United States
Environmental Protection
Agency

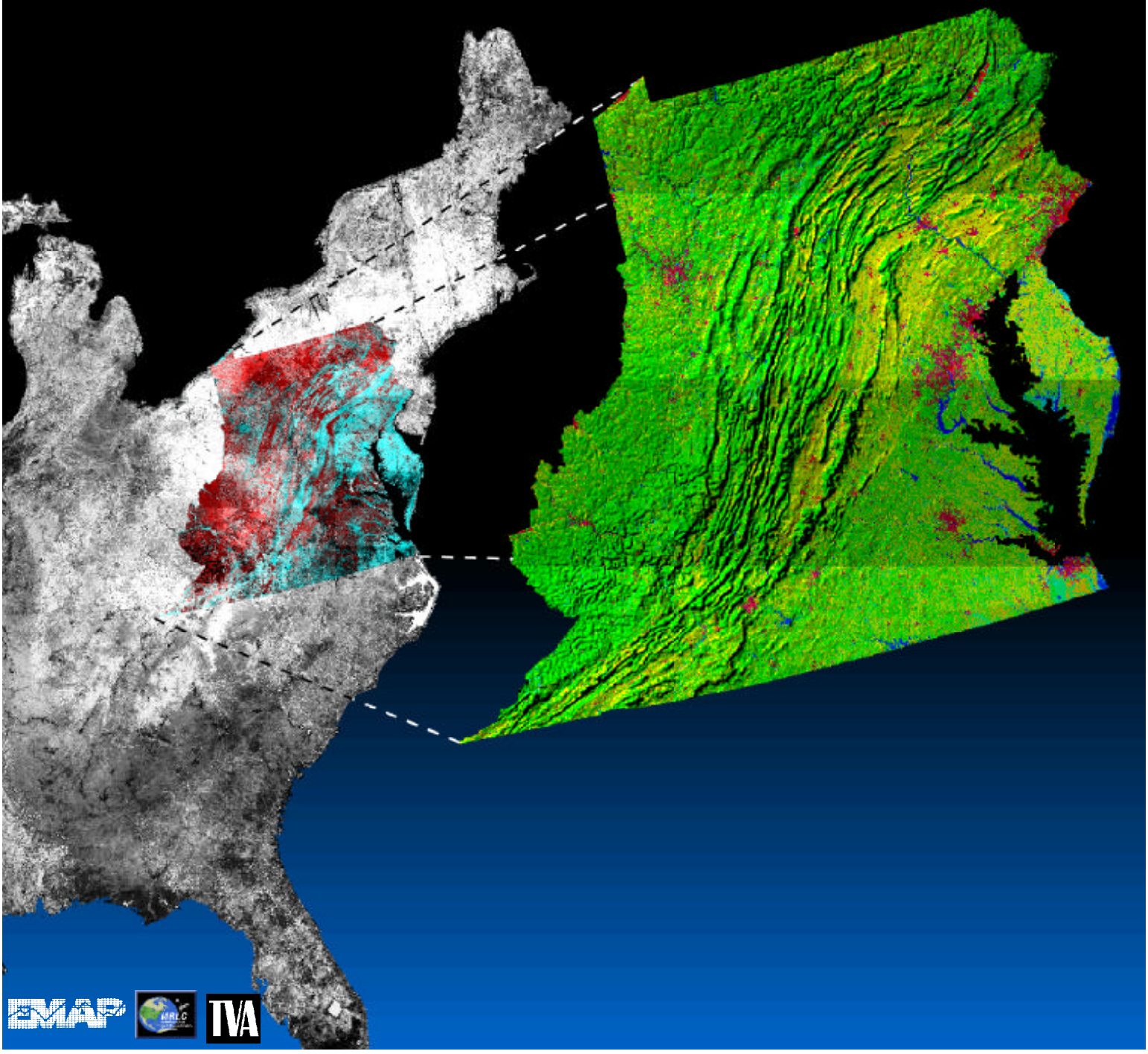
Office of Research and
Development
Washington DC 20460

EPA/600/R-97/130
November 1997

EPA

An Ecological Assessment of the United States Mid-Atlantic Region

A Landscape Atlas



EMAP MRLC TVA

An Ecological Assessment of the United States Mid-Atlantic Region:

A Landscape Atlas

K. Bruce Jones[1], Kurt H. Riitters[2; 5], James D. Wickham[2], Roger D. Tankersley Jr.[3], Robert V. O'Neill[4], Deborah J. Chaloud[1], Elizabeth R. Smith[2], and Anne C. Neale[1]

1 Environmental Sciences Division, U.S. Environmental Protection Agency, Las Vegas, Nevada

2 Environmental Research Center, Tennessee Valley Authority, Historic Forestry Building, Norris, Tennessee

3 Department of Geography, University of Tennessee, Knoxville, Tennessee

4 Environmental Sciences Division, U.S. Department of Energy, Oak Ridge National Laboratory, Oak Ridge, Tennessee

5 Currently: Biological Resources Division, U.S. Geological Survey, Knoxville, Tennessee

Dedication

This Atlas is dedicated to our friend and colleague Mason J. Hewitt, whose leadership and inspiration made many of the landscape analyses and displays used in this atlas possible. Mason pioneered and laid much of the foundation for Geographic Information System applications in the EPA. He made it possible for many government agencies to use and apply indicators highlighted in this atlas. Mason also contributed substantially to the education of many young people through the Boy Scouts of America, teaching young people how to respect and live in harmony with their natural environment. Mason's impact on the conservation of our environment will be felt for years to come, but his kindness, leadership, and vision will be sorely missed.

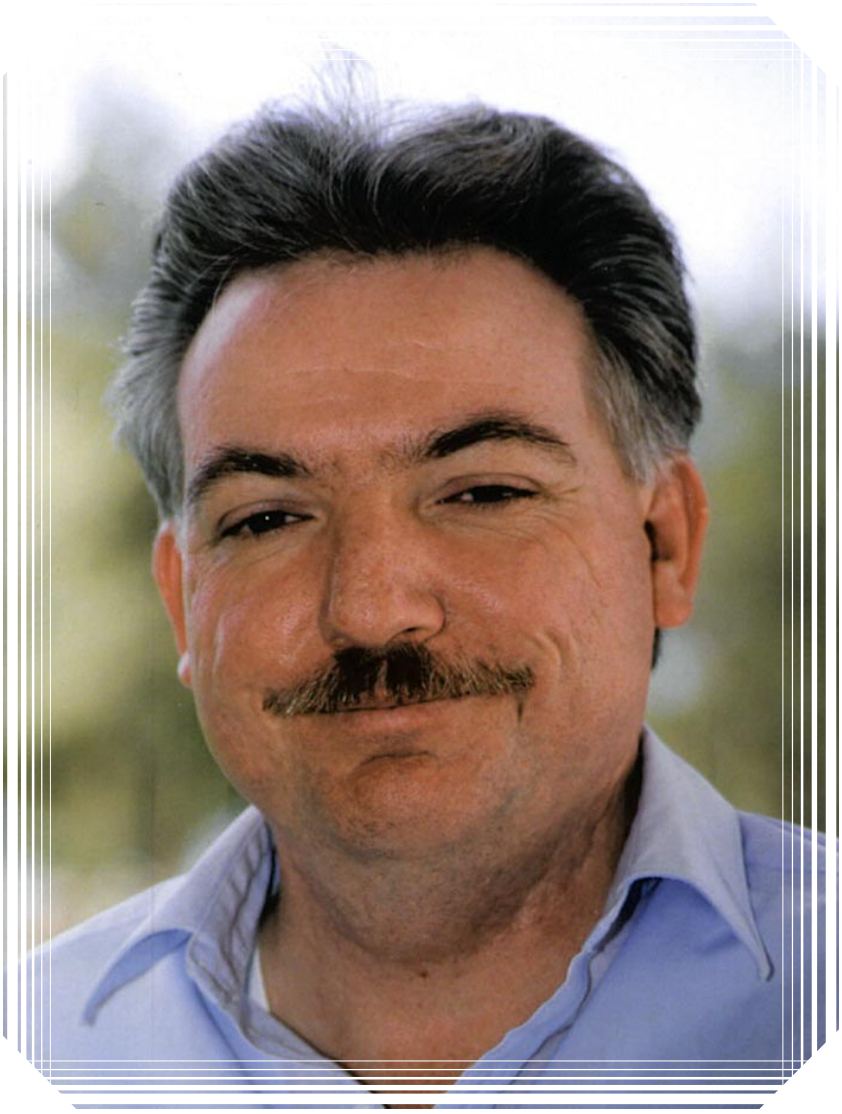


Table Of Contents

Chapter 1. **Taking a Broader View** 1

Purpose and Organization of This Atlas 2
Landscape Ecology and the Analysis of Broad–Scale Environmental Condition 3
How Can Landscape Indicators Help Us Understand Environmental Conditions? 4
How Were the Landscape Indicators Selected? 6
How Were the Landscape Indicators Measured? 10
How Were the Landscape Indicators Summarized? 14
How to Read the Maps and Charts in this Atlas 15

Chapter 2. **The National Context** 17

Data Sources 17
Human Use Patterns 20
Forest Patterns 22
Patterns Affecting Water Quality 26
National Context Summary 28

Chapter 3. **The Mid–Atlantic Region** 31

Biophysical Setting of the Mid–Atlantic Region 31
Humans in Landscapes in the Mid–Atlantic Region 38
Water 49
Riparian Indicators 49
Watershed Indicators 52
Forests 60
Landscape Change (1970-1990) 67

Chapter 4. **A Comparative Assessment of Mid–Atlantic Watershed Conditions** 77

Acknowledgements 87

Glossary 89

Appendix. Additional Information About the Indicators in Chapter 3 91

Suggested Further Reading 103

Chapter 1: Taking a Broader View

Environmental quality affects our health, our quality of life, the sustainability of our economies, and the futures of our children. Yet pressures from an increasing population coupled with the need for economic development and an improved standard of living often have multiple effects on our natural resources. So just as a person with a less-than-healthy lifestyle is more prone to infection, a weakened ecosystem is more vulnerable to additional stress. Unfortunately, it is often difficult to see these changes in environmental quality because they occur slowly or at scales we do not normally consider.

There is growing public, legal, and scientific awareness that broader–scale views are important when assessing regional environmental quality. In the past, media attention has concentrated on dramatic events, focusing our environmental awareness on local or isolated phenomena such as cleaning up Superfund sites, stopping pollution from a drainage pipe, saving individual endangered species, or choosing a site for a county landfill. In an era of environmental regulations, measures of environmental quality were based on legal standards, like those for drinking water or air quality. As a result they reflected a limited view of the environment and the multiple factors that contribute to environmental problems. In response, scientists studied fine–scale model systems and often considered humans to be external factors. Today, our perceptions are changing. We realize that humans and our actions are an integral part of the global ecosystem, and that the environment is complicated and interconnected with human activities across local and regional scales. We have begun to take a broader view of the world and of our place in natural systems.

Technological advancements have made it easier to obtain new views of overall environmental quality. Computers and satellites allow us to study larger patterns and processes. Combined with a better understanding of how the pieces fit together, these technologies help us to assess where we are now with regard to environmental quality, to envision where we hope to be in the future, and to identify the steps we need to take. This atlas takes advantage of these advanced technologies in assessing environmental condition over the mid–Atlantic region of the United States.

Just as we now watch broad–scale weather patterns to get an idea of whether it will rain in the next few days, we can develop a better assessment of current environmental condition by combining regional and local–scale information. Broad–scale weather patterns are important because they affect and constrain what happens locally on any given day. By taking a broader view of the environment, or widening our perspective about how the environment is put together, it becomes easier to see where changes occur and to anticipate future problems before they materialize.



The Chesapeake Bay Program is one of the groups which helped to identify the environmental issues of concern in the mid–Atlantic region. The Chesapeake Bay watershed covers a large portion of the area considered in this atlas.



In the past, public and legal attention has been focused on site–specific environmental problems such as what is coming out of individual drainage pipes.

Purpose and Organization of this Atlas

This atlas is an environmental assessment of the mid–Atlantic region of the United States (Figure 1.1). The assessment was done using measurements derived from satellite imagery and spatial data bases. The information presented in this atlas is intended to help the reader visualize and understand the changing conditions across the region, and how the pattern of conditions can be used as a context for community–level situations. This atlas does not provide site–specific analyses of small areas such as individual woodlots. This atlas was developed as part of the Environmental Monitoring and Assessment Program (EMAP), and is part of a larger, multi-organizational effort to assess environmental condition in the mid-Atlantic Region.

The atlas is divided into four chapters with one appendix. This chapter introduces the reasons for doing a broad–scale regional analysis of environmental condition.

Chapter 2 places the mid–Atlantic region into the context of the lower 48 states. In Chapter 3, the landscape conditions in the mid–Atlantic region are analyzed and interpreted in terms of a set of ecological indicators, summarized by watersheds within the region. Chapter 4 summarizes the overall picture painted by these landscape indicators and compares relative conditions among watersheds in the region. The Appendix provides methodological information which is not in Chapter 3, and has a listing of all indicator scores for every watershed in the mid–Atlantic region.

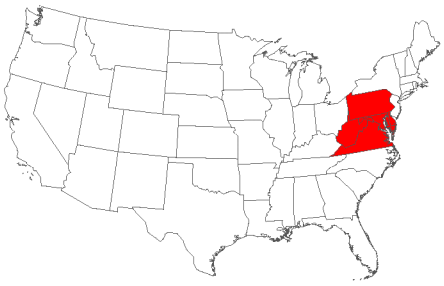




Figure 1.1.

The mid–Atlantic region.

Landscape Ecology and the Analysis of Broad–Scale Environmental Condition

To most people, the term "landscape" suggests either a scenic vista or a backyard improvement project. To ecologists and other environmental scientists, a landscape is a conceptual unit for the study of spatial patterns in the physical environment and the influence of these patterns on important environmental resources. Landscape ecology is different from traditional ecology in several ways. First, it takes into account the spatial arrangements of the components or elements that make up the environment. Second, it recognizes that the relationships between ecological patterns and processes change with the scale of observation. Finally, landscape ecology includes both humans and their activities as an integral part of the environment.

There are many applications for landscape ecology and broad–scale information in regional assessments. For example, we can identify the areas that are most heavily impacted today by combining information on population density, roads, land cover, and air quality. In the mid–Atlantic region, we already have good information (from the U.S. Census Bureau) about which counties are most urbanized. But which counties have only a small proportion of adjacent forest cover along the stream length? Which counties are characterized by a high degree of forest fragmentation? What about information for watersheds instead of counties? Broad–scale measurements can be taken in order to make relative comparisons of these indicators over the entire region. Broad–scale data can also help in identifying the most vulnerable areas within the region. Vulnerable areas are not yet heavily impacted, but because of their circumstances they are in danger of becoming so. One example might be a watershed that has a relatively high percent of forest cover, but is also experiencing rapid population gains. Such an area might be more vulnerable to forest fragmentation than a similar area with less population or less forest area.

The ability to place localities into a regional context is another benefit of this approach. Some individual cities and neighborhoods in the mid–Atlantic Region may seem isolated, perhaps within a large forested area. However, all are connected by physical features and by ecological processes. Water flows from one place to another, roads provide a connecting infrastructure, and land cover patterns of forest and agriculture form a connected backdrop for all of our activities. While land management decisions are made and implemented at a local scale, a regional perspective can guide our decisions and make us better stewards of our environment. By placing our homes, neighborhoods, and government organizations into a regional landscape picture, we can begin to make informed decisions that consider not only our goals and actions, but our neighbors' as well.



Figure 1.2 illustrates how a single community is linked to the landscape at several different scales and across different mapping units (watersheds and counties in this example). A small city is highlighted in the middle of the figure. At this scale we concentrate on individual land parcels and roads, and our decisions are based on a local perspective. Broader–scale perspectives emerge as we follow the lines up either side of the figure. We see that the community is part of both a watershed (left) and a county (right), which, in turn, are components of groups of watersheds and counties. These larger groups are components of the entire region.

How Can Landscape Indicators Help Us Understand Environmental Conditions?

An indicator is a value calculated by statistically combining and summarizing relevant data. Well–known economic indicators include the seasonally–adjusted unemployment percentage and number of housing starts, both of which indicate overall economic condition. In these indicators, seasonal adjustment is made with a model, and most economists look at several indicators together instead of just one at a time. Similarly, landscape indicators can be measurements of ecosystem components (such as the amount of forest) or processes (such as net primary productivity), and modeled adjustments can be used to help interpret the measurements in order to understand overall ecological conditions.

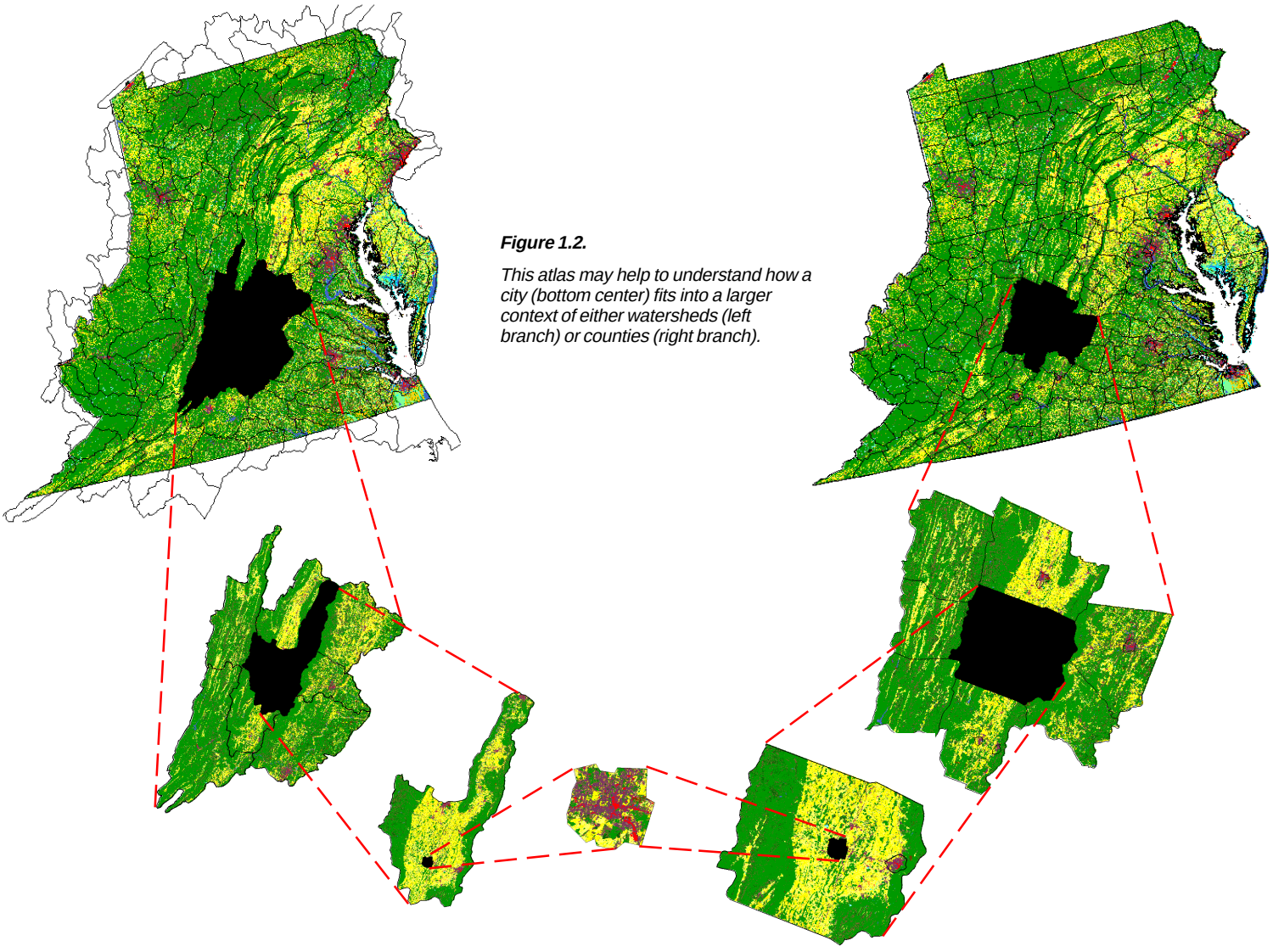


Figure 1.2.

This atlas may help to understand how a city (bottom center) fits into a larger context of either watersheds (left branch) or counties (right branch).

Figure 1.3 shows an example of measuring spatial patterns as an indicator of stream conditions. The distribution of streamside land cover has been mapped for the same county that was shown in Figure 1.2. Stream segments that are green have adjacent forest, and segments that are yellow and red have adjacent agriculture and urban land cover, respectively. The pattern of streams in relation to land cover is an indicator of conditions within the stream. Forests filter pollutants, preventing them from reaching the water, whereas agriculture and urban land often contribute pollutants to streams. A simple summary indicator might be the percentage of stream length in the county that is adjacent to forest land cover. To refine this indicator, a model might help to account for "natural" conditions, for example whether or not forest was the natural land cover for the county.

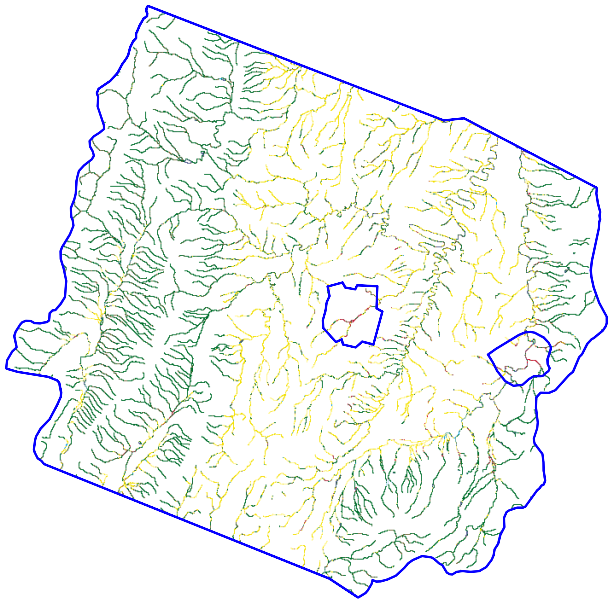


Figure 1.3.

Spatial patterns of land cover in relation to streams for a county in the mid–Atlantic region. Stream segments are colored green, yellow, or red, depending on whether the segments are adjacent to forest, agriculture, or urban land cover.





How Were the Landscape Indicators Selected?

As a starting point for selecting indicators, we considered what people in the region said they cared about. For example, concern for wildlife populations provides a reason to examine indicators of habitat fragmentation. Fragmentation of natural habitats can severely affect animal populations, as shown by the conceptual model illustrated in Figure 1.4. Concerns from the mid–Atlantic were then matched to our ability to take meaningful measurements, recognizing that some things just can't be measured very well given the available data or models. As a result of workshops and advice from people in the mid–Atlantic region, four general environmental themes were identified — people, water, forests, and landscape change. Figures 1.5 and 1.6 are pictorial representations of key landscape attributes that affect the sustainability of environmental condition across broad scales. Figure 1.5 shows some key landscape components that sustain a high quality environment, and Figure 1.6 shows some human modifications of the landscape that can reduce the sustainability of natural resources. These illustrations represent some of the important landscape indicators analyzed in this atlas.

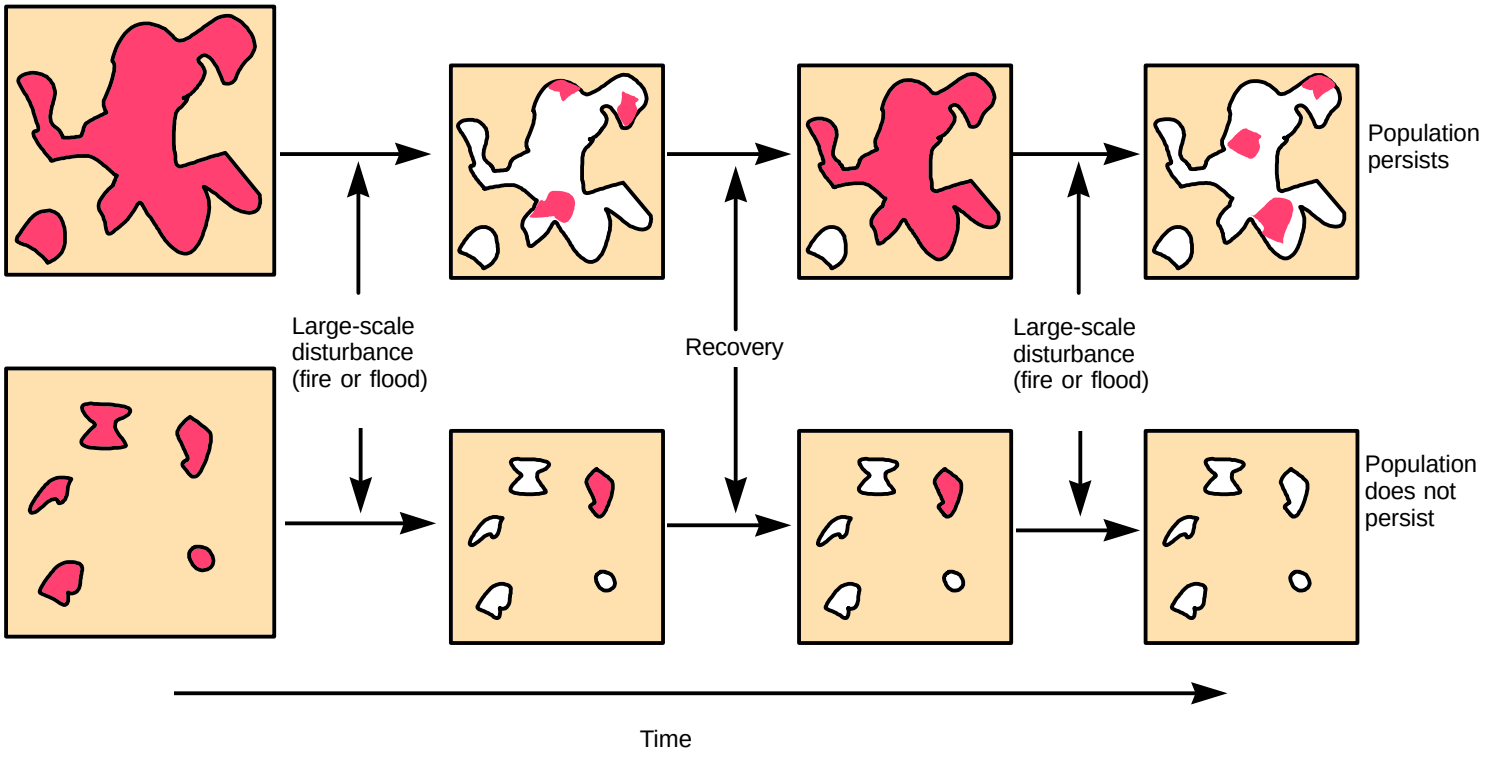


Figure 1.4.

Habitat fragmentation can result in the loss of a species due to natural disturbance. In this example larger, more connected habitat sustains the species over time, whereas smaller, more isolated habitat loses the species over time. (In this example, tan is non-habitat, red is occupied habitat, and white is unoccupied habitat.)



Forest connectivity is crucial for the persistance of forest species, especially in areas with moderate amounts of agriculture





Riparian zones filter sediments and pollutants, especially in agricultural areas, in addition to providing important wildlife habitats

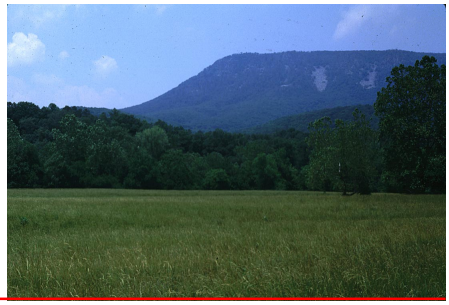
The number of forest scales surrounding a point in the landscape determines the variety of forest species found there





Large blocks of interior forest habitat are important for many forest species

Forest edge habitat is important for many species that require more than one habitat type to survive



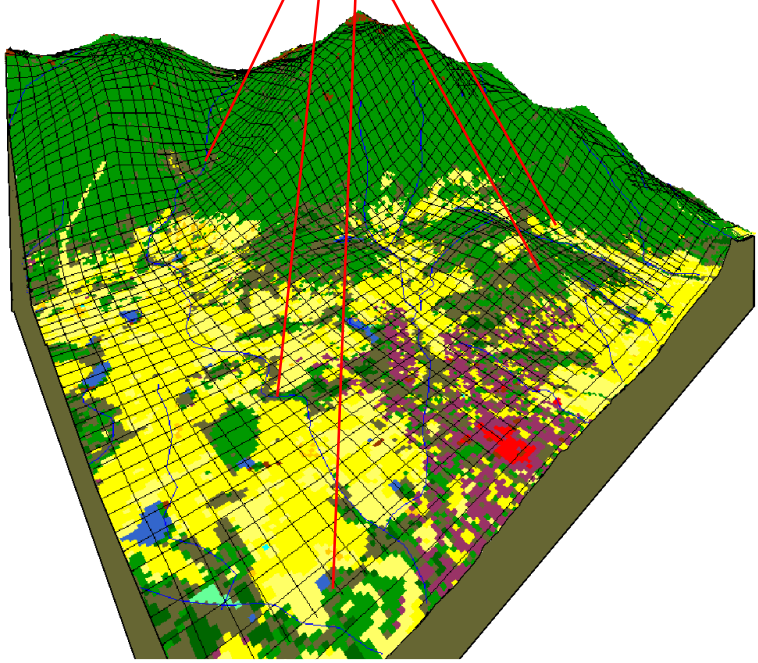
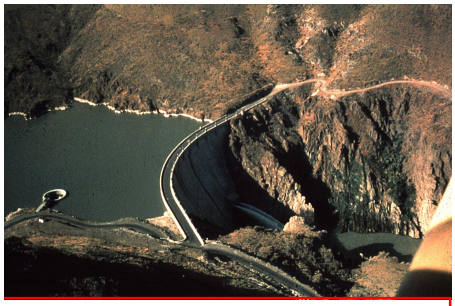


Figure 1.5.

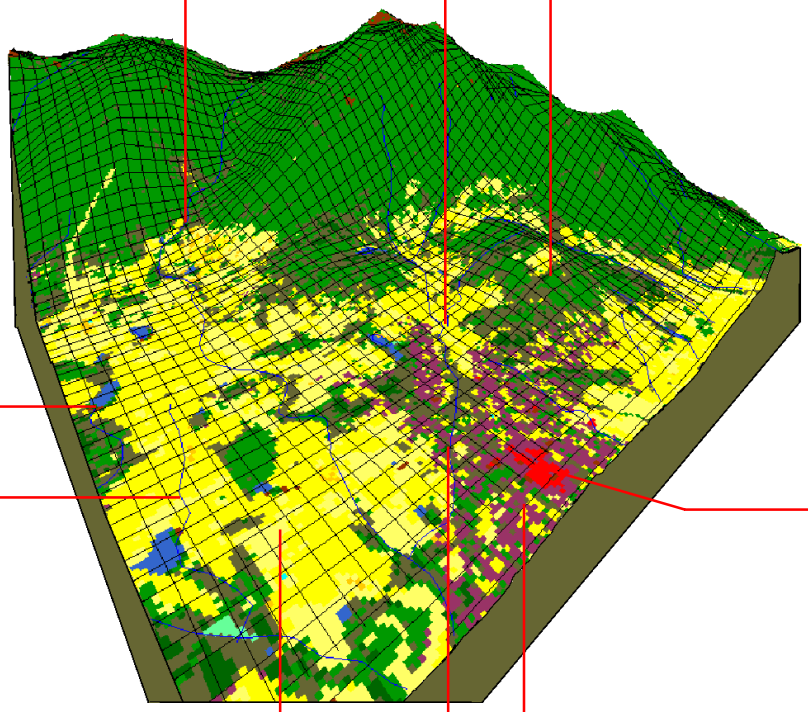
A pictorial representation of some landscape components that sustain a high–quality environment.



Agriculture on steep slopes increases soil loss and sediment loading to streams



Dams alter the natural habitats and hydrology of streams



Agriculture areas near streams increase stream sediment loads and chemical inputs





The amount and location of agriculture in a watershed influences landscape pattern

Figure 1.6

A pictorial representation of some human modifications of the landscape that reduce the sustainability of natural resources

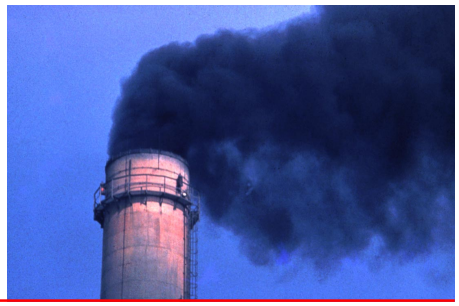


Humans reduce riparian cover along streams, which decreases filtering capacity



Forest harvest practices influence forest connectivity and patch sizes

Air pollution spreads across the landscape, affecting regional air quality





Roads near streams increase sediment and pollution loads by increasing surface runoff



Population growth results in loss of forest and changes in overall watershed landscape pattern

The indicators reported in this atlas are not appropriate for addressing some kinds of questions. For example, they are not intended to assess conditions for very small areas. The goal was to develop a consistent and comprehensive look at the entire region, and there were trade–offs between the level of detail and the size of the area that could be considered. Future work would look at smaller areas using more detailed data sets. The regional perspective would be a valuable guide to determine where this additional expense might be warranted. The indicators reported here were not evaluated in absolute terms; only relative comparisons were made. In order to set absolute standards like the ones which exist for drinking water and air pollution, the system must either be very simple or intensively studied to provide very detailed scientific information. Regional ecosystems are simply too complicated to set absolute standards using our current technology and understanding.

Landscapes are very complicated, and the generality of the conceptual models is an accurate reflection of level of scientific understanding concerning landscape dynamics. Scientists who study landscape ecology are trying to improve our ability to interpret landscape indicators relative to environmental values. The improvements will help to interpret the information that is contained in this atlas and may suggest new landscape indicators that we have not considered. In the meantime, it is worth exploring how much is known about regional environmental conditions and what conclusions can be made using state of the art landscape indicators.

How Were the Landscape Indicators Measured?

Many kinds of data were used to prepare the indicators shown in this atlas. Federal agencies were the primary source for data, including maps of elevation, watershed boundaries, road and river locations, population, soils, land cover, and air pollution. Sources included the U.S. Geological Survey (USGS), the U.S. Environmental Protection Agency (USEPA), the U.S. Department of Agriculture (USDA), the U.S. Census Bureau, and the Multi–Resolution Land Characteristics Consortium (MRLC).

Data collected by satellites were used to map land cover and its change over time. The sensors carried on satellites measure the light reflected from the Earth's surface. Because different surfaces reflect different amounts of light at various wavelengths, it is possible to identify land cover from satellite measurements of reflected light. Figure 1.7 illustrates the differential reflectance properties of water, sediments suspended in water, and land surfaces for a typical satellite image. Examples of land cover maps derived from satellite images appear later in this atlas.

In a typical digital map, data are stored as a series of numbers for each map. These maps can be thought of as checkerboards, where each grid square (or pixel, which is an abbreviation of "picture element") represents a data value for a particular landscape attribute (for example soils, topography, or land cover type) at a specific location.

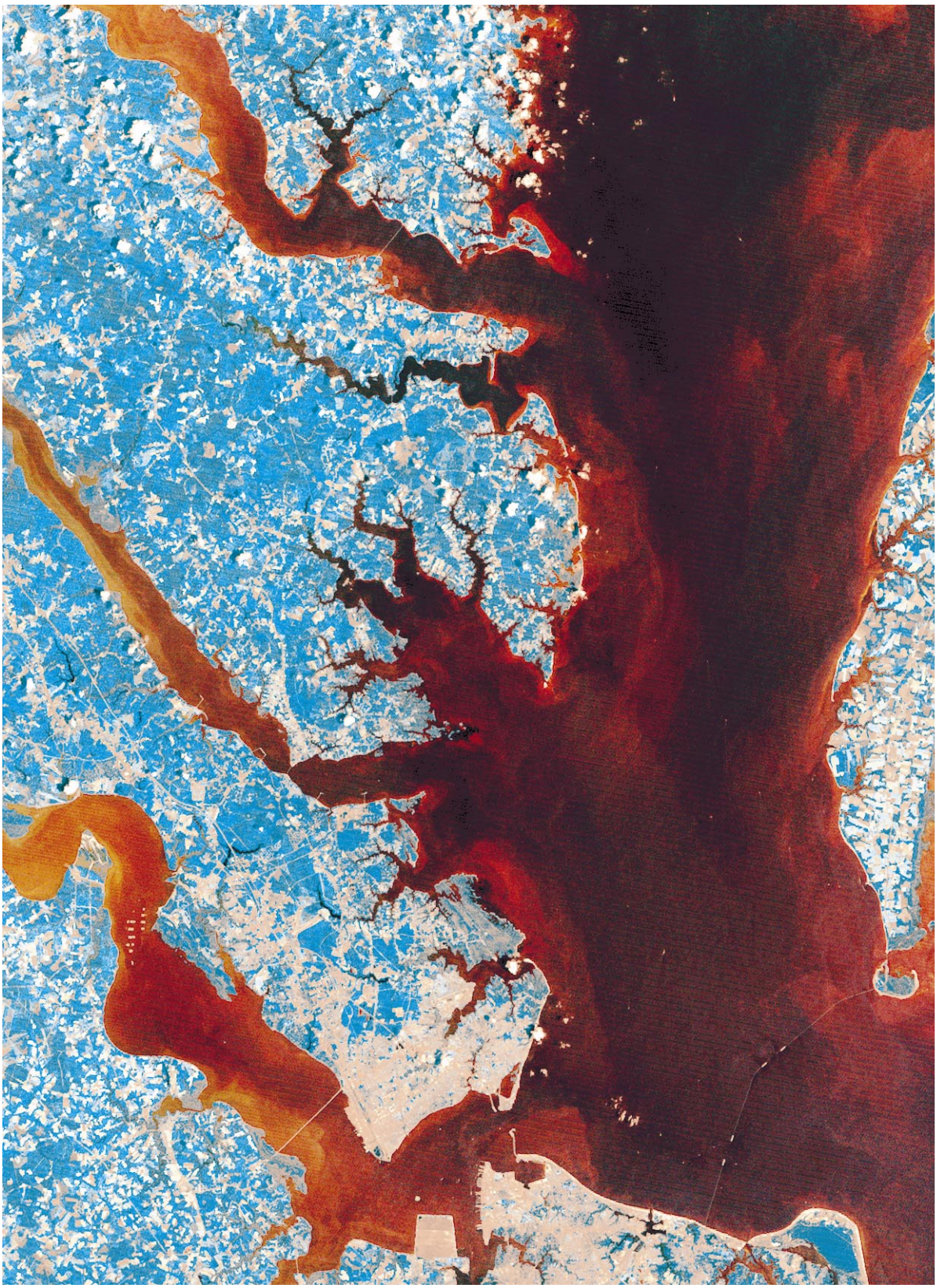


Figure 1.7.

Illustration of differential light reflectance properties for water, sediments suspended in water, and land surfaces over a portion of eastern Virginia and the Chesapeake Bay. These images can be manipulated in various ways to extract information about the Earth's surface.
Source: North American Landscape Characterization Program

Several techniques are used to take a measurement of a landscape indicator. One method ("overlaying") simply examines maps of different themes in order to extract information about spatial relationships among the themes (Figure 1.8). For example, by overlaying maps of land cover and topography, we can look at the occurrence of agriculture on steep slopes. These relationships are then stored as a new map which combines the information from the original set of maps. Another method ("spatial filtering") can be thought of as using a "sliding window" to calculate indicator values within small areas that are part of a larger map (Figure 1.9). Spatial filtering is used here to create surface maps of indicator values; these surface maps help us to visualize the spatial pattern of indicators in more detail than is provided by the watershed–level summaries described in the following section.

Land cover (with agriculture in red) is combined with topography to indicate agriculture on steep slopes. The combined map shows agriculture on slopes greater than 3%.

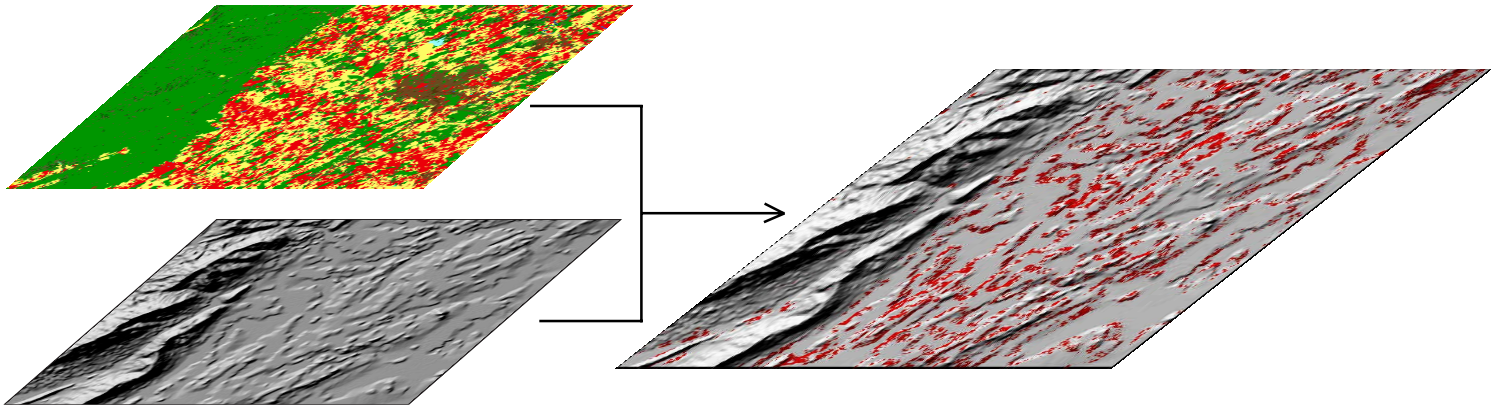


Figure 1.8.

Example of overlaying digital maps to produce a new map of an indicator.

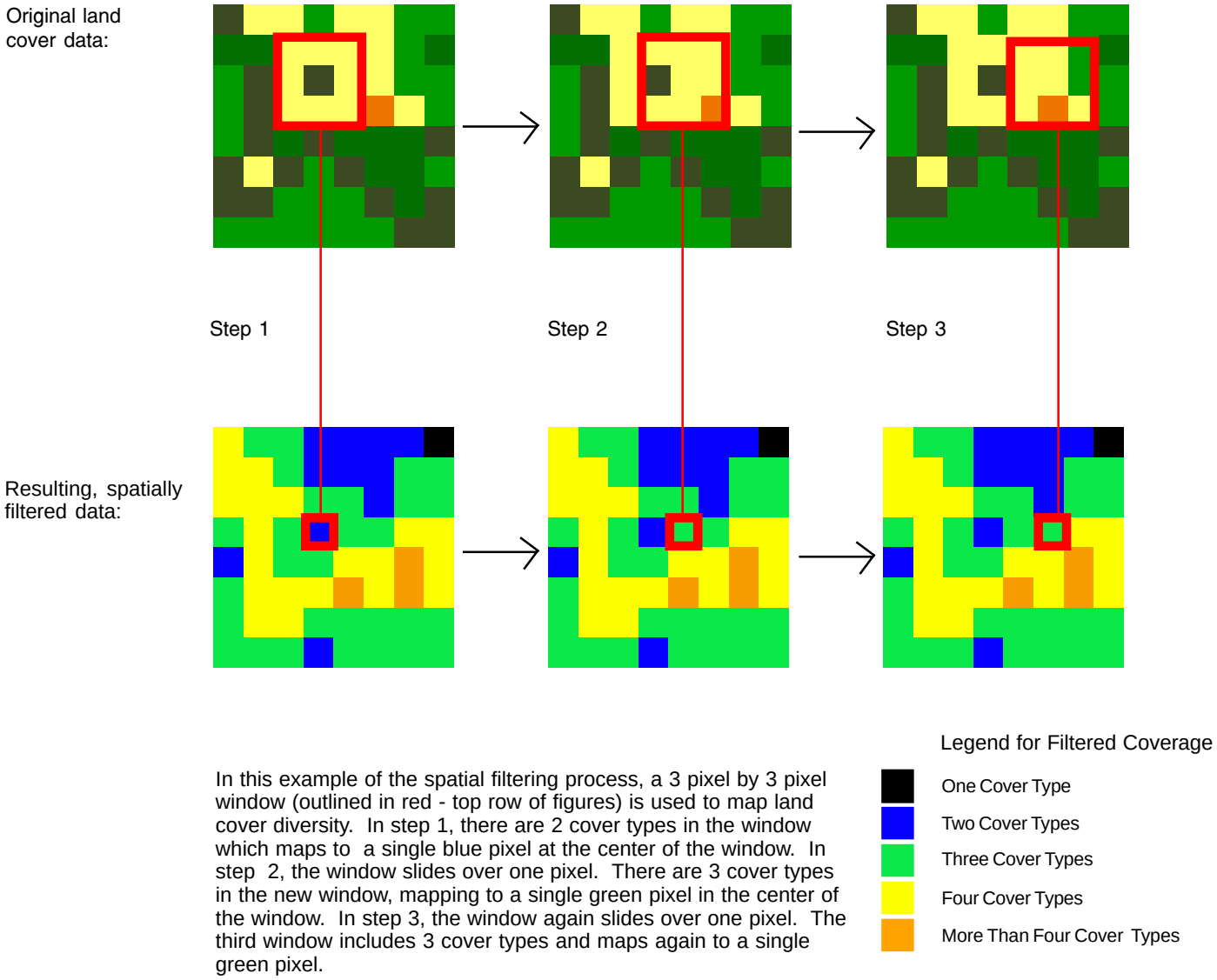


Figure 1.9.

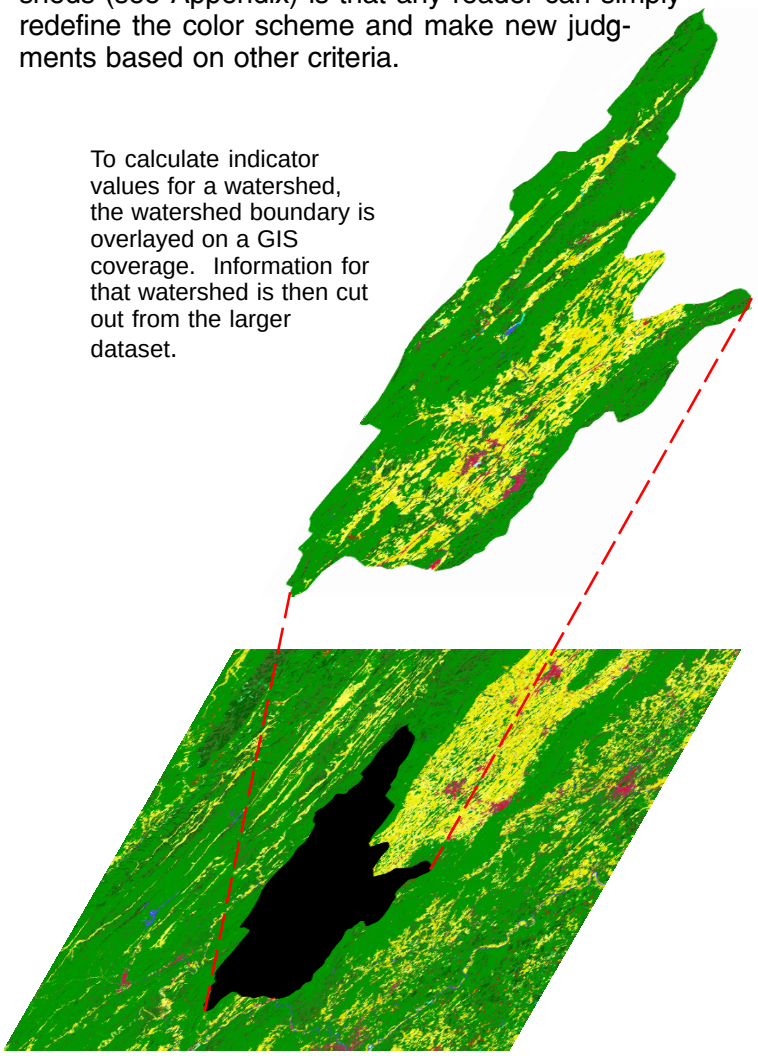
Illustration of spatial filtering which creates a surface map.

How Were the Landscape Indicators Summarized?

This atlas uses watersheds, as defined by USGS hydrologic accounting units, to summarize landscape indicator values (Figure 1.10). Roughly speaking, hydrologic accounting units follow watershed boundaries. In many ecological studies, especially those which assess water–related concerns, watersheds are an appropriate unit for summarizing data. A watershed is defined as an area of land that is drained by a single stream, river, lake, or other body of water. The dividing lines between watersheds are formed by ridges. Water on one side flows into one stream, while water on the other side may flow into a different stream. Thus, watersheds are a natural unit defined by the landscape. Strictly speaking, the USGS hydrologic accounting units are not watersheds in the classical sense of a topographically–defined catchment area. They are used in this atlas because they are generally accepted and consistent across the entire nation.

To determine relative condition, the watersheds were ranked by the values for a given indicator, from highest to lowest, and then were divided into five groups. Each group had an equal number of watersheds; at the national scale (Chapter 2) there were approximately 425 watersheds in each group. At the mid–Atlantic regional scale (Chapters 3 and 4) there were 25 watersheds in each group. All watersheds within the same group were colored with one of five colors, using green to represent more-desirable conditions and red to represent less-desirable conditions. Maps based on rankings are useful for comparing relative conditions, but they do not convey the actual values of the indicators. That information is summarized in the companion bar charts which show the number of watersheds with different indicator values. By looking at the map and bar chart together, it is possible to estimate the ranges of indicator values associated with a given watershed group.

As a practical matter, the authors of this atlas made judgment calls when assigning 'red' and 'green' colors to the maps, and 'more desirable' and 'less desirable' interpretations to the indicator values. For example, forest edge was colored 'green' and interpreted as 'more desirable' when its values were high because the measurement was included as an indicator of a type of habitat. Similar judgment calls were made for other indicators. Higher values for the vegetation-increase indicator were considered to be a negative impact because much of this change did not represent restoration of the potential natural vegetation, but rather was more strongly associated with human activities. One of the advantages of presenting indicator scores for all watersheds (see Appendix) is that any reader can simply redefine the color scheme and make new judgments based on other criteria.



