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Perspectives on the Nature and Definition of Ecological Regions

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ABSTRACT / Among environmental managers, recognition of the importance of integrating management activities across agencies and programs that have different responsibilities for the same geographic areas has created an awareness of the need for a common hierarchical framework of ecological regions (ecoregions) to implement the strategy. Responding to this need in the United States, nine federal agencies have signed a memorandum of understanding on the subject of developing a common framework of ecoregions. However, considerable disagreement over how to define ecoregions and confusion over the strengths and limitations of existing frameworks stand in the way of achieving this goal. This paper presents some perspectives on the nature and definition of ecoregions related to this confusion and provides a brief overview of the weight of evidence approach to mapping ecoregions, using an example initiated by the US Environmental Protection Agency. To effectively implement ecosystem assessment, management, and research at local, regional, and national levels, research is needed to increase our understanding of ecoregions. We must find ways to illustrate the nature of ecoregion boundaries and the variability of characteristics within ecoregions as they relate to management issues. Research must also be conducted on comparing existing frameworks and developing indices of ecological integrity to effectively evaluate their usefulness.

Environmental management historically has focused on individual natural resources. State and federal agencies, as well as nongovernmental organizations, have organized their assessment, research, monitoring, and management strategies largely around specific subjects such as forests, grasslands, streams, lakes, wetlands, wildlife, fish, agriculture, and mining. Since the late 1980s, however, many of these agencies have been advocating a shift toward integrating their activities and using a more holistic ecosystem management approach (US GAO 1994). This shift is related in large part to increased recognition of the interrelatedness of all ecological components—biotic, abiotic, terrestrial, and aquatic—as well as to a greater acceptance that humans are an important biological component (McDonnell and Picket 1993, US GAO 1994, Omernik and others 2000). Even agency names reflect this apparent move toward an ecosystem focus. In 1994, for example, the former US Soil Conservation Service became the Natural Resources Conservation Service.

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In a report on actions needed to implement an ecosystem management approach, the U.S. Government Accounting Office (US GAO 1994) stipulated the need for a common geographic framework that would allow management to be conducted by ecological rather than political or administrative regions. The GAO report observed the lack of agreement across agencies regarding a national framework of ecological regions, but stated that a government-wide approach to ecosystem management might ultimately require such agreement. Since the publication of the GAO report, some progress has been made toward the development of a common framework. First, an interagency, international group supported by the North American Free Trade Agreement–relatedCommission for Environmental Cooperation (CEC) developed and published maps of two broad levels of ecological regions for North America (CEC 1997). Second, some initial steps have been taken to develop a common geographic framework of ecological regions for the United States at the next hierarchical level below the two mapped by the CEC (McMahon and others 2001). Third, most of the major resource management agencies have agreed on the next more detailed level of ecological regions for many parts of the United States (e.g., Bryce and others 1998, Chapman and others 2001, Griffith and others 2001, McGrath and others 2001, Woods and others 2001).

Although the number of examples of consensus on the delineation of ecological regions is increasing, considerable disagreement about definition still remains within many agencies and among academics. Moreover, because of the existence and ongoing development of different geographic frameworks that are either called ecoregions or used as such, much confusion exists among the users and potential users. This paper has three objectives: (1) to present some perspectives on the nature and definition of ecoregions that help explain the confusion and disagreement; (2) to provide a brief overview of the weight of evidence approach to mapping ecoregions, using the example of framework initiated by the US Environmental Protection Agency (EPA); and (3) to outline some future directions for ecoregion research.

Why We Cannot Agree on How to Delineate Ecoregions

The numerous reasons for disagreement over how to delineate ecoregions include

1. disagreement on the definition of ecosystems
2. the complexity of the nature of ecoregions and ecoregion boundaries
3. bias toward particular characteristics
4. inability or reluctance to embrace a holistic ecosystem concept and preoccupation with specific objectives and reductive methods
5. disagreement on whether to use quantitative (rule based) or qualitative (weight of evidence) approaches
6. disagreement over whether watersheds comprise ecoregions
7. investment in existing frameworks and reluctance to change

This paper does not elaborate on all of these issues. Some of the issues, such as distinguishing between watersheds and ecoregions, have been covered at length in the literature (e.g., Omernik and Griffith 1991, Omernik and Bailey 1997, Griffith and others 1999, Bryce and others 1999a, Omernik 2003). The merits and limitations of qualitative (weight of evidence) versus quantitative (rule based) methods of regionalization have been addressed in Omernik and Gallant (1990), Omernik (1995), Gallant and others (1995), and McMahon and others (2001). However, issues that have received little attention include the general lack understanding of the nature of ecoregions and ecoregion boundaries and the apparent inability or reluctance to understand and adopt a holistic ecosystem approach for the assessment and management of environmental resources.

