CHAPTER 5

Ecoregions: A Spatial Framework for Environmental Management

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1.0 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 impact 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 ecological regions 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 majority of environmental research is of the single-medium/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, personal communication). Efforts to assess, research, and manage the ecosystems (multipurpose/multimedia, or lower right-hand portion of Figure 1) are normally carried out via extrapolation from data gathered from single-medium/single-purpose research (e.g., effects of logging road construction on salmonid production in streams) or in some cases through single-medium/multipurpose studies such as using indicator species. The problem is that little effort is being expended on studying ecosystems holistically and attempting to define differences 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, in order to maximize the meaningfulness

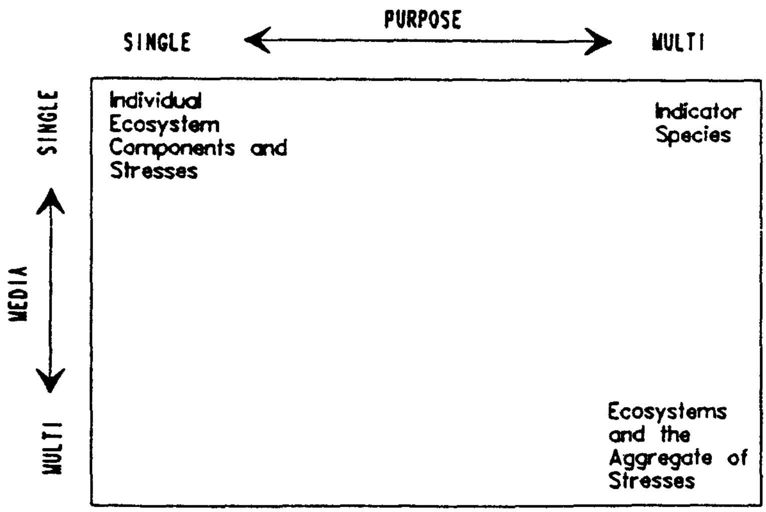

Figure 1. Types of environmental research.

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 a clear understanding of ecosystem regionalities is the common belief that to be scientifically correct, regions must be quantitatively developed and that they are objective realities (Hart 1982a). In a review of regionalization, Grigg (1967) appeared to conclude that to be effective regionalization must be quantitative or objective, apparently based on the assumption that certain processes determine spatial patterns of geographical phenomena at certain scales. His principles of regionalization clearly reflect this belief. Grigg noted that this line of thinking was especially true of the work of geographers in eastern Europe and Russia, although he foresaw a change in this point of view. The idea that subjective approaches might be appropriate was generally Western (particularly North American). To date, attempts to define ecological regions using only quantitative techniques have met with little success. However, efforts to understand and even map ecosystem regionalities in a "scientifically correct", purely quantitative way, appear to be growing. Levin (1992) has acknowledged that "the problem of pattern and scale is the central problem in ecology," but he stressed that to gain an understanding of the patterns of ecosystems in time and space and the causes and consequences of patterns, we must develop the appropriate measures and quantify these patterns. The "patterns" Levin referred to are doubtless the regionalities of ecosystems, or ecological regions, that occur at all scales. What we must also realize, however, is that valuable as this type of research is, it is likely to bear fruit only if sufficient, complementary qualitative geographic research on ecosystems and the aggregate of ecosystem components and human imposed stresses is also conducted.

The development of ecological regions has been, and will probably continue to be, challenging and controversial. Until quite recently, another criticism that has impeded geographers in the development of effective regions has been that to base an ecological approach on the assumption that different regions have different capacities for organisms (including humans) was believed to be subscribing to "environmental determinism". 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. Advances in remote sensing and geographic information systems have obviously greatly increased the efficiency of the regionalization efforts, but qualitative analyses continue to be invaluable in providing meaning to regional responses in remote sensing products and map interpretation.

2.0 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 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 logs we read descriptions of the different mosaics in 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 for this 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 comprised 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., USGS 1982), climate (e.g., Trewartha 1943), and soils (U.S. Department of Agriculture 1981). Another reason for using single-purpose frameworks, as mentioned in the preceding section, stemmed from the belief 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; Holdridge 1959; Brown and Lowe 1982; Brown and Reichenbacher, in press). 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. A more detailed explanation of Bailey's approach and its limitations with respect to attempts to use it to frame aquatic ecosystems are given later in this chapter.

