Delineation, Peer Review, and Refinement of Subregions of the Conterminous United States

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Subregion maps and descriptions prepared by
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Abstract

This paper briefly describes the background of the U.S. Department of Agriculture (USDA) Forest Service National Hierarchical Framework of Ecological Units and the methods used for delineating map units at the subregion planning and analysis scale. The process for scientific review and continuous refinement of ecological units and associated data of subregions is also presented.

Citation

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Overview of Subregion Development and the Need for Peer Review and Refinement

The U.S. Department of Agriculture (USDA), Forest Service has been implementing the National Hierarchical Framework of Terrestrial Ecological Units over the past decade, following official adoption of the system on November 5, 1993, as policy and direction for using an ecological approach to management of natural resources (USDA Forest Service 1993). The framework consists of eight hierarchical levels of ecological units that are grouped into four planning and analysis scales: ecoregions, subregions, landscapes, and land units (Cleland et al. 1997).

Maps of ecoregions and subregions have been delineated across the conterminous United States to provide a consistent basis for planning, analysis, and implementation of management policy within the agency. This paper provides information on delineation methods, and guidance for peer review and subsequent refinement of ecological units mapped at the subregion level.

Background

The national framework employs a regionalization, classification, and mapping system to stratify the Earth into progressively smaller areas of increasingly uniform ecological conditions and potentials. Ecological types are classified and ecological units are mapped based on associations of biotic and environmental factors that directly affect or indirectly express solar energy, temperature, moisture, and nutrient gradients, as well as natural disturbance regimes that regulate the structure and function of ecosystems. These factors include climate, geology, physiography, soils, air, hydrology, and potential natural vegetation.

An interative process is used to develop subregions. Units are conceptualized and mapped by studying whole systems and relationships among their respective components, with boundaries refined as additional information becomes available (Cleland et. al. 1992). Through a regionalization process, ecomappers initially evaluate broader scale information to map subregions from the top down. Subsequently, finer scale information, including ecological unit inventories conducted at lower tiers of the hierarchy, are used to refine boundaries from the bottom up. In this iterative process, continental-scale regions of similar climate are successively subdivided into smaller units of increasing uniformity, and boundaries of these units are then refined through finer scale ecological mapping.

This dual top-down bottom-up process enables comprehension of whole systems, as well as interactions and feedback loops occurring within and across hierarchical tiers. The process also facilitates accurate location of boundaries rendered by incorporating information that is only discernible at finer spatial scales, with revisions and interpretations made in a series of successive approximations. Distinguishing subregion boundaries intended to differentiate mountainous units from adjacent plains, for example, is best accomplished by first recognizing broad-scale patterns through regionalization from the top down, followed by careful boundary adjustment facilitated by use of fine-scale topographic information such as high-resolution digital elevation models.

Delineation of Subregions

The 1976 map of ecoregions of the United States (Bailey 1976) provided a starting point for the first delineation of USDA Forest Service subregions at the section level, followed in 1980 by a book of map unit descriptions (Bailey 1980). In 1994, a nationally coordinated project refined subregions and produced the next approximation map of sections of the United States (Bailey et al. 1994), which was accompanied by a book of map unit descriptions (McNab and Avers 1994). In following years, subregion maps were published to the subsection level in several regional projects. These projects included efforts in Forest Service Regions 5 (Goudey and Smith 1994), Regions 8 and 9 (Keys et al. 1995), Region 1 (Nesser et al. 1996), and Region 2 (Freeouf 1998). Unpublished maps were eventually produced by all Forest Service Regions of the country, in cooperation with agency colleagues and state partners, using principles of ecological unit design presented in the National Hierarchy (Cleland et al. 1997). A nationally coordinated project was begun in the late 1990s to edit and compile these individual subregion maps into a consistent national product.

Subregions are delineated based on ecological relationships and factors that are often similar to ecoregions, but that change at a finer scale. Accordingly, sections nested within larger ecoregions (provinces), which are subcontinental-size areas of similar climatic-vegetational zones, are used to successively refine earlier approximations. Ecoregional province boundaries largely represent climatic gradients, and most often are zones of transition rather than abrupt, discrete boundaries. Conversely, section and subsection boundaries are often based on distinct physiographic breaks identifiable by examining distinguishable changes in surficial geologic deposits reflected by potential vegetation or patterns in soil texture and drainage, strong topographic boundaries and other morphometric properties, and other features of the Earth's surface. Province boundaries are generalized to reflect subtle continuous changes in macroclimate, whereas section and subsection boundaries nested beneath provinces may be quite irregular due to actual changes of on-the-ground physiographic or geologic features. Hence, fine-textured crenulations occur within lower-level delineations; however, these crenulations are cartographically masked at higher levels.