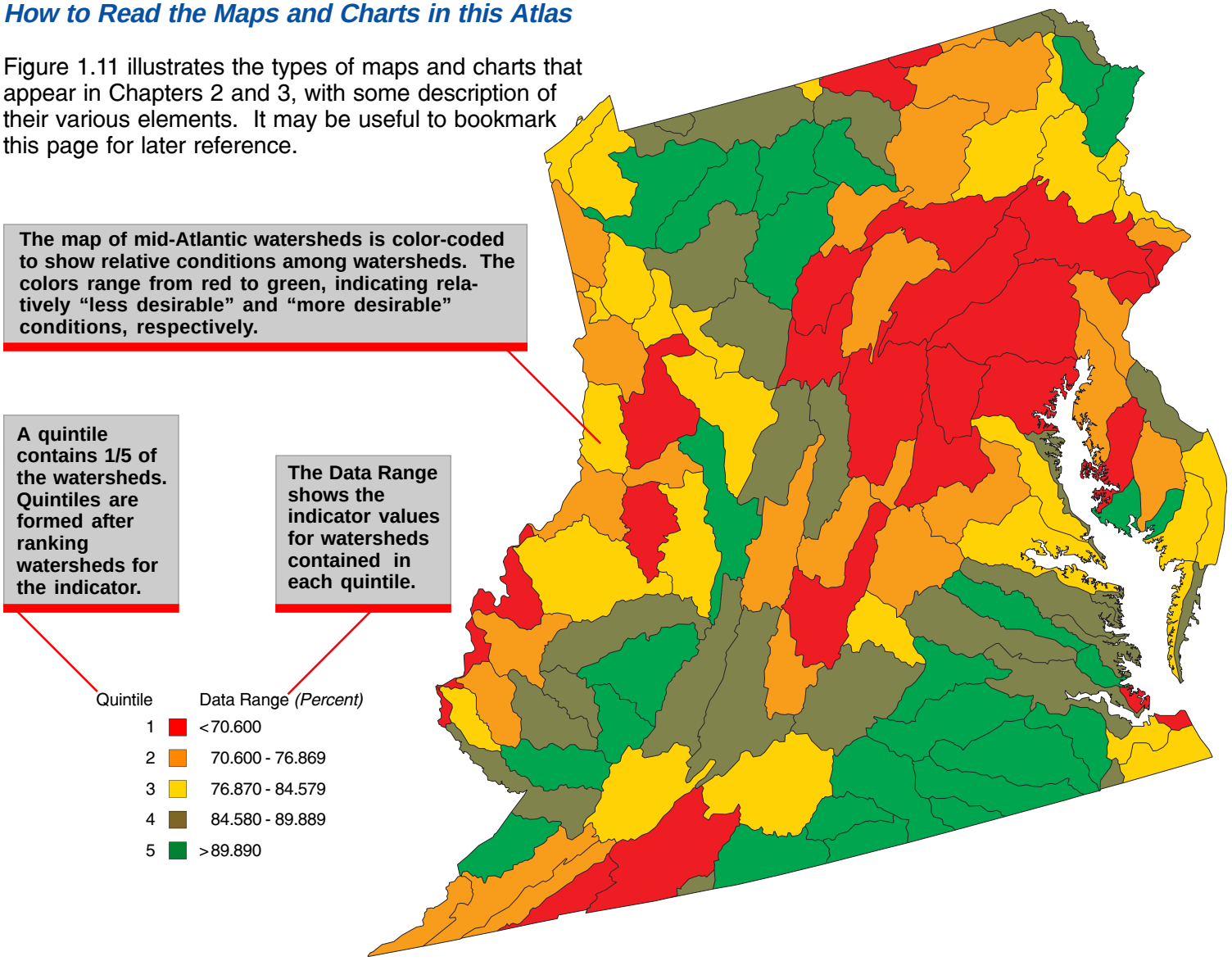
To calculate indicator values for a watershed, the watershed boundary is overlayed on a GIS coverage. Information for that watershed is then cut out from the larger dataset.

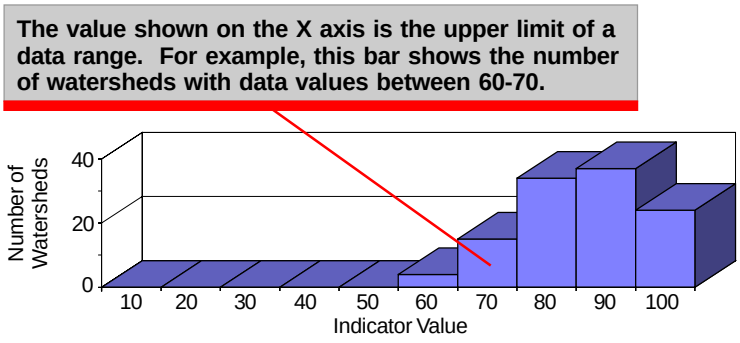
Figure 1.10.

Illustration of the cookie–cutter process that was used to summarize information by watershed.

How to Read the Maps and Charts in this Atlas

Figure 1.11 illustrates the types of maps and charts that appear in Chapters 2 and 3, with some description of their various elements. It may be useful to bookmark this page for later reference.





A brief explanation of the essential methods is given. Details are in the Appendix.

Woody landcover along streams was calculated as the percent of streamlength with forest landcover types. By intersecting a buffer zone around each stream with the landcover, a dataset is created which records all landcover types within a specified distance to stream center.
Sources: USGS 1:100,000 River Reach 3 stream data, and MRLC 30 meter Landsat land-cover data.

Figure 1.11.

How to read the maps and charts in this atlas.

Chapter 2: The National Context

Before looking in detail at the mid–Atlantic region, it is helpful to place the region within a national perspective. This chapter paints a picture of the lower 48 United States, showing differences and patterns among watersheds at a continental scale. A national context helps us interpret the overall condition of the mid–Atlantic region, relative to the rest of the country. It also helps to determine if the conditions like those found in the mid–Atlantic region exist elsewhere.

While it would be desirable to look in great detail over the entire nation, in practice only a few aspects of environmental condition can be described in a consistent fashion nationwide. The coarse–scale maps in this chapter show watershed rankings based on a variety of landscape indicators (Table 2.1). The rankings portray relative conditions across the nation but do not show the absolute values of indicators for each watershed. Indicator values are summarized in the companion bar charts.

Data Sources

Four main data sources were used here. The most important was a national map of land cover (Figure 2.1) which shows areas dominated by urban communities, water, or vegetation such as forest, crops or pasture. Although the resolution (spatial and land cover) is fairly coarse (1 square kilometer units, each assigned to 1 of 9 general land cover classes), the familiar national pattern is apparent — forests in the East, grasslands and crops in the Midwest, and shrublands, deserts, and mountain forests in the West. The mid–Atlantic region is typical of other eastern regions — coastal and riverside urban areas, agricultural valleys and coastal plain, and forested mountains and plateaus. Relative to other regions in the United States, the complexity of land cover in the mid–Atlantic region can make spatial pattern an important factor for environmental decisions.

Three other sources of information were used to calculate landscape indicators nationwide. Figure 2.2 shows the maps of roads, streams, and watersheds. Clearly, not all the roads and streams are included. These maps may be appropriate for a nationwide overview, but much more detailed maps are needed for regional assessments such as the mid–Atlantic analysis. The watershed boundaries identify 2,099 individual watershed units.

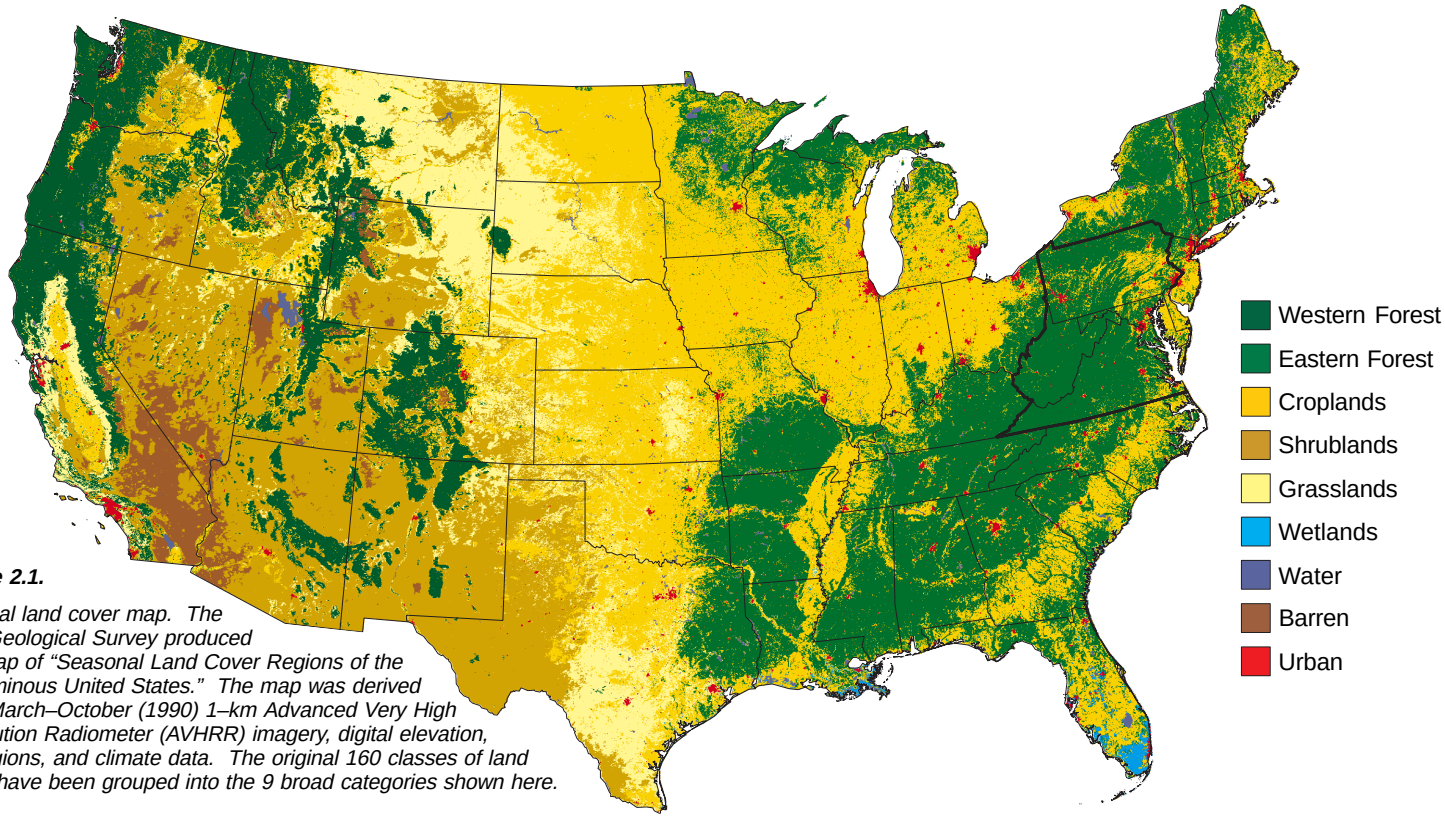


Figure 2.1.

National land cover map. The U.S. Geological Survey produced this map of "Seasonal Land Cover Regions of the Coterminous United States." The map was derived from March–October (1990) 1–km Advanced Very High Resolution Radiometer (AVHRR) imagery, digital elevation, ecoregions, and climate data. The original 160 classes of land cover have been grouped into the 9 broad categories shown here.

For each watershed, the nine indicators included in this chapter were calculated from land cover and from the spatial relationships among roads, streams, and land cover. The maps are color–coded to show relative conditions among watersheds (as described in Chapter 1).

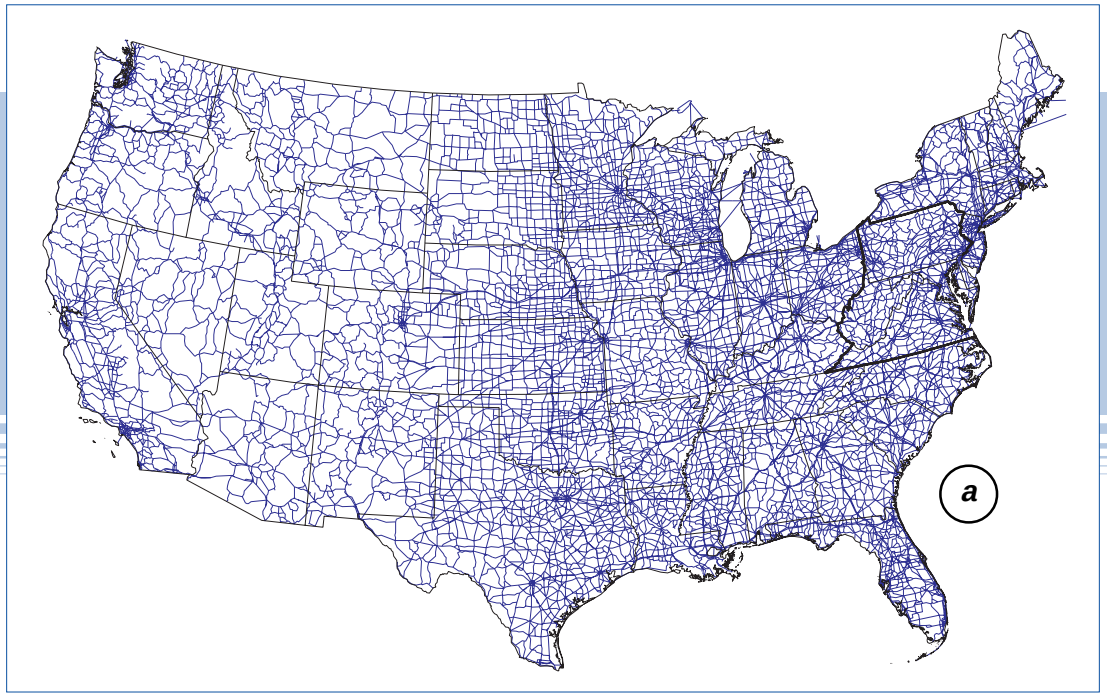
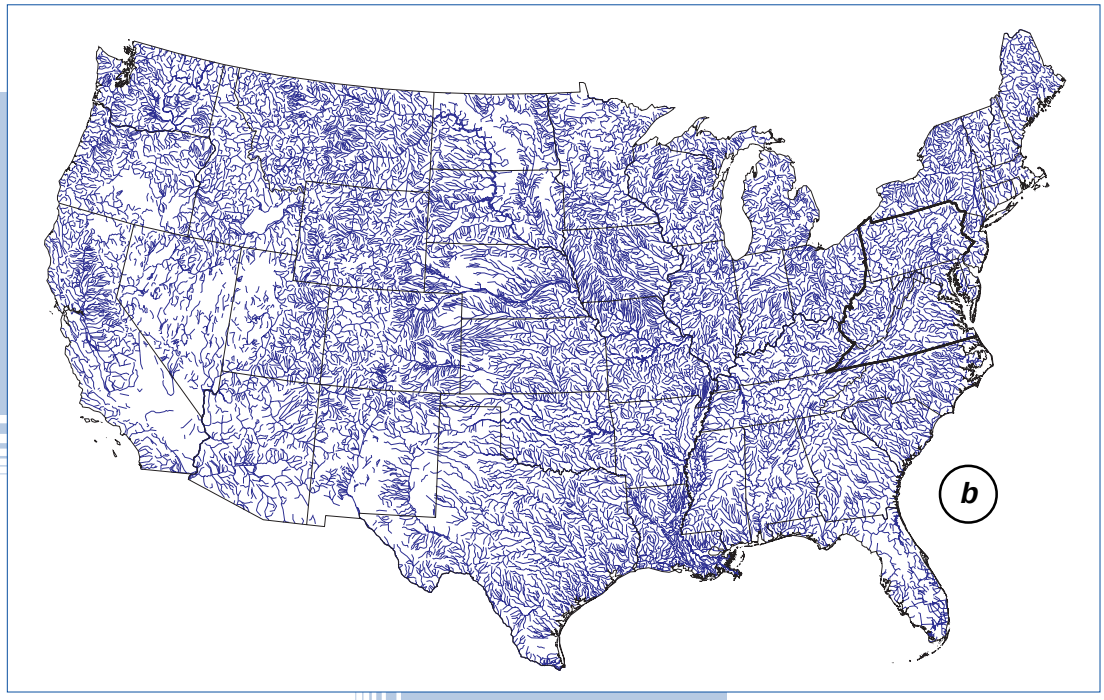


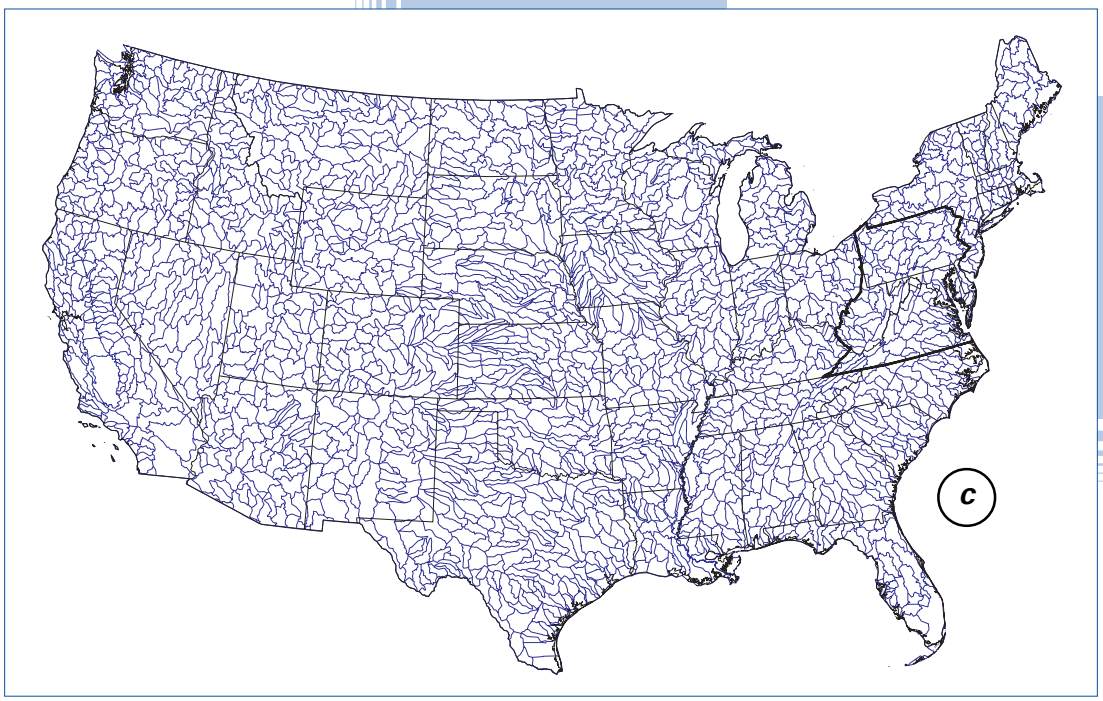
Figure 2.2.

National maps of (a) roads, (b) rivers, and (c) watershed boundaries. The maps are from the ArcUSA distribution of the U.S. Geological Survey Digital Line Graph maps of rivers (1973) and roads (1980), and the U.S. Geological Survey map of 8–digit hydrologic accounting units.

Table 2.1. List of landscape indicators used for the national context.

U–Index (proportion of watershed area with anthropogenic land cover)
Agriculture Index (proportion of watershed area with agriculture land cover)
Number of natural land cover types per unit area
Proportion of watershed that has forest land cover
Average forest patch size as a percentage of watershed area
Index of forest connectivity
Proportion of total stream length with forest land cover
Proportion of total stream length with anthropogenic land cover
Number of roads crossing streams per unit stream length


b


c

Human Use Patterns

One of the simplest and most informative indicators of environmental impact is the extent to which humans have changed the natural vegetation to crops or urban land cover. These indicators are easy to interpret because profound land cover changes influence almost every aspect of the environment from wildlife habitat to soil erosion.

The national maps of human use intensity (Figure 2.3) show watershed rankings for both total human use (agriculture plus urban, Figure 2.3a) and agriculture alone (Figure 2.3b). Urban areas are relatively minor in terms of total area, and farming areas are more extensive, so the two maps are very similar. Most of the human land use has occurred in the central United States and along the eastern seaboard. Higher elevations and the dry southwest appear to have been less impacted by conversion to agricultural or urban land cover. Like most of the eastern coast, the mid–Atlantic region has a complicated pattern of land use that deserves more detailed attention.

The chart gives some details about the distribution of human use intensity among watersheds. About 10% (200) of the nation's watersheds have been almost com-

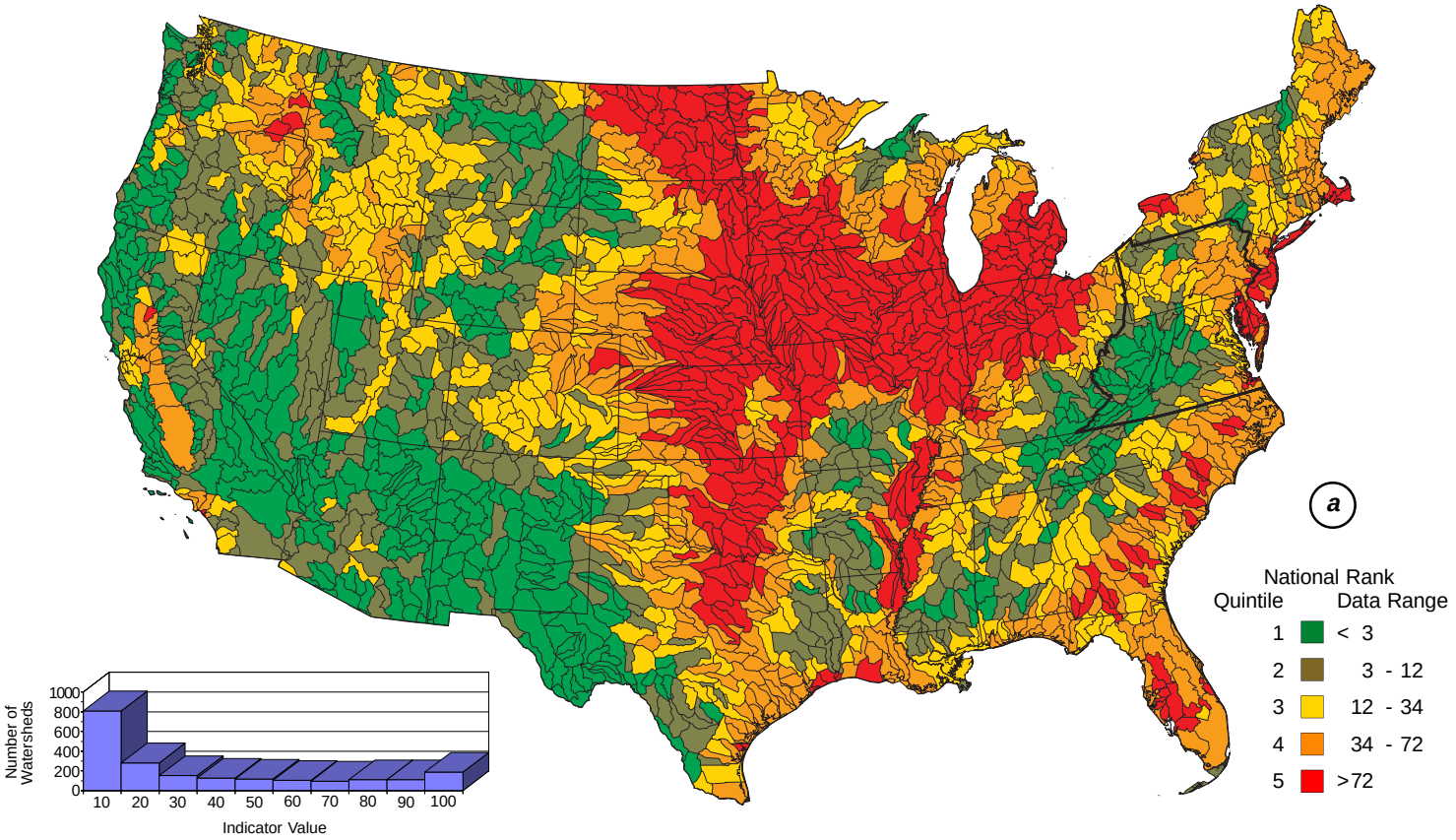
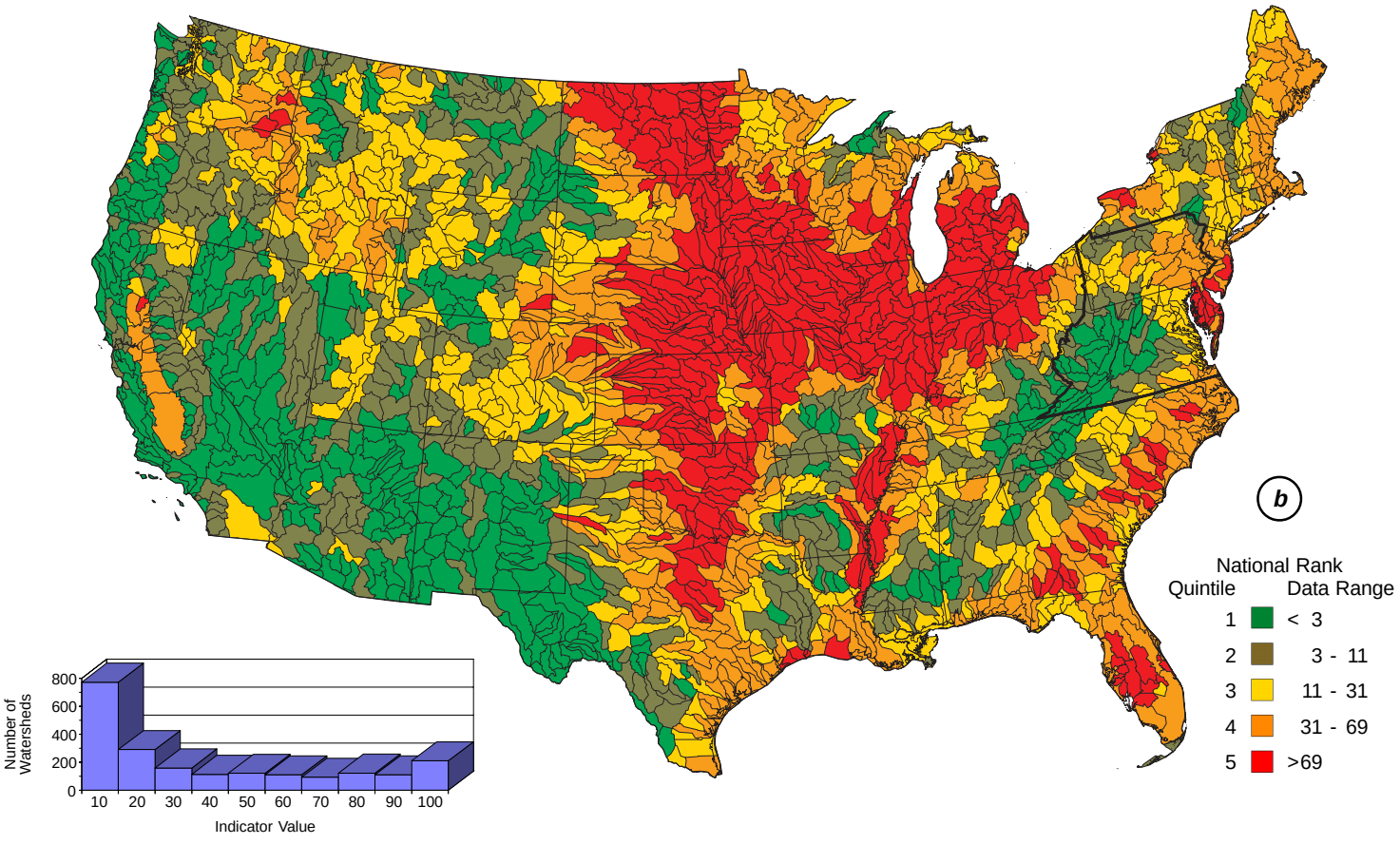


Figure 2.3.

Proportion of watershed area with: (a) agriculture or urban land cover, (b) agriculture land cover.

pletely converted to agricultural land. These are located mostly in the fertile central United States.

About 40% (800) of the watersheds have only small amounts of agriculture. These watersheds are primarily located in arid and mountainous areas. Some human uses of the land are undetectable at this scale. For example grazing, an important agricultural activity in the western United States, does not change the grassland cover type designation at this scale.



The complicated spatial patterns in the mid–Atlantic region are evident in the map of land cover diversity (Figure 2.4). The map shows the watershed ranking for the number of different natural land cover types (anything except urban and agriculture) per unit area. These rankings are based on the original 160–class version of land cover and not the 9–class version shown in Figure 2.1.

The greatest diversity of natural land cover is found in the western United States, where large changes in elevation produce different vegetation types at the top and bottom of the same watershed. But there are also diverse watersheds in coastal areas, including parts of the mid–Atlantic region.

Forest Patterns

Forest patterns are particularly relevant in the eastern United States because forests are the dominant natural vegetation cover. In contrast, natural land cover in the western United States also includes grasslands and shrublands, so forest patterns alone do not describe departures from potential natural vegetation types. We used three different indices of forest pattern in the watersheds: amount of forest, average forest patch size, and forest connectivity. The resulting national rankings of watersheds for these forest indices are shown in Figure 2.5.

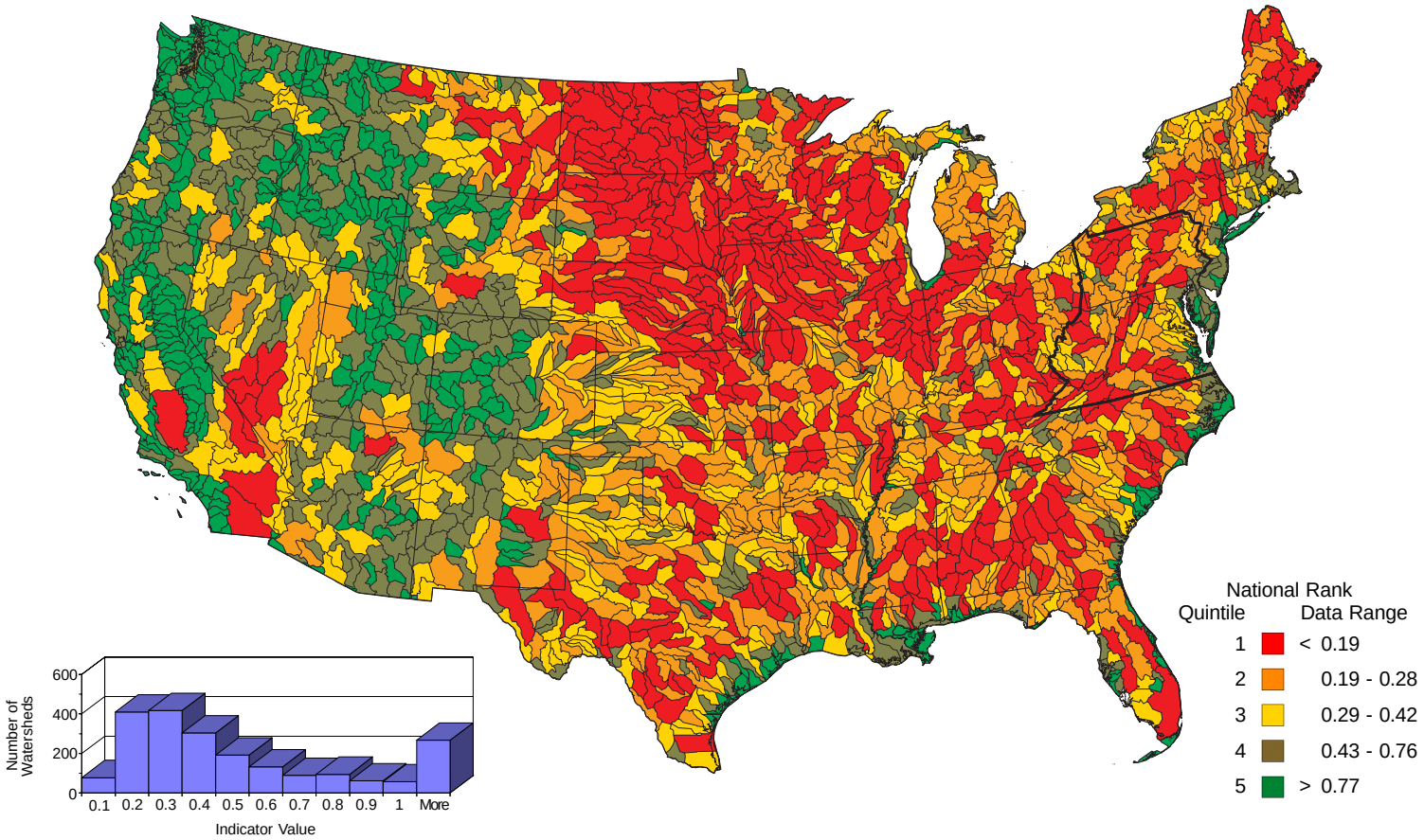


Figure 2.4.

Number of natural land-cover types per 100 square kilometers of watershed area.

The first map (Figure 2.5a) shows the watershed rankings of forest area, expressed as the percentage of total watershed area. Patterns of forest loss are evident along the east coast, and once again the mid–Atlantic region has a complicated pattern that will be interesting to explore in more detail. The chart indicates that about 20% (400) of the nation's watersheds are almost completely forested, and that about 30% have little forest cover. About 100 watersheds have no forests at all when measured at this scale. Forest cover is the most common vegetation type in nearly all of the watersheds east of the Ohio River. Many western watersheds are only forested at higher elevations.

The two other maps are different ways of looking at whether the forests that do occur in a watershed are continuous, or fragmented into smaller patches. Figure 2.5b shows watershed rankings of average forest patch area or size, expressed as a percentage of total watershed area. Figure 2.5c shows watershed rankings of forest connectivity, defined as the probability that a randomly–selected forested spot on the map is adjacent to another forested spot.

All three maps have a similar pattern. Forest cover is usually continuous where most of the watershed is forested. In other cases, such as some watersheds in the southwest, forest cover is a minor component overall, and yet is still continuous where it does occur.

Compared to potential natural cover conditions, forest loss and fragmentation of the remainder is significant in the northeast United States, along the east coast, and in the Mississippi River valley. The patterns in the mid–Atlantic region are typical of those found in other places in the eastern half of the country.

Although the three maps have a similar pattern, the charts illustrate different views obtained by using different indicators. The distribution of watersheds is more or less uniform for the indicator based on percentage of forested area. The charts for the other two indicators suggest that in most watersheds, the average forest patch is a small percentage of total area, but that forest cover tends to be connected in whatever amount actually exists.



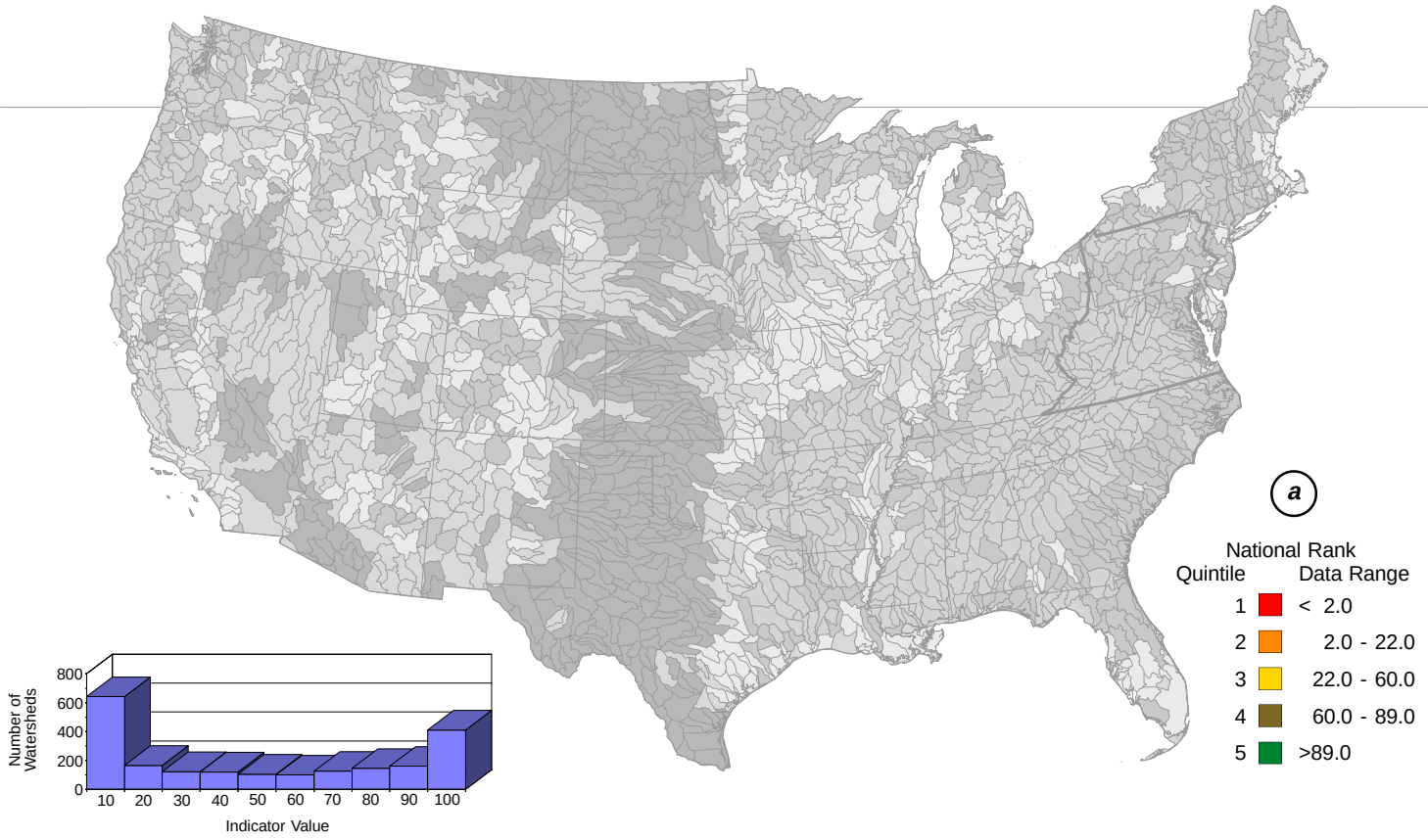
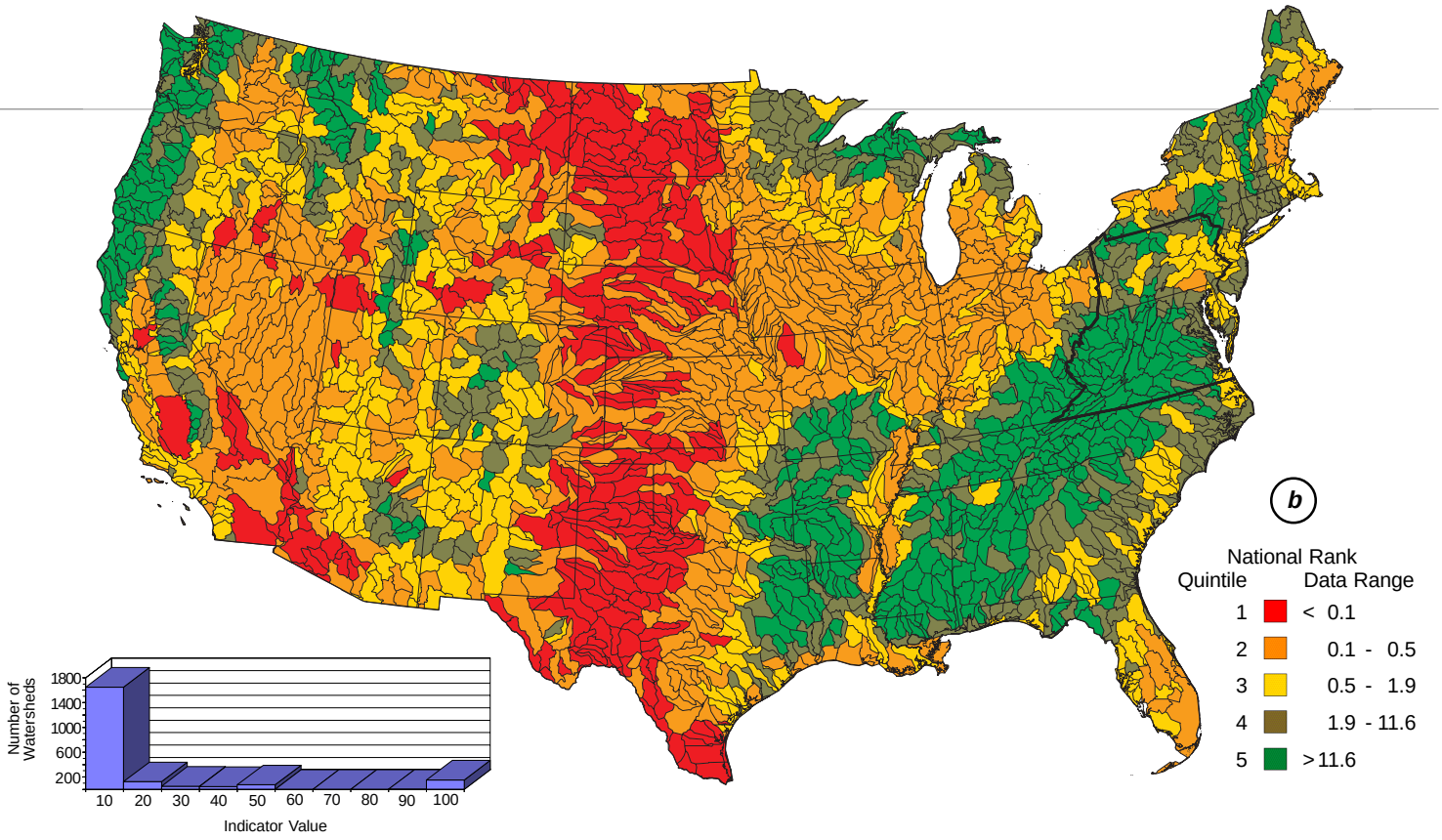
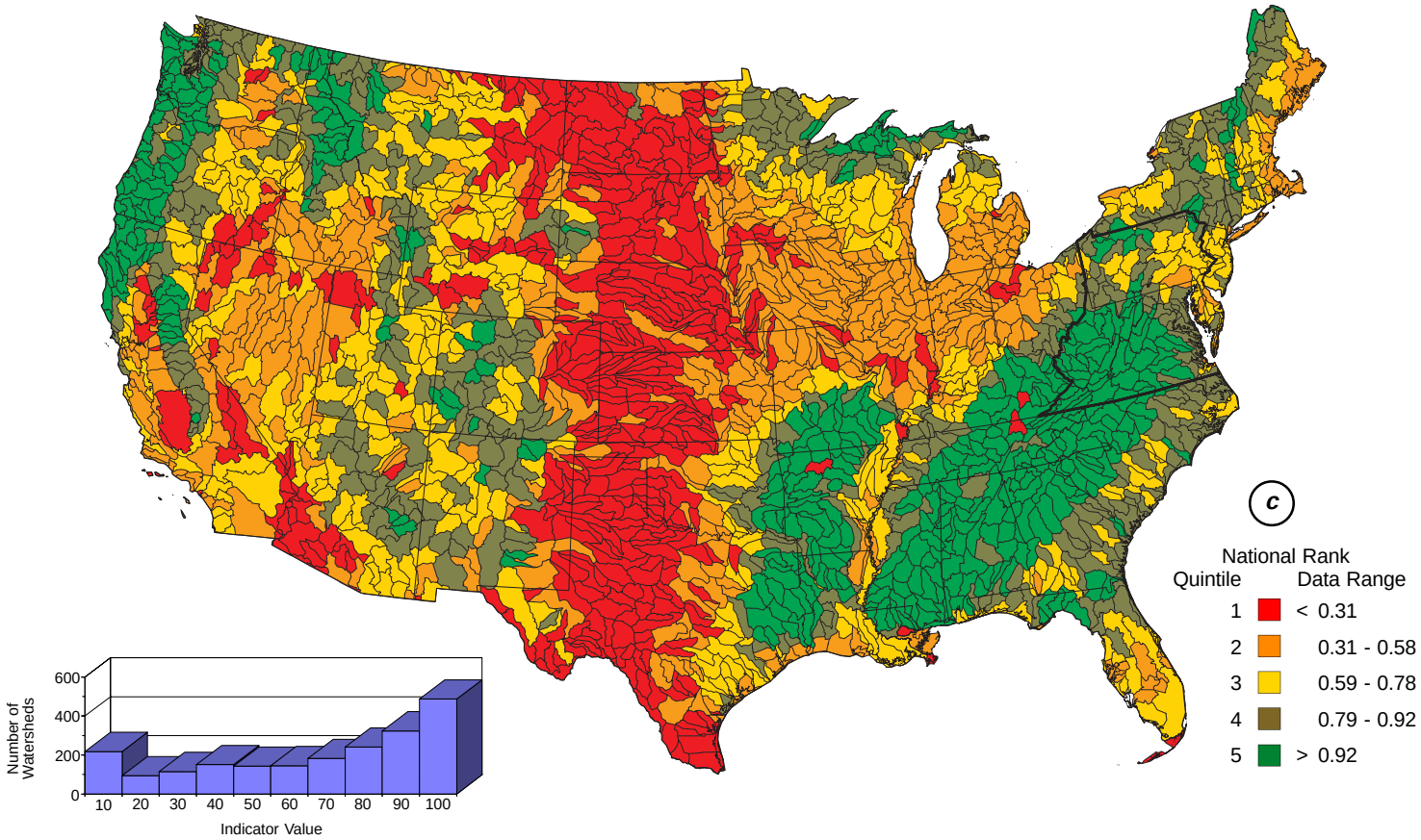


Figure 2.5.

Three forest pattern indicators: (a) percentage of watershed that is forested, (b) average forest patch size as a percentage of total watershed area, and (c) index of forest connectivity.


b
National Rank
Quintile
Data Range
1 < 0.1
2 0.1 - 0.5
3 0.5 - 1.9
4 1.9 - 11.6
5 >11.6
Number of Watersheds
1800
1400
1000
600
200
10 20 30 40 50 60 70 80 90 100
Indicator Value


c
National Rank
Quintile
Data Range
1 < 0.31
2 0.31 - 0.58
3 0.59 - 0.78
4 0.79 - 0.92
5 > 0.92
Number of Watersheds
600
400
200
0
10 20 30 40 50 60 70 80 90 100
Indicator Value

Patterns Affecting Water Quality

Water quality and aquatic life are intimately related to land cover near streams. The plant life near streams is referred to as riparian vegetation. It forms an important buffer zone protecting water quality. Natural vegetation absorbs agricultural nutrients, slows the rate of water movement, and is a settling zone for soil particles suspended in runoff. Riparian conditions are often evaluated within a few meters of a stream, but the larger landscape context is also important.

One way to measure environmental conditions is to look at whether streams flow through predominantly forested or developed landscapes within a watershed. If there are no large urban areas or agricultural zones anywhere near streams, then it is less likely that water quality is being affected by these land uses. If forest cover dominates in the vicinity of streams, then there is greater opportunity for forests to buffer the conditions within streams.

Watershed rankings of the proportions of stream length dominated by different land cover types are shown in Figure 2.6. These proportions are based on forest cover (Figure 2.6a) or urban and agriculture cover (Figure 2.6b) within about one–half kilometer of streams in each watershed. In the eastern United States, the rankings for forested riparian zones show a contrast between the highly developed northeast and the more rural southeast. The mid–Atlantic is a transition zone between these regions. Rankings based on the proportion of agriculture

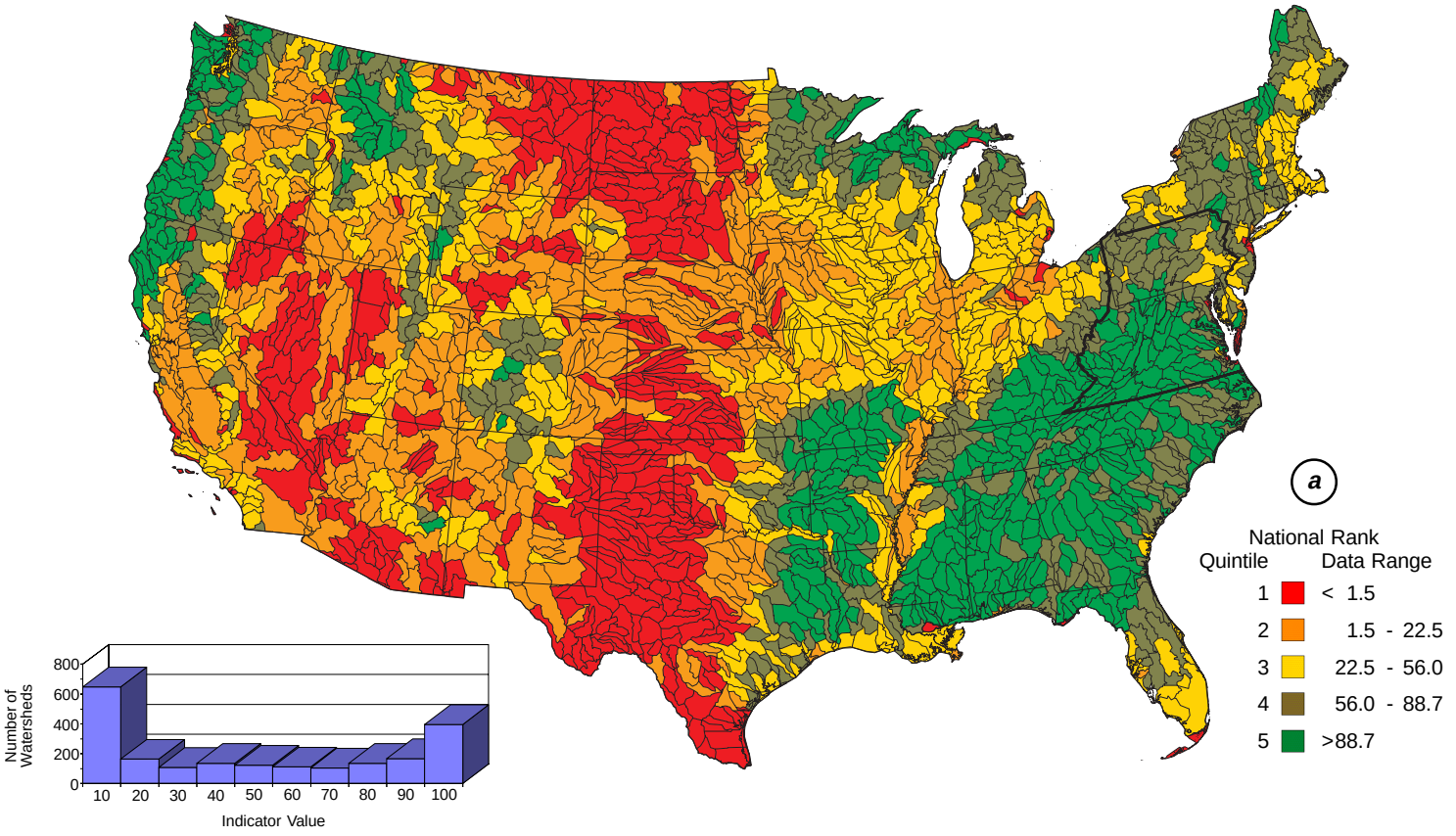


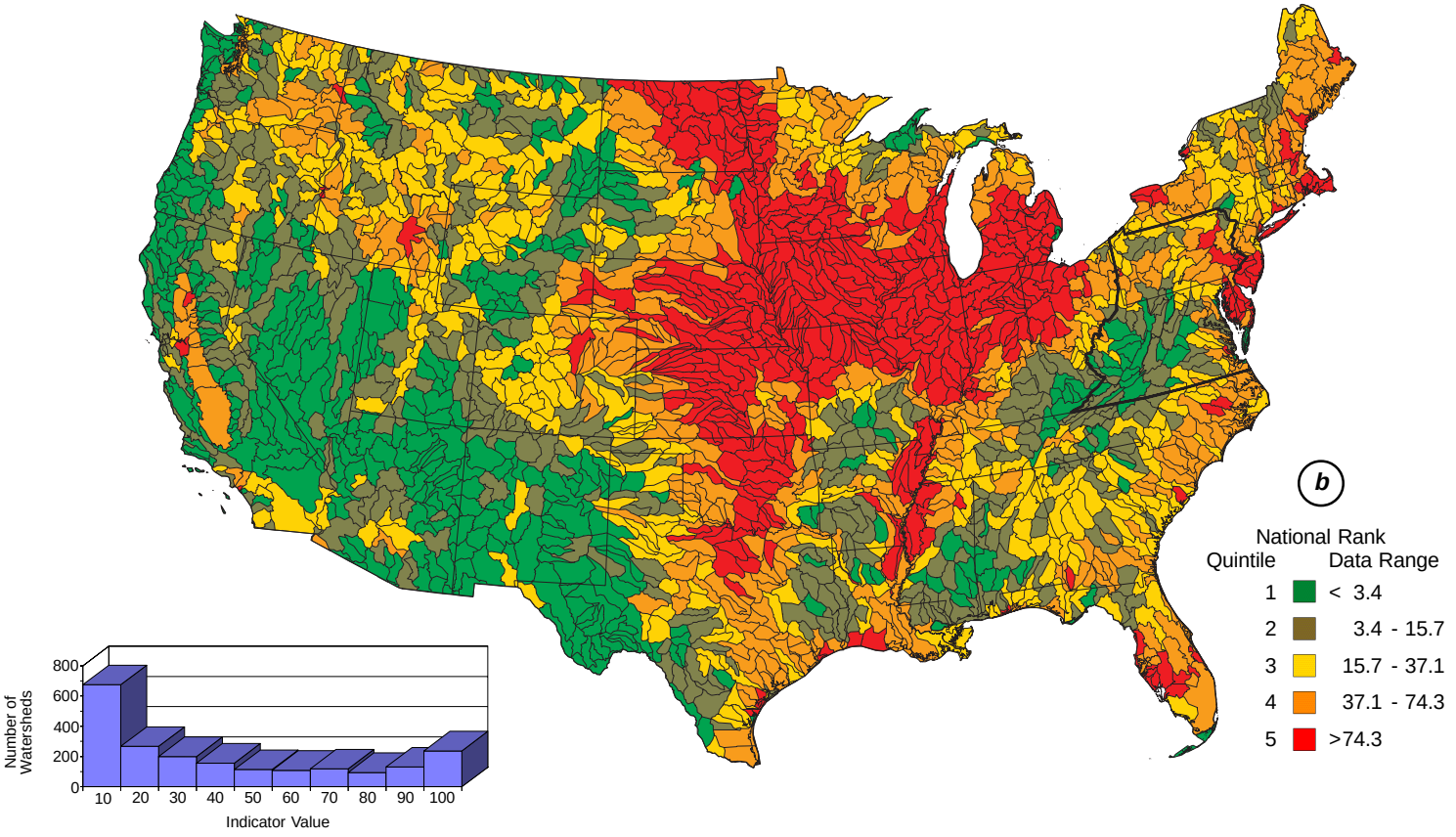
Figure 2.6.