The need for an ecoregional/reference site framework to facilitate the development of biological criteria was recognized in the late 1970s. This need was part of a larger concern for a framework to structure the management of aquatic resources in general (Warren 1979) and was coupled with an increasing awareness that there was more to water quality management than addressing water chemistry, which had been the primary focus. The biota must be considered as well, as must the physical habitat and the toxicity (Karr and Dudley 1981).

The earliest attempts within the Environmental Protection Agency (EPA) to classify streams and other aquatic resources adapted Bailey's (1976) ecoregion classification. It was felt that the character of streams reflects the aggregate of the characteristics in the watersheds they drain. Because Bailey's scheme incorporated a number of these characteristics and was intended to show differences in patterns of ecosystems, it appeared to provide a logical framework. However, an attempt to use the scheme for classifying aquatic ecosystems proved unsuccessful and resulted in the development of a different framework believed to be more effective (Hughes and Omernik 1981*a*; Omernik et al. 1982) Although Bailey's approach, which is based on the work of Crowley (1967), considers a number of characteristics, it depends largely on a single characteristic at each hierarchical level, and therein appears to be the problem. At the "section" level, for example (there are roughly 53 sections in the conterminous United States), the regions are based primarily on Küchler's (1964, 1970) potential natural vegetation. At Bailey's next more detailed "district" level, Hammond's (1970) land surface form regions are used. These characteristics are helpful in identifying ecoregions in some parts of the country, but not others. The Sand Hills of Nebraska, a relatively large, homogeneous ecological region, recognized on nearly every small-scale map of soils, physiography, geology, vegetation, and land use, was not identified at Bailey's section level because of the way in which Küchler's classification was applied. Although Hammond's land surface form is useful for defining ecoregions in some areas at the scale of Bailey's districts, it is very ineffective in others such as the Southern Rockies where elevational and vegetative differences are far more important. Here, Hammond land surface form map units, based on physiographic characteristics such as high mountains with greater than 3000 feet of local relief and less than 20% of the area gently sloping, often cover the gamut of ecosystem variations in the larger ecological region they occupy.

The first compilation of ecoregions of the conterminous United States by EPA 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 other's ongoing work until after the maps had been compiled. This situation has subsequently changed

