ECOLOGICAL STEWARDSHIP

A Common Reference for Ecosystem Management

Volume II

- Biological and ecological dimensions
- Humans as agents of ecological change

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Editors

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A practical reference for scientists and resource managers

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The Use of Ecological Classification in Management

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Key questions addressed in this chapter

- *How do we use biophysical classifications and ecological assessments in decision-making?*
- *How do we use hierarchical classification systems?*
- *How do we develop a common, ecologically based classification that works for all the partners?*

Keywords: Ecological units, mapping, land cover, landscape, habitat type, desired future conditions

1 INTRODUCTION

Ecological classification systems range over a variety of scales and reflect a variety of scientific viewpoints. They incorporate or emphasize varied arrays of environmental factors. Ecological classifications have been developed for marine, wetland, lake, stream, and terrestrial ecosystems. What are the benefits of ecological classification for natural resource management planning and implementation?

This chapter is written primarily from the viewpoint of the U.S. Forest Service in its efforts to implement multiple public mandates for federal land and draws heavily from USFS experience in ecological classification and mapping. It is also the viewpoint of an agency "standing at the borders looking outward." National Forests recognize they are linked to others by the common goals of a healthy sustainable environment and stable prosperous communities.

This chapter presents examples of ecological classification systems and their use. It includes examples of ecological and other classification systems being used together, generally for landscape and regional planning and examples of public organizations working together to identify common ecological unit boundaries for inventory, monitoring, and management purposes. Grossman et al. (this volume) discuss the development of a variety of classification systems and the technical merits and difficulties of combining them.

1.1 Key Questions

Central to the development of this chapter are the following questions posed to the Ecological Classification science and management teams:

1. "How do we use a variety of biophysical classifications and ecological assessments in decision-making?" and
2. "How do partners develop a common, ecologically based classification that works for all the partners?"

1.2 Scope of the Management Chapter

This chapter discusses the use of ecological classification in integrated resource inventory, planning and assessment from site specific to national scales. It focuses on management considerations in ecological unit surveys and the use of mapped ecological units. Generally, a few basic concepts underlie the use of ecological units. These are constant and transferable among terrestrial and aquatic ecosystems and from region to region.

The resource manager, newly interested in ecological classification, may be overwhelmed by the wide array of classification systems in use and perhaps by the controversies surrounding their scientific underpinnings. As the state of scientific understanding regarding ecosystems has evolved, so has the science and art of ecological classification and mapping. Indeed each field application has a unique developmental history often based upon the school of thought prevalent at the time and place it was developed.

1.3 Approaches to Ecological Classification and Mapping

To understand the use of ecological classification, it is important to understand ecosystem attributes. Ecosystems are complete interacting systems of organisms and their environment. Ecosystems are described at many scales ranging from microsites to the biosphere and vary in composition, structure, and function. All ecosystems grade into others; all are nested within a matrix of larger ecosystems. Ecosystems are continually changing and the changes are not always predictable.

Ecosystem complexity is important for sustaining life but this complexity makes it difficult to determine the function and significance of individual ecosystem components, structures and processes. Ecosystems are more than the aggregate of their parts. The conditions and processes occurring across larger ecosystems affect and often override those of smaller ecosystems, and the properties of smaller systems affect and emerge in the context of larger systems.

What is ecological classification? Ecological classification systems are based on associations among physical and biological factors identified in the classification process. First, interrelationships among biota and the environment are studied at several relevant scales or levels of generality. "Important" variables and scales are identified through data analysis and synthesis. Taxonomic classes are formulated by integrating this information and defining categories based on mutual relationships. These classes allow identification of criteria to meaningfully map geographic areas (Driscoll et al. 1984).

Map units are based on the criteria or relationships identified by the taxonomic system used. Taxonomic systems help us organize our knowledge while mapping units transfer this knowledge to the specific areas where it can be applied. However, the concept of a map unit is not the same as that of a taxonomic class. Taxonomic classes are actually models based on a sample of a larger population. "The advantage of mapping" according to Rowe (1996), "is that every part of the terrain has to be confronted; there is no avoiding those in-between and oddball units that an a priori classification is apt to ignore". In addition, a map unit may be composed of more than one taxonomic class. In this case, the most common case, mapping rules are developed by evaluating the mode, range, relative abundance and distribution of taxonomic classes within the area of interest. Units can then be mapped and used with full knowledge of the important attributes inherent in the taxonomic classification and the mapping rules.

An ecosystem supports vegetation of varied age and community structure over time. Ecological classifications can be separated into two categories based on the way they deal with changes in time. Maps that are used to describe land and aquatic units that behave in a similar manner over time are referred to as biophysical maps. These map boundaries change only when new information indicates they do not reflect long term potential. Existing or historic status maps are used to describe ecosystems or ecosystem components at a point in time. These map boundaries are expected to change every time an area is surveyed.

Ecological types and map unit concepts are three dimensional. They are based on the integration of biotic and abiotic characteristics above and below ground which distinguishes them from classifications of individual ecosystem components such as cover types, soils or remote sensing classifications which are based on spectral or thermal signatures.

Ecological classification and mapping are conducted at a variety of scales or levels of generality (see Haufler et al., this volume). A hierarchical classification can systematically divide the country into progressively smaller areas of land and water having similar physical and biological characteristics and ecological processes. Linkages among units of different scales in a hierarchical system are based upon the dynamics of various energy, water, nutrient and disturbance cycles. Recognizing environmental conditions at a higher level of organization sets a framework for understanding patterns and interactions at lower levels.

Ecological classification and mapping provide a framework for integrating information on the composition, structure and function of ecosystems. It is the explicit integration of information gained through ecological classification, mapping and additional environmental inventory that allows identification of ecosystems and the development of models of ecosystem behavior. It is within this context that ecological units are used to characterize ecosystems over time and space and to test cause-and-effect relationships.

1.4 Benefits of Using an Ecological Unit Framework in Management

Ecological classification systems are versatile tools that can be used to resolve issues, determine management direction, and implement ecologically based management approaches. They can be used when managers characterize the environment, inventory resource conditions, conduct environmental analyses, establish desired future conditions, monitor trends in natural resources, and establish priorities for conservation and restoration activities. They provide a means to link models of ecological processes to specific areas. The uses of ecological classification have expanded as understanding of ecosystem needs has progressed.

Ecological classification systems are useful in addressing fundamental management questions such as what constitutes conservation, preservation, restoration and proper management. Ecological unit maps are used to provide an ecological context for planning and management. They contribute to our ability to demonstrate the potential for a variety of alternatives at local, landscape, and regional scales and help establish the logical scope of planning and analysis activities. They add geographic specificity to documents and efforts to communicate the logic underlying management decisions (Avers et al. 1994, Carpenter et al. 1995).

Ecological units provide a framework for describing and understanding ecosystems and an expedient and cost-effective means of ordering and managing information about them. They improve our ability to:

- integrate knowledge from multiple disciplines, traditionally separated,
- develop and share resource data and information across administrative and jurisdictional boundaries, and
- communicate technical information to specialists and lay people through the use of common terminology, common maps, and standardized data.

Hierarchical frameworks, which integrate units of multiple scales by nesting small units within larger ones, have additional benefits (Avers et al. 1994) They:

- help clarify the relationships between ecological patterns and the processes which influence them,
- maximize the use of resource inventory information among multiple geographic scales, and
- foster broad application and appropriate extrapolation of research results.

1.5 Overview of Ecological Classification Activity in the Forest Service

The evolutionary histories, the pace and approaches to the development and use of ecological classification in the USFS have varied among National Forests and within Regions. Aquatic and terrestrial ecosystem classification and inventory efforts have evolved independently of each other. Forest-by-Forest efforts have proceeded from the ground level up, generally investing in local and site classification first, then landscape, regional and hierarchical systems. Today, Forests are working toward an integrated global to local hierarchical system that addresses terrestrial and aquatic ecosystem management needs and that supports multipurpose, multiscale inventory, monitoring, and research.

For terrestrial systems, the evolution from single resource classification and mapping toward an integrated hierarchical approach began in the late 1970s. Ey 1984, the need for some standardization within the agency was recognized (Bockheim 1984). Systems used at that time display differences in terminology and delineation criteria, including differences in how land use information was included. The quality of environmental predictions, the ability to integrate wildlife needs and effects, the ability to assess the relationships among contiguous land units at one or more scales, and the integration of aquatic and terrestrial components varied from system to system as well (Bailey 1984).

An agency-wide review of the status of water unit classification was conducted in 1987 (USDA Forest Service WO-INS 1987). Aquatic ecosystem classification was not in widespread use at that time. The agency task force recommended a four-level information hierarchy be adopted for aquatic classification and information management that is roughly commensurate with the lower four levels displayed in the aquatic hierarchy today. Level one was designated the most general and level four the most site specific. Most of the systems in use were "first cut" systems and based on a single data element. Although systems were found at various levels of resolution, most of the effort was directed at the site level and there was little integration across scales.

Most lake classification conducted at Level 1 (the broadest level) was related to general fish habitat or origin of the lake and underlying geology. Level 2 lake classifications were related to some aspect of water condition or lake bottom structure.

Most wetland classification efforts were based on the U.S. Fish and Wildlife Service method (Cowardin et al. 1979).

Table 1. The Forest Service National Hierarchical Framework for using ecological units (adapted from Avers et al. 1994).

Planning and Analysis Scale	Purpose, Objectives, General Use	Ecological Units
Ecoregion Global Continental Regional	Broad applicability for modeling and sampling, strategic planning and assessment, international planning	Domain Division Province
Subregion	Strategic and multi-agency scale analysis and assessment, data aggregation. Generating and testing research hypotheses. Technology transfer and data extrapolation.	Section Subsection
Landscape	Multiple resource assessment and analysis. Tactical and long term operational planning, data aggregation, research, and monitoring design.	Land Type Association
Land Unit	Project planning and implementation, environmental effects analysis, project monitoring and evaluation.	Landtype Landtype phase

Streams were the primary focus of agency aquatic classification efforts of the time. Parrott et al. (1989) concluded that even though stream classification systems had been developed by several workers, classifications had only been implemented and documented in a few geographic areas. They also pointed out that no hierarchical stream classification system was in widespread use at that time, although Platts (1980) had proposed a hierarchical classification as early as 1980.

The New Perspectives initiative of 1992 highlighted the need to demonstrate the scientific basis for ecosystem management, to conduct more holistic management, and to incorporate biodiversity conservation into planning and management activities. For these reasons, the Forest Service officially adopted the National Hierarchical Framework of Ecological Units (Table 1) in 1993. In 1995, the agency released a companion generic hierarchical framework for characterizing aquatic ecosystems that described the linkages between terrestrial units and aquatic biophysical environment maps (Avers et al. 1994, Maxwell et al. 1995) (Fig. 1).

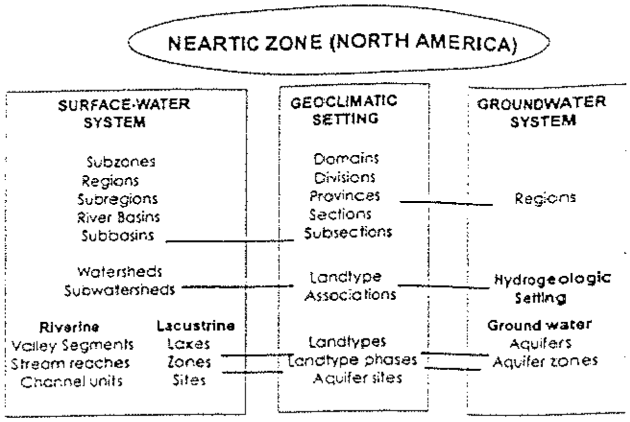

Fig. 1. General framework of aquatic ecological unit hierarchy. Primary linkages between aquatic systems and terrestrial (geoclimatic) systems are shown (Maxwell et al. 1995).

The task of changing from existing conditions of terrestrial and aquatic classification and inventory within the U.S. Forest Service, to that recommended through The National Hierarchy is a challenging one. The Forest Service must be innovative in using existing classifications to the best advantage, while strategically providing additional information and expertise to meet the criteria at multiple levels in the National Hierarchy. The proceedings of the national workshop: *Taking an Ecological Approach to Management* (USFS 1992) provide the most recent descriptions of ecological classification approaches among the Forest Service Regions. The intent of the regional presentations was to provide information that would lead to a strategy to integrate physical, biological, and socio-political information from the National Forest System lands and adjacent lands into an ecological approach to management. Therefore, it is not surprising that classification was a central piece in each presentation.

Since the adoption of the National Hierarchical Framework, the Forest Service has pursued the revision of existing maps and information in a simultaneous top-down and bottom-up fashion. Broadscale efforts are most easily documented. At the national level the USFS publication *Description of the Ecoregions of the United States* (Bailey 1980) was revised (Bailey 1995). All Forest Service regions contributed to a map *Ecoregions and Subregions of the United States* (Bailey et al. 1994) and its companion document *Ecological Subregions of the United States: Section Descriptions* (McNab and Avers 1994). The USFS in cooperation with NRCS published the map *Ecological Units of California: Subsections* (Goudey and Smith, 1994) by subdividing the Sections on the 1994 map (Bailey et al.). Albert (1995) produced *Regional Landscape Ecosystems of Michigan, Minnesota, and Wisconsin: A Working Map and Classification (Fourth Revision: July 1994)* through a cooperative agreement with the North Central Forest Experiment Station by request of the Upper Great Lakes Biodiversity Committee. The most recent publication, which involved two National Forest System regions, three research stations (now organized to two), the Northeastern Area of State and Private Forestry, and numerous collaborators was a map to the subsection level called *Ecological Units of the Eastern United States — First Approximation* (Keys et al. 1995).

Today, technology such as GIS, computer spreadsheets and database programs are important tools to classify, locate, and interpret ecological units at all scales. Regions are experimenting with map overlay and multivariate statistical techniques and the use of modeling to investigate landscape variability within units in response to natural disturbance and management.

