Ecoregions: A Framework for Managing Ecosystems

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Background

IN RECENT YEARS THERE HAS BEEN AN INCREASING AWARENESS that effective research, inventory, and management of environmental resources must be undertaken with an ecosystem perspective. Resource managers and scientists have come to realize that the nature of these resources (their quality, how they are interrelated, and how we humans affect them) varies in an infinite number of ways, from one place to another and from one time to another. However, there *are* recognizable regions within which we observe particular patterns (Frey 1975). These regions generally exhibit similarities in the mosaic of environmental resources, ecosystems, and effects of humans, and can therefore be termed "ecological regions" or "ecoregions." Definition of these regions is critical for effectively structuring biological risk assessment, which must consider the regional tolerance, resilience, and attainable quality of ecosystems.

There is general agreement that these ecological regions exist, but there is considerable disagreement about how to define them (Gallant et al. 1989, Omernik and Gallant 1990). Some of this disagreement stems from differences in individual perceptions of ecosystems, the uses of ecoregions, and where humans fit into the picture. Most, however, agree with a general definition that ecoregions comprise regions of relative homogeneity with respect to ecological systems involving interrelationships among organisms and their environment. Rowe (1990, 1992) has argued that ecoregions subsume patterns in the quality and quantity of the space these organisms (including humans) occupy. He implied that the organisms as a group, or singly, are no more central to the system than the space they occupy. Each is a part of the whole, which is different in pattern in space as well as time. This more holistic definition appears to be gaining acceptance (Barnes 1993).

Canadian resource managers have been at the forefront of developing ecoregional frameworks and stressing the need for an ecoregional perspective (Government of Canada 1991). They have argued that the lion's share of environmental research is of the single-medium or single-purpose type (Figure 1), whereas much of the focus and concern of environmental management has recently been on the entire ecosystem, including biodiversity, effects of human activities on all ecosystem components, and the attainable conditions of ecosystems (Wiken, pers. comm.). The problem is that little effort is being expended on studying ecosystems holistically and attempting to define differences

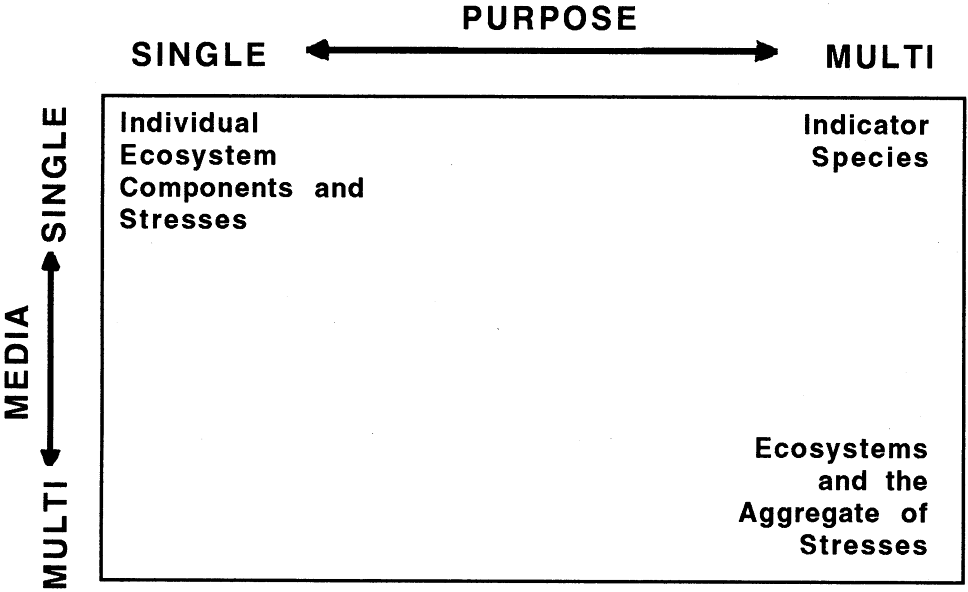


Figure 1. Types of Environmental Research

in patterns of ecosystem mosaics. Wiken is not suggesting, nor am I, that this is an "either–or" situation or that the balance should be reversed. Certainly we must continue basic research on processes and the effects specific human activities (and human activities in aggregate) have on environmental resources. However, to maximize the meaningfulness of extrapolations from these studies and the use of data collected from national or international surveys, we must develop a clearer understanding of ecosystem regionalities.