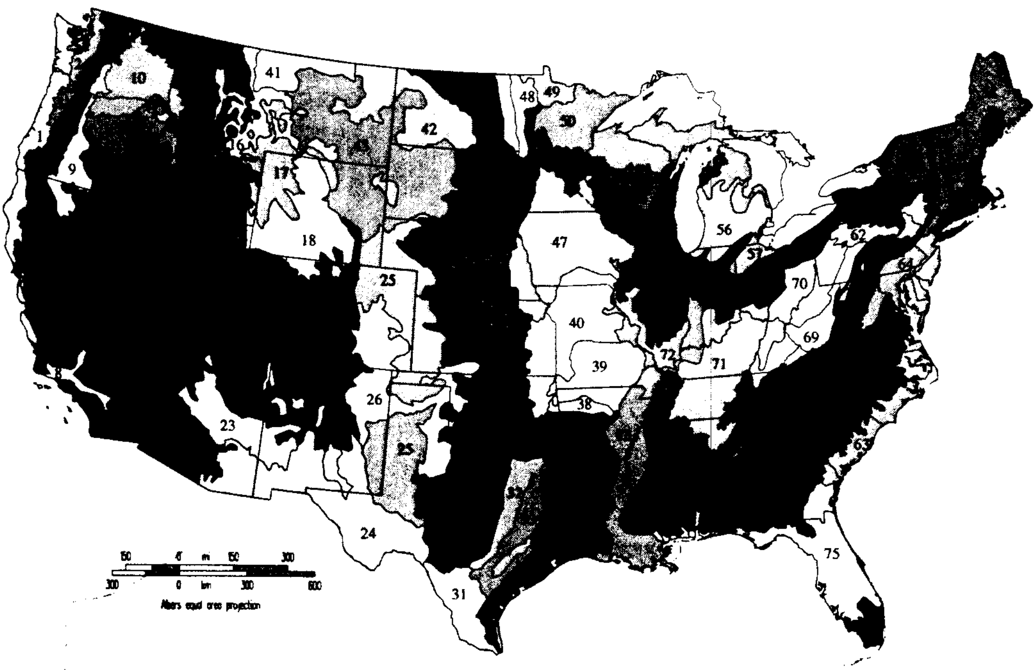

Figure 2. Ecoregions of the conterminous United States. 1 Coast Range, 2 Puget Lowland, 3 Willamette Valley, 4 Cascades, 5 Sierra Nevada, 6 Southern and Central California Plains and Hills, 7 Central California Valley, 8 Southern California Mountains, 9 Eastern Cascades Slopes and Foothills, 10 Columbia 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. (Adapted from Omernik, J. M., *Ann. Assoc. Am. Geographers*, 77: insert, 1987.)

and those responsible for the design and development of both ecoregion frameworks are now collaborating in a multicountry, multiagency 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 1994. 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 and national assessments require more detailed levels such as are provided by EPA's Ecological Areas of the Conterminous United States (Figure 3) [a revision of Aggregations of Ecoregions of the Conterminous United States by Omernik and Gallant (1990)] or Environment Canada's Ecozones (Wiken 1986). 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

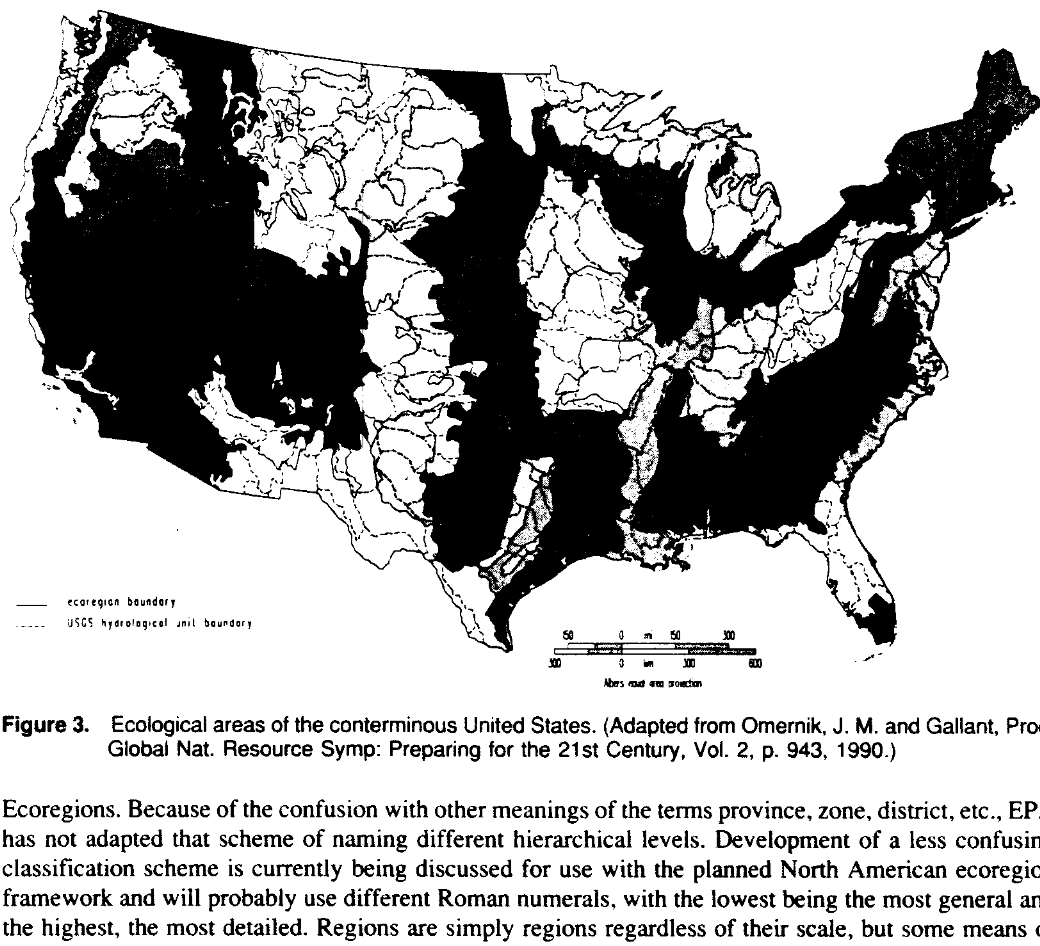

Figure 3. Ecological areas of the conterminous United States. (Adapted from Omernik, J. M. and Gallant, Proc. Global Nat. Resource Symp: Preparing for the 21st Century, Vol. 2, p. 943, 1990.)

