Ecoregions: A Geographic Framework to Guide Risk Characterization and Ecosystem Management

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Two central tenets of the ecosystem management paradigm are integrity and sustainability. Recognizing, maintaining, and/or restoring ecosystem integrity and sustainability present a major challenge to those attempting to implement an ecosystem approach to management. One way to begin to define and apply these concepts is to become familiar with the status of the ecosystems in question through characterization. Characterization involves spatial definition as well as a description of ecosystem qualities and behavior. An ecoregion framework is a characterization tool appropriate for describing an ecosystem's natural potential and variability as well as its typical response to various human disturbances. Using examples from the mid-Atlantic Highland region of the United States, we discuss the merits of using ecoregions both as an organizing framework that identifies region-specific disturbances and risks to ecosystems and as a reporting framework for interpreting research and assessment results. With an ecoregion approach, land managers can develop management strategies that are consistent with regional expectations and predictive of ecosystem response to various land use practices.

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The definition and operating principles of ecosystem management continue to evolve as they are tentatively applied to real landscapes and management situations. A major difficulty in moving from the conceptual to the applied realm in ecosystem management is the concern for maintenance of natural ecosystem capacity (structure, function, and complexity) along with the traditional human cultural, economic, and political dimensions of resource management and commodity extraction (Grumbine, 1994; Salwasser and Pfister, 1994; Super and Elsner, 1994). Integrating these elements means using a holistic management approach while striving toward imprecisely defined and untested goals of "sustainability" and "ecosystem integrity" (Haeuber and Franklin, 1996; Soulé, 1994). However, before we can tell whether we have retained (or regained) ecosystem integrity or sustainability, we must characterize ecosystems by recognizing their capacities and potentials as well as their range of responses to human disturbance.

An important component of characterization is determining appropriate boundaries for ecosystems at various levels of detail. In a review of ecosystem management literature from 1933 to the present, Grumbine (1994) found that two of the ten themes that appeared repeatedly involved the geographic framework for an ecosystem approach: (1) the importance of defining the management unit as an analog of the ecological unit, and (2) the need to move freely across ecological scales. Other recent authors have suggested that management unit boundaries be flexible and project-specific (Bourgeron and Jensen, 1994; Christensen et al., 1996; Lackey, 1998). Slocombe (1993) saw mapping ecosystem-based management units as an ongoing research need and a prerequisite for implementing other facets of ecosystem management. He suggested that the management region not only reflect ecological boundaries but also include common human cultural and socioeconomic similarities.

Ecological regions have been proposed as an appropriate geographic framework for ecosystem management because they depict ecosystem patterns at various scales and also include human cultural patterns and effects (Bourgeron and Jensen, 1994; Clarke and Bryce, 1997: Kaufmann et al., 1994;

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Omernik, 1995). Ecoregion maps in a hierarchy of scales have been published by federal agencies and several nongovernmental conservation organizations (Bailey, 1995; The Nature Conservancy, 1997; Omernik, 1995; World Wildlife Fund, 1998). Nine federal agencies recently signed a "Memorandum of Understanding" to develop a common framework for defining ecological regions as a way to achieve "a more integrated ecological approach to resource management" (U.S. Department of Agriculture, U.S. Department of the Interior, and U.S. Environmental Protection Agency, 1996).

In this paper, we discuss the merits of using ecoregions as an organizing and interpretive framework for an ecosystem approach to management. Ecoregions characterize ecosystems, circumscribe regional disturbances and risks to ecosystems, serve as an ecological context for interpreting research and assessment analyses, and provide the largest relatively homogeneous areas in which to extrapolate results. We demonstrate that the physical differences between geographic areas result in differences in type, extent, and intensity of human use and disturbance. Region-specific patterns in resource availability and use, as well as the resultant effects, suggest the need for region-specific management. We build this rationale using examples from the Appalachian Highland region of the eastern U.S. to expand a series of premises. Though most of the examples in the text refer to aquatic ecosystems, the concepts are also applicable to terrestrial ecosystems.

(1) Ecoregions depict ecosystem patterns at various scales and provide visual evidence of ecosystem differences.

Ecosystems are abstract entities that resist definition (Kay and Schneider, 1994; Rowe, 1997). They have been defined as ecological units within which biological components interact with their physical environment to produce an exchange of materials (Ehrlich, Ehrlich, and Holdren, 1977; Odum, 1959). Ecosystems may range from microscopic to continental scales (Christensen et al., 1996; Salwasser and Pfister, 1994). Their dynamic nature makes it difficult to define them spatially. To do so requires that we create discrete areas from an ecological continuum (Bryce and Clarke, 1996).

In addressing this "ecosystem as moving target" issue, Urban (1994) developed an analogy between the "unit pattern" concept in forestry and the importance of repeating landscape pattern in landscape ecology. At a fine scale, the forest community is constantly undergoing change, but at a broad scale, the pattern may appear relatively stationary. Therefore, ecosystem structure can be inferred from spatial changes in the repeating pattern of the biotic and abiotic elements, from the broadest scale at which the unit pattern repeats itself (the continental scale) through various hierarchical levels to the local landscape scale. Below a certain minimum resolution the repeating landscape pattern disappears to become a collection of individual phenomena.

Ecological regions, or ecoregions, are depictions of ecosystem patterns, created through a classification process that captures the spatial pattern (or unit pattern) of relatively homogeneous landscape areas at specific scales (Bailey, 1995; Omernik, 1995). Ecoregions reflect the visual pattern of earth's landscape (Figure 1). In this article, we use ecoregions at two levels (levels III and IV) of the five-level hierarchy developed at the U.S. Environmental Protection Agency (Omernik, 1995). Levels I and II classify ecosystems at a continental scale for the North American continent. Level III represents national-scale ecoregions for the U.S. Level IV regions are the more detailed ecoregions for state-level applications, and level V are the most detailed ecoregions for landscape-level or local level projects. For this project we used the level IV subdivisions of three level III ecoregions in the Appalachian Highlands: the Blue Ridge Mountains, the Ridge and Valley, and the Central Appalachians (Figure 2).

Ecoregions are developed through an iterative process that involves map analysis, the collaboration of regional experts, an extensive literature review, and a final integration of all available information. Mapped boundaries reflect the spatial coincidence in characteristics of geographical phenomena such as climate, physiography, geology, soil, vegetation, and land use. The ecoregion delineation is completed by drawing lines directly onto 1:250,000 scale topographic maps for digitization, and correcting for topography where appropriate to produce a precise line. The line may depict a sharp break or a gradual transition zone depending on the interplay of the component factors. Further discussion of the development of ecoregion methodology may be found in Bryce and Clarke (1996), Gallant et al. (1989), Griffith et al. (1994), and Omernik (1995).

