Map Supplement

Ecoregions of the Conterminous United States

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Abstract. A map of ecoregions of the conterminous United States has been compiled to assist managers of aquatic and terrestrial resources in understanding the regional patterns of the realistically attainable quality of these resources. The ecoregions are based on perceived patterns of a combination of causal and integrative factors including land use, land surface form, potential natural vegetation, and soils. A synoptic approach similar to that used to define these ecoregions is also useful for applications of the map. Initial efforts to use the framework are at the state level of resource management; they center on aquatic ecosystems — mainly attainable ranges in chemical quality, biotic assemblages, and lake trophic state.

Key Words: ecoregions, ecosystems, cartographic analysis, resource management, regional geography.

SOME of the most difficult problems plaguing resource managers center on the regional representativeness of data and research results and on defining attainable ecosystem conditions or quality. Interrelationships among natural and anthropogenic factors affecting ecosystem quality vary spatially and temporally in such a complex fashion that mathematical and other models developed to predict land use/resource quality relationships are of questionable value when used outside the specific area in which they were developed. To assist in the development and extrapolation of such relationships one needs a qualitative understanding of the regional patterns of ecosystems.

I have compiled maps of ecoregions[1] of the United States to alleviate these problems and to provide a geographic framework for more efficient management of ecosystems and their components. This geographic framework can establish a logical basis for characterizing ranges of ecosystem conditions or quality that are realistically attainable. For most of the conterminous U.S., particularly regions of cultivated cropland, it is unrealistic to expect an attainable quality of water and land resources at the level possible before major human settlement. What is realistically attainable is a quality possible given a set of economically, culturally, and politically acceptable protective measures that are compatible with regional patterns of natural and anthropogenic characteristics.

Neither the concept of ecological regions nor the attempt to delineate them is new. Designing regional classifications that illustrate ecological regions and that incorporate spatial patterns of several factors has been an evolutionary process. One of the earliest efforts was on a global scale (Herbertson 1905). Not only did Herbertson take the then unpopular approach of considering the distribution of a combination of characteristics in defining his "major natural regions," he also recognized the importance of considering the distribution of human development (land use).

In this evolutionary process to define ecological regions, there are two notable examples of classifications that have been developed for the U.S. The first is the *Land Resources Regions and Major Land Resource Areas of the United States*, originally developed by Austin to aid in making decisions about national and regional agricultural concerns (Austin 1972; U.S. Department of Agriculture 1981). The scales at which the map units for this classification were drawn and the bias toward agricultural applications limit applicability of the classification for defining ecoregions. The

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second example is the map, *Ecoregions of the United States* (Bailey 1976). In compiling this map, Bailey considered climate, potential natural vegetation, soils, and land surface form. However, each hierarchical level of classification of Bailey's ecoregions is based primarily on alignments from a particular map. Ecoregion sections (the smallest units shown on Bailey's map) are, for example, based on map units or groups of map units from Kuchler's map of potential natural vegetation (Kuchler 1970). Ecoregion divisions (two steps up in size from the section level on Bailey's map) are, on the other hand, based on climate (Trewartha 1943).

The approach used in this paper for defining ecoregions grew out of an effort to classify streams for more effective water quality management and was inspired by the philosophies of Warren (1979) and Bailey (1976). In the initial stage of this work we used Bailey's ecoregion map as the spatial framework for examining aquatic ecosystems (Hughes and Omernik 1981; Omernik, Shirazi, and Hughes 1982). As our research progressed, we developed a more satisfactory scheme for defining aquatic ecoregions. The approach is based on patterns of terrestrial characteristics, and therefore the regions are not exclusive to aquatic ecosystems but depict terrestrial ecosystems as well.

As we examined spatial patterns of stream quality data, we saw the need for an alternative classification for regionalizing water resource management. Land Resource Regions were too coarse and, for most of the country, Major Land Resource Areas were too small (U.S. Department of Agriculture 1981). Bailey's ecoregions proved inadequate in most areas, primarily because each depended on a single mapped characteristic (potential natural vegetation) at the section level of classification. Although hydrologic units (U.S. Geological Survey 1982) should not be considered for illustrating ecological regions, they have been used extensively as a geographical framework for water resource management. We found the hydrologic units least helpful of the available spatial classifications, mainly because topographic drainage areas do not correspond closely to the causal and integrative characteristics that help define regional patterns in ecosystem quality.