Ecoregions. Because of the confusion with other meanings of the terms province, zone, district, etc., EPA has not adapted that scheme of naming different hierarchical levels. Development of a less confusing classification scheme is currently being discussed for use with the planned North American ecoregion framework and will probably use different Roman numerals, with the lowest being the most general 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 (personal communication) 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.

3.0 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 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 insure 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 involving more than one state covering similar ecological regions and subregions 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 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 ecoregion provide a case in point (Figures 4 and 5). Most of these discontinuous subregions are in Pennsylvania and Virginia and only small parts of each subregion occur in West Virginia and Maryland. Where a number of reference sites within each subregion are needed to determine within-region variability, realistically attainable quality (discussed later in this chapter and in greater detail in Hughes, Chapter 4), and between-region differences, the number of sites available within either West Virginia or Maryland is likely to be insufficient.

Typically a project to refine ecoregions, define subregions, and locate sets of reference sites begins with a data collection meeting. This meeting should include those people who have spatial perceptions of the environmental resources and ecosystem patterns in the particular regions covered, those who have knowledge of data sources, and those who will be eventual users of the framework. It is important to include representation from the various state and federal agencies that have mutual interests in resource quality (aquatic and terrestrial) in the particular ecoregions covered by the project. Data needs include medium-scale (generally 1:250,000 to 1:1,000,000) mapped information on causal and integrative factors such as bedrock and surficial geology, soils, land use, hydrology, physiography, and existing and potential vegetation, as well as available interpretations (written or mapped) of biomes or ecosystems. Some of the most important sources of information are the "mental maps" of ecosystem patterns held by scientists and resource managers who have studied the area.

Remote sensing data, particularly data from National Oceanic and Atmospheric Administration (NOAA) and Advanced Very High Resolution Radiometer (AVHRR), are also helpful in defining ecological regions. The wide swath width per scene (up to 27,000 km), pixel resolution of approximately 1 km^2, and suitability for combination into average, seasonal, or annual classes such as "vegetation greenness" (Loveland et al. 1991) make AVHRR data appropriate for broad-scale regional analysis of ecosystem patterns. These data appear to be especially helpful in attaining consistency across international borders and other areal units where mapped resource materials on landscape characteristics vary in quality, availability, and type.

Based on the information gathered, and using the methods outlined by Omernik (1987), Gallant et al. (1989), and the publications in preparation covering the recent state and multi-state subregionalization projects, a first approximation of refined ecoregions and subregions is then complied. However, the methods are continually being refined. Each new project reveals its own unique set of problems and challenges, but much of the knowledge gained from involvement in the variety of geographic areas covered and the variety of scales on which the work has been conducted can be applied to new projects and areas.

Critical to the process of interpreting and integrating the source material is the care that must be taken to avoid defining regionalities of particular ecoregion components such as fish or macroinvertebrate characteristics, or patterns in a single, or a set of, chemical parameters. At the onset of each project, and at the initial idea and data gathering meetings, the question of whether ecoregions or special purpose regions are desired is always asked. When the interest is on a particular subject such as eutrophication, sensitivity of surface waters to acidification, or nutrient concentrations in streams, special purpose maps rather than ecoregion maps are appropriate and can be developed (e.g., Omernik 1977; Omernik and Powers 1983; Omernik and Griffith 1986; Omernik et al. 1988). But response to the question in nearly every case has been that ecoregions are the desired regional framework. The primary interest of most state environmental resource management agencies has been in developing biological criteria, but there has also been concern for a mechanism to structure the assessment and management of nonpoint source