In response to the US GAO report (1994) on developing a common geographic framework of ecological regions to be used by all of the resource management agencies, a group called the National Interagency Technical Team (NITT), of which I was a member, formed to address the problem (McMahon and others 2001). The NITT and an interagency steering committee created a Memorandum of Understanding (MOU) entitled "Developing a Spatial Framework of Ecological Units of the United States," which was signed in 1996 by the heads of nine federal resource management agencies. The task faced by the NITT was difficult, largely because of the lack of agreement over the definition of ecoregions and how they should be mapped. This problem and its ramifications were noticed by an ecologist who was invited to attend one of the early NITT meetings and who, after observing a day of discussion, was asked for his comments. He responded that it was like watching a group of people packing for a trip without first agreeing on where they were going and learning what the place was like. Instead, he said, they appeared to be throwing things into suitcases without knowing if they would be needed.

To some, the logical course toward developing a common framework of ecological regions would be to compare the underpinnings of the various existing frameworks used, or considered for use, for ecosystem management. This course seems necessary because each of these frameworks was developed by different people, with different methods, and for purposes somewhat different from those the GAO report and NITT addressed. The NITT did generally agree that the common framework should identify regions of similarity in the mosaic of biotic, abiotic, terrestrial, and aquatic ecosystem components, with humans being considered part of the biota (McMahon and others 2001). The committee also agreed that the new common framework would allow the integration of assessment and management strategies across agencies and programs with different missions and responsibilities for the same geographic areas.

However, the NITT was reluctant to delve into the reasons for the differences in the existing frameworks and to evaluate them against the broader purpose of a common framework. This is not meant to be negative criticism of the NITT members. The NITT's participants were well-intentioned and should be commended for their efforts. Their reluctance to objectively examine the existing frameworks was understandable. It is only natural for individuals and their agencies and programs that have major investments in published maps and reports to believe that their framework fits the broader purpose. Probably more often than not these claims are not defensive but are based upon perceptions weighted toward specific objectives, or biased toward certain characteristics because of training in specific disciplines.

Our perceptions of the definition of ″ecosystems″ and how ecological regions should be defined are shaped not only by the agencies or programs with which we are associated, but also by our educational backgrounds and previous experiences. Zonneveld (1988) commented that geographers, biologists, landscape architects, soil scientist, regional planners, foresters, agronomists, and conservationists of all kinds bring their biased views to the meaning of the term ″ecology.″ The same is naturally true about how ecoregions should be defined. Those with a background in soil science would understandably start with soil maps and consider other geographical phenomena as they are associated with soils. Geologists would be prone to start with geology and use other characteristics as they relate to geology. Plant ecologists would probably base their regions more heavily on patterns of potential and existing vegetation, physiographers on physiography, climatologists on climate, and so on.

A major barrier to adopting ecosystem management strategies, as well as to recognizing and defining ecoregions, lies in an apparent resistance to, and lack of recognition of, the necessary changes in mind-sets and methods. Terms that typify the conceptual and discussion stages of the ecosystem management paradigm include *multiscale, long term, holistic, multi-stakeholder,* and *multipurpose.* On the other hand, those that characterize the planning and implementation stages are quite often different, commonly including *local* (or *case study* or *watershed*), *short term, reductionistic, single problem,* or *single issue* (Wiken 1997). This difference probably results from a general lack of experience in and acceptance of holistic integrative approaches, along with a reliance on reductive science. Some believe that holistic ecosystem research is simply not considered proper science (Kay and Schneider 1994). However, by relying completely on reductive methods, we are unable to gain an understanding of the true nature of ecological regions, which comprise dynamic, variegated landscapes (Bekoff 2000). Box (1994) stressed that one of the key requisites to implementing ecosystem management is ″shifting from reductive and disciplinary work to synthesis and interdisciplinary analysis of systems. This ′shift′ should not be thought of as an *either or* thing; rather, holistic, integrative methods must be incorporated into the process. Reductive research in ecosystems will still be imperative.″ Holling (1996) summarized the complementary nature of the two approaches as ″two streams of science, one reductive and certain, and the other integrative and uncertain,″ with the first ″providing the bricks for the edifice″ and the second ″the architectural design.″ McHarg (1997) echoed this thought, stating that, ″reductionism need not be superseded, but certainly it must be augmented to include synthesis and holism.″

Perhaps the biggest impediment to agreeing on how to define ecoregions lies in the inherent complexity of ecosystems, which makes it difficult for people to agree on a definition of the term as well as a method for delineating ecological regions. McDonald (1994) wrote of ″ ... the dilemma of modern regional geography: called upon to organize space into useful and comprehensible units, it is also expected to provide a stable analytical framework for spatial realities whose parameters are constantly shifting.″ This dilemma certainly applies to ecosystems. Clearly, ecosystems are *moving targets* (Kay and Schneider 1994, Salwasser and Pfister 1994, Holling 1996). Their features are multiple, uncertain, and unpredictable (Holling 1996), which helps explain why some have claimed that ecosystems exist only as conceptual units and that their delimitation varies, depending on goals of particular studies (e.g., Marin 1997).