Since the last review in 1984, progress has been made toward consistency in classification criteria, although the procedural steps for classification and mapping are not uniform nationally. This is partly because of the need to maximize the use of existing information, partly because the field of geostatistics is going through a period of rapid evolution, and partly because of the wide variation in access to modern technologies. Initial priorities for achieving consistency currently lie among forests at the land type association level, and among federal agencies at the land type association, section, subsection, and province levels.

Clearly, ecological classification systems have become a more integral part of Forest Service planning and management efforts (USDA Forest Service 1992, WO-INS 1993). Ecological surveys have been on-going for several decades; therefore, more Forests now have access to survey information and more Forests have access to multiple levels of classification. The major emphasis is still on terrestrial classification; however, the need for aquatic classification is now widely recognized. The earlier observation of little integration of aquatic and terrestrial components in classification still holds true however.

Cross-boundary, cross-agency cooperation in ecological classification development and mapping is increasing. The Forest Service is increasingly involved with state agencies and organizations to develop units at landscape and regional scales for statewide or watershed-wide planning purposes. In 1996, the Forest Service signed a memorandum of understanding (MOU) relative to "Developing a spatial framework of ecological units of the United States" with eight other federal agencies among the Department of Agriculture, the Department of Interior, and the U.S. Environmental Protection Agency (Case Study 13).

2 SITE LEVEL APPLICATIONS

Ecological units are depicted on maps but ecological unit maps alone do not fully characterize ecosystems. Ecological units are used in combination with inventories and maps of existing vegetation, wildlife, aquatic systems, air quality, and human development to characterize the complexes of life and environment we call ecosystems at any point in time. The type of past human use, the intensity of management, and degree of current human development in or around the area you are managing all affect the degree an ecosystem may deviate in composition, structure and/or function from its potential natural state. Ecological units provide information on ecosystem potential and capability but do not substitute for a well thought out prescription based on all available evidence.

2.1 Integrated resource inventory

The transition from multiple-use management to ecosystem management is marked by a desire to integrate knowledge from multiple disciplines that have traditionally been separated (see also McCleery et al. this volume). Multidisciplinary cooperation in data gathering and analysis is a prerequisite to implementation of this holistic approach. Ecological units allow managers to provide a consistent context for other spatially referenced information. Ecological units provide a spatial framework for this integration and a conceptual basis for analyzing cause and effect relationships. This ultimately results in an increased ability to analyze resource interactions and management tradeoffs.

Ecological classification and mapping can aid in the integration of resource information in several ways. Ecological classifications by definition integrate multiple environmental factors. Maps of ecological units provide a spatial framework for structuring a variety of resource inventory and monitoring work, thus contributing to the progressive accumulation of knowledge about area ecosystems. Where ecological types have been developed but mapping is not available, single resource inventories can be modified to collect sufficient data to allow identification of ecological types as part of the inventory database.

The use of ecological units, as a standard base for conducting and recording inventory information, is more efficient and cost effective than after-the-fact integration of single resource inventories using a map overlay process. Ecological classification and mapping organize information in a spatial context. Data development and expansion occur in several stages. Data are first collected and analyzed to develop ecological types and to provide interpretations by ecological type for management use. Then, ecological units are mapped and sampling is undertaken to ensure the reliability of the map unit descriptions. Finally, as additional resource information needs are identified, the classification units can be used to stratify additional sampling and then used to look for natural associations or correlation with environmental factors already inventoried.

An ecological unit framework provides an ecological context for assimilating new information which is not provided by merely overlaying maps from multiple independent surveys. The generation of map polygons through a mechanical process of map overlay does not guarantee you can establish the ecological relationships with sufficient accuracy for management at the site level. Many of the boundaries from an overlay approach will not be coincidental, resulting in the presence of map "slivers," which need to be allocated individually to some management or analysis area.

Historically, scientists and managers have inventoried resources by identifying and mapping those characteristics that are important to human use through the development of various classification systems or "taxonomies." Physical components of the environment have been described and classified based upon their morphological characteristics and the associated properties. Similarly living things have been classified according to those morphological and physiological characteristics that affect their adaptability to the environment. Site conditions determine a location's capability or suitability for various uses. Capability and suitability determinations are often referred to as "interpretations" of a classification and are what make classifications valuable to managers.

Monitoring is an important part of ecosystem management. Scientists and managers are encouraged to monitor changes in ecosystem composition, structure and processes to detect changes in ecosystem health. The schematic presented in Fig. 2 provides examples of compositional, structural, and functional characteristic that are often measured in inventory, monitoring, and research programs.

Ecosystem structure is defined here as the vertical and/or horizontal arrangement of ecosystem components viewed in a particular geographic setting at a particular time. Information on composition and structure are needed to describe the functional characteristics of ecosystems. Physical, chemical, and biological processes link multiple resource components to each other and influence their distribution, arrangement, and abundance. Limits to the rate of change include: limited amounts of nutrients, moisture, energy, and space; limitations due to the physiology,

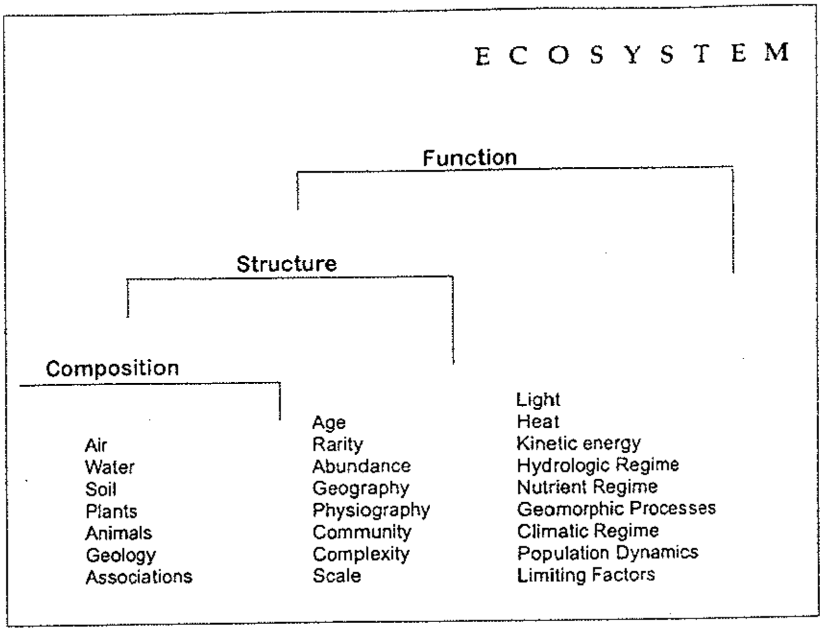

Fig. 2. Ecological characteristics that can be measured or described and the processes which must be examined in determining the response of a given ecosystem to natural disturbance and management.

age, and trophic status of biological organisms; and limitations imposed by disturbance regimes.

Ecological unit maps help identify the spatial interdependence of ecosystems. The inherent capabilities of an ecosystem depend upon the interactions and associations of environmental factors in a given area. This includes the functional linkages such as transfers of heat, moisture, nutrients, sediments, seeds, etc. among diverse but contiguous systems. It includes environmental values that accrue by the mere juxtaposition of diverse areas. For example, wetland ecosystem capability includes the ability to produce biomass in the form of various species assemblages; the productivity of the wetland is influenced by nutrient inputs from the adjacent uplands; and the wildlife habitat value of the wetland is influenced by the juxtaposition of the wetland and upland.

Field inventory represents a significant investment; therefore, steps that enhance the quality and completeness of data collection and mapping should be a high priority for managers. The quality of an ecological unit inventory rests on the ability of the survey crew to allocate land correctly to an ecological type and to recognize the landscape patterns that provide a degree of homogeneity to ecological units. Classification and mapping require personnel with good judgment, training and field experience.

Ecological units are most reliably mapped using relatively permanent features of the environment such as soils, rock, waterbodies, and landforms in combination with vegetation indicators. Using soil, vegetation, and landform indicators together, mappers can compensate for the limitations of any one alone. The use of plant indicators increases the ease and efficiency of mapping if used carefully. Limitations are that plants and plant associations may change over time, especially in areas of repeated or severe site disturbance. Past events can cause certain vegetation patterns that will not persist. Long-lived species may be out of step in the contemporary environment because of a lag in adjusting to environmental change. Herbaceous species do not always reflect soil conditions of importance to deeper-rooted trees or they may reflect features of no importance to trees. After certain kinds of severe disturbance, ground flora may be difficult to interpret accurately. On severely disturbed sites, soil erosion may have eliminated typical soil characteristics and changed site potentials.

Ecological classification and inventory produce information on several ecosystem components at once, an advantage over single resource inventories. Surveys provide information on the size and location of units that often have implications for ecology and management.

The following case studies provide an overview of inventory and mapping activities among a variety of ecosystems and which meet the requirements of a variety of disciplines. Several show the use of completed maps to stratify sampling for additional information that contributes to integrated resource management. Even though the data collected and methods of inventory may vary between terrestrial and aquatic systems, it is apparent that the integration of biotic and abiotic information is a common feature.

Case Study 1 summarizes a contemporary example of data collection for ecological classification and mapping of terrestrial uplands and shallow water wetlands on the Hiawatha National Forest, Michigan and identifies several uses of this baseline inventory in management. *Case Study 2* provides an example of an integrated stream inventory system. *Case Study 3* provides an evaluation of the use of ecological classification in inventorying wildlife habitat attributes in Michigan.

Case Study 1 in Integrated Resource Inventory: Hiawatha National Forest Ecological Classification (ECS), and Inventory of Uplands and Shallow Water Wetlands — Contemporary example of data collection and mapping

Ecological Classification:

This effort is based upon the National Hierarchical Framework of Ecological Units (Avers et al. 1994). Work on the upland component of the classification was begun in the 1980s. Work on the wetland portion was begun in the 1990s. The Land Type Associations (LTA) range in the 1,000s of acres in size, Ecological Land Types (ELT) range in the 100s of acres, and Ecological Landtype phases (ELTP) range in the 10s to 100s of acres.

Description:

1. Initial classification development included the collection of comprehensive plot information on landform, soil, vegetation, and hydrologic factors to develop ELT and ELTP units through the integration of biotic and abiotic data.
2. ECS mapping and inventory has been completed on over 95 percent of the 0.5 million acres in the Hiawatha National Forest western half. The process consists of the delineation of ELTP polygons (minimum size 5 acres) on low level color infrared aerial photography combined with verification plots in each ELTP unit. The plot information is entered into a relational database and consists of a listing of vegetation with relative dominance, a soil characterization to 5 m. or water table, and hydrological information including depth to ground water and water chemistry (pH and electrical conductivity) in wetlands.
3. Polygons identified with ELTP codes are in the process of being transferred from aerial photography to an automated database.

The inventory database with over 4,000 plot entries enables queries to isolate information about specific geographical locations or virtually any combination of species, soil, or hydrologic factors. Soil monitoring for management impacts will be stratified by ELT and ELTP designation. The small scale classification, inventory, and mapping of ELT and ELTP units was used to refine regionalized LTA boundaries and descriptions at a higher scale in the National Hierarchical Framework of Ecological Units.

The ECS mapping and inventory data serve as baseline data and as a basic framework for a variety of management uses and proposed activities. Some specific examples include project area analysis to identify management options in a planning unit of several thousand acres. ECS mapping and ELTP and ELT descriptions are used to compare the present natural community to the potential community and the desired future condition. Existing and potential old-growth communities are stratified by ECS units to identify preferred options in the implementation of an old-growth strategy.

Contacts

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Case Study 2 in Integrated Resource Inventory: Inventory and Mapping of Freshwater Streams on the Chequamegon National Forest, Wisconsin — Integrated inventory for use in protection, restoration, and assessment of stream environments

Ecological Classification

The USDA Forest Service has recently adopted *A Hierarchical Framework of Aquatic Ecological Units in North America (Neartic Zone)* (Maxwell et al. 1995) to group environmental situations in a hierarchical fashion. Within this framework there is category named stream valley segments that is defined by a general set of attributes. Using this framework as a guide, the Chequamegon National Forest collected, over a four-year period, a suite of physical, chemical, and biological data through the range of environmental situations within the national forests of Wisconsin.

Description

Effective management of aquatic resources is premised on the notion of optimizing productivity within a particular environmental situation. This optimum or goal is frequently called a reference site. What is lacking in this process is a consistent and logical method of grouping these environmental situations into similar classes. We were able to classify the National Forest streams into 13 discrete valley segment types or classes by statistically analyzing data, such as bank full width, maximum water temperature, alkalinity, and fish and mussel distribution and abundance. With this information we subsequently typed and mapped all Forest streams as one of these 13 classes. We then stratified the stream network by class and sampled those valley segments that had not been sampled previously to verify the efficacy of the classification process. This new data set demonstrated that we had correctly typed and mapped the forest streams with 68 percent accuracy.

In the future, we will use this process to describe the range of variation within each stream type so we can apply established techniques, like the index of biotic integrity, to tailor actions by the Forest Service in a more appropriate and efficient manner. Moreover, we now have the ability to identify the abundance or scarcity of stream types that will enhance our efforts to select special management areas and to stratify monitoring efforts as described in the forest plan. Valley segment types will also be used to identify and prioritize stream segments for restoration or enhancement and as a basis for conducting threatened and endangered species surveys.

This effort will be expanded to determine the relationship of stream valley segments to the next higher (subwatershed) and lower (stream reach) tiers within the framework, so we can begin to understand the form and function of streams within the context of landscape ecology. Armed with such knowledge we should be able to provide some answers to the elusive issue of cumulative effects of forest management on stream environments.

Contact

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Case Study 3 in Integrated Resource Inventory: Establishing Wildlife Habitat Capability for Planning — Value in existing and potential natural vegetation

Ecological Classification

Ecological land types (ELT) and ecological land type phases (ELTP) developed for the Huron-Manistee National Forest, MI (Cleland et al. 1993) were evaluated for this study. Groups of ELTPs were chosen as a spatial and logistical compromise between ELTP's and ELTs. The statistical procedures used by Cleland et al. (1994) in development supported the contention that some ELTPs were similar and could be combined into groups without significantly compromising their usefulness.