Three discrete mountainous ecoregions comprise our study area in the Appalachian Highlands: the Blue Ridge Mountains, the Ridge and Valley, and the Central Appalachian Plateau (Figure 2). Each area has its distinctive ecological character as well as a superimposed human cultural pattern. During the era of colonial settlement, the northern Blue Ridge Mountains (66, Figure 2) served as a topographic barrier to limit migration westward from the coastal plain and piedmont. Though the steep, forested slopes of granite and

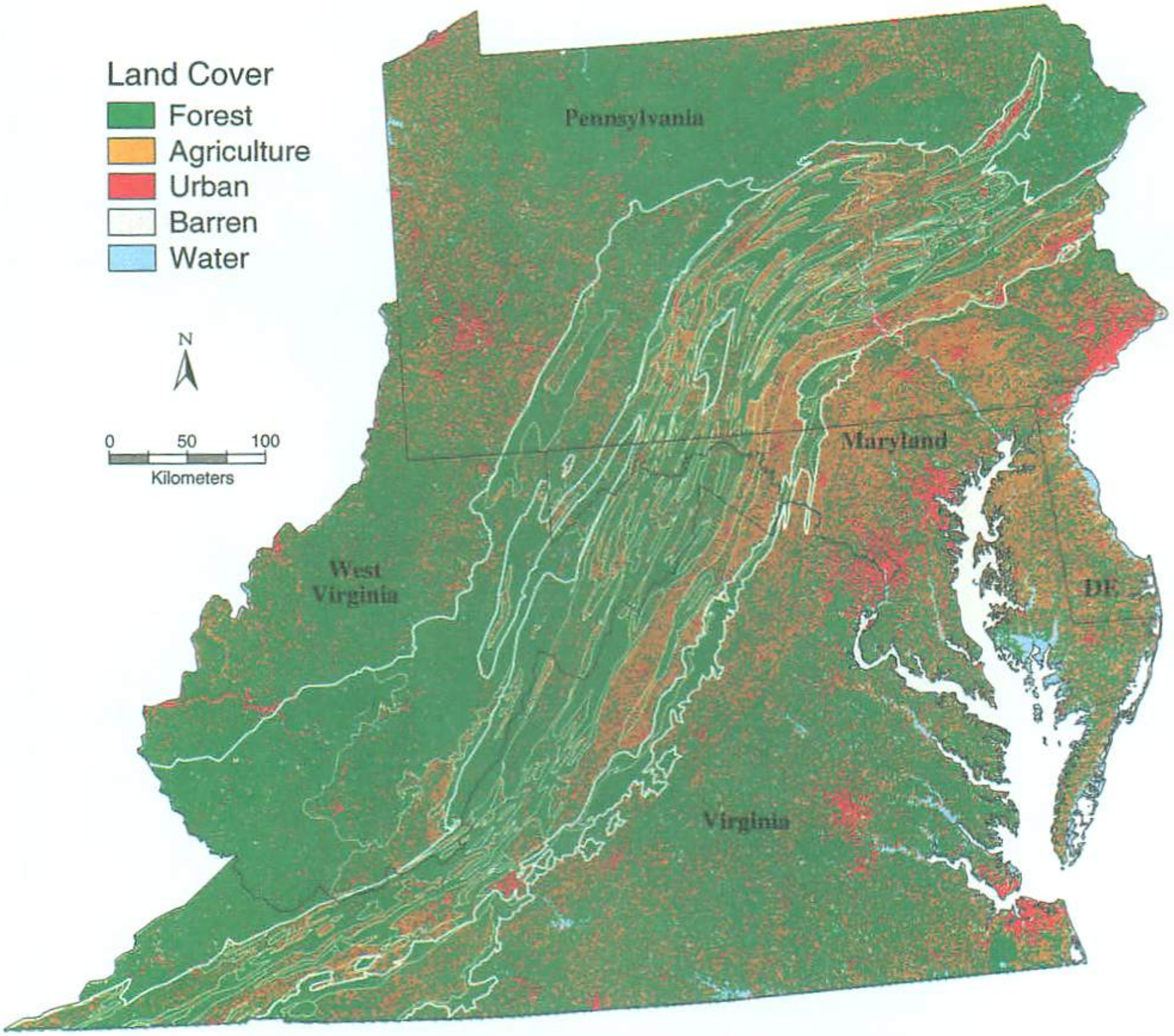

Figure 1. Thematic Mapper satellite image of the Appalachian Highlands ecoregions showing correspondence between ecoregion lines (in white) and major landcover areas. Data obtained by the Multiresolution Land Characteristics Consortium and interpreted at the Earth Resources Observation Systems Data Center. Map overlay designed by Suzanne Pierson, OAO corporation.

basalt did not suggest an agrarian landscape, soil in the hollows and on the gentler slopes was deep and fertile enough to support farms (Gathright, 1976). Today, the number of farms has declined, and the northern Blue Ridge remains largely covered by second growth forest. The region is presently experiencing increased recreational development, but it has no major urban centers and has the lowest population density of the three regions in our study area (Raitz, Ulack, and Leinbach, 1984).

West of the Blue Ridge Mountains, the limestones, sandstones, and shales that form the Ridge and Valley Ecoregion (67, Figure 2) are products of Cambrian seas that once submerged the interior of North America (Gathright, 1976). Folding and selective erosion of these strata left steep, parallel ridges of resistant sandstone and rounded shale knobs alternating with limestone and shale valleys. Today the ridges, with steep slopes and thin, infertile soils, remain forested, but the level, arable valleys experience intensive farm use, as well as expanding urban and industrial pressures. The anthracite coal area in the northeastern part of this region, though declining in production today, has been producing coal since 1790 and played a major role in the early industrialization of the eastern U.S. (Whitney, 1994; Figure 3).