Proportion of total streamlength that is: (a) forested, or (b) agriculture and urban.

or urban land cover in riparian zones show similar patterns in the eastern United States. Many watersheds in the Upper Mississippi River basin have relatively high proportions of urban or agriculture land cover near streams and rivers. The differences are more complicated in the western United States because non–forest vegetation may also be shrublands or grasslands.

Nationwide, the charts indicate that about 40% of the watersheds have riparian landscapes that are at least 70% forested, but an equal number of watersheds have very little forest cover in riparian landscapes. About 10% (200) of the watersheds have riparian landscapes that are nearly all agriculture or urban, and about 30% are almost completely undeveloped.

Spatial variation in land cover near streams and rivers across the nation suggest some potentially large differences in sediment and contaminant loadings to streams and rivers between regions. For example, the Upper Mississippi River basin has relatively more watersheds with agricultural and urban riparian zones, and this may contribute to relatively higher levels of sediment loadings in the streams and rivers. Large forested areas of the Appalachian Mountains have high proportions of forested riparian zones, and relatively little agriculture. Sediment and contaminant loadings to streams in these areas are likely lower than in the Upper Mississippi River basin.



Water quality is also related to larger patterns of land use over entire watersheds. For example, roads near streams affect water quality not only as direct pollution sources, but also because they represent paths for rapid runoff. The frequency of roads crossing rivers was expressed here as the number of road crossings per unit river length in each watershed. This expression helps to adjust for differences in the total length of rivers between watersheds.

The map of watershed rankings for this indicator (Figure 2.7) is complicated, and it does not closely resemble the national patterns found earlier when looking at land cover. The mid–Atlantic region, like most of the northeast and upper midwest, has extensive road networks. The mountainous areas of the mid–Atlantic have more crossings than would be expected based on land cover alone; this is so because most roads in the mountains follow river valleys and can cross the same river many times.

National Context Summary

Several important features of the mid–Atlantic region can be identified by placing it into a national context. The mid–Atlantic region certainly has complicated spatial patterns of land cover, and the finer–scale analyses shown later in this atlas seem warranted. In fact, the mid–Atlantic region should be an excellent case study area because of the variety of conditions that it contains.

Some patterns in the mid–Atlantic region are typical of other areas along the eastern seacoast. This means that what is learned in the mid–Atlantic may be applicable in other regions. Because the mid–Atlantic is also a transition zone between regions of more or less impact to the north and south, further studies here may also be relevant to environmental monitoring in these other areas.

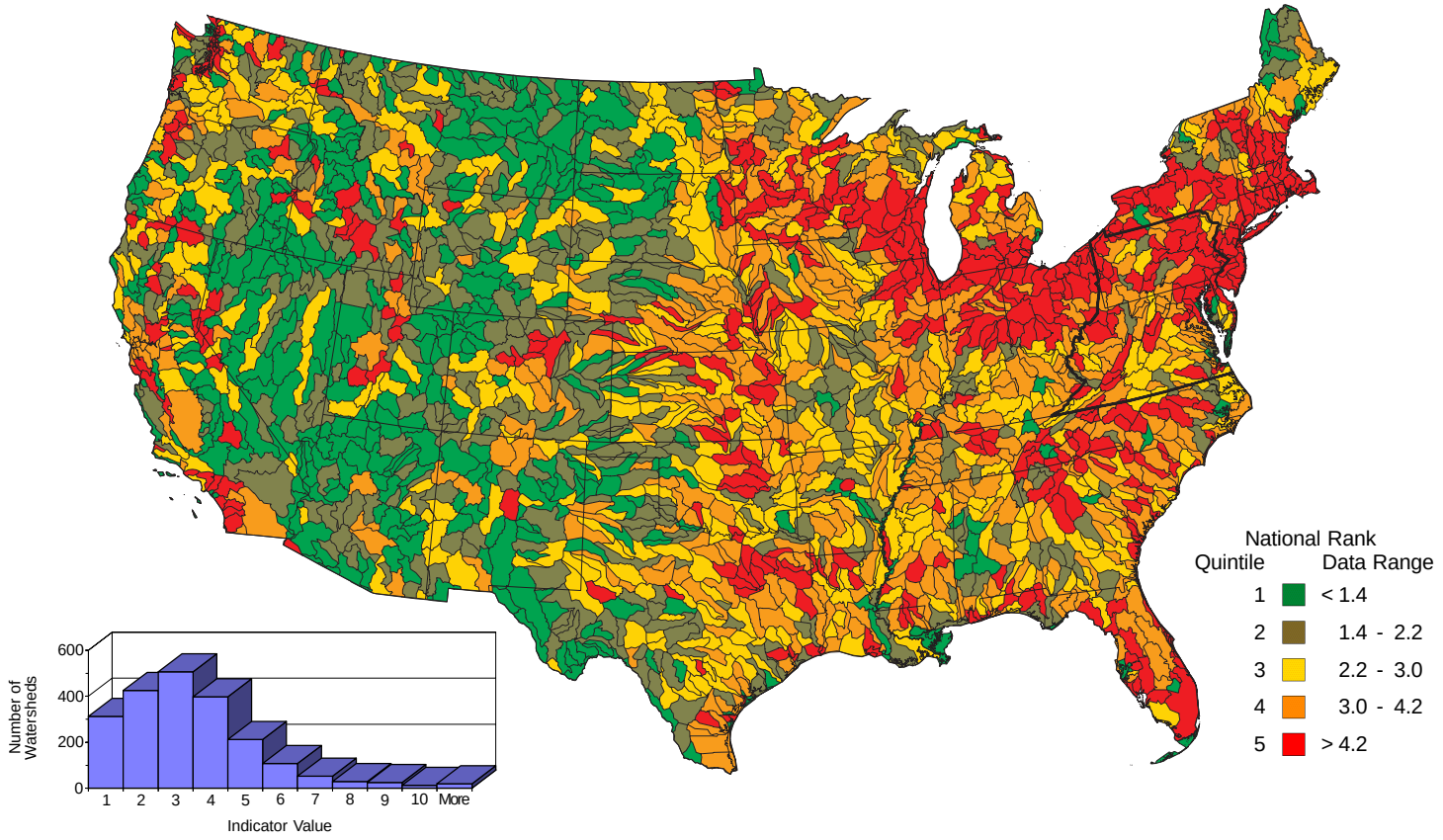


Figure 2.7.

Number of road–stream crossings per 100 kilometers of streams.

The mid–Atlantic is probably not the most highly impacted region in the eastern United States, but it is different from the less impacted areas that are found at higher elevations in the south and west. The complexity of patterns in the region creates an opportunity to consider a full range of environmental strategies from restoration of the more developed areas to protection aimed at particular resources such as high–elevation forests or wetlands. This brief look at the mid–Atlantic region in a national context has confirmed that many broad–scale aspects of environmental quality can be explored here.

Chapter 3: The Mid–Atlantic Region

This chapter illustrates some landscape indicators that can be used to assess watershed conditions in the mid–Atlantic region (Table 3.1). The comparative assessment that is reported in the next chapter is based on these indicators. Each environmental measure is discussed separately, with maps to illustrate the relative rankings or groupings of watersheds and charts to show the distributions of indicator values. The Appendix lists the actual indicator values obtained for every watershed. The methods and data used to construct the maps and charts are briefly described in this chapter, and more detailed methods are provided in the Appendix.

We begin by looking at the biophysical setting of the mid–Atlantic region and present maps of the data used to calculate indicator values. Included are regional pictures of topography, rivers, watershed boundaries, and land cover. An important criterion when choosing digital data was consistency across the region. Consistency is essential because the goal is a regional comparative assessment, and many detailed maps of relatively small areas were not used for this reason.

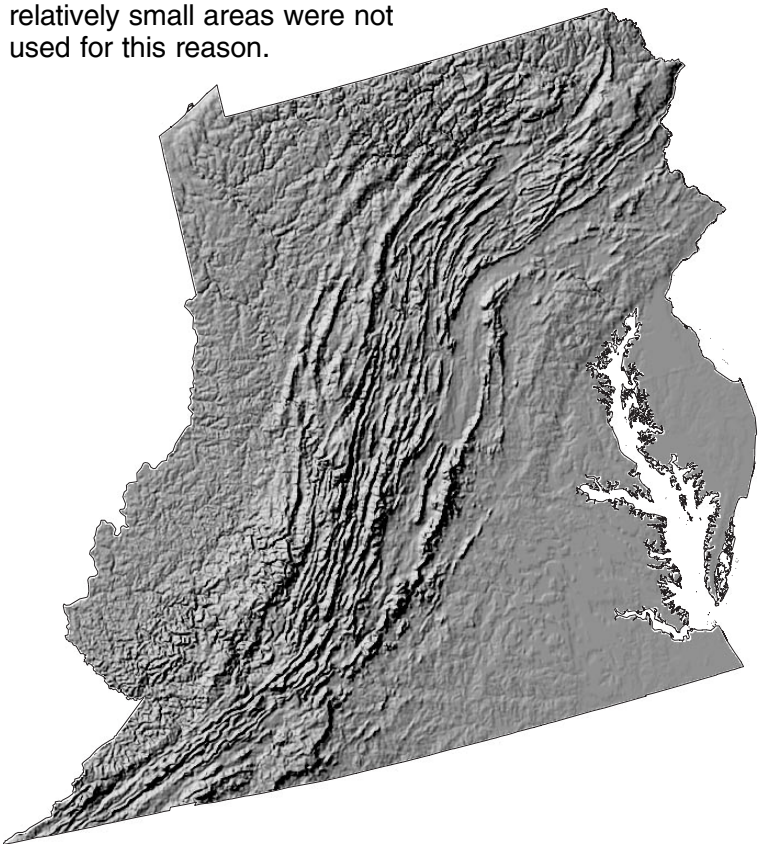


Figure 3.1

Shaded relief map of the mid–Atlantic region. Source: U.S. Geological Survey, Digital Elevation Model, 3 arc–second.

The indicators are grouped according to four themes — people, water, forests, and landscape change. These groups are subjective, and any given indicator could be relevant to more than one theme. For example, an indicator of forest cover along streams appears as part of the "water" theme, but it also describes certain aspects of forest condition as well as human impacts. The concluding section about landscape change is based on analysis of satellite imagery over a 15–year period from the 1970s to the 1990s.

Biophysical Setting of the Mid–Atlantic Region

The mountains, valleys, and coastal plains form the backdrop for all of the physical and biological processes that shape the region. When you look at a map of the region — whether it is a physical map, a vegetation map, or even a socio–political map — the most striking features of the landscape are created by topographic variation (Figure 3.1). The variety of the different physiographic regions — Blue Ridge Mountains, Ridge and Valley, Coastal Plain — creates one of the most diverse physical and ecological regions in the nation.

In the western section of the mid–Atlantic, the Appalachian Mountains rise thousands of feet to dominate the landscape for hundreds of miles in any direction. The great valley of the Appalachians, stretching from Pennsylvania to Alabama, provides fertile agricultural lands and gently sloping areas for human development. To the east of the Appalachians, the coastal plain stretches to the Chesapeake Bay, one of the most important natural resources of the mid–Atlantic region. The estuarine and wetland habitats surrounding the bay are associated with lowland areas and slowly draining soils which have been washed from the western mountains.

Topography and soils have a direct and dramatic effect on the biological character of the mid–Atlantic region. The diversity of plants and animals is tied to variations in sunlight and moisture, the basic building blocks for ecological communities. The amount and timing of sunlight varies from one hillside to the next, depending on the direction, or aspect, of the slope. In the northern hemisphere, south–facing slopes receive more sunlight than northern faces and this, in turn, causes differences in available energy and soil moisture. The depth and nutrient content of the soils themselves also influence available resources. All of these variations are reflected in the arrangement of plant and animal communities that respond to ecological conditions. Even in the relatively

flat coastal plain, a difference of just a few feet of elevation or a slightly different aspect can dramatically change the species composition of an ecosystem. Topography is one of the most important considerations for any landscape ecological assessment.

Streams and rivers direct the flow of water across the landscape and are a dominant feature in the mid–Atlantic region (Figure 3.2). In addition to carrying water, streams transport sediment and nutrients that replenish downstream areas. Because streams also transport pollutants, it is important to look both upstream and downstream when assessing water quality issues. The connected nature of the stream network requires us to examine not only the streams of immediate concern, but also how those streams fit into the regional picture of streamflow and water quality.

Table 3.1 List of landscape indicators used to assess watershed conditions in the mid–Atlantic region. (The abbreviations are used in tables of indicator values in Chapter 4 and in the Appendix.)

POPDENS	*Population density (number of people per square kilometer)*
POPCHG	*Population change (percentage change from 1970 to 1990)*
UINDEX	*Human use index (proportion of wateshed area with agriculture or urban land cover)*
RDDENS	*Road density (average number of kilometers of roads per square kilometer of watershed area)*
NO3DEP	*Average annual wet deposition of nitrate (1987 and 1993)*
SO4DEP	*Average annual wet deposition of sulfate (1987 and 1993)*
OZAVG	*Average annual value of the W126 ozone index (1988 and 1989)*
RIPFOR	*Proportion of total streamlength with adjacent forest land cover*
RIPAG	*Proportion of total streamlength with adjacent agriculture land cover*
STRD	*Proportion of total streamlength that has roads within 30 meters*
DAMS	*Number of impoundments per 1000 kilometers of stream length*
CROPSL	*Proportion of watershed with crop land cover on slopes that are greater than three percent*
AGSL	*Proportion of watershed with agriculture land cover on slopes that are greater than three percent*
STNL	*Potential nitrogen loadings to streams*
STPL	*Potential phosphorus loadings to streams*
PSOIL	*Proportion of watershed with potential soil loss greater than one ton per acre per year*
FOR%	*Percent of watershed area that has forest land cover*
FORFRAG	*Forest fragmentation index*
EDGE7	*Proportion of watershed area with suitable forest edge habitat (7 hectare scale)*
EDGE65	*Proportion of watershed area with suitable forest edge habitat (65 hectare scale)*
EDGE600	*Proportion of watershed area with suitable forest edge habitat (600 hectare scale)*
INT7	*Proportion of watershed area with suitable interior forest habitat (7 hectare scale)*
INT65	*Proportion of watershed area with suitable interior forest habitat (65 hectare scale)*
INT600	*Proportion of watershed area with suitable interior forest habitat (600 hectare scale)*
INTALL	*Proportion of watershed area with suitable interior forest habitat at three scales*
FORDIF	*Departure of the largest forest patch size from the maximum possible for a given amount of anthropogenic land cover*
NDVIDEC	*Decrease in normalized difference vegetation index from 1975 to 1990*
NDVIINC	*Increase in normalized difference vegetation index from 1975 to 1990*
NDVITOT	*Total change in normalized difference vegetation index from 1975 to 1990*
1STDEC	*Difference between observed and expected decreases in normalized difference vegetation index from 1975 to 1990 in first–order stream regions*
1STINC	*Difference between observed and expected increases in normalized difference vegetation index from 1975 to 1990 in first–order stream regions*
1STTOT	*Difference between observed and expected total change in normalized difference vegetation index from 1975 to 1990 in first-order stream regions*
NDVI3%	*Proportion of watershed with normalized difference vegetation index decreases from 1975 to 1990 on slopes greater than three percent*



Figure 3.2.

Streams and water bodies in the mid–Atlantic region.
Source: U.S. Environmental Protection Agency, River Reach File Version 3 (RF3), derived from U.S. Geological Survey Digital Line Graph – streams, 1:100,000–scale.

The landscape indicators in this atlas are summarized by watersheds, using the national map of watershed boundaries that was shown in Chapter 2. A subset of that map covering just the mid–Atlantic region (Figure 3.3) was used to summarize the landscape indicators in this chapter. The figure illustrates one of the problems in using naturally–defined units such as watersheds to assess conditions over politically–defined units like states — parts of some watersheds lie outside of the assessment region. As a result, the indicators calculated for these watersheds are probably not as reliable as the indicators calculated for watersheds that had complete data coverage.

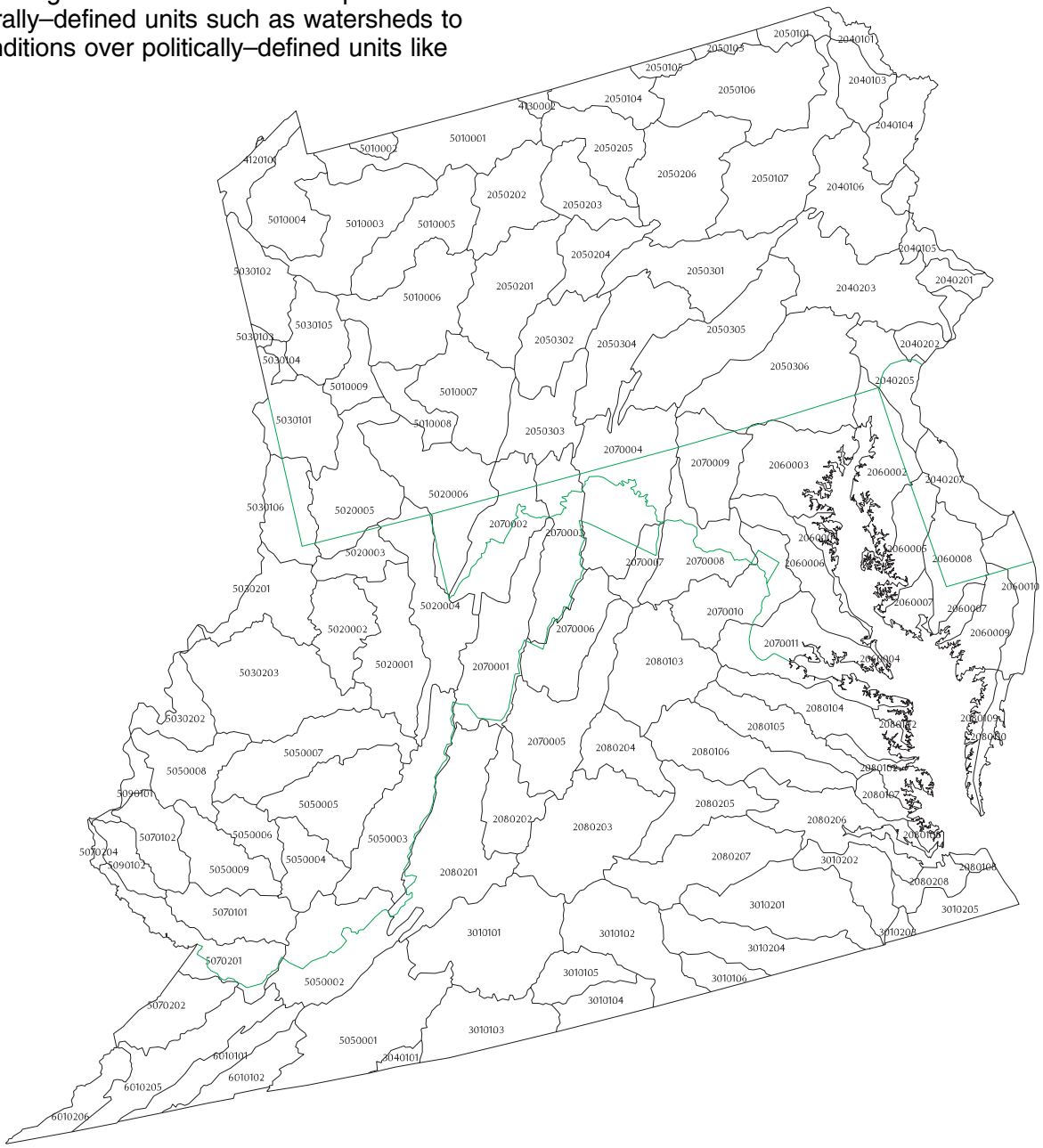


Figure 3.3.

Watershed boundaries within the mid–Atlantic region. The numbers are USGS hydrologic unit codes (HUCs). See Table 3.2 for watershed names. Source: U.S. Geological Survey, Hydrologic Unit Code Boundaries (HUC250), 1:250,000–scale.

Table 3.2 Watershed names

2040101	Upper Delaware
2040103	Lackawaxen
2040104	Middle Delaware-Mongaup-Brodhead
2040105	Middle Delaware-Musconetcong
2040106	Lehigh
2040201	Crosswicks-Neshaminy
2040202	Lower Delaware
2040203	Schuylkill
2040205	Brandywine-Christina
2040207	Broadkill-Smyrna
2050101	Upper Susquehanna
2050103	Owego-Wappasening
2050104	Tioga
2050105	Chemung
2050106	Upper Susquehanna-Tunkhannock
2050107	Upper Susquehanna-Lackawanna
2050201	Upper West Branch Susquehanna
2050202	Sinnemahoning
2050203	Middle West Branch Susquehanna
2050204	Bald Eagle
2050205	Pine
2050206	Lower West Branch Susquehanna
2050301	Lower Susquehanna-Penns
2050302	Upper Juniata
2050303	Raystown
2050304	Lower Juniata
2050305	Lower Susquehanna-Swatara
2050306	Lower Susquehanna
2060002	Upper Chesapeake Bay
2060003	Gunpowder-Patapsco
2060004	Severn
2060005	Choptank
2060006	Patuxent
2060007	Blackwater-Wicomico
2060008	Nanticoke
2060009	Pocomoke
2060010	Chincoteague
2070001	South Branch Potomac
2070002	North Branch Potomac
2070003	Cacapon-Town
2070004	Conococheague-Opequon
2070005	South Fork Shenandoah
2070006	North Fork Shenandoah
2070007	Shenandoah
2070008	Middle Potomac-Catoctin
2070009	Monocacy
2070010	Middle Potomac-Anacostia-Occoquan
2070011	Lower Potomac
2080102	Great Wicomico-Piankatank
2080103	Rapidan-Upper Rappahannock
2080104	Lower Rappahannock
2080105	Mattaponi
2080106	Pamunkey
2080107	York
2080108	Lynnhaven-Poquoson
2080109	Western Lower Delmarva
2080110	Eastern Lower Delmarva
2080201	Upper James
2080202	Maury
2080203	Middle James-Buffalo
2080204	Rivanna
2080205	Middle James-Willis
2080206	Lower James
2080207	Appomattox
2080208	Hampton Roads
3010101	Upper Roanoke
3010102	Middle Roanoke
3010103	Upper Dan
3010104	Lower Dan
3010105	Banister
3010106	Roanoke Rapids
3010201	Nottoway
3010202	Blackwater
3010203	Chowan
3010204	Meherrin
3010205	Albemarle
3040101	Upper Yadkin
4120101	Chautauqua-Conneaut
4130002	Upper Genesee
5010001	Upper Allegheny
5010002	Conewango
5010003	Middle Allegheny-Tionesta
5010004	French
5010005	Clarion
5010006	Middle Allegheny-Redbank
5010007	Conemaugh
5010008	Kiskiminetas
5010009	Lower Allegheny
5020001	Tygart Valley
5020002	West Fork
5020003	Upper Monongahela
5020004	Cheat
5020005	Lower Monongahela
5020006	Youghiogheny
5030101	Upper Ohio
5030102	Shenango
5030103	Mahoning
5030104	Beaver
5030105	Connoquenessing
5030106	Upper Ohio-Wheeling
5030201	Little Muskingum-Middle Island
5030202	Upper Ohio-Shade
5030203	Little Kanawha
5050001	Upper New
5050002	Middle New
5050003	Greenbrier
5050004	Lower New
5050005	Gauley
5050006	Upper Kanawha
5050007	Elk
5050008	Lower Kanawha
5050009	Coal
5070101	Upper Guyandotte
5070102	Lower Guyandotte
5070201	Tug
5070202	Upper Levisa
5070204	Big Sandy
5090101	Raccoon-Symmes
5090102	Twelvepole
6010101	North Fork Holston
6010102	South Fork Holston
6010205	Upper Clinch
6010206	Powell

Land cover is the product of human land uses on the backdrop of the biophysical setting. A map of land cover is essentially a picture of the dominant vegetative, water, or urban cover in an area. The map of land cover in the mid–Atlantic region (Figure 3.4) is based primarily on images taken by the Landsat satellite (Thematic Mapper) earlier in this decade. The land cover map was prepared by the Multi–Resolution Land Characterization (MRLC) project, a Federal effort to create similar maps for the entire country. The resolution of the land cover data is 30 meters, so each pixel (picture element) represents an area about the size of the infield of a major league baseball park. Although individual pixels are far too small to be rendered accurately here, the visual impression of broad–scale regional patterns is readily apparent.

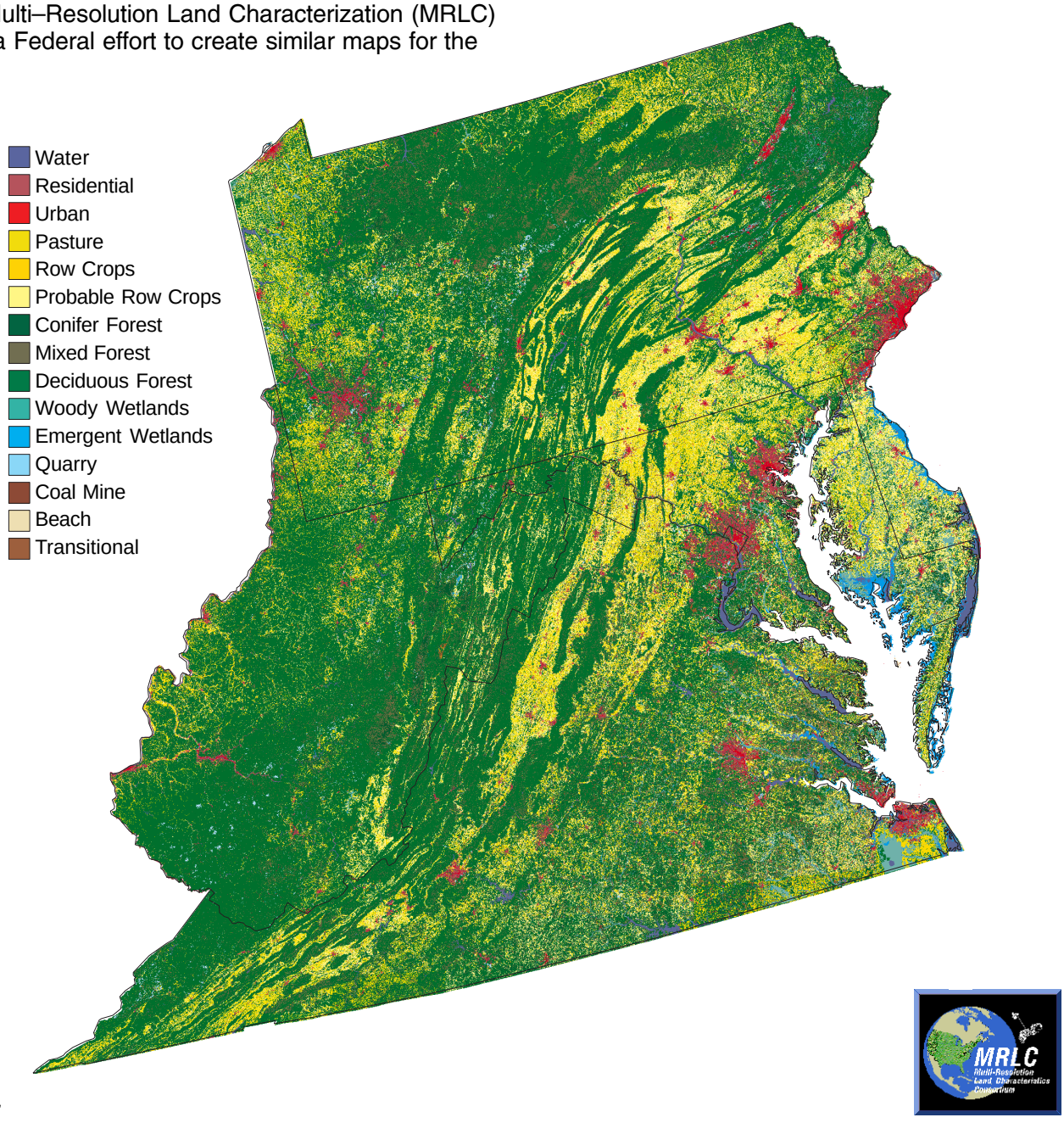


Figure 3.4.

Land cover in the mid–Atlantic region, ca. 1990. Source: Multi–Resolution Land Characteristics (MRLC) Consortium, derived from Landsat Thematic Mapper (TM) data, 30 meter resolution (shown here at 90 meter resolution).

The two most dominant land-cover types in the mid–Atlantic region are forest, which covers about 70% of the area and agriculture, which covers about 25% of the area. Most of the watersheds are primarily forested, and some approach complete forest cover (Figure 3.5). Only a few watersheds have less than one–third forest cover. Where forests have been removed, agriculture and urban land-cover become more dominant, yet they are rarely as extensive as forest in terms of total cover. The median amount of urban land cover per watershed is about 2%, and only five watersheds have more than 25% urban land cover. Agriculture is an extremely important land use in the region, yet only six watersheds have more than 50% of that land cover overall, and the median amount is only about 25%.

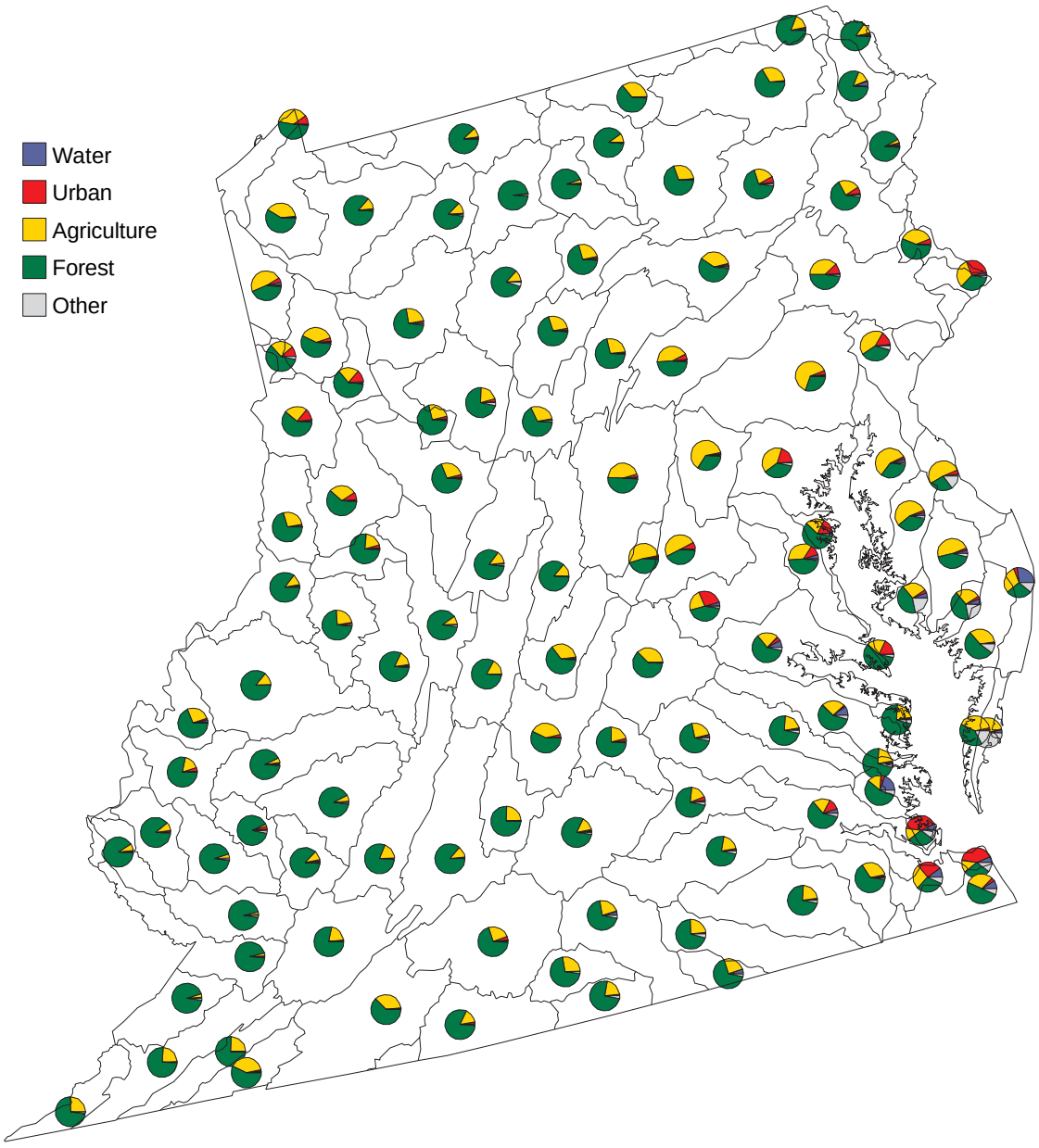


Figure 3.5

Proportion of forest, agriculture, urban, water, and other land cover types for watersheds in the mid–Atlantic region.

Humans in Landscapes in the Mid–Atlantic Region

Humans structure the landscape for their purposes, and landscapes constrain human activities. For example, humans may decide the shapes and sizes of individual agricultural fields, but regional patterns of topography, soils, and geology determine if there can be fields at all. Because human–dominated landscapes are used for different purposes which impose different patterns, land use history is always important for understanding local landscapes. The interplay between humans and landscapes has created a tapestry of multi–scale patterns in the mid–Atlantic region, and combinations of these two factors influence the sustainability of ecological processes that maintain a high quality environment. Figures 3.6 through 3.16 illustrate some of these patterns.

Population Density and Change

According to the United States Census Bureau, the population of the mid–Atlantic region in 1990 was about 26,000,000 people, which represents about 10% of the total population of the United States. The watershed rankings for population density (people per unit area) are illustrated in Figure 3.6. As would be expected, the watersheds with the highest density of people are

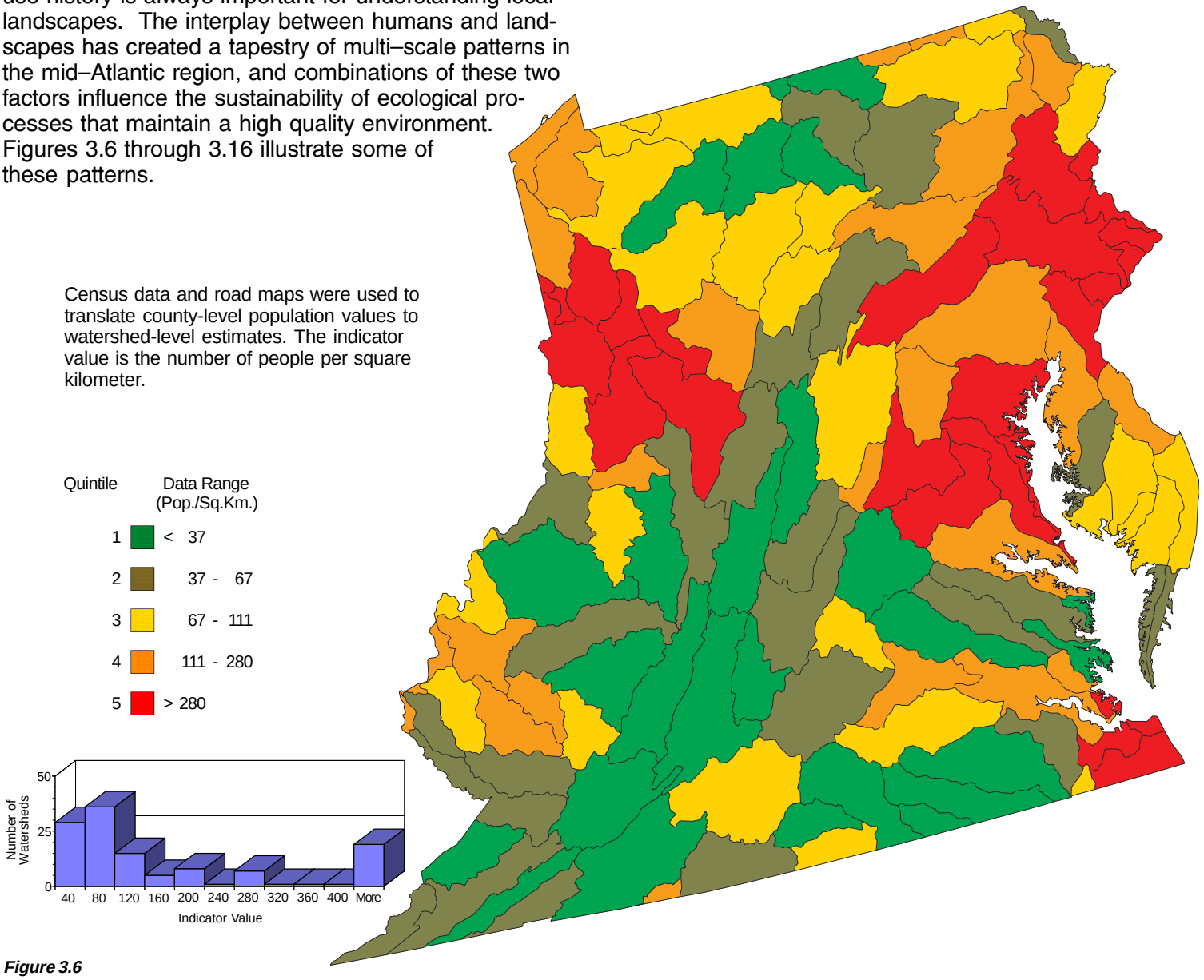
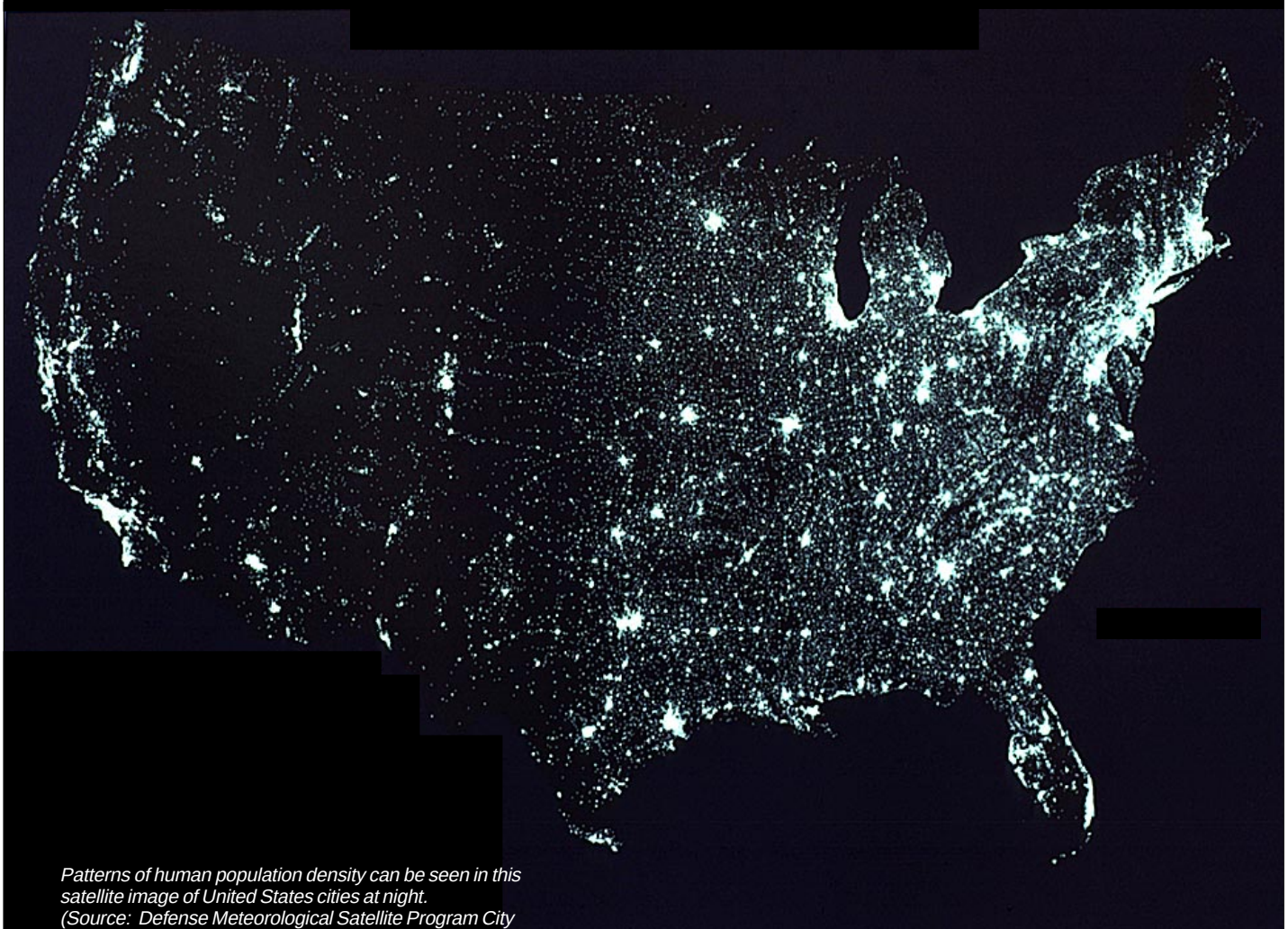


Figure 3.6

Population density in the mid–Atlantic region. Source: U.S. Census Bureau, 1990 census.



Patterns of human population density can be seen in this satellite image of United States cities at night. (Source: Defense Meteorological Satellite Program City Lights Program)

located around the larger metropolitan areas — Norfolk, Washington–Baltimore, Philadelphia, and Pittsburgh — and the watersheds with the least density are located in rural and mountainous areas. The chart indicates a median population density of about 70 people per square kilometer. The watershed with the highest population density has over 3,500 people per square kilometer, while the watershed with the lowest population density has about 11 people per square kilometer.

Between 1970 and 1990, the population density increased in some watersheds and decreased in others (Figure 3.7). The median change for all watersheds was an increase of about 10 people per square kilometer, and the extreme values were a gain of 197 and a loss of 15 people per square kilometer. A quarter of the watersheds in the region had either no change or a reduction in population. The most noticeable losses in population densities occurred in watersheds near the Pittsburgh metropolitan area. Some of the larger gains were in watersheds just outside of the Baltimore–Washington area, and in a few watersheds on the DelMarVa peninsula east of the Chesapeake Bay which includes parts of Delaware, Maryland, and Virginia.

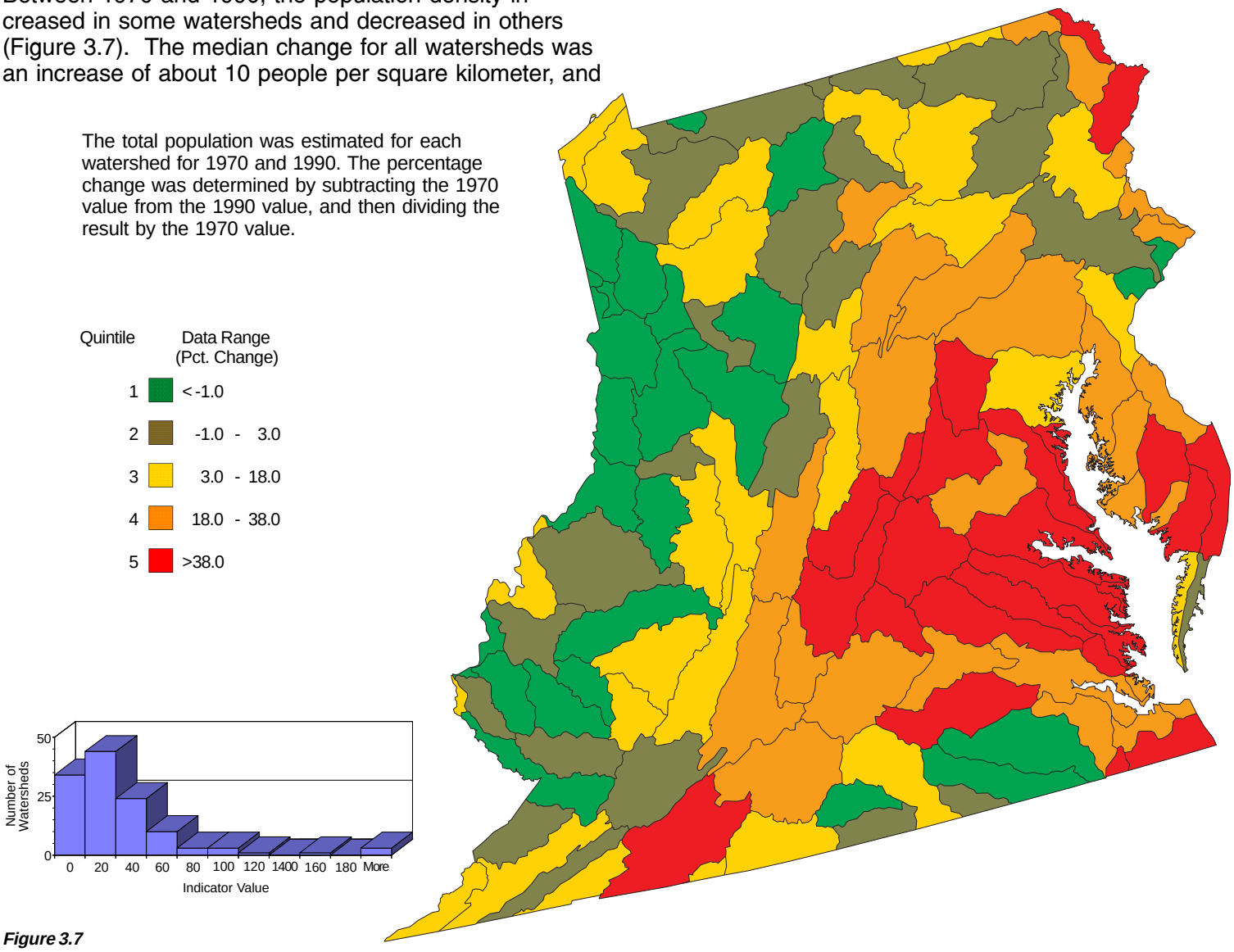


Figure 3.7

Population change (1970 to 1990) in the mid–Atlantic region. Source: U.S. Census Bureau, 1970 and 1990 census.

Human Use Index

The proportion of an area that is urbanized or used for agriculture is a measure of human use known as the U–index. We often assume that humans tend to simplify their environment, because agricultural fields and urban areas, for example, are less complex than the natural land cover that they replace. At landscape scales, however, the map of human land use displays complicated patterns (Figure 3.8). The scale at the transition from simple to complicated patterns might be a measure of the scale to which humans have structured a landscape, or conversely, the scale at which geophysical processes constrain human activity. By looking at regional patterns of the U–index, it is possible to identify those areas which have experienced the greatest land cover conversion from forest cover that historically dominated the region.



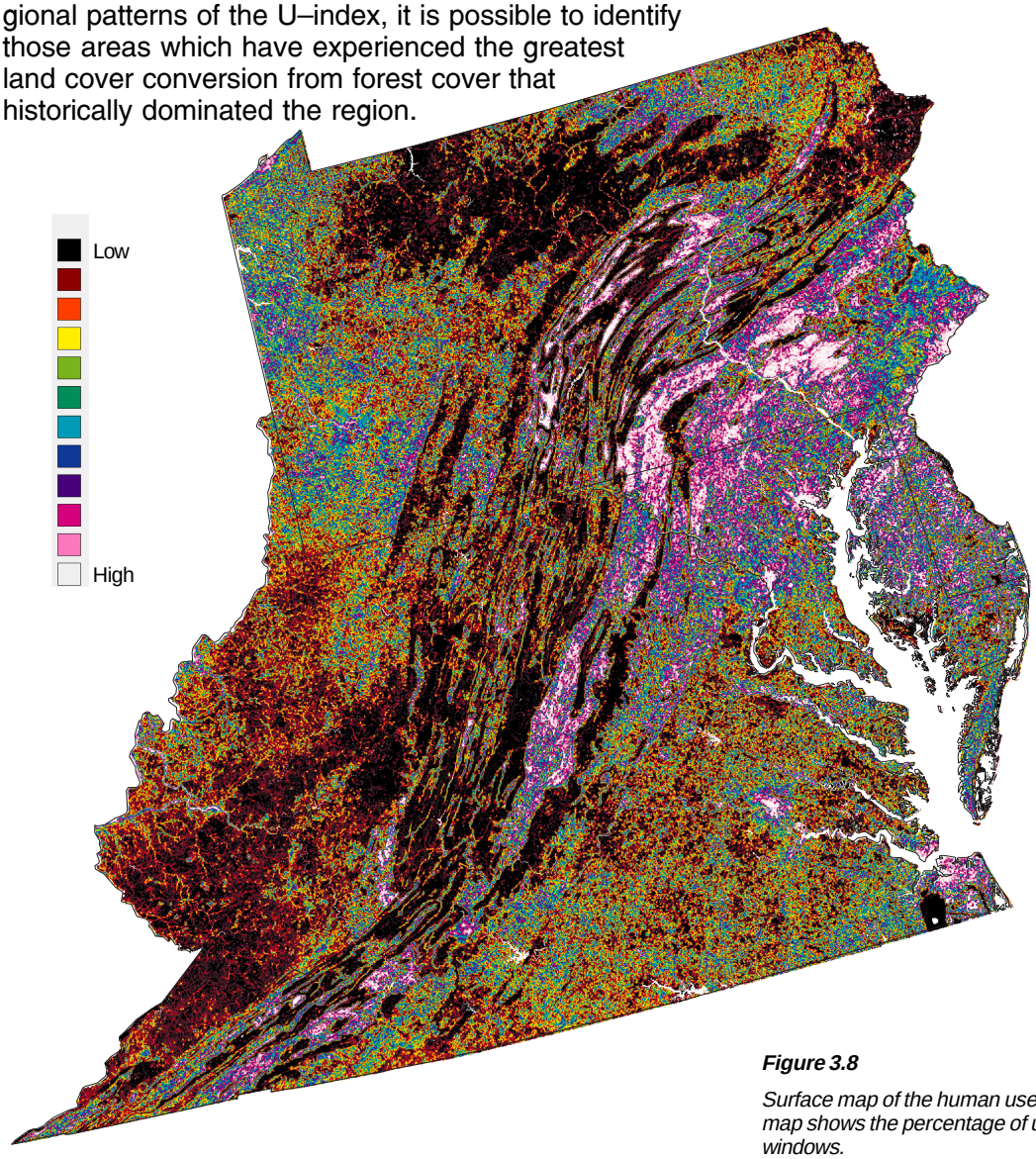


Figure 3.8

Surface map of the human use index (U–index) in the mid–Atlantic region. The map shows the percentage of urban and agriculture land cover within 65–hectare windows.