Another problem we face in delineating ecoregions is that although the framework is hierarchical, the boundaries are not precise and the regions at the different levels of detail do not nest perfectly. However, in mapping ecoregions, we represent the boundaries as lines. Some boundaries are shown as being smooth and general, whereas others are finely crenulated, but almost always, the boundaries are represented as lines. In fact, ecoregion boundaries are *areas,* rather than lines, where the predominant characteristics of one region meet the predominant characteristics of another. On a map of Level I ecological regions of North America (Commission for Environmental Cooperation 1997), the boundary between the Great Plains and the Eastern Temperate Forests is represented by a crenulated line, reflecting boundaries of smaller and more detailed ecological regions of lower hierarchical levels (Figure 1). The Great Plains ecological region is distinguished from the Eastern Temperate Forests ecological region in that the former is much drier, generally grass covered and mostly plains, whereas the latter is a mostly forested mosaic of plains, hills, and low mountains. The broad area where the characteristics of each of these ecological regions meet covers entire states (Lewis 1966, Rossum and Lavin 2000) (Figure 2). Entire Level III ecoregions, including the Central Oklahoma/Texas Plains (commonly called the Cross Timbers region),

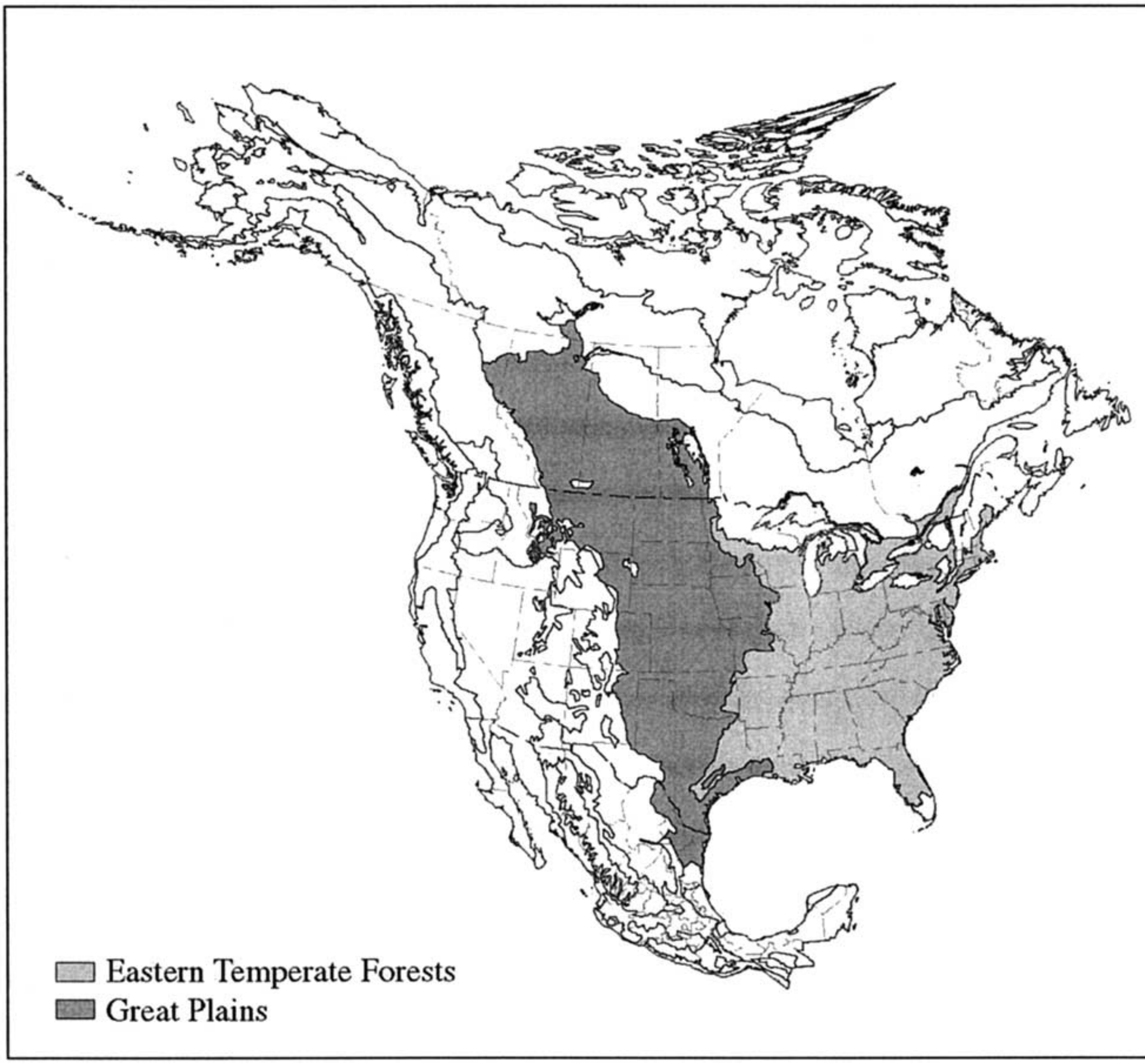

Figure 1. The Great Plains and Eastern Temperate Forests ecological regions. The names and identification numbers for level I ecological regions are given in CEC 1997.

the Central Irregular Plain of eastern Kansas and western and northern Missouri, and the Central Corn Belt Plains of northern and central Illinois occupy the fuzzy boundary between the two Level I ecoregions.

Another example, at a lower (more detailed) level, can be seen at the boundary between the Northern Basin and Range and Central Basin and Range ecoregions in the western United States (US EPA 2003). The Northern Basin and Range is cooler than the Central Basin and Range and has fewer mountain ranges. The Northern Basin and Range is underlain mostly by volcanic rocks and has a potential natural vegetation of mostly sagebrush steppe, whereas the Central Basin and Range has a mosaic of sedimentary and volcanic rocks, and a potential vegetation of mostly saltbrush-greasewood, Great Basin sagebrush, and some juniper-pinyon woodland. Soils in the Northern Basin and Range are mostly Mollisols. In the Central Basin and Range, Aridisols predominate. Each of the distinguishing characteristics (including geology, physiography, climate, and soils) is important in determining the mosaic of terrestrial and aquatic plants and animals in each of these two ecoregions. The problem is that if the boundary is based mainly on geology, it will be different than if it is