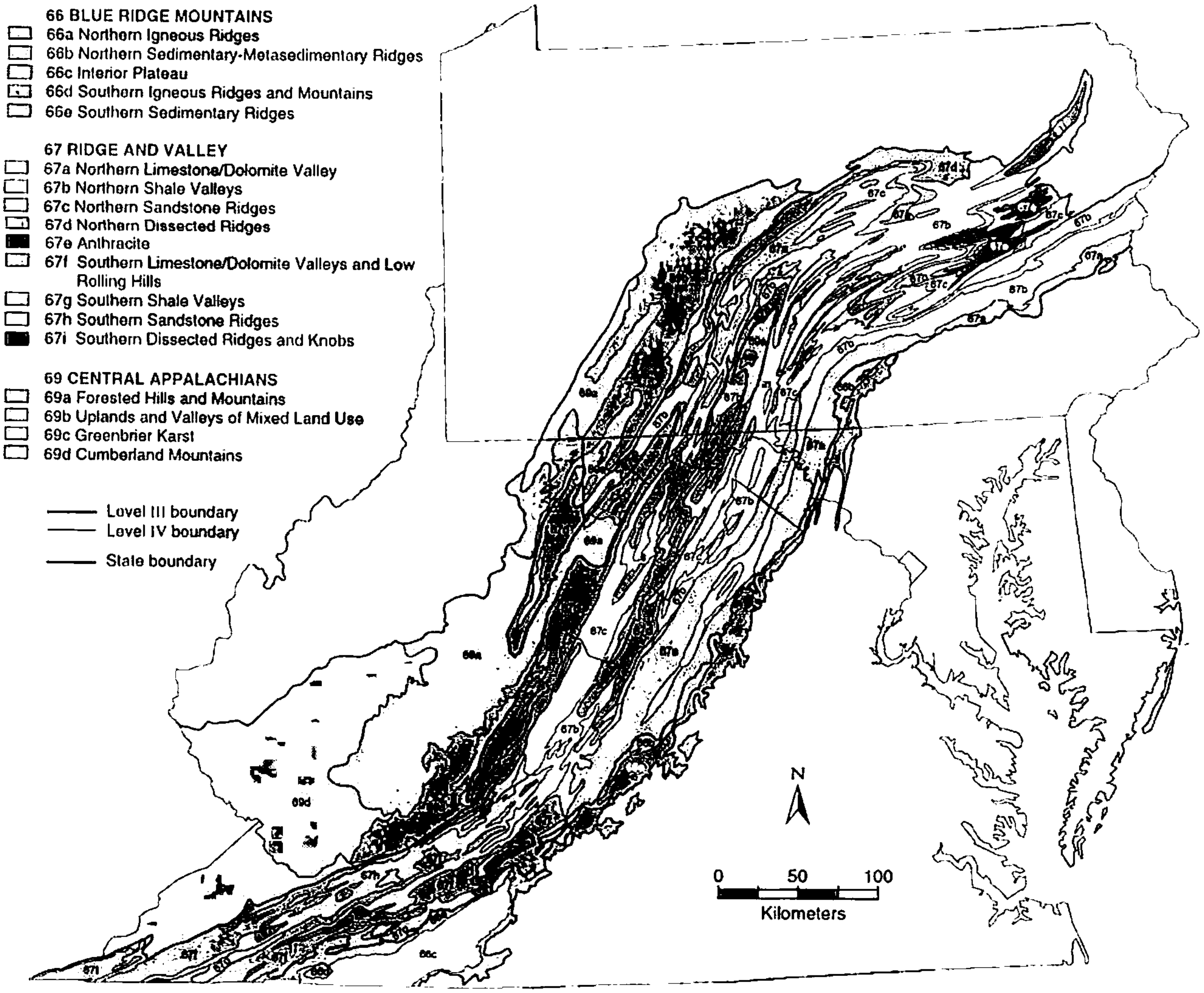

Figure 2. Two hierarchical levels (level III and level IV) for the Appalachian Highlands ecoregions that include the Blue Ridge Mountains (66), the Ridge and Valley (67), and the Central Appalachian Plateau (69) (Woods et al., 1996).

The Central Appalachian Plateau (69, Figure 2) includes the Allegheny Mountains in the north and the Cumberland Mountains and Greenbriar Karst to the south (Woods et al., 1996). Though the geology is similar to that of the Ridge and Valley ecoregion, here the strata of sandstone, shale, and conglomerate, rather than being folded, lie relatively flat and undeformed except for some gentle folding in the Allegheny Mountains. However, the high dissection of the plateau gives the impression of a rugged mountainous terrain. Strata of soft, bituminous coal are a major element of the layered geology (Figure 3). Arable limestone areas, on the other hand, are not as widely distributed in this ecoregion as in the Ridge and Valley region to the east. As a result, coal mining and silviculture, rather than commercial agriculture, are the major land uses in this ecoregion.

(2) Ecoregions include characteristic, minimally disturbed areas that can serve as references against which to compare the condition of more altered systems.

Haeuber and Franklin (1996) state that the core of ecosystem management is sustainability, achieved through the maintenance of biological integrity and the avoidance of ecosystem degradation. Salwasser and Pfister (1994) define ecosystem management as a process for sustaining desired conditions or producing desired outcomes for environments, communities, and economies. These somewhat conflicting views prompt several questions: (1) how do we define and maintain biological integrity, (2) how do we measure degradation, (3) which of the desired conditions

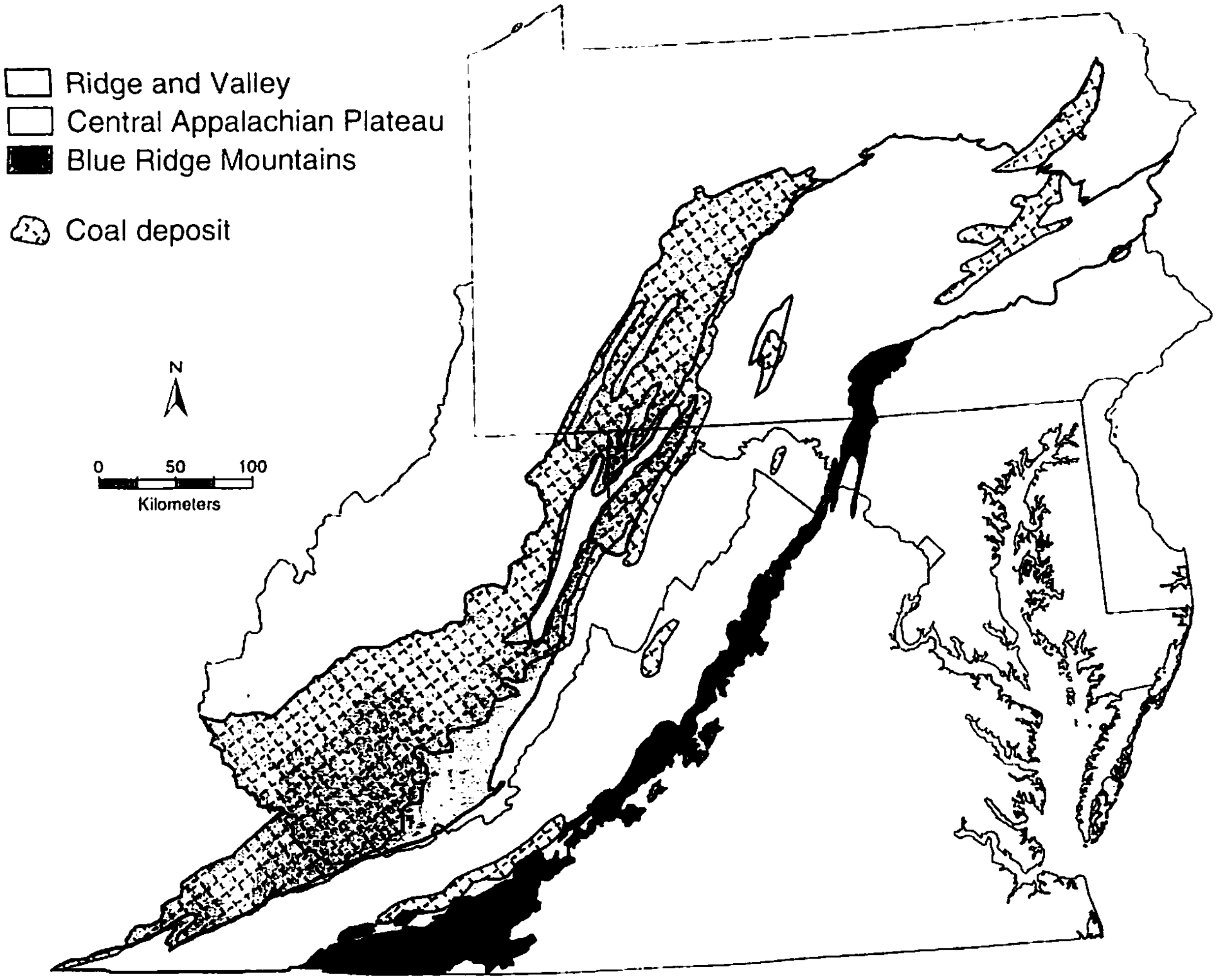

Figure 3. Distribution of coal deposits in the study area.

sustains ecosystem and biological integrity, and (4) how attainable is this desired condition?

