mappable, repeatable, and distinguished from one another by differences in various structural or functional characteristics.

At global, continental, and regional scales, ecosystem patterns correspond with climatic regions, which change mainly due to latitudinal, orographic, and maritime influences (Bailey 1987, Denton and Barnes 1988). Within climatic regions, landforms modify macroclimate (Rowe 1984, Smalley 1986, Bailey 1987), and affect the movement of organisms, the flow and orientation of watersheds, and the frequency and spatial pattern of disturbance by fire and wind (Swanson et al. 1988). Within climatic - geomorphic regions, water, plants, animals, soils, and topography interact to form ecosystems at Land Unit scales (Pregitzer and Barnes 1984). Thus ecological systems exist at many spatial scales, from the global ecosphere down to regions of microbial activity. The challenge of ecosystem classification and mapping is to distinguish natural associations of ecological factors at different spatial scales, and to define ecological types and map ecological units that reflect these different levels of organization.

And while the association of these multiple biotic and abiotic factors is all important in defining ecosystems and ecological units, all factors are not equally important at all spatial scales. At coarse scales, the important factors are largely abiotic, while at finer scales both biotic and abiotic factors are important. Furthermore, the level of discernible detail, the number of factors contributing to ecosystems, and the number of variables used to characterize these factors progressively increase at finer scales. Hence the data and analysis requirements, as well as the investments for ecosystem classification and mapping, also increase for finer-scaled activities.

The conditions and processes occurring across larger ecosystems affect and often override those of smaller ecosystems, and the properties of smaller ecosystems emerge in the context of larger systems (Rowe 1984). Moreover, environmental gradients that affect ecological patterns and processes change at different spatial scales. Thus, it is useful to conceive of ecosystems and their underlying biophysical environments as occurring in a nested geographic arrangement, with smaller ecosystems embedded in larger ones (Allen and Starr 1982, O'Neill et al. 1986, Albert et al. 1986). This spatial hierarchy is organized in decreasing orders of scale by the dominant factors affecting ecological systems. Ecosystems become networked, however, when non-adjacent systems exhibit similar structure and function with respect to specific biota (for example, sedentary plants as opposed to wide ranging animals) and various processes; hence the networking of ecological systems is scale dependent (Allen and Hoekstra 1992). Networking of ecosystems occurs most often at lower levels of the hierarchy, and depends upon requirements, environmental tolerances, and dispersion mechanisms of biota, as well as other factors that affect biotic-abiotic interactions within and across local, landscape and regional ecosystems.

Life and Environmental Interactions

Life-forms and environment have interacted and codeveloped at all spatial and temporal scales, one modifying the other through feedback. Appreciating these interactions is integral to understanding ecosystems. At a global scale, for example, scientists have theorized that the evolution of cyanobacteria, followed by terrestrial plants capable of photosynthesis, carbon fixation and oxygen production converted the earth's atmosphere from a hydrogen to an oxygen base and still sustain it today. At a continental scale, the migration of species in response to climate change, and the interaction of their environmental tolerances and dispersal mechanisms with landform controlled migration routes formed today's patterns in the distributions of species. At a landscape scale, life-forms, environment, and disturbance regimes have interacted to form patterns and processes. For example, pyrophilic communities tend to occupy droughty soils in fire-prone landscape positions, produce volatile foliar substances, and accumulate litter, thereby increasing their susceptibility to burning. At yet finer scales, vegetation has induced soil development over time through carbon and nutrient cycling, enabling succession to proceed to communities with higher fertility requirements.

In each of these examples, life forms and environment have modified one another through feedback to form ecological patterns and processes. These types of relationships underscore the need to consider both biotic and environmental factors while classifying, mapping and managing ecological systems.

Spatial and Temporal Variability

The structure and function of ecosystems change through space and time. Consequently, we need to address both spatial and temporal sources of variability while evaluating, classifying, mapping, or managing ecosystems (Delcourt et al. 1983, Forman and Godron 1986). At a land unit scale, for example, the fertility of particular locations changes through space because of differences in soil properties or hydrology, and at ecoregion scales, conditions vary from colder to warmer because of changes in macroclimate. These relatively stable conditions favor certain assemblages of plants and animals while excluding others because of biotic tolerances and such processes as competition. These environmental conditions are classified as ecological types and mapped as ecological units.

Within ecological units, ecosystems may support vegetation that is young, mature, or old, and they may be composed of communities that are early, mid-, or late successional. These relatively dynamic conditions also benefit certain plant and animal species and assemblages. Conditions that vary temporally are classified and mapped as existing vegetation, wildlife, water quality, and so forth.

These examples illustrate that ecological units do not provide all the information needed to classify, map and manage ecosystems. Ecological units address the spatial distributions of relatively stable associations of ecological factors that affect ecosystems. When combined with information on existing biotic conditions and ecological processes, the National Hierarchy of Ecological Units provides a means of addressing spatial and temporal variations that affect the structure, function and management potentials of ecosystems. Adding our knowledge of processes to this information will enable us to evolve better information.