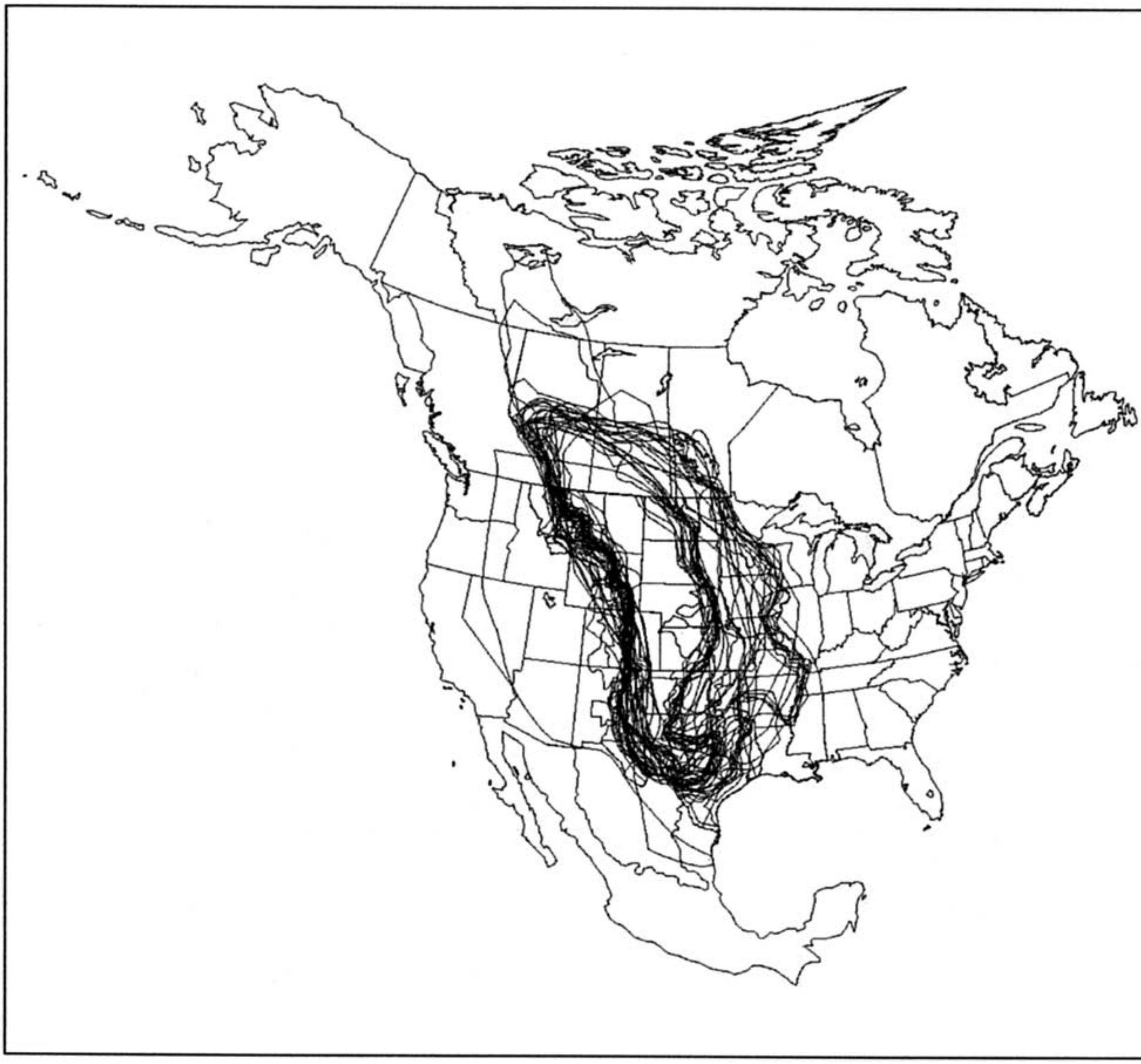

Figure 2. "Fifty versions of the Great Plains" (Rossum and Lavin 2000). Permission granted by Blackwell Publishing, Oxford, UK.

based primarily on vegetation, different yet again if it is based on soils, and different from all of these if it is based mainly on physiography. Like many ecoregion boundaries, this one comprises a transition area that varies in width from one place to another.

One could attempt to illustrate the complexity of ecoregions boundaries such as the one between the Northern Basin and Range and the Central Basin and Range by using lines from selected maps of the more important determining or reflective characteristics such as soils, physiography, vegetation, geology, climate, and land use. The figure would look something like the *spaghetti* map of the Great Plains by Rossum and Lavin (2000) (Figure 2), but with fewer lines. However, this would not accurately represent the nature of the boundary and might suggest to some that a map overlay approach to defining the boundary was appropriate. In approximating the location of ecoregion boundaries, it is important to examine as much mapped information as possible on each of the different geographic phenomena that help distinguish ecoregions.

There is a strong tendency, however, for people mapping ecological regions to base each boundary on a single determining characteristic, and an even stronger tendency to choose that characteristic based on their area of specialization or background. Furthermore, this is usually done, whether consciously or subconsciously, with a desire to have the region serve a particular purpose. As a result, many mapped geographic frameworks labeled ecoregions were in fact compiled to address specific purposes. The existence of these different ecoregion frameworks, and the confusion over the nature of ecoregions and their boundaries, could be in part responsible for an observation that "many of the interest groups that in the early 1990s were pushing for ecosystem management as a new paradigm for management of public lands have largely abandoned the effort" (Yaffee 1999, citing personal conversation with S. Barth). People simply have a difficult time comprehending the concept of ecosystem management, much less ecoregions. The terms mean different things to different people (Yaffee 1999).