Description: A case study was conducted to evaluate the effectiveness of using an ecological classification system to reduce sample variance in descriptions and predictions of wildlife habitat attributes. This would occur by supplementing inventories of information on existing vegetation (USFS vegetation information system maps) with information on potential site conditions as expressed by groups of USFS ecological land type phases. Existing vegetation conditions were classified according to the U.S. Forest Service's Corporate Database System. The system classified vegetation according to dominant commercial tree species, size, and stocking density. Permanent openings and wetlands were not differentiated. Overlays of the ELTP groups and the existing vegetation classification were used to further stratify the landscape, providing a time referenced template to guide habitat inventory. This template subsequently allowed inferences regarding successional trajectories, historical disturbance regimes, and the effects of management on understory species compositions.

Generally, vegetation attributes associated with the overstory (e.g., canopy cover, tree size, tree stocking) were sufficiently described using only the existing vegetation classification. However, precision was generally enhanced when using the ecosystem template for understory (e.g., shrub cover, shrub species composition) and ground level (e.g., herbaceous cover, downed woody debris) attributes. "Relative efficiency tests" measure the tradeoffs associated with increased costs because of more plots versus increased precision because of a better classification scheme. The results of these tests suggested that this is a cost effective approach for collecting understory and ground level information. Although trends from the relative efficiency tests supported the use of this approach, some tests suggested that microsite variation in physiography and soils further influences forest composition and understory recruitment. Also, the time since the last disturbance and the type of disturbance event have been demonstrated to have tremendous effects on understory and ground level vegetation. These inconsistencies relate to scale and should be addressed relative to the management or planning objectives.

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2.2 Desired Future Conditions

Ecological units are important in devising desired future conditions (DFCs) that can be attained and perpetuated. The varying responses of each ecological unit to an array of management activities means multiple outcomes are possible at any given site. Ecological unit descriptions are used to compare the present natural community to the potential community and the desired future condition. For example, at the end of a 50-year planning horizon, on the same site, a land manager has the option of establishing a 90-year-old longleaf pine forest with an open canopy, dense grass understory, and many snags; or, with a different management regime, a 40-year-old loblolly pine stand with a closed canopy, sparse understory and few snags. The choice made is the desired future condition. In the process of choosing, ecological classification provides information on site potential and response to management which allows each management scenario to be analyzed in terms of its economic efficiency, social and cultural acceptability, and ability to sustain healthy and productive ecosystems.

Ecological classifications evolved partially because of the recognition that several disciplines were collecting similar data for separate purposes such as rating productivity, identifying capability, susceptibility to various hazards, or suitability for specific activities such as road construction, log landings, cold water fisheries, farming, and range among others. Single resource inventories do provide high quality information and interpretations for a limited number of uses. The advantage of integrated ecological and resource inventories is that in the long run they reduce the overall data collection needs associated with multiple resource management, lend themselves easily to extrapolation of information from one unit to similar units, and they facilitate understanding of cause and effect relationships.

Suitability ratings combine information on potential productivity with information on the limitations imposed on management such as the cost of mitigation or decreases in productivity due to soil compaction, pollution, or erosion. Productivity, capability, and suitability ratings group areas that share a quality in common but which are not necessarily similar in other important ways. For example, two areas may be level and suitable for road building but have very different biological capabilities.

In local applications, ecological approaches to classification are desired to overcome limitations in the use of single purpose or limited purpose classifications or artificial rating systems. For example, vegetation based approaches do not give precise estimates of productivity and use constraints. They do not provide models of functional ecosystems necessary for understanding, describing, and predicting environmental effects such as the effect of acid rain impacts on long term site productivity and aquatic resources, etc. Soil and pure landtype or geomorphologic approaches are seldom informative enough to predict habitat and potential forage for range or wildlife management or to predict the presence of rare, threatened and endangered species. Monitoring of non-traditional uses of the forest such as the collection of medicinal herbs, may be helped if the ecological classification is used to establish correlative relations with species to be monitored.

Natural systems provide "reference conditions" which are used as a base of comparison with existing conditions to assess ecosystem health or with conditions predicted as a result of proposed management or natural events. The stability and integrity of ecological systems depend upon many intricate feedback mechanisms among life forms and the environment. Current ecosystem management applications are based on the assumption that the stability and functional integrity of an ecosystem is reflected in its composition and structure. Resilience is defined in light of natural change agents. Hence, ecological classification systems based on "natural conditions" are used to establish standards and criteria for measuring environmental quality and ecosystem integrity.

Ecological classification systems can be used to develop guidance on when management actions or land use allocations will irreversibly or irretrievably affect ecosystem potential. They can provide information useful in determining the costs and benefits associated with (1) managing within existing ecosystem capability, (2) enhancing natural capability through amendments, or (3) managing for species against the natural tendencies of the site. They also provide a yardstick for gauging the success of restoration activities.

Ecological unit inventories provide a framework for organizing, storing, and conveying information on various ecosystem parameters. Databases can be constructed from information associated with ecological types. Each type developed will have a unique list of attributes (e.g., spodic soil, marine deposits, white-cedar swamp), descriptive statistics (e.g., average annual precipitation, fire frequency, flood frequency, infiltration rate, etc.), interpretations (e.g., high erosion hazard, 45–55 site index, suitable for pond development, potential lynx habitat, etc.), and process models (e.g., succession, nutrient transformation pathways) associated with it. Inventoried ecological units provide information about the geographic location, distribution (percent of landscape), and spatial diversity of types within and among units. Ecological units may also be viewed as cartographic entities that can be linked to tabular data in a relational database.

The case studies in this section are drawn from different parts of the country. They provide examples of using ecological classification as a basis for predicting changes over time and predicting what conditions are prevalent where. *Case Study 4* uses empirical data to test FIBER 3.0, a growth and yield model specified and constructed using habitat types (ELTPs) in New England. *Case Study 5* describes studies to test the soil–landform–vegetation relations within landtypes and to verify productivity values associated with landtypes developed for the Interior Uplands in the southeastern United States.

Ecological classification and mapping can be combined with other information to set site specific or area specific standards and expectations. *Case Study 6* demonstrates adaptive management at the site level. Desired future conditions were modified on a specific land type to take advantage of natural ecosystem processes resulting in cost saving and greater environmental protection. *Case Study 7* presents the Boise Cascade Ecosystem Diversity Matrix which is used to establish regional baseline conditions and monitor change over time. *Case Study 8* discusses the use of reference sites to assess functional impairments in open water habitat in Lake Ontario.

Case Study 4 in Desired Future Conditions: Fiber 3.0: An Ecological Growth Model for Northeastern Forestry Types — A use of ecological type concepts in modeling

Ecological Classification

Habitat types (Leak 1982) in the northeastern US have been defined by landform, soils, and typical climax tree species following the multifactor approach of Hills (Hills and Pierpont 1960). The relationships between tree species and soil/landform conditions vary with climate and bedrock mineralogy and each habitat type exhibits a characteristic successional pattern, indicative of the tree species that will most likely regenerate and compete. Heavy cutting changes the successional stage, but not the characteristic successional sequence or climax forest type. Heavy disturbance, such as agricultural use and fire, may change the relationships of tree cover to soils and landform during the recovery period.

Description

FIBER 3.0 is a revision of FIBER (Solomon et al. 1986b), a stand projection growth model developed to simulate the growth and structural development of forest stands across New England. The acronym stands for "Forest Increment Based on an Ecological Rationale." Predictions such as those from the FIBER 3.0 model are critical in efforts to maintain diversity and habitat conditions. The internal structure of the most recent version was constructed using six habitat types (Leak 1982) which expands the applicability of the model and improves its reliability over a wide range of sites. The habitat types specified are: sugar maple-ash, beech-red maple, oak-white pine, hemlock-red spruce, spruce-fir, cedar-black spruce.

To test the ability of FIBER 3.0 to accurately follow changes in forest structure, species composition, and wildlife habitat, over 700 non-disturbed USFS Forest Inventory and Analysis plots (FIA) across the state of Maine were classified into one of the six habitat types and modeled for 30 years. Comparisons between the actual remeasured and predicted values were made in 1959, 1972, and 1982 show good correspondence, validating the underlying assumptions of the model and, hence, the interpretations associated with each of Leak's habitat types. The comparison of the predicted growth rates and successional changes in species composition are demonstrated in graphic and tabular form (Fig. 3) (Table 2).

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Case Study 5 in Desired Future Conditions: Terrestrial Classification and Inventory in the Highland Rim and Cumberland Plateau Physiographic Regions — Interpreting vegetation for management

Ecological Classification

The system described here (Smalley 1986) was adapted from the Land System Inventory of Wertz and Arnold (1975). The five levels of the system are equivalent to the lower five levels of the National Hierarchical Framework of Ecological Units (Avers et al. 1994). The system is applicable to the Highland Rim/Pennyroyal and Cumberland Plateau physiographic provinces encompassing 29 million acres in parts of Tennessee, Alabama, Georgia, Kentucky, and Virginia. The development of the system can best be described as a process of successive stratification of the landscape based on the interactions and controlling influences of environmental factors — physiography, climate, geology, topography, and soils. Because the current species composition and structure of Rim and Plateau forests is more a function of repeated disturbances than an indi-

Table 2. Changes in species percentages of total stand basal area for spruce fir habitat type on USFS inventory and analysis plots in Maine using actual and FIBER 3.0 predicted values.

	Year	Species														
		bf	rs	bs	ws	he	ce	wp	sm	rm	yb	pb	be	wa	as	total
Actual	1959	25.1	25.7	0.4	3.4	0.6	11.0	1.3	2.6	9.1	5.6	3.9	3.0	1.1	3.4	100.0
Predicted	1969	28.0	25.6	1.4	3.6	0.8	8.1	1.2	3.1	8.1	4.9	3.5	2.5	1.4	4.0	100.0
Actual	1971	30.9	28.3	0.4	4.0	0.6	8.3	1.2	2.4	7.6	3.7	3.5	1.7	1.1	3.4	100.0
Actual	1982	29.8	28.7	0.4	4.4	0.6	7.2	1.5	2.4	8.4	3.4	3.9	1.4	0.7	4.2	100.0
Predicted	1984	31.8	26.2	2.5	4.0	1.0	6.0	1.1	3.4	7.3	4.0	2.7	1.7	1.8	3.3	100.0
Predicted	2004	35.2	27.7	3.4	4.2	0.9	4.8	0.9	3.2	6.3	3.3	2.2	1.1	1.7	2.6	100.0

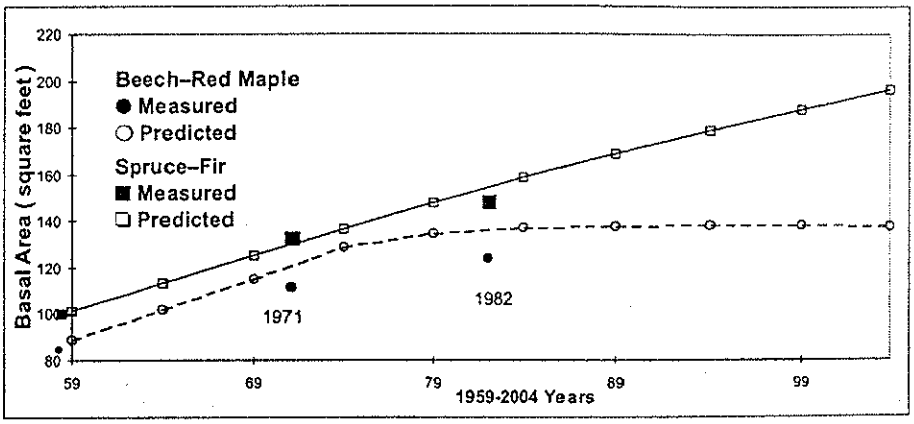

Fig. 3. Comparison of actual and FIBER 3.0 predicted average basal areas on USFS Inventory and Analysis plots in Maine for 2 different forest habitat types.

cation of succession and site potential, vegetation was relegated to a minor role in the development of the land classification system.

The most detailed level (landtype) is mapped at a scale of 1:24,000; individual units may vary from 5 to 100 plus acres depending on topography. To date (Sept. 1996) about 150,000 acres of State Forest and Wildlife management Areas (Smalley et al. 1996) and 300,000 acres of forest industry lands have been mapped at the landtype level. Average cost is about $0.25 per acre. The mapping process (mylar sheets over 1:24,000 quadrangle maps) has reinforced Rowe's maxim "...that every part of the terrain has to be confronted; there is no avoiding those in-between and oddball units..." Thus, as the survey progressed, landtype descriptions were refined and new landtypes identified and described. The system has been extended to the Upper Coastal Plain of west Tennessee and the southern Allegheny Plateau in mid- and northern Kentucky. After the map units are entered in a GIS, the next step in developing management plans will be to merge the landtypes with existing plant community information.

Description

Recent efforts have been directed toward testing the soil–vegetation–landform relationships of the landtypes. An intensive study of the soils and vegetation on three major landtypes on the Mid-Plateau near Crossville, TN revealed that landtypes significantly affected magnitudes of temporal and spatial soil variability (Hammer et al. 1987). The morphological features of soils, when precisely described and interpreted with respect to landtypes, are indicators of patterns of movement and relative amounts of available soil moisture and can be a valuable aid in predicting potential forest site productivity. The land classification system for the Mid-Plateau groups forest soils into landform units having relatively homogeneous chemical and physical properties.

Plant community–landform relationships have been studied on the 26,000 acre Prentice Cooper State

Forest and Wildlife Management Area on the south end of Walden Ridge (Mid-Plateau) west of Chattanooga, TN (Arnold et al. 1996) Although the techniques used did not permit the development of predictive models, relatively discreet plant communities were found to occur on four major landtypes. Apparently, the land classification system for the Mid-Plateau divides the landscape into logical, ecologically distinct units.

Wheat and Dimmick (1987) studied plant community–landform relations on two Western Highland Rim sites. Three ridge landtypes supported similar communities; distinct communities were found on north slopes with limestone chert, south slopes with limestone chert, and in stream bottoms having good drainage.