The regional pattern of human use is reflected in the watershed rankings over the region (Figure 3.9). The accompanying bar chart shows that the highest U–index value for a watershed is about 70%, which means that 70% of that watershed has agriculture or urban land-cover. The lowest value is about 3%, and the median value is about 30%. The proportion of area with urban or agriculture land cover exceeds 50% in about 15 watersheds, and about the same number of watersheds have U–indices less than 10%.

Roads

Roads and other transportation corridors are designed to connect the human–dominated elements of a landscape. The network of roads in the mid–Atlantic region permits access, commerce, and communication throughout the region. Roads also impact the connectivity of ecosystems, and ecosystem connectivity influences the dispersal of plants and animals. Sometimes roads restrict dispersal, as in the case of animals that are unable to cross roads, and sometimes they enhance it, in the case of plant species that spread along disturbed roadsides.

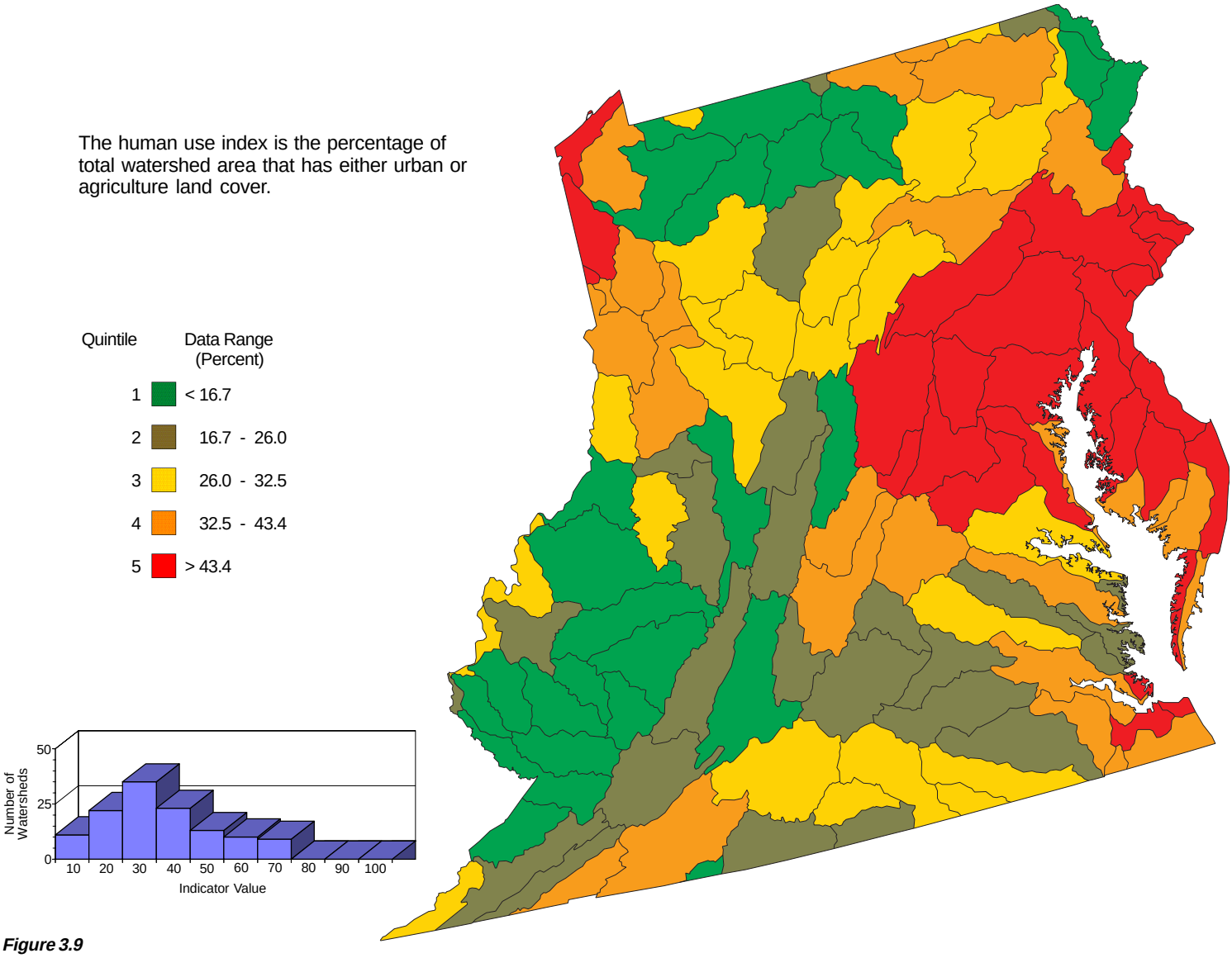


Figure 3.9

The human use index in the mid–Atlantic region.

The influence of any road extends for some distance, depending on factors such as road size, traffic volume, and type of use. There are few places in the mid–Atlantic region that are entirely free of their influence.

According to the road maps used in this atlas, there are about 700,000 kilometers of roads in the mid–Atlantic region. This dataset includes all types of roads categorized by the United States Geological Survey as Class 1 (Interstates, United States highways) through Class 4 (minor roads and city streets) . Placed end to end, these roads would circle the Earth more than 17 times. It is no wonder that roads are one of the most important human features in the mid–Atlantic landscape today.

In fact, there are so many roads that a detailed regional map cannot be shown on a single page. Instead, the regional distribution of roads is indicated (Figure 3.10) by using a coarse–scale indicator of relative road density. On this map, bright colors indicate places that have higher road density, and dark colors indicate places with lower road density. It is immediately apparent that roads are not distributed uniformly throughout the region; their locations are directly comparable to the maps of population, elevation, and land cover shown earlier. There are more roads in urban areas than in rural areas, and there are more roads in the eastern half of the region than in the western half.



Figure 3.10

Surface map of road density in the mid–Atlantic region. The map shows an estimate of total length of roads within each square–kilometer window. Source: U.S. Geological Survey, 1:100,000–scale Digital Line Graphs —– Transportation.

There are concentrations of roads along the corridors that link urban areas, and areas with the fewest roads show up as dark patches, especially along the higher–elevation ridges. The watershed rankings of road density over the region (Figure 3.11) further illustrates this pattern. Watersheds surrounding urban areas have the highest concentration of roads, while mountainous watersheds in the west have the lowest.

Air Pollution

Air pollution is truly a regional phenomenon, because air does not stop at political boundaries. It is one of the more important human–caused stresses in the mid–Atlantic region. Air pollution presents a changing spatial pattern over the landscape as pollution sources and circulation patterns change over time. The atmosphere interacts with the terrestrial watersheds below in many ways.

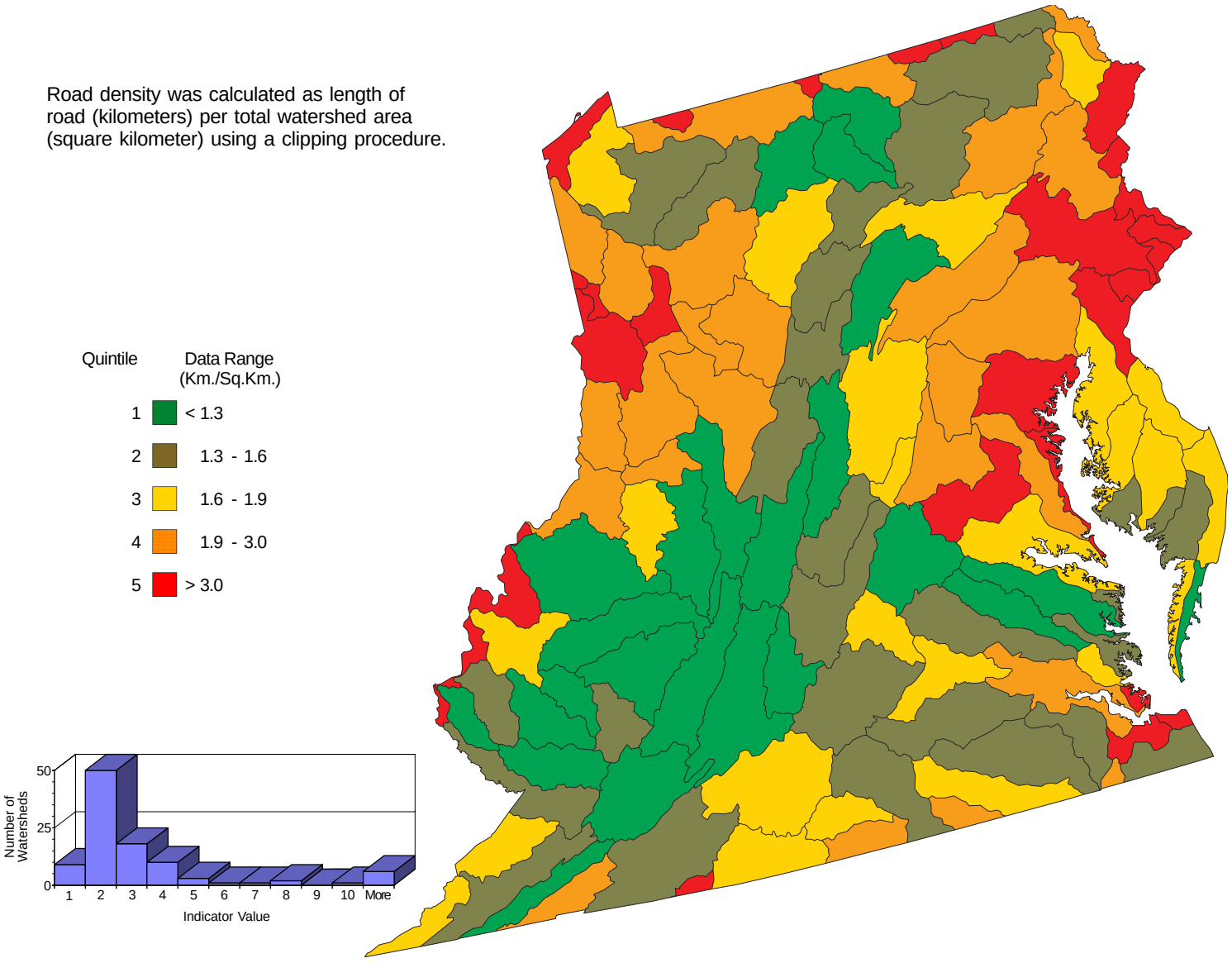


Figure 3.11

Road density in the mid–Atlantic region.

Figures 3.12 through 3.15 show regional patterns of estimated annual sulfate and nitrate deposition and cumulative annual ozone concentrations, averaged over several years. Nitrate deposition appears to increase from south–to–north within the region; the highest levels are found in central Pennsylvania, extending east to the Pocono Mountains and south through western Maryland and northern West Virginia along the ridges of the Appalachian Plateau. The lowest levels occur in central and southern Virginia, and along the extreme western portion of the region. This regional pattern of nitrate deposition may reflect prevailing winds from the west that carry air pollutants from other regions.

Terrestrial features can influence pollution deposition indirectly. For example, air pollution deposition models predict a topographic trend as well as a south–to–north trend in the region. Estimated nitrate wet deposition (Figure 3.12a) and sulfate wet deposition (Figure 3.12b) are greater at higher elevations because topographic features influence the deposition of rain and fog which carry these pollutants dissolved in water droplets. The surface maps of sulfate and nitrate deposition appear almost identical because the measurement scales have been normalized to make it easier to see relative trends across the region. This also helps to highlight the topographic effect on air pollution deposition. However, the two maps are different enough to yield slightly different watershed rankings for nitrate (Figure 3.13) and sulfate (Figure 3.14) deposition.

The map of watershed rankings for tropospheric (surface) ozone (Figure 3.15) demonstrates that not all pollution indicators follow the same regional pattern. The ozone index is not closely associated with topography, but rather with the distribution of urban and agricultural areas. This map was prepared from extremely coarse–scale information, and the surface map for this index (not shown here) has only several dozen pixels for the entire region. Even at this coarse scale, there are obvious differences across the mid–Atlantic.

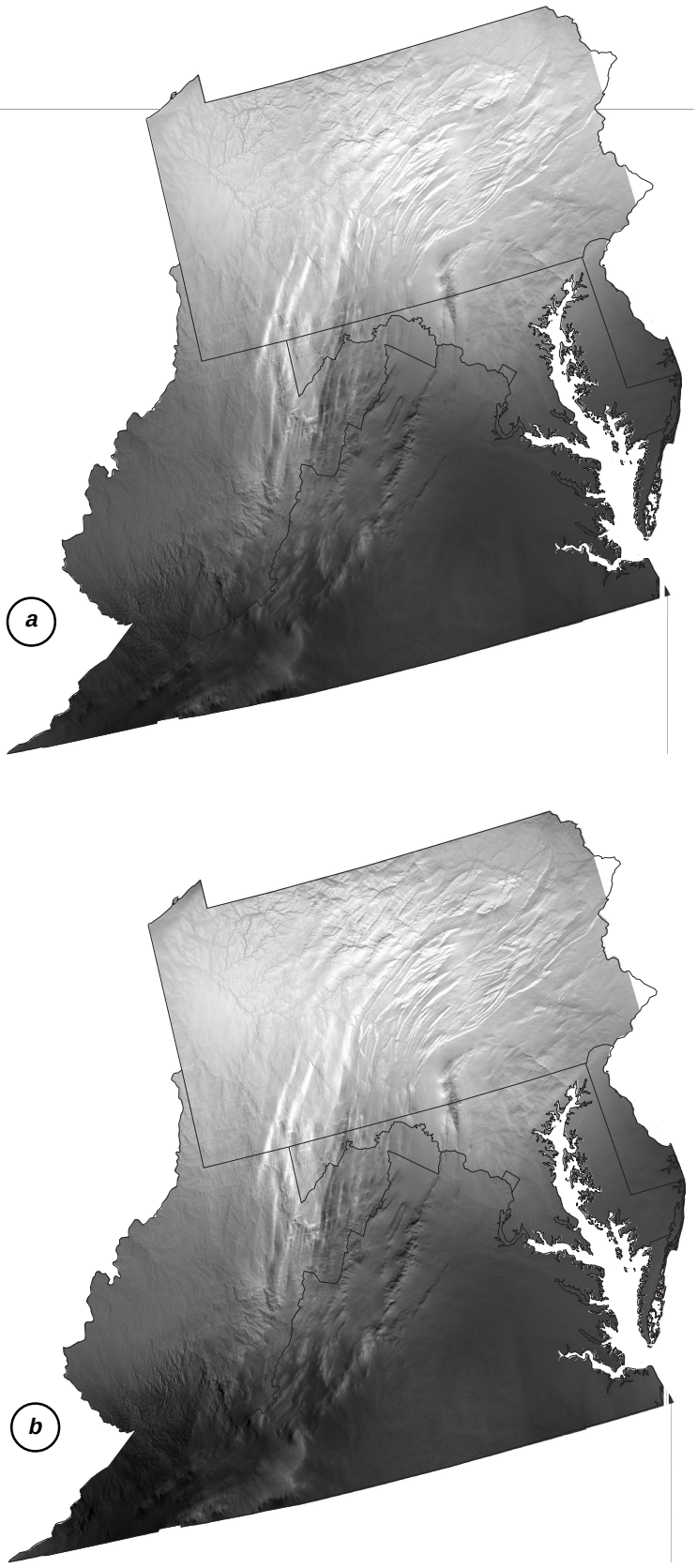
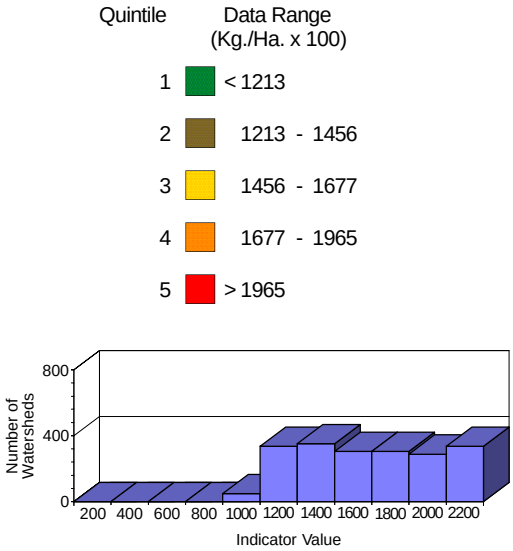


Figure 3.12a

Surface maps of estimated average annual wet deposition of (a) nitrate, and (b) sulfate for 1987 and 1993 in the mid–Atlantic region. Source: J. Lynch, Pennsylvania State University.

Average annual wet deposition of nitrate was estimated from data for 1987 and 1993 by resampling the original maps at 90-meter resolution and then finding average pixel values for each watershed.



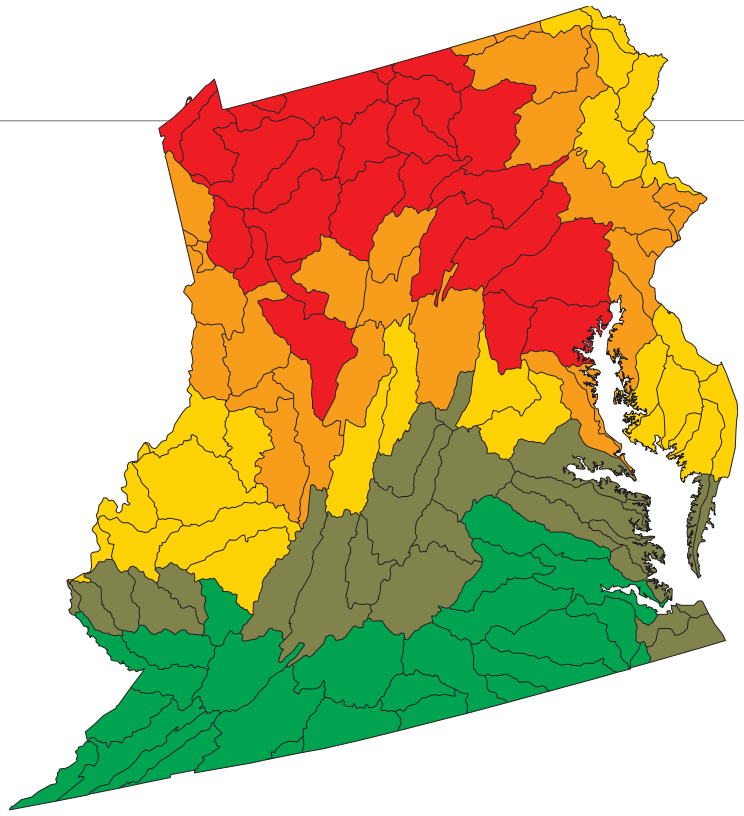
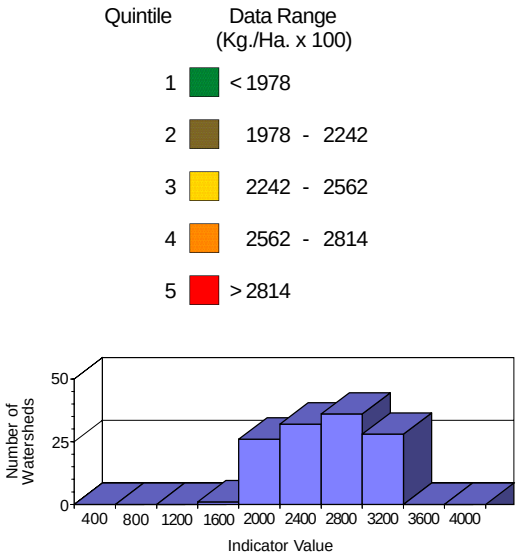


Figure 3.13

Average annual wet deposition of nitrate in the mid–Atlantic region (average of 1987 and 1993).

Average annual wet deposition of sulfate was estimated from data for 1987 and 1993 by resampling the original maps at 90-meter resolution and then finding average pixel values for each watershed.



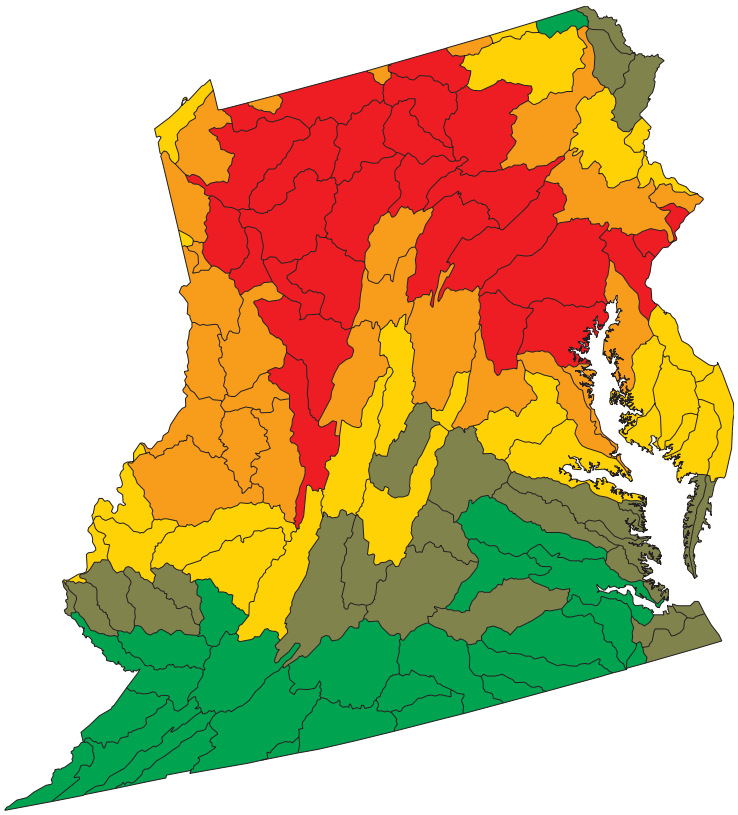
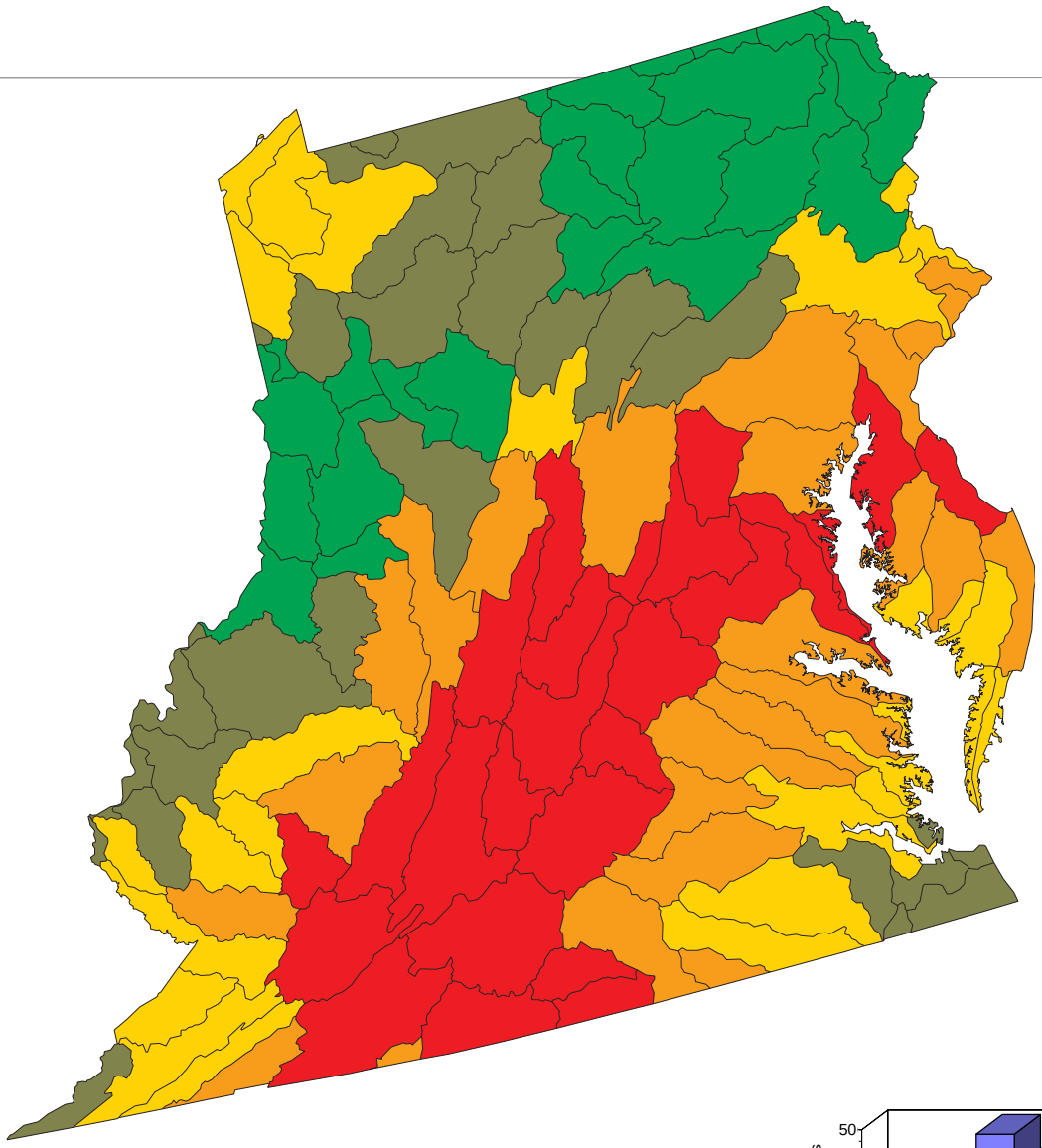


Figure 3.14

Average annual wet deposition of sulfate in the mid–Atlantic region (average of 1987 and 1993).



Average annual ozone exposure was estimated from data for 1988 and 1989 by resampling the original maps at 90-meter resolution and then finding average pixel values for each watershed

Quintile	Data Range (W126 Index)
1	< 39
2	39 - 41
3	41 - 44
4	44 - 48
5	> 48

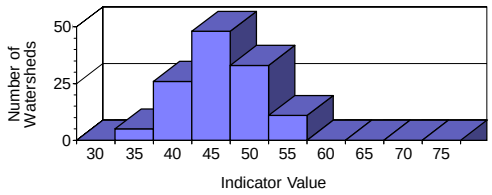


Figure 3.15

Average annual value of the W126 ozone index (1988 and 1989) in the mid–Atlantic region. Source: U.S. Environmental Protection Agency.



Air pollution disperses quickly over large regions.

Landscape Units

Landscape analysis methods provide the opportunity to look at regional patterns of land use at a range of scales. Maps of land cover are created one pixel at a time, which ignores some of the information about local–scale patterns of land cover. By recognizing these local patterns, new landscape map themes can be created which suggest the types and intensities of human activities that are occurring in a given place. For example, if you are standing in a spot that is forested, and if most of the spots around you are also forested, then it is likely that you are in a part of the landscape that has a general land use or activity theme of "forest." If, however, your forested spot is embedded in a pattern of forest and agriculture, then it is more likely that your part of the landscape has the land use theme of "rural agriculture" instead of "forest." But land cover alone is not always an accurate guide to actual land use. For example, if the pattern surrounding your forested spot is mainly urban, then you might be standing in an area with a "city park" theme, but (without more information) it could just as easily be an area that is planned for "future development."

A landscape may be described by the relative proportions of forest, agriculture, and developed (urban) land cover it contains. The map of landscape units for the mid–Atlantic region (Figure 3.16) has 19 classes, labeled with combinations of the letters F, A, and D, referring to forest, agriculture, and developed land cover. The labels are interpreted as follows. An upper–case letter indicates an area with more than 60% of that land cover, and a lower–case letter indicates an area with less than 40% of that land cover. The ordering of letters corresponds to the relative amounts of land cover in an area. If a land cover is less than 10% of an area, the corresponding letter is left out.

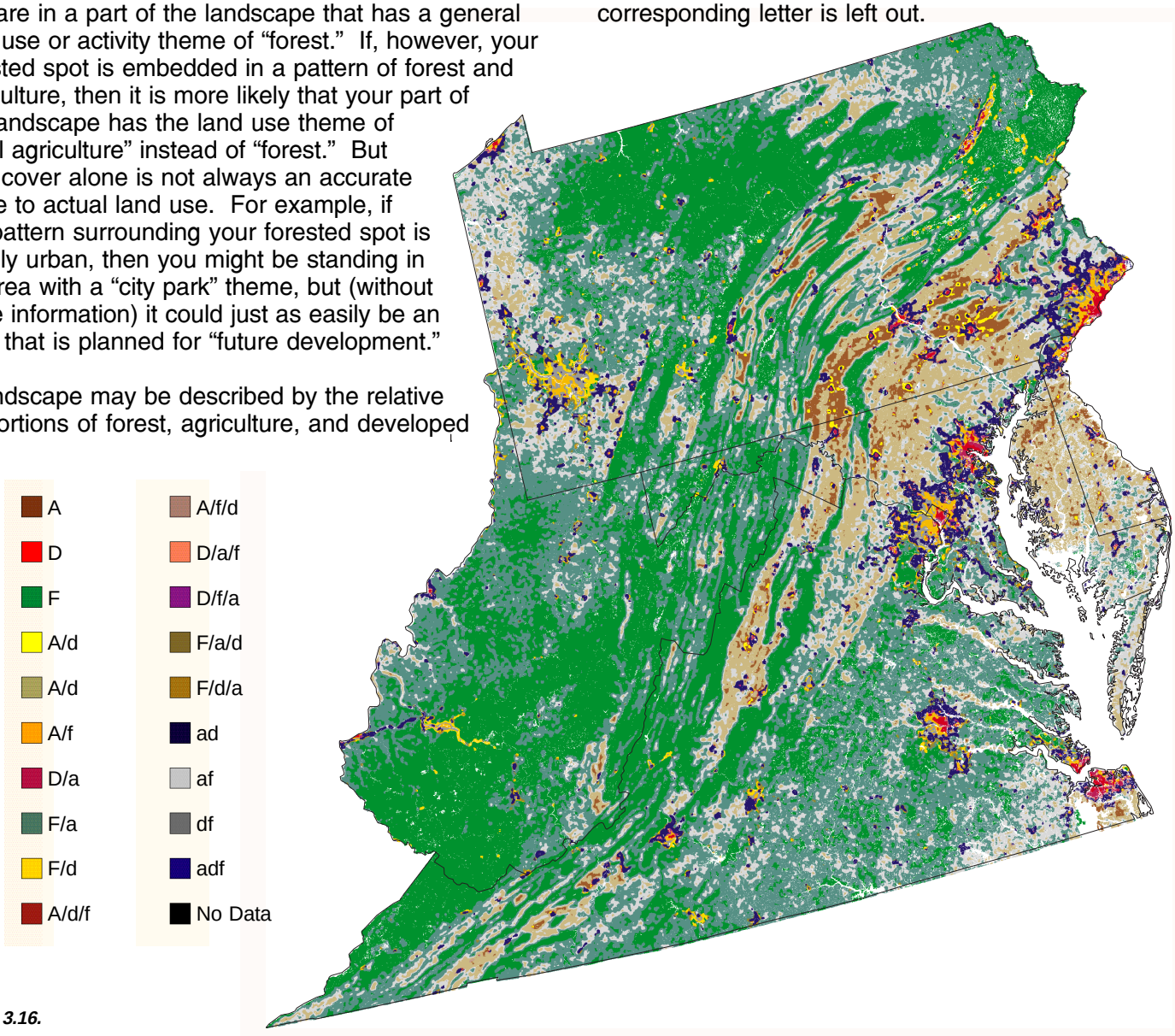


Figure 3.16.

Landscape units in the mid–Atlantic region (see text for explanation).

Compare this map with the map of land cover presented earlier (Figure 3.4). Some individuals with a practiced eye can perform the "mental blending" of land cover proportions that the computer did to create the map of landscape units. The phenomenon is similar to some people's ability to see the pattern hidden in 3–D stereograms. For many people, however, it helps to use a computer to extract the "hidden" information. By simplifying the patterns into these landscape units, we can identify zones of human use that are difficult to see using the land cover map alone.

Water

Everyone knows the importance of water. But many people do not realize how much its quality depends on the surrounding landscape. Water quality, like landscape condition, is an integrated response to environmental stress and land management practices at watershed scales.

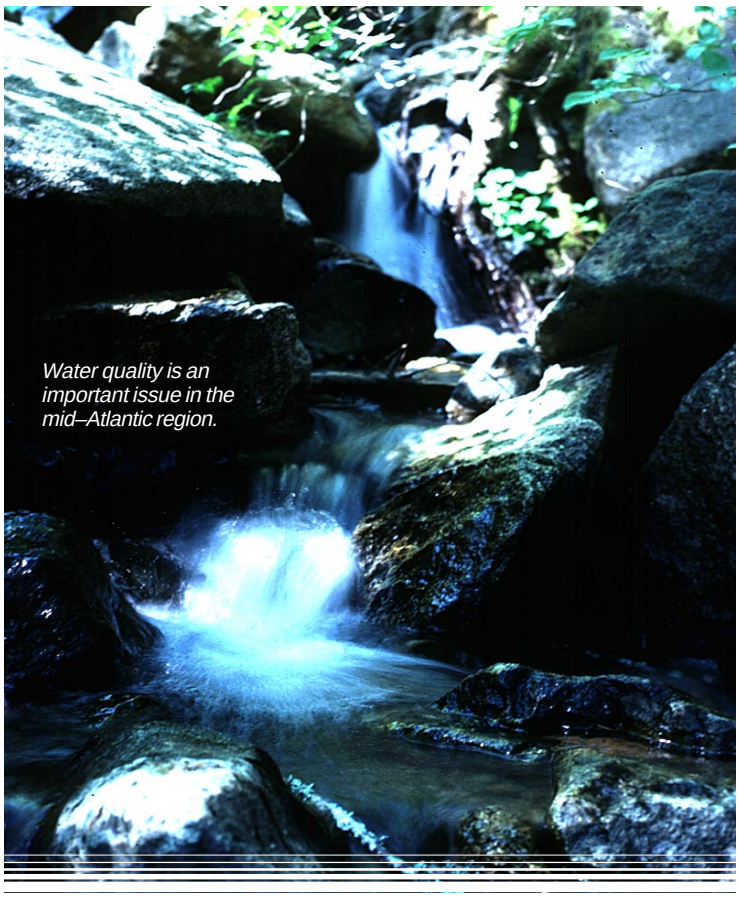
This section presents landscape indicators that are related to water quality in the streams of the mid–Atlantic region. "Riparian" indicators describe landscape conditions near streams and "watershed" indicators describe conditions over entire watersheds. The riparian indicators include measures of human activities near streams. The size and amount of riparian buffers along streambanks is an important determinant of soil loss and sediment movement, which in turn affect water quality. The group of watershed indicators presented here primarily measure the potential for soil and nutrient losses from surrounding landscapes which would ultimately be deposited in streams. Put simply, watersheds covered by forests are likely to be in better condition than watersheds with high percentages of intensive land uses. Because intact riparian areas buffer streams from the potentially adverse effects of watershed–scale events like erosion, both types of indicators need to be evaluated when considering overall landscape influences on stream condition and water quality. The interplay of processes operating over the entire watershed with processes in the riparian zone will ultimately determine the condition of streams in the mid–Atlantic.

Riparian Indicators

The vegetation along a stream influences the condition of both the stream bank and the water in the stream. This strip of vegetation, known as the riparian zone, is commonly described by the types of vegetation it contains



Riparian areas are especially important in agricultural landscapes.



Water quality is an important issue in the mid–Atlantic region.

and by the presence of roads and other human activities. In an ideal situation, many pollutants and fertilizers will be intercepted or absorbed by the riparian vegetation, and this helps to keep the streams healthy. Bank erosion is also mitigated by intact riparian vegetation. The conditions of the riparian ecosystem over a whole watershed can be studied in order to learn where, for example, a restoration project would most improve water quality. Similarly, a characterization of riparian conditions over the entire mid–Atlantic region can help to identify which watersheds are most likely to see improved water quality as a result of riparian improvements.

Forest and Agricultural Land Cover Along Streams

Forested riparian zones are a natural part of the healthiest stream ecosystems in the eastern United States. They provide an effective barrier to runoff of water, pollutants, and excess fertilizer, and support a variety of valuable plant and wildlife species. Conversely, when forests are removed right up to the stream, the riparian zone not only loses its natural buffering capacity but now becomes a potential source of pollution and excess fertilizer. Agricultural practices usually employ fertilizers, pesticides, and other chemicals that are essential to crop growth and yield. These chemicals can more readily be moved into streams which flow through agricultural fields, in comparison to streams which flow through forests. The maps on these pages illustrate differences among watersheds in the length of stream that has either forest or agriculture cover in the riparian zone.

Figure 3.17 shows the relative percentage of stream length in each watershed that has forested riparian zones. The urban areas of eastern Pennsylvania, Maryland, and northern Virginia have the least percentage of forest in riparian zones. Western Pennsylvania, southeastern Virginia, and portions of West Virginia have the greatest percentage of forested riparian cover. The chart indicates that all watersheds in the mid–Atlantic region have at least 50 percent of their total

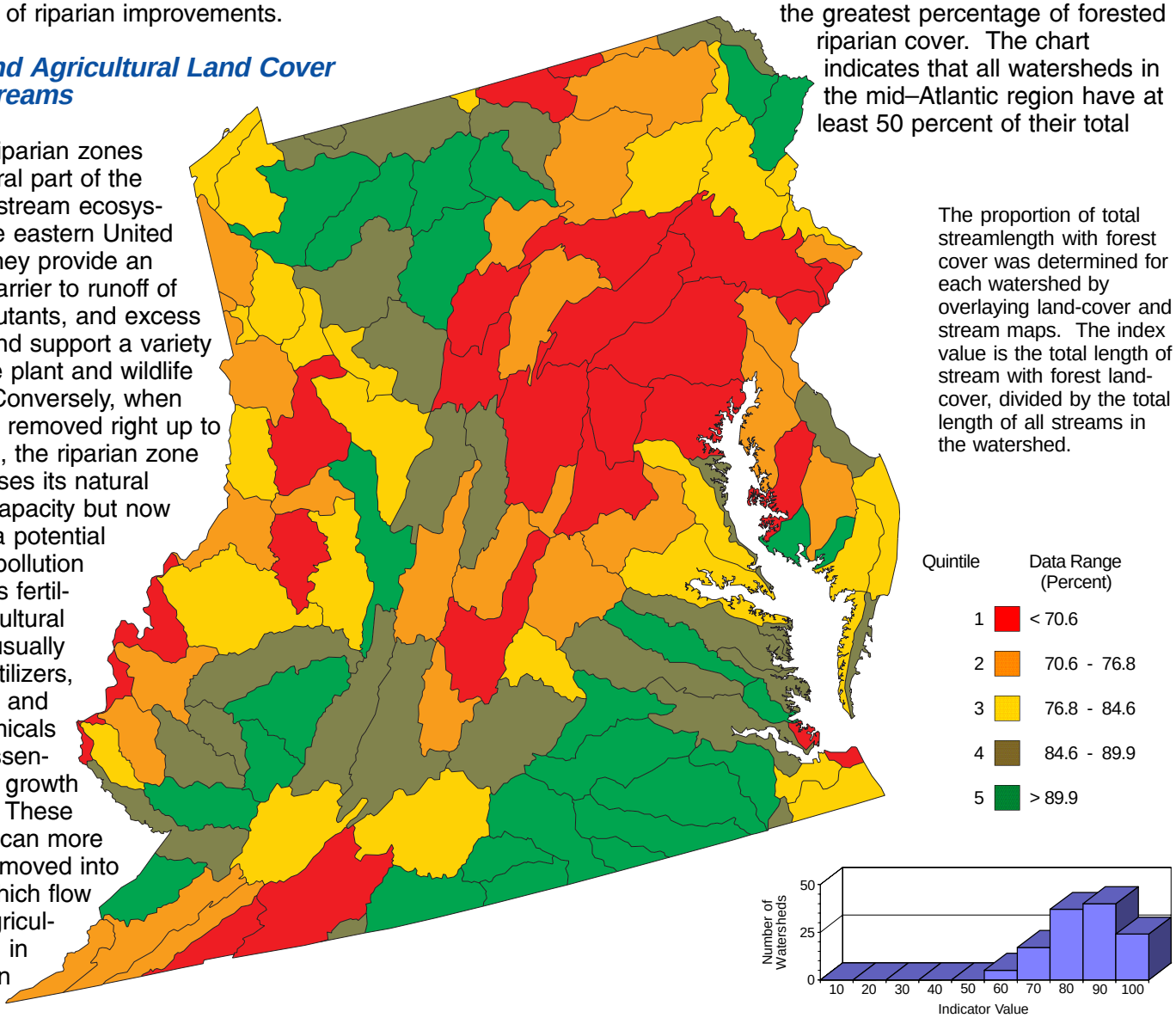


Figure 3.17

Proportion of total streamlength with adjacent forest land cover in the mid–Atlantic region.

stream length in forest cover, and that over half of the watersheds have at least 80% riparian forest cover.

Whereas the distribution of riparian forests is an indicator of natural buffering capacity, the distribution of agricultural land cover in riparian zones is an indicator of potential problems. Figure 3.18 shows the percentage of stream length in each watershed that has agricultural land cover in the riparian zone. Because forest and agriculture are the two most common land cover types in the mid–Atlantic region, this figure is almost the inverse of the riparian forest map. But not quite, because agriculture is not the only non–forest land use in the region. Although only a handful of watersheds have more than 30% of their stream length with agricultural land cover, every watershed has at least some agriculture in the riparian zone. The watersheds with the highest potential for negative impacts are in eastern Pennsylvania, Maryland, and northern Virginia.

Roads Along Streams

Roads affect stream water in many ways and roads in close proximity to streams have the most potential for adverse effects on stream water quality. Since roads have an impervious surface, and ditches are built to channel water from roads into streams, the rate of water runoff is higher where there are more roads. This contributes to increased scouring of streambanks and channel alteration. Although large spills of pollution are rare and often quickly contained, small spills of petroleum products, antifreeze, and other vehicle–related chemicals happen every day on every mile of road in the region. These small spills eventually go somewhere, usually into streams. Road construction near streams is a temporary stress on water quality, but after construction, the roadsides remain. Routine maintenance, including salting during the winter, can increase pollution and sediment loadings to streams and contribute to poorer water quality. Cumulatively, these changes can reduce water quality and fish habitat suitability in streams. For these and other reasons it is important to consider how the proximity of roads to streams might influence regional water quality.

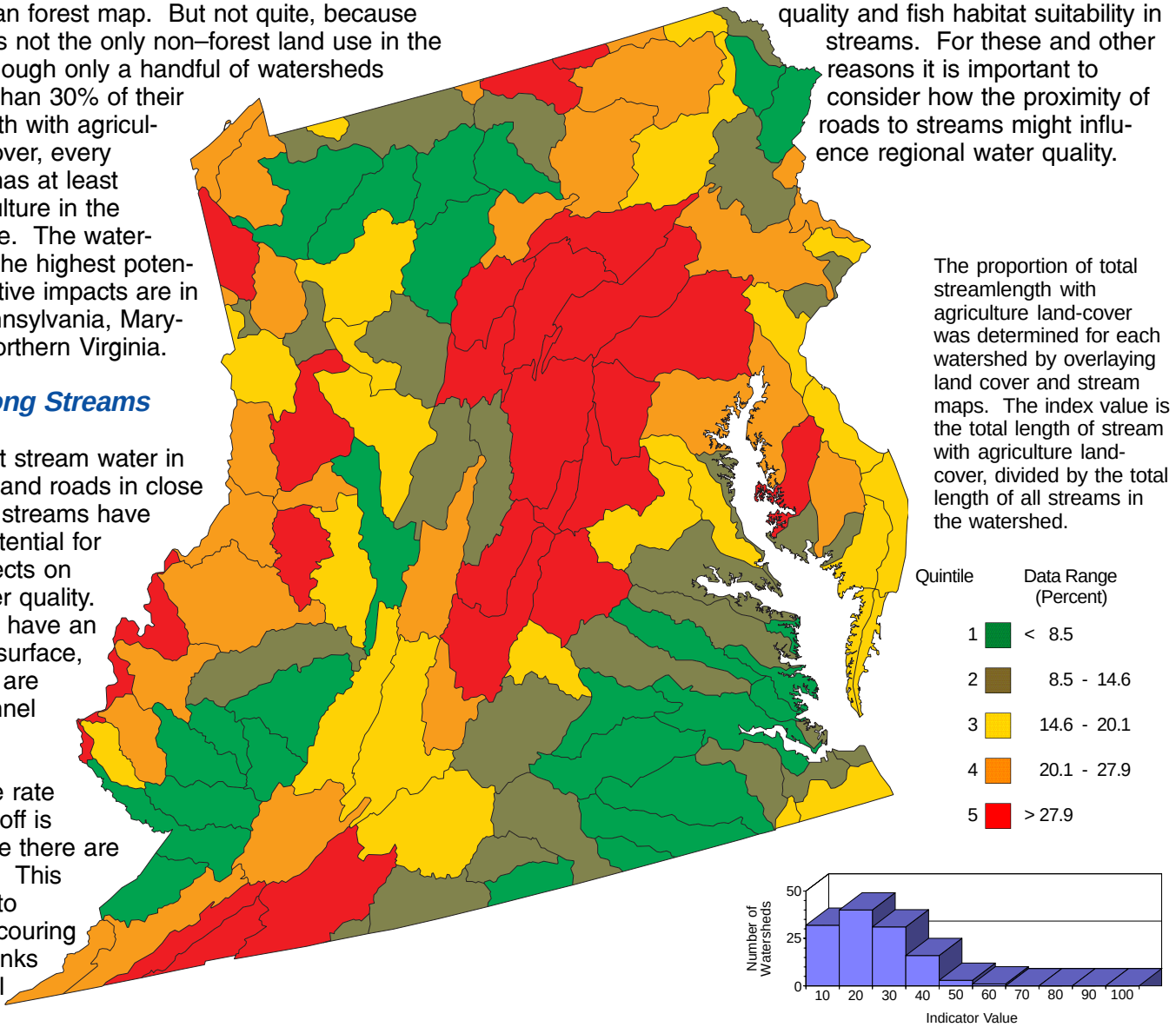


Figure 3.18

Proportion of total streamlength with adjacent agriculture land cover in the mid–Atlantic region.

Watershed Indicators

The regional pattern of roads along streams (Figure 3.19) may be surprising because many of the watersheds with a high incidence of roads along streams are located in remote areas which do not have a lot of roads in comparison to the rest of the mid–Atlantic region. The explanation lies in the topography of the region. Road construction is more difficult in steeper topography and, as a result, the roads are often located in the relatively flat areas along streambeds. Furthermore, the highly dissected topography that is characteristic of the Appalachian Plateau often forces the roads to cross streams several times in a short distance. So while there may be relatively fewer roads in these areas, they are nearly all located adjacent to streams and hence have relatively high values for the indicator. Certainly traffic volume and the type of traffic will also influence the actual impacts of roads near streams, but such information is generally not available in a format suitable for regional–scale analyses.

While streamside conditions are important, it is also important to have indicators of potential impacts on water quality from sources throughout the watershed. It was mentioned earlier that the watershed indicators presented here are primarily concerned with soil erosion and runoff processes. These indicators are relatively easy to determine from regional databases. In any case, erosion processes are extremely important. The results of increased erosion may include reduced agricultural productivity, reduced storage capacity of lakes and reservoirs, increased water treatment costs, introduction of pesticides and fertilizers to water sources, loss of habitat for fish and other species, and reduced recreation potential.

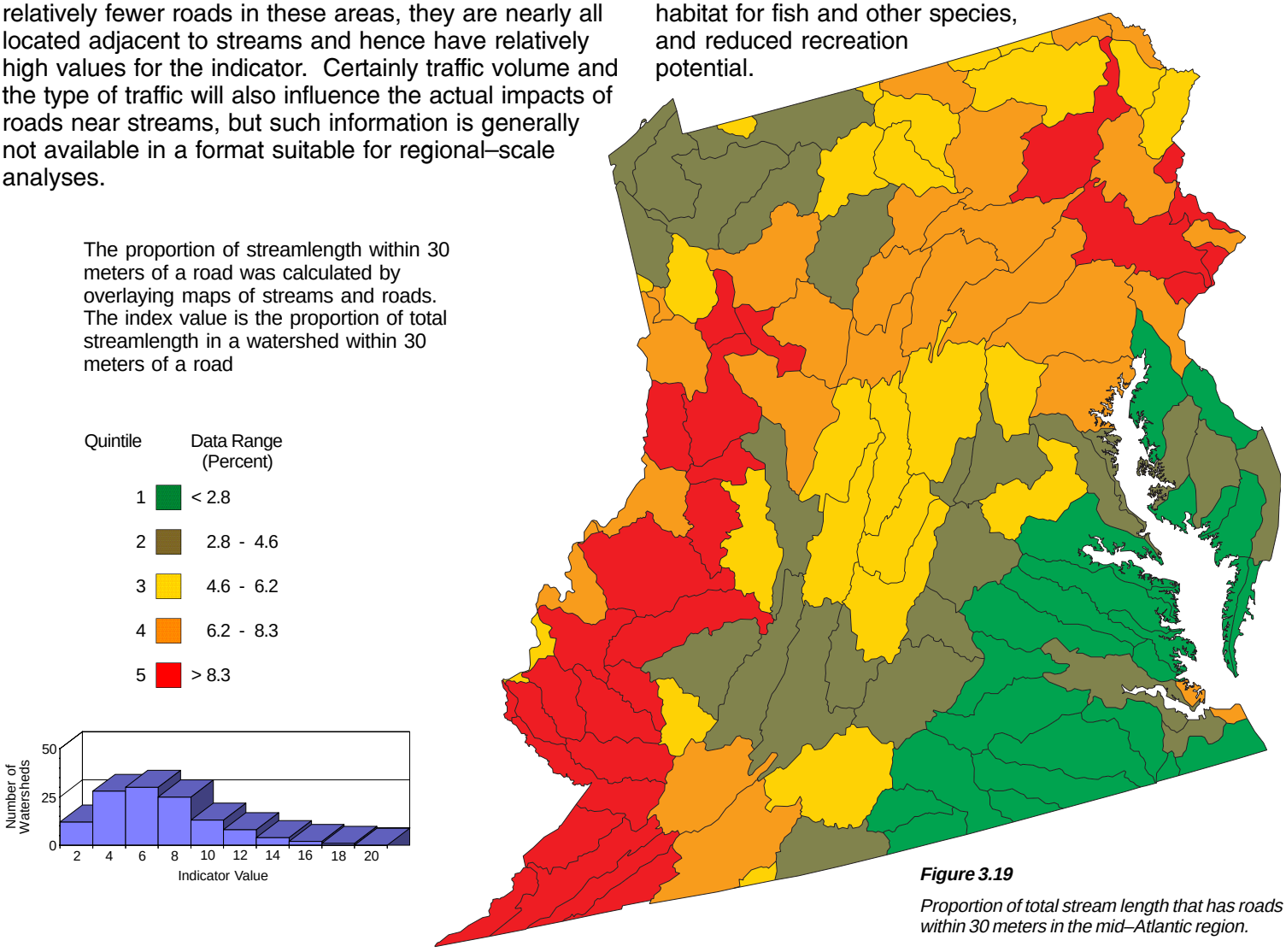


Figure 3.19

Proportion of total stream length that has roads within 30 meters in the mid–Atlantic region.

Impoundments

There are three major reasons why dams are built. They provide a stable water supply for human uses, they control flooding, and they channel water through generators which produce electricity. While all of these are good reasons, it is unfortunate that an essential feature of dam design is to disrupt all of the natural processes associated with stream flow. Dredges operating to keep river channels open for navigation are evidence that sediment is deposited behind dams, and fish ladders around dams demonstrate the direct effects on wildlife populations. Dams have other, less well–known effects. For example, many dams are built to raise the water 'head' or pressure behind the dam, and water is tapped from the deepest parts to generate electricity. Deep water usually contains less dissolved oxygen than surface water, and this can impact life in streams below the dam unless special measures (for example, adding oxygen) are taken.