None of the available classifications afforded a means to evaluate representativeness of areas within ecoregions, to assess within-region variation, or to estimate the representativeness of entire watersheds. Such a mechanism is necessary for evaluating existing data, for designing sampling schemes to address regional representativeness, and for assessing regional patterns of attainable ecosystem quality.

My approach for defining ecoregions is based on the hypothesis that ecosystems and their components display regional patterns that are reflected in spatially variable combinations of causal factors. These causal factors include climate, mineral availability (soils and geology), vegetation, and physiography. Although these factors interact, the importance of each factor in determining the character of ecosystems varies from place to place. I believe that by analyzing a combination of small-scale maps of the important causal factors and of integrative factors (such as land use), distinct regional patterns of ecosystems can be perceived.

The map presented here is compiled at the relatively small scale of 1:7,500,000. It is intended to provide a general illustration of ecoregions for national level planning, management, and analysis. More detailed regional maps will be published at a larger scale (1:2,500,000) and are intended for use at state and regional levels. On these larger-scale maps, distinctions will be made between areas that are most typical and areas that are generally typical of each ecoregion.

Component Maps

To define ecoregions, it was necessary to examine factors that either cause regional variations in ecosystems or integrate causal factors. In general, because of the interrelatedness of many of the factors, the mapped pattern of one factor also appeared in maps of other factors. This is an advantage in defining ecoregions because it reinforces the distinctiveness of particular areas. I found a combination of the following four small-scale maps to be most useful: *Major Land Uses* (Anderson 1970), *Classes of Land-Surface Form* (Hammond 1970), *Potential Natural Vegetation* (Kuchler 1970), and soils maps from various sources. I refer to these as the component maps.

Land use provides a strong integrative tool for revealing ecosystem patterns in most of the U.S. because it reflects spatial patterns in potentials and capacities of the land. Much of the U.S. is in forest or agriculture (or some mosaic of the two) because of the relative capacity for that land use, which in turn reflects (and in effect integrates) characteristics of soils, physiography, and climate. Exceptions to this include the relatively small percent of the country that is urbanized and the portions of the country (particularly in the East) that have been farmed, regardless of suitability, because of their proximity to urban areas or to the portion of the country that was first settled. The usefulness of land use for defining ecoregions is supported by its value as a predictor of spatial patterns of components of ecosystem quality such as stream nutrient levels (Omernik 1977) or alkalinity of surface waters (Omernik and Powers 1983).

Compared to the other component maps, Anderson's land use map (1970) is fairly detailed and accurate. The detail and accuracy are relatively consistent throughout the map owing to the spatial uniformity in the type and accuracy of the source materials used to compile the map. The fact that the map is not current does not detract from its utility. In fact, the land use mosaic that existed at the time the map was compiled probably reflected regional patterns of agriculture/forest land use potential better than would a more up-to-date land use map. Recent shifts in land use, such as increased acreage in irrigated agriculture and decreased acreage in cultivated cropland near densely populated areas, may mask patterns of agriculture/forest potential in some areas.

Potential natural vegetation was defined by Kuchler (1970, 89) as "the vegetation that would exist today if [human beings] were removed from the scene and if the resulting plant succession were telescoped into a single moment." It, too, is a strong integrative tool for illustrating aquatic ecosystem patterns. However, unlike the land use map, it is not as accurate, nor is the accuracy or level of detail consistent from one part of the country to another. The map was based on a variety of sources (mostly maps) of varying accuracy, scale, and level of generality. Moreover, the map reflects one person's perception of the vegetation that would exist in the absence of human modifications.

Hammond's land surface form map (Hammond 1970) synthesizes regional patterns of slope, local relief, and profile type (e.g., how much of the more gently sloping land is located near the larger streams or in the interfluves) into relatively homogeneous classes of land surface form. The map was compiled in a more general, broad-brush way than either the land use or the potential natural vegetation map.

The classification scheme of the soil taxonomy map (U.S. Department of Agriculture 1970) was the most appropriate for our purposes, but because of its inaccuracies (resulting largely from the poor data base and inappropriate cartographic techniques used in its compilation (Gersmehl 1977)), we also relied on other small-scale regional and state-level soil maps (Simonson 1975; U.S. Department of Agriculture 1937, 1957, 1964, 1973, 1984).