Also adding to the confusion surrounding ecoregions is the lack of an appropriate means of evaluating their usefulness. This is a major dilemma. We can evaluate mapped frameworks designed for single purposes, such as agricultural potential, sensitivity of surface waters to acidification, and forest productivity, by examining data on characteristics that indicate differences in these subjects. For example, patterns of data on alkalinity of surface waters indicate regional differences in sensitivity to acidification (Omernik and Powers 1983). Ecological regions, on the other hand, have a general purpose. They are intended to show patterns in the capacities and potentials of ecological systems. Again, ecoregions are areas of similarity regarding patterns in the mosaic of biotic, abiotic, aquatic, and terrestrial ecosystem components, with humans being considered part of the biota (McMahon and others 2001). Although ecoregions are helpful for many specific purposes, such as developing regional nutrient criteria and biological criteria for streams (Davis and others 1996, US EPA 1998, Rohm and others 2002), they cannot be expected to correspond perfectly to patterns in any one characteristic. Patterns of nitrogen concentrations in streams are not the same as those of phosphorus concentrations, and neither is the same as patterns of surface water alkalinity. Studies on the regional patterns of water quality in reference (minimally impacted) streams in Ohio have shown that the patterns of individual chemical characteristics correspond to some but not all of the Level III ecoregions in the state. However, by means of a principal-components analysis of these data, with the nutrient richness characteristics grouped on one axis and the ionic strength characteristics grouped on the other, it became clear that an *index of water quality* was different for all of the ecoregions (Whittier and others 1987, Griffith and others 1999).