A large barrier to developing this understanding is the common belief that to be scientifically correct, regions must be quantitatively developed and that they are objective realities (Hart 1982a). Although this belief is being defused with increased understanding of ecosystems, the need to combine art with science in regional geographic research, including the development of ecoregions, continues to meet resistance (Golledge et al., 1982; Hart 1982a, 1982b, 1983; Healey 1983). This resistance is not universal, however, particularly in applied areas such as military intelligence. Military geographers, when tasked to define regions within which broad-scale military operations or specific types of operations may be conducted, have long employed qualitative techniques to filter such aspects as the relative inaccuracies and differences in levels of generality in mapped information (Omernik and Gallant 1990). In this case, the focus is on defining areas within which there is likely to be similarity in general or particular combinations of conditions regarding such factors as physiography, climate, geology, soil type, vegetation, and land use. Knowledge of spatial relationships between geographic phenomena, the relative accuracy and level of generality of mapped information, and differences and appropriateness of classifications on maps of similar subjects, allow the geographer to screen each piece of intelligence (data source) and delineate the most meaningful regions. The test of these regions is in their ultimate usefulness, rather than in the scientific rigor of a particular qualitative mapping technique.

Ecoregion Definition

Ecoregions occur and can be recognized at various scales. If one is viewing the conterminous United States from a satellite, one can recognize broad ecoregions, including the semiarid-to-arid basin, range, and desert areas of the West and Southwest, and the rugged mountains of the West. The latter typically contain a mosaic of characteristics ranging from alpine glaciated areas at or above timberline, to dense coniferous forests, to near-xeric conditions at lower elevations and in rain shadow areas. Other such broad ecological regions include the glaciated Corn Belt and associated nutrient-rich intensively cultivated areas in the central United States and Upper Midwest, and the contrasting nutrient-poor glaciated regions of forests and high-quality lakes and streams in the Northeast and northern Upper Midwest. At a larger scale (closer to the earth), one can recognize regions within these regions, and at successively larger scales, regions within those regions.

The recognition of these regions is nothing new. They have long been perceived by people from all walks of life—from the earliest explorers in whose diaries we read descriptions of the flora, fauna, climate, and physiography in the different regions they traveled, to present-day ecologists and resource managers who are attempting to understand the effects human activities are having on ecosystems. The problem has been in defining the regions. Although most resource managers have a general understanding of the spatial complexities in ecosystems and how they can be perceived at various scales, they tend to use inappropriate frameworks to research, assess, manage, and monitor them. One reason is that until recently there have been no attempts to map ecosystem regions, so rather than make interpretations, managers have chosen surrogates. These surrogates have often been single-purpose frameworks of a particular characteristic believed to be important in causing ecosystem quality to vary from one place to the next. The most commonly used single-purpose frameworks have been potential natural vegetation (e.g., Küchler 1964, 1970), physiography (e.g., Fenneman 1946), hydrology (e.g., U. S. Geological Survey 1982), climate (e.g., Trewartha 1943), and soils (U.S. Department of Agriculture 1981). Another reason for using single-purpose frameworks stems from the belief (mentioned in the preceding section) that a scientifically rigorous method for defining ecological regions must address the processes that cause ecosystem components to differ from one place to another and from one scale to another.

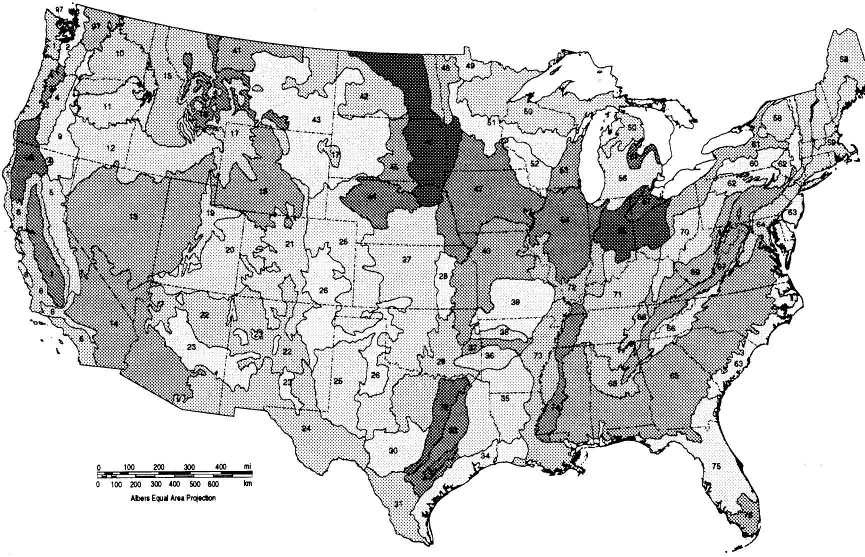
Several classifications have been developed to address biotic regions, or biomes, but with the implication that these classifications define ecosystem regions as well. This is understandable, because the perception that ecosystems comprise more than differences in biota and their capacities and interrelationships, although not new, has gained wide acceptance only relatively recently. Most of these mapped classifications reflect patterns in vegetation and climate and have been regional in scale (e.g., Dice 1943; Brown and Lowe 1982; Brown and Reichenbacher, in press; Holdridge 1959). Very few have been global (e.g., International Union for Conservation of Nature and Natural Resources 1974; Udvardy 1975). Bailey's ecoregions (Bailey 1976, 1989, 1991; Bailey and Cushwa 1981), although based on a number of landscape characteristics, rely on the patterns of a single characteristic at each hierarchical level. These regions have been developed at regional and global scales.