Several other maps were consulted, generally to verify the regional accuracy of each of the component maps and to support further the patterns that indicated ecoregions. The most helpful for this purpose were *Surficial Geology* (Hunt 1979), *Physical Divisions* (Fenneman 1946), and *Land Resource Regions and Major Land Resource Areas of the United States* (U.S. Department of Agriculture 1981). Maps in *Climates of the United States* (Baldwin 1973) and the *Census of Agriculture* (U.S. Bureau of The Census 1969, 1974, 1978) were also used.

Ecoregion Delineation

The four most important component maps were analyzed together to sketch out regions that were relatively homogeneous in their soils, land use, land surface form, and potential natural vegetation and to tabulate the identifying classes of each. The key to this process was distinguishing the regional homogeneity in a combination of characteristics from the heterogeneity in each characteristic. Some ecoregions could be clearly and easily delineated because of the distinctiveness of all four characteristics relative to adjacent ecoregions; other regions were less distinct and were distinguished by broader classes (or groupings) of some of the characteristics or even by fewer characteristics.

These ecoregions are commonly on the order of 130,000 km^2; they range from 15,000 km^2 to 330,000 km^2. Ecoregion size is a function of within-region homogeneity relative to between-region variation. The regions should be at a scale that is useful for resource management. For our purposes, ecoregions should be large enough to contain entire topographic watersheds of at least 500 km^2 but not so large as to aggregate contrasting relatively homogeneous areas that contain entire watersheds of at least 500 km^2. Some larger regions have a patchwork of conditions that are common throughout the region but are too patchy to allow individual ecoregions to be delineated at this scale of analysis. The Central Appalachian Ridge and Valley Ecoregion, for example, is characterized by contrasts; there, watersheds of at least

500 km^2 all contain forested mountains and agricultural valley bottoms.

After roughly sketching the regions, I delineated the boundaries. This involved a map overlay process and qualitative analysis of the relative accuracy and level of generality of each map. Using the sketched map and the table of characteristics that typify each region, I selected a particular combination of maps to delineate each ecoregion. Usually, the maps and classes of characteristics that were most useful for differentiating any two adjacent ecoregions were different from those used for defining the boundaries between these ecoregions and neighboring ecoregions. Since each component map was compiled at a different level of generality, and each map varies in its level of accuracy (relative to the true locations of the characteristics represented as well as to the source material used in map compilation, both within and between maps), the usefulness of the alignments of each map for drawing ecoregion boundaries varies.

Each component map was enlarged or reduced to a 1:2,500,000 scale colored overlay format. After overlaying combinations of these component maps and evaluating and compensating for the level of generalization of each map, I drew the ecoregion boundaries to reflect the conditions that typified each ecoregion (see Table 1, printed on the back of the map supplement). An example of how this was done is shown in Figure 1. In this illustration, the boundary between the Willamette Valley and Cascades Ecoregions was defined by the presence of: different land surface form characteristics (plains with hills vs. high mountains), different land uses (mostly cropland vs. forest and woodland mostly ungrazed), different soils (xerolls vs. udic soils of high rainfall areas), and different potential natural vegetation (conifers and Oregon oakwoods vs. fir). In most cases, the alignments shown in Figure 1 illustrate where these differences occur. In some cases, other characteristics appear in the component maps, usually in the transition areas between ecoregions. Where this happens, mapped characteristics were grouped according to similarity: for example, in the Willamette Valley/Cascades Ecoregion boundary area, the land use mosaic defined as "cropland with pasture, woodland, and forest" is grouped with the adjacent "cropland"; and the land use defined as "woodland and forest with some cropland and pasture" is grouped with the adjacent "forest and woodland mostly ungrazed." Thus I defined ecoregions by overlaying the component maps, by noting the predominant characteristics of each ecoregion (Table 1), by evaluating for differences in accuracies and generalities among the component maps, and by understanding the obvious regional interrelationships among component characteristics.[2]

The final step was to color code each ecoregion to convey a sense of the broader, multiregion patterns. I did this by selecting a color for each ecoregion that conveyed the common perception of that ecoregion, which in turn reflected the ecoregion's vegetative cover and/or land use. Regions characterized mostly by cropland were assigned shades of brown; regions characterized by forests were assigned shades of green; and regions characterized by wetland or very wet forest were assigned shades of blue. Grasslands were generally illustrated by shades of yellow, and very arid areas, shades of pink or red. Regions characterized by a range of vegetative cover or land use, such as the Central Appalachian Ridge and Valley Ecoregion, were generally assigned a color to illustrate the strong contrast with adjacent regions.