Clatterbuck (1996) attempted to classify the vegetation on the 19,901-acre Cheatham Wildlife Management Area as a basis for multiple resource planning, including wildlife habitat management. The land classification system for the Western Rim provided a useful initial stratification of the landscape for plant community analysis. However, to gain a better understanding of the diverse upland deciduous forest, it was necessary to further aggregate and segregate the vegetation and landform variables. Probably, the lack of a strong relationship between plant communities and landforms was due to past disturbances by fire and timber harvesting for charcoal production.

Contact

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Case Study 6 in Desired Future Conditions: Classification, Inventory and Monitoring of Desired Future Conditions on Range Land in the Ashley National Forest, Utah — Managers use units in adaptive management

Ecological Classification

In the 1970s a Land Systems Inventory was developed on the Ashley National Forest. Elements of this approach are discussed by Godfrey and Cleaves (1991) and Godfrey (1977). The terminology and scale are now consistent with the National Hierarchy of Ecological Units (Avers et al. 1994). Landtype associations (LTAs) included information on geology, geomorphology and geomorphic processes that were useful in this application. Landtypes, smaller units, provided more detail on other features such as slope, soils, and vegetation.

Description

Components of an ecological approach to management might include the following: classification, inventory, capabilities of land units, values of land units, a published decision stating desired condition and actions to achieve desired condition. Monitoring is included to see if these actions were taken, to see if the desired condition was achieved by those actions, and to see if the desired condition and associated actions are appropriate over time.

Ashley National Forest managers in the 1960s decided that some canyon bottoms should be managed to include graminoid–forb communities with high values for livestock forage and watershed protection. This decision was based upon the dominant traditional use of that portion of the Forest. This same desired condition was specified in the Forest Plan adopted in 1986. Though there was no ecological classification, canyon bottom lands with obviously deeper soils than adjacent slopes were identified because the potential production was higher and these areas were also suitable for cattle grazing.

Later, two landtype phases were identified for these canyon bottoms through systematic land classification and inventory One phase occurs as fans at the base of drainages formed from the sediment washed from steep, erosive side slopes of an adjacent landtype. Another landtype phase is on the wider, flat bottoms where alluvial (water laid) deposition parallels the drainages. Both landtype phases were plowed and seeded in the early 1960s. By the 1990s the seeding on the fans had been 70–90% covered with eroded sediment and the seeded species were replaced by native species well adapted to disturbance including Salina wild rye. On the bottom land type, seeded species persisted as dominants or at least as understory dominants with sagebrush and rubber rabbit brush.

In the 1960s when the seeding was planned and completed, the Ashley National Forest had no information on the rate of sediment deposition on the fans. By the 1990's classification and inventory was available, and monitoring studies documented the contrasting status of the seeding on the two landtype phases. As a result the desired future condition was changed on the fan landtype. Instead of seeding the fans, it was decided that the presence of Salina Wild rye which was naturally abundant there, should be the basic desired condition for watershed and ungulate forage. The change was based on inherent features of the land and economic values. Livestock grazing would likely have been considered the primary factor of vegetation change if comparative information on geomorphic processes and associated plant succession among identified landtypes had not become available. While grazing had *some* influence, this was extremely minor compared to geomorphic processes.

To provide for future decisions, monitoring efforts must remain active. Additional observations and studies indicate a need for greater refinement of the classification and inventory of this canyon bottom landtype. In addition, new values have emerged. Analysis based on a landscape approach in the 1990's validates the value of these bottoms for ungulate forage with adjacent side slopes providing cover for wildlife. Elk, which were absent or rare in the 1960s, have become relatively abundant.

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Case Study 7 in Desired Future Conditions: Boise Cascade Ecosystem Diversity Matrix — Establish regional baseline conditions and monitor change over time

Ecological Classification

The strategy demonstrated in this application requires the use of a land classification system that identifies inherent variability in the physical environment and then influences the plant and animal associations for any given site. Either ecological land types or habitat types (Daubenmire 1968) may be used as long as the units of land are described in a hierarchical fashion with each succeeding level becoming more homogeneous to satisfy the need for increasing specificity. This example uses habitat types nested within the Southern Batholith of Idaho (Haufler et al. 1996). Boise Cascade is using the Section, and in some areas, groups of Subsections from ECOMAP (Avers et al. 1994) to bound the development and application of individual matrices.

Description

The ecosystem diversity matrix (Fig. 4) classifies landscapes based on existing vegetation structure (the y-axis), potential vegetation structure (the x-axis), relative moisture and elevation gradients (generally, dry, low elevation to more mesic, high elevation as one proceeds from left to right on the x-axis), and primary historical disturbance regime (note the two successional trajectories depending on disturbance history). Existing vegetation conditions are described in sufficient detail to allow differentiation of biological communities at a scale compatible with land planning objectives (e.g., a forest stand as delineated by homogenous overstory vegetation).

Ecosystem management means blending an understanding of natural disturbance regimes with appropriate management tools to provide for both biodiversity and resource use. Historical ranges of variability provide essential information for understanding natural disturbance regimes and for evaluating the status and health of existing stands of vegetation (with this understanding being a guide rather than a goal for desired future conditions). Information on historic range of variability can be used to help identify successional stages that were in significant abundance or areas that typically supported substantial acreages of old growth. One way of describing a desired future condition for ecosystem diversity is to assign an areal percentage to each type/growth stage combination in the matrix. The matrix forces planners to recognize the dynamic processes at work in the landscape, and to incorporate a temporal component into the planning process. Another use of the matrix may be to track acres meeting certain compositional and structural requirements within each unit (i.e., condition).

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Case Study 8 in Desired Future Conditions: Assessing Open Water Habitat Conditions in Lake Ontario —Using reference sites to assess functional impairments

Ecological Classification

The Aquatic Habitat Classification System (AHCS) was developed to supplement the Cowardin et al. (1970) approach to classification (Busch and Sly 1992). The AHCS provides information on ecological processes that help us assess the functions performed by habitat units in support of fish or wildlife in the Lake Ontario Basin. Here we discuss the open water and near-shore subsystems (Fig. 5). The near shore subsystem reaches to the 25 m contour as (1) that is the maximum depth to which wave activity exerts its influence (Sly 1991) and (2) thermocline development in Lake Ontario is restricted to the top 25 m (Sly 1991).

Description

Functional impairments reflected in biological, chemical, or physical stresses were evaluated for 88

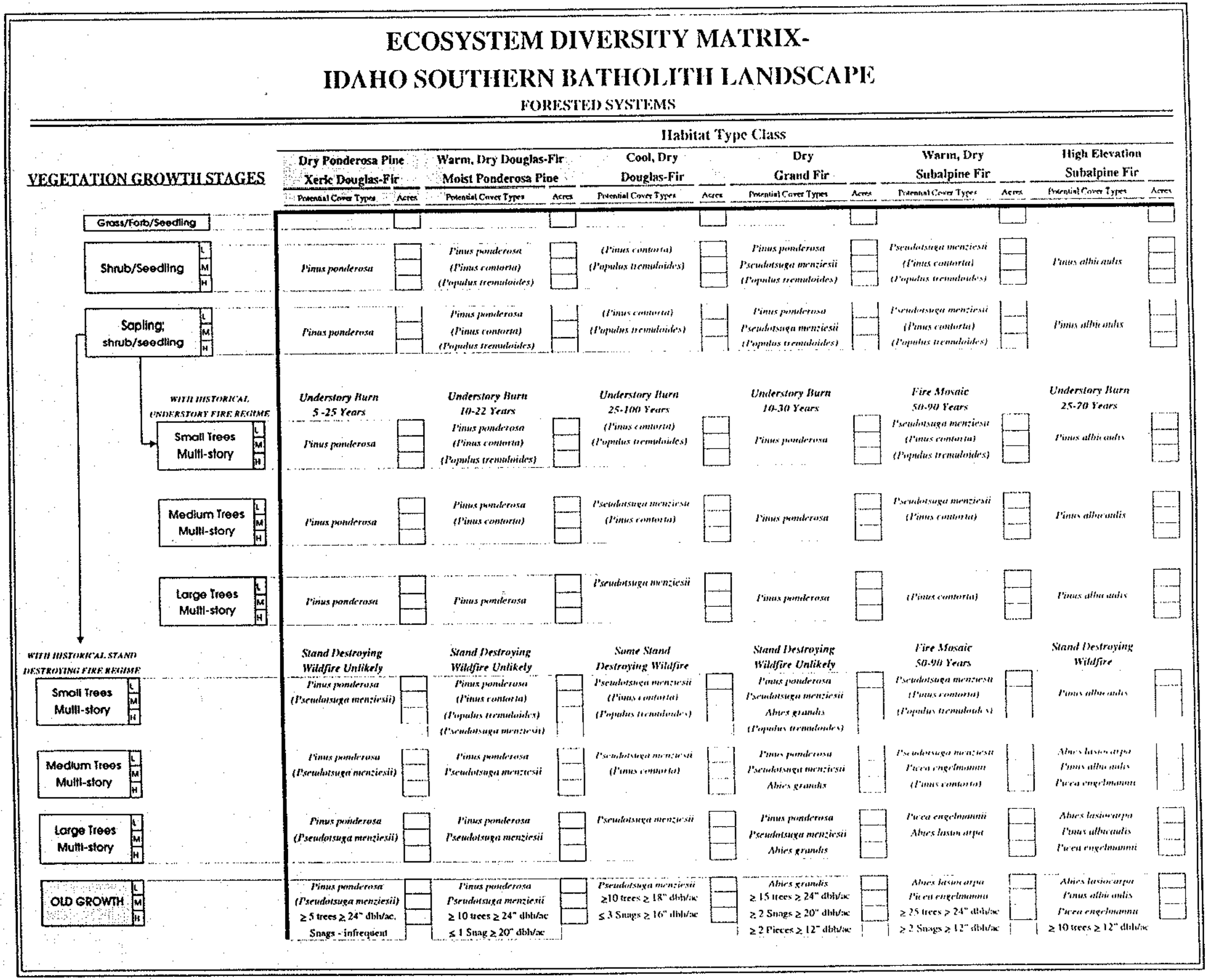

Fig. 4. Ecosystem Diversity Matrix for the Idaho Southern Batholith (Haufler, et al. 1996).

System	Sub-system	Division	Sub-division	Class 1
Lake	Open water	Circulator basin		
			Open Water	Water column
			Major embayment	Substrate
			Relict trench	Plant material
			Sub-basin < 25 meters	Water quality
			Sub-basin > 25 meters	
	Near shore	Shoreline		
			Shoreline for 100 m & littoral zone < 3 m	
			Wetlands	
			Tributary and embayments	
			Special features	

Fig. 5. Simplified diagram of Aquatic Habitat Classification System (AHC).

habitat categories (Class level — Sly and Busch 1992). Stress factors were developed from literature sources and from consultations with natural resource managers (Busch et al. 1993). The criteria for rating each type of stress were (1) the severity of the ecological impact, defined as a significant change or shift in the efficiency or direction of the energy flow between trophic levels, and (2) the expected permanence of the stress defined by time (week, season, year, decades, or permanent). The Lake Ontario habitat information inventory available from Busch et al. (1993) provided the information base and a list of functionally distinct habitat units.

After a specific habitat unit was delineated, the degree of impairment for each category (physical, chemical, biological) was determined using the Delphi technique (Zuboy 1981; Crance 1987). An effort was made to separate the natural from the anthropogenic restrictions. The functional concerns were addressed by comparing impacted areas to reference sites within the basin that have maintained their structure and are able to support ecosystem functions needed for a healthy state (Martin 1994).

The habitats making up the Lake Ontario ecosystem between roughly 1960–1990 (focus 1970–90), were impaired, functioning at 50% of the level of unimpaired habitats (Busch and Lake 1996). The impairments were caused almost equally by biological, chemical and physical stressors. Biological stresses were most severe in the "open water" habitats which comprised 67% of the basin's surface. The cause was a dramatic increase in distribution and abundance of exotic species, most notably the sea lamprey and zebra mussel. (Environment Canada and USEPS 1995). Other contributing factors included artificial changes in primary production and instability within the native fish community caused by loss of native species such as lake trout, Atlantic salmon, blue pike (*Stizostedion vitreum glaucum*), and deepwater sculpin.

Chemical stresses were highest in the "tributary and embayments" habitat category. The impacts include fish tumors, wildlife deformities, and degradation of aquatic biota caused by chemical accumulation from the sediments or watershed (Hartig and Law 1994, Koonce et al.). Physical stresses were primarily from physical and water-flow changes caused by hydropower development, construction of harbor facilities, and maintenance dredging for harbors in the tributaries (Smith 1995). Remaining shoreline littoral and wetland habitats were not identified as being heavily stressed.

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3 LANDSCAPE, WATERSHED, AND REGIONAL PLANNING

Ecological units are used to characterize landscapes, watersheds, and regions for planning and to provide a context for their analysis. Ecological units at each scale, internalize vertical and horizontal structure and the functional relationships among ecosystem components over time. Thus, they provide a basis for predicting the response of the ecosystem to various natural events and management over time. Hierarchical frameworks of ecological units integrate units of multiple scales by nesting small units within larger ones. The various patterns recognized in the composition, distribution, and successive arrangement of small units are used in ecosystem management applications to characterize the structure of the larger system they nest within (O'Neil et al. 1986). The theories of landscape ecology are used to interpret the natural variability displayed by this hierarchical ecosystem organization. Ecoregions, landscapes, and watersheds provide a context for understanding dynamic ecological processes such as disturbance regimes and nutrient cycling that the aggregation of smaller units into larger ones by ownership or political boundaries cannot provide.

3.1 Ecosystem-Based Planning and Assessment

Although ecological units cannot provide all the information needed for planning and decision-making, they provide a logical basis for examining the complexity, interdependencies, and interactions among societal needs, myriad ecological processes, existing conditions, and the range of possibilities given ecological potentials. Often the stakeholders of public land do not agree on the management objectives of a project or even fully understand the benefit of or "need" for management. Ecological classification, mapping, and integrated inventories provide baselines to model the potential effects of multiple management scenarios at local, landscape, and regional scales. They also provide the spatial and temporal contexts within which "ecologically informed" decisions can be made. Figure 6 identifies ecological units as the basic template for integrating information in ecosystem-based planning.