We can begin to define biointegrity, measure degradation, and assess the sustainability of ecological integrity through the use of an ecoregional reference model. Each ecoregion expresses its natural potential capacity in areas of minimal human disturbance (Frissell et al., 1997; Warren, 1979). Presumably, because of their minimally impaired status, these areas also harbor biotic assemblages that represent ecosystem biointegrity (Frey, 1977; Karr and Dudley, 1981). A representative group of least-disturbed streams in each ecoregion may be expected to capture the range of natural variability in aquatic systems within the region (Hughes, 1995). These minimally disturbed streams and watersheds can serve as references against which to compare the condition of streams stressed by human activities (Hughes, 1995; Hughes, Larsen, and Omernik, 1986). Though a stream of any disturbance type compared with others may be called a reference, the term "reference" in water quality parlance traditionally has been used to mean a control or benchmark.

Though ecological systems are in continual flux, human-induced change is more extensive and rapid than the slow evolution of climatic or geologic changes in ecosystem capacity and character (Vitousek et al., 1997; Warren, 1979). Thus, the regional reference condition provides a relatively stable model of biointegrity against which to assess degradation in anthropogenically altered systems. Conversely, reference ecosystems also indicate how well these altered systems maintain a measure of ecosystem integrity. Though many of these managed systems are sustainable, they do not all maintain ecosystem integrity. If one of the goals of ecosystem management is to preserve a "critical mass" of ecosystem integrity, then the sustainability of integrity can be

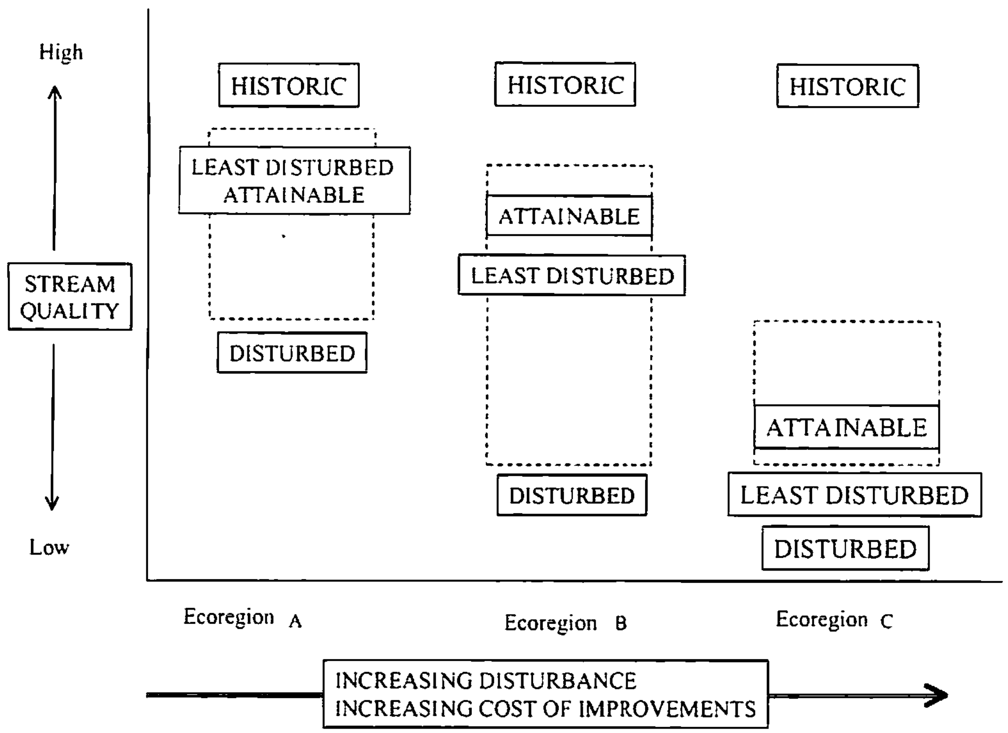

Figure 4. The variations in stream water quality as it was historically, as it is presently at disturbed and least-disturbed sites and watersheds, and as it might be attained through various management strategies for three hypothetical ecoregions of different disturbance levels. The dashed boxes represent the range in attainability at various levels of effort.

measured by how closely the altered system mimics the structural and functional aspects of the reference systems over the long term.

Regional expectations for water quality, represented by stream reference conditions, must also be balanced against realistic goals for the attainability of improved water quality. Attainability goals vary according to the extent and duration of regional disturbance, and they are also based on the region's social and economic ability to implement management strategies that will achieve maximum progress toward improved aquatic ecosystem conditions. To illustrate differences in attainability goals, we examine the interplay of stream conditions for three different hypothetical ecoregions as they were before extensive human disturbance (historic condition), as they exist today in least-disturbed streams (reference condition), and as they might be with the application of various management strategies (attainable stream quality) (Figure 4). The extent of the regional disturbance and the difficulty in affecting change increase between ecoregions A and C. In ecoregion A, with low human population levels and few watershed stressors, sufficient numbers of least-disturbed streams resembling historic conditions still exist; therefore it may be possible for attainable stream quality to approach reference conditions without heroic management efforts. In ecoregion B, minimally disturbed reference areas are more difficult to find, and more effort and expense are required to improve disturbed sites. In this region, though it may be humanly possible to attain a stream quality higher than the least-disturbed (reference) sites, most likely economic and political realities will ensure that the attainable condition of streams will fall short of the reference goal. In ecoregion C, disturbance levels are so high that existing reference sites hardly differ in quality from the disturbed sites. In such highly exploited regions, where the search for acceptable reference areas is very difficult, historical or paleoecological information may be used to develop criteria for reference ecosystems (Chovanec et al., 1995; Hughes et al., 1998). In highly disturbed regions, goals for attainable stream quality may have to exceed the field reference model in order to achieve meaningful improvements in stream quality.

(3) With human use over time, ecoregions develop characteristic patterns of human disturbance.

Ecoregions define areas of ecological resources that attract particular human uses. The same factors that determine non-anthropogenic ecosystem characteristics and ecoregion boundaries (climate, topography, geology, soil, etc.) also influence the types of human activities in a particular region. For example, constraints on human activities in the

Table 1. A possible ranking of disturbance categories and aquatic ecosystem stressors in three Appalachian Highland ecoregions

	Blue Ridge Mountains (66)	Ridge and Valley (67)	Central Appalachians (69)
Disturbance Categories	1. Recreational and second home development 2. Acid deposition 3. Logging	1. Agriculture—Row crop and intensive animal feeding 2. Mining 3. Acid deposition 4. Logging	1. Mining 2. Acid deposition 3. Logging 4. Agriculture
Stressors	Sediment Nutrients Bacteria Acidification	Bacteria Sediments Nutrients (agricultural and urban) Ground water contamination Channelization Pesticides Acid mine drainage Acidification (ridges)	Valley fill (headwaters) Acid mine drainage Acidification (aerial deposition) Sedimentation Bacteria Nutrients

mid-Appalachian highlands were particularly evident during early European settlement when topography, soil capability, and mineral availability greatly influenced migration patterns, farming practices, and the growth of industry (Raitz, Ulack, and Leinbach, 1984). Changing cycles of human use through time create a regional pattern of disturbance, dependent upon the interplay of natural resource capabilities, cultural adaptations, available technology, and the potential for economic return. The present-day character of an ecoregion is a combination of natural capabilities and cultural modifications overlaid on the physical template.