The first compilation of ecoregions of the conterminous United States by USEPA was performed at a relatively cursory 1:3,168,000 scale and was published at a smaller 1:7,500,000 scale (Omernik 1987) (Figure 2). The approach recognized that the combination and relative importance of characteristics that explain ecosystem regionality vary from one place to another and from one hierarchical level to another (Gallant et al., 1989; Omernik and Gallant 1990). This is similar to the approach used by Environment Canada (Wiken 1986). In describing ecoregionalization in Canada, Wiken (1986) stated:

> Ecological land classification is a process of delineating and classifying ecologically distinctive areas of the earth's surface. Each area can be viewed as a discrete system which has resulted from the mesh and interplay of the geologic, landform, soil, vegetative, climatic, wildlife, water and human factors which may be present. The dominance of any one or a number of these factors varies with the given ecological land unit. This holistic approach to land classification can be applied incrementally on a scale-related basis from very site-specific ecosystems to very broad ecosystems.

Hence, the difference between this approach to defining ecoregions and most preceding methods is that it is based on the hypothesis that ecological regions gain their identity through spatial differences in a combination of landscape characteristics. The factors that are more or less important vary from one place to another at all scales. One of the strengths of the approach lies in the analysis of multiple geographic characteristics that are believed to cause or reflect differences in the mosaic of ecosystems, including their potential composition. All maps of particular characteristics (e.g., soils, physiography, climate, vegetation, geology, and land use) are merely representations of aspects of that characteristic. Each map varies in level of generality (regardless if at the same scale), relative accuracy, and classification used. Subjective determinations must be made in the compilation of all maps regarding the level of generality, the classification to be used, and what can be represented and what cannot, whether the map is hand drawn or computer generated. Everything about a particular subject cannot be shown once the map scale becomes smaller than 1:1. Hence, an ecoregion that exhibits differences in characteristics such as physiography or soils may not be depicted by a map of one of those subjects because of the classification and level of generality chosen, as well as the accuracy of the author's source materials. On the other hand, because ecosystem regions reflect differences in a combination of characteristics, use of multiple sources of mapped information permit the detection of these regions. It is simply a matter of safety in numbers.

Although the approaches used by EPA and Environment Canada are remarkably similar, particularly regarding their use of qualitative, or subjective analyses, the initial compilation of ecoregions maps in both countries was completely independent. Authors of the maps in both countries were unaware of the oth-



1 Coast Range, 2 Puget Lowland, 3 Willamette Valley, 4 Cascades, 5 Sierra Nevada, 6 Southern and Central California Plains and Hills, 7 Central California Valley, 8 Southern California Mountains, 9 Eastern Cascades Slopes and Foothills, 10 Columbia Plateau, 11 Blue Mountains, 12 Snake River Basin/High Desert, 13 Northern Basin and Range, 14 Southern Basin and Range, 15 Northern Rockies, 16 Montana Valley and Foothill Prairies, 17 Middle Rockies, 18 Wyoming Basin, 19 Wasatch and Uinta Mountains, 20 Colorado Plateaus, 21 Southern Rockies, 22 Arizona/New Mexico Plateau, 23 Arizona/New Mexico Mountains, 24 Southern Deserts, 25 Western High Plains, 26 Southwestern Tablelands, 27 Central Great Plains, 28 Flint Hills, 29 Central Oklahoma/Texas Plains, 30 Edwards Plateau, 31 Southern Texas Plains, 32 Texas Blackland Prairies, 33 East Central Texas Plains, 34 Western Gulf Coastal Plain, 35 South Central Plains, 36 Ouachita Mountains, 37 Arkansas Valley, 38 Boston Mountains, 39 Ozark Highlands, 40 Central Irregular Plains, 41 Northern Montana Glaciated Plains, 42 Northwestern Glaciated Plains, 43 Northwestern Great Plains, 44 Nebraska Sand Hills, 45 Northeastern Great Plains, 46 Northern Glaciated Plains, 47 Western Corn Belt Plains, 48 Red River Valley, 49 Northern Minnesota Wetlands, 50 Northern Lakes and Forests, 51 North Central Hardwood Forests, 52 Driftless Area, 53 Southeastern Wisconsin Till Plains, 54 Central Corn Belt Plains, 55 Eastern Corn Belt Plains, 56 Southern Michigan/Northern Indiana Till Plains, 57 Huron/Erie Lake Plain, 58 Northeastern Highlands, 59 Northeastern Coastal Zone, 60 Northern Appalachian Plateau and Uplands, 61 Erie/Ontario Lake Plain, 62 North Central Appalachians, 63 Middle Atlantic Coastal Plain, 64 Northern Piedmont, 65 Southeastern Plains, 66 Blue Ridge Mountains, 67 Central Appalachian Ridges and Valleys, 68 Southwestern Appalachians, 69 Central Appalachians, 70 Western Allegheny Plateau, 71 Interior Plateau, 72 Interior River Lowland, 73 Mississippi Alluvial Plain, 74 Mississippi Valley Loess Plains, 75 Southern Coastal Plain, 76 Southern Florida Coastal Plain, 77 North Cascades, 78 Klamath Mountains