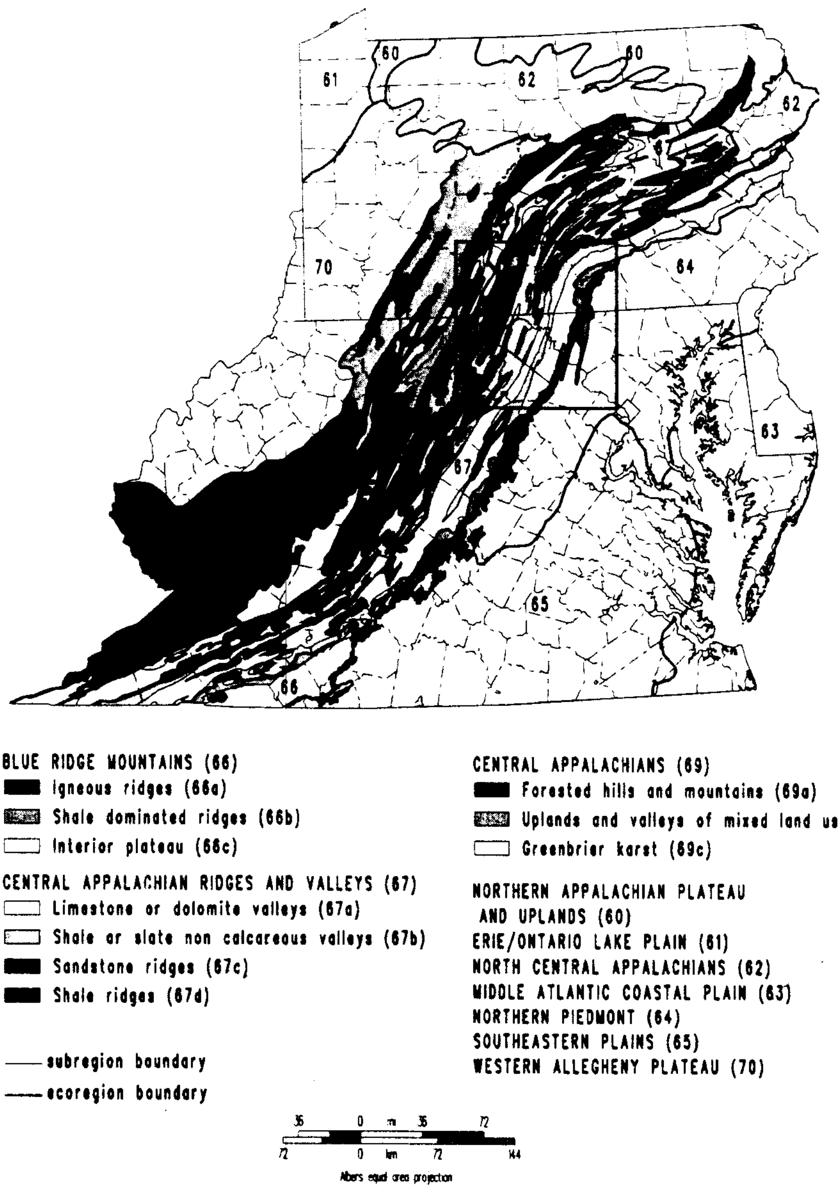

Figure 4. Ecoregions and subregions of the Blue Ridge, Central Appalachian Ridges and Valleys, and Central Appalachians of EPA Region 3. (Boxed portion is enlarged in Figure 5)

pollution as well as a variety of environmental resource regulatory programs. The attractiveness of an ecoregional framework is that, although not fitting any one purpose perfectly, it has general applicability to many environmental resource management needs, and facilitates reporting and transfer of information between subject areas (e.g., wetlands, surface waters, forestry, soils, and agriculture).

4.0 REFERENCE SITES

Upon completion of the initial revision of ecoregions and delineation of subregions, sets of reference sites are identified for each subregion. As with the regionalization, this process is collaborative, but