Considering all major impoundments, dams are relatively abundant in the mid–Atlantic region (Figure 3.20). They are distributed throughout the region, with a surprising number occurring on flatter topography in the coastal plain. The pattern may be surprising because most people associate dams with mountainous terrain, but only the largest, electricity–producing structures are built in those areas, and the largest dams are the ones most people see. Figure 3.21 shows the watershed rankings for the number of dams per 1,000 kilometers of stream length. The values range from 0 (16 watersheds have

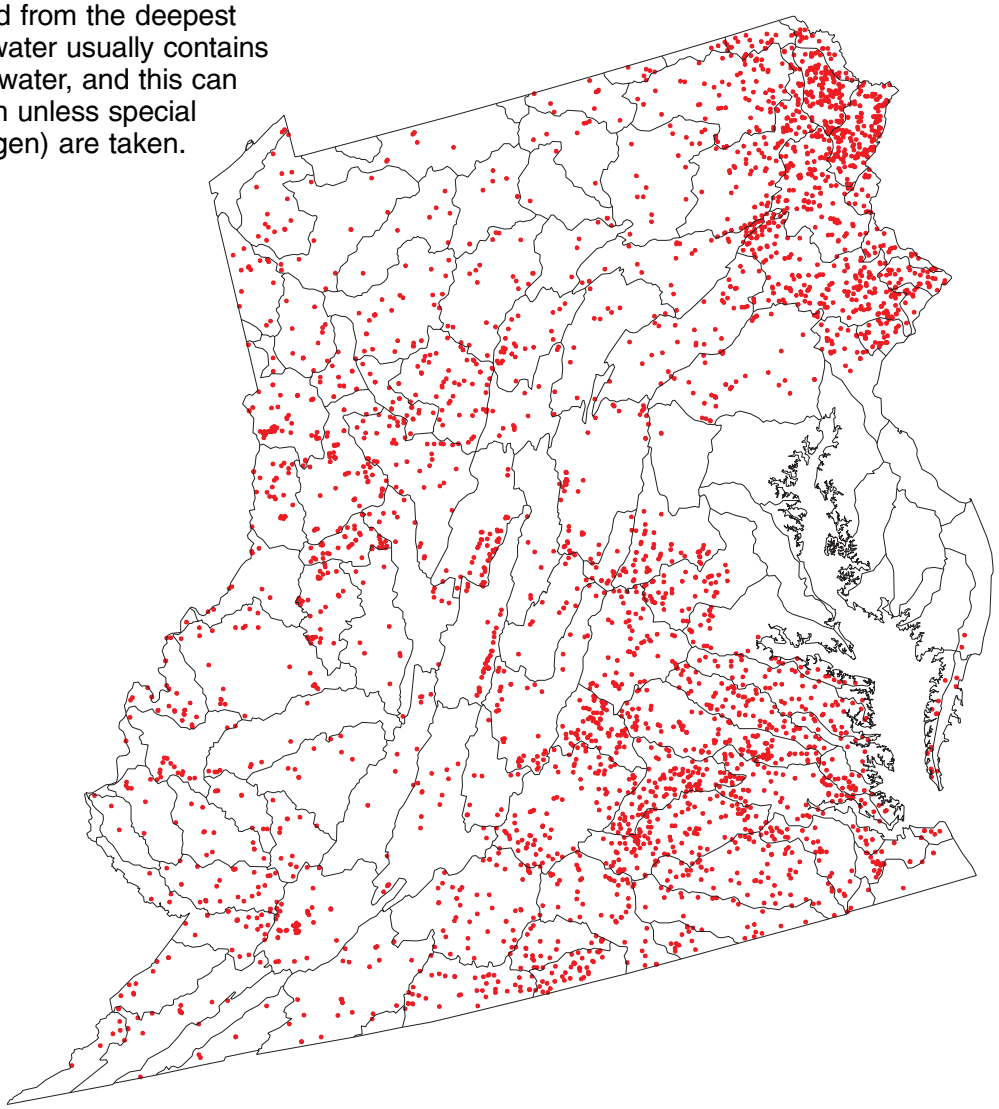


Figure 3.20

Locations of large water impoundments in the mid–Atlantic region. Source: U.S. Geological Survey.

no large dams) to about 85 dams per 1,000 kilometers of stream. The watersheds with the highest density of dams are in the northeastern portion of the region, particularly along the Delaware River. There are also some high densities in watersheds in southeastern Virginia.

Agriculture on Steep Slopes

Unless special measures are taken, agriculture tends to increase soil erosion, which ultimately deposits sediment in streams and lakes. Potential soil erosion from cropland is related to the steepness of slopes being cultivated and the farming methods used. Percent slope is a measure of steepness that is calculated as the ratio of vertical rise in elevation per horizontal distance traveled. The U.S. Department of Agriculture has classified slopes into six categories. Based on this classification, slopes greater than 3% have a greater risk for soil erosion. For comparison, a 3% slope is about half as steep as the steepest hill on which roads are built.

Figure 3.22 illustrates the watershed rankings for the percentage of watershed area that has crop land cover on slopes greater than 3%. Figure 3.23 shows the same

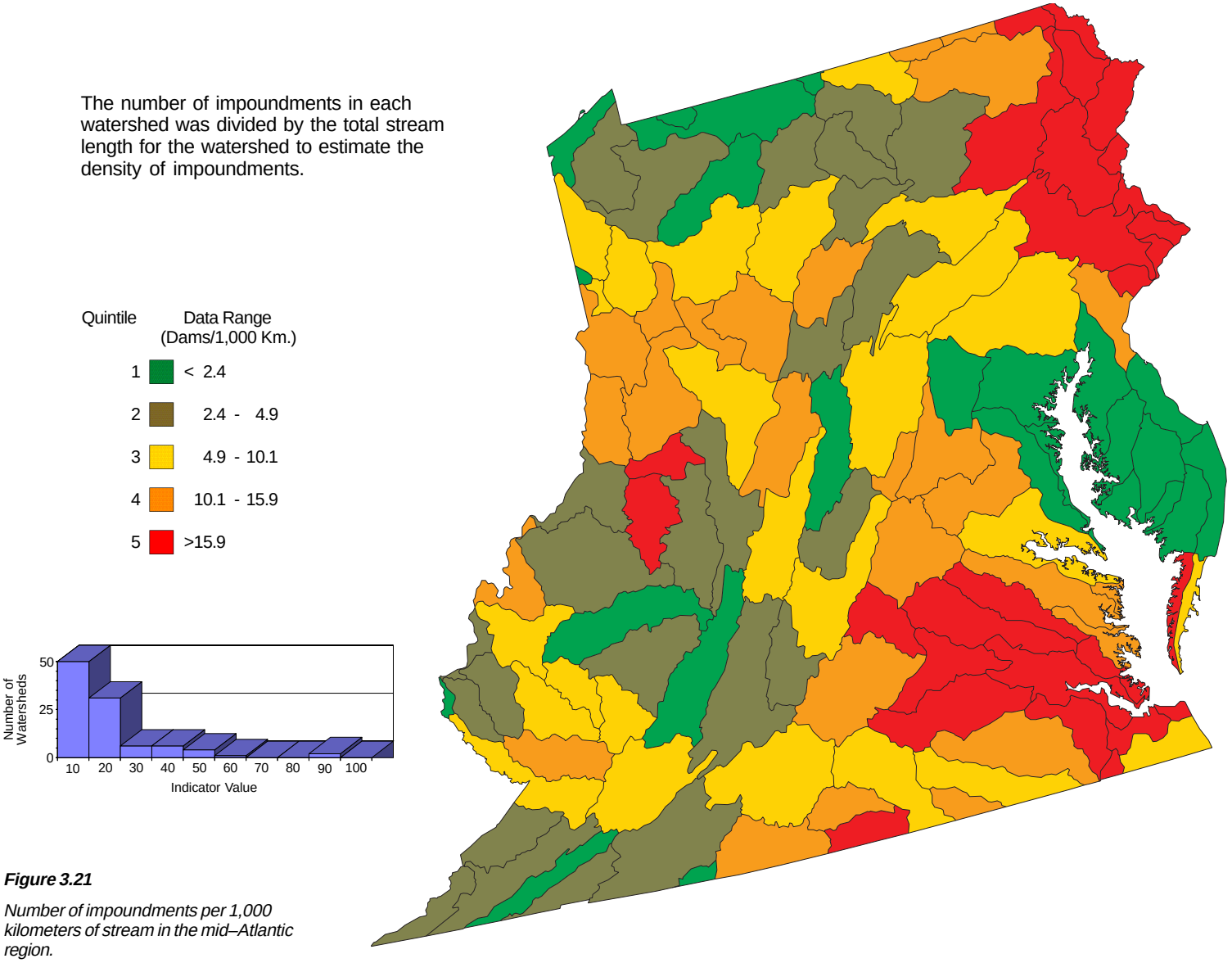


Figure 3.21

Number of impoundments per 1,000 kilometers of stream in the mid–Atlantic region.

picture, but this time considering all agriculture land cover types (crops plus pasture). Crops are typically cultivated, a practice that removes ground cover, exposes soil, and makes surface erosion more likely on crop lands in comparison to pasture lands. But pastures on steep slopes are also potentially at risk to erosion, especially in comparison to forest cover on the same slope.

Every watershed in the mid–Atlantic region has some agriculture on steep slopes. The proportions are lower in remote mountainous areas since there is less agriculture there, and in some predominantly agricultural regions such as the Delmarva peninsula because there are fewer steep slopes. The combination of steep slopes and agriculture occurs most often on the foothill margins of the great valleys in the mid–Atlantic region, where agriculture is a dominant local land use.

Nitrogen and Phosphorus Export to Streams

Despite the many benefits, there is a potential negative impact of fertilizers, animal wastes, and other nonpoint source pollutants coming from agricultural fields and pastures. The problem was first identified decades ago

The proportion of watershed area that has crop land cover on slopes greater than three percent was calculated by overlaying maps of percent slope and land cover, and dividing the area of crop land cover on steep slopes by the total area of the watershed.

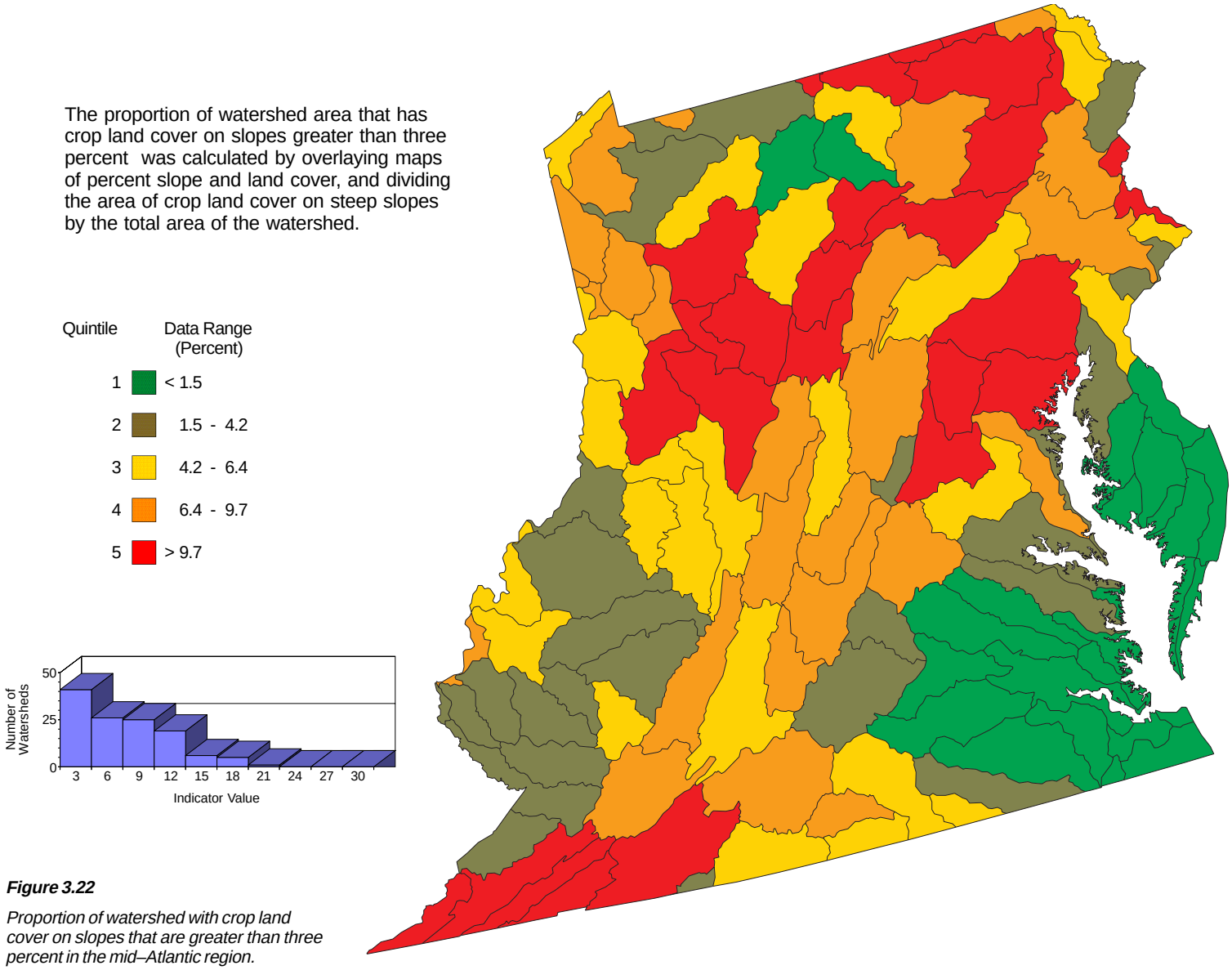


Figure 3.22

Proportion of watershed with crop land cover on slopes that are greater than three percent in the mid–Atlantic region.

as part of the awareness of lake eutrophication. Lake eutrophication is a process by which excess nutrients in lake water make it easier for undesirable plants to thrive, which in turn consume other resources and adversely affect lake water quality for other purposes. Similarly, the Chesapeake Bay Program has recognized the impact of nitrogen and phosphorus loadings on the productivity of the Chesapeake Bay and other coastal bays. As a result, the Chesapeake Bay Program has developed a number of watershed models to assess sources of nitrogen and phosphorus loadings to the Bay; these models have resulted in watershed–wide plans to reduce these two pollutants. The potential effects of the export of nitrogen and phosphorus from farmlands to streams have been intensively studied for several decades. It is now possible to survey the scientific literature to determine how much nitrogen and phosphorus export can be expected for different types of land uses in different areas.

The scientific literature provides a simple predictive model of nitrogen and phosphorus loadings to streams which is based only on land cover (see Appendix). Of course, this model does not reflect actual fertilizer appli-

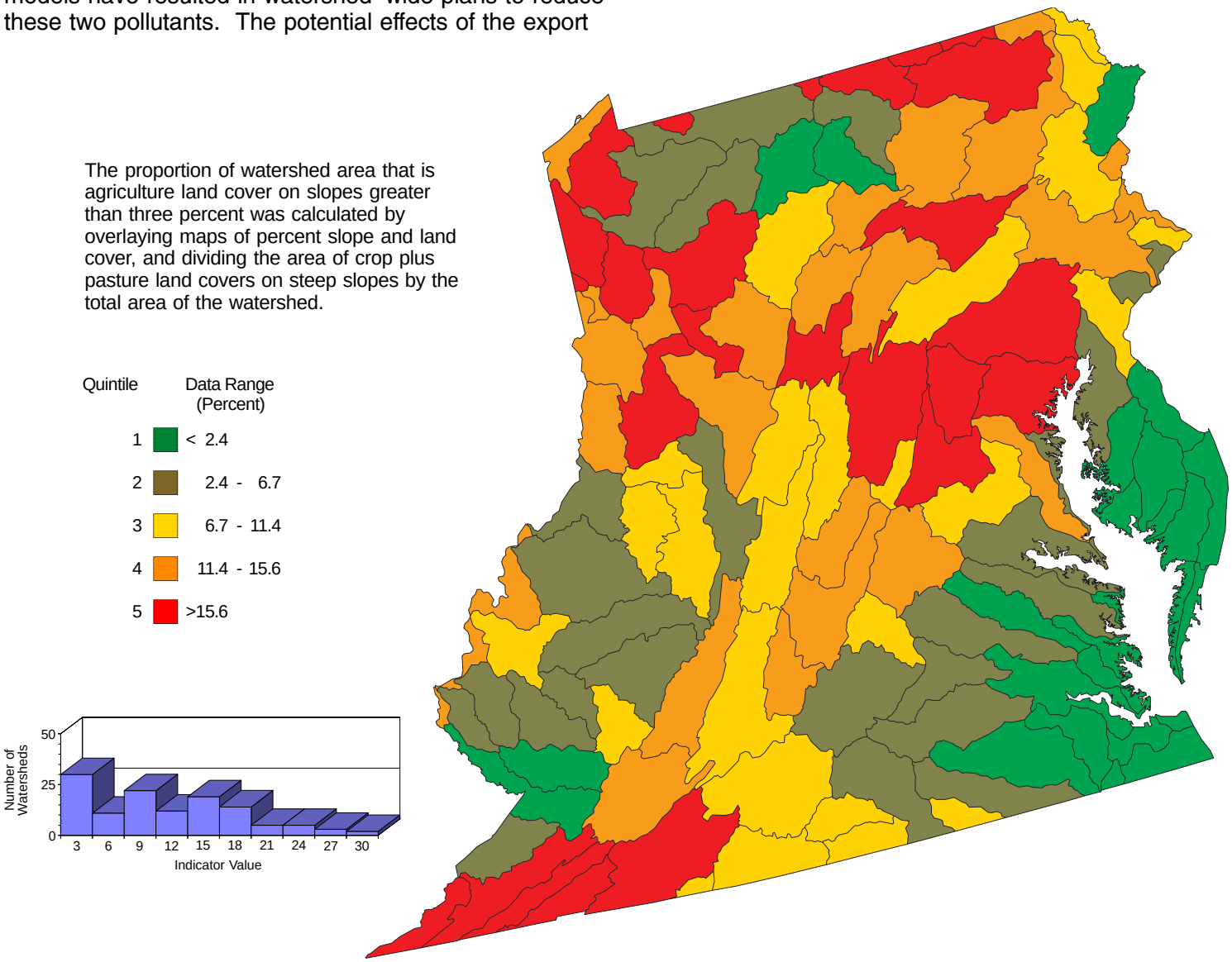


Figure 3.23

Proportion of watershed with agriculture land cover on slopes that are greater than three percent in the mid–Atlantic region.

cation rates which determine local export amounts. However, over a large area such as the mid–Atlantic region, this type of model is valuable as a screening tool to rank watersheds based on potential impacts assuming that average fertilizer rates are used throughout the region. In a nutshell, if there are no agricultural lands in a watershed, then fertilizer application is near zero. Such a watershed has less risk of impacts than a watershed for which 30% of the area is used for agriculture. One major drawback of this simple model is that it ignores fertilizer applications in urban areas, where areas such as lawns, gardens, and golf courses can receive heavy fertilizer doses several times a year.

Figure 3.24 shows watershed rankings for estimated nitrogen (in nitrate form) exports from agricultural lands in the mid–Atlantic region. These ranks also apply for phosphorus (in phosphate form), but the actual amounts differ for the two elements as shown in the charts. The map shows that the watersheds on the DelMarVa peninsula and northern end of the Chesapeake Bay have the highest potential for fertilizer export based on land cover patterns. This pattern suggests why the Chesapeake Bay is such a concern, and why land use practices along the Susquehanna River are of concern to the Bay's water quality stewards.

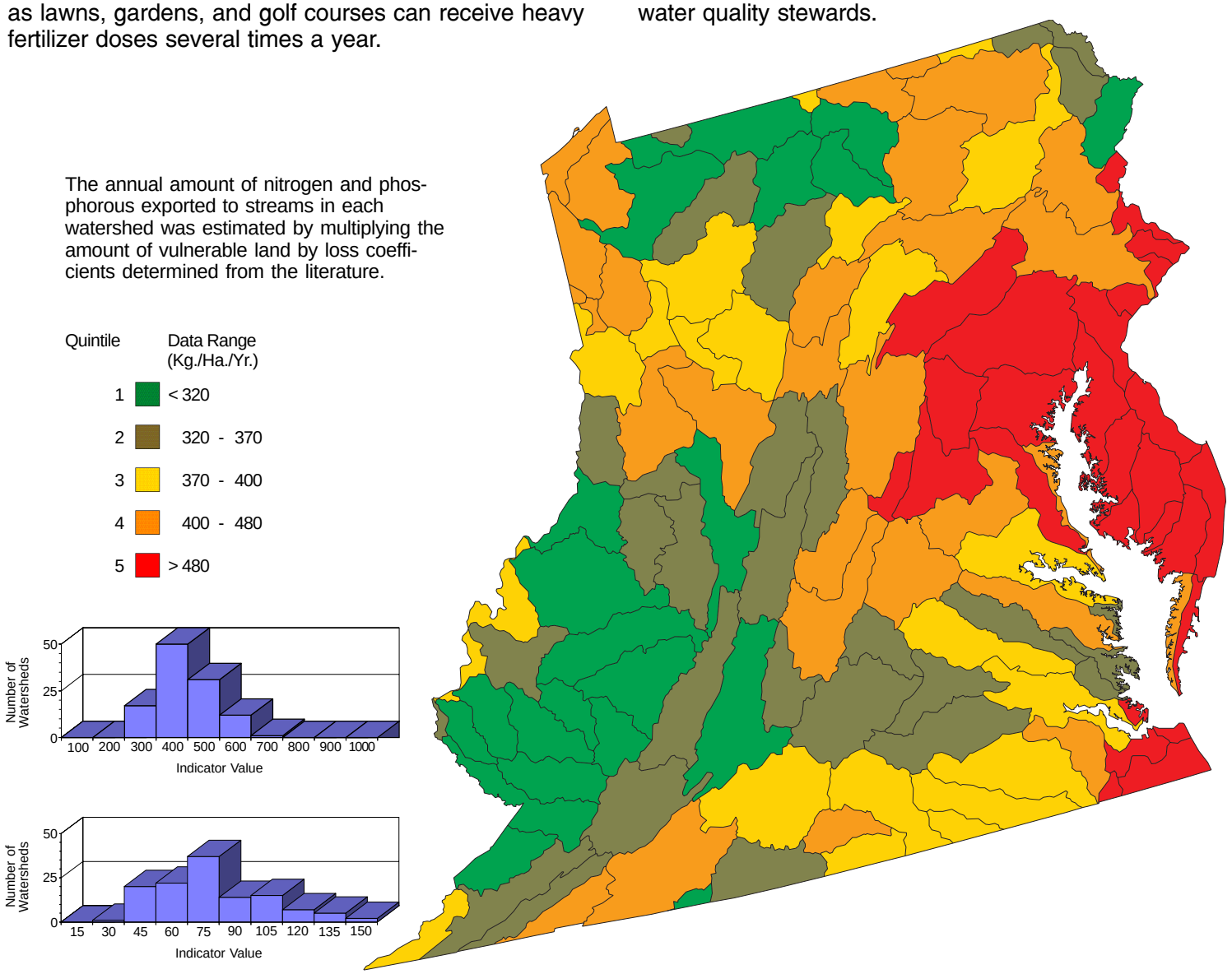


Figure 3.24

Potential nitrogen (top) and phosphorous (bottom) loadings to streams in the mid–Atlantic region. The map and legend reflect the nitrogen values.

Soil Loss

A significant portion of the Federal budget is devoted to the reduction of soil loss in the United States. Soil erosion is important because eroded soil can be transported to a stream where it becomes sediment and because topsoil erosion reduces productivity of agricultural lands. Topsoil is expensive to replace and natural soil–forming processes would require thousands of years to replenish soil already lost from the nation's farmlands. One of the tools developed by agricultural scientists to estimate soil loss from farm lands is the Universal Soil Loss Equation, or USLE. The USLE is intended to show farmers how agricultural practices reduce, or contribute to, soil erosion. The USLE is not generally applied to non–agricultural land uses, nor is it used to estimate wind erosion. Soil texture, slope, land cover, precipitation, and cropping practices are the primary data that go into the USLE (see the Appendix). The soil loss estimated from the model is given in tons of soil lost per acre per year.

Figure 3.25 shows the watershed rankings for the percentage of watershed area that could experience greater than one ton per acre per year of soil loss. As shown in the chart, the proportion of area in a watershed where soil erosion exceeds the threshold value ranges from less then 1% to over 35%. The watersheds surrounding the Chesapeake Bay and the Delaware River estuary show the greatest potential for soil loss.

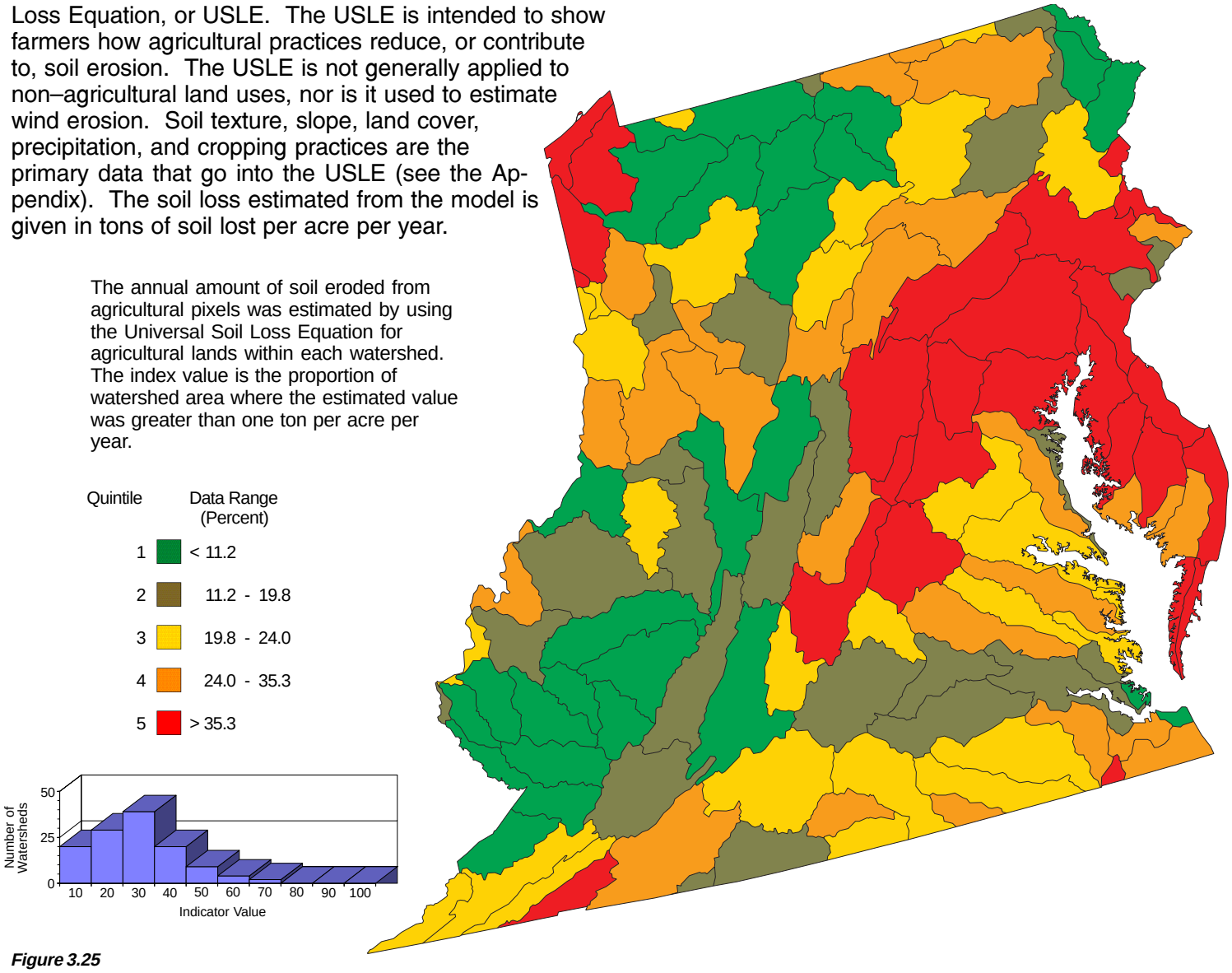


Figure 3.25

Proportion of watershed with potential soil loss greater than one ton per acre per year in the mid–Atlantic region.

Forest Land Cover

At one time, nearly all parts of every watershed in the mid–Atlantic region were forested. Today, the remaining forest helps indicate the probable condition of streams within each watershed. The forest is not the only indicator, however, because the specific types and patterns of non–forest land cover are also important.

The proportion of forest cover in each watershed was calculated from the land cover map. The results are summarized in Figure 3.26 which shows the watershed rankings for this indicator, and in the chart which indicates the values obtained. Watersheds with high proportions of forest are located in the northwest and southwest portions of the mid–Atlantic region. Watersheds with relatively low proportions of forest cover are clustered around the upper Chesapeake Bay and near major urban centers in the region.

Overall, about 70% of the region has forest cover. The chart illustrates that most of the watersheds in the region are primarily forested, and a majority of watersheds have at least 60% forest cover. Forests occupy less than 50% of the area in the 15 to 20 watersheds that are the most highly–developed and have the most agriculture cover.

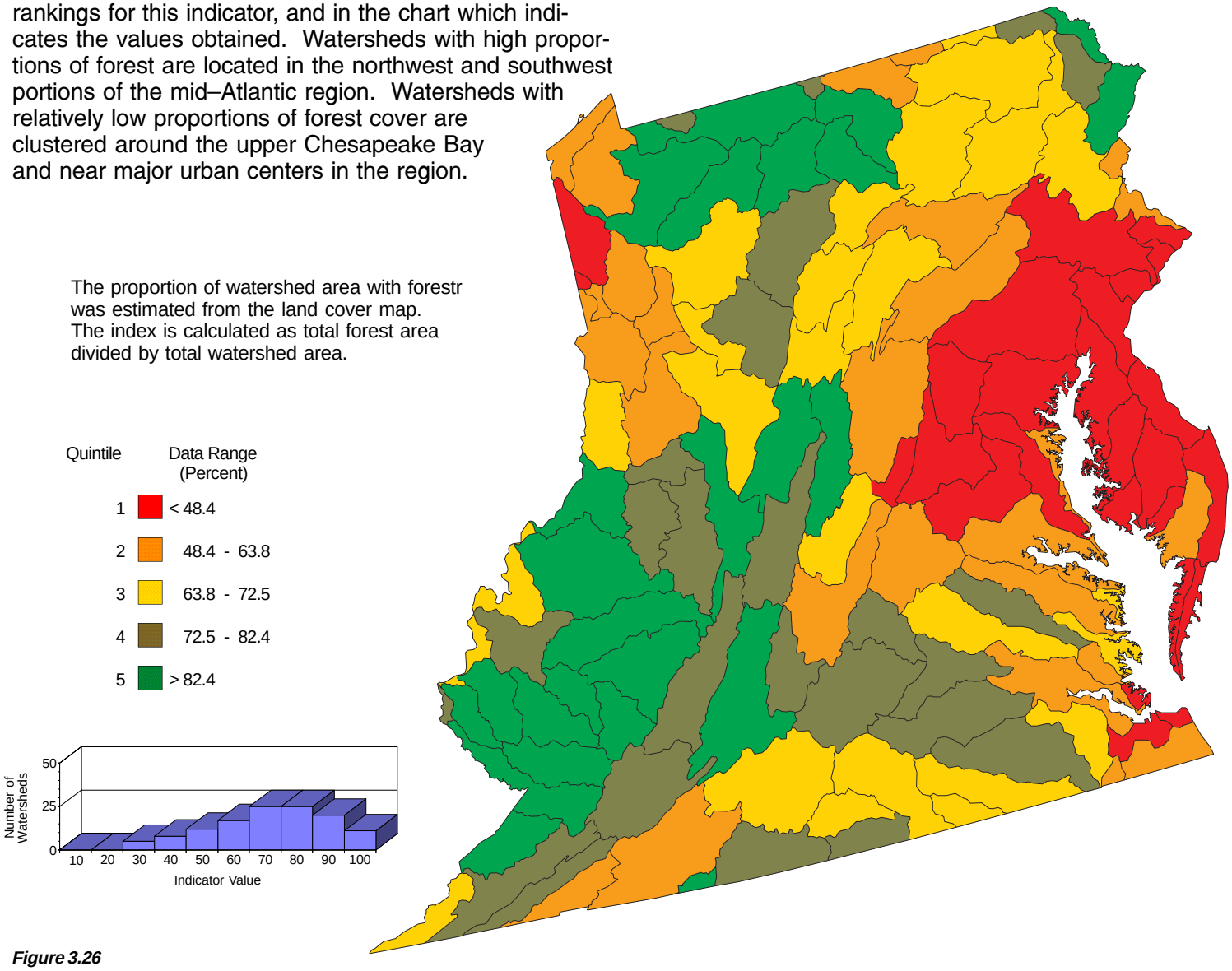


Figure 3.26

Proportion of watershed that is forested in the mid–Atlantic region.

Forests

Forests are important elements of natural and human–dominated landscapes. Forests benefit both humans and wildlife species, providing wood fiber, outdoor recreation, wildlife habitat, and regulation of some hydrologic functions. They dominate most of the mid–Atlantic region today. Historic patterns of land use and development have created the present distribution of forests from what once was essentially all forest. These patterns have also caused changes in the plant and animal species which live in forested environments.

Four related views of forest cover patterns are presented in this section. Earlier, in the context of stream conditions, the watersheds were ranked based on the proportion of area with forest cover (Figure 3.26). In this section, the pattern of the existing forest cover is described as it affects various environmental values, particularly wildlife habitat.

Forest Fragmentation

As in other regions of the United States, forest fragmentation is an important issue in the mid–Atlantic region. Although the phrase has several meanings, it is used here to describe a formerly continuous forest that has been broken up into smaller pieces. In the eastern United States, forest loss is generally associated with conversion to agriculture and urban cover types. These human land uses remove some forest and leave the remaining stands in smaller, isolated blocks. The pattern of forest loss is as important as the amount lost. For example, a checkerboard pattern exhibits more fragmentation than a clumped pattern of the same amount of forest. As described and illustrated in Chapter 1, the degree of connectivity can affect the sustainability of forest species within and among watersheds. Areas with large blocks of continuous forests support a variety of interior forest species, whereas areas with small, fragmented forests support fewer interior forest species and more edge–dwelling species. However, high levels of connectivity may also promote the spread of certain tree diseases across the landscape. Our assessment of forest connectivity is related to habitat for interior forest species; therefore, high levels of forest connectivity are considered the most desirable conditions, and low levels of connectivity are considered the least desirable conditions.

A variety of indicators have been used in the past to assess fragmentation. For any one of the indicators, the apparent degree of fragmentation is highly dependent upon the definition of forest, the scale at which forests are mapped, and the scale at which fragmentation is measured. For example, if a given area is completely covered by forests of any type, then it would not appear to be fragmented by that definition of “forest.” If, however, the same area was mapped at a finer scale which recognized, say, age class differences within the forest, then the “forest” of each age class would appear to be fragmented. Similarly, apparent fragmentation increases as smaller and smaller breaks in the forest canopy are recognized. At some scale, each tree could be considered as a separate island. These differences simply suggest that meaningful interpretations of fragmentation measurements require knowledge of how, and at what scales, the measurements were taken (see Appendix).

Figure 3.27 shows watershed rankings for the fragmentation indicator. Forest fragmentation is highest in watersheds around the Chesapeake Bay and in western Pennsylvania. But as indicated in the chart, forested spots in even the most fragmented watersheds are still likely to be adjacent to another forested spot. In about half of the watersheds in the mid–Atlantic region, there is at least a 90% chance that any given forested pixel is adjacent to another forested pixel.

A comparison with the earlier map of forest area percentage (Figure 3.26) shows, as expected, that fragmentation is generally higher in watersheds with lesser proportions of forest cover. Places that don’t follow the trend are places for which there are forest pattern differences. For example, some watersheds in eastern Pennsylvania have higher forest fragmentation than is expected based on the amount of forest there. The reverse is true in some watersheds in mountain regions.



Forest Edge Habitat

Edge habitat occurs at the boundaries between different types of land cover. Species that require edge habitat use the resources in two or more vegetation types. Some birds, for example, nest in forests and forage in nearby fields. Forest edge habitat is fairly common throughout most of the mid–Atlantic region because there is at least some forest nearly everywhere, and few areas are completely forested. Partial forest cover is what creates forest edge habitat, no matter what the scale. In our assessment, we have made the judgement that more edge is desirable, as it promotes species diversity across the landscape. However, forest–edge habitat can also be viewed as undesirable. Certain nest parasitic bird species (e.g., cowbirds) have their greatest impact on other native species in areas where edge habitat is common. The analysis of edge habitat provided in this atlas should provide useful information on edge habitats, whether edge is considered desirable or undesirable.

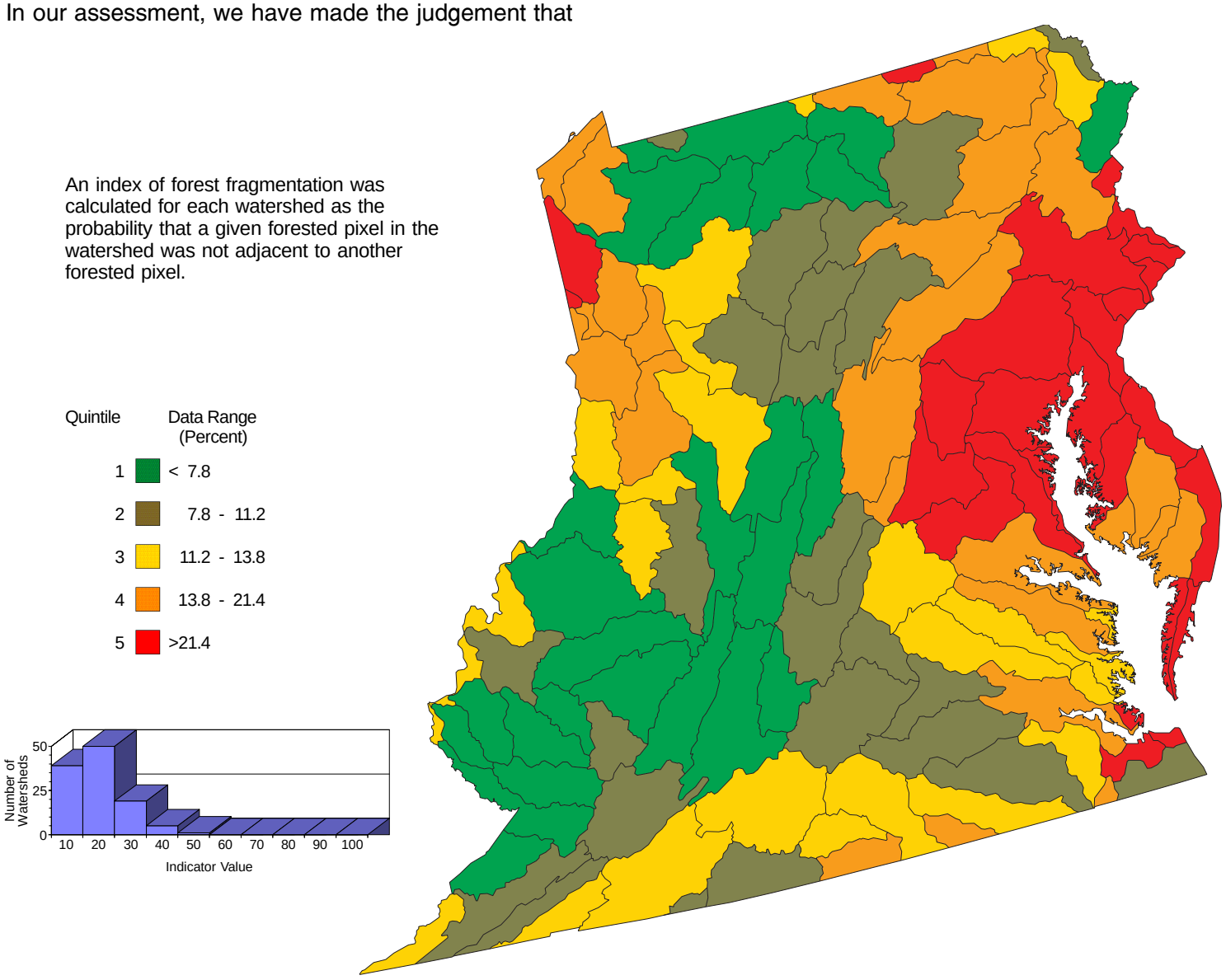


Figure 3.27.

Forest fragmentation index in the mid–Atlantic region.

Because fragmented forests have more edge habitat, the fragmentation map shown earlier could be a guide to forest edge. That map, however, is only one realization of the fragmentation indicator at a particular scale. It is unlikely that many species perceive forest edges exactly like that. Some species may require watershed–size areas made up of mostly edge habitat, but others need just a bit of edge within a forest. Without a particular species in mind, there is no single answer to the question of how much forest edge habitat there is. Multiple–scale approaches are necessary to assess habitat for many species. Looking at different scales helps us to understand if, and how, habitat measurements at one scale might be extrapolated to other scales.

Maps of forest edge habitat at three scales (Figure 3.28) were prepared by using calculation windows of about 7, 65, and 600 hectares. The maps illustrate how the apparent habitat picture changes with window size. Species that require more extensive areas of edge find less suitable habitat in the region, and such habitat is concentrated in the more heavily–fragmented watersheds. The areas of suitable habitat derived from a 600 hectare calculation window appear to be predictable from the those generated from smaller–sized windows. However, the reverse is not true; that is, it would be very difficult to predict the spatial distribution of habitat generated from the smallest window size based on the habitat map produced from the largest window size. This means that species with finer–scale landscape requirements would not necessarily benefit from protecting the habitat of species with broader–scale landscape requirements. The maps of watershed ranks for each window size (Figure 3.29) capture the regional patterns. It is clear that the complex spatial pattern in the urban areas to the north and west of the Chesapeake Bay provide extensive edge habitat. In some cases, the rank of a watershed changes for different window sizes, which indicates scale–dependent pattern differences between watersheds. The charts demonstrate that there are fewer watersheds with suitable forest edge habitat for species with large area requirements.

The amount of forest edge habitat in each watershed was estimated by using a spatial filter to map forest edges with three different window sizes. The proportion of total watershed area above a threshold forest edge value was used as the index.

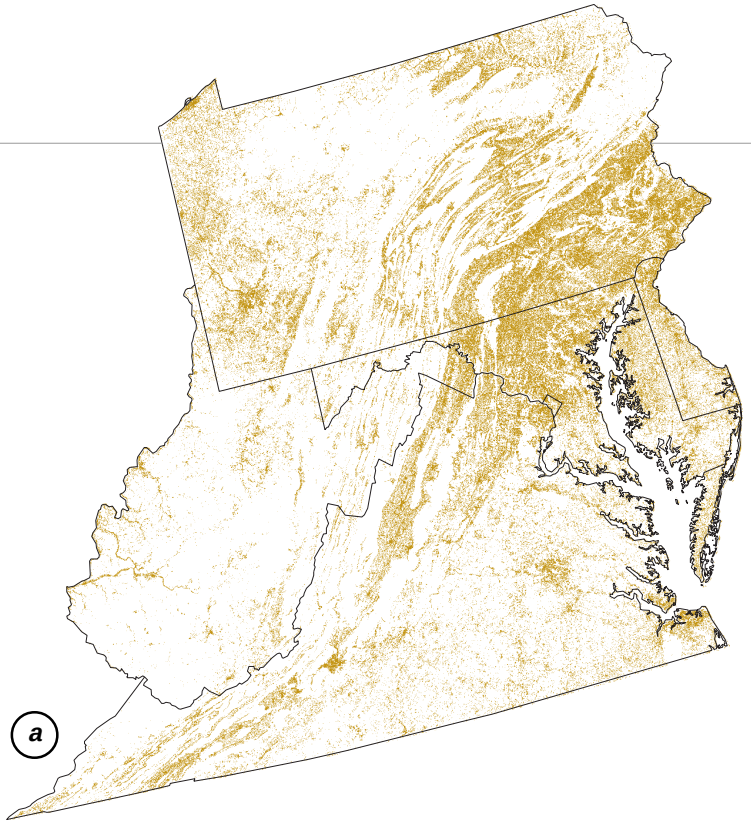


Figure 3.28.
Surface maps of forest edge habitat, shown in olive, at (a) 7 hectare, (b) 65 hectare, and (c) 600 hectare scale in the mid–Atlantic region (see text for explanation).

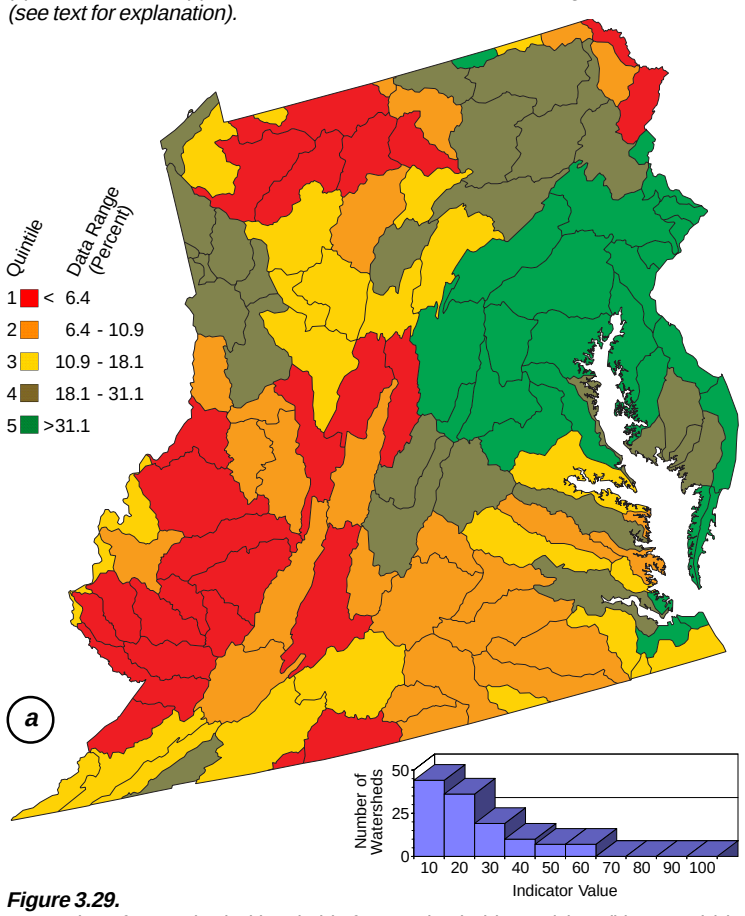
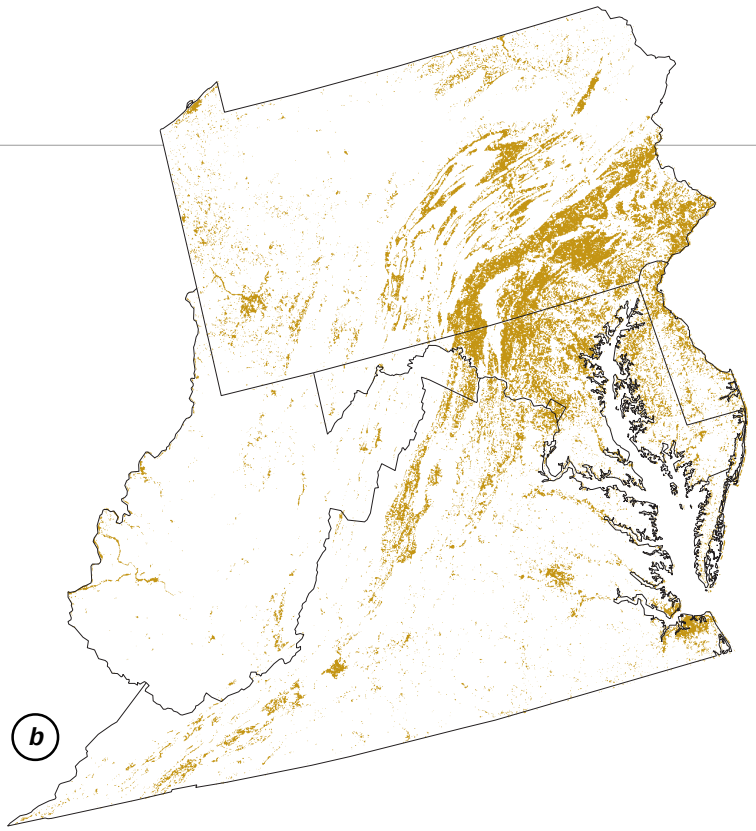
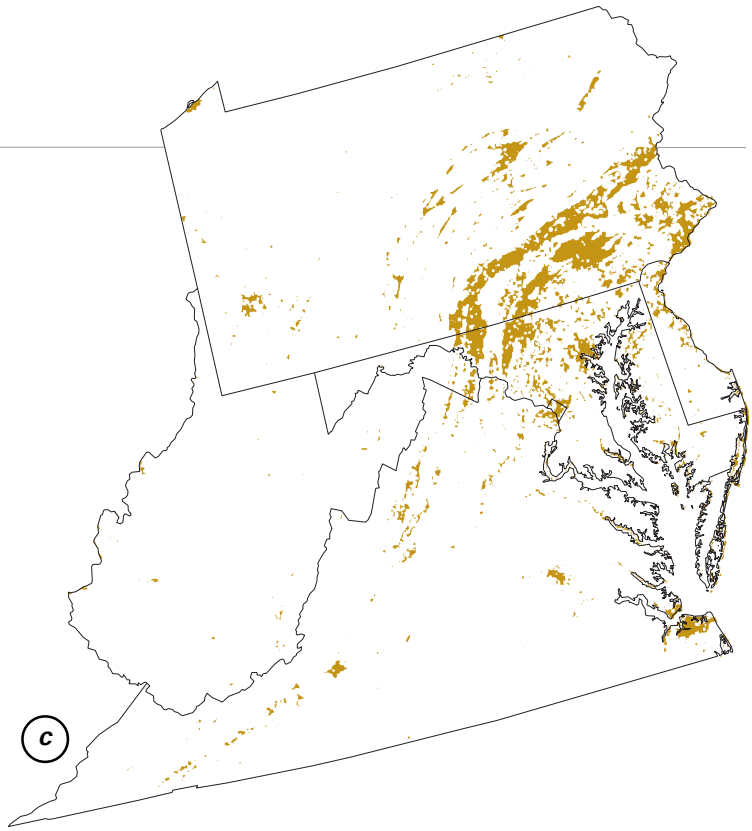
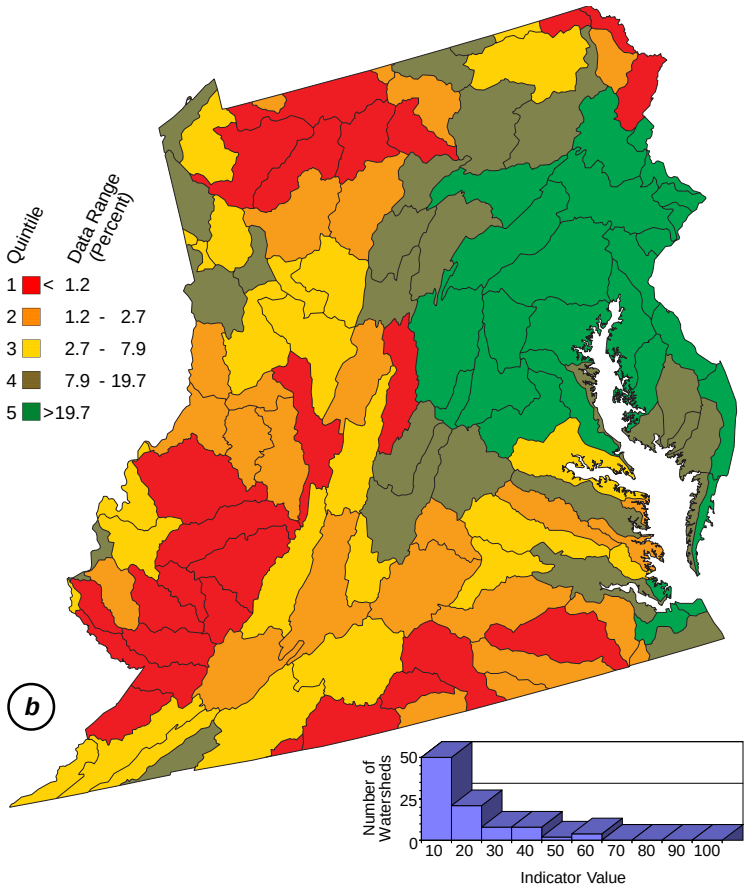
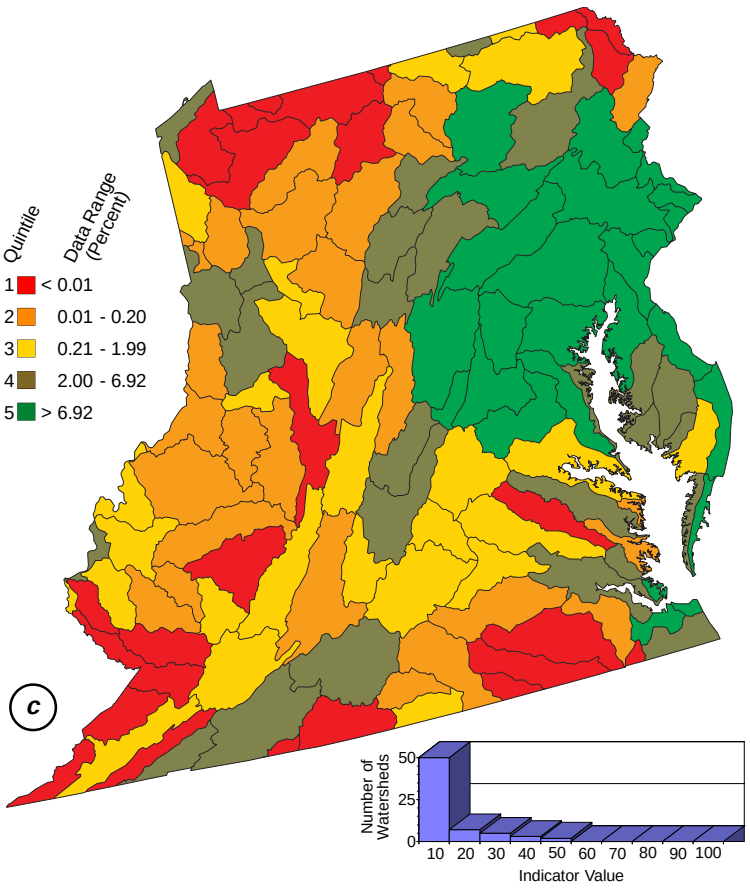


Figure 3.29.
Proportion of watershed with suitable forest edge habitat at (a) 7, (b) 65, and (c) 600 hectare scale in the mid–Atlantic region.


b


c


Quintile
Data Range (Percent)
1 < 1.2
2 1.2 - 2.7
3 2.7 - 7.9
4 7.9 - 19.7
5 >19.7
b
Number of Watersheds
0
25
50
10 20 30 40 50 60 70 80 90 100
Indicator Value


Quintile
Data Range (Percent)
1 < 0.01
2 0.01 - 0.20
3 0.21 - 1.99
4 2.00 - 6.92
5 > 6.92
c
Number of Watersheds
0
25
50
10 20 30 40 50 60 70 80 90 100
Indicator Value

Interior Forest Habitat

In contrast to edge species a variety of wildlife species, require nearly the opposite type of habitat — large tracts of continuous forest cover. Interior forest habitats are relatively rare and easily lost, so forest interior species sometimes become the focal point for debates over human activities such as road–building. In the mid–Atlantic region, interior forest is most likely to be found where the percentage of forest is high and fragmentation is low. But like edge habitat, interior forest exists at many scales. Salamanders need different amounts of forest habitat than bears, and differences such as these call for a multiple–scale analysis.