Beginning in the late 18th century, eastern Pennsylvania became the focal point for waves of immigrants that followed the axes of parallel valleys and mountain passes to populate the western plateaus (Mitchell, 1972; Raitz, Ulack, and Leinbach, 1984). In the agrarian society of the late 1700s most of the settlers arriving in the mid-Appalachian region expected to make a living through farming. Those settlers unable to afford the rich farmland in the limestone valleys of the Ridge and Valley ecoregion (67a, Figure 2) adopted frontier farming methods on the forested Blue Ridge and on the plateaus of the Central Appalachians (69, Figure 2; Mitchell and Muller, 1979; Raitz, Ulack, and Leinbach, 1984). However, farming on thin, sloping woodland soils exceeded the capacity of these regions. In the span of 150 years, soil and nutrient loss made even subsistence farming too difficult there, and by the 1930s the trend toward farmland abandonment began (Hart, 1991). The limestone valley farms, on the other hand, located on fertile soil characteristic of this region, have maintained high productivity, despite the division of farms among succeeding generations and the economic pressures to expand production (Hart, 1991).

Other patterns of human disturbance in the Central Appalachians depended on the evolution of technology. The extraction of timber and coal was delayed by inaccessibility and isolation from eastern markets until the 1870s, when the railroad finally penetrated the region (Caudill, 1963). The cycle of timber removal ensued, with complete clearing by the 1920s, followed by erosion of the deforested hillsides, frequent fire in the regenerating brush fields, and eventual reforestation. The land use pattern of coal mining has followed economic cycles and advancements in efficient extraction technology. Underground mines of the 19th and early 20th centuries were outnumbered by strip mines in the 1950s, and, more recently, mountaintop removal operations have been increasing in the Cumberland Mountains.

It is evident that the presence or absence of particular resources and their spatial extent among ecoregions determine the types of regional disturbance and their ecological effects (Table 1). Agriculture, a major human activity in the Ridge and Valley, is a minor element in the forested Blue Ridge and Central Appalachian Plateau. Mining, though present in both the Ridge and Valley and the Central Appalachian Plateau, is limited to the northeastern portion of the Ridge and Valley, but widely distributed across the entire plateau ecoregion. The types of stressors or ecological effects on aquatic ecosystems also vary between regions (bottom row, Table 1). Aerial photographs show the accumulated patterns of human disturbance in these highland ecoregions. In the Central Appalachians most of the remaining farmland, as well as urban and industrial development, is confined to narrow alluvial lands near streams (Figure 5A). Upland forested areas show the pattern of strip mining. On the ridges of the Ridge and Valley ecoregion, both clearcut (a in Figure 5B) and selective cut (b in Figure 5B) logging occur where steep slopes and infertile soil have discouraged agricultural clearing. The shale and limestone valleys, on the other hand, have level topography and a soil capability to support farming, as well as urban and industrial development (c in Figure 5B).

(4) The accumulation of human disturbances results in an array of risks to aquatic ecosystems that is ecoregion-specific.

The previous three sections have demonstrated how a region's physical characteristics influence human settlement and resource utilization, and conversely, how human pressures create a regional disturbance pattern. Over time the accumulation of human activities begins to affect stream ecosystems and aquatic biota. To illustrate the patterns of risks to aquatic ecosystems in the three Appalachian Highland ecoregions, we used map analysis, aerial photo interpretation, and field information to screen 56 randomly selected streams and their watersheds for human disturbances (Figure 6). Topographic maps gave a summary of watershed physical characteristics, population distributions, and farm/forest land use patterns. Aerial photographs updated the map information and showed some activities, such as logging, that were not included on maps. Site visits provided stream reach physical habitat and riparian zone information, as well as anecdotal information about the stream and watershed. We were particularly interested in those activities that influenced changes in vegetative cover, channel morphology, sedimentation, and chemical loading.

Using this information, we identified and ranked human alterations to riparian and upland areas and used the rankings to assign scores to the watersheds, creating a relative risk index (Bryce et al., 1999). The scores ranged from 1 to 5, with the rankings signifying minimal risk to highest risk of impairment. Stream biota in watersheds with few disturbances were considered at low risk of impairment; biota in watersheds subject to multiple disturbances over larger areas were considered at high risk. A randomized site selection allowed us to infer regional condition and to estimate the proportion or number of stream kilometers in the study area that were at various levels of risk due to human alterations (Stevens, 1997).

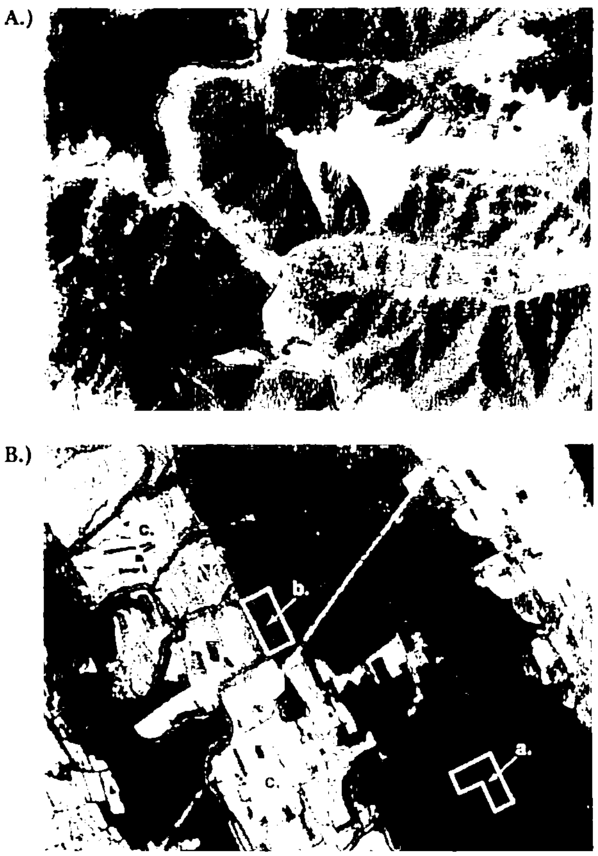

Figure 5. A. Aerial photograph of the Central Appalachian ecoregion showing urban and agricultural development in the alluvial valleys and strip mining on the forested slopes. B. Aerial photograph of the Ridge and Valley ecoregion. On the forested ridges (a) marks a clearcut area, (b) a selective cut area, and (c) identifies a shale valley.

Ecoregion-specific stressor patterns are apparent in the distribution of risk index scores for aggregations of the three ecoregions (Figure 7). Ridge watersheds (Blue Ridge Mountains and ridges of the Ridge and Valley ecoregion; 66 and 67 in Figure 2) have the largest proportion (about 53% or 27,983 km) of stream resource having low to moderate risk scores (scores of 1,2, or 3). Many of these are forested, headwater systems. The regions' elevation, lack of flat terrain for farming and urban development, and paucity of mineral resources limit the number and magnitude of risks to aquatic ecosystems. However, recreational development and logging, both selective- and clear-cut, contribute sediment and nutrients; also, acid deposition threatens aquatic life in high elevation streams. The Virginia Trout Stream Sensitivity Survey of 1987 found that 6% of 194 streams sampled in the Virginia Blue Ridge were acidic (Webb et al., 1989). Of the