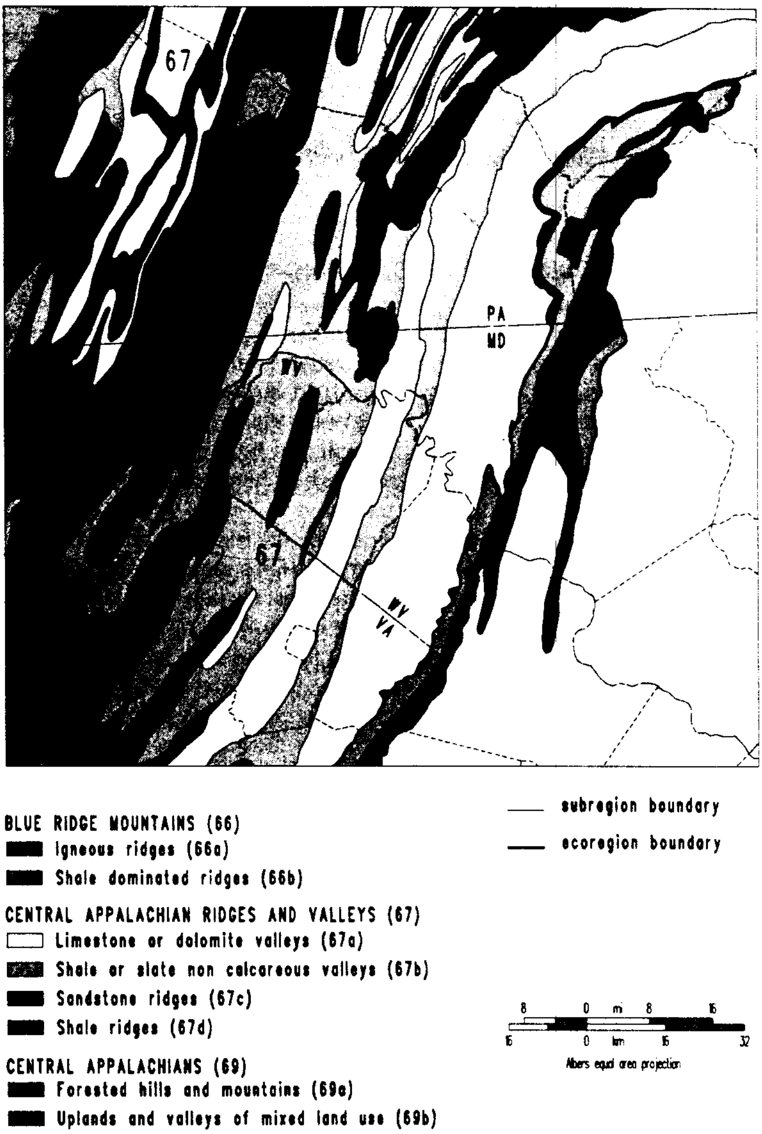

Figure 5. A portion of the ecoregions and subregions of EPA Region 3.

normally with heavier involvement of state biologists and ecologists. In general, sets of reference sites are selected for each region and subregion to get a sense of the regionally attainable conditions regarding aquatic ecosystems. Attainable quality refers to those conditions that are realistic, rather than "pristine", 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 et al. 1986; Gallant et al. 1989; Hughes, Chapter 4).

An initial selection of reference sites is normally accomplished by 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. 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 about when a stream becomes a stream 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.

4.1 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. Also included should be 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. 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 manage 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.

Visits to a number of stream reference sites in each region allow a visual subjective analysis of within- and between-region similarities and differences regarding stream habitat conditions as well as landscape characteristics of the ecoregions and subregions the reference sites/watersheds occupy. Here it is important to maximize the number of sites visited and to spend only as much time at each site as is necessary to evaluate regionalities in site characteristics and the natural and anthropogenic factors that may cause within-region differences. Sampling at each site at this stage should not go beyond turning over a few rocks and/or roughly sorting a leaf pack. Not only is this a helpful cursory method of evaluating stream and habitat quality, it would be practically impossible to restrain most biologists from the activity when they are at the stream site. Final selection of sets of stream reference sites is made by state resource managers and biologists after they have visited and evaluated all candidate reference sites.

4.2 The Concept of Pristine and Least-Disturbed Conditions

It must be understood that reference sites do not represent "pristine" conditions, conditions that 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 is to imply an absence of human impact. Even sites in remote mountainous areas have been impacted by human-caused atmospheric pollutants. Reference sites representing least-disturbed ecosystem conditions are a moving target of which humans and natural processes are a part. The idea that conditions were pristine in North America prior to European settlement has been convincingly challenged in the past couple of decades (Denevan 1992). Humans have probably played a major role in shaping landscape pattern and molding ecosystem mosaics for thousands of years. It is unrealistic to attempt to map the ecosystem regions and reference site conditions that we believe would exist if humans were removed from the scene, unless of course we are all willing to move to another planet. It is also inadvisable (perhaps stupid or self-destructive would be better words) to fail to recognize the impact we humans are having on the overall system of which we are but one part, and what we must do to maintain the integrity of the system.