Figure 2. **Ecoregions of the Conterminous United States (from Omernik 1987)**

er's ongoing work until after the maps had been compiled. This situation has subsequently changed and those responsible for the design and development of both ecoregion frameworks are now collaborating in a multi-country, multi-agency effort [including the U. S. Geological Survey/Earth Resources Observation Satellite (USGS/EROS)] to develop an ecoregional framework for the circumpolar Arctic-Subarctic region. At the time of this writing, a draft of ecoregions of Alaska, consistent with the ecoregions of Canada, has been completed. Publication of this map is planned for 1995. An additional goal of this group is to develop a consistent ecoregional framework for North America.

Needs for ecoregional frameworks exist at all scales. Global assessments require the coarsest levels, such as the Level I Ecological Regions of North America illustrated on the front cover of this issue. National assessments require more detailed regionalizations such as are provided by the Level II Ecological Regions of North America [Figure 3, reflecting Environment Canada's Ecozones (Wiken 1986) and a revision of aggregations of Ecoregions of the Conterminous United States by Omernik and Gallant (1990]. The scale of state-level needs is more appropriately addressed using EPA's Ecoregions (Omernik 1987) or subregions (Gallant et al., 1989, Clarke et al., 1991), and Environment Canada's Ecoprovinces or Ecoregions. Because of the possible confusion with other meanings of the terms province, zone, district, etc., EPA has not adapted that scheme of naming different hierarchical levels. Instead, EPA is adopting the Roman numeral scheme used by the North American collaborative effort [for which see the article by Wiken and Lawton in this issue], with the lowest numerals being the most general regions and the highest, the most detailed. Regions are simply regions regardless of their scale, but some means of identifying different hierarchical levels is no doubt needed. More detailed ecoregions that would be helpful at local levels, such as defined by Thiele (pers. comm.) for a part of the Grande Ronde Basin in Oregon, have not been developed for the United States. Obviously, the more detailed the hierarchical level (the larger the scale), the more time-consuming the chore of completing ecoregions on a per-unit-area basis.

Refinement of Ecoregions and Delineation of Subregions

A number of states—notably Ohio, Arkansas, and Minnesota—have used the first approximation of ecoregions published in 1987 to develop biological criteria, and to set water quality standards and lake management goals. Most states, however, found the resolution of regions delineated on Omernik's (1987) 1:7,500,000-scale map to be of insufficient detail to meet their needs. This has led to several collaborative projects with states, EPA regional offices, and the EPA Environmental Research Laboratory in Corvallis, Oregon, to refine ecoregions, define subregions, and locate sets of reference sites within each region and subregion. This work is being conducted at a larger scale (1:250,000) and includes the determination of ecoregion and subregion boundary transition widths. These projects currently cover Iowa, Florida, and Massachusetts, and parts of Alabama, Mississippi, Virginia, West Virginia, Maryland, Pennsylvania, Oregon, and Washington. Results of much of this work is in varying stages of completion; some maps with accompanying texts have been submitted to journals for consideration of publication and others are being prepared for publication as state and EPA documents.