Both spatial and temporal sources of variability are important when evaluating the environmental effects of various management alternatives; therefore, planning and assessment activities generally require consideration of several scales simultaneously. For example, to discern the cumulative effects of timber harvest over

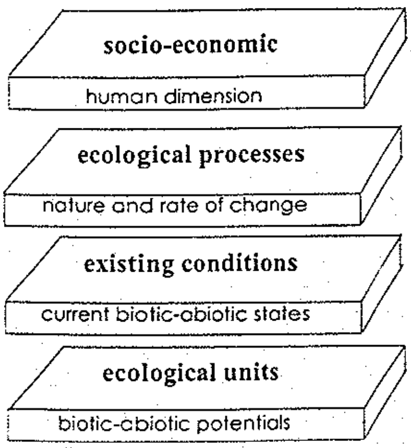

Fig. 6. Ecological units developed at appropriate scales provide an ecological context for examining the complexity, interdependencies, and interactions among societal needs, myriad ecological processes, existing conditions, and the range of possibilities given ecological potentials (Cleland et al. 1995).

time, we need to examine conditions and processes occurring above and below the level where activity is being considered. Changes in plant community composition and age-class structure are immediately evident within the harvested area. Changes in vernal pool habitat can be detected at micro-sites, the fragmentation of breeding bird habitat would be noticeable at landscape or regional scales, and changes in runoff would be detected within a watershed context.

Ecological units provide a basis for establishing and testing assumptions related to ecosystem form and function. Ecosystem conditions and thresholds to change defined in this process are used to model and predict natural responses. Then, managers can identify and evaluate cumulative effects related to the timing and distribution of management activities. The accuracy of this effects analysis will depend upon the degree to which (1) the dynamic and functional relationships among biotic and abiotic ecosystem components have been established and (2) they are conveyed through mapping and interpretation of the units. The amount of information conveyed by any map relates to both the level of detail incorporated in the classification and the level of resolution possible at a given mapping scale. As the scale of mapping increases, the amount of variability contained within each unit increases and details are generalized. The ecological unit map compilation scale and the natural scale of the phenomenon to be analyzed should be similar.

A recurring task in implementing ecosystem management is determining the scope and intensity of planning and analysis activities. The areas of analysis must be bounded geographically in order to identify the amount of information and resources necessary for conducting tasks. Commonly this involves considerations of land ownership, legislative or administrative policy, public issues and concerns, and ecological processes or need. Ecological units can be used to determine the geographic extent of planning and analysis activities by linking public issues, management questions, and environmental needs to appropriate units at appropriate scales. Ecological units can be aggregated hierarchically as classified or non-hierarchically according to the characteristics and features significant to resolve an issue.

Comprehensive, intensive ground surveys of environmental conditions and ecosystem potential are not currently available across all ownerships for broad scale, strategic planning. Frankly, support for such an approach is limited due to a number of concerns. One is that important decisions cannot or should not be postponed until comprehensive surveys are completed. There is concern over the high up-front costs of ground survey, worries about waste due to the collection of unnecessary information or information with limited analytical value, and fear of government intrusion.

Probst and Thompson (1996) recommend the use of top-down, holistic, iterative approaches that use concepts developed from detailed studies and analyses as a more economical, pragmatic means to meet the need for information for policy-making and strategic planning. A multi-scaled, spatial framework that establishes an ecological context for data synthesis and analysis is a critical component of this approach. Multi-scaled, because comprehensive assessments of economic, social, and environmental conditions are achieved through a process of successive approximations. Ultimately the underlying assumptions are tested through monitoring and evaluation, including field sampling. The virtue of this approach is that assumptions and data collection needs are clearly stated. Hierarchical frameworks of ecological units provide a vehicle for integrating information spatially and across multiple scales.

Beyond site level planning, in landscape and regional planning, the use of ecological units multiplies. Ecological classification contributes to multiscale and multidisciplinary planning and assessment activities. Time and cost efficiencies are realized and coordination is improved due to common terminology and maps. *Case Study 9* presents an approach to multiscale planning on the Ottawa National Forest, MI. *Case Study 10* from the Lowman Ranger District, ID, demonstrates the use of terrestrial and aquatic classification in watershed analysis. *Case Study 11* provides an example of a multi-scale assessment of neotropical migratory birds distribution using the concept of successive top-down approximation.

Case Study 9 in Ecosystem Based Planning and Assessment: Ottawa National Forest Planning — An approach to multiscale planning

Ecological Classification

Work on the Ottawa National Forest Ecological Classification and Inventory began in the early 1970s. Initial development followed a multifactor site classification approach. The Eastern Region then adopted the nested hierarchical concept of Wertz and Arnold (1975) which has now evolved to the National Hierarchical Framework (Avers et al. 1994). The principle of simultaneously integrating multiple factors rather than using predetermined classifications (e.g., soil) followed and is continuing. Nearly 1.5 million acres of public and private lands within the forest have been classified and mapped to date.

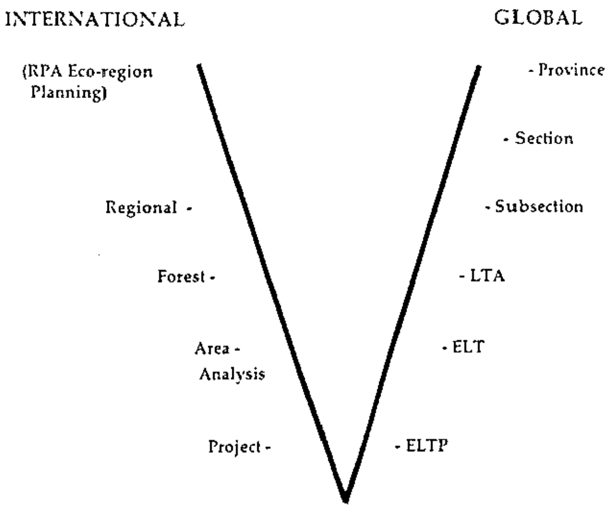

Fig. 7. Decision levels and associated ecological information levels used in the Ottawa National Forest Plan.

Description

Forest Level Planning resulted in the long-term allocation of future forest conditions to large units of land with activities and outputs scheduled by decades. The forest planning model (Fig. 7) was developed to aid forest level, management area, and project level analysis and decision-making (Jordan et al. 1984). The model incorporated the use of ecological units at three scales: the landtype association (LTA), landtype (ELT), and landtype phase (ELTP). The data, maps and interpretations associated with each unit enhanced the ability of the planning team to model existing and potential resource conditions, management practices, management standards, costs, resource yields and environmental effects at multiple scales. The use of a nested geographic system assured that decision choices made at each level were guided by a common set of assumptions and relationships.

Management Areas (MAs) are areas dedicated to a specific set of land uses compatible with a long-term desired future condition (DFC) described in terms of vegetative type composition objectives, planned recreation opportunity spectrum class, desired road density, commodity production and wildlife emphases among others. Prescriptions developed for each area identify the standards, guidelines, and activities to be carried out toward this condition. LTAs were used to identify areas suitable for desired uses and capable of meeting desired future conditions in the manner prescribed. The criteria used in this analysis included: existing vegetative composition, tree species potential, potential productivity, percentage composition by site unit (ELTs), existing recreation opportunity class, existing road density, unique wildlife habitat potential, land ownership pattern, road construction cost, exist-

Table 3. Examples of management area prescriptions and associated LTAs.

LTA	Acres	Management Prescription					
		1.1	2.1	3.1	3.2	4.1	6.1
1	28,788	X		X	X	X	
2	178,478	X	X	X	X	X	X
3,4,7	134,910		X	X	X	X	X
5	50,691		X				X
6	56,705	X	X	X			X
9,10	79.420		X	X	X		X
11	47,016		X	X	X		X
12,13	66,012	X	X	X	X		X
14,17	92,243	X		X		X	
14A	11,100					X	X
16,19	70,567	X		X			X
18	12,156	X		X		X	X

ing and potential wildlife habitat, specific public issues, existing sensitivity levels, and existing visual quality objectives.

The Ottawa National Forest made a decision to coincide LTA and management area boundaries for analysis and land allocation purposes. The results of the suitability analysis displayed in *Table* 3 illustrates how this worked. Production of high quality hardwoods was a part of the prescription 2.1 and the table illustrated that this objective could be achieved on any of eleven LTAs. High quality saw timber is not likely to occur in LTA 1 where the soils are dry and sandy nor on the rest of the LTAs excluded from Rx 2.1 for a variety of environmental reasons.

From another viewpoint, we know LTA 2 could produce high-quality hardwoods as specified in management prescription 2.1, but it can also meet the conditions specified in any of the other prescriptions. This type of analysis allowed for flexibility in developing alternatives to meet a range of societal and economic needs while eliminating from consideration those areas without a natural capacity to meet a certain need. Another benefit of bounding management areas by LTA is that the standards and guidelines governing management activities could be tailored for a good fit. Key variations within and among management area prescriptions and LTAs were represented in FORPLAN, the optimization model most commonly used during the first round of forest planning. Forest plan analysis was conducted at the LTA scale. Data about resource limits, management costs and product yields were drawn from site, compartment, land type, and land type phase data and aggregated to the LTA scale.

Implementation of the forest plan required additional analysis at the opportunity area level and at the project level. The land types provided capability information at the opportunity area, which helped determine the location of long-term local road corridors, identify operating periods and appropriate road standards, locate areas suited for hardwood saw timber, softwood saw timber, aspen, softwood pulpwood, hardwood pulpwood, and hemlock based on ecological potential; determine areas of even-aged and uneven aged management of northern hardwoods relative to vegetation management objectives for the opportunity area; compare possible wildlife habitat component opportunities and their spatial arrangement.

The land type phase provided detailed information for project layout and design and was used in conjunction with information on existing conditions. It aided in choosing site specific practices, species regeneration options and methods, harvest layout and methods, local road standards, potential productivity by tree species, to identify opportunities for wildlife habitat improvement, etc.

Ecological classification has provided a valuable framework for integrating information and evaluating management alternatives at forest wide, area wide, and project levels on the Ottawa National Forest. Lack of surveys in some areas and database limitations constrained the use of ecological units during the first round of forest planning. The Ottawa NF has continued field survey activities at the land type level in the intervening years. The expanded information and computer databases with enable more integration in the upcoming forest plan revision process.

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Case Study 10 in Ecosystem Based Planning and Assessment: Deadwood Landscape Approach with the National Hierarchical Framework — A ground-up analysis of structure, composition, and function

Ecological Classification

Ecological units provide critical information to maintain ecosystems within limits compatible with both present human needs and the capacity of the ecosystem to provide these and future needs. Ecological units representing all scales of the USFS terrestrial hierarchy (Avers et al. 1994) and the riverine portion of the aquatic hierarchy (Maxwell et al. 1995) were used to frame this analysis. The Deadwood Landscape is located within Section M332A - the Idaho Batholith (Bailey 1994). Habitat type classes (Teck and Steele 1995), landtype phases, and channel reach types were nested within larger terrestrial and aquatic units during characterization and analysis.

Description: Analyses are seldom carried out at only one scale because one size does not fit all needs. The Deadwood Assessment can be classified as a mid-scale, landscape or watershed assessment that draws upon information at multiple levels of both the terrestrial and aquatic hierarchies for information and context. This analysis complies with NFMA requirements and determines opportunities to be carried into the NEPA process. The analysis process itself combines recommendations from the Federal Guide for Watershed Analysis (USFS 1995) and Forest Landscape Analysis and Design (USFS 1992).

Aquatic and terrestrial ecological units were important in characterizing the watershed and identifying reference conditions to be used in the synthesis and interpretation phase of the project. During synthesis and interpretation, desired future conditions, resource capabilities, sensitive species, sensitive areas, and local constraints and concerns are weighed and balanced against each other. Ecological units will also be critical as the project moves into the design phase and the determination of site specific and cumulative effects.

An experimental approach was developed to link aquatic and terrestrial ecosystem components, from the ground up, into correlated mapping units to be consistently described, mapped, and extrapolated across the 153,000 acre Deadwood Watershed. The various aspects of this analysis are described below.

- Ten habitat types provided the framework to organize vegetation attributes available from timber stand examination and a "Most-Similar-Neighbor" sample inference procedure (Moeur et al. 1995). Twenty-six vegetation growth stages (RMSTAND) were defined using DBH (diameter at breast height), size class, canopy closure class, and vertical structure. Seral stages identified were sorted into early seral, mid-seral, late seral, and climax classes for trees and understory.
- Fire history and fire scar analysis demonstrated the role of fire with a diversity of seral stages. This information, along with knowledge of seral stage by habitat type, was applied to classify areas by historic fire regime. Insect and disease hazard rates were determined. Cumulative effects were calculated using the Prognosis model (FVS) and GIS (Teck and Steele 1995). The GIS query results were incorporated in the Ecosystem Diversity Matrix of the Idaho Southern Batholith Section (See Case Study 6). A diversity matrix is under development for riparian ecosystems.
- Analysis of fishery potential involved a comparison of streams in natural conditions (Overton et al. 1995) to streams with similar geology, landtypes, and channel reach types found in the Deadwood watershed. A hierarchical approach was used to evaluate information by watershed, subwatershed, and channel reach type and by fish habitat attributes.
- Landtypes provided the silviculturist and other resource specialists information on soils, vegetation, hydrology and management qualities such as roads, wood, water, forage, recreation. This provided the silviculturist, hydrologist, and fisheries biologist with a common ecological language.
- Land type associations, nested within the watershed, were attributed with stream and existing vegetation coverages in addition to the performance characteristics identified and associated through the land systems inventory and the channel reach typing. Performance characteristics are measurable attributes such as soil productivity, in stream fine sediment, hill slope erosion, stream width-depth ratios, in stream large woody debris, and structure, composition, and function of terrestrial and riparian vegetative habitat type classes. Dominant habitat types were identified for each of twelve landtype associations. This attribution related vegetation characteristics to the landtype and also soil erosion hazards.
- Four subsections in the Deadwood landscape were evaluated for potential vegetation in a terrain model used in the Columbia River Basin Assessment (1994). This provided a means to evaluate site potential at a larger geoclimatic setting than the LTA scale.
- The Deadwood landscape analysis used GIS to link models and evaluate various geographical orientations and functions of terrestrial components. Through analysis the forest was able to identify reference ranges of variability (RRV) for selected ecological units based on the inherent land capability. These are also useful for mapping ecological units according to the National Hierarchy (Avers et al. 1994).