USE OF ECOLOGICAL UNITS

Ecological units provide basic information for natural resource planning and management. Ecological unit maps may be used for activities such as delineating ecosystems, assessing resources, conducting environmental analyses, and managing and monitoring natural resources.

Ecosystem Mapping

To map ecosystems, or places where life and environment interact, we need to combine two types of maps: maps of existing conditions of biota that change readily through time, and maps of potential conditions of environments that are relatively stable. Existing conditions change due to particular processes that operate within the bounds of biotic and environmental, or ecological, potentials. Existing conditions are inventoried as current vegetation, wildlife, water quality, and so forth. Potential conditions are inventoried as ecological units. When these maps are combined, biotic distributions and ecological processes can be evaluated, and results can be extrapolated to similar ecosystems. The integration of multiple biotic and abiotic factors, then, provides the basis for defining and mapping ecosystems.

Fundamental base maps are key to mapping ecosystems and integrating resource inventories. These maps include the primary base map series, showing topography, streams, lakes, ownership, political boundaries, cultural features, and other layers in the cartographic features file. On this base, the next set of layers could include terrestrial or aquatic ecological units. Next would be layers of information on existing vegetation, wildlife populations, fish distribution, cultural resources, demographics, economic data, and other information needed to delineate ecosystems to meet planning and analysis needs.

GIS will provide a tool for combining these separate themes of information, and representing the physical, biological, and social dimensions to define and map ecosystems. But scientists and managers using this technology must actually integrate information themes, comprehend processes, and formulate management strategies. These tasks will not be accomplished mechanically.

Resource Assessments

The hierarchical framework of ecological units can provide a basis for assessing resource conditions at multiple scales. Broadly defined ecological units (for example, ecoregions) can be used for general planning assessments of resource capability. Intermediate scale units (for example, landtype associations) can be used to identify areas with similar natural disturbance regimes (for example, mass wasting, flooding, fire potential). Narrowly defined land units can be used to assess site specific conditions including distributions of terrestrial and aquatic biota; forest growth, succession, and health; and various physical conditions (for example, soil compaction and erosion potential, water quality).

High resolution information obtained for fine scale ecological units can be aggregated for some types of broader scale resource assessments. Resource production capability, for example, can be estimated based on potentials measured for landtype phases, and estimates can be aggregated to assess ranger district, national forest, regional, and national capabilities.

Environmental Analyses

Ecological units provide a means of analyzing the feasibility and effects of management alternatives. To discern the effects of management on ecosystems, we often need to examine conditions and processes occurring above and below the level under consideration (Rowe 1980). For example, the effects of timber harvesting are manifest not only at a land unit scale, but also at micro-site and landscape scales. Although the direct effects of management are assessed at the land unit scale, indirect and cumulative effects take place at different points in space or time, often at higher spatial scales. We can minimize conflicting resource uses (for example, remote recreational experiences versus developed motorized recreation, habitat management for area sensitive species versus edge species) if we consider the design and effects of projects at several scales of analysis. Ecological units defined at different hierarchical levels will be useful in conducting multi-scaled analyses for managing ecosystems and documenting environmental effects (Brenner and Jordan 1991, Jensen et al. 1991).

Watershed Analysis

The national hierarchy provides a basis for evaluating the linkages between terrestrial and aquatic systems. Because of the interdependence of geographic components, aquatic systems are linked or integrated with surrounding terrestrial systems through the processes of runoff, sedimentation, and migration of biotic and chemical elements. Furthermore, the context of water bodies affects their ecological significance. A lake embedded within a landscape containing few lakes, for example, functions differently from one embedded within a landscape composed of many lakes for wildlife, recreation for people, and other ecosystem values. Aquatic systems delineated in this indirect way may have many characteristics in common, including hydrology and biota (Frissell et al. 1986). Overlays of hierarchical watershed boundaries on terrestrial ecological units are useful for many watershed analysis efforts. In this case, the watershed becomes the analysis area, which is both superimposed by and composed of a number of ecological units which affect important hydrologic processes such as water runoff and percolation, water chemistry, and ecological function due to context.

Desired Future Conditions

Desired future conditions (DFC's) portray the land or resource conditions expected if goals and objectives are met. Ecological units will be useful in establishing goals and methods to meet DFC's. When combined with information on existing conditions, ecological units will help us project responses to various treatments.

Ecological units can be related to past, present, and future conditions. Past conditions serve as a model of functioning ecosystems and provide insight into natural processes. It is unreasonable, for example, to try to restore systems like oak savannas or old-growth forests in areas where they did not occur naturally. Moreover, natural processes like disturbance or hydrologic regimes are beyond human control. Ecological units will be helpful in understanding these processes and in devising DFC's that cab attained and perpetuated.