Species with smaller area requirements should enjoy a region–wide distribution based on the habitat map for the smallest window size, whereas species with larger area requirements should have more restricted and patchy distributions (Figure 3.30). Suitable large–window habitat is concentrated and relatively well–connected in mountainous areas, with little or none appearing in the most urbanized areas. Although there are some differences in watershed rankings of interior forest habitat proportions for the three window sizes (Figure 3.31), overall patterns are similar.

With such a high threshold value for "suitability" (90% forest in a window), the proportion of watershed area that is suitable decreases rapidly with increasing area requirements. The charts illustrate that in most of the watersheds, at least half of the area is considered suitable by the small–window analysis. The number of watersheds with half of the area in large–window interior blocks is much smaller.

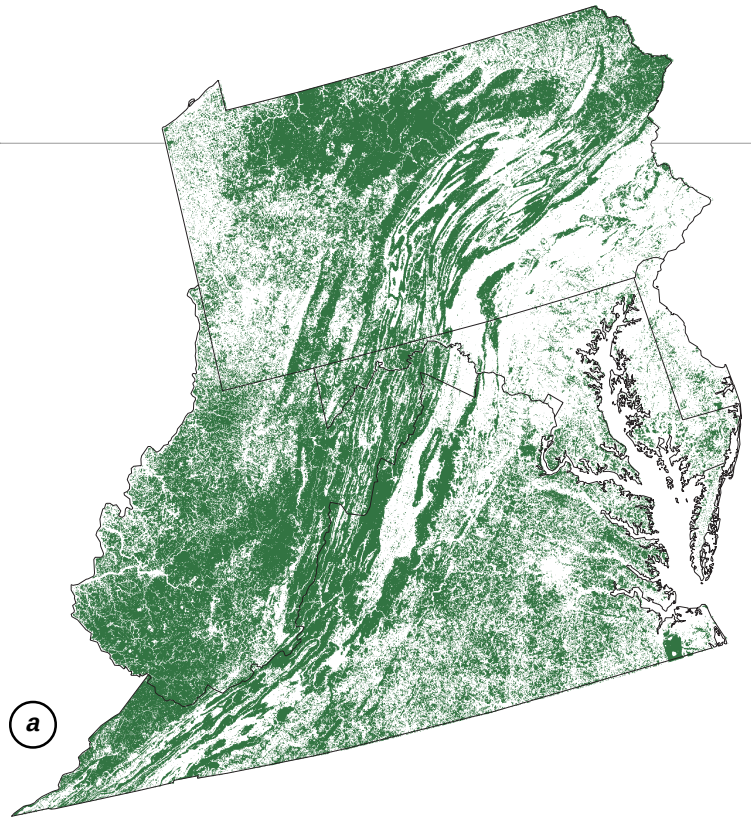


Figure 3.30
Surface map of interior forest habitat, shown in green, at (a) 7 hectare, (b) 65 hectare, and (c) 600 hectare scale in the mid–Atlantic region (see text for explanation).

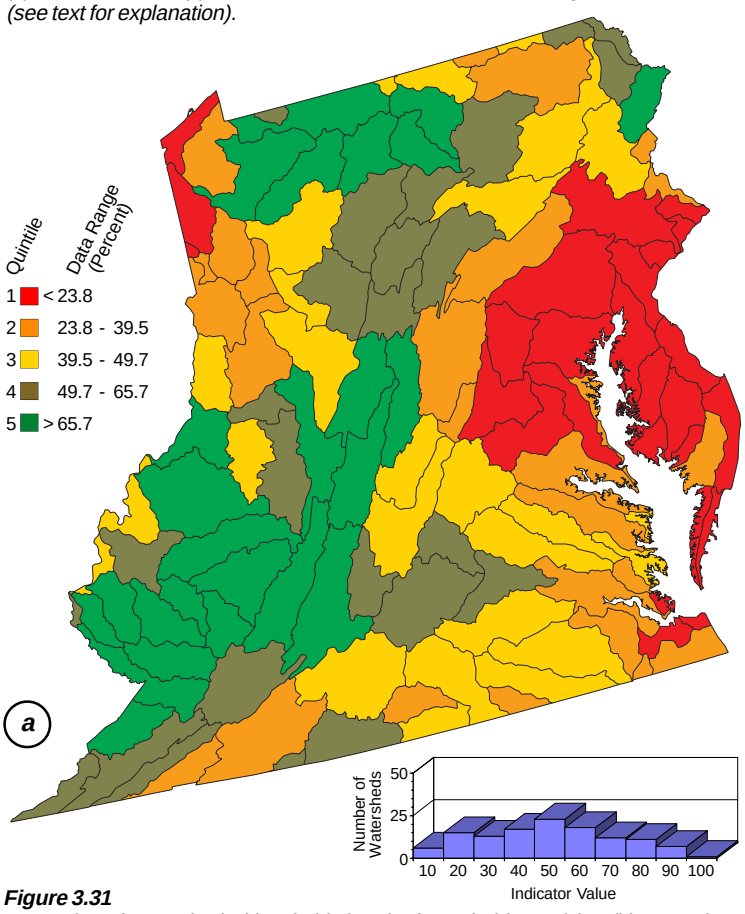
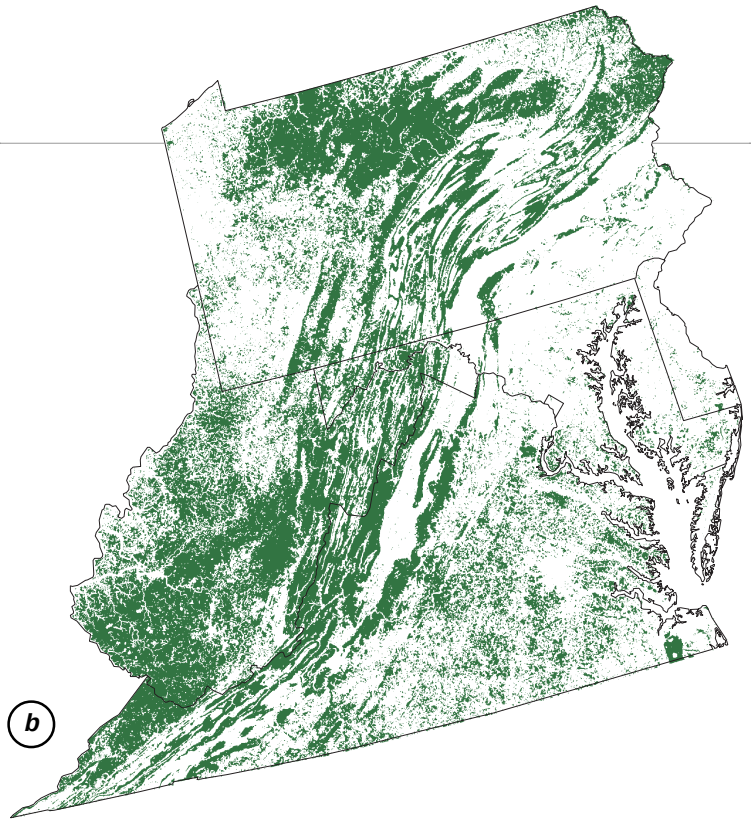
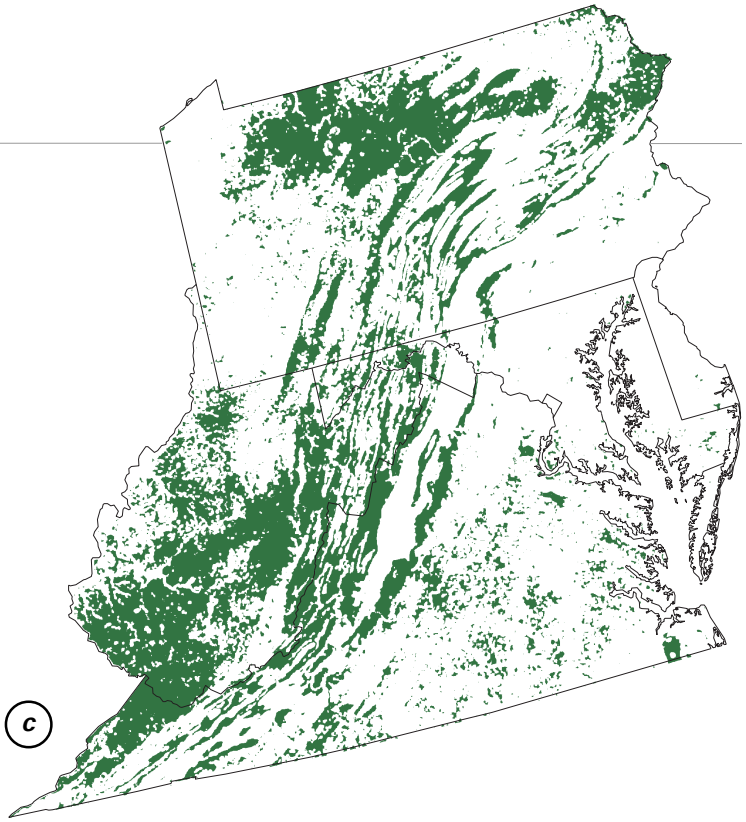


Figure 3.31
Proportion of watershed with suitable interior forest habitat at (a) 7, (b) 65, and (c) 600 hectare scale in the mid–Atlantic region.

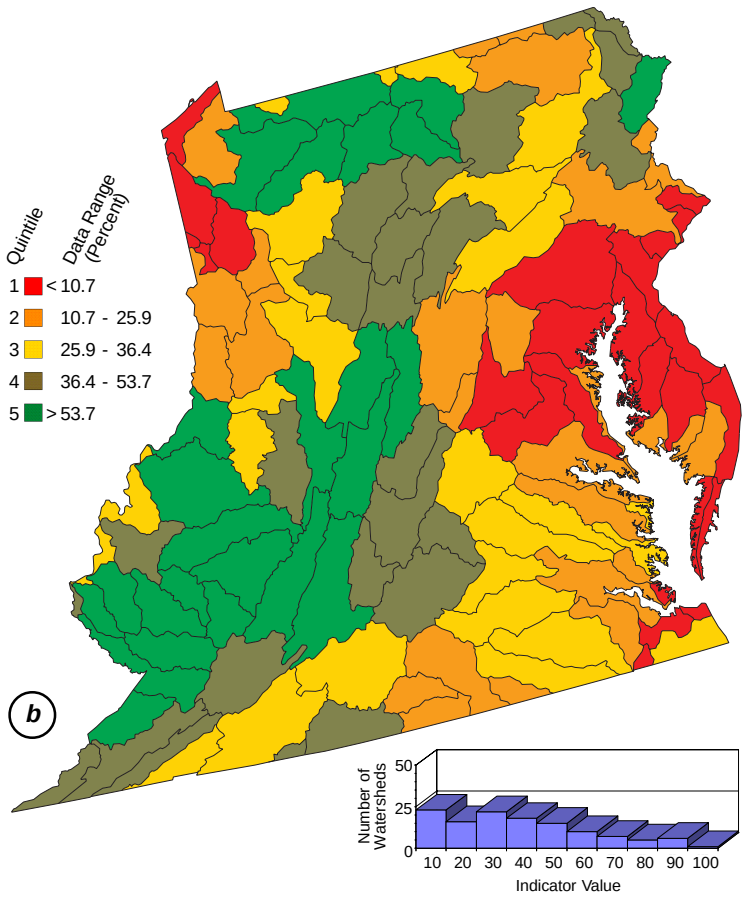
The amount of interior forest habitat in each watershed was estimated by using a spatial filter to map forest density with three different window sizes The proportion of total watershed area above a threshold forest density value was used as an index.



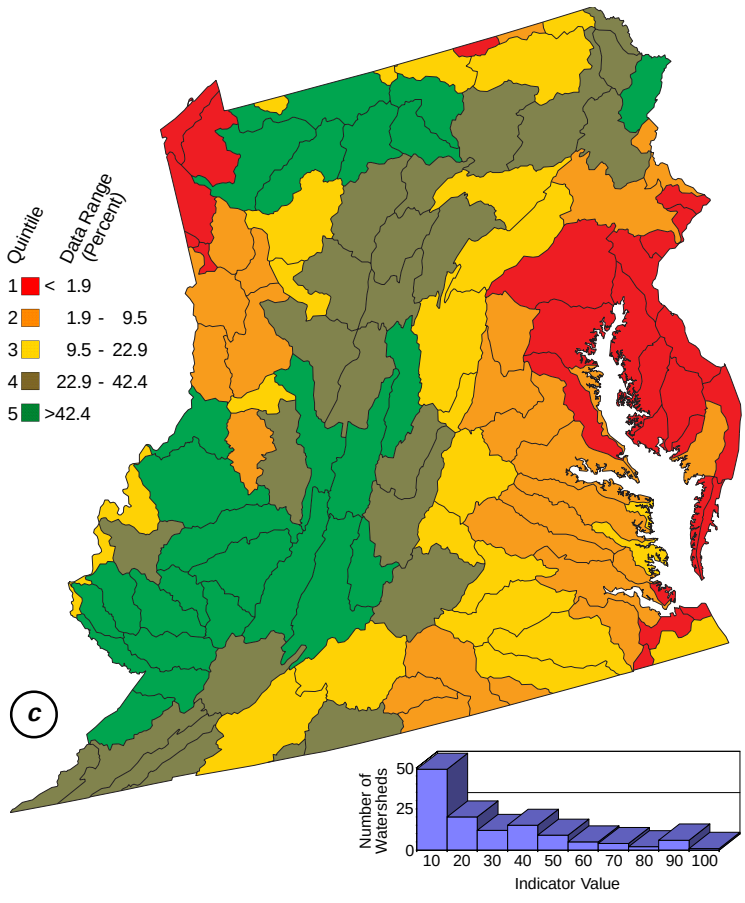
b



c


Quintile
Data Range (Percent)
1 < 10.7
2 10.7 - 25.9
3 25.9 - 36.4
4 36.4 - 53.7
5 > 53.7
Number of Watersheds
0
25
50
10 20 30 40 50 60 70 80 90 100
Indicator Value

b


Quintile
Data Range (Percent)
1 < 1.9
2 1.9 - 9.5
3 9.5 - 22.9
4 22.9 - 42.4
5 >42.4
Number of Watersheds
0
25
50
10 20 30 40 50 60 70 80 90 100
Indicator Value

c

Another possible indicator combines information from all three scales of analysis. A watershed with adequate interior habitat at all three window sizes might have a greater diversity of interior forest species. Watersheds that have a higher proportion of area which supports more scales of habitat are identified in Figure 3.32. These are generally the watersheds identified in the single–scale analysis using the largest window size.

The Largest Forest Patch in Relation to the Amount of Forest Land Cover

About 30 years ago, A.W. Kuchler made maps of potential natural vegetation, or vegetation that would occur if influenced by only natural processes such as weather and fire. In the mid–Atlantic region, Kuchler's maps show that the potential natural vegetation is almost exclusively forest, and areas with other cover types represent departures from natural conditions.

Previous discussion introduced the concept of forest fragmentation (Figure 3.27). Consider a watershed with a certain amount of forest cover. If the forest is in one continuous patch, then the area of the largest forest patch equals the total forest area. If the largest patch is smaller than this expected value, then fragmentation has occurred and the remaining forest cover is discontinuous.

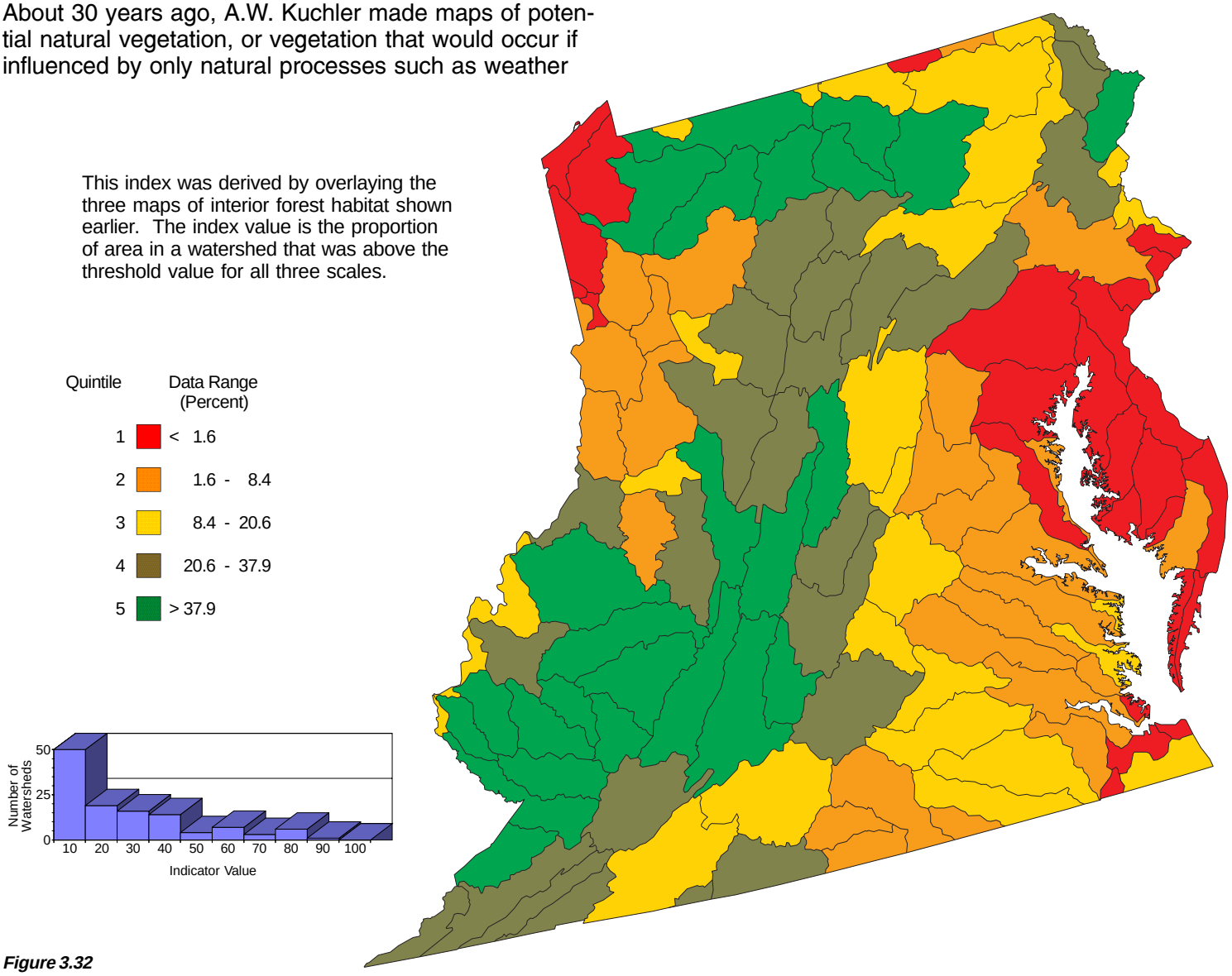


Figure 3.32

Proportion of watershed with suitable interior forest habitat at three scales in the mid–Atlantic region.

Figure 3.33 shows the results of plotting the proportion of each watershed in the largest forest patch versus the proportion of urban and agriculture (non–forest, or anthropogenic land cover) in each watershed. The double–hatched line in Figure 3.33 is the expected value without forest fragmentation. The figure indicates that the size of the largest forest patch becomes less than expected (that is, fragmentation becomes more important at a watershed scale) when human–altered land cover occupies about 25% of the watershed. A curve has been drawn through the points in an effort to more clearly show the observed relationship. Figure 3.34 ranks all watersheds based on their departure from the expected values given in Figure 3.33.

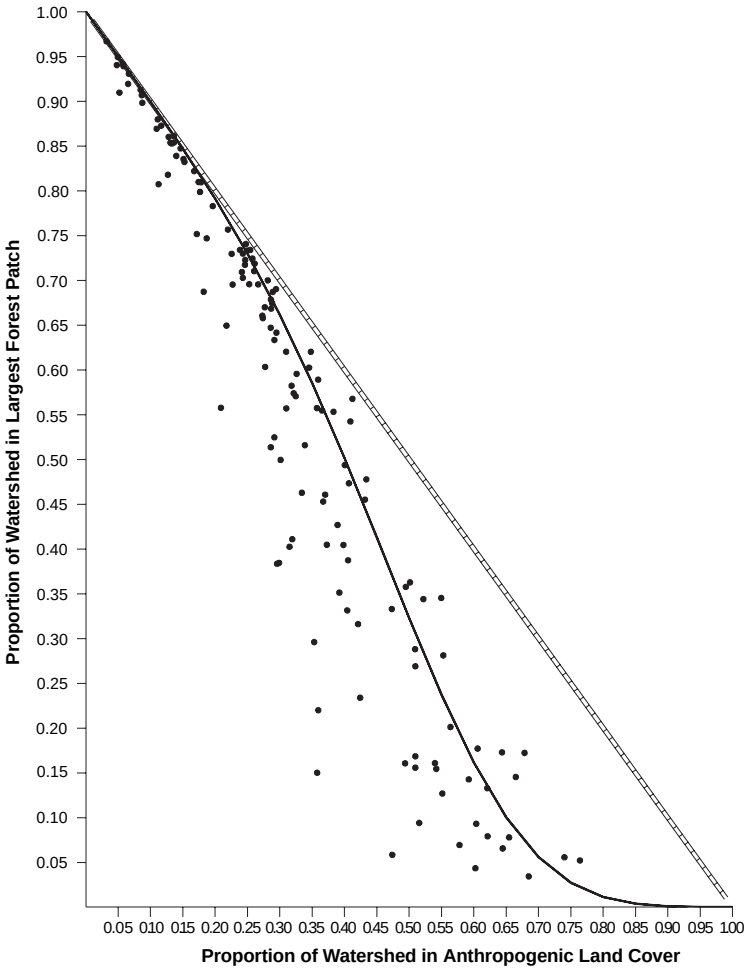


Figure 3.33

Proportion of the watershed in the largest forest patch in relation to the proportion in anthropogenic (non–forest) land cover (see text for explanation).

Landscape Change (1975–1990)

A common perception is that patterns of forested, agricultural and urban areas remain constant over time. In fact, land cover changes occur all the time. In this section we present patterns of vegetation change measured by comparing satellite images from 1975 and 1990. The change is determined by using a vegetation measure called the Normalized Difference Vegetation Index or NDVI (see Appendix) which was calculated for each pixel on each of the two dates. NDVI is a measure of the relative greenness of an area. NDVI values range between 0 and 1; high values usually indicate presence of forest, whereas low values generally indicate bare ground, pavement, or a water body. Positive changes in NDVI indicate a greening up of an area (for example, reestablishment of forests, maturing of lawns), whereas negative changes indicate losses in greenness (for example, clearing of a forest for development, forest dieback caused by an insect infestation). However, observed changes are usually more difficult to interpret (see discussion below). When the NDVI values are essentially the same at both dates, then there has been no change. When the value is greater in 1975 than 1990, we interpret this as vegetation loss during that 15–year period. When the value in 1975 is less than 1990, we interpret this as vegetation gain. Total vegetation change is taken to be the sum of loss and gain on an area basis.

Comparison of temporal changes in reflectance measures from satellites, such as NDVI, can be useful for gaining insight into land cover changes when land cover maps from two different dates are not available. Interpreting the measurements relative to land cover change is not simple, because some changes in reflectance are not changes in land cover. Crop rotation is a good example. Change in NDVI measurements may be the result of seeing a field in production on one date and fallow on the other. Interpretation of these measurements for actual land cover change requires a lot of additional work beyond calculating their difference over time. Because of the additional work needed to interpret actual land cover change and because NDVI data were not available over the entire region, these indicators were not used in the synthesis which appears in the next chapter.

Despite the complications, the amount and spatial pattern of NDVI change is important. For example, many of the decreases in NDVI turn out to be associated with road improvements, new residential developments, urbanization projects, and construction of reservoirs. A good example is the vegetation loss associated with the construction of Interstate 295 east of Richmond which is illustrated in Figure 3.35. In the central Pennsylvania Mountains, some large blocks of vegetation gain suggest recovery from a gypsy moth infestation. Other gains in NDVI appeared to be the result of maturing vegetation in residential developments. Gains in NDVI appear to be associated with both natural and anthropogenic processes, whereas non–crop rotation NDVI losses appear to be more consistently associated with anthropogenic activities.

These examples show that, after calibration, NDVI changes over time can help answer several ecologically–important questions, such as how much change has occurred, whether or not change is evenly distributed over all the watersheds in the region, and whether or not vegetation change concentrated in the headwater re-

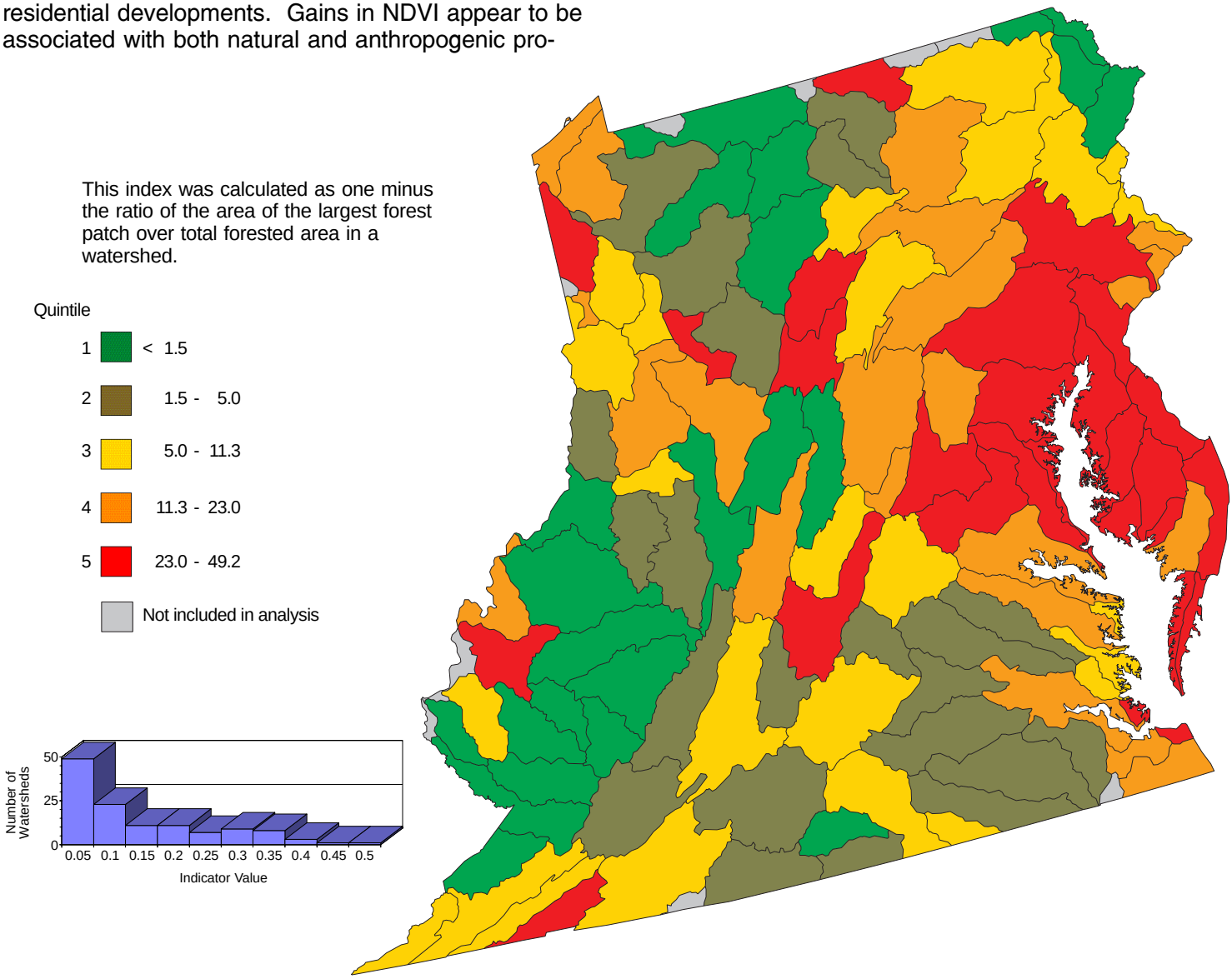


Figure 3.34.

Departure of the largest forest patch from the maximum possible for a given amount of anthropogenic cover in the mid–Atlantic region.

gions of streams. Regional–scale differences among watersheds can be large. For example, Figure 3.36 shows vegetation change for three watersheds in the region. In one of the watersheds, about 3% of the surface area shows change, and in another two the value is about 35%. The next section describes some regional patterns in NDVI change, recognizing that more work is needed for confident interpretations of land cover change.

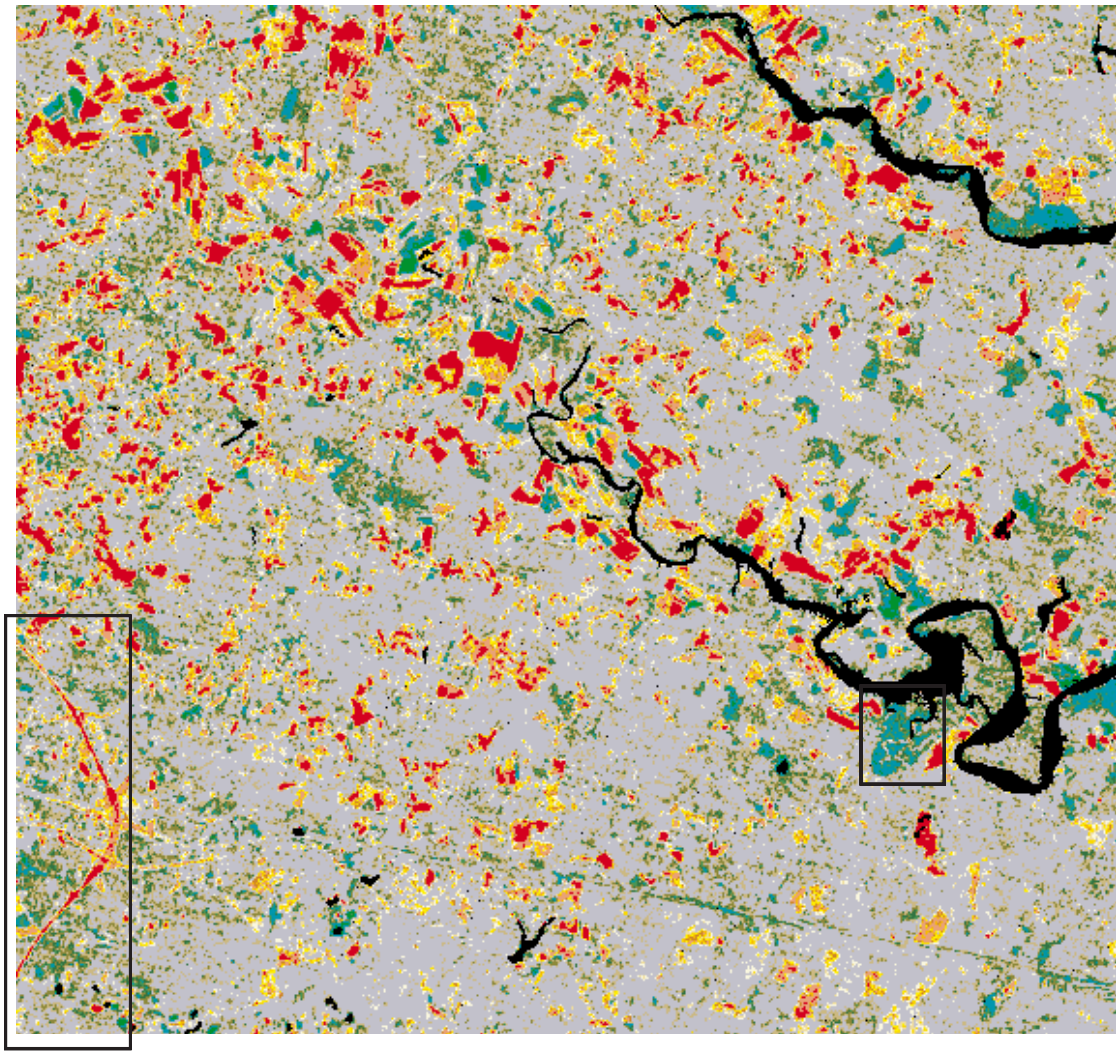


Figure 3.35.

Vegetation change east of Richmond, VA. The NDVI loss east of Richmond (box at lower left) corresponds to the construction of Interstate 295 between 1975 and 1990. The box at lower right illustrates differences in NDVI that are associated with periodic exposure of aquatic vegetation in a tidal marsh. Source: North American Landscape Characteristics Program, Landsat Multi–Spectral Scanner image.

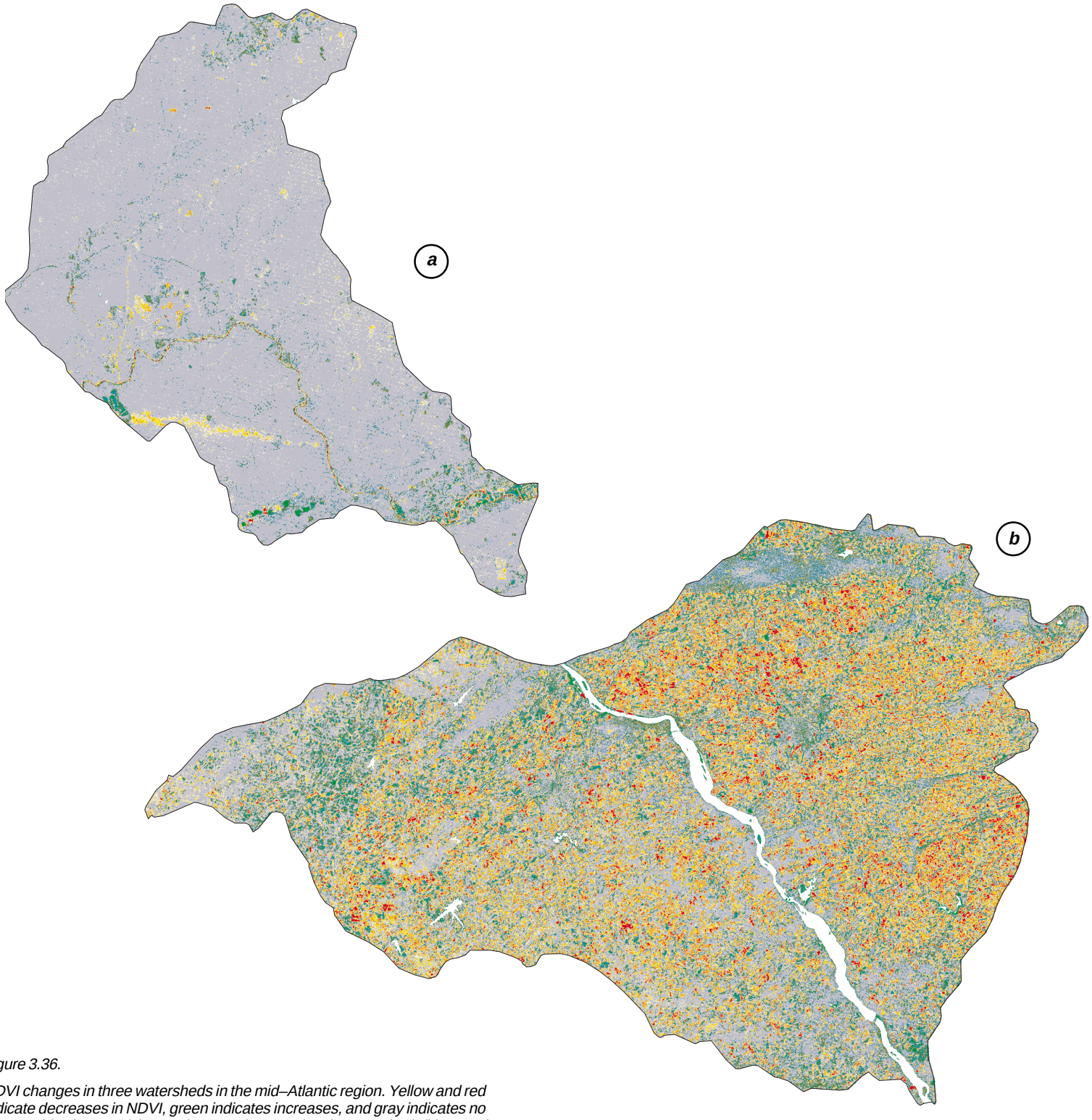
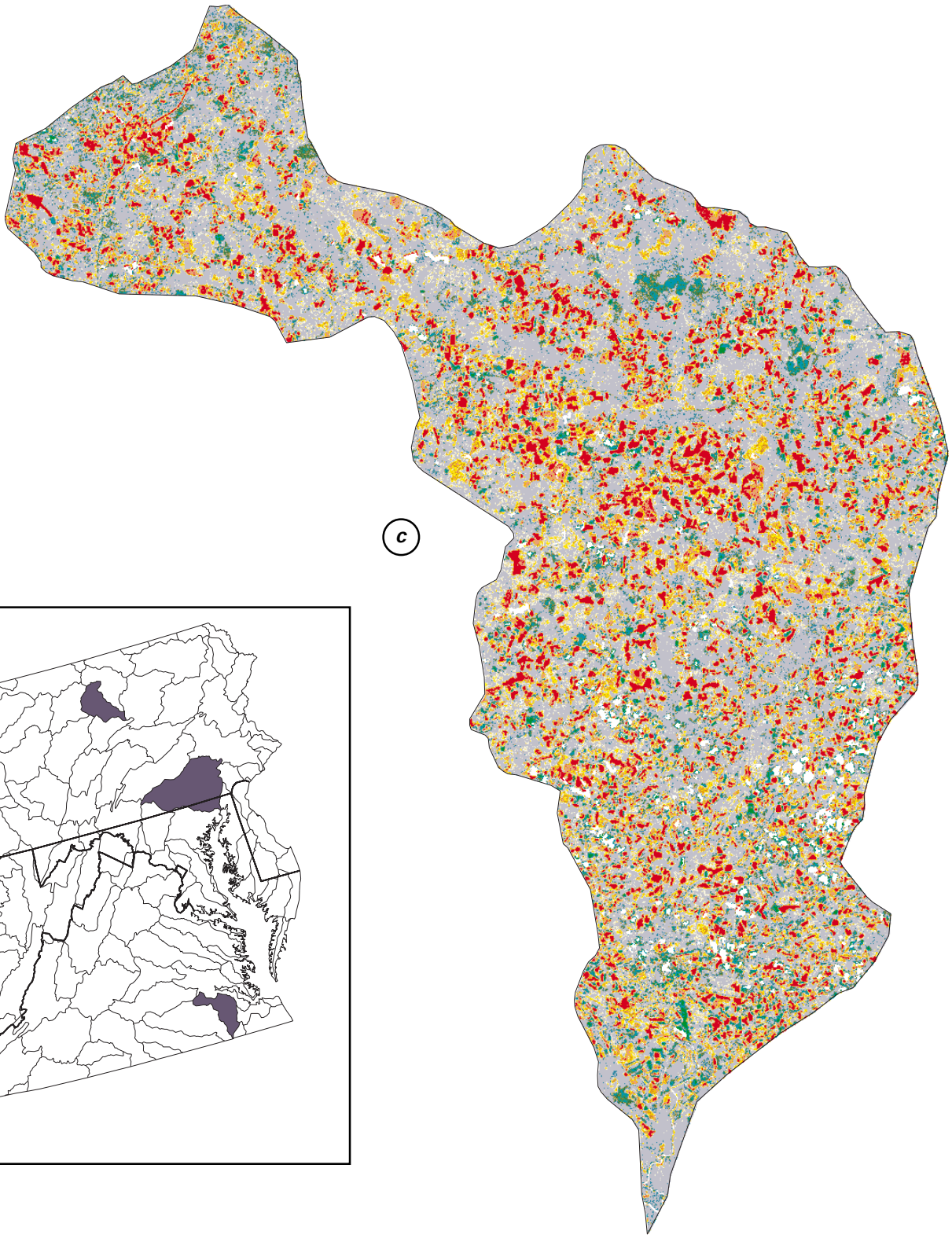


Figure 3.36.

NDVI changes in three watersheds in the mid–Atlantic region. Yellow and red indicate decreases in NDVI, green indicates increases, and gray indicates no discernable change. (a) A north–central Pennsylvania watershed. (b) A south–east Pennsylvania watershed. (c) A southeast Virginia watershed. Source: North American Landscape Characteristics Program, Landsat Multispectral Scanner images.



c

Vegetation Change Among Watersheds

Figures 3.37 through 3.39 show the rank ordering of watersheds in terms of vegetation loss, gain, and total change. Vegetation gain and loss have a regional pattern with the highest rates of change along the eastern seaboard and decreasing westward. But there are some exceptions. On the vegetation loss map (Figure 3.37), there are moderate to high rates of loss in the Appalachian Mountains, and low rates of loss along the western edge of the Coastal Plain in Virginia. On the vegetation gain map (Figure 3.38), there are some high amounts of gain scattered throughout the western portion of the region and some low amounts of gain on the coastal plain. The color pattern on the vegetation gain map is similar to the color pattern on the population map shown earlier in this chapter (Figure 3.6).

There appears to be some correlation between vegetation gain and loss. In other words, gain and loss appear to be high together, or low together, on average. This correlation pattern is evident in the total change map (Figure 3.39). Areas of loss and gain may be correlated because the areas of highest loss (initial clearing of forests) and gain (maturing lawns) tend to be near each other within expanding suburban areas surrounding cities. Figure 3.39 shows the clearest pattern of high rates of change along the coast and decreasing westward.

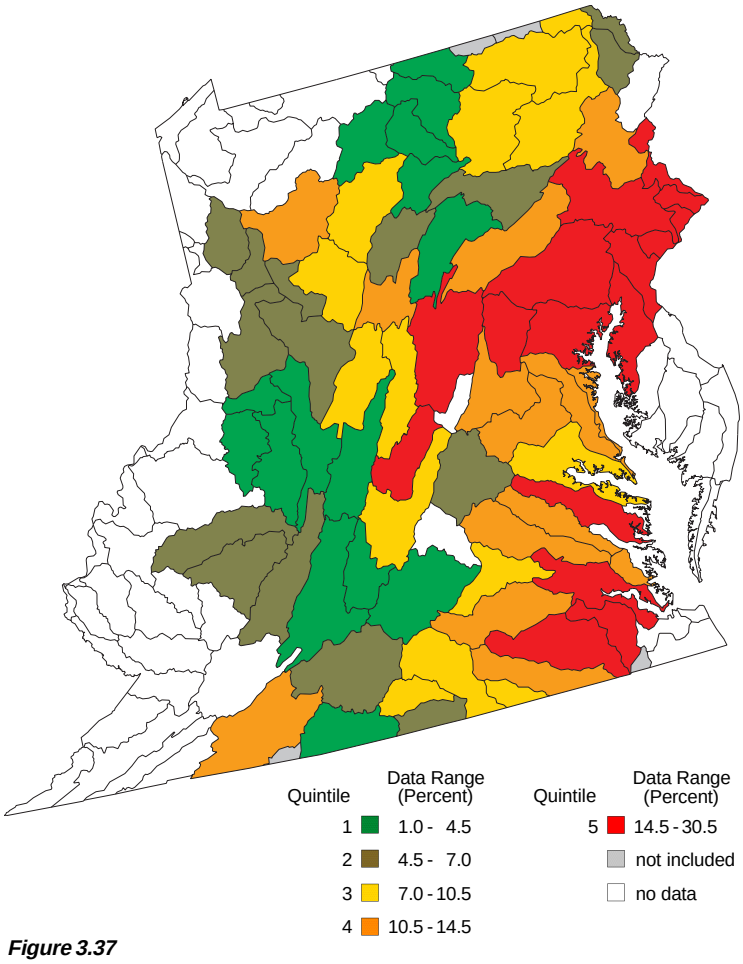


Figure 3.37

Decreases in the NDVI from 1975 to 1990 in the mid–Atlantic region (see text for explanation).

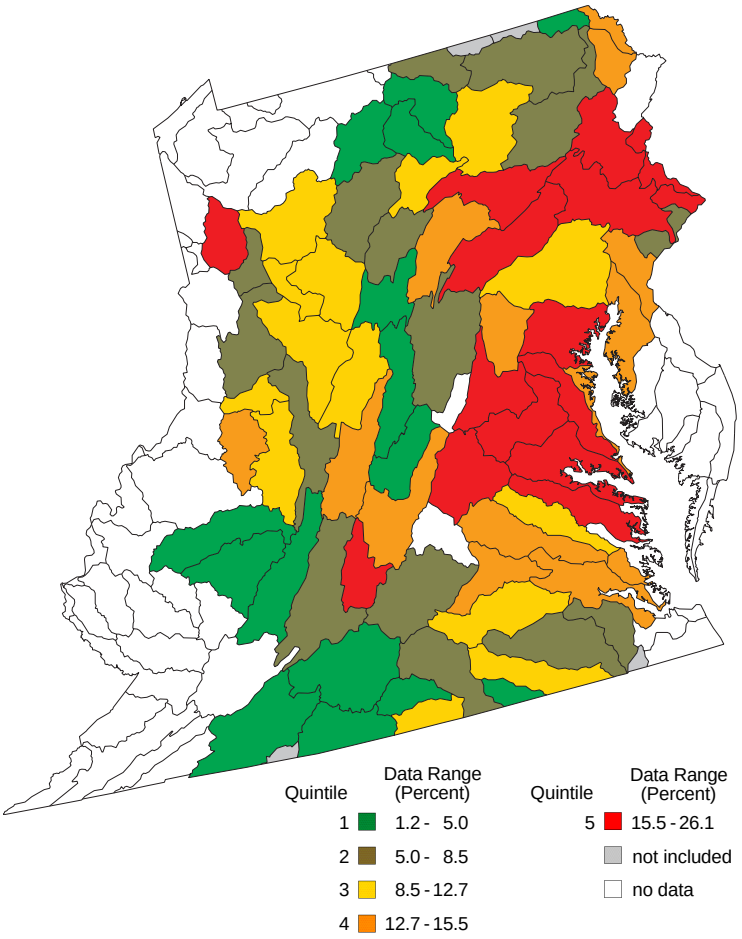


Figure 3.38

Increases in the NDVI from 1975 to 1990 in the mid–Atlantic region (see text for explanation).

Vegetation Change Within Watersheds

We have seen that vegetation change is not uniformly distributed over the region. Some watersheds show high rates of vegetation change, while others are low. What about changes within individual watersheds? Is vegetation change uniformly distributed within a watershed?

To answer this question, we divided each watershed into two sections: first–order stream regions, and all higher–order stream regions. First–order streams are small streams at the top of the watershed. A second–order stream is formed at the confluence of two first–order streams, a third–order stream is formed at the confluence of two second–order streams, and so on. The first–order stream region in a watershed is the area that drains into all first–order streams in that watershed. This area is usually the steepest portion of the watershed and therefore can be more impacted by the loss of vegetation. We compared the observed change in the first–order region with the expected value if the change were evenly distributed (without regard to stream order) throughout the watershed.