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Case Study 11 in Ecosystem based planning and assessment: Assessment of the Ecological Distribution of Midwestern Neotropical Migratory Birds (NTMB) — A multiscale assessment using a top-down successive approximation approach

Ecological Classification

Ecological provinces defined as part of the National Hierarchical Framework of Ecological Units adopted by the USDA Forest Service (Bailey et al. 1994, McNab and Avers 1994) were used in this example.

Description: Conservation of neotropical migratory birds (NTMBs) is a concern throughout North America. In midwestern North America (defined as 16 states and three Canadian provinces), biologists and conservationists recognize that species viability cannot be insured by evaluating and improving local habitats if conditions and influences outside the region do not support critical life functions. Thus local efforts should fall within a general conservation plan that is applicable throughout much or all of a species range (Thomas et al 1990, Probst and Wienrich 1993). A multi-scale assessment of the geographic and ecological distribution of midwestern NTMBs was conducted to elucidate the relationships among local, regional, and continental conditions and populations at those corresponding scales.

The U.S. Fish and Wildlife Partners in Flight (PIF) database (1980) was modified to identify 187 NTMBs that breed in the Midwest and 47 regional high-priority species for assessment. These priority species represent diverse taxonomic groups using a wide range of habitats. The Breeding Bird Survey (BBS) identified 57 Midwestern species that are declining nationally; trends in the midwest may be important to 47 of these. Ecological provinces provided a meaningful context for aggregating and summarizing data from the PIF physiographic database and provide a basis for relating that to the area and distribution of ecosystems and the trends in vegetation, succession, land use, and landscape structure.

Table 4 summarizes the NTMB numbers by habitat within each province. Eleven habitat classes were developed by pooling vegetation classes from 1-km resolution AVHRR imagery for analysis and these were collapsed into six for this table. The habitat map is a general survey suited only for assessing large-scale patterns as the habitat types contained mixed vegetation types.

Within a regional context cover types, forest types, and their area and distribution are important determinants of animal distributions and populations. At subregional and human landscape scales, major considerations include the distribution of forest types, forest age classes, and non-forest habitats within the context of ecosystem capabilities, disturbance frequency and pattern, and successional pathways (Thompson et al. 1993).

In addition, habitat age and age-distribution are critical determinants to avian habitat associations. Midwestern NTMB showed patterns among upland (dry) versus lowland (wet) ecosystems, conifer versus deciduous forests, and shrub/sapling versus mature forests. Analysis along single and multiple gradients can help explain species distribution and abundance at scales from continental to local if the range of sample variability is reduced by framing the analyses within

Table 4. Number of midwestern neotropical migratory birds and priority species (in parentheses) that breed in land covers and ecological provinces. Species can be associated with more than one land cover class, so rows and columns do not sum to species totals. (From Probst and Thompson, 1996).

Habitat	Province*							
	212	222	251	331	332	M222	M334	NTMB
Shrub/sapling	65(14)	54(16)	54(11)	51(8)	48(8)	35(8)	29(3)	95(22)
Forest	71(19)	34(10)	35(6)	31(3)	27(4)	20(5)	20(2)	94(24)
Agri./Dev.	38(5)	38(5)	40(6)	39(6)	39(6)	31(4)	29(4)	47(6)
Grassland	26(6)	25(6)	39(15)	35(9)	33(8)	20(5)	21(4)	45(16)
Savannah	27(6)	30(6)	33(6)	31(3)	34(5)	27(5)	20(2)	39(7)
Aquatic	8(1)	6(1)	6(1)	6(1)	6(1)	4(1)	0(0)	8(1)
Totals	129 (30)	124 (30)	136 (33)	126 (23)	125 (27)	93 (21)	81 (10)	187(47)

*Based on Bailey et al. (1994) and McNab and Avers (1994): 212 = Laurentian Mixed Forest Province; 222 = Eastern Broadleaf Forest (continental); 251 = Prairie (Temperate); 331 = Great Plains — Palouse Dry Steppe; 332 = Great Plains Steppe; M222 = Ozark Broadleaf Forest — Meadow; M334 = Black Hills Coniferous Forest.

ecological units or broad vegetation zones. For example, prairie-wetland complexes contain extreme moisture gradients over relatively short distances; bird species' distributions which overlap each other along this gradient may be more effectively assessed within this general context.

Geographical and ecological distribution information derived from multi-scaled assessment are the types of information needed in continental conservation efforts.

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3.2 Monitoring and Evaluation

Monitoring information is compared with baseline information on the condition, distribution, capability and potential productivity of ecosystems which ecological classification and mapping can help provide. Monitoring is conducted on National Forests to ensure that activities planned are being implemented and to ensure that management is conducted according to the standards and guidelines prescribed. Monitoring is also conducted to determine if the overall plan had the intended results, and to understand and analyze changes in resource conditions and availability over time.

Hierarchical frameworks of ecological units provide information about the geographic patterns in ecosystems. These patterns can be used to identify representative ecological units for sampling. Knowledge gained from such monitoring can then be extended to analogous unsampled ecological units. (Avers et. al. 1994). The stratification provided by a nested geographic system accommodates extensive monitoring needed to track the status of populations and to understand the forces effecting change, as well as, intensive monitoring which is often used to test hypotheses and fine tune measurement techniques.

Ecological classification aids in the interpretation of inventory and monitoring data in a number of ways. Reference conditions, represented by ecological units, are used to add value to conditions and trends. Ecological units internalize vertical structural and functional relationships which reflect the influence of various ecological processes over time and space (Rowe and Sheard 1981). Probabilities associated with various natural disturbances can contribute to risk assessment. Understanding ecosystem functions can assist in interpreting the non-monetary costs so difficult to account for in cost-benefit analyses. Effective inventory and monitoring must focus on critical diagnostic attributes that are comparable over time and space. Stratified sampling schemes test the hypothesis that units with similar attributes behave similarly (Maxwell et al. 1995).

Case studies in this section demonstrate the use of ecological classification as a tool for monitoring and evaluation of environmental conditions and trends. *Case Study 12* describes the value of ecoregionalization for water quality monitoring. In *Case Study 13* bioregions are developed to provide an ecological context for interpreting wildlife habitat data. *Case Study 14* discusses the reporting of the Canadian National Forest Inventory data by Ecozone.

Case Study 12 in Monitoring and Evaluation: A Protocol to Identify Stream Reference Sites — Using EPA ecoregions in water quality monitoring

Ecological Classification

Environmental Protection Agency Ecoregions of the Conterminous United States (Omernik 1986, 1987).

Description

The need for an ecoregional/reference site framework to facilitate the development of biological criteria was recognized in the late 1970s. This need was part of a larger concern for a framework to structure the management of aquatic resources in general and increasing awareness that there was more to water quality than addressing water chemistry, which had been the primary focus. Biota must be considered as must physical habitat and toxicity.

Reference sites are selected for each region and subregion to get a sense of the regionally attainable conditions regarding aquatic ecosystems. Attainable quality refers to those conditions that are realistic, rather than "pristine." Therefore candidate streams must be "relatively undisturbed" yet representative of the ecological region they occupy. An initial selection of reference sites is usually accomplished by interpreting 1:1,000,000 and 1:250,000 scale maps with guidance from state resource managers as to minimum stream and watershed sizes for each region or subregion and locations of known problem areas and point sources to avoid. The minimum number of sites necessary for each region or subregion is a function of the size and complexity of the subregion. Small or homogeneous regions may require five or six, complex regions or areas where reference streams represent different stream sizes generally require more.

Once sets of candidate reference sites have been identified for each region, they should be reviewed by state biologists and regional experts. Then field verification of the ecoregion delineations is coupled with visits to representative sets of reference sites. The regions must make sense to those who know and manage the area and are developing the biological criteria for evaluating water resource quality. It is also useful to include experts from adjacent states. Visits to a number of reference sites in each region provide a visual subjective analysis of within-and between-region similarities and differences as well as landscape characteristics within the ecoregion and watershed the streams occupy.

Reference sites representing least-disturbed ecosystem conditions are a moving target of which humans and natural processes are a part. The objective of the reference site network described here is to identify water quality conditions that are attainable within the established pattern of human land use within a region. This differs then from reference sites selected with the objective to study pristine conditions for research and historical purposes. Although the quality of the set of streams reflects the range of best attainable conditions given the current land use patterns in the regions, this does not imply that the quality cannot be improved. A comparison of the difference in the areal patterns of water quality among the reference sites with patterns in natural landscape characteristics should provide a sense for the factors that are responsible for within-region differences in quality.

For the most part, only very small streams have watersheds completely within any one subregion. Larger streams that more closely meet size criteria for reference sites tend to drain areas in two or more subregions. Sets of references sites for these types of subregions must consist of watersheds that have similar proportions in different subregions. In selecting reference sites, care must be taken to avoid including anomalous stream sites and watersheds.

An evaluation of the framework intended to depict patterns in the aggregate of ecosystem components is not an easy task. An appropriate test is not how well patterns of a single ecosystem component, such as fish species richness or total phosphorus in streams, match ecoregions. Alternative approaches appear more effective. Work by Larsen et al. (1988) in Ohio uses principal component analysis to link chemistry with nutrient richness and ionic strength and work by Karr et al. (1986) groups biotic characteristics to express biotic integrity.

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Case Study 13 in Monitoring and Evaluation: Regionalization of the California Wildlife Habitat Relationships (CWHR) Database — An ecological context for data interpretation

Ecological classification

Sixteen bioregions (Welsh 1994) were developed as an organizational framework for the California WHR information system (Airola 1988) in the state of California. The bioregions are of finer scale than the biotic provinces of Bailey (1976) and Udvardy (1975) and a coarser scale than the 24 developed by Barry (1991) though conceptually consistent with them. The approach used to define these bioregions was grounded in the literature of biogeography with an emphasis on the dynamic nature of "natural" communities along the continuum of ecological to evolutionary processes interacting with regional climates and physiography which determine natural biotic patterns through time.

Description

This system of bioregions was developed in response to a lack of regional focus in the statewide WHR database. California contains the most diverse array of habitats in the continental United States. Consequently, the use of a statewide database is often too coarse in resolution when dealing with animal species that may occupy different habitat (i.e. vegetation types) at different times of the year and in different geographic settings within the state. This system of bioregions permits database users to query the database with a focus on regional relationships within California when examining natural resources issues and their potential management impacts on wildlife species. It is important to recognize that the bioregionalized database is not limited to animals endemic to a particular bioregion. Two secondary objectives were to emphasize the value of the bioregional concept in resource planning, and the importance of thinking in terms of dynamic processes in order to reflect accurately how natural systems function through space and time.

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Case Study 14 in Monitoring and Evaluation: Integration Of The Canadian National Forest Inventory (CanFI) at the Ecoregion Level — National and regional reporting

Ecological Classification

The National Ecological Framework for Canada (Ecological Stratification Working Group 1995) covers all of

Canada except for the Great Lakes and marine systems. The scale of application is 1:2,000,000 to 1:10,000,000.

Description: Every 5 years the federal Canadian Forest Service compiles the latest forest inventory information available from the ten provinces and two territories into a national compendium. Canada's Forest Inventory 1991 (Lowe et. al. 1994) replaces the 1986 version as the authoritative national statement on the distribution and structure of forest resources. The inventory is a spatially referenced database containing the best information available in 1991. The national inventory is produced with the cooperation of both provincial and territorial forest inventory agencies through the Canadian Forest Inventory Committee (CFIC). Until recently the national inventory data could only be made available spatially by administrative boundaries, e.g., provincial boundaries for analytical purposes. In 1993, Environment Canada began to work with CFS to integrate the National Ecological Framework and its associated databases with CanFI, a grid cell based database. This was completed in 1995 (Hirvonen and Lowe 1996).

The national ecological framework, using CanFI as well as other information, is now used to develop and present indicators of sustainable forest management by ecozone (the most general level of the national ecological hierarchy), for inclusion both in Canada's national set of comprehensive environmental indicators and for tracking certain criteria and indicators of sustainable forest management established by the Canadian Council of Forest Ministers (1995). This integration of databases is also used for general health of the forest reporting.

Data historically have been compiled by administrative units (forest districts, province) and not by ecological units, therefore much effort is required to compile forest data by the ecological units. Incompatibility of data among provinces is a concern (different age classes, methods of compiling attributes measured, etc.). The nature of the forest inventories currently is such that tracking specific attributes over time is difficult.

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4 SEEKING A CLASSIFICATION THAT WORKS FOR ALL PARTNERS

How can a common ecological classification system be developed for use by multiple agencies, organizations and landowners? Development of a common classification involves agreement on common objectives. It also involves identification of the appropriate classification concepts, data standards, naming conventions, mapping protocols, and the appropriate multi-scaled hierarchical structure or structures if a multi-scaled system is desired (Grossman et al. this volume).

A number of technical avenues are being explored by scientists and managers to determine the feasibility of a common classification to meet the needs of all partners. Efforts are underway to examine the benefits of merging and linking existing systems taxonomically and spatially. Still others are exploring the proposition that a single ecological classification system may not be necessary if common data standards and map themes are developed.

Grossman et. al. (this volume) evaluated the conceptual similarities and differences among the most prominent abiotic, biotic, and integrated (a.k.a., biotic–abiotic or multifactor) classification systems at a variety of scales and distilled the following basic concepts. The attributes of an ideal system include:

- to be integrated fully with the desired application(s) and products,
- to have a systems orientation; be based on the structure and function of the system,
- to consider spatial and temporal scale properties of the system,
- to be dynamic and allow for environmental and biological change,
- to take hierarchy theory into account.

This challenging agenda calls for integrating new ideas from scientific fields such as conservation biology and landscape ecology. Probably the most complex discussion is whether to integrate aquatic and terrestrial classification objectives, protocols, and hierarchical structures. To date there is no clear statement of what exactly this aquatic–terrestrial integration would mean, the scales where integration should occur, and the anticipated benefits to management of addressing this integration through a common classification rather than through existing separate hierarchical structures, or through modeling, or assessment.