Applications

The primary function of the ecoregion map is to provide a geographic framework for organizing ecosystem resource information. This framework should allow managers, planners, and scientists to: (1) compare the similarities and differences of land/water relationships; (2) establish water quality standards that are in tune with regional patterns of tolerances and resiliences to human impacts; (3) locate monitoring, demonstration, or reference sites; (4) extrapolate from existing site-specific studies; and (5) predict the effects of changes in land use and pollution controls. Applications will vary from one state and region to another, as will the issues of concern such as nonpoint source pollution, eutrophication, and sensitivity of forest and water resources to acidification. Resource management interests and priorities in the Western Corn Belt Plains are understandably different from those in the Northern Lakes and Forests or in the Wyoming Basin. In spite of (or perhaps because of) these differences, there is a universal need to understand the spatial patterns of realistically attainable conditions and quality of ecosystems.

Use of the map should be consistent with the scale and method at which it was compiled and presented. It is not intended for precise, large-scale quantitative analysis or inventory. These ecoregions are merely areas within which there is

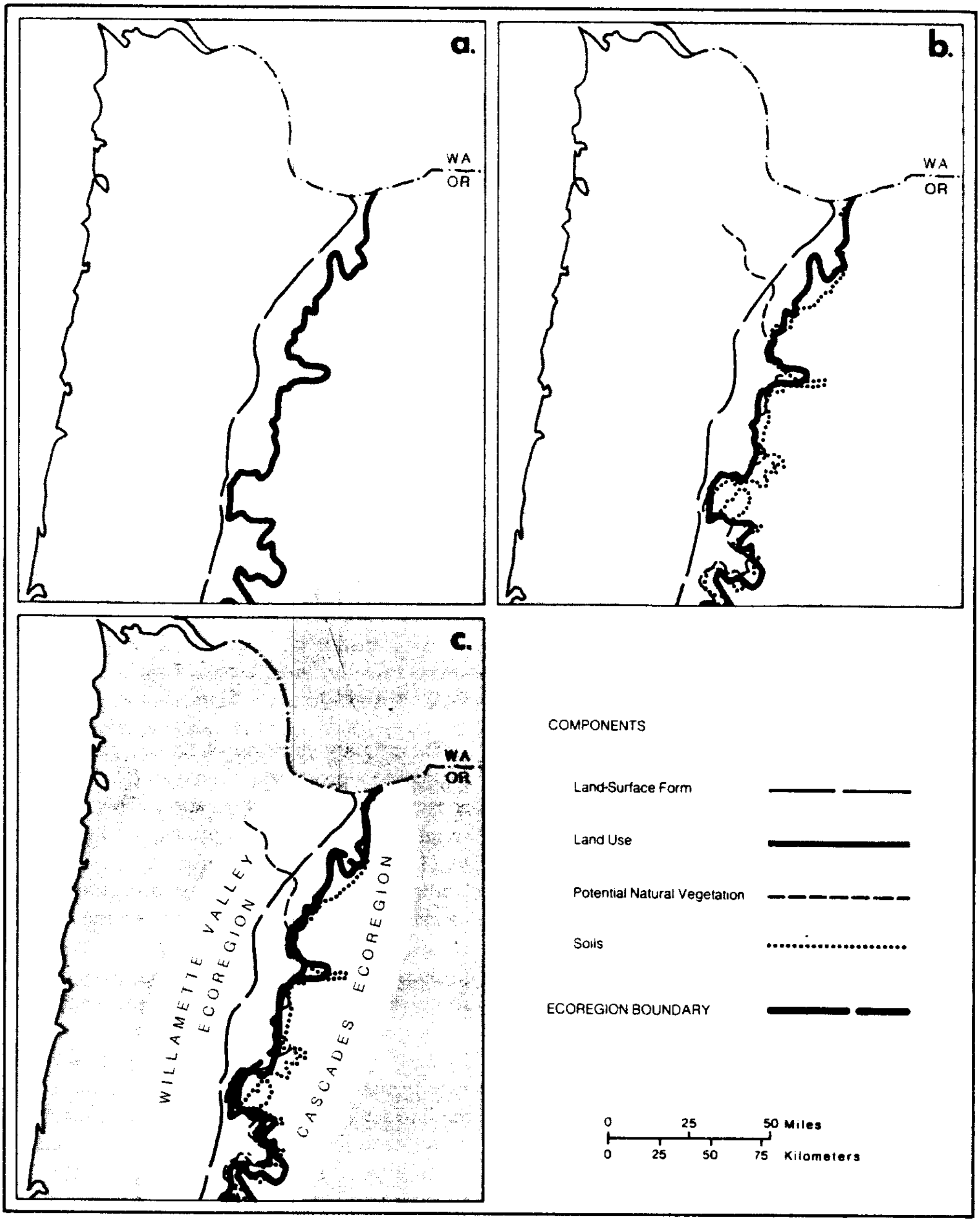

Figure 1. Variations in boundaries of mapped characteristics along the Willamette Valley/Cascades Ecoregions boundary. Figure 1a illustrates the difference between the land use and land surface form boundaries; 1b illustrates the similarity in alignment and generality of the land use, potential natural vegetation, and soils boundaries as compared with the land surface form boundary. The level of generality and accuracy with which the land surface form map was compiled probably accounts for the lack of agreement between that component and the other three. The true alignment of the boundary between the two land surface form types is probably closer to the alignments of the other components because of the associations between the two land surface form types and characteristics in vegetation, land use, and soils. Hence, the ecoregion boundary (1c) was based on a subjective determination of the relative accuracy and generality of each of the component maps.

likely to be less variation in ecosystems than within broader state or major river basin areas or within ecological regions defined using a single characteristic or for a particular purpose. Some ecoregions are characterized by a high level of within-region homogeneity in ecosystems, whereas others have considerable within-region heterogeneity.

Rowe and Sheard (1981) and Bailey (1983) have stressed that ecoregion maps are products of hypotheses that must be tested and improved.[3] The ecoregion map accompanying this text was completed after considerable verification; documentation is still in progress (see Larsen et al. 1986). Initial efforts to use this ecoregion framework also serve as verification projects and are underway in Ohio, Colorado, Texas, Arkansas, Oregon, and Minnesota. These statewide projects focus on aquatic systems, mainly attainable ranges of chemical quality, biotic assemblages, and lake trophic state.