Physiography and geologic substrate are used as the primary basis for identifying section boundaries because these components provide the major control over ecosystems within climatic vegetational zones of provinces at the next higher level. Because subsections are smaller parts of sections, it follows that similar components are important in their delineation, although additional information germane to particular areas is also incorporated, including patterns in potential vegetation, soil groups and great groups, and hydrography.

Surface water, such as lakes and rivers, was considered a characteristic of ecological subregions, not a criterion of their delineation. Lakes, for example, were not delineated as discrete units, but were enclosed within larger bounding ecological units that included part of the surrounding watershed. The inseparable linkage between water and land within a subregion is evident because aquatic chemistry and quality is strongly influenced by the climate, geology, soils, and vegetation of the adjacent land. The ecosystems of varying scale encompassed by a subregion that includes a large lake or river are characterized by the interaction and exchanges of energy and material between land and water, not simply the biota that occupy each of them. Additional information on this topic is presented by Omernik and Bailey (1977).

Relationship of Ecoregions to Subregions and Finer Scale Ecological Units

USDA Forest Service implementation of the national hierarchy includes the establishment and support of four Geographic Information System (GIS) layers of ecological units for planning, analysis, and management of natural resources: ecoregions, subregions, landscapes, and land units (table 1).

Table 1. National Hierarchy of Ecological Units

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

Ecoregions adapted from Bailey (1976), which include domains, divisions, and provinces, were developed through a regionalization or top-down process based on differences in global, continental, and regional climatic regimes and gross physiography. Climate differences were inferred where discontinuities appeared in physiography and/or vegetation physiognomy.

The subregion tiers include sections and subsection levels. Subregions are also developed through a regionalization or top-down process, but are refined through finer scale ecological unit inventory or a bottom-up process. The landscape tier includes only landtype associations, which are defined through a top-down and bottom-up process of ecological mapping. Finally, the land unit tiers include landtypes and landtype phases. Land unit ecological units are designed and mapped in the field based on ecological properties following a bottom-up ecological unit inventory process.

Standards for the four official GIS layers of ecological units are to be included in the USDA Forest Service GIS Data Dictionary, and will be updated through a change management process. Data for the four official GIS layers will be stored in the Natural Resource Information System (NRIS), will be updated as ecological units are refined, and will be maintained for USDA Forest Service and other users.

Methods

Ecological units at all hierarchical levels are identified by the integration of physical and biological components of the Earth, which include climate, geomorphology, geology, soils, hydrology, and potential natural vegetation. All components are considered and evaluated in the placement of boundaries, but their importance varies with scale. Scale is among the most important concepts in producing hierarchical ecological maps because the relative importance of factors used to map ecological units varies with scale, and scale bounds the degree of detail of information displayed at each level.

Map Unit Design. Sections are subdivisions of provinces based on climatic, physiographic, and biotic characteristics that distinguish units from neighboring units. A number of mapped information sources were used at scales ranging from 1:2,500,000 to 1:7,500,000 to delineate sections, with final delineations made by generalizing more detailed information on base maps of 1:7,500,000.

Subsections are subdivisions of sections based on multiple factors including surficial geology, lithology, geomorphic processes, soils, climate, hydrology, and potential natural vegetation. Subsections delineations were compiled at scales ranging from 1:500,000 to 1:1,000,000, and are presented at a map scale of 1:3,500,000. Because ecological mapping is an iterative top-down, bottom-up process, mapping of subsections provided the opportunity to refine the published 1994 section boundaries.

Work Activities–Regional Products. Regional program managers coordinated the mapping and description of ecological units at the subregional scale across the United States, engaging many people and disciplines working in Federal, State and nongovernmental organizations in the mapping process. Regional subregion mapping was compiled at scales of 1:500,000 and 1:1,000,000 by regional or State teams, and was recompiled at a scale of 1:1,000,000 for this publication.

Numerous national, regional and State sources of information were used in mapping ecological units. The most important included the Quaternary Geologic Atlas of the United States, U.S. Geological Survey (USGS); State Soil Geographic Soil Database (STATSGO), Natural Resources Conservation Service; Ecoregions and Subregions, Environmental Protection Agency (EPA); Hammond's Classes of Land-Surface Form, USGS; State Natural Heritage Maps and Classifications; Physiographic Maps; Land Cover Types; and State Natural Habitat Regions and Vegetative Life Zones of Puerto Rico.