Hence, to evaluate the effectiveness of ecoregions, and to compare the usefulness of the different existing frameworks, we must test them against measures that relate to their purpose, which is to facilitate ecosystem research, assessment, and management of whole ecosystems, thereby allowing integration of these activities across agencies and programs. These measures must therefore collectively relate to the health and integrity of ecosystems as a whole rather than the quality of individual components. This evaluation ideally should be through the use of indices of ecological integrity and, to date, no such indices have been developed. Although a number of people have addressed the issue of measuring ecosystem health and the development of indices to accomplish the goal (e.g., Schaeffer and others 1988, Anderson 1991, Karr 1993, Wicklum and Davis 1995, O'Connell and others 1998), none have suggested ways to incorporate key aspects of abiotic as well as biotic components of both aquatic and terrestrial ecosystems. Because the various factors important to characterizing the relative health or condition of ecosystems vary from one place to another, the indices would need to be regionally calibrated, which would introduce circularity to the evaluation process (Omernik 1995).

A Weight-of-Evidence Approach to Mapping Ecoregions

About 15 years before the GAO's plea for a common ecoregion framework and the subsequent debate and confusion over the usefulness of ecosystem management, the EPA began developing a framework of ecoregions (Omernik 1987, Gallant and others 1989). The impetus for this work was the need to provide a geographic framework that would allow state and regional water resource managers to structure their regulatory programs more effectively by accounting for the regional differences in potentials and capacities of the environment. The development of this framework was based on the following logic:

- The quality and quantity of water at any point reflects the aggregate of the characteristics upgradient from that point.
- Water quality and quantity will tend to be similar within areas where this *aggregate* is similar.
- Therefore, for effective water resource research, assessment, and management, these regions within which there are similar geographical phenomena that affect water quality and quantity must be defined.
- Reference watersheds and areas within each region

can then be identified to determine expectations, criteria, and appropriate management practices (Hughes and others 1986, Hughes 1995, Omernik 1995, Bryce and others 1999b).

The method used to define these ecoregions involved identifying areas within which there is spatial coincidence in characteristics of geographical phenomena associated with differences in the quality, health, and integrity of ecosystems (Omernik 1995, Griffith and others 1999, Omernik and others 2000). These factors included geology, physiography, vegetation, land use, climate, hydrology, terrestrial and aquatic fauna, and soils. The combination and relative importance of these characteristics varies from one place to another, regardless of the hierarchical level (Wiken 1986, Omernik 1995, Omernik and others 2000). Because the processes that affect the health and integrity of ecosystems vary infinitely in space and time, the method of mapping ecoregions is necessarily one of pattern analysis rather than identification of ecological processes.

This method of defining ecoregions has been termed the *weight of evidence* approach (McMahon and others 2001). The approach recognizes that the quality and quantity of environmental resources that make up ecosystems, and the way they are interrelated, vary infinitely in space and time, and that to determine regions within which there is spatial coincidence in the geographic phenomena that cause or reflect regional differences in ecosystems, one must filter through the maps and other materials that represent the geographic nature of each characteristic (Omernik 1995). The relative importance of each characteristic varies from one region to another at all scales. A major strength of the approach lies in the scrutiny and analysis of multiple geographic phenomena associated with spatial differences in the mosaic of ecosystems. Maps of particular characteristics, such as physiography, geology, vegetation, and soils, are simply representations of aspects of those characteristics. Each map is different in purpose, level of generality (even if at the same scale), relative accuracy, and classification used. In the compilation of all maps, subjective determinations must be made concerning the classification used, the level of generality, and what can and cannot be represented, regardless of whether the map is computer generated or hand drawn. Hence, although quantitative Geographic Information Systems (GIS) methods might be helpful for predictive modeling and ecological response to management, especially at smaller regional and local levels, they cannot account for the spatial differences in the relative importance of geographic characteristics that are important in determining ecological regions (Bailey 1988).

One example of the weight-of-evidence approach for mapping Level III ecoregions can be seen in the way two subdivisions of the Great Plains—the Western High Plains and the Southwestern Tablelands—were distinguished. Through analysis of maps of the many geographic phenomena that are associated with differences in ecosystems, the Western High Plains were found to be higher and drier than the Central Great Plains to the east. Also, in contrast to the irregular, mostly grassland or grazing land of the Northwestern Great Plains to the north, much of the Western High Plains comprise smooth to slightly irregular plains having a high percent of cropland. Grama-buffalo grass is the potential natural vegetation in this region, as compared to mostly wheatgrass-needlegrass to the north. The northern boundary of the Western High Plains coincidentally is also the approximate northern limit of winter wheat and sorghum and the southern limit of spring wheat, reflecting a phenological break likely to affect other biotic components of ecosystems. Unlike most adjacent Great Plains ecoregions, particularly the Western High Plains, little of the Southwestern Tablelands is arable and in cropland. Whereas the Western High Plains is relatively flat, much of the Southwestern Tablelands contains irregular topography, hence sharp differences exist between the regions regarding habitat for faunal components of ecosystems. Sitting atop the Ogallala aquifer, the Western High Plains contains numerous playas important to migratory birds, and much of the cropland is irrigated. These characteristics are uncommon or absent in the Southwestern Tablelands. Because of the sharp differences in physiographic, aquatic, and land use characteristics between the two regions, one would expect significant differences in water quality and quantity, and mosaics of plants and animals.