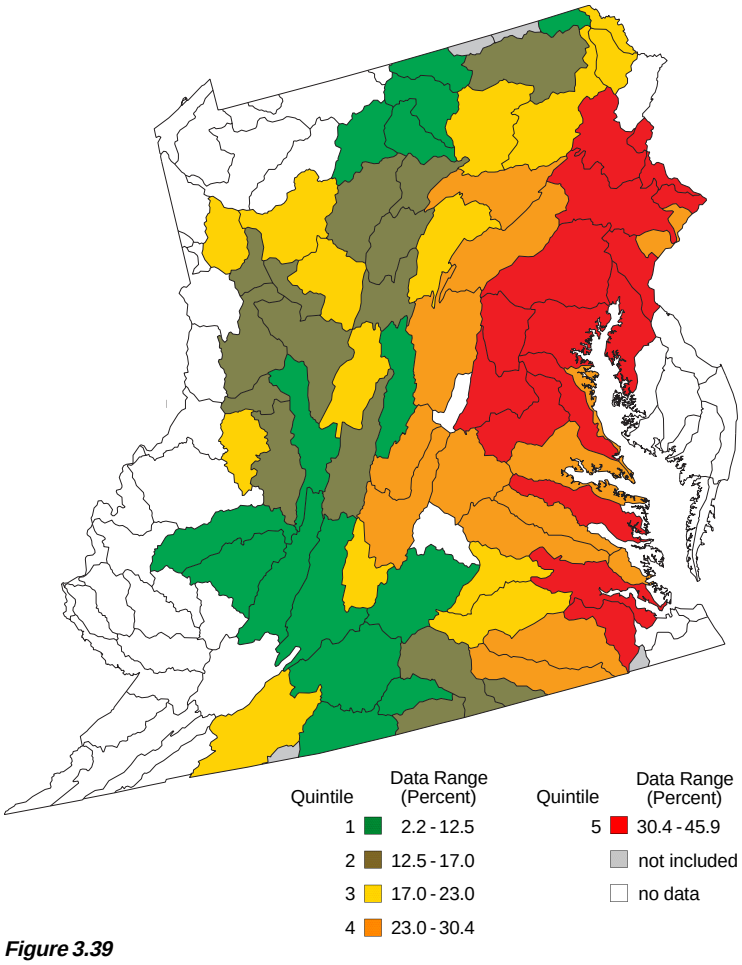


Figure 3.39

Total change in the NDVI from 1975 to 1990 in the mid–Atlantic region (see text for explanation).

Figures 3.40 through 3.42 show the difference between observed and expected values for vegetation loss, gain, and total change in first–order stream regions. When vegetation loss is high across the whole watershed (orange or red in Figure 3.37), the loss in the first–order region tends to be higher than expected (red in Figure 3.40). The opposite seems to be the case for vegetation gain. When vegetation gain is high across the whole watershed (red in Figure 3.38), it tends not to occur in the first–order region (green in Figure 3.41). This pattern suggests that some portion of vegetation gain is associated with human activities. People tend to avoid developing land in the first–order region where slopes are steep. Thus, we would expect that vegetation gain associated with human activity would be concentrated in the higher–order stream regions of the watershed.

Comparison of the expected versus observed map for total vegetation change in first–order streams (Figure 3.41) with that across the whole watershed (Figure 3.39) does not show a clear pattern, which might be expected because of the opposite trends seen earlier for vegetation loss and gain.

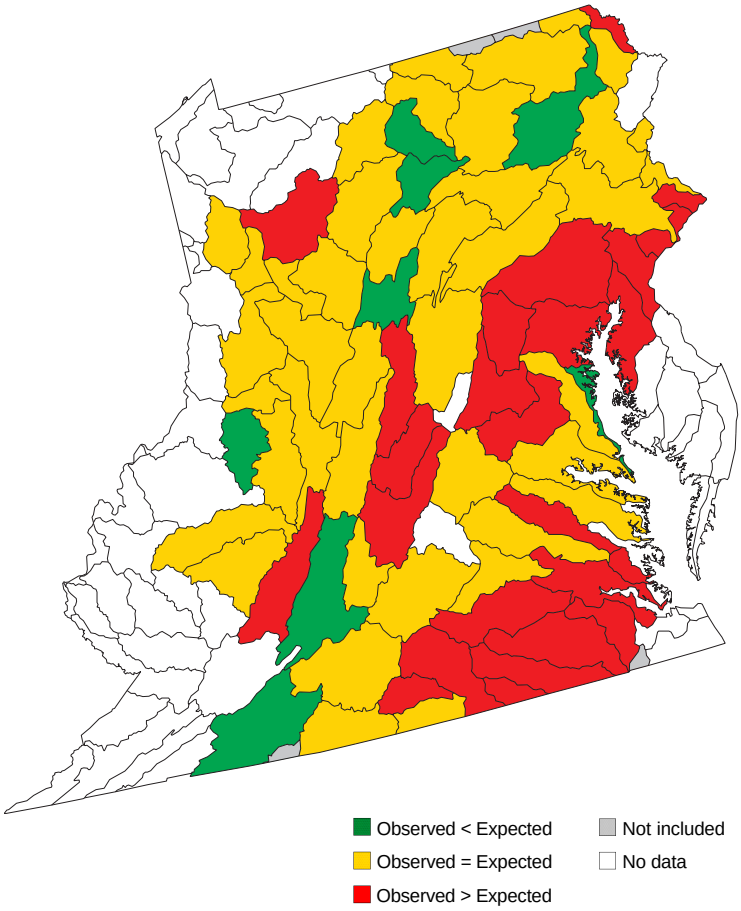


Figure 3.40

Differences in observed and expected decreases in the NDVI from 1975 to 1990 in first–order stream regions in the mid–Atlantic region (see text for explanation).

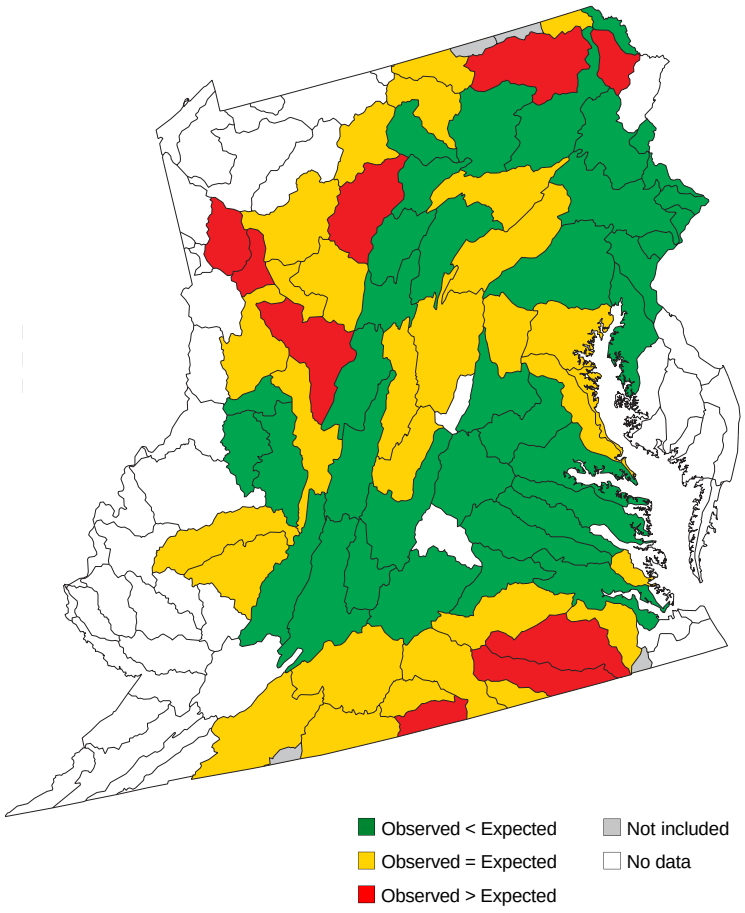


Figure 3.41

Differences in observed and expected increases in the NDVI from 1975 to 1990 in first–order stream regions in the mid–Atlantic region (see text for explanation).

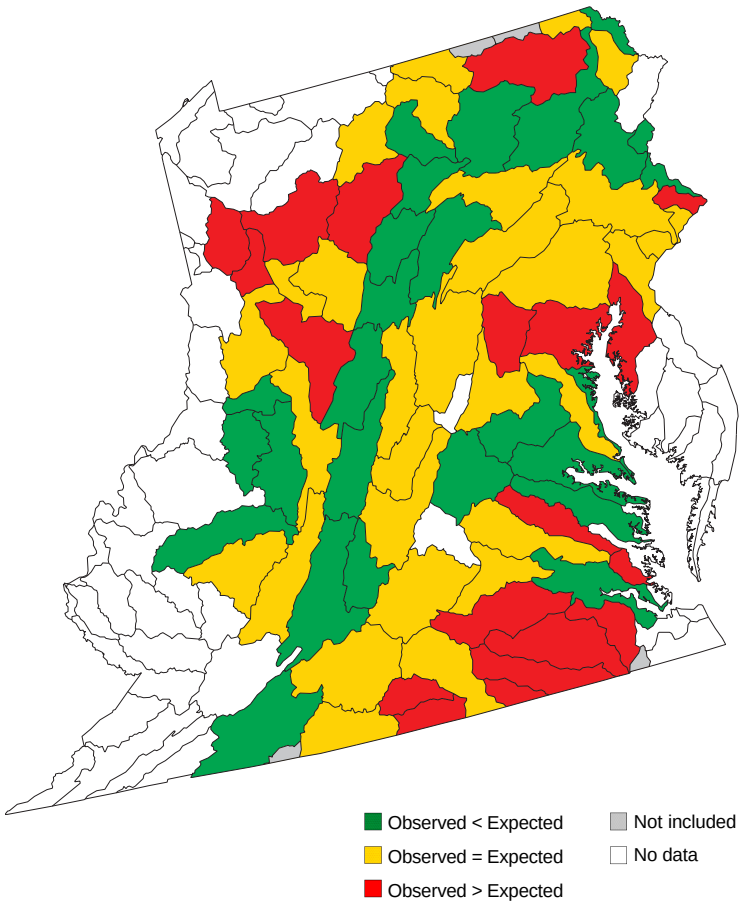


Figure 3.42

Differences in observed and expected total change in the NDVI from 1975 to 1990 in first–order stream regions in the mid–Atlantic region (see text for explanation).

Vegetation Loss on Steep Slopes

When vegetation is removed, the soil surface is exposed to erosion. The steeper the slope, the greater the potential erosion. Figures 3.43 and 3.44 show the pattern of vegetation loss on slopes greater than 3%. Not surprisingly, there is little problem on the Coastal Plain, where land is generally flat, nor is there much in the Piedmont of south–central Virginia. Important areas of vegetation loss on steep slopes include eastern Pennsylvania, extending south to the Chesapeake Bay and west along the Maryland Panhandle into western Pennsylvania, central Virginia in the Ridge and Valley Physiographic Province, and southwestern Virginia in the southern Appalachian Mountains.

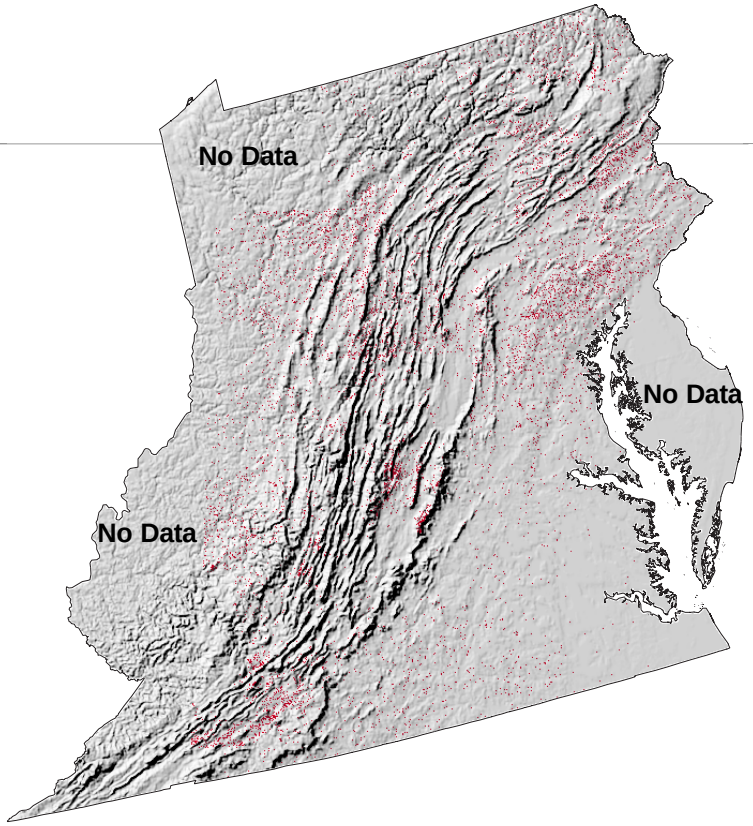


Figure 3.43
Surface map of decreases in the NDVI from 1975 to 1990 on slopes greater than three percent in the mid–Atlantic region (see text for explanation).

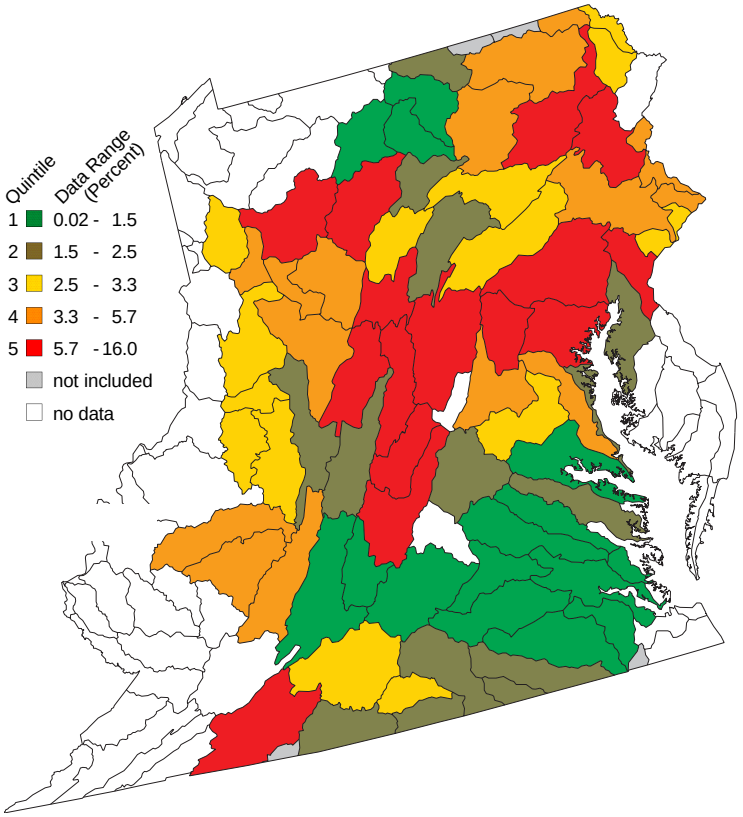


Figure 3.44
Proportion of watershed with decreases in the NDVI from 1975 to 1990 on slopes greater than three percent in the mid–Atlantic region (see text for explanation).

Chapter 4: Comparative Assessment of Mid–Atlantic Watershed Conditions

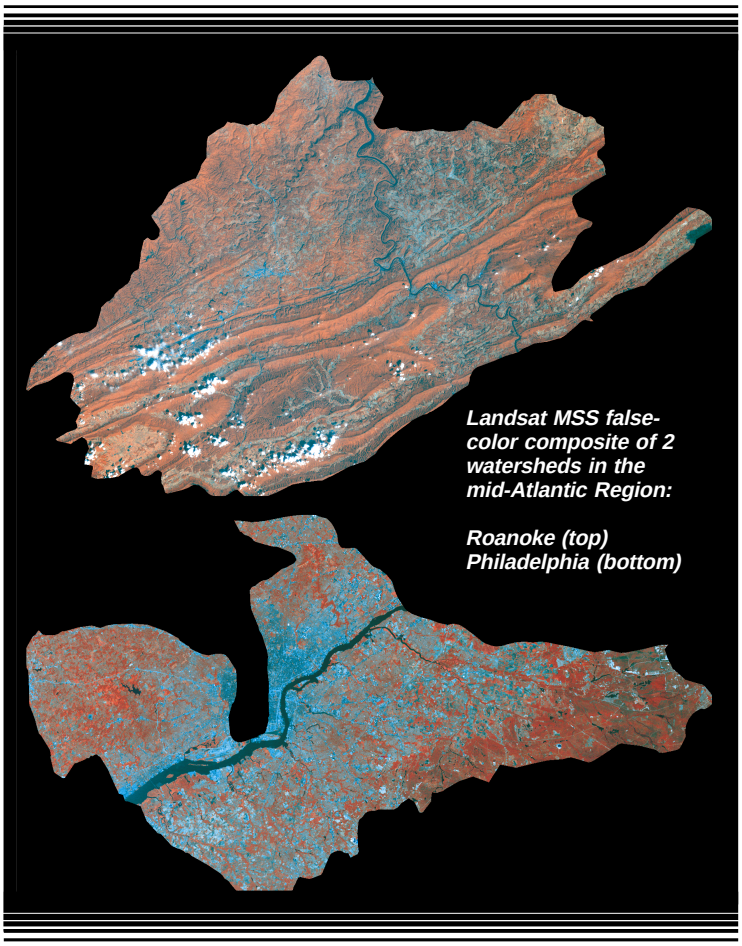
This chapter summarizes the indicators presented in Chapter 3, in order to identify changing environmental conditions across the region. A simple way to do this can be adapted from the magazine, *Consumer Reports*. When rating products, *Consumer Reports* provides relative scores on performance or features to help the consumer decide which brand to purchase. As applied here, each indicator from Chapter 3 could be considered as a guide to relative watershed "performance" for an indicator, and that could help in determining which watershed to "buy."

The watershed ranks for each indicator are presented in a *Consumer Reports* format in Table 4.1 (see discussion on Data Interpretation, inset on next page). It is possible to get an idea of the relative condition of a watershed by reading across a row and counting the number of boxes of a particular color. Watersheds dominated by green and khaki colors are in better relative condition (more desirable) than those dominated by red and orange (less desirable). Table 4.1 can be used by readers to identify conditions of watersheds relative to a particular question or interest. For example, the reader may want to know how their individual watershed rates relative to other watersheds in the region with regard to a set of forest habitat indicators. The table provides a way for readers to explore different combinations of indicators for the watershed they live in, and to compare their area to neighboring watersheds. Because watershed ranks are shown, each column contains an equal number of the different colors (recall that there is an equal number of watersheds in each of the 5 groups).

Of course, an atlas is about maps. Maps show the spatial distributions that cannot be seen in tables. A simple summary of the data in Table 4.1 is shown on the maps in Figure 4.1. The map at the upper left shows the number of indicators for which a given watershed was ranked in the top 20% (most desirable) of all watersheds. The map at the bottom right shows the number of indicators for which a given watershed was ranked in the lowest 20% (least desirable) of all watersheds.

Comparisons of the maps suggests some general conclusions. Relative to all other watersheds in the mid–Atlantic region, the watersheds in southeastern Pennsylvania and the northern end of the Chesapeake Bay have consistently lower values for all of the landscape indicators. Conversely, there are a few watersheds in southwestern and north–central portions of the region that have consistently higher scores across all the indicators.

Although the maps are valuable for their simplicity and ability to show watersheds that have consistently higher or lower scores, a more sophisticated technique is needed to group all of the watersheds into categories of environmental quality. Cluster analysis is a statistical technique that is often used to find groups based on the similarity of data values. One familiar example of the clustering technique is the assignment of new hospital patients to groups of similar risk, based on factors such as age, medical history, and other factors.



Landsat MSS false-color composite of 2 watersheds in the mid-Atlantic Region:

Roanoke (top)
Philadelphia (bottom)

A cluster analysis was done using nine of the 32 indicators from Chapter 3 (see inset below). These nine indicators were selected because they represent a broad range of environmental condition measurements and were not highly correlated with each other overall. The procedure identified nine groups of watersheds (Figure 4.2). The mean indicator scores for each cluster (Table 4.2) can be inspected to see how the groups are different.

Cluster Analysis

Some additional details might be helpful for readers with a statistical background. A minimum-distance-to-mean routine was used for the cluster analysis, and the results were checked using canonical discriminant analysis. Canonical discriminant analysis is useful for finding combinations of variables that explain the variability in the clusters. It is possible to determine if there is good separation between clusters by using bivariate plots of canonical scores. If the clusters identified were not distinct in bivariate canonical space, then it is likely that there is no real difference between the clusters.

Several iterations of the cluster analysis were undertaken using different combinations of variables and transformations. The iteration that produced the most distinct separation of clusters in canonical space was taken as the solution.

Nine indicators were used in the cluster analysis because it is better to use indicators that are not strongly correlated. The nine indicators used were:1) 1990 population density, 2) population change, 3) road density, 4) proportion of streamlength with roads within 30 meters, 5) proportion of watershed with agriculture on slopes greater than three percent, 6) proportion of watershed streamlength with adjacent forest cover, 7) proportion of watershed supporting forest interior habitat at three scales, 8) average atmospheric sulfate wet deposition, and 9) number of water impoundments per 1,000 stream kilometers. Pair-wise correlations were less than ± 0.5 in all but two cases. Population and road density are naturally correlated. Both were kept to emphasize population impacts because many of the landscape indicators used (e.g., forest interior habitat) are naturally low when population pressures are high. Agriculture on steep slopes (> 3%) and streamlength with adjacent forest were moderately inversely correlated. Both were kept because they measure different aspects of the environment. The former is an indicator of erosion potential and the latter is an indicator of water quality and habitat. Because of the strong correlation between population and road density, only roads were included in assigning relative cumulative impact scores (see Table 4.2).

Because cluster analysis is sensitive to large differences in data values, all indicators were transformed using either logit, log (base e), or square root transformations. After transformation, all variables ranged between -10 and 10. The cluster means shown in Table 4.2 have been back-transformed to their original values for presentation.

Plots of the first and second canonical scores showed that clusters 1, 2, 3, 8, and 9 formed distinct groups, and that clusters 5 and 6 were well separated from clusters 4 and 7. Distinct separation of clusters 5 and 6 and clusters 4 and 7 were evident on plots of the 1st and 3rd and 1st and 4th canonical scores, respectively. These results suggest that the clusters are probably different from each other. Examination of individual indicator values by watershed groups (clusters) supports this conclusion.

Note: Some of the watersheds on the regional boundary were not included in the statistical analysis because most of their area is outside the mid-Atlantic Region. These “edge” watersheds often had unrealistic, extreme values for one or more indicators, and extreme values have undesireable consequences on cluster analysis. The watershed encompassing Philadelphia(code 2040202 in Figure 3.6) was also excluded because of its extreme values; most of the watershed, however, does lie within the regional boundary. Based on its indicator values, the Philadelphia watershed probably belongs in cluster 6.

Cluster means were used to rank the groups according to relative cumulative impact. The ranking was done by reading down the columns and marking (red in Table 4.2) the three cluster means with the most extreme values. The three highest values were marked for population density, population change, road density, roads by streams, agriculture on steep slopes, atmospheric sulfate deposition and impoundment density; higher values for these indicators suggest potential negative impact. The three lowest values were marked for forests by streams and proportion of the watershed supporting interior forest habitat at three scales; lower values for these indicators suggest potential negative impact.

After identifying the three values in each column, the number of red values for each cluster was counted in each row. This count is interpreted as a measure of relative cumulative environmental impact for that group of watersheds. The score was then used to rank the watershed groups. Higher scores suggest greater adverse impact than lower scores. These numbers were used to interpret watershed conditions as follows.

Data Interpretation

The following information should help explain how to interpret Table 4.1. Boxes shaded in gray indicate that no data was available for that indicator. This problem was confined to the vegetation change indicators for about 40 watersheds. Also, for most of the indicators in Chapter 3, a relatively high or low value has a clear meaning relative to landscape condition. For example, high values of soil loss suggest greater erosion problems. But the interpretation is less clear for other indicators, such as forest edge, the vegetation increase indicators, and impoundment density. A high proportion of forest edge suggests more clearing of forests, which many people would consider to be a negative impact. Increasing edge habitat, however, can increase the abundance of some wildlife game species, which many people would see as a positive impact.

In addition, many of the indicators shown in Chapter 3 are correlated with each other. If indicators are positively correlated, then they tend to increase or decrease together. If they are negatively correlated, then one tends to decrease as the other increases. In both cases, the value of one indicator can be predicted from the value of the other, and so there is no “new” information to be gained from the second one. For example, where forest density is high, the amount of forest edge is necessarily low, and where atmospheric nitrate wet deposition is high, atmospheric sulfate wet deposition also tends to be high. The reason for presenting correlated indicators in Chapters 3 and 4 is to provide information in different terms. If only a small set of uncorrelated measures were presented, then much of the real–world meaning of landscape patterns would be lost — it would be up to the reader to know which indicators that did not appear were correlated with the ones that were presented. For example, farmers may be more interested in nitrate deposition, instead of its correlate sulfate deposition, because nitrogen is a component of fertilizer. Likewise, deer hunters may be more interested in the location of edge habitat, not in an inversely correlated measure of high forest density. By studying maps of all the indicators for all watersheds, the reader is able to compare and see which are correlated, and choose which ones to consider, based on his or her own perspectives. Finally, the fact that some of the indicators are correlated should be viewed as an opportunity and not a problem; by restoring values for a given indicator it is likely that other indicators will also change.

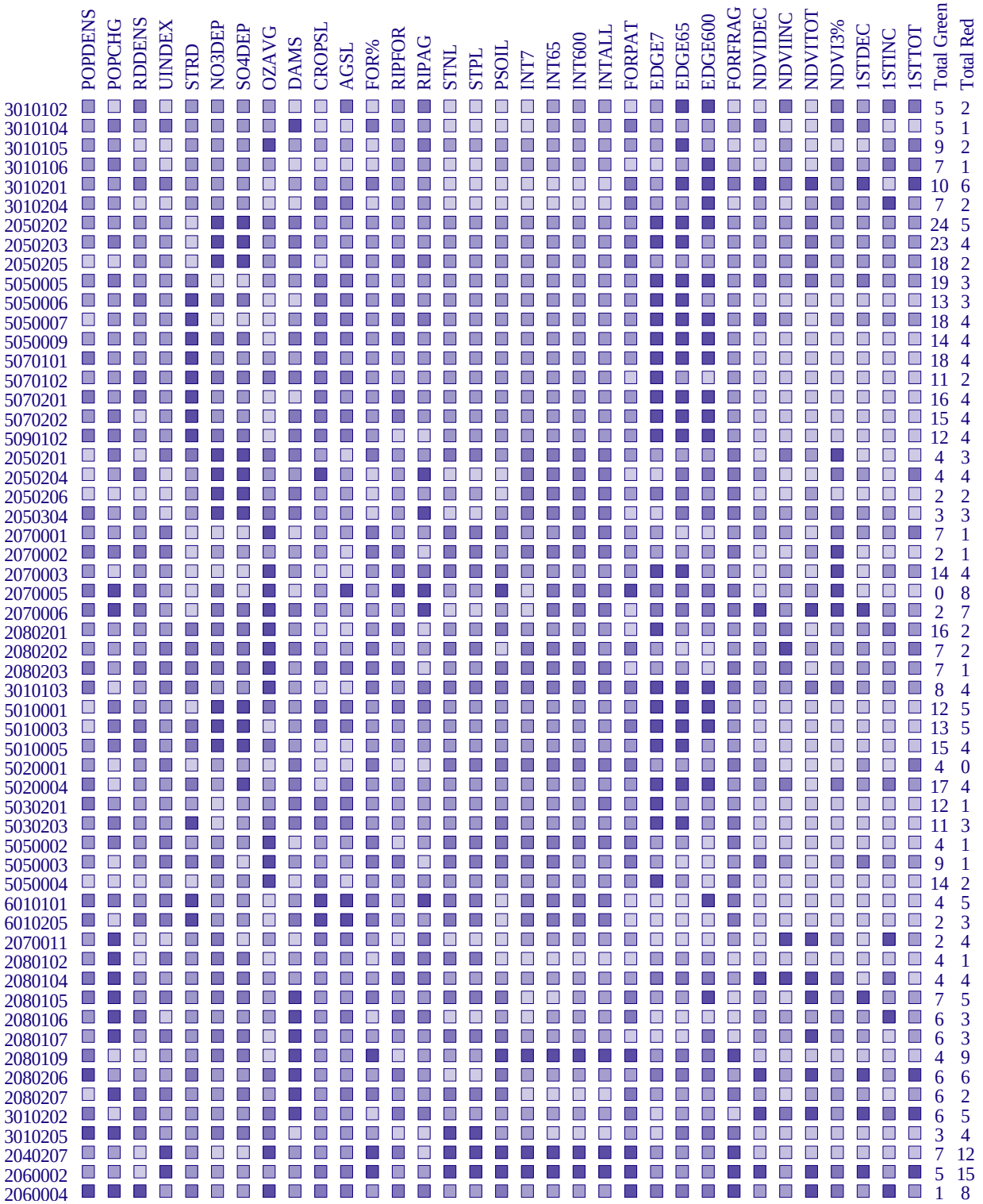


Table 4.1

Summary of watershed rankings by indicator. The color scheme of green, khaki, yellow, orange, and red represents the first– through fifth–ranked groups of watersheds, respectively. This table includes all watersheds used in the cluster analysis.

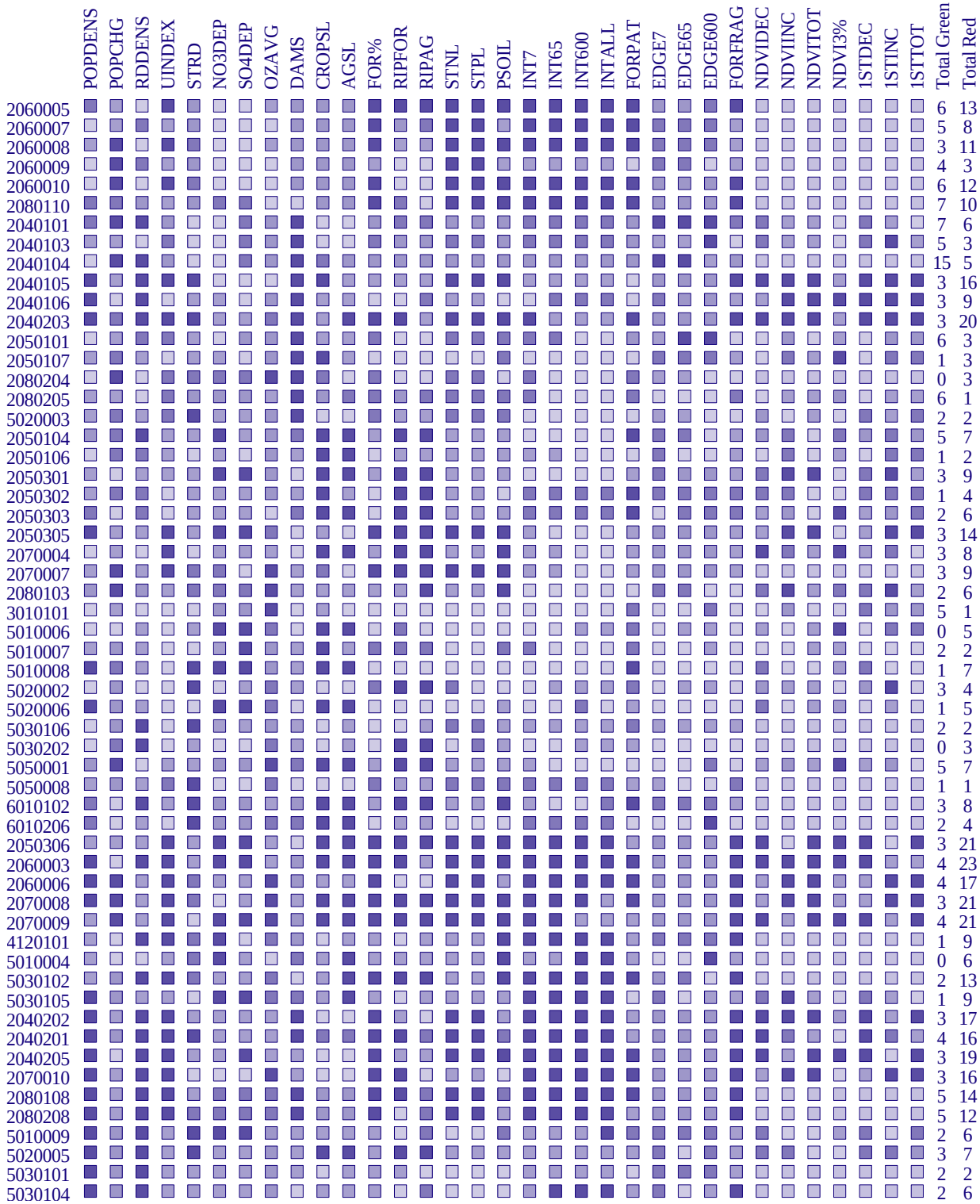


Table 4.1 continued

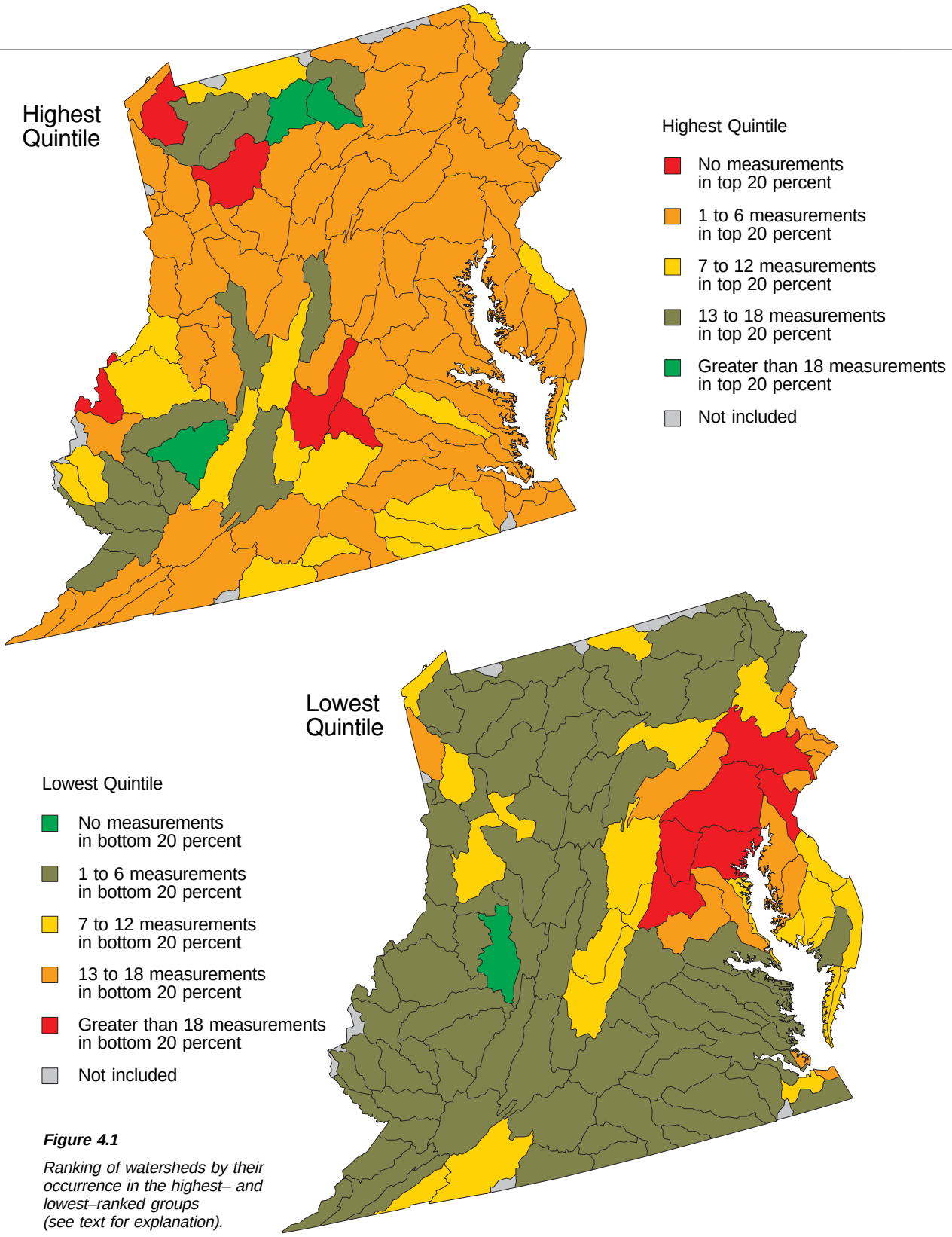


Figure 4.1

Ranking of watersheds by their occurrence in the highest– and lowest–ranked groups (see text for explanation).

Figure 4.2.

Results of the cluster analysis and ranking of watersheds based on indicator values. The ranking is based on the column of relative cumulative impact scores that is shown in Table 4.2.

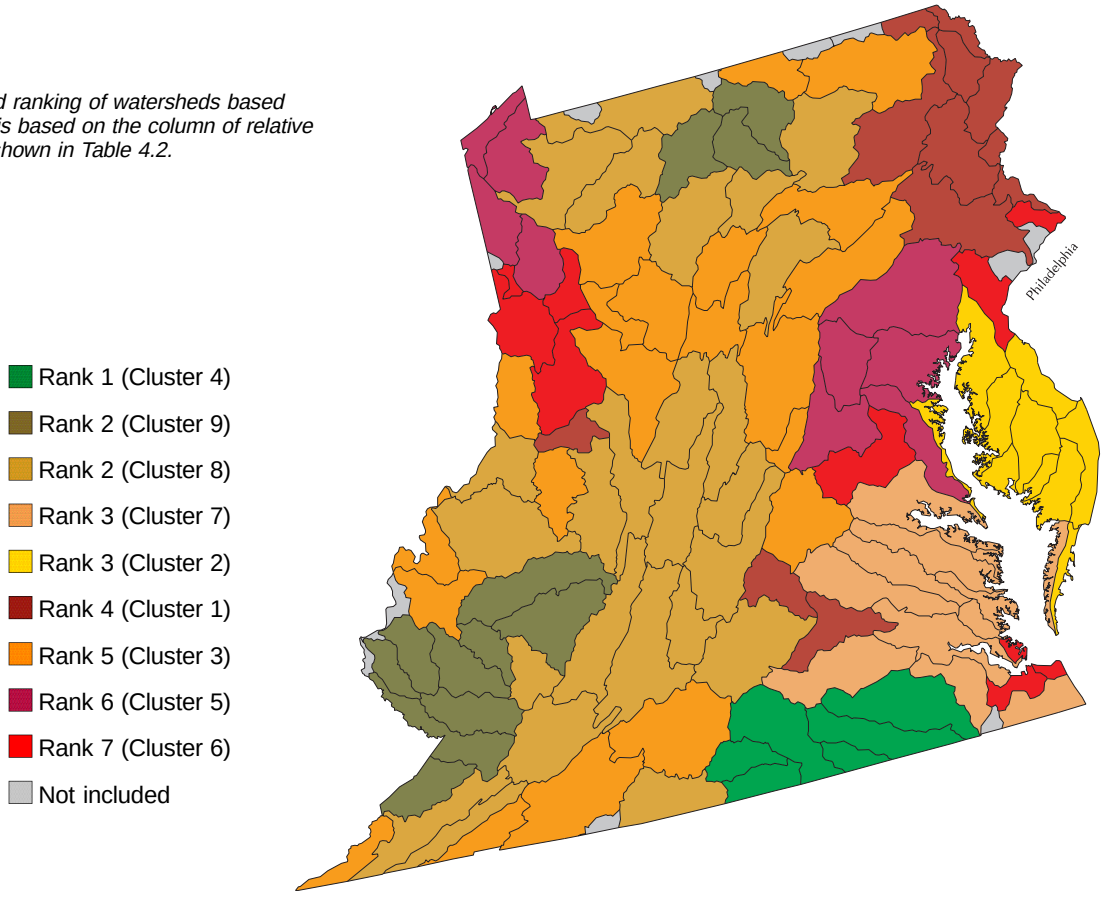


Table 4.2

Cluster mean indicator values and relative cumulative impact score (see text for explanation).

	Mean values by Indicator[1]									
Cluster	A*	B	C	D	E	F	G	H	I	RCI
1	175	21.5	2.46	6.34	8.92	84.48	20.18	2272	41.96	3
2	111	31.6	1.68	2.54	0.33	82.55	0.59	2435	0.18	2
3	88	7.5	1.89	6.94	15.24	72.63	16.33	2468	8.67	4
4	28	-3.5	1.66	1.69	6.03	93.60	5.79	1877	11.99	0
5	325	10.9	2.44	4.78	20.29	70.82	1.29	2825	2.85	5
6	982	-2.6	4.06	7.11	7.19	73.64	0.78	2607	15.67	6
7	78	66.7	1.54	1.88	1.12	88.65	6.6	2056	19.27	2
8	38	10.1	1.32	5.48	9.66	83.85	37.46	2377	4.43	1
9	28	-4.0	1.13	9.93	3.28	89.97	68.97	2290	4.26	1

[1]Indicator Codes:
A.1990 population density; B. Population change (1970 – 1990); C. Road density; D. Proportion of watershed streamlength that had roads within 30 meters; E. Proportion of watershed with cropland and pasture on slopes > 3 percent; F. Proportion of watershed streamlength with adjacent forest; G. Proportion of watershed supporting interior forest habitat at three scales; H. Average annual atmospheric sulfate wet deposition (1987 and 1993); I. Number of impoundments per 1,000 kilometers of stream length

RCI.Relative cumulative impact (the number of red values in a given row)

*Not included in RCI scoring - see discussion of cluster analysis.

Note: The correlations with other indicators in Chapter 3 that are greater than ± 0.55 are as follows.

A. Forest edge habitat in 7 hectare, 65 hectare, and 600 hectare scales, and the forest fragmentation index; B. None; C. None; D. None; E. Crop land cover on slopes > 3 percent, vegetation loss on slopes > 3 percent; F. Percent forest land cover, crop land cover on slopes > 3 percent (inversely), forest edge in 7 and 65 hectare windows (inversely), and the forest fragmentation index; G. U–index, percent forest land cover, soil loss index, total vegetation change (inversely), total vegetation change (inversely), nitrogen and phosphorous export from watershed, vegetation loss and total vegetation change in first–order stream regions (inversely), interior forest habitat at 7, 65, and 600 hectare scale; forest edge habitat at 7 hectare scale (inversely), forest fragmentation index (inversely); H. Average annual nitrate wet deposition; I. None

Cluster 4 (Rank 1)
Watersheds in this group are found along the south–central portion of the region, along the border with North Carolina. None of the indicator means for this group were colored red. The relative cumulative impact score is 0, the highest condition ranking among the nine clusters. Population pressures, road density, and atmospheric sulfate deposition are low. Values for agriculture on steep slopes and impoundment density are moderate. The score for riparian vegetation is the highest among the nine groups. The biggest adverse impact is the low value for the proportion of the watershed supporting interior forest habitat at three scales.

Cluster 9 (Rank 2)
Watersheds in this group are located in the southwestern portion of the region and north–central Pennsylvania. This group has the highest score for roads adjacent to streams, and thus a relative cumulative impact score of 1. Although road density is generally lower in these watersheds, the roads that do occur are often adjacent to streams because the watersheds are on the Appalachian Plateau. In this area, most land is on steep slopes, and so not only is stream density higher but also the roads that do appear tend to follow valleys. The watersheds in this group have the highest amounts of forest and riparian forest cover, and impacts from population, roads, agriculture, and impoundments are relatively low.

Cluster 8 (Rank 2)
Watersheds in this group are located mostly in the Ridge–and–Valley region and in northern Pennsylvania. The principal adverse impact is a relatively high amount of agriculture on steep slopes, which gave this group a relative cumulative impact score of 1.

Cluster 7 (Rank 3)
Watersheds in this group are located in southeastern Virginia on the Coastal Plain. The principal adverse impacts are high scores for impoundment density and population change, which gave this group a relative cumulative impact score of 2. Also, forests in these watersheds tend to be more fragmented than in other watersheds in the region.

Cluster 2 (Rank 3)
Watersheds in this group are largely restricted to the Delmarva Peninsula. The principal adverse impacts are a high score for population change and a low score for proportion of the watersheds supporting forests at three scales, which gave this group a relative cumulative impact score of 2.

Cluster 1 (Rank 4)
Watersheds in this group are located mainly in eastern Pennsylvania, with others scattered throughout the region. The principal adverse impacts for watersheds in this group are high scores for population density and change, road density, and number of impoundments per 1,000 stream kilometers, resulting in a relative cumulative impact score of 3. Interestingly, the score for the proportion of the watershed supporting interior forest habitat at three scales is in the upper third of all groups.

Cluster 3 (Rank 5)
Watersheds in this group are scattered throughout the Ridge–and–Valley and Appalachian Plateau Physiographic Provinces. The principal adverse impacts for watersheds in this group are high scores for roads near streams, agriculture on steep slopes, sulfate deposition, and a low score for riparian forest cover, resulting in a relative cumulative impact score of 4.

Cluster 5 (Rank 6)
Watersheds in this group are found along the northwestern margin of the Chesapeake Bay and in northwestern Pennsylvania. The adverse impacts for these watersheds are high scores for population density, road density, agriculture on steep slopes, and sulfate deposition, and low scores for riparian vegetation, and proportion of the watersheds supporting interior forest habitat at three scales. Watersheds in this group have a relative cumulative impact score of 5.

Cluster 6 (Rank 7)
Watersheds in this group are in the most urbanized areas of the region, including the Pittsburgh, Philadelphia, Washington, and Norfolk metropolitan areas. The principal adverse impacts for watersheds in this group are high scores for population density, road density, amount of roads near streams, sulfate deposition, and impoundment density, and low scores for riparian vegetation and proportion of the watersheds supporting interior forest habitat at three scales. Their relative cumulative impact score of 6 is the highest of all clusters.

In addition to interpreting the indicators presented in Chapter 3, the information in this chapter might serve other purposes, including identifying watersheds that currently are the most impacted, and by which stresses; identifying areas that currently are in desirable condition, but that might be vulnerable to adverse changes because of human–induced stresses; identifying areas that are in desirable condition for some resources or services but not for others; and identifying watersheds where restoration and risk reduction efforts might be most effective.

The discussion of watershed clusters (above) suggests which watersheds are the least– and most–impacted today in terms of the indicators used. The watersheds in clusters 4, 9, and 8 generally have desirable scores for all indicators, with only one or two exceptions. In contrast, the watersheds in clusters 5 and 6 are in the least desirable condition, because human populations are high and the values for habitat indicators are low.

The human population indicators could also be used to identify vulnerable watersheds. The watersheds in cluster 1 now have relatively desirable conditions for water and habitat, but population density is relatively high and is increasing faster than most other watersheds. Environmental conditions related to water and habitat in these watersheds may be more vulnerable than in other watersheds with less population pressure. For example, cluster 8 is similar to cluster 1 in terms of habitat indicators, but population density in cluster 8 is only about one–fifth of cluster 1, and is increasing at about half the rate as in cluster 1.

Some watersheds appear to be in a desirable condition for one environmental resource, but in a less–desirable condition relative to another. For example, the watersheds in cluster 2 are in better relative condition from a water quality perspective, but provide little interior forest habitat. The watersheds in cluster 3 have an opposite pattern, with relatively more interior forest habitat but less–desirable values for water–related indicators such as the amount of crop land cover on steep slopes.

The results of the cluster analysis might be used to guide restoration or preventative “best management practices” (BMPs). BMPs are site–specific approaches to minimizing environmental damage or controlling pollution associated with intensive land uses. Examples include the timely establishment of vegetative cover and storm water detention ponds in areas cleared for residential or commercial development. An example of restoration is the creation of artificial wetlands to replace natural wetlands lost in developed areas. Used together, BMPs and restoration efforts can address a variety of environmental concerns.

In general, most ecological restoration efforts and management practices are site-specific, requiring more detailed information than the landscape indicators can provide. The information in this atlas, however, can be used to guide broad-scale restoration efforts, and to identify areas where more intensive study and restoration may be needed. Consider the watersheds in cluster 4. These watersheds have a fairly high percentage of forest (about 70%) but the amount of forest in large, contiguous blocks (as measured by the proportion of the watershed supporting interior forest habitat at three scales) is low (about 6%). Field studies in the mid–Atlantic region have shown that some bird species require large tracts of continuous forest to survive. If the forest land in those



watersheds were configured in large blocks, more of these area–sensitive species might find suitable habitat there. This type of information can help land managers to focus their efforts where restoration and management are most needed.

These are only a few examples of how relative conditions can be interpreted regarding overall impacts, conditions for different environmental resources, watershed vulnerability, and ecological restoration. Many other interpretations are possible because the indicators used in the analysis can be related to several different aspects of environmental condition. The reader is invited to use the information in this atlas to make his or her own interpretations of landscape conditions in the mid–Atlantic region.





Acknowledgements

Many people contributed to this atlas.

We thank Curt Edmonds, Karl Hermann, Bill Kepner, Clay Lake, Bob Schonbrod, Sumner Crosby, Terry Slonecker, Dan Heggem, Rick Kutz, Tom Pheiffer, Rick Batiuk, Kent Mountford, Nita Sylvester, Kim Devonald, Stu Kerzner, Laura Jackson, Brian Spavin, Ann Pitchford, and Don Garofalo of the EPA, and Carolyn Hunsaker of the Oak Ridge National Laboratory, for their assistance and input during many phases of the project. We are especially grateful to Rick Kutz and Tom Pheiffer for organizing a series of review workshops with scientists and stakeholders who live in the mid–Atlantic region, and Rick Cooksey (U.S. Forest Service), Diane Eckles (U.S. Fish and Wildlife Service), Larry Fogelson (Maryland Office of Planning), Charlie Yuill (Univ. of West Virginia), Jeff Waldon (Fish and Wildlife Exchange), Phil Hager (Worester County Planning Dept.), Carl Hershner (Virginia Institute of Marine Sciences), Cully Hession (Philadelphia Academy of Sciences), Bill Jenkins (Maryland Dept. of Natural Resources), Rick McCorkle (U.S. Fish and Wildlife Service), Sandi Patty (Maryland Dept. of Natural Resources), Larry Pamotto (Delaware Dept. of Natural Resources), Nancy Roth (Versar, Inc.), Bob Shedlock (U.S. Geological Survey), Ann Sloan (Maryland Dept. of Natural Resources), Tom Stockton (Maryland Dept. of Natural Resources), Joe Tassone (Maryland Office of Planning), Paul Tubach (James City County Planning Dept), Lisa Wainger (Institute for Ecological Economics, Univ. of Maryland), Oliver Weatherbee (Center for Remote Sensing, Univ. of Delaware), and John Wolf (Maryland Dept. of Natural Resources), who participated in review workshops and provided comments on various parts of the atlas. We thank Steve Paulsen, Gil Veith, Ed Martinko and others in the Environmental Monitoring and Assessment Program for their gracious support over the years, and Denice Shaw of the EPA whose hard work led to completion of several region–wide databases used to calculate indicators in this atlas. We also acknowledge Jim Vogelmann, June Thormodsgard, John Dywer, and Tom Loveland of the U.S. Geological Survey, EROS Data Center, whose collective vision has made multiple–scale, regional assessments possible, and Doug Norton (EPA) for his efforts in helping EPA to adopt a broader, landscape view of the environment. We thank Tom DeMoss, Greene Jones, and Rick Linthurst of the EPA for providing the institutional leadership for the development of and support for this and other projects in the mid–Atlantic region. We are grateful to Kent Mountford, Rick Cooksey, Ron Landy, Charles P. Nicholson, the TVA Clean Water Initiative, and the BLM Phoenix Training Center (Phoenix, AZ) for photographs used in this atlas. We thank Vern Meentemeyer (Univ. of Georgia), Jim MacMahon (Utah State Univ.), Ron Foresta (Univ. of Tennessee), Kent Price (Univ. of Delaware), and Jianguo Wu (Arizona State Univ. West) for technical reviews of the atlas. We are grateful to the EPA Science Advisory Board, Ecological Processes and Effects Committee, for suggestions about the approaches used in this Atlas. We thank technical editors Donna Sutton (Lockheed Martin) and Barbara B. Smith. Atlas layout and graphic design by Garry Pyle (Tennessee Valley Authority).

The EPA, through its Office of Research and Development (ORD), partially funded and collaborated in the research described here, in cooperation with the Tennessee Valley Authority, and the Oak Ridge National Laboratory. It has been peer reviewed by the EPA and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation by EPA for use.



Glossary

Anthropogenic Cover
Land cover associated with human activities, such as agricultural fields, rock quarries, and urban areas. Literally, “land cover created by humans."