Desired future conditions can be portrayed at several spatial scales. We can minimize conflicting resource uses (for example, remote recreational experiences versus developed motorized recreation, habitat management for area-sensitive species versus edge species) if we consider the effects of projects at several spatial scales of analysis. Ecological units will be useful in delineating land units at relevant spatial scales for planning DFC's.

Resource Management

Information on ecological units will help establish management objectives and will support such management activities as the protection of habitats of sensitive, threatened, and endangered species, or the improvement of forest and rangeland health to meet conservation, restoration, and human needs. For example, information on current productivity can be compared to potentials determined for landtype phases, and areas producing less than their potential can be identified (Host et al. 1988). Furthermore, long term sustained yield capability can be estimated based on productivity potentials measured for fine scale ecological units.

Monitoring

Monitoring the effects of management requires baseline information on the condition of ecosystems at different spatial scales. Through the ecological unit hierarchy, managers can obtain information about the geographic patterns in ecosystems. They are thus in a position to design stratified sampling networks for inventory and monitoring. Representative ecological units can be sampled and information can then be extended to analogous unsampled ecological units, thereby reducing cost and time in inventory and monitoring.

By establishing baselines for ecological units and monitoring changes, we can protect landscape, community, and species level biological diversity; and other resource values such as forest productivity, and air and water quality. The results of effectiveness and validation monitoring can be extrapolated to estimate effects and set standards in similar ecological units.

Evaluation of air quality is an example of how the National Hierarchical Framework of Ecological Units can be used for baseline data collection and monitoring. The Forest Service is developing a National Visibility Monitoring Strategy that addresses protection of air quality standards as mandated by the Clean Air Act (USDA Forest Service 1993). Key to this plan is stratification of the United States at the subregion level of the national hierarchy into areas that have similar climatic, physiographic, cultural, and vegetational characteristics. Other questions dealing with effects of specific airborne pollutants on forest health, such as correlation of ozone with decline of ponderosa pine and other trees in mixed conifer forest ecosystems in the San Bernardino Mountains of southern California, will require establishment of sampling networks in smaller ecological units at landscape or lower levels.

Contemporary and Emerging Issues

The National Hierarchy of Ecological Units is based on natural associations of ecological factors. These associations will be useful in responding to contemporary and emerging issues, particularly those that cross administrative and jurisdictional boundaries. Concerns regarding biological diversity, for example, can be addressed using the ecological unit hierarchy (Probst and Crow 1991). Conservation strategies can be developed using landscape-level units as coarse filters, followed by detailed evaluations and monitoring conducted to verify or adjust landscape designs. We can rehabilitate ecosystems and dependent species that have been adversely affected by fire exclusion, fragmentation, or other results of human activities if we grow to understand the natural processes that species and ecosystems codeveloped with, and then mimic those processes through ecosystem management.

Species may become rare, threatened, or endangered because their habitat is becoming degraded, because they are specialists endemic to a particular area, or because they are at the edge of their natural range. In the first two instances, protection and recovery efforts are warranted. In the latter case, however, it may be futile to try to maintain biota where they are predisposed to decline. At a minimum, populations at the edge of their range can be evaluated for genetic diversity, and recovery programs can be administered accordingly. Species and community distributions can often be related to ecological units, which can be useful in their inventory and protection.

The emphasis on sustaining and restoring the integrity of ecosystems may aid in arresting the decline of biological diversity and preempt the need for many future protection and recovery efforts Developing basic information on the nature and distribution of ecosystems and their elements will enable us to better respond to issues like global warming, forest health and sustainability, and biological diversity.

The hierarchical framework of ecological units was developed to improve our ability to implement ecosystem management. This framework, in combination with other information sources, is playing an important role in national, regional, and forest planning efforts; the sharing of information between forests, stations, and regions; and interregional assessments of ecosystem conditions.

Regions and stations, with national guidance, are coordinating their design of ecological units at higher levels of the national hierarchy. Development of landscape and land unit maps is being coordinated by appropriate regional, station, forest and ranger district level staff. As appropriate, new technologies (for example, remote sensing, GIS, expert systems) should be used in the design, testing and refinement of ecological unit maps.

The classification of ecological types and mapping of ecological units pose a challenge to integrate not only information, but also the concepts and tools traditionally used by various disciplines. The effort brings together the biological and physical sciences that have too often operated independently. Specialists like foresters, fishery and wildlife biologists, geologists, hydrologists, community ecologists and soil scientists will need to work together to develop and implement this new classification and mapping system. The results of these concerted efforts will then need to be applied in collaboration with planners, social scientists, economists, archaeologists and the many other specialties needed to achieve a truly ecological approach to the management of our nation's National Forests and Grasslands.

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