It is important to observe that as sharp as the differences appear along some boundaries of ecoregions, such as that between the Western High Plains and the Southwestern Tablelands, the ecological boundaries are not precise and do not follow specific characteristics. Although there is a common tendency for people to draw the ecoregion boundary between the two regions along one characteristic—in this case the sharpest topographic break (or apparent edge of the cliff)—many ecological characteristics do not recognize the ecoregion boundary as being that precise. Even along seemingly sharp boundaries such as these there are transitions. Birds of prey, for example, might be more likely to nest in the more rugged portions of the Southwestern Tablelands, but depend on rodents found on the plains within the Western High Plain. The break in vegetation from cropland in the Western High Plains to juniper, grasses, and shrubs of the Southwestern Tablelands does not occur at the edge of the cliff (where it is sharp), but generally a short distance beyond, on the more level land above the cliff, reflecting the gradation in soil type and depth and effect of the aquifer along the border. As is the case in mapping any ecoregion boundary, it is important to consider all aspects of ecosystems—biotic, abiotic, terrestrial, and aquatic.

The weight-of-evidence approach of regionalization depends heavily on the tacit knowledge of the map compiler. The practice of using tacit knowledge and art has had a long tradition in the mapping of soils (Hudson 1992). In order to create accurate maps of soil patterns, effectively extrapolating from information sampled from a tiny fraction of the soil beneath the earth's surface, one must first learn to visualize the landscape in a holistic sense—"as an entity unto itself" (Hudson 1992). This necessitates developing an understanding of the basic interrelationships between soils and patterns of geographic phenomena, such as vegetation, climate, physiography, bedrock and surficial geology, hydrology, and land use. The same is true for mapping ecological regions, except that in this case the objective is to define regions where there are similarities in the mosaics of all ecosystems and their components.

After publication of the first hierarchical level of the EPA framework (Omernik 1987), coarser (more general) hierarchical levels were developed in connection with an effort to define ecological regions for North America (CEC 1997). To avoid confusion among individuals and agencies within the United States and among different countries regarding names for each of the levels, a Roman numeral classification scheme was adopted. Level I is the coarsest level, dividing North America into 15 ecoregions. At Level II, the continent is subdivided into 52 ecoregions. Level III, which is the level of detail of the original work published in 1987, is a further subdivision of Level II. For much of the conterminous United States, Level IV, a subdivision of Level III, has also been mapped (e.g., Griffith and others 2001, McGrath and others 2001).

The more detailed development of Level IV ecoregions was initiated and funded largely by state and regional regulatory agencies that wanted refinement of the Level III regions and delineation of subregions. At first, the projects to refine and subdivide the ecoregions involved mainly research geographers and state water quality resource management agency personnel. However, since 1994, when the NITT was formed to develop a common interagency framework of ecological regions, efforts have been made to include all of the major federal resource management agencies in the ecoregion refinement and subdivision projects. The goal for each of these collaborative projects was to attain consensus across agencies and ultimately consistency in ecoregion frameworks for the entire nation.

To decrease the inconsistency in the ways the regions are defined, which would be inevitable if the responsibility for development of the framework were delegated to regional experts in different parts of the country, a small team of geographers affiliated with EPA have facilitated the state-level projects. It has taken at least 2 years to complete each of these projects. The several steps include data gathering and review meetings, to which regional experts from academia and state and federal resource management agencies are invited. With input from these regional and local experts, the EPA-affiliated team compiles the various iterations of draft maps and descriptions. After general agreement has been reached on Level III and IV ecoregions for a particular state, field verification of the map is conducted, with the length of trip depending on the size and complexity of the subject state or region. Participants in these exercises, many of whom also become coauthors of the final mapped products, include experts on the soils, vegetation, geology, physiography, water quality, and fauna of the area. Based on decisions made on these trips, modifications are made to the map and descriptions, and a final product is prepared and submitted for peer review and subsequent publication.