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 comprise 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 impacted by urbanization and industries, and all streams relative to watersheds of 30 mi^2 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 comprise 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.

4.3 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. Subregions of the Southern Rocky Mountains Ecoregion are, for example, characterized by different combinations of vegetation, elevation, land use, and climate characteristics (Gallant et al. 1989). Although factors such as geology and soils are also important, the other factors appear to be the most important in this ecoregion. One subregion consists of disjunct areas at or above timberline with heavy snowpack and most of the alpine glacial lakes in the ecoregion. Another comprises the areas generally at lower elevations with coniferous forest, steep gradient streams, and little to no grazing activity, because of limitations such as soil productivity. Still another subregion consists of the areas, generally at even lower elevations, where mixed forest and grazing are common. Yet another subregion is made up of the drier portions of the ecoregion, generally bordering adjacent predominantly xeric ecoregions. For the most part, only very small streams have watersheds completely within any one of these subregions. Larger streams more closely meeting size criteria for reference sites tend to drain areas in two or more subregions. Sets of reference sites for these types of subregions must therefore consist of watersheds that have similar proportions in different subregions. When selecting these sites one must account for the fact that minimally disturbed conditions often vary considerably from one subregion to another. Streams/watersheds within each set should be similar to one another regarding "relative disturbance" and should reflect higher water quality than streams with watersheds with similar proportions in each subregion but with greater human impact.

4.4 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 normal, 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.

5.0 AERIAL RECONNAISSANCE OF ECOREGIONS

Visits to ecoregions are critical for verifing the regions and the approximations of boundary transition widths. Although often prohibitive because of cost, and time consuming because of visibility limitations in some regions, overflights are invaluable. By visualizing regions from different distances above the ground we can more easily distinguish the "forest from the trees." When we are too close to a subject, our attention is drawn to details. When we attempt to regionalize from this vantage point we have a tendency to define regions based on all of the details and relationships we have observed. When standing back away from the subject, we are able to observe the patterns in the sum of these details and interrelationships. Certainly many factors that are important in molding ecosystem regionalities miss the eye when we visualize the earth from a distance, but many if not most of the general characteristics that affect the quality, quantity, and distribution of ecosystem components can be perceived from a distance. These interrelated characteristics include land surface form, vegetation, and land use. Differences in patterns of these characteristics reflect differences in soils, geology (bedrock and surficial), climate, hydrology, and biological diversity.

As in the interpretation of any map, there are caveats to consider when verifying ecosystem patterns from the air. One must take into consideration the season, as well as precipitation and temperature deviations (both long and short term) and how they may have affected vegetation and land cover patterns. Patterns in human activities must be considered as well, and these often vary as a function of ownership or political unit, as well as ecoregion, which reflect differences in potential and capacity. When flying over the Southern Rocky Mountains along the Wyoming/Colorado state line in mid-1980, I noticed differences in timber management practices between states. North of the line in Wyoming, patterns of logging activity were apparent, whereas south of the line they were not. This may not have been a difference in state practices. It may have reflected differences in ownership, say, between federal and state or federal and private. Regardless, such within-ecoregion differences in land use and land cover must be distinguished from ecoregional characteristics.

Remote sensing data such as that from AVHRR data are often useful in sorting these patterns. Vegetation greenness classes derived from periodic AVHRR NDVI (normalized difference vegetation index) composites during the growing season are particularly useful in revealing differences in combinations of land cover characteristics (Loveland et al. 1991). These tools should be especially helpful in ultimately quantifying the landscape characteristics that make up ecoregions at various scales. Large-scale remote sensing data, such as high-altitude aerial photography and Landsat or SPOT satellite imagery, can be useful as well. However, the use of larger-scale (covering smaller areas) materials is also expensive and they must be carefully evaluated for representativeness. For example, whereas many thematic maps are the products of interpretations that include consideration of seasonal and year-to-year differences, Landsat imagery and high-altitude aerial photography are snapshots of conditions at a particular time. The real value of this larger-scale imagery may be in screening reference sites, where determining the relative extent of human disturbance is a major issue.