During map compilation at 1:1,000,000, regional and State teams integrated source information that led to revision of earlier iterations of section, province, division and domain lines mapped in "Ecoregions and Subregions of the United States" (Bailey et al. 1994). In their consideration of aquatic systems during ecological mapping and description, compilers also used the Hierarchical Framework of Aquatic Ecological Units of North America (Maxwell et. al. 1995) and Cowardin's classification of wetlands and deep water habitats of the United States(Cowardin et al. 1979). In addition to physical and biological components, principal classes of land use are included to give insight into human use of land and water resources within ecological units.

<u>Work Activities–National ECOMAP Team:</u> The 2005 national map of subregions of the conterminous United States was created by regional teams over the course of years. A national team representing the three branches of the USDA Forest Service was tasked with compiling and evaluating subregion maps developed within individual USDA Forest Service regions.

Results of the evaluation were presented at a national ECOMAP meeting of regional soil scientists and ecologists in April 2002, and a process for further evaluation and refinement was agreed to for achieving national consistency. The process followed by the national team included examining the content and context of polygons that were atypically large or small, subdividing or grouping map units based on important factors used in the initial mapping process, obtaining subsequent review from respective regions of the national team's recommendations, and incorporation of regional recommendations into the final map.

<u>Delineation</u>. GIS was used to match sources of information with different scales and map projection. It also applied information intended to delimit similar features that lacked spatial congruency due to data quality issues. Ecological units were not simply generated from maps of individual components, however, but were integrated conceptually from a number of spatial data sources using map unit design criteria. In addition to mapped data, other sources of information included State heritage programs, National Resources Conservation Service, and expert knowledge of local and regional scientists most familiar with areas they mapped.

<u>Sources of Information</u>. Types of information that were used in the review and revision of sections and subsections included the following:

- Surficial geology: USGS Quaternary Geology of the United States.
- Land-surface form: National Atlas Map 62, Classes of Land-Surface Form.
- STATSGO: General soil associations of each State.
- State information: Forest habitat regions or natural regions of each State.
- Potential natural vegetation: National Atlas Map.
- Existing vegetation: Forest type groups of the United States, advanced very high resolution radiometer information, National Land Cover Data (NLCD) land cover types
- Elevation, precipitation, temperature, and length of growing season.
- Draft common ecological regions of the conterminous United States: "Common Spatial Framework of Ecological Units for the United States" (1:7,500,000).
- USDA Forest Service publications for ecoregions and subregions.

Sources of information were compared within polygons under review. Multiple components including climate, landform, geologic formations, soils, water and potential natural vegetation were evaluated sequentially, and recommendations for revising polygons were formulated and proposed. Expert knowledge of ecomappers was relied on for synthesis of component data, assessment of ecological uniqueness, and design of map units. The following techniques were used to compare component information, evaluate ecological significance, and delineate subregions:

> Using land-surface form, geology, and major land resource areas as sources of information to help identify physiographic breaks and to help adjust or fine-tune existing section lines (section lines were not arbitrarily added or deleted).
> If available, transferring State natural regions or forest habitat regions to the base map for evaluation or comparison with surficial geology, associated soils, and land-surface form.
> Using STATSGO soils and surficial geology to determine if there was a significant relationship with forest habitat regions or if existing subregion lines needed to be adjusted only for a suitable grouping of surface geology, land-surface form, and associated soils.
> Comparing the significance of common ecological regions and EPA State ecosubregion maps with draft subregion boundaries to determine the need for further refinement and/or stratification.
> Integrating aquatic systems with groupings of similar surficial geology.
> Using Kuchler's potential natural vegetation, existing vegetation, and regional climate data to review logical integration of surficial geology and soils association patterns.
> Reviewing resultant map units against subregion map unit design criteria and province concepts.
> Using landscape data and/or landtype associations to evaluate subregion concepts and integration of component information.

<u>Attributes and Descriptions</u>. The following attributes are being provided for subregions. Information was derived from source maps used in the mapping process.

1. Name and symbol.
2. Fenneman's physiographic divisions.
3. CONUS soil attributes (nine soil properties)
4. National Landcover Data class name.
5. Kuchler's potential natural vegetation.
6. Climate (PRISM data summarized for eight climatic variables)

The attribute data are part of the information used to allow comparisons of physical conditions and provide a basis for multivariate analysis to facilitate the review process. Additional information will be provided through the peer review and refinement process described in this paper.

A narrative description was prepared for each section that was designed to give users a brief summary of the ecological characteristics making each map unit unique from its neighbors (McNab et al. 2007). Future plans include the presentation of more complete narrative descriptions for both sections and subsections.