The process of refining ecoregions and defining subregions is

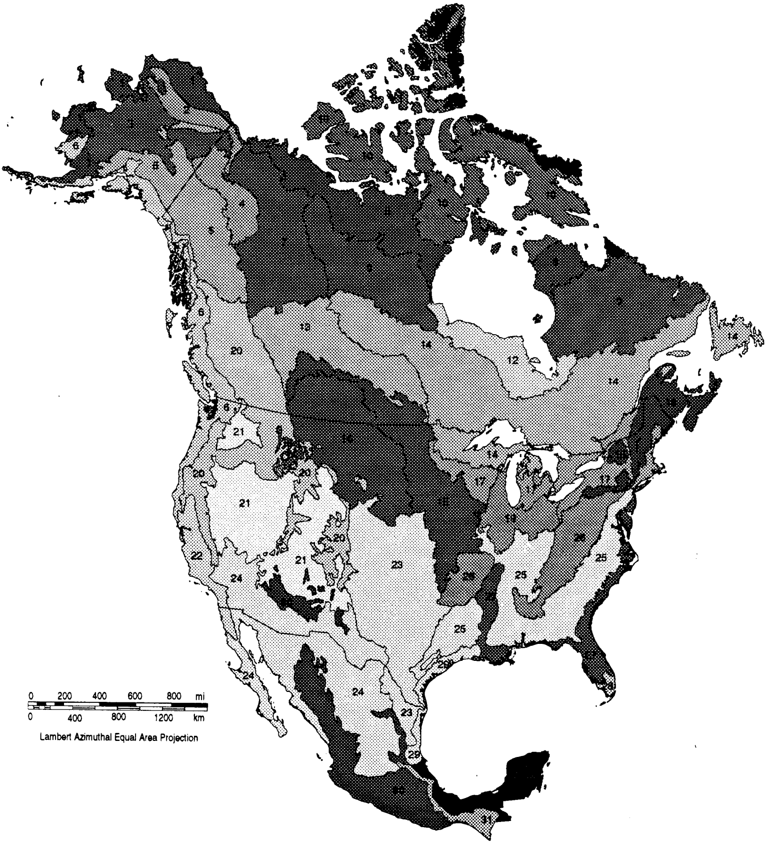


Figure 3. Level II Ecological Regions of North America

similar to the initial ecoregion delineation. The main difference, besides doing the work at a larger scale, is in the collaborative nature of the projects, which include scientists and resource managers from the states and EPA regions covered (and, in many cases, other governmental agencies), as well as geographers at the EPA Environmental Research Laboratory in Corvallis, Oregon. This particular mix of expertise is necessary to maximize consistency from one part of the country to another and to ensure that the final product is useful. The process merely documents the spatial patterns that effective resource managers already recognize. Therefore, interacting with scientists and resource managers who know local conditions is essential in the delineation of ecoregions, particularly at lower hierarchical (larger-scale) levels.

Although some of these ecoregionalization projects have involved only one state, a number have focused on delineation of subregions within one or more ecoregions covering more than one state. One such project encompasses the portions of the Blue Ridge, Central Appalachian Ridges and Valleys, and Central Appalachian Ecoregions that cover Pennsylvania, West Virginia, Virginia, and Maryland (Figure 4). The advantage of this type of project is that it encourages data sharing across state lines and calibration of sampling methods by ecoregion rather than political unit. It also provides a reality check regarding the quality of data collected by different states within the same region. Because natural ecological regions rarely correspond to spatial patterns of state boundaries, or to any other political unit, there are numerous cases where a state covers only a small portion of an ecoregion or subregion that has its greatest extent in neighboring states. The distinctly different subregions of the Central Appalachian Ridges and Valleys

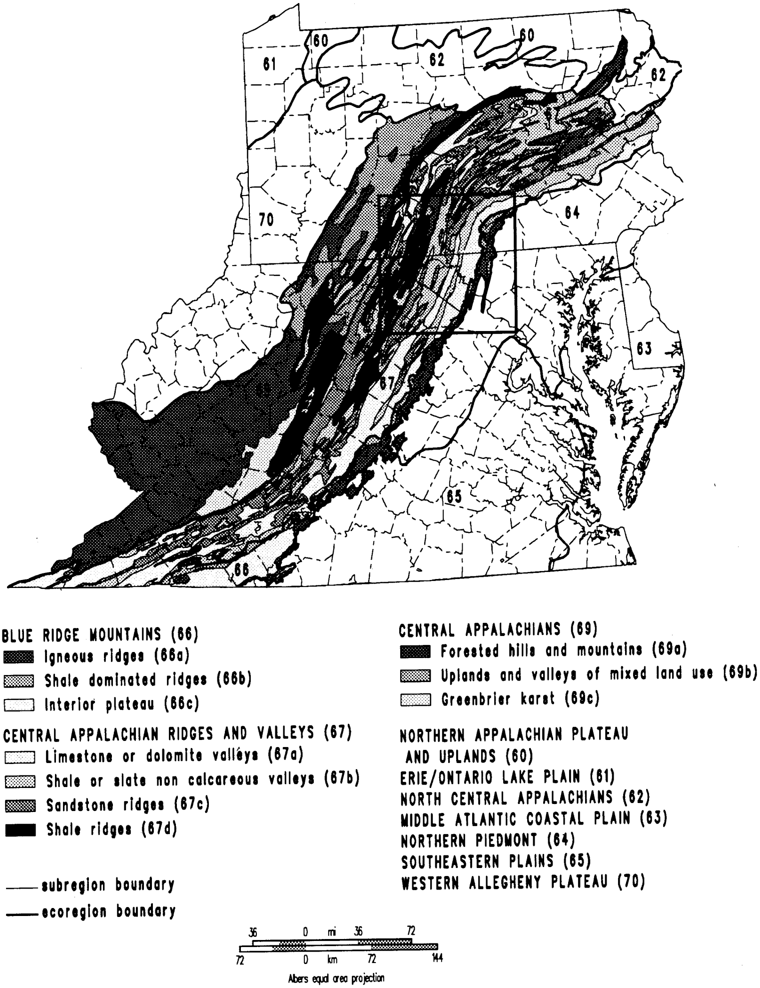


Figure 4. **Ecoregions and Subregions of the Blue Ridge, Central Appalachian Ridges and Valleys, and Central Appalachians of EPA Region 3**

ecoregion provide a case in point (Figures 4 and 5). Most of these discontinuous subregions are in Pennsylvania and Virginia, with only small parts of each in West Virginia and Maryland.