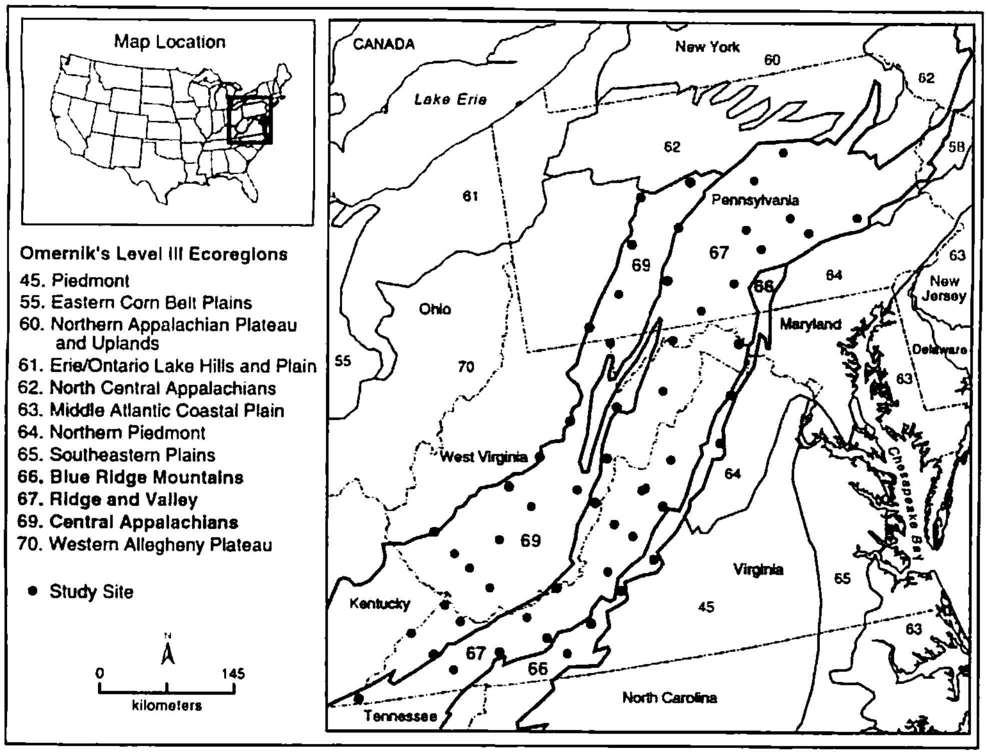

Figure 6. Map of 56 randomly selected stream sites in the three ecoregions of the study area that were screened for all human disturbances detectable using map analysis, aerial photo interpretation, and field information.

high elevation (> 300 m) forested streams sampled in the ridges of the Ridge and Valley region during the National Stream Survey of 1986, an estimated 17–18% were acidic (Herlihy et al., 1993).

In the Central Appalachians ecoregion, about 50% (or 12, 575 km) of stream length fell in watersheds scoring in the high risk categories (scores of 4 or 5), mainly due to underground and surface mining activities. Differences in disturbance response occur between the north and south portions of this region (69b and 69d, Figure 2). In the north, the prevalence of sandstones and other resistant base-poor rocks make streams susceptible to acidification from mine drainage. In the south, in the Cumberland Mountains, mine drainage is as widespread as it is in the north, but the presence of weatherable overburden neutralizes acidic drainage and reduces heavy metal toxicity (Herlihy, Kaufmann, and Mitch, 1990). However, there are other factors, in this case topographic differences, that make the Cumberland Mountains vulnerable to the effects of mining. The sharp ridge topography encourages the practice of mountaintop removal to extract coal. This mining method, where the over-

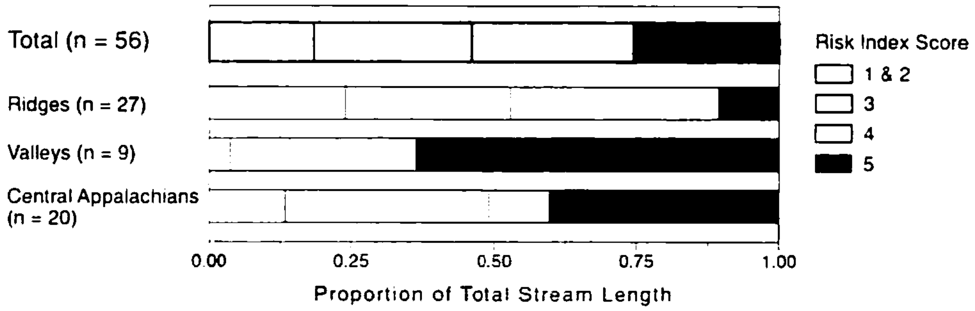

Figure 7. The distribution of risk index scores for 56 streams and watersheds in three Appalachian Highland ecoregions expressed as population estimates for the proportion of total stream length. The three ecoregions represented are the ridges of the Ridge and Valley (67c and d in Figure 2), the Valleys of the Ridge and Valley (67a and b), and the Central Appalachian Plateau (69).

burden is pushed into adjoining valleys to bury headwater streams, is exempt from the recontouring regulations of standard strip mining. In the north, stream restoration for streams subject to acid mine drainage is expensive but possible. In the south, headwater streams affected by mountaintop removal are not restorable.

In the valleys of the Ridge and Valley ecoregion, approximately 96% (or 10,088 km) of stream length is in the higher risk categories because of urbanization, agriculture, and stream channelization. Each of the three regions in our study area receive anthropogenic nutrient additions, but in the valleys nutrient levels are particularly excessive because of intensive agriculture and, most recently, the growth of concentrated animal feeding operations (chickens, turkeys, hogs, and cattle). As an example, in northeast West Virginia the production of broiler chickens has tripled in the last 10 years. A single farmer with three 20,000-bird poultry houses, raises 360,000 chickens per year and must dispose of 540 tons of manure during that time (Ward, 1998). However, the financial return from the poultry business is not sufficient to support building manure storage facilities and management systems. As a result, manure is often stored in uncovered piles to wash away when it rains, or it is spread on fields as fertilizer. The effects of these nutrient additions vary in valley streams depending upon topography, geology, and soil characteristics. In shale valleys, streams lack a groundwater influence and become sluggish and subject to algal blooms in the summer. In the limestone areas, on the other hand, underground flow augments surface flow year round, diluting nutrient concentrations; but the porous limestone substrate is highly susceptible to nutrient infiltration. Particularly in karst areas, the underground streams, sinkholes, and caverns provide a direct access for nutrients to reach extensive groundwater aquifers.