A means to evaluate the potential to merge existing classifications is to classify and map a common area using multiple systems and then work to reconcile the differences. Differences which usually appear are related to the characteristics and attributes defined by the classification, differences in where boundaries are placed on the ground, differences because of variable scales or levels of generality in definitions, and differences in vegetation characteristics because of the time period of reference.

Maps partition environmental gradients and encompass a certain degree of landscape complexity which varies by the intensity of mapping. Key discussions in the development of a common classification will revolve around the logic underlying the delineation of map polygons. Both qualitative and quantitative methods have been promoted although most people agree that the process is a combination of science and art. A measure of successful standardization is inherent in the idea of replicability in the generation of map products (Omernik 1995, Host 1996). Once boundaries are agreed upon, map units can be tested to determine how accurately ecological classification descriptions and interpretations meet their design objectives. Boundary lines should be revised where descriptions or interpretations of ecological units and actual ecosystem response are at odds.

4.1 Incentives and Barriers to Cooperation

Should partners collaborate in the development of a common classification system? Each organization will have its own particular reason for participating and its own measure of success. However, some general needs and anticipated benefits can be articulated as a baseline for measuring progress. General incentives are:

- to draw on the combined expertise from many organizations to better understand the ecosystem and its components,
- to help recognize and share solutions to mutual problems,
- to provide a system which consistently holds up to intense scientific and public scrutiny,
- to help communicate to lay persons the basis for differences in management prescriptions among sites and among agencies and organizations,
- to achieve economies of scale when investing time and money in database development,
- to achieve economies of scale when developing ecological models, planning models and decision support systems which incorporate ecological classification,
- to coordinate inventory and monitoring strategies,
- to increase our ability to compare management experiences,
- to establish research in representative areas and extrapolate scientific findings,
- to empower local and regional stewardship and initiative,
- to improve early detection of ecosystem stresses,
- to address better broad-scale issues such as biodiversity conservation, wetland preservation, water quality protection, and ecosystem health.

Barriers exist to cooperation in the development of a common system across agency and organization boundaries. The use of sophisticated statistical processes and the language of ecological classification is often complex and with many nuances so that managers are not sure of the benefits and technical tradeoffs. Organizations with a substantial investment in current resource inventories may be unwilling to provide resources to integrate new concepts and information. Multipurpose classifications do not optimize utility for all purposes; therefore, managers or specialists may be unwilling to allocate resources to a common purpose, or, individuals may have allegiance to a given classification.

Public land cannot provide all the goods and services required by a growing population. The public has different expectations for public land than for private land and for private industrial versus private non-industrial land management. Therefore, increased attention needs to focus on appropriate, cost-effective means of transferring the benefits of ecological classification to private lands. Ecological classification is an efficient tool for education.

4.2 Integrating Existing Classifications and Maps

Valuable information is gained by identifying commonalities, strengths and weaknesses among existing classification systems. For example, Table 5 provides a comparison of the ability of soil, vegetation, and integrated approaches to classification to provide capability and forest productivity information at the local scale. The process of comparison identifies how compatible or complementary existing systems are. Advances toward comprehensive data collection and analysis approaches, originally designed to overcome the limitations of existing classifications, have done much to

Table 5. Comparison of the utility and restrictions of several common environmental classification approaches (source Cleland et al. 1994).

Classification and Objective	Use Considerations
Soil surveys provide knowledge of soil properties critical in planning for any on-the-ground project; for example, equipment limitations and standards and guidelines for road construction are based on soil properties	They often inadequately predict timber production potential (Carmean 1975,1979; Esu and Grigal 1979) and do not provide enough information about potential natural vegetation to guide management decisions involving the manipulation or preservation of vegetation.
Habitat types identify areas with similar climax communities and can provide information about plant community composition and succession. Often, there are predictable relationships between ecologically important soil factors and the distribution of ground flora.	Potential forest productivity is not a criterion used in development of the habitat types so that wide ranges in productivity can occur within a type. Areas similarly classified may have different functional attributes. Habitat types do not provide enough information about ecosystem components other than vegetation to develop many capability and suitability ratings. It may be difficult to accurately classify disturbed sites.
Ecological types provide knowledge of plant community composition, structure, succession, and soil and hydrologic properties.Productivity is an inherent consideration in development. Can better classify disturbed sites. Areas similarly classified have similar functional attributes which allows extrapolation of cause and effect information.	Like all classification and rating systems, the quality assurance and quality control methods used in development will determine the accuracy and ultimate utility to meet the desired use.

further the emergence of more highly-integrated land classification products (Sims et al. 1996).

Compatibility of objectives, criteria, and resolution must be addressed for systems to be integrated at a given scale. To develop a hierarchical system, the interaction among multiple scale must also be addressed. Ecological classifications can be organized as spatial or taxonomic hierarchies. Both can be used to create maps. Spatial frameworks are map frameworks explicitly designed to partition the landscape based on analysis of environmental gradients and landscape patterns. In spatial hierarchies lower level units are aggregated geographically to form higher level units. The highest units are described by the range of conditions they encompass geographically.

In taxonomic systems, lower level classification types are nested conceptually within the higher levels, but the fact that those classification types are combined at the next higher level does not guarantee that they are geographically associated in a particular landscape. Landscape relationships become evident when mapping taxonomic types at an individual scale but, the geographic patterns are not carried upward to the description of the next level of the hierarchy.

Several major hierarchical classification systems in use and pertinent to the development of a common classification in the United States are presented for comparison below. These systems are organized into spatial and taxonomic hierarchies.

Tables 6 and 7 present the principal map unit criteria and map scale for the spatial hierarchies used for terrestrial and surface-water ecosystems by the USFS. The USFS National Hierarchical Framework of Ecological Units is a regionalization, classification and mapping system for stratifying the earth into progressively smaller areas of increasingly uniform ecological potential. Among the units presented in these tables three types of biophysical environments are recognized: geoclimatic, zoogeographic, and aquatic (see Grossman et al. this volume). The terrestrial, aquatic, and groundwater hierarchies presented in Fig. 1 converge into a Nearctic zone at the global scale. Intended uses were presented earlier in this document.

A major stimulus for the Environmental Protection Agency (EPA) to develop an ecoregional framework has come from a need to assess existing and attainable surface water quality. The most immediate needs being to develop regional biological criteria and water quality standards and goals for non-point source pollution. The EPA has invested in the development of a four-level hierarchy of ecoregions beginning with a first approximation map entitled "Ecoregions of the Conterminous United States" (Omernik 1986, 1987), which shows 76 ecoregions at a scale of 1:7,500,000. Within this hierarchy, Level I is the most general, Level IV is the most detailed.

The premise behind the EPA approach is that ecological regions can be identified by analyzing the patterns and composition of biotic and abiotic phenomena, reflecting differences in ecosystem quality and integrity (1989; Omernik 1987, 1995). These phenomena include geology, physiography, vegetation, climate,

Table 6. USFS National Hierarchical Framework of Ecological Units, scale and principal map unit design criteria (adapted from Avers et al. 1994).

Map Unit	Criteria	Scale
Domain	Subcontinental area of broad climatic similarity	1:15,000,000
Division	Differentiated by continental climate reflected in common vegetative life forms.	1:30,000,000 to 1:7,500,000
Province	Differentiated primarily by the effects of continental weather patterns interacting with broad landforms and that correspond to broad vegetation regions. Provinces display similarities in geologic age, stratigraphy, lithology, and soil forming processes. Also differentiated are highlands or mountains where changes in elevation correspond with differences in climate, vegetation and soil.	1:15,000,000 to 1:3,500,000
Section	Broad regions of similar geomorphic process, stratigraphy, geologic origin, topography, regional climate and dominant associations of potential natural vegetation.	1:7,500,000 to 1:1,000,000
Subsection	contain common landforms due to common lithology, surficial geology, and/or geomorphic history. also differentiated are mesoscale climatic zones which influence plant community compositions or species dominance.	1:3,500,000 to 1:250,000
Land Type Association	Based upon the effective interaction among landform, geomorphic process, elevation, vegetation and local climate. Display repeatable patterns of soils, plant communities, stream types, lakes, wetlands, and rock types.	1:250,000 to 1:40,000
Ecological Land Type	Unique combinations of soil morphology, soil depth, landscape position, geomorphic process and hydrology are expressed by commonalities in the structure and composition of potential natural communities and basic land capability.	1:60,000 to 1:24,000
Ecological Land Type Phase	Similar to land types but smaller and more narrowly defined. Microclimate, internal drainage, and soil texture, structure and morphology influence the productivity and successional tendencies of the site.	1:<24,000

Table 7. Abbreviated criteria for designing ecological units for aquatic ecosystems (Maxwell et al. 1995).

Map Unit	Criteria	Map Scale
Domain	Fish family patterns.	1:7,500,000
Region	Fish dispersal and vicariance.	1:7,500,000
Subregion	Fish vicariance and endemism.	1:7,500,000
Basin	Fish endemism and genetics.	1:2,000,000
Subbasin	Physiography.	
Watershed	Fish genetics watershed and stream network morphology.	
Valley Segment s and Lake Types	Geomorphology, climatic regime, and hydrologic regime.	1:63,000 to 1:24,000
Stream Reach and Lake Zone	Channel and lake morphology.	1:24,000 to 1;12,000
Channel Units and Lake Sites.	Site specific habitat features, hydraulics, substrate etc.	1: <12,000

soils, land use, wildlife, and hydrology. The relative importance of each characteristic varies from one ecological region to another, regardless of hierarchical level. This approach can be used at each hierarchical level by considering factors to a greater level of detail.

Land Resource Regions (LRR) and Major Land Resource Areas (MLRA) are regional scale classifications developed by The Natural Resource Conservation Service as a basis for making decisions about national and regional agricultural concerns, identifying needs for research and resource inventories, providing a broad base for extrapolating the results of research and as a framework for organizing and operating resource conservation programs (USDA Ag. Handbook 296

1984). LRRs and MLRAs are based on soils, climate, water resources and land use. The delineations draw particularly heavily on concepts underlying Soil Taxonomy and information collected through the National Cooperative Soil Survey.

The U.S. Fish and Wildlife Service's Classification of Wetlands and Deepwater Habitats is intended to "describe taxa, arrange them in a system useful to managers, furnish units for mapping and provide uniformity of concepts and terms" (Cowardin et al. 1979). Five major systems form the highest levels of this classification scheme: Marine, Estuarine, Riverine, Lacustrine, and Palustrine. The first four include both wetland and deep water habitats but the Palustrine includes only wetland habitats.

The Nature Conservancy's mission is to protect biological diversity. They are working to provide a complete listing of all communities that represent variation in biological diversity and to identify communities that require protection. The classification is intended to address protection of all natural systems, rare or not. The terrestrial classification hierarchy is based on existing rather than potential vegetation types which range from early successional through climax associations and include types that are maintained by both natural disturbance regimes and human activity. The terrestrial hierarchy is a modification of UNESCO (1973) and Driscoll et al. (1984).

The Nature Conservancy is also developing an aquatic classification system (Grossman et al., this volume). The Conservancy's classification represents a continental scale approach to setting priorities for freshwater biodiversity protection. The Conservancy's classification system is hierarchical and allows for the characterization of aquatic communities on both abiotic and biotic levels. The abiotic component of the classification framework defines the context and describes the physical structure of aquatic ecosystems at five spatially-nested scales: aquatic province, aquatic section, watershed type, macrohabitat, and microhabitat. The biotic component of the classification framework provides guidelines for identifying, naming and characterizing aquatic communities at two hierarchical levels: alliance and association.

Proper comparisons of the accuracy and compatibility of objectives among systems are easiest when data types and measures are the same. The earlier stated proposition, that a single ecological classification system may not be necessary if common data standards and map themes are developed, is based on the premise that accessibility to extensive standardized databases and accurate spatial information will provide an environment where it will be easier to generate specific ecological classification and interpretive products than to develop a common system to meet all needs (see Grossman et al., this volume). Not everyone agrees that this approach will give the degree of integration necessary to manage ecosystems as a whole rather than as the sum of its parts.

Part of the evolution of existing classifications toward a common classification system is the merging of spatial and non-spatial databases and incorporating temporal information within a spatial framework. Taxonomic and place dependent systems organize spatial and temporal information differently. For example, the U.S. Forest Service National Hierarchical Framework of Ecological Units is a spatial hierarchy. The Forest Service surveys and maps ecological units which are then used to structure information in a database. Potential natural vegetation information is described and bounded by the unit. The varied species composition, plant associations, and vegetative structures which occur over time are carried as attributes of the site mapped. Rarity and abundance values can be generated from information on unit composition throughout all levels of the hierarchical system. In the absence of complete inventories, percent composition can be estimated by applying information on distribution patterns.

The Nature Conservancy conservation database provides an example of a different database structure. TNC describes existing natural communities and associated environmental conditions using their taxonomic system. Differences because of species composition, plant association, or seral stage are each considered significant for distinguishing new classes. In a database, site variables are carried as attributes of the community which has incorporated species composition, plant association, and vegetative structure into its definition. Rarity and abundance are communicated through a state, national, and global ranking system rather than from direct measurement or estimation of areal composition within a defined area.

4.3 Promising Partnerships

Activities to link classifications among agencies and organizations are moving forward. For the U.S. Forest Service, the National Hierarchy serves as the central reference point for all efforts to link existing systems. At the national level, nine federal agencies have entered into a Memorandum of Understanding (MOU) to develop a common spatial framework of ecological units for the United States *Case Study 15*. Many federal agencies and national organizations are already working with state partners to achieve consistency in ecological classification and to standardize its use.

Other important partnership efforts revolve around linking federal and state efforts and obtaining consistency in the application of regional and national systems across state boundaries. Collaborative efforts in subsection mapping between the USFS and state natural resource agencies, and others have already been mentioned (Section 1.5). In addition, the Northeast Area Association of State Foresters endorsed the implementation of ecological classification following the USFS Hierarchy as a key component in the implementation of more ecological approaches to management in that twenty state area (Ecosystem Management Strategy Team 1994). Wisconsin and the USFS have signed a formal agreement called the Wisconsin Accord which clarifies the relationship between previous state work in Habitat Type Classification (Kotar et al. 1988, Kotar and Burger 1996) and the USFS National Hierarchy.