Reference Sites for Aquatic Ecosystems

Upon completion of the initial revision of ecoregions and delineation of subregions, sets of reference sites are identified for each to get a sense of the regionally attainable conditions regarding aquatic ecosystems. "Attainable quality" refers to those conditions that are realistic, rather than "pristine," which implies the unrealistic turning back of the clock and the absence of humans in the ecosystem. Candidate stream sites must be "relatively undisturbed" yet representative of the ecological region they occupy. (Hughes, 1995; Gallant et al., 1989; Hughes et al., 1986).

An initial selection of reference sites is normally accomplished by

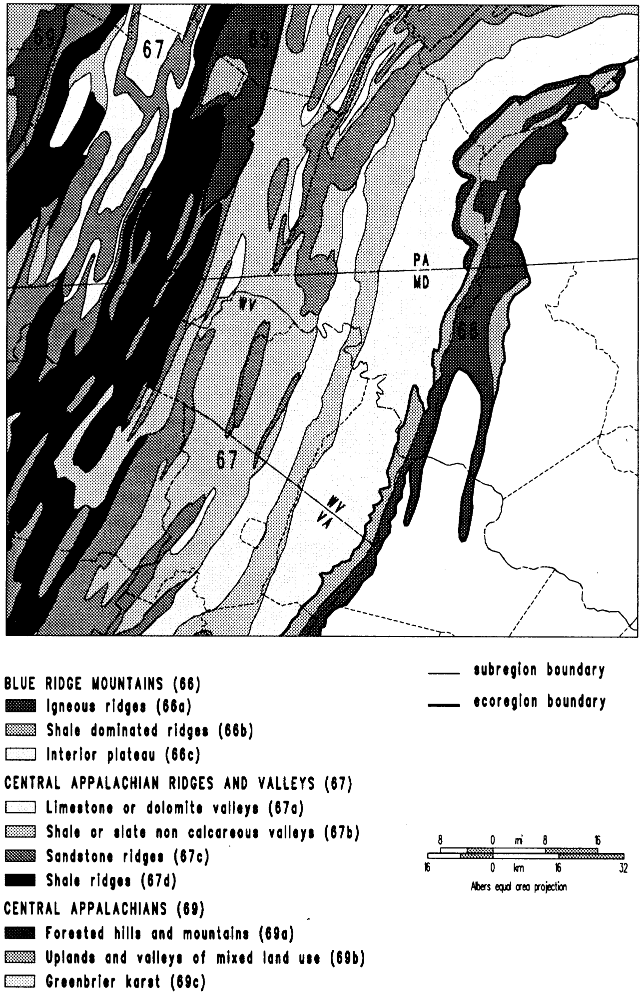


Figure 5. A Portion of the Ecoregions and Subregions of EPA Region 3

interpreting 1:100,000- and 1:250,000-scale maps with guidance from state resource managers as to minimum stream sizes for each subregion and locations of known problem areas and point sources. The probable relative lack of disturbance can be interpreted from topographic maps, particularly the recent 1:100,000-scale series. General determinations of the extent of recent channelization, woodland or forest, urbanization, proximity of roads to streams, and mining and other human activities can be made using these maps. U.S. Geological Survey (USGS) flow records can be consulted to approximate the minimum watershed size necessary for each subregion, but state water resource managers and regional biologists generally have a better idea which streams are of interest because of their intimate understanding of their own areas. Intermittent streams are often considered valued resources if the enduring pools are of sufficient size. State and regional experts should also be consulted regarding the minimum number of sites necessary for each region or subregion. The minimum number is generally a function of the size and complexity of the subregion. For some small or very homogeneous regions, the point of diminishing returns may be reached with a number of five or six, whereas in other complex regions and in areas where reference sites representing different stream sizes are a concern, a much larger number would be desirable.

Field Verification of Reference Sites, Ecoregions, and Subregions. Once sets of candidate reference sites have been identified for each region, they should be reviewed by state biologists and regional experts. Based on their personal knowledge of the region, these regional experts may choose to add or delete potential sites. Then field verification of the ecoregion and subregion delineations is conducted, coupled with visits to representative sets of reference sites within each ecoregion and subregion. Ideally this field work is conducted by the entire group collaborating on the particular regionalization/reference site project. Hence, it should include the geographers responsible for delineating the regions, subregions, and boundary transition widths, as well as compiling the initial list and map of candidate watersheds. The regional biologists and water resource managers who provided information used to define the regions and locate sets of reference sites, and who will eventually use the framework, should also be included. The best test of the regional framework and sets of reference sites is their ultimate usefulness. The regions must make sense to those who know and manager the resources in the area and are developing the biological criteria. Lastly, it is useful to include in the field verification exercises experts from other agencies and biologists from adjacent states who are considering use of the ecoregion/reference site approach in their assessment and regulatory programs.