Summary

The ecoregions map of the conterminous U.S. is based on the premise that relatively homogeneous areas exist and that these areas can be perceived by simultaneously analyzing a combination of causal and integrative factors including land surface form, soils, land use, and potential natural vegetation. The map was compiled to assist managers of aquatic and terrestrial resources in understanding regional patterns of the attainable quality of these resources. More synoptic analyses, at increasingly larger scales, are necessary in order to develop a more quantitative understanding of the ranges of attainable resource quality (within and between regions) and the spatial factors that permit regional predictive capabilities.

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Notes

1. The term *ecoregions* was coined by J. M. Crowley (1967) and popularized by Robert G. Bailey (1976) to define a mapped classification of ecosystem regions of the U.S. Unlike many coined terms or words used to express special new meanings, such as *landscape* or *stream order*, there is little disagreement or misunderstanding about the meaning of *ecoregion*. Ecoregions are generally considered to be regions of relative homogeneity in ecological systems or in relationships between organisms and their environments.
2. A few ecoregions are not distinguished by a particular characteristic or set of characteristics on one of the four component maps; hence the few blank spaces on Table 1. In all but one of these cases, soils was the apparent nondistinguishing component. This does not mean that these particular ecoregions lack homogeneity in soils relative to adjacent ecoregions; it simply means that the available small-scale maps do not reflect this homogeneity. Maps are only representations and, because of the classifications or techniques employed in compiling them, they sometimes miss the obvious. For example, the Nebraska Sand Hills Ecoregion, which is one of the more homogeneous ecoregions in the country, stands out on nearly every national map of land surface form, soils, potential natural vegetation, and land use; yet this region was not distinguished on Fenneman's map of physical divisions (1946) or Bailey's map of ecoregions (1976).
3. In so stating, I believe Rowe and Sheard (1981) and Bailey (1983) recognized the evolutionary process of ecoregion mapping. Clearly maps that may be revised and refined at some later date serve valuable purposes. For example, regional and national maps of surface water alkalinity (Omernik and Kinney 1985; Omernik and Griffith 1986; Omernik and Powers 1983) that were recently published with full knowledge that they would be revised have served a crucial role in clarifying patterns of the extent of surface water sensitivity to acidification. This mapping was a key in the design of the National Surface Water Survey (Linthurst et al. 1986).

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