In the last two sections, we demonstrated that human use over time results in an ecoregion-specific pattern of disturbance and ecological effects. Agriculture, mining, acid deposition, and logging are the main anthropogenic dis-

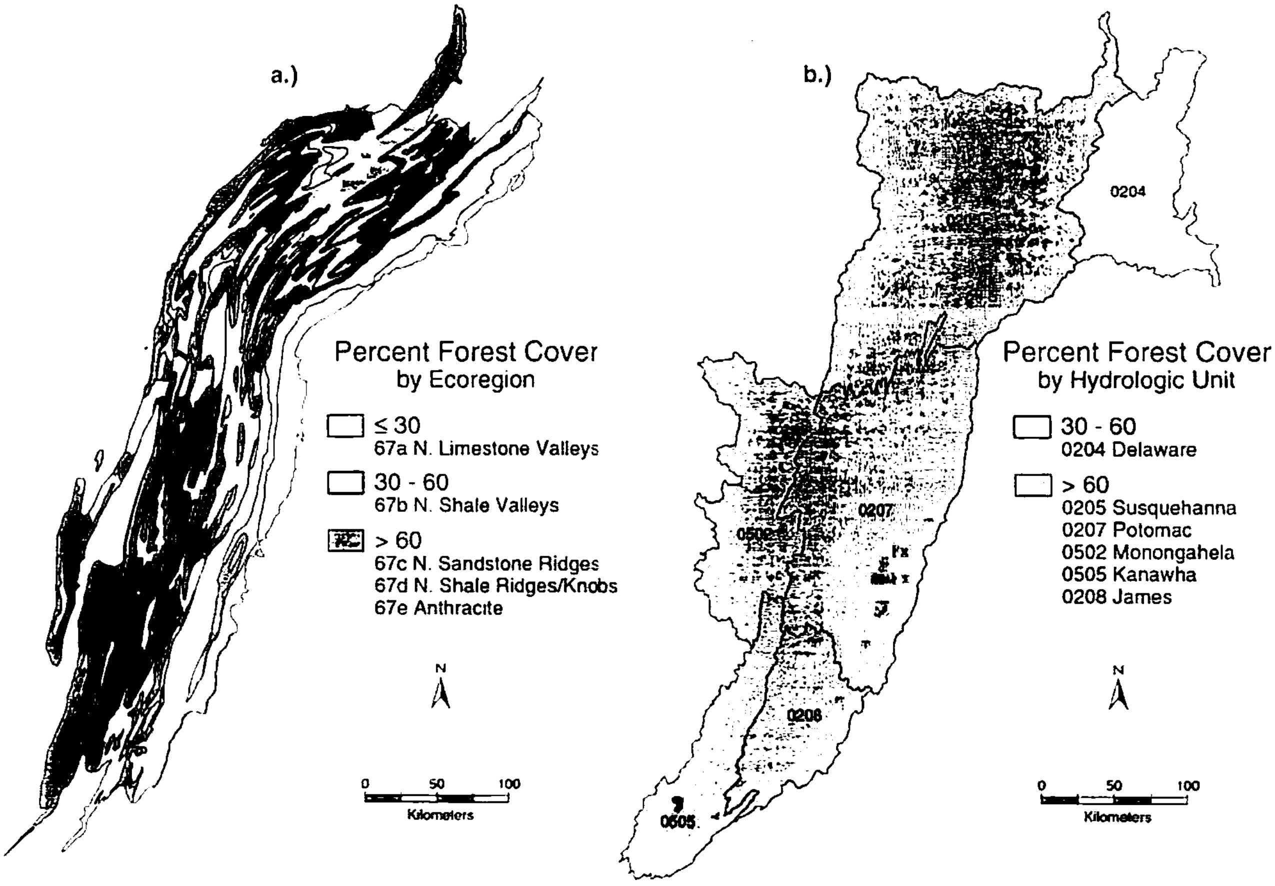

Figure 8. a. Map of forest cover for the Ridge and Valley ecoregions (level IV division of region 67, Figure 2). b. Map of forest cover for 4-digit hydrologic units covering the same area.

turbances of the three highland ecoregions (Table 1). It is evident from the table and the examples given above that categories of risk, such as mine drainage or excess nutrients, may be present in more than one ecoregion, but their extent and severity vary from region to region. The table also shows how the disturbance categories and stressors might be ranked among the three highland ecoregions. The same stressor may provoke a different response among ecoregions depending upon the region's resiliency or vulnerability to that stress (Bryce and Clarke, 1996; Bryce et al., 1999; Griffith et al., 1994). This observation has implications for ecological risk management in that the same stress may be ranked differently among ecoregions. With such a ranking, regional management strategies can be applied relative to the intensity and extent of the various risks.

(5) Ecoregions serve as a reporting framework that reveals distinct patterns in environmental data because the regions correspond to the spatial distribution of resources.

Basins (watersheds or hydrologic units) or political boundaries are often used as stratification and reporting frameworks for data analysis and interpretation. Basin frameworks are useful for research involving fish distribution patterns or the conservation of fish stocks, nutrient cycling, and watershed pollution loadings. However, spatial differences in landscape characteristics, ecosystems, or environmental resources are rarely partitioned by topographic divides (Omernik and Bailey, 1997; Omernik and Griffith, 1991). River basins in areas of topographic relief often straddle several ecoregions and cover territory that is too heterogeneous to clearly reveal resource patterns. Patterns in environmental data may be overlooked when using a framework that does not correspond to the spatial distribution of resources or human activities.

To illustrate how the choice of reporting framework affects the interpretation of environmental data, we compared maps of forest cover for level IV ecoregions (67a–e, Figure 2) and for 4-digit hydrologic units in the northern Ridge and Valley area (Figure 8). In both ecoregion and basin depictions, the units were chosen to be roughly comparable in size. The resulting map for hydrologic units shows that their upland-lowland nature homogenizes the spatial pattern of forest cover. All but one hydrologic unit is 60–90% forested. The Great Valley and other agricultural valleys, with the lowest area in forest, do not appear on the map because their features are averaged in with the more forested upslope areas. On the ecoregion map, the spatial pattern is more closely preserved. The extensively developed limestone valleys show the least amount of forest cover (about 28%), followed by the shale valleys that are not as intensively farmed (about 53% forest). The other three ecoregions are predominantly forested (64–85%). When ecoregion boundaries are superimposed on a satellite view of the region classified to show forest cover (Figure 1), the correspondence between ecoregions and the actual forest pattern is apparent.

We also examined spatial patterns in nitrogen export to streams in the Ridge and Valley area. In the valleys, soils are naturally higher in nutrients than in the mountains, and they export a higher background level of nutrients. Added to this background nutrient export level is nutrient runoff from agricultural fertilizers, human waste, and concentrated animal feeding operations. In contrast, on the ridges there may be some aerial deposition of nitrate and temporary pulses of nutrients into streams from logging activities, but, in general, anthropogenic nutrient additions to high elevation streams are considerably lower than valley streams. To estimate regional annual nitrogen export po-

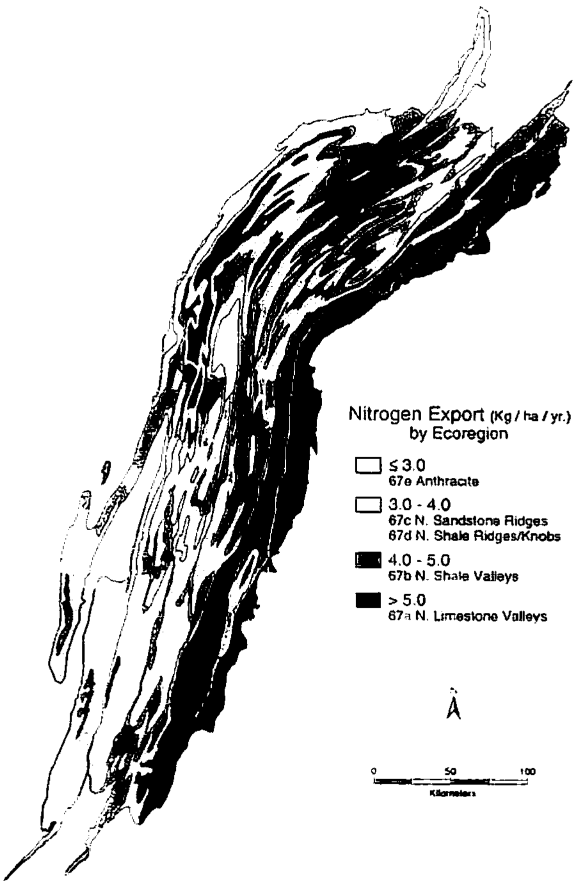

Figure 9. Map of nitrogen export (kg/ha/yr) by ecoregion for the Ridge and Valley area.