Key to the quality and ultimate usefulness of the final map is the multidisciplinary and multiagency nature of the framework's development. This is particularly important in the field verification process, where experts with different backgrounds from different agencies and academic departments discuss differences in region and boundary identification, with the goal of reaching consensus on a framework that identifies ecological regions rather than regions that address spatial differences in more specific subjects such as plant communities, agricultural potential, geological characteristics, water quality, or physiography. By participating in these exercises and learning from one another, experts in different fields recognize the existence of the general purpose ecological regions and gain a better understanding of their usefulness for integration of resource management activities.

Future Directions

The effective implementation of ecosystem assessment, research, and management at all scales is dependent on development of an increased understanding of the nature of ecological regions. We must develop ways to illustrate the nature of ecoregion boundaries and the variability of characteristics within the regions that are important to ecosystem management. Work should continue on the development of a common framework of ecoregions for the United States and North America. The effort ideally should be extended to the world. To better understand the usefulness and limitations of the different existing frameworks, we should compare and evaluate them for their effectiveness in addressing specific and general management needs. Also, we must develop better ways to make these evaluations, specifically those concerning general-purpose ecoregions.

Although GIS methods are inappropriate for defining ecoregions, they should be extremely helpful in illustrating the nature of ecoregion boundaries and within-region variability. Several studies have shown that specific characteristics of nationwide databases of certain geographic characteristics correspond almost perfectly with many ecoregion boundaries and reveal somewhat unique patterns within many ecoregions (Loveland and others 1995, Vogelmann and others 2001, Shirazi and others 2003). However, as one might expect, the correspondence is not the same for data sets of different characteristics. For example, although the national land cover data sets (Loveland and others 1995, Vogelmann and others 2001) and a depiction of characteristics in a combination of soil texture and percent rock from the nationwide State Soil Geographic Data Base (Shirazi and others 2003) are in agreement in recognizing numerous ecoregion boundaries, many boundaries are recognized by one data set but not the other. It should be possible to begin to illustrate the nature of ecoregions and ecoregion boundaries by using GIS techniques to depict the combinations of characteristics that distinguish one region from those that distinguish another. A complicating factor, however, is the fact that the number and set of characteristics important in giving each region its identity vary from one region to another, regardless of the hierarchical level. Another problem is the lack of spatially consistent nationwide data sets.

Continuing the collaborative state- and regional-level projects to refine Level III ecoregions and develop Level IV ecoregions is critical for advancing our understanding of ecoregions and moving toward attaining consistency and consensus in ecoregion frameworks for the United States. The products of these projects have also aided in better understanding the regional nature of land cover change, which has relevant implications for environmental management (Loveland and others 2002). Also important have been the efforts by the CEC to develop the coarser levels (I and II) of a common framework for North America (CEC 1997). These regions have been used to examine the effectiveness of protected areas (Wiken 1999), to monitor the conservation of grassland habitats (Gauthier and Wiken 2003), and to develop ecologically based planning, implementation, and evaluation units for cooperative bird conservation in the United States and North America (Fitzpatrick 2002). At the time the map of ecoregions of North America was compiled, it was in agreement with the US EPA framework for the United States. However, the ecoregion mapping for the continent should now be further developed at lower hierarchical levels (III and IV) and revised to incorporate the modifications that have resulted from the subsequent collaborative regional projects and NITT work in the United States. Eventually, an effort should be made to develop a spatially consistent framework of ecological regions for the world. This effort should be done in a way that incorporates coauthorship of experts in ecoregion mapping from the different continents and countries.

Lastly, comparisons should be made of the different existing frameworks that are titled ″ecoregions″ or are used for ecosystem management. Some of these frameworks were developed for purposes that some could argue do not address ecosystems in the broadest sense of the word. For example, the World Wildlife Fund (WWF) ″Terrestrial Ecoregions of North America″ (Ricketts and others 1999) was developed to identify areas of unique biodiversity. For the conterminous United States, these regions were adapted from Omernik 1995, with many of the modifications identifying areas of ″exceptionally distinct assemblages and unique habitats″ (Ricketts and others 1999). When evaluated against data reflecting the purposes of the WWF, these regions could be more helpful than an ecoregion framework designed for ecosystem management in a broader sense—integration across all environmental resource programs and agencies. It should be stressed that general purpose ecoregions are not meant to replace specific purpose frameworks such as that of the WWF. When the primary concern is addressing specific problems, such as unique habitats of endangered species, agricultural potential, or preservation of vegetative complexes, specific frameworks based on characteristics associated with those issues should be developed. On the other hand, to reduce the confusion over the many frameworks that use the term *ecoregion* in their title, the strengths, limitations, and specific purposes of each must be clarified. The titles of each framework should reflect its primary purpose. Evaluations and comparisons of the most commonly used frameworks should be made with data for a variety of environmental and ecological conditions. Most important, research should be conducted on the development of indices of ecological integrity to evaluate the frameworks appropriately for the purpose of ecosystem management.

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