Land type associations are being developed or planned with state leadership in New Jersey, Minnesota, Michigan, Wisconsin, New Hampshire, Missouri, Massachusetts, Pennsylvania, New York and Vermont.

In 1992, the Minnesota Department of Natural Resources and the Chippewa National Forest began a cooperative project called the Chippewa Demonstration Area to develop ecological units, descriptions, identification keys and interpretations at all levels on two shared Land Type Associations to demonstrate their use (Hanson and Hargrave 1996). In Indiana, ecological land types and land type phases, developed for the Hoosier National Forest, were presented in field guide format to support application of the system within appropriate natural divisions on adjacent public and private lands at the request of the State Forester (Van Kley et al. 1994).

The EPA Environmental Research Laboratory in Corvallis, Oregon is involved in several collaborative projects with states and EPA regional offices to refine ecoregions, define subregions, and locate sets of reference sites within each region and subregion. This work is being conducted at a 1:250,000 scale. These projects cover Iowa, Florida, Massachusetts and parts of Alabama, Mississippi, Virginia, West Virginia, Maryland, Pennsylvania, Oregon, and Washington (Omernik 1995).

The Nature Conservancy (TNC) and its Natural Heritage Program (NHP) cooperators have been involved in many collaborative efforts throughout the United States including the standardization of vegetation classification protocols and nomenclature for ground survey and remote sensing applications, and the collaborative development of ecological units at a variety of scales. A recent decision to incorporate a bioregional framework into their regional and national conservation planning places them at the center of federal, state, and international efforts to develop a common spatial framework of ecological units. The Nature Conservancy and the US Forest Service have established a cross reference of systems in the Northeastern United States. *Case Study 14* shows the attributions of subsections with TNC regional alliances.

Several contemporary partnership efforts cross the Canadian-U.S. border. The publication *Ecoregions of Alaska* (1994) involved state, federal, and Canadian cooperation (Omernik 1995). Uhlig and Jordan (1996) examined Canadian and American national hierarchical frameworks and proposed a joint project involving the Ontario Ministry of Natural Resources, the Canadian Forest Service, and the U.S. Forest Service in the Upper Great Lakes region. A North American Framework is being developed for Canada, the United States, and Mexico (Omernik, personal communication, 1996).

Broad-scale assessments can contribute considerable information toward the development and refinement of a common classification system. For example, work in the Columbia River Basin, covering parts of Oregon, Washington, Montana, Idaho, Northern California, Nevada, and Utah, involved the collection and synthesis of survey data from the states, the USFS, BLM, NPS, TNC and other sources. Classifications for a variety of purposes have been developed. Management alternatives were constructed and evaluated using models incorporating the biophysical and potential vegetation components of ecological units (Reid et al. 1995).

In 1990, the United States Geological Survey (USGS) initiated NAWQA as a comprehensive survey of the status and trends of ground and surface water quality in the United States. Physical, chemical and biological data will be collected from study areas that correspond to hydrologic units based on the drainages of major rivers and aquifers. They will be further stratified according to Frissell et al.'s (1986) classification framework. NAWQA researchers are currently assessing the use of ecoregions to stratify their national sampling (Higgins, pers. comm. 1996, McMahon, pers. comm. 1996).

Multi-organizational efforts such as the Federal Geographic Data Committee (FGDC) and the USFS Common Survey Data Structure (CSDS) projects are working toward common data and survey standards among multiple agencies and organizations. National standardized databases available today include the Natural Resource Conservation Service STATSGO and SSURGO databases, The Nature Conservancy Conservation Data Base System, the USFWS wetland inventory database and the USGS STORET water quality database.

A key area for future collaboration involves the integration of ecological classification and remote sensing products. A key linkage is being sought in the standardization of vegetation classification nomenclature. The USFWS National GAP Analysis is using remote sensing technology to identify native plant and animal species and natural communities represented on conservation lands (Scott et al. 1993). The land and water classification system for Gap Analysis seeks to link to the United Nations Educational, Scientific and Cultural Organization (UNESCO 1973) system as modified (Driscoll 1984), the USFWS classification (Cowardin et al. 1979), and the remote sensing land cover classification (Anderson et al. 1976).

Case Study 15 in Promising Partnerships: Memorandum of Understanding on Developing a Spatial Framework of Ecological Units of the United States — Partnerships among agencies of the U.S. Department of Agriculture, the U.S. Department of the Interior, and the Environmental Protection Agency

Ecological Classification

A common spatial framework for defining ecological units of the United States based on naturally occurring and recognizable features such as soil, geology, geomorphology, climate, water, and vegetation will be developed. Guides for this work will include the National Hierarchical Framework of Ecological Units (ECOMAP, 1993) developed primarily by the Forest Service; the Land Resource Regions and the Major Land Resource Area (MLRA) framework (USDA Agriculture Handbook 296, 1981, revised 1984) developed primarily by NRCS; the EPA Ecoregion Framework (Omernik 1995); and other references, as appropriate, depicting biological and physical components of the environment.

Description

A Memorandum of Understanding was entered into by the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), Forest Service (FS), and Agricultural Research Service (ARS); the U.S. Department of the Interior, Bureau of Land Management (BLM), U.S. Geological Survey (USGS), Fish and Wildlife Service (FWS), National Biological Service (NBS), and National Park Service (NPS); and the U.S. Environmental Protection Agency (EPA).

The MOU documents and defines the responsibilities of the cooperating agencies to develop a common spatial framework for defining ecological units of the United States. It also provides a vehicle for other Federal agencies with natural resource management responsibilities to become part of the cooperative effort nationwide.

The growing interest by federal and state agencies in adopting a more integrated ecological approach to resource management has clarified the need for a common spatial framework for defining ecological units. This common framework will provide a basis for interagency coordination and will permit individual agencies to structure their strategies by the regions within which natural biotic and abiotic capacities and potentials are similar. These ecological units transcend local, state, and national boundaries.

Considering the broad responsibilities and interests of all agencies, it is desirable and mutually beneficial to cooperate and integrate interdisciplinary technical information on environmental factors such as soils, vegetation, geology, geomorphology, water, climate, and others into a common ecological framework, with associate descriptions and digital databases. Development of a common ecological framework will be consistent with standards developed by the Federal Geographic Data Committee (FGDC) according to the Office of Management and Budget (OMB) Circular A-16 and Executive Order 12906 (Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure) signed April 11, 1994.

Cooperating agencies will use the framework for defining ecological units, with associated narrative descriptions and digital databases to (a) reduce duplication of effort and promote effective, efficient, and scientifically sound management of natural resources; (b) geographically organize and share research, inventory, and monitoring information; (c) facilitate coordinated approaches to characterization and assessment of the Nation's land and water; and (d) enhance program management and technical coordination among parties representing private, tribal, state, and federal interests.

Development of a common spatial framework for defining ecological units will necessitate recognition of the differences and functions of the three existing guides listed above. Commonality and refinement of these guides will be the basis for evolution of the common spatial framework and related databases. Signatory agencies will collaborate on a State-by-State and/or regional project basis using interagency standards and procedures until a set of common and joined ecological units is developed for the entire Nation.

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Case Study 16 in Promising Partnerships: Attribution of USFS Subsections in the Northeastern United States with TNC Regional Alliances — Linking existing classifications for mutual benefit

Ecological Classification

This example shows work and outcomes from cross-referencing alliances of the TNC Eastern Regional Community Classification (Sneddon et al 1994) to 88 subsections in the northeastern United States. The subsections were developed according to criteria associated with the USFS National Hierarchy (Avers et al. 1994) and are depicted on the map, *Ecological Units of the Eastern United States: a First Approximation* (Keys et al. 1995). The Nature Conservancy's Eastern Regional Alliance classification describes 128 alliances which share a similar species composition, vegetation structure and environmental setting (Sneddon et al. 1994). The regional classification provides a correlation of alliances identified among states participating in the Natural Heritage Programs in the TNC Eastern Region.

Description

The USFS New England/New York Subregional ECOMAP (NE/NY ECOMAP) team was interested in obtaining information on vegetation types and distribution to help in the delineation and characterization of Subsections. Information on the abundance and distribution of potential natural communities (PNC) is important for mapping ecological units, but is not generally available at the subsection scale. The NE/NY ECOMAP team entered into a cooperative agreement with the Eastern Region Office of The Nature Conservancy to attribute existing regional alliances to subsections and identify late successional communities as a first approximation of PNC.

TNC Eastern Region ecologists worked with state natural heritage ecologists, panels of experts and their state biological conservation databases, to determine which regional alliances occurred within each subsection and which approximated PNC. A 3-point scale was used to document the certainty vested in each occurrence. The scale is 1: probably occurs, 2: definitely occurs, 0: definitely not present. This resulted in a matrix of subsections vs. regional alliances. Expert judgment was used to classify each alliance as restricted, limited, widespread or occasional in occurrence within the subsection thus providing qualitative information on distribution and abundance for future reference.

Now both organizations can query the database to determine which and how many alliances occur in each subsection; and which and how many subsections are associated with each alliance. With the attribution completed, it is possible to aggregate and ascribe information to higher levels of the USFS National Hierarchy and to group subsections by any characteristic used as an attribute within the conservation database. For example, coarse distribution maps can be developed for each alliance by querying for presence within the database.

The subsection map provides a geoclimatic context for TNC ecologists to evaluate their classification and correlation efforts among states. Communities which were dissimilar were expected to separate along some ecological unit boundary. Communities classified similarly are expected to either cluster geographically within or among a subsection, or section, or province unless they are associated with some environmental characteristic(s) which explains a discontinuity in distribution. In the latter case, the distribution of calcareous fens is disjunct but logical due to the strong confining influence of mineral and hydrologic factors at a local scale and the broad climatic zone where conditions are suitable for the species.

Work in this area is ongoing and being evaluated by TNC to develop "ecoregional planning units" for Conservancy conservation action across the nation (Anderson et al. 1996). In addition to the benefits of this general characterization, the USFS Eastern Region Research Natural Areas program is also planning to use this information to provide a cross-check of natural area representation beyond National Forest boundaries and to clarify the USFS role in state, regional, and national biodiversity conservation efforts.

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5 SUMMARY

The objective of this chapter was to describe the uses of a variety of biophysical classifications and ecological assessments in decision-making, and to identify ways that partners can work toward use of a common ecologically based classification system. The benefits of using ecological classification in natural resource planning, implementation, and monitoring were presented first for the local level, then for regional and landscape level planning. Case studies were used to highlight the varied uses of ecological classification and to highlight ways that classification supports partnerships and decision-making. Examples were predominantly for management of terrestrial systems on National Forests.

But aquatic amd wetland examples and non-Forest Service examples were included that demonstrate that the objectives and methods of employing ecological units in planning, management, and monitoring are similar.

Ultimately, the performance of any system depends on the degree to which it is compatible with its objectives and the scale of analysis in which it is used. The case studies presented in this chapter provide examples of appropriate uses and demonstrate how to test the validity of the assumptions embedded within the classifications. It is advantageous to use ecological classification systems to solve multiple resource management problems.

5.1 Key Science and Management Concepts

Ecological classification and mapping provide a bridge between science and management. It is important for managers to understand the assumptions underlying the definition of ecological types and ecological units if they are to participate in the testing of those assumptions during regular management activities. Table 8 identifies key concepts managers should recognize.

Ecological classification and mapping provide information on ecological potential which is used to establish desired future conditions at single scales, and, in nested geographic systems, at multiple scales. Ecological units can be used to structure integrated resource inventories or integrate existing multidisciplinary information. Ecological classification and mapping provide information useful in program planning and can be used to enhance coordination and cooperation among multiple disciplines and multiple agencies. Table 9 identifies key concepts to help managers use ecological classification and mapping appropriately.

Table 8. Key science concepts related to the use of ecological classification and mapping systems in management.

Key topic	Concepts
Ecological classification systems	exist for terrestrial, freshwater, marine, and wetland ecosystems, integrate multiple biotic and abiotic characteristics in three dimensions, and are used to identify and map areas of different biological and physical potentials.
Ecological units	partition environmental gradients, provide a framework for integrating multiple types of resource information, display spatial relationships among ecosystems and follow taxonomic and mapping rules.
Hierarchical systems	provide a context for relating landscape patterns to processes, and can be spatial or taxonomic in nature.
Criteria for combining classifications	common objectives, common classification concepts, common data standards, common naming conventions, common mapping rules, and common taxonomic and/or spatial hierarchical structure

Table 9. Key concepts related to the use of ecological units in natural resource management.

Key topic	Concept
Ecological units	must be combined with other environmental, social, and economic information for sound decision-making. provide an expedient and cost-effective means of ordering and managing information about ecosystems. provide a spatial structure for information management. provide the hypothesis that the area within each ecological unit is consistent with the description provided for it, provide the hypothesis that the area within each ecological unit will respond as predicted by the interpretation of its environmental characteristics.
A hierarchical framework of ecological units	provides a context for evaluating cumulative effects, allows aggregation of fine scale data into regional databases while preserving ecological meaning. provides a framework for describing the composition, structure and function of ecosystems. and. contributes to our ability to demonstrate the potential for a variety of alternatives at local, landscape, and regional scales.

5.2 Conclusions

It is clear that good classification systems are, without exception, based on sound science. Brief developmental histories are included in each of the case studies presented. Taken as a whole, they illustrate the evolution of ecological classification principles and concepts. Regardless of classification approach, similar environmental factors and variables have emerged as useful discriminators of ecological condition and potential.

This leads to the conclusion that a higher degree of compatibility among existing systems can be achieved as more information is collected and analyzed. Grossman et al. (this volume) discuss the major classification approaches in widespread use today and present a matrix of key attributes that highlight similarities and differences among them.

Where single-resource or single function classifications and maps already exist, managers can evaluate the potential to merge them by mapping a common area. The degree of difference among the maps and the varied effects of using them to make management decisions can then be evaluated. Managers can work with scientists to reconcile the differences and provide assessments of the trade-offs relative to a range of uses.

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