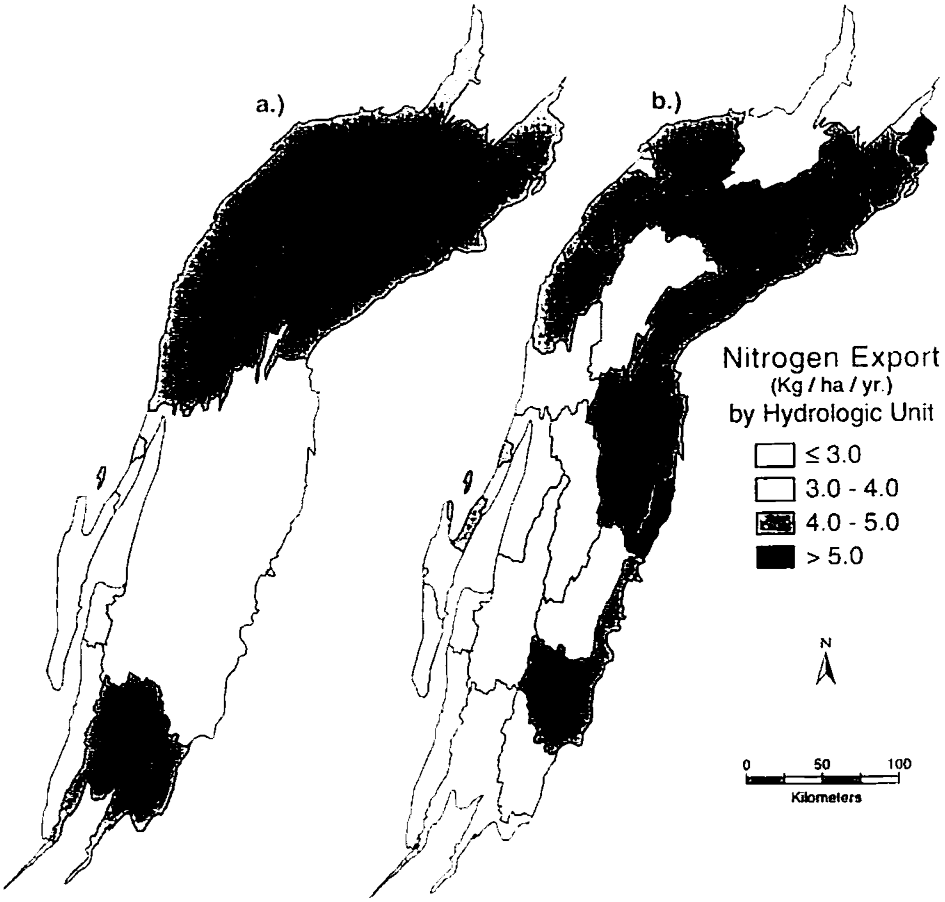

Figure 10. a. Map of nitrogen export (kg/ha/yr) by 4-digit hydrologic unit for the Ridge and Valley area. b. Map of nitrogen export (kg/ha/yr) by 8-digit hydrologic unit for the Ridge and Valley area.

tential, median export coefficients for particular land covers (Reckhow, Beaulac, and Simpson, 1980; Young, Marston, and Davis, 1996) were multiplied by the area of each within the ecoregion or hydrologic unit and then summed for all land covers. The map of nitrogen export (kg/ha/yr) by ecoregion for the northern Ridge and Valley (67a–e, Figure 2) illustrates a pattern consistent with the patterns of human use and characteristic regional vulnerability discussed in sections 3 and 4 (Figure 9). All of the areas of maximum nitrogen export (> 5.0 kg/ha/yr) are found in limestone valleys with higher concentrations of urban and agricultural use. Shale valleys have intermediate values (between 4 and 5 kg/ha/yr), and the three forested ecoregions have the lowest values (< 4 kg/ha/yr). The map for corresponding hydrologic units shows a gradual increase in nitrogen export values from southwest to northeast (Figure 10a). The higher export values (4–5 kg/ha/yr) for the northern hydrologic units (204 and 205) reflect the predominance of valleys there and their accompanying land uses. When smaller 8-digit hydrologic units are used, a more detailed picture emerges (Figure 10b).

While both ecoregion and hydrologic unit frameworks can be used for reporting, they are not equivalent in their capacity to portray differences in nitrogen export values. The pattern on the hydrologic unit map shows that high export values may originate in valleys (because there are more valleys in the north). The pattern on the ecoregion map indicates not only a valley origin, but it distinguishes between valley types. Because the hydrologic units span areas of high topographic variability, the distinction between forest and valley and shale and limestone valleys is lost, as is the overriding impact of the Great Valley on the eastern perimeter of the region. Patterns such as these in environmental data may be revealed in sharp focus with an ecoregion framework because it preserves the spatial configuration of resources, unlike spatial frameworks that do not recognize ecological patterns (e.g., political boundaries, hydrologic boundaries). Using the ecoregion framework, the same patterns may be retained throughout the characterization process—from the description of the ecosystems, human resource use, and consequent risks to ecosystems to data analysis and reporting.

Summary

One of the distinctions of an ecosystem approach to management is the recognition that there may be limits to the capacities of ecosystems to provide for human needs over the long term. As a result, there is renewed determination to maintain the integrity and sustainability of ecosystems. One way to begin to define and apply these concepts in the real world is to become familiar with the regional differences in the states or conditions of the ecosystems in question through characterization. In this paper, using examples to expand a series of premises, we have demonstrated the utility of ecoregions as a characterization tool to guide ecosystem management. To summarize:

- Ecoregions are depictions of ecosystem patterns created through a classification process that captures the spatial pattern of relatively homogeneous landscapes at specific scales.
- An ecoregional reference model defines potential natural ecosystem character, against which degradation and sustainability may be measured.
- The same factors that define ecoregions also influence human settlement patterns and resource use; consequently characteristic patterns of human disturbance develop within ecoregions.
- The accumulation of human disturbances result in an array of risks to aquatic ecosystems that is ecoregion-specific.
- An ecoregion framework serves as a reporting medium that reveals distinct patterns in environmental data because it reflects the natural ecosystem pattern as well as superimposed human disturbances.

Using an ecoregion approach, managers can align management practices to match regional risks and vulnerabilities and develop management standards that are consistent with regional expectations. Presently, ecoregions have been used mainly by state water quality agencies in the development of biological criteria (Hughes et al., 1994; Larsen et al., 1986; Rohm, Giese, and Bennett, 1987). Though the focus of this paper was on water resource management, the same principles of risk characterization apply to terrestrial management. The fact that a group of sites within an ecoregion share physical components (e.g., climate, soil, geology, vegetation, etc.) suggests that they will respond similarly to a particular management approach. If this is true, then research or monitoring results from a limited number of sites (in the same class and region) may be extrapolated to the geographic area of the ecoregion. Thus, ecoregions offer an economy of scale by providing the largest geographic area within which management strategies may be standardized and applied beyond a site or individual watershed.

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