The Concept of Pristine and Least-Disturbed Conditions. It must be understood that reference sites do not represent "pristine" condition—those which would exist if humans were removed from the scene, or pre-European settlement conditions. To select such sites is impossible. There are no pristine areas in the United States, or in the world for that matter, if the term implies an absence of human impact. The idea that conditions were pristine in North America prior to European settlement has been convincingly challenged recently (Denevan 1992). Humans have probably played a major role in shaping landscape pattern and molding ecosystem mosaics for thousands of years.

Reference sites representing least disturbed ecosystem conditions are a moving target of which humans and natural processes are a part.

Like the mosaic of geographic conditions that shape ecosystem patterns, that which can be categorized as "least disturbed" is relative to the region in which a set of reference sites is being selected. In the Boston Mountains Ecoregion (in Arkansas and Oklahoma), minimally impacted reference sites include streams having watersheds without point sources, little grazing activity, and a relative lack of recent logging activity and road building. In this region, stream reference sites and their watersheds come close to mirroring the present perception that most people have of high-quality stream conditions. In the Huron/Erie Lake Plain Ecoregion (in Ohio, Indiana, and Michigan), on the other hand, there are no streams with watersheds that are not almost completely in cultivated agriculture. Many are also heavily affected by urbanization and industries, and all streams relative to watersheds whose extents are 30 square miles or more have been channelized at one time or another. However, there are some streams that are relatively free of impact from point sources, industries, and major urbanization, that have not been channelized for many years so that the riparian zones have been allowed to grow back into woody vegetation with the channels becoming somewhat meandering. These types of streams and watersheds would constitute relatively undisturbed references for the region. 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. An analysis of the differences in the areal patterns of water quality from reference sites (the biota in particular) with patterns in natural landscape characteristics (such as soil and geology, and human stresses including agricultural practices), should provide a sense for the factors that are responsible for within-region differences in quality. A measure of how much the quality can be improved can then be derived through changing management practices in selected watersheds where associations were determined.

Selecting Reference Sites For Small and/or Disjunct Subregions. The approach for selecting sets of reference sites for subregions is the same as for the larger ecoregions. The maximum stream and watershed sizes of sites representative of subregions are normally smaller, of course, because the subregions are smaller and in many cases discontinuous, such as subregions of the Central Appalachian Ridges and Valleys (Figures 4 and 5). Where subregions represent bands of different mosaics of conditions, as is the case in some western mountainous ecoregions, it may be necessary to choose reference sites that comprise watersheds containing similar proportions of different subregions.

Anomalous Sites. In selecting reference sites, care must be taken to avoid including anomalous stream sites and watersheds. This can be particularly difficult when such streams are very attractive and represent the best conditions in a region. For example, an ecoregion or subregion typified by flat topography and deep soils, where minimally impacted streams with low gradients, no riffles, and sand or mud bottoms are the norm, may also include a small area of rock outcrops and gravels in which streams have some riffles and gravel substrate. Obviously the habitat in these streams is different than elsewhere and therefore the quality regarding biological diversity and assemblages cannot be expected in other parts of the region. Certainly streams such as this one should be protected and not be allowed to degrade to standards and expectations set for streams typical of most of the region, but neither should the typical streams be expected to attain the quality of an anomaly.

Watersheds and Ecoregions

One of the most common spatial frameworks used for water quality management and the assessment of ecological risk and nonpoint source pollution has been that of hydrologic units (or basins or watersheds). The problem with using this type of framework for geographic assessment and targeting is that it does not depict areas that correspond to regions of similar ecosystems or even regions of similarity in the quality and quantity of water resources (Omernik and Griffith 1991). Patterns in Major Basins and USGS Hydrologic Units (USGS 1982), which comprise groupings of major basins with adjacent smaller watersheds and interstices, have no similarity to patterns of ecoregions, which do reflect patterns in aquatic ecosystem characteristics (Figure 6). Many, if not most, major basins drain strikingly different ecological regions.