6.0 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.

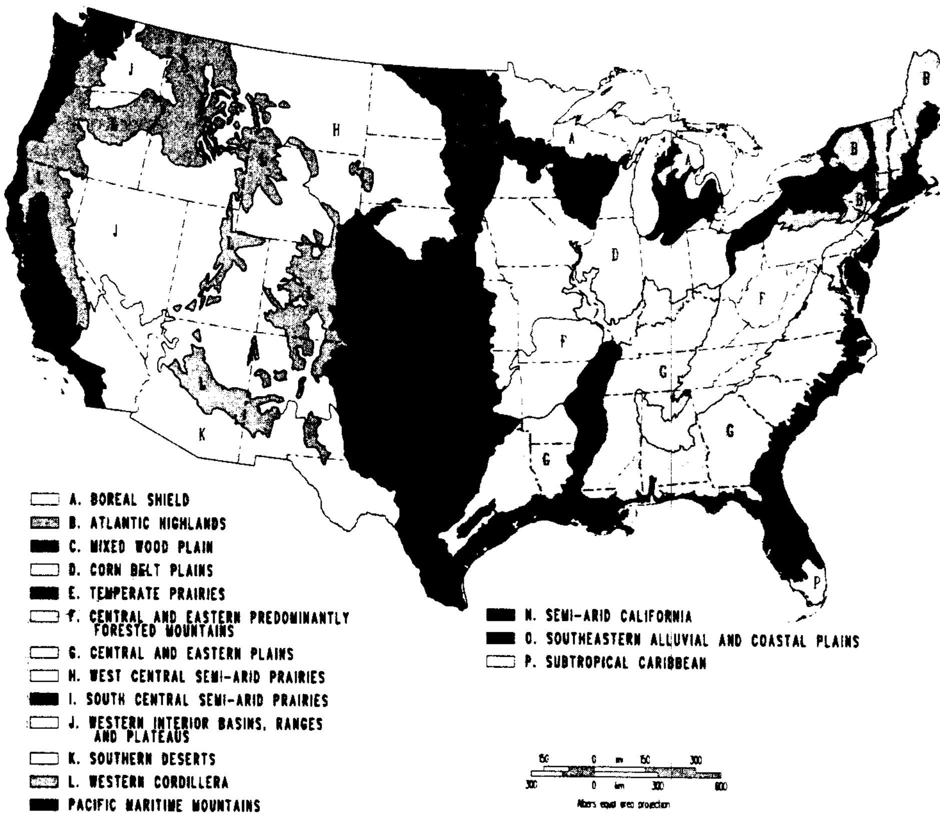

Figure 6. Omernik ecoregions and USGS hydrologic units.

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 believing 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, and 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. A recent national conference titled "Watershed '93," at which approximately 230 presentations were given over a week-long period, included no papers with titles addressing the applicability and limitations of a watershed or basin framework for ecological risk assessment and resource management (USEPA, 1994). Watershed studies are a necessity, but equally important is the development of an understanding of the spatial nature of ecosystems, their components, and the stresses we humans put upon them.

In most areas, the use of watersheds is an obvious necessity in defining and understanding spatial patterns of aquatic ecosystem quality and addressing ecological risk. It should be noted that in major portions of the country, topographic watersheds either cannot be defined or their approximation has little meaning (Hughes and Omernik 1981). Regions characterized by karst topography, extensive sandy soils, lack of relief, or excessive aridity are examples of areas where watersheds are less important. Reference streams draining watersheds that are completely within a particular region tend to be similar to one another when compared to reference streams in adjacent regions. Larger streams draining more than one ecoregion will reflect characteristics from each of the regions, with the relative influence of each region depending on its proportion of the total watershed, as well as differences in flow contributions from each region and, of course, point sources. Streams in arid regions that have large proportions of their watersheds in adjacent mesic or hydric regions will tend to have a different attainable quality than streams with similar watershed sizes that have smaller proportions of their basins in well-watered ecosystems. Water quality expectations for streams that have watersheds completely within the arid regions will generally be different than those for the other stream types. However, in many arid areas, spatial differences in subsurface watershed characteristics have a stronger influence on water quality than the size or characteristics of the surface watershed.

7.0 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 et al. (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 USEPA Science Advisory Board (SAB 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.

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