Peer Review and Revision of Subregions

Initial peer review of the draft subregion map was made by persons familiar with the delineation process and regional ecosystems: Milo Pyne, Regional Botanist, The Nature Conservancy; Julian Campbell, Conservation Scientist, Kentucky Natural Heritage Program; David Taylor, Forest Botanist, Daniel Boone National Forest; Glendon Smalley, retired Soil Scientist, USDA Forest Service; Art Goddard, Soil Scientist, USDA Forest Service. Additional review and refinement of subregions was provided by Federal and State ecologists in New England, the Lake States, and Missouri.

This approximation of subregions will also be peer reviewed by reputable scientists familiar with the national hierarchy. These scientists will include leaders in USDA Forest Service research (e.g., Drs. Tom Crow, Tom Spies, Marie-Louise Smith, Bill Leak), academia (e.g., Drs. Burton Barnes, David Hix, George Host, David MacFarland, Walter Schroeder), the Nature Conservancy (e.g., Dr. Pat Comer, Mark Anderson), state departments of natural resources (e.g., Drs. John Almendinger and Eunice Padley), and others. Reviewers will use this paper to provide insight into methodology used in identification and delineation of subregion ecological units. A peer review will be coordinated by the national data steward and completed within 1 year of this publication.

National Refinement of the Subregions Layer

Every 5 years, a team of regional data stewards and the national data steward will be responsible for updating the subregion layers. Proposals for refinement will be coordinated by regional data stewards, and will be accompanied by the following documentation: (1) a summary of proposed changes and their significance relating to subregion mapping conventions and criteria described in this paper, (2) boundary placement on a controlled GIS base, (3) a list of information that substantiates proposed changes, (4) attributes used to describe subregions, and (5) references for information sources used. Regions are encouraged to hold State/local workshops to finalize proposals. This information must be submitted to the national data steward for final approval and incorporation in the GIS Data Dictionary. A national workshop may prove useful in accomplishing this task. Change management for the ecoregions layer will be coordinated and approved by the national data steward with results incorporated in NRIS and the GIS Data Dictionary. Updates will be posted on the intranet and Internet on a 5-year cycle, and may be in the form of an official series publication. Ongoing review and revision of subregions is desirable and necessary as our knowledge of ecosystem characteristics increases and data are obtained from bottom-up projects.

Conclusions

The first maps of ecological subregions at the section and subsection scale of the National Hierarchy of Ecological Units are complete for the conterminous United States. Subregion maps should be used for purposes that are consistent with the scale of source materials used to compile them. For example, subsection maps are designed for broad-scale ecosystem assessment or analysis and should not be used in substitute of detailed analyses for project-level applications. Detailed applications such as fire regime condition class reference modeling or fire risk assessments, however, can readily apply these broader scale units to differentiate areas with similar communities that occur within different climatic or physiographic settings. Broader scale ecological unit maps assist in setting context and addressing ecological variables that change at coarse spatial scales—variables that influence many fine-scaled patterns and processes of interest to the natural resource management community.

Natural resource planning, assessment, reporting, and management should be enhanced at national to local scales given these new map tools. The USDA Forest Service National Forest Inventory and Analysis (FIA) program now offers summaries of conditions and trends occurring in the Nation's forest lands through the 2005 section and subsection maps on their Web site. Using a consistent set of spatial analysis and reporting units at the appropriate scale will benefit end users of the FIA program. The USDA Forest Service Forest Health Monitoring program by State and Private Forestry will use ecological units to track and summarize information made available through their assessment. The separation of soils in relatively young, glaciated subregions of the country from highly weathered soils of nonglaciated subregions could assist in evaluating or projecting effects of atmospheric deposition on forest health, for instance.

Regional assessments have used this mapping system where it was available in the past, including the Southern Resource Assessment (Wear and Greis 2002), the Great Lakes Ecological Assessment (Cleland et al. 2001), and the Greater Yellowstone Assessment (Nesser et al. 2001). The system has also been used in the designation of research natural areas to optimize locations and ensure representation of the full array of local ecosystems (Snyder et al. 1999).

Interpretations of the 2007 map "Ecological Subregions: Sections and Subsection of the United States" will continue through time. With application, the system will be validated and improved. Our comprehension of multiscaled ecological systems will also be improved as the system is tested and employed by both research and management communities. Understanding hierarchically structured ecological systems, through space and time, will enable more effective assessments of resource conditions and trends. Natural resource planning and management strategies designed to ensure sustainable resource management will benefit as a consequence.

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