The recent stress on "a watershed approach," although an excellent idea in that it changes the focus from dealing with predominantly point types of environmental problems to including those of a spatial nature, carries the implication of geographic targeting. The perception is that, by looking at ecosystems and individual environmental resources within a watershed context, we are taking a giant step forward toward understanding ecological risk, ecosystem potential, and, ultimately, more effective ecosystem management. Although the rhetoric may be better, in reality what is being done may be little different than what has been done before. We now call case studies "watershed studies." The real problem is that we may be fooling ourselves into be

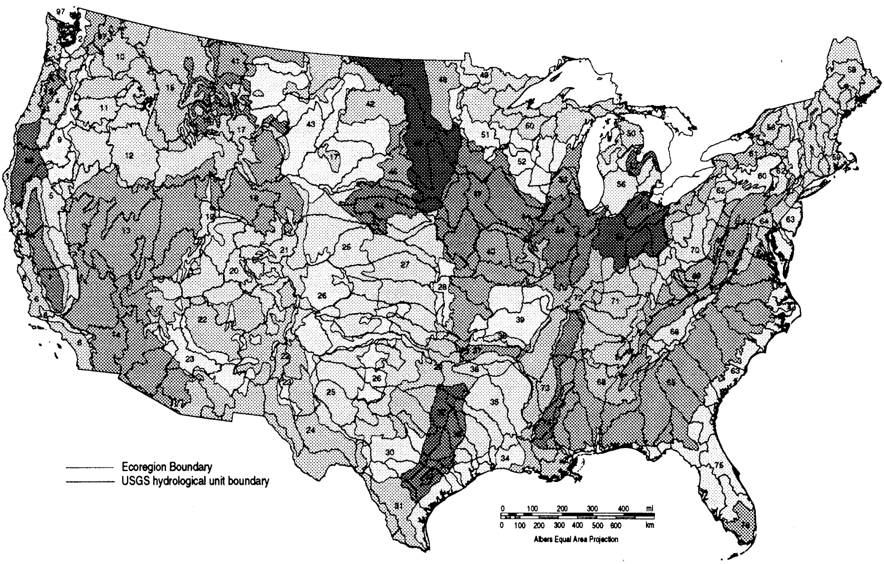


Figure 6. Omernik Ecoregions and U.S.G.S. Hydrologic Units

lieving that by adopting a "watershed approach" we are providing a spatial context within which to better understand and manage ecosystems. Use of watersheds is critical for ecosystem research, assessment, and management, but it should be done within a natural ecoregional framework that subsumes patterns in the combination of geographical characteristics (e.g., soils, geology, physiography, vegetation, land use) associated with regional differences in ecosystems. We must develop an understanding of ecosystem regionalities at all scales, in order to make meaningful extrapolations from site-specific data collected from case studies or watershed studies, or whatever they are called.

Evaluating Ecoregions

As with any new tool, the usefulness of ecoregions must be evaluated. However, the evaluation of a framework intended to depict patterns in the aggregate of ecosystem components is not an easy task. Although commonly done, 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. The work of Larsen and others (1988) in Ohio showed that the patterns of any one chemical parameter often do not demonstrate the effectiveness of ecoregions in that state. However, when the chemistry portion of water quality was illustrated for the Ohio reference sites using a principal components analysis, with a combination of components comprising nutrient richness on one axis and a combination of components comprising ionic strength on the other axis, the ecoregion patterns became quite clear. Similarly, methods of grouping biotic characteristics to express biotic integrity, such as the index of biotic integrity (IBI) (Karr et al., 1986), have effectively shown ecoregion patterns (Larsen et al., 1986). Because of the nature of ecoregions, the ideal way of evaluating them would be through use of an ecological index of integrity. Such an index has yet to be developed and would need to be regionally calibrated. Hence, there is necessarily some circularity in the evaluation process.

It must be recognized that the concept and definition of ecoregions are in a relatively early stage of development. The U.S. EPA Science Advisory Board (1991), in their evaluation and subsequent endorsement of the ecoregion concept, strongly recommended further development of the framework, including collaboration with states regarding the subdivision of ecoregions, definition of boundary characteristics, and evaluation of the framework for specific applications. They saw the need for research to better understand the process by which the regions are defined, and how quantitative procedures could be incorporated with the currently used, mostly qualitative methods to increase replicability. To date, qualitative methods, although used for many applications where the usefulness of the results is more important than the scientific rigor of the technique used, have not been widely accepted. Research must be conducted to demonstrate how the two approaches are complementary. We need to examine the use of art in science, rather than assuming an "either–or" scenario. As we increase our awareness that a holistic ecosystem approach to environmental resource assessment and management is necessary, we must also develop a clearer understanding of ecosystems and their regional patterns. Essential to this is the development of ecological regions and indices of ecosystem integrity.

Acknowledgments

The ecoregion and reference site concepts have been developed through the efforts of many people, too many to acknowledge individually here. The strength and useful-

ness of the framework lies in the collaborative way it has been and is being developed - closely tied to its applications. State and federal resource managers and scientists who helped generate, carry out, evaluate, and otherwise contribute to the various "ecoregions" projects should receive much of the credit for the success of those projects. While not wishing to slight my fellow geographers, and the soils scientists and geologists who have all made invaluable contributions, I feel a special sense of gratitude to the biologists and ecologists for their ideas, mental maps, and understanding. Especially deserving of acknowledgment are the people my geographer colleagues and I have learned from and worked with at the EPA laboratory in Corvallis.

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