Bar Chart
A graphic representation of the frequency of different data values using rectangles with heights proportional to the frequencies.

Cluster Analysis
A statistical procedure which groups members of a population into similar categories (clusters) on the basis of more than one ecological indicator.

Coarse Scale *see* **Scale**

Comparative Assessment
An analysis of environmental characteristics which proceeds by evaluating members of a population relative to other members (as opposed to an analysis of characteristics relative to a standard or preferred condition).

Conceptual Model
An abstract framework used to organize ideas and information into a form that is more easily examined. These models are often helpful when searching for commonalties between apparently unrelated phenomena, or when defining the scope of inquiry when organizing and interpreting measurements of biological conditions.

Cumulative Environmental Impact
The net result of more than one stress applied to a given unit of the landscape.

Digital Map
An electronic representation of a portion of the earth’s surface that stores both the geographic location of an object and descriptive data about the object.

Ecological Indicator
A characteristic of the environment that is measured to provide evidence of the biological condition of a resource (Hunsaker and Carpenter 1990). Ecological indicators can be measured at different levels including organism, population, community, or ecosystem. The indicators in this volume are measures of ecosystem–level characteristics.

Fine Scale *see* **Scale**

HUC
Hydrologic Unit Code, used by the U.S. Geological Survey to reference hydrologic accounting units throughout the United States. In this atlas, used interchangeably with watershed.

Index Value
The realized measurement of an indicator for a given landscape unit.

Landscape Conditions
The apparent status or characteristics of a landscape unit as measured by one or more landscape indicators.

Landscape Ecology
The study of the distribution patterns of communities and ecosystems, the processes that affect those patterns, and changes in pattern and process over time (Forman and Godron 1986).

Landscape Indicator
A characteristic of the environment that is measured to provide evidence of the biological condition of one or more resources at the ecosystem level. See also “ecological indicator” and “landscape ecology”.

Landscape Unit
Designed to identify repeating patterns associated with dominant land uses in an area, and defined by the relative proportions of forest, agriculture, and developed (urban) land cover contained in that area.

Model
A representation of reality used to simulate a process, understand a situation, predict an outcome, or analyze a problem. A model is structured as a set of rules and procedures, including spatial modeling tools that relate to locations on the earth’s surface.

Net Primary Productivity
A measure of carbon flux over a given landscape unit, roughly, the actual amount of organic matter created by green plants, whether it accumulates in plants, is eaten by animals, or becomes dead material over a fixed time interval (after Waring and Schlesinger 1985).

Pixel
A contraction of the phrase "picture element". The smallest unit of information in an image or raster map. Referred to as a cell in an image or grid.

Quintile
Any of the four values that divide the items of a frequency distribution into five classes with each containing one fifth of the total population. For example, one–fifth of the watersheds in a population have indicator measurements less than the first quintile. In this atlas, a "quintile" also refers to one of the five groups formed by the dividing values.

Riparian Zone
The area of vegetation located on the bank of a natural watercourse, such as a river, where the flows of energy, matter, and species are most closely related to water dynamics. In this volume, the "riparian zone" specifically refers to the linear corridors associated with streams and stream–side vegetation.

Scale
1. The spatial or temporal dimension over which an object or process can be said to exist, as in, for example, "the scale of forest habitat".
2. The spatial, attribute, and temporal parameters associated with making an observation or measurement, usually including resolution, extent, window size, classification system (nomenclature), and lag. Important because measured values often change with the "scale of measurement".
3. The way in which objects, parts of objects, or processes are related as the scale of measurement changes. For example, fractal models are used to describe some types of "scaling behavior".
4. The amount of information or detail about an area. For example, "coarse–scale" maps have less detailed information than "fine–scale" maps. Related terms include "broad–scale" (covering a large area). The cartographic terms "large–scale" and "small–scale" are (contrary to expectation) equivalent to "fine–scale" and "coarse–scale", respectively.

Spatial database
A collection of information that contains data on the phenomenon of interest, such as forest condition or stream pollution, and the location of the phenomenon on the earth's surface.

Spatial Pattern
Generally, the way things are arranged on a map. For example, the pattern of forest patches can be described by their number, size, shape, distance between patches, etc. The spatial pattern exhibited by a map can also be described in terms of its overall texture, complexity, and other indicators.

Sediment Loading
The solid material transported by a stream, expressed as the dry weight of all sediment that passes a given point in a given period of time.

Watershed
A region or area bounded by ridge lines or other physical divides and draining ultimately to a particular watercourse or body of water.

Appendix: Additional Information about the Indicators in Chapter 3

This appendix describes the methods that were used to create the maps and charts of the indicators that are shown in Chapter 3. The information is organized by indicator. The reader may also refer to Chapter 1 for a description of some common computer operations such as overlaying, cookie–cutting, spatial filtering, and watershed ranking.

Table A.1 shows all the indicator values obtained for all watersheds in the mid–Atlantic region. The listed "HUC" number can be used to locate individual watersheds by using Figure 3.3. A few watersheds, indicated by italicized "HUC" numbers in the table, were on the edge of the region. Most of the area of these watersheds lies outside of the region, so the values obtained for these watersheds are probably less reliable than others. The unreliable values were not used in the cluster analysis in Chapter 4.

Population density and change (POPDENS and POPCHG).

The United States Census Bureau compiles population statistics by sampling units that are not watersheds, and so it was necessary to convert these (county–level) statistics to a per–watershed basis. The procedure was based on differences in road density across the region, assuming that the population is distributed in proportion to road occurrence. A map of local road densities in 1 km^2 windows across the region was prepared by using the U.S. Geological Survey Digital Line Graph map of all roads for the entire region. The total of all these window scores was then calculated for each county. The population within a given window was then estimated by dividing the road density for that window by the total road density score for the county that the window was in, and multiplying the result by the total population for the county.

The population for a watershed was then estimated by overlaying the map of watershed boundaries on the derived map of population, and summing the population estimates in that watershed. Population change was derived by repeating the procedure for Census data taken in 1970 and 1990, subtracting the 1970 per–watershed estimates from the 1990 estimates, and, for each watershed, expressing the result as a percentage of the 1970 estimate.

Human use index (UINDEX)

Two different methods were used to create the two maps of the human use index. The surface map for the mid–Atlantic region was produced by using a spatial filter. The window size was about 65 hectares and contained 729 pixels in a 27x27 pixel window. The window was moved one pixel at a time across the land cover map. At each step, the number of pixels that had agriculture or urban land cover were counted. Dividing this sum by the number of pixels in the window (729) yielded the index value which was then mapped at the location corresponding to the center of the window. A second spatial filter was then applied to "smooth" the surface map. The smoothing filter found the median index value in 9x9 pixel windows (about 7 hectares). The final map is shown at 7–hectare resolution.

The watershed map was produced by using a cookie–cutter procedure to extract the land cover information for each watershed separately. The number of pixels with agriculture or urban land cover was then counted in each watershed, and the total was divided by the total number of pixels for a given watershed to yield the per–watershed index value.

Road density (RDDENS)

The United States Geological Survey road maps are very detailed maps which are available as digital line drawings. To create the surface map of relative road density, the line drawings were first converted to raster images (or bitmaps) with a resolution of 90 meters. That is, each 90–meter by 90–meter square in the region that contained at least one road segment was coded as containing a road. Then a spatial filter was applied to this 90–meter resolution map. The window size was approximately 1 km^2 and contained 121 pixels in a 11x11 pixel window. The window was moved one pixel at a time across the land cover map. At each step, the number of pixels that were coded as containing at least one road segment were counted. The road density score was obtained by dividing this sum by the number of pixels in the window (121), and this score was then mapped at the location corresponding to the center of the window. This procedure tends to emphasize the importance of the first occurrence of a road in a given location, and to give less weight to subsequent occurrences.

To create the watershed map of road density, a different procedure was used. The line drawings representing all roads were clipped using the watershed boundaries, so that a per–watershed value could be calculated. The total length of roads in each watershed was divided by the total area of the watershed. The resulting value represents road density as road length (kilometers) per unit area (square kilometers).

Air pollution (NO3DEP, SO4DEP, OZAVG)

The source maps are based on regional–scale models (J. Lynch, Penn State University; A. LeFohn, Asle and Associates) which extrapolate measurements made at a set of sampling stations across the eastern United States. Nitrate and sulfate wet deposition estimates (in kg/ha) are from 1987 and 1993. The ozone models predict the W126 indicator which is a measure of cumulative annual exposure above a critical threshold value. Values for 1988 and 1989 were used. All of these source maps were resampled to 90–meter resolution for our analyses.

Landscape units

The land cover map was analyzed using the spatial filtering technique. The window size was about 590 hectares and contained 6,561 pixels. The window was moved one pixel at a time across the land cover map. At each step, counts were made of the number of pixels that were forest, agriculture, and urban in the window. Then, a landscape unit type was assigned to the location at the center of the window by using rules which are described in the text. To simplify the resulting map, a majority–rule spatial filter was applied and the resolution was reduced to about 7 hectares. The majority–rule filter examined all landscape pattern types within 7–hectare windows and assigned the most common type to the whole window.

Forest and agriculture land cover along streams (RIPFOR, RIPAG)

Maps of forest and agriculture land cover along streams were created by using the overlay technique. The map of streams was converted to a raster format with 30–meter pixels. This version of the streams was overlaid on the land cover map to determine the stream length that flowed through forest and agriculture land cover. The length of streams flowing through forest and agriculture land cover, respectively, was divided by the total length of streams in each watershed to arrive at the index value. A 30 meter pixel size was used because it was consistent with the pixel size of the land cover map. The proportions would change with different stream pixel sizes, depending on the amount of forest and agriculture land cover in the riparian zone defined by the pixel size.

Roads along streams (STRD)

The procedure was similar to that used for the preceding indicators. Road and stream maps were converted to a raster format with 30 meter pixels, and then overlaid. The number of pixels where both a road and a stream occurred was divided by the total number of stream pixels in the watershed.

Impoundment density (DAMS)

The U.S. Geological Survey defines large dams as those that are able to store at least 5,000 acre–feet of water. The source data were converted into a map of point locations, and overlaid on the watershed map. The number of dams in each watershed was then divided by the total stream length for the watershed to estimate the density of impoundments. The density estimate is expressed as the number of dams per 1,000 kilometers of streams.

Crop land and agriculture land on steep slopes (CROPSL, AGSL)

Agriculture on steep slopes was mapped by overlaying the slope map and the land cover map. Percent slope is calculated from the U.S. Geological Survey digital elevation model (DEM) as the vertical rise in elevation per horizontal distance traveled. After overlaying the two maps, the proportion of watershed area that was crop, or agriculture, on slopes greater than three percent was found by using the cookie–cutting technique.

The three percent threshold value was taken from U. S. Department of Agriculture studies that classified slopes into six categories. Based on this classification, slopes greater than or equal to three percent have a greater risk of soil erosion.

Potential nitrogen and phosphorus loadings to streams (STNL, STPL)

A literature survey of North American nutrient export studies (Young and others, 1996, in the *Journal of Environmental Management*) provided coefficients for estimated export (kg/ha/yr) for nitrogen and phosphorus under different types of land uses. To estimate total nutrient export potential on a per–watershed basis, the reported median coefficients for comparable agricultural uses were multiplied by the amount of land cover in the agriculture land cover classes. The coefficient–times–land use model was developed in 1980 for the United States Environmental Protection Agency by Rechow and others (US EPA 440/5–80–011, Washington, DC). The coefficients reported for nitrogen varied from 2.6 to 6.2 kg/ha/yr, with a median value of 3.9 kg/ha/yr. The values reported for phosphorous ranged from 0.3 to 1.5 kg/ha/yr, with a median value of 0.7 kg/ha/yr.

Soil loss potential (PSOIL)

The Universal Soil Loss Equation (USLE) estimates soil erosion from agricultural lands as a function of rainfall, soil type, slope, and land cover characteristics. The basic equation is:

A = R * K * LS * C * P, where A is long–term average annual soil loss (tons/acre/year), R is the long–term erosive potential of rainfall, K is the soil erodibility factor, LS is the length–slope factor, C is cover and management factor, and P is the support management factor (e.g., strip cropping, buffer–strip cropping). Representative values for the mid–Atlantic region would be R=200, K=0.37, LS=0.93, C=0.12, and P=0.5. An R value of 200 (tons/acre/year) is typical of the eastern seaboard in the northern part of the region (e.g., Philadelphia). A K value of 0.37 is representative of a loamy soil (e.g., Hagerstown silty clay loam at the USDA research station in State College, PA). A LS factor of 0.93 would be found on a 6% slope that extended for 200 feet. A C value of 0.12 is representative of corn with a ground cover of residue (e.g., dead) vegetation, and a P value of 0.5 is representative of farming practice of tilling and planting along contours. Under these conditions the estimated soil loss is 4.1 tons/acre/year. In contrast, if a bare soil surface was exposed to typical rainfall patterns, that surface would lose 200 tons/acre/year of soil, or about 50 times as much as the representative example. The difference is due to soil type (percent sand, silt, clay), slope, the type of cover, and the type of management.

We created a map for each parameter in the model (rainfall erosive potential, soil erodibility, length–slope, cover and support management), and simply multiplied the values in each map on a pixel–by–pixel basis. R factor values were taken from USDA Agricultural Handbook 537, soil erodiblity was taken from USDA, Soil Conservation Service digital soil maps, and length–slope values were taken from USGS DEM data. The C factor was the median value for corn under all reported crop residue conditions. The C factors for corn were used because it is the most common crop in the region, and the land cover data available did not distinguish between different agricultural crops. The support management factor was set to that for contour tillage and planting because most farmers plant crops along contours, not perpendicular to them, and more detailed information was not available.

The area of each watershed with the potential for soil losses greater than 1 ton per acre per year was then found by summing the number of pixels in each watershed that exceeded this threshold value. The indicator is the proportion of the watershed above that threshold value.

Forest land cover (FOR%)

The cookie–cutter procedure to extract the land cover information was applied to each watershed separately. The number of pixels with forest land cover was then counted in each watershed, and the total was divided by the total number of pixels for a given watershed to yield the per–watershed index value.

Forest fragmentation (FORFRAG)

Forest fragmentation was assessed here at a resolution of about one–tenth hectare by using a version of the land cover map which had only two lumped categories, forest and non–forest. The fragmentation statistic measures the probability that a randomly selected forested spot in a watershed is not adjacent to another forested spot.

Higher values indicate higher fragmentation. The statistic was calculated separately for the forest cover within each watershed in the mid–Atlantic region, rather than using a sliding window technique.

Forest edge habitat (EDGE7, EDGE65, EDGE600)

Forest edge habitat differences among watersheds were assessed by the sliding window technique. The fragmentation indicator described above was used, but calculated in a small window that was placed within a watershed. If the calculated indicator value exceeded one–half the maximum value for that amount of forest, then the center of the window was marked as suitable edge habitat. After moving the calculation window throughout the watershed, the proportion of the watershed that was labeled suitable was calculated and used as the indicator value. The exact window sizes used were 7.29ha, 65.61ha, and 590.49ha.

Forest interior habitat (INT7, INT65, INT600, INTALL)

The sliding window technique was used to assess interior forest habitat. The proportion of forest cover was calculated within a window that was placed within a watershed. If the proportion of forest exceeded a threshold value of 90%, then that place in the watershed was considered to be suitable interior habitat. After placing the calculation window everywhere in a watershed, the proportion of the watershed that was suitable habitat was determined. These proportions were then used to rank the watersheds.

The proportion of watershed area supporting three scales of interior forest habitat was calculated as the proportion of pixels in a watershed that exceeded the threshold value for all three window sizes (7.29ha, 65.61ha, and 590.49ha).

Departure of the largest forest patch size from the maximum possible for a given amount of anthropogenic cover (FORDIF)

Each forest patch was determined with a routine that finds all adjacent pixels of the same cover type and then assigns them a unique value, and also retains the original land cover value. There are as many unique values as there are patches in the watershed. From these data, we created a file of forest patches and sorted it to find the largest forest patch. A proportion was calculated using the watershed area as the denominator. The proportion was then subtracted from 1.0 minus the U-index to derive the indicator value.

Calculation of NDVI and its change (NDVIDEC, NDVIINC, NDVITOT)

NDVI is calculated from satellite spectral reflectance data in the red and infrared wavelengths, using the equation: NDVI = (infrared – red) / (infrared + red). The reason that NDVI in particular, and all vegetation indices in general, are able to distinguish plants from all other surface features is that vegetation reflectance jumps dramatically in the infrared region of light, and is strongly absorbing (not reflective) in the red region. For vegetation, typical infrared and red values might be 0.8 and 0.1 respectively, giving an NDVI value of 0.78. For other earth surface features, the infrared and red reflectance values are more similar. Because of this, the numerator tends to be close to zero (or even slightly negative) while the denominator tends to double. NDVI values for nonvegetative surfaces are typically close to or less than zero. Once the NDVI maps are made for each date, differences are calculated simply by subtraction. The resulting differences range negative to positive, centered on zero (0). Values close to zero indicate that there has not been a change in land cover. Calculating the difference of temporal satellite images usually yields an approximately normal distribution. For a normal distribution, about 70% of the values are within one standard deviation of the mean, which is zero in this case. Previous research has shown that one standard deviation is an accurate threshold to distinguish change from no change. We chose one standard deviation as our change/no change threshold.

NDVI change within watersheds (1STDEC, 1STINC, 1STTOT)

Observed values for the three aspects of vegetation change come simply from the change that occurred in the first order stream region. Expected values come from the product of the change over the whole watershed multiplied by the proportion of the watershed in the first order stream region. It was necessary to choose a threshold to decide if a calculated difference between observed and expected was significant. We chose $\pm$0.25% of the watershed area as the threshold. This threshold is arbitrary but splits the observed versus expected map for total vegetation change into approximately equal thirds.

NDVI loss on steep slopes (NDVI3%)

Vegetation loss on slopes greater than 3% was created using the overlay technique. The NDVI change data was overlaid upon the USGS DEM data which were reclassified into percent slope. Proportional values were calculated by dividing the amount NDVI loss, gain, or total change by total watershed area.

HUC	POPDENS	POPCHG	UINDEX	RDDENS	NO3DEP	SO4DEP	OZAVG	RIPFOR	RIPCROP	STRD	DAMS	CROPSL	AGSL	STNO3L	STPL	PSOIL	FOR %	FORFRAG	EDGE7	EDGE65
2040101	51.72	54	13.08	2.74	1634	2050	34.27	86.16	10.04	6.51	32.33	5.99	8.12	320	46.9	9.51	84.46	10.16	6.28	0.47
2040103	114.53	35	15.25	1.7	1570	2087	35.45	91.94	7.2	6.05	85.41	5.59	7.72	330	50.5	10.19	79.97	12.43	7.87	1.18
2040104	76.16	81	6.54	3.61	1536	2150	37.81	92.54	2.82	5.69	86.57	1.75	2.08	280	35.2	3.05	90.6	6.16	3.1	0.95
2040105	625.06	25	44.03	7.71	1629	2443	43.79	77.06	20.95	9.68	37.64	13.68	15.04	490	106.4	37.38	54.73	25.16	34.07	22.04
2040106	488.13	13	32.46	2.73	1677	2435	38.24	83.24	12.89	7.18	42.02	7.5	11.02	400	73.8	23.57	65.79	13.98	24.85	19.77
2040201	1291.56	20	64.36	6.92	1696	2634	47.08	71.17	17.36	6.87	47.12	5.48	6.98	520	113.8	31.08	34.13	42.39	58.94	45.78
2040202	3533.76	-5	67.84	16.01	1792	2817	47.72	66.29	10.27	10.65	49.04	2.11	3.18	480	98.3	11.27	31.12	39.12	59.78	52.57
2040203	816.35	-1	50.95	3.32	1850	2799	41.66	69.06	26.48	10.15	45.89	9.46	15.15	470	97	38.38	48.01	25.88	43.65	36.17
2040205	596.15	15	59.22	3.17	1882	2913	47.64	73.35	19.83	6.68	12.17	5.4	10.33	510	108.2	41.71	36.84	34.47	52.29	38.13
2040207	171.27	29	58.17	1.74	1588	2483	49.11	86.21	14.98	2.71	0	0.06	0.09	620	146.4	51.06	25.99	25.66	42.66	28.65
2050101	63.98	21	17.16	1.38	1594	1961	32.75	84.58	16.31	6.57	31.32	8.97	12.28	330	53.1	13.19	81.19	11.75	9.44	1.05
2050103	115.7	8	27.66	10.13	1872	2459	37.16	75.89	26.38	5.67	12.26	13.84	18.56	390	71.6	22.14	71.66	15.97	16.82	4.18
2050104	28	2	35.77	2.62	1984	2815	37.23	56.73	43.69	6.6	5.45	17.14	24.68	430	82.6	30.16	63.67	15.65	25.74	11.46
2050105	153.98	4	43.38	10.22	1941	2653	38.48	59.03	41.11	5.63	13.61	20.31	26.65	470	98	34.35	56.05	21.48	31.62	13.88
2050106	74.74	1	32.6	1.45	1852	2518	34.91	74.34	27.08	5.48	12.85	15.62	21.61	410	79.2	26.59	66.05	17.71	21.96	7.61
2050107	178.88	0	30.97	2.19	1814	2563	33.56	79.01	16.28	8.32	24.46	10.27	13.74	390	71.2	19.73	67.35	14.66	22.3	13.49
2050201	87.48	0	17.81	1.67	1993	2882	39.92	93.47	4.41	3.91	4.87	6.29	7.3	320	49.7	9.95	81.76	8.1	6.84	1.47
2050202	20.45	-5	3.21	0.89	2098	3020	40.02	96.29	3.15	5.67	2.76	1.12	1.52	260	29.3	1.7	96.56	1.97	0.72	0.01
2050203	26.74	1	5.19	0.98	2176	3182	37.7	94.8	4.56	5.57	2.81	1.43	1.95	270	31.9	2.23	94.01	2.87	2.35	0.87
2050204	85.36	19	29.48	1.47	2052	2934	37.93	71.5	27.31	7.81	2.44	10.8	13.9	390	72.6	23.44	69.98	8.47	17.21	14.79
2050205	61.71	4	10.95	0.99	2157	3172	36.67	87.96	11.78	5.85	3.23	4.4	6.47	300	41.8	8.12	88.67	4.7	6.39	2.19
2050206	58.67	10	30.12	1.54	2008	2886	33.18	74.58	25.1	7.86	4.11	9.32	12.89	400	74.3	21.48	69.09	9.93	20.15	16.54
2050301	145.45	6	40.54	1.77	2031	2967	36.01	67.61	32.46	7.8	9.27	12.46	18.58	440	88.3	31.74	57.87	14.07	29.45	22.74
2050302	109.05	0	29.89	1.51	1918	2780	39.37	67.52	30.92	8.22	11.8	11.69	14.67	400	74.8	23.82	69.75	7.76	18.12	14.03
2050303	50.56	6	31.5	1.38	1745	2629	42.22	70.48	30.57	7.46	3.89	12.63	16.13	410	78.5	24.46	67.12	9.18	18.08	11.87
2050304	44.5	26	28.59	1.29	1966	2872	40.43	73.57	27.98	6.56	3.42	9.32	14.04	390	69.6	24.51	70.66	8.78	16.77	10.55
2050305	279.69	21	50.46	2.25	2041	3015	41.13	66.13	33.4	7.64	8.9	6.28	10.52	480	98.2	43.67	48.37	16.34	40.67	39.6
2050306	254.35	30	69.31	2.57	2081	3148	44.35	56.85	43.68	8.22	6.43	17.72	28.41	570	128.7	63.69	29.62	30.06	57.23	50.92
2060002	207.94	30	63.37	1.69	1822	2802	48.47	76.79	26.51	2.77	0	2.23	3.77	570	130.5	58.24	33.54	27.45	44.42	30.78
2060003	707.08	12	61.31	3.77	2071	3168	47.99	64.96	26.05	7.14	0	15.01	22.29	520	111.7	39.53	36.87	30.39	51.32	39.38
2060004	695.28	50	38.56	3.51	1688	2576	49.17	86.82	8.58	4.22	0	3.87	5	420	79.6	18.75	58.92	21.42	25.55	13.34
2060005	55.52	32	60.24	1.7	1645	2530	46.69	69.4	32.14	2.8	0	0.11	0.2	570	128.4	56.14	35.96	25.28	38.09	20.33
2060006	861.58	38	49.37	2.34	1744	2691	48.81	82.02	15.46	2.92	0	8.95	12.11	490	103.7	34.06	46.49	24.5	36.55	22.86
2060007	83.15	37	32.94	1.37	1510	2324	43.52	92.07	8.78	1.18	0	0	0	520	114.8	26.94	41.64	16.69	25.84	15.16
2060008	100.37	45	52.36	1.67	1574	2441	44.64	75.81	25.9	2.99	0	0	0	560	125.6	48.67	42.39	16.95	24.15	10.86
2060009	63.4	47	37.45	1.43	1478	2303	43.62	81.64	17.75	2.32	0	0	0	490	103.5	34.02	54.06	14.19	19.78	7.91
2060010	86.09	39	47.39	1.61	1485	2330	44.27	80.79	17.68	2.82	1.31	0.02	0.02	540	121.1	38.77	28.21	22.47	34.68	22.24
2070001	13.12	30	18.22	0.85	1516	2428	49.23	76.71	23.9	4.72	9.01	9.11	11.28	340	55.8	14.91	81.25	6.6	8.07	3.16
2070002	43.24	1	16.76	1.36	1678	2584	46.14	84.93	14.1	5.82	12.26	6.68	8.21	330	50.2	10	82.43	7.49	6.32	1.46
2070003	24.53	9	14.66	1.08	1457	2335	49.07	88.96	12.34	4.67	1.97	6.26	8.23	320	48.6	11.15	84.79	6.09	5.51	0.83
2070004	69.04	37	49.48	1.69	1695	2605	48.08	66.79	35.58	5.23	7.93	9.48	15.61	470	96.4	43.14	49.89	15.67	33.73	30.95
2070005	40.46	38	42.42	1.47	1370	2285	53.01	68.33	35.69	5.61	9.03	7.59	15.08	420	79.3	39.09	57.05	10.64	25.39	18.77
2070006	42.73	53	35.74	1.38	1285	2143	53.68	75.73	30.07	5.59	4.62	7.74	14.34	400	73.5	33.46	63.84	9.38	20.35	14.56
2070007	181.1	73	55.28	1.89	1435	2309	52.87	70.63	31.96	4.51	14.99	3.98	8.64	480	97.5	53.26	43.78	17.93	39.32	32.05
2070008	617.11	49	57.69	1.92	1669	2618	50.79	65.57	35.15	3.84	13.31	11.61	23.5	490	102.1	49.93	41.28	25.65	43.43	28.62
2070009	249.76	55	66.48	1.93	2008	3058	48.83	53.31	50.22	5.71	0.72	15.15	27.37	540	117.2	64.87	32.85	28.48	59.28	53.77
2070010	1154.66	33	54.32	4.1	1608	2532	49.8	70.6	18.18	5.36	12.51	4.54	7.06	460	91.9	21.85	43.33	27.71	43.23	30.81
2070011	173.57	56	30.89	1.67	1430	2243	48.06	83.8	10.45	2.17	7.73	2.54	3.52	390	72	21.83	62.27	14.64	16.4	5.77
2080102	29.93	72	24.05	1.52	1325	2096	43.94	86	7.94	1.45	12.65	0.24	0.56	360	60.6	20.03	72.19	11.55	10.64	2.55
2080103	31.34	145	38.3	1.25	1228	2073	53.85	70.84	33.4	3.13	13.28	6.39	11.93	420	77.9	35.35	61.3	13.15	21.77	10.15
2080104	49.19	191	33.59	1.29	1306	2079	46.69	88.78	9.6	1.43	14.65	1.5	2.36	400	73.5	25.78	57.52	14.43	18.34	9.72
2080105	36.78	197	23.84	1.26	1214	1998	46.64	93.56	6.68	1.52	23.85	1.34	2.04	360	61.8	19.81	73.03	11.79	9.32	1.43
2080106	32.7	84	28.66	1.31	1159	1958	46.27	89.72	11.43	1.64	20.18	1.47	2.96	370	64.5	24.02	67.88	12.36	12.86	3.78
2080107	165.66	87	23.62	1.79	1295	2072	42.61	93.48	4.58	2.18	29.41	0.28	0.58	360	61	14.89	55.86	12.76	13.48	7.17
2080108	1898.02	35	60.93	5.7	1343	2157	40.65	65.85	9.19	7.63	17.85	0.04	0.06	480	97.7	11.01	29.32	32.08	56.68	50.23
2080109	49.77	5	43.41	1.65	1372	2154	43.78	79.12	20.02	1.44	55.57	0.11	0.18	470	96	42.02	40.34	23.79	31.15	14.27

HUC	POPDENS	POPCHG	UINDEX	RDDENS	NO3DEP	SO4DEP	OZAVG	RIPFOR	RIPCROP	STRD	DAMS	CROPSL	AGSL	STNO3L	STPL	PSOIL	FOR %	FORFRAG	EDGE7	EDGE65
2080110	39.7	1	33.78	1.18	1379	2184	43.88	84.96	15.83	2.16	6.9	0.02	0.05	500	104.5	40.75	23.42	26.56	39.3	22.74
2080201	12.45	30	12.69	0.89	1304	2139	51.11	85.95	15.34	3.72	2.54	5	6.85	310	44.8	11.06	86.63	4.48	5.37	1.3
2080202	34.04	21	24.14	1.1	1308	2159	49.47	72.23	23.82	4.37	3.82	7.59	13.9	350	57.8	22.79	75.43	6.46	10.62	4.34
2080203	37.12	35	18.69	1.33	1225	2086	51.15	87.63	13.65	3.44	12.88	2.99	5.78	320	47.6	14.98	80.38	8.07	7.16	1.55
2080204	75.53	50	24.97	1.59	1233	2107	51.54	83.87	18.87	3.29	30.34	3.69	7.58	350	56.4	21.21	74.21	11.01	10.5	2.71
2080205	258.15	32	24.65	1.75	1115	1931	46.93	91.64	8.44	2.18	36.32	1.42	2.74	350	55.9	17.93	73.47	10.6	10.64	4.12
2080206	274.03	33	34.64	2.55	1193	1961	41.79	86.14	7.8	3.18	16.93	0.29	0.5	390	71.4	18.6	59.6	15.21	19.21	10.38
2080207	66.38	74	24.28	1.45	1150	1979	46.31	92.62	7.15	1.59	24.81	1.4	2.81	340	55.1	19.17	74.39	10.75	8.4	1.55
2080208	1205.09	35	60.58	4.26	1286	2082	40.04	79.56	11.52	3.92	20.78	0.16	0.3	520	113.9	25.65	30.4	24.63	45.85	40.22
3010101	64.49	24	28.62	1.74	1102	1869	50.25	83.05	18.64	4.58	6.37	6.42	11.01	370	64	22.97	69.88	12.31	13.03	5.28
3010102	26.38	5	27.29	1.34	1118	1928	48.4	93.36	8.91	1.17	9.46	4.23	6.62	370	65	23.94	69.36	12.47	8.21	1.12
3010103	49.27	9	17.44	1.83	1006	1726	48.82	90.32	10.22	4.17	10.9	5.68	7.77	330	51.7	13.78	81.68	10.08	4.36	0.61
3010104	91.15	1	24.61	2.06	1045	1794	48.81	93.1	7.41	1.89	19.2	5.91	7.19	370	65.1	21.12	74.11	13.88	7.25	1.42
3010105	31.27	-6	29.41	1.63	1041	1790	49.3	93.1	8.68	1.73	13.73	8.65	11.26	400	73.7	27.66	69.94	13.68	7.54	0.73
3010106	31.39	0	29.16	1.91	1129	1948	44.66	93.45	7.37	1.56	10.12	5.07	7.65	380	68.8	25.2	67.14	13.89	11.47	1.94
3010201	11.28	-10	25.76	1.45	1122	1903	42.9	94.5	6.18	2.16	13.62	0.99	1.6	370	66.1	21.41	73.32	10.96	8.51	0.92
3010202	44.47	18	34.79	1.4	1158	1916	41.25	90.12	10.73	2.11	17.7	0.28	0.36	430	84.6	31.45	64.39	12.71	12.3	1.49
3010203	78.41	432	41.23	2.26	1137	1896	40.39	87.53	14.57	2.48	17.47	0.28	0.32	480	103.7	36.48	56.79	14.51	15.25	1.41
3010204	17.99	-5	28.13	1.68	1119	1909	43.47	93.95	7.6	1.78	7.52	2.9	4.38	390	70	23.39	71.02	11.67	9.9	1.42
3010205	318.68	120	37.26	1.36	1326	2185	39.91	84.22	15.45	2.75	6.56	0.04	0.04	600	142.1	28.55	51.28	9.73	16.19	9.22
3040101	111.23	12	13.62	3.5	928	1632	48.06	89.42	10.54	4.87	0	1.81	9.3	290	37.5	11.35	86.05	10.59	1.09	0
4120101	242.11	4	47.21	3.74	2122	2529	41.69	80.73	20.72	4.5	1.67	6.06	13.12	450	87.9	36.89	52.32	21.29	26.03	11.11
4130002	27.22	1	24.75	13.05	2033	2810	38.96	77.97	24.3	5.07	0	10.61	17.37	370	62.4	19.53	75.16	13.72	10.39	1.44
5010001	73.13	0	11.65	2.16	2167	3009	40.98	87.59	12.48	4.54	1.58	3.61	6.05	300	41.2	8.56	87.42	5.17	4.51	0.61
5010002	102.53	-5	26.03	9.74	2125	2781	41.41	85.32	16.48	5.29	0	7.54	16.12	360	58.4	22.93	73.75	10.09	11.11	1.76
5010003	79.32	0	13.99	1.31	2192	2949	42.74	93.63	5.73	3.27	2.6	2.81	5.87	310	42.5	10.96	85.27	5.9	5.13	0.64
5010004	124.42	3	40.42	1.65	2084	2709	43.43	77.2	24.72	3.67	4.61	7.96	19.74	420	77	37.99	58.84	16.81	17.7	2.78
5010005	33.25	3	15.1	1.32	2127	2966	41.64	93.99	5.13	3.68	2	5.14	6.62	320	47.4	9.61	84.57	6.54	6.01	1.09
5010006	72.35	5	28.89	1.94	2085	2922	40.22	85.21	14.89	6.75	5.74	13.64	16.91	390	72.7	22.19	70.59	13.06	11.58	1.84
5010007	165.53	-4	26.65	1.92	1943	2849	38.97	87.59	11.04	6.35	13.49	9.76	12.14	380	66.9	19.45	72.62	11.03	12.34	3.35
5010008	365.61	0	29.56	2.16	2032	2929	38.24	81.42	17.45	8.51	12.47	11.41	16.2	390	70.1	24	69.99	13.37	14.37	5.08
5010009	1469.23	-12	35.93	3.63	2071	2952	38.17	80	11.78	9.67	10.23	7.62	12.48	390	71.2	18.76	63.3	19.54	19.93	8.42
5020001	32.63	10	17.66	1.25	1731	2649	44.23	83.37	17.16	5.42	2.85	5.87	8.58	330	51.6	14.83	81.57	8.05	6.72	1.66
5020002	62.83	-4	26.11	1.62	1631	2588	40.49	64.56	34.57	8.53	15.9	5.72	9.13	360	62	21.23	73.14	13.53	10.84	2.2
5020003	183.11	2	22.7	1.98	1714	2656	39.19	76.38	20.95	10.11	30.81	6.02	9.41	350	57.2	16.98	76.26	11.66	8.47	2.56
5020004	38.85	5	11.12	0.98	1899	2860	45.14	94.26	5.72	3.58	3.95	4.62	6.2	300	41.9	8.19	87.64	5.53	3.48	0.47
5020005	551.28	-12	38.93	2.75	1853	2811	38.03	65.76	29.49	11.67	11.99	9.75	16.14	410	78.1	28.11	60.5	19.14	20.31	7.26
5020006	422.35	-11	31	1.91	1987	2938	41.24	81.4	17.1	6.24	9.3	11.21	15.57	400	73.5	24.8	68.13	11.96	16.55	6.47
5030101	626.81	-15	38.73	4.54	1822	2749	38.07	73.24	17.1	8.12	14.92	5.92	13.1	390	69.8	23.29	59.71	19.74	22.36	10.03
5030102	135.94	-4	55.13	2.74	1957	2667	41.81	70.66	28.77	4.22	5.98	8.21	21.2	470	93.4	47.66	42.73	25.47	30.5	9.99
5030103	344.62	-10	52.2	42.52	1689	2430	41.64	73.02	20.14	4.56	0	8.96	19.2	450	89.9	41.75	46.39	25.94	28.53	7.89
5030104	825.99	-10	39.84	3.05	1950	2795	39.19	80.12	12.03	6.72	5.9	6.85	13.39	400	71.9	23.8	59.78	20.62	21.79	6.3
5030105	546.17	-11	43.17	2.16	2093	2923	39.75	77.94	21.26	4.89	5.15	8.27	18.12	420	79.3	33.25	56.29	19.94	22.1	5.6
5030106	84.21	-9	28.82	2.98	1731	2787	36.75	77.37	21.4	8.8	10.82	5.44	14.71	360	58.7	25.04	69.54	13.68	9.53	2.33
5030201	41.53	-2	12.81	2.58	1602	2690	38.28	76.49	22.77	6.99	3.22	2.19	4.07	310	42.8	10.43	85.06	7.17	3.17	1.21
5030202	68.42	3	29.06	3.11	1498	2501	39.58	61.85	36.87	7.01	11.73	6.11	13.5	370	61.5	25.38	67.51	13.25	12.77	6.01
5030203	19.07	2	13.62	1.22	1569	2585	41.06	76.87	23.62	10.69	3.19	3.72	6.46	310	43.9	11.29	85.98	7.24	3.47	0.89
5050001	27.29	42	36.53	1.54	1085	1844	48.85	68.51	32.64	7.29	4.01	11.7	22.43	410	74.7	32.76	62.75	13.23	16.22	7.78
5050002	32.1	1	21.97	1.19	1094	1802	51.96	77.6	23.38	7.65	8.56	9.16	14.43	350	57.5	19.18	77.42	8.2	8.42	2.68
5050003	13.29	9	19.63	0.9	1406	2243	51.97	85.59	15.33	3.84	2.34	8	11.41	340	55.2	16.9	79.78	6.36	6.99	3.38
5050004	75.54	4	13.3	1.54	1212	1949	49.59	91.35	7.07	6.06	5.63	4.18	6.71	300	42.1	8.36	85.59	7.81	4.5	1.17
5050005	30.07	3	8.73	0.88	1463	2298	48.37	93	6.18	4.17	2.55	2.74	4.15	280	36	5.62	90.18	4.88	2.36	0.33
5050006	197.63	-7	8.65	1.3	1359	2223	43.21	86.14	5.6	12.91	5.8	2.23	2.79	280	33.6	2.08	90.21	5.25	3.46	0.96
5050007	58.43	-6	5.84	1.15	1581	2525	43.8	89.31	9.39	8.85	2.31	2.48	3.77	270	33	3.7	93.57	4.07	1.14	0.13
5050008	111.07	-1	20.89	1.76	1457	2409	40.05	73.43	24.37	11.52	6.58	5.51	10.12	340	52.5	15.48	78.09	9.79	8.89	5.01
5050009	113.11	-4	6.66	0.98	1251	2038	42.62	89.72	7.24	11.79	5.33	1.9	2.79	270	32	2.51	92.86	4.8	1.8	0.54

HUC	POPDENS	POPCHG	UINDEX	RDDENS	NO3DEP	SO4DEP	OZAVG	RIPFOR	RIPCROP	STRD	DAMS	CROPSL	AGSL	STNO3L	STPL	PSOIL	FOR %	FORFRAG	EDGE7	EDGE65
5070101	46.89	-1	4.96	1.06	1093	1776	45.37	91.18	4.63	13.12	10.57	1.66	2	270	30.6	1.44	94.58	4.04	0.7	0.07
5070102	89.46	-2	11.25	1.34	1352	2206	41.48	76.25	24.92	15.16	3.57	3.42	6.2	290	39.4	7.54	88.27	6.73	4.22	1.93
5070201	45.03	-14	4.79	1.44	1118	1813	44.04	89.51	5.39	15.91	9.88	1.58	2.04	270	30.4	1.43	93.86	4.07	0.66	0.05
5070202	29.52	1	5.74	1.57	1071	1724	42.91	89.89	7.25	17.76	3.54	2.06	2.66	270	31.4	2.02	93.65	4.79	0.74	0.04
5070204	156.39	10	21.75	7.21	1356	2149	41.64	67.11	29.72	8.46	0	3.91	14.1	330	47.6	17.94	72.55	12.78	11.48	5.16
5090101	256.26	-2	27.73	10.33	1467	2380	39.98	63.35	30.67	6.08	2.73	6.46	12.72	370	62.3	20.14	65.78	13.45	12.89	11.44
5090102	40.7	1	8.47	1.16	1321	2128	42.08	83.85	17.93	13.68	2.68	1.81	5.21	280	33.9	5.69	90.62	5.95	2.08	0.47
6010101	34.4	2	24.27	1.02	967	1626	43.73	73.95	28.9	9.87	1.33	10.87	17.78	360	60.9	22.65	75.2	9.07	10.92	2.74
6010102	55.96	10	42.1	2.61	892	1508	45.1	58.16	39.9	10.01	2.67	12.85	25.7	430	80.8	39.61	57.39	13.75	26.24	15.38
6010205	40.31	11	25.27	1.44	1023	1701	42.3	73.3	26.25	12.62	3.72	10.47	17.86	360	60.3	22.06	74.35	10.38	11.68	4.91
6010206	45.63	17	27.38	1.82	1115	1857	41.3	73.13	25.79	9.85	4.27	10.62	17.87	370	63.7	23.19	72.24	11.23	12.31	3.99

HUC	EDGE600	INT7	INT65	INT600	INTALL	FORDIF	NDVI DEC	NDVI INC	NDVI TOT	1ST INC	1ST TOT	1ST DEC	NDVI 3%
2040101	0	62.69	50.4	36.04	30.52	0.0155	4.7	13.07	17.77	11.11	16.19	5.08	2.83
2040103	0	54.61	39.98	26.89	22.07	0.0152	6.46	15.42	21.87	15.63	21.71	6.08	3.13
2040104	0.14	77.92	73.06	69.84	61.22	0.0152	—	—	—	—	—	—	—
2040105	9.76	23.87	16.43	9.3	8.51	0.0767	18.3	22.81	41.11	20.39	38.88	18.49	5.29
2040106	14.43	45.83	38.43	31.15	27.7	0.1048	14.35	17.9	32.25	17.08	31.36	14.28	5.81
2040201	26.42	3.08	0.3	0	0	0.1835	26.11	15.88	42	13.78	41.34	27.56	3.9
2040202	43.52	5.41	1.21	0.07	0.07	0.1493	18.91	6.61	25.52	5.95	25.38	19.43	2.69
2040203	24.7	22.3	14.83	7.44	6.77	0.3117	16.96	21.95	38.92	21.32	38.56	17.24	5.65
2040205	19.32	8.13	2.16	0	0	0.2651	27.3	12.95	40.25	9.49	32.14	22.65	7.3
2040207	9.47	6.99	1.49	0.02	0.01	0.2807	—	—	—	—	—	—	—
2050101	0	57.64	41.62	22.75	18.92	0.0125	7.62	2.8	10.42	2.59	9.93	7.34	5.65
2050103	0.81	43.02	24.07	4.04	3.36	0.0533	7.66	4.84	12.5	4.42	12.42	8	5.26
2050104	0.54	40.59	29.37	19.69	17.48	0.4922	3.62	8.12	11.74	7.74	10.98	3.24	2.34
2050105	2.15	26.52	10.85	1.03	0.6	0.0884	2.8	13.76	16.56	12.77	15.25	2.48	1.48
2050106	0.39	37.38	23.12	13.38	12.34	0.0784	7.59	8.04	15.64	7.04	13.43	6.39	4.89
2050107	4.48	44.31	33.74	22.96	20.54	0.07	10.41	8.19	18.6	6.29	14.68	8.39	6.15
2050201	0.03	63.62	52.02	39.67	35.72	0.0124	9.11	7.76	16.88	8.17	16.76	8.59	6.12
2050202	0	92.46	90.25	91.07	85.92	0.0009	0.94	1.22	2.17	1.16	2.02	0.86	0.68
2050203	0.11	88.1	84.87	81.4	78.08	0.0384	1.15	1.8	2.95	1.16	1.91	0.75	0.62
2050204	5.51	56.51	48.15	32.95	30.97	0.0636	3.26	11.6	14.86	10.58	13.39	2.81	1.53
2050205	0.14	79.36	73.96	71.3	66.1	0.0212	1.22	3.61	4.83	3.94	5.03	1.09	0.79
2050206	9.62	54.26	47.31	41.31	37.99	0.1993	7.74	10.06	17.8	9.55	17.11	7.56	3.48
2050301	7.41	39.86	31.5	19.99	18.64	0.1601	6.16	22.09	28.25	21.69	27.58	5.89	3.22
2050302	2.76	57.02	48.66	34.95	32.45	0.3166	5.48	7.77	13.25	6.2	11.18	4.98	3.19
2050303	2.4	51.45	40.55	23.64	21.18	0.2825	10.49	3.88	14.37	3.39	12.28	8.89	6.25
2050304	2.03	55.69	45.13	29.66	27.32	0.067	4.05	13.46	17.51	12.1	15.63	3.53	2.41
2050305	29.21	33.89	28.9	21.51	20.56	0.1743	12.04	17.02	29.06	16.76	28.68	11.92	2.7
2050306	35.28	10.84	5.21	1.68	1.6	0.2377	24.86	10.98	35.83	10.14	35.93	25.79	10.04
2060002	10.2	10.75	4.23	0.87	0.77	0.2897	30.52	15.38	45.9	12.01	37.87	25.86	1.71
2060003	20.41	11.6	4.06	0.23	0.17	0.2996	18.93	17.63	36.55	12.89	27.43	14.54	8.7
2060004	2.96	27.46	14.16	2.8	2.4	0.2567	11.99	14.39	26.39	13.83	24.72	10.89	2.29
2060005	2.11	11.19	2.3	0.13	0.12	0.3541	—	—	—	—	—	—	—
2060006	6.92	17.44	6.64	0.63	0.49	0.3457	14.01	20.38	34.39	19.69	33.78	14.09	3.58
2060007	5.65	21.7	10.66	0.97	0.87	0.3306	—	—	—	—	—	—	—
2060008	2.33	19	7.07	0.61	0.56	0.3035	—	—	—	—	—	—	—
2060009	1.5	31.02	15.96	4.23	3.59	0.1198	—	—	—	—	—	—	—
2060010	12.82	10.26	2.94	0.26	0.2	0.4436	—	—	—	—	—	—	—
2070001	0.48	67.14	57.23	42.4	38.02	0.1305	2.01	13.49	15.49	11.94	13.67	1.73	1.54
2070002	0.04	65.74	53.74	37.31	31.94	0.0104	8.42	9.33	17.74	8.36	16.27	7.91	6.76
2070003	0.03	70.66	60.05	46.91	41.14	0.0061	7.9	3.4	11.3	2.4	8.87	6.47	6.26
2070004	21.35	32.09	24.13	14.71	13.43	0.1475	16.79	7.43	24.23	5.52	18.35	12.83	6.05
2070005	6.21	43.11	38.02	33.32	31.93	0.3419	10.43	13.15	23.58	9.33	17.31	7.98	7.82
2070006	5.26	49.5	43.02	36.29	33.5	0.0852	21.07	4.74	25.81	3.44	19.98	16.54	16.16
2070007	16.68	25.69	20.17	15.6	14.4	0.166	—	—	—	—	—	—	—
2070008	8.66	16.72	9.03	2.49	2.39	0.2607	13.64	22.01	35.65	19.76	33.54	13.78	4.76
2070009	37.89	15.47	11.12	7.9	7.31	0.1898	19.11	13.3	32.41	12.51	30.89	18.38	7.14
2070010	13.34	15.67	7.38	2.08	1.71	0.2979	12.08	26.16	38.24	23.93	36.16	12.23	3.18
2070011	0.83	36.16	21.41	7.88	6.74	0.194	10.09	20.27	30.36	16.44	25.27	8.83	1.31
2080102	0.2	48.65	31.48	13.05	11.45	0.0682	—	—	—	—	—	—	—
2080103	1.4	39.85	27.29	15.09	14.27	0.0638	5.34	19.22	24.56	15.65	20.48	4.83	1.59
2080104	3.51	33.6	19.55	7.21	5.94	0.1415	15.42	16.07	31.49	7.9	16.23	8.33	1.53
2080105	0	46.99	28.37	8.09	6.78	0.0276	13.5	12.05	25.55	11.55	25.95	14.4	0.91
2080106	0.23	42.67	25.97	8.57	7.06	0.045	10.77	14.48	25.26	13.82	24.65	10.83	0.71
2080107	3.33	33.94	18.94	4.75	3.89	0.0561	13.01	12.81	25.82	10.15	21.97	11.82	0.38
2080108	40.91	9.37	4.83	0.87	0.84	0.2398	—	—	—	—	—	—	—
2080109	4.21	13.65	3.75	0.11	0.05	0.3904	—	—	—	—	—	—	—

HUC	EDGE600	INT7	INT65	INT600	INTALL	FORDIF	NDVI DEC	NDVI INC	NDVI TOT	1ST INC	1ST TOT	1ST DEC	NDVI 3%
2080110	15.67	5.57	0.56	0	0	0.3528	—	—	—	—	—	—	—
2080201	0.01	76.55	69.05	58.63	55.34	0.0552	2.04	6.84	8.88	6.16	7.72	1.56	1.26
2080202	0.31	61.71	53.48	44.89	43.15	0.0493	1.44	16.81	18.25	13.72	14.73	1.01	0.85
2080203	0.21	62.04	49.98	36.17	32.21	0.0662	4.25	7.87	12.13	3.97	6.34	2.37	1.37
2080204	0.3	50.62	36.44	21.03	19.05	0.017	—	—	—	—	—	—	—
2080205	1.5	50.61	34.37	16.37	13.26	0.0307	8.06	14.86	22.92	13.75	21.91	8.16	1.02
2080206	3.85	33.96	20.57	8.22	7	0.1967	16.84	14.83	31.67	12.25	28.56	16.31	0.31
2080207	0.16	49.66	32.8	16.28	13.08	0.0274	11.33	10.27	21.6	10.21	22.07	11.86	1.34
2080208	31.24	11.51	4.69	0.62	0.6	0.2171	—	—	—	—	—	—	—
3010101	2.32	45.59	32.64	19.57	17.84	0.0352	6.54	2	8.55	1.62	7.16	5.54	3.16
3010102	0.01	40.49	22.25	5.61	4.49	0.0666	8.91	5.34	14.24	4.94	14.43	9.49	2.03
3010103	0	57.67	44.12	31.31	26.14	0.0158	3.84	3.54	7.38	3.49	7.08	3.59	1.89
3010104	0.21	41.28	23.17	7.14	5.7	0.0365	5.76	8.78	14.54	9.17	15.17	6	1.76
3010105	0.02	37.9	19.92	3.5	2.72	0.0157	7.1	4.27	11.37	4.26	12.11	7.85	2.48
3010106	0	37.96	19.78	5.43	4.39	0.075	9.28	4.71	13.99	4.79	14.6	9.81	2.31
3010201	0	47.98	30.31	11.43	9.45	0.018	19.73	7.89	27.62	8.22	29.04	20.82	0.88
3010202	0.03	37.22	18.84	4.94	4.24	0.0319	27.46	6.15	33.61	6.27	34.09	27.82	0.18
3010203	0	27.86	8.76	0	0	0.02	25.83	8.58	34.41	8.32	33.75	25.43	0.09
3010204	0	44.8	27.8	11.23	9.7	0.0187	10.52	12.67	23.2	14.19	25.65	11.46	1.56
3010205	2.72	35.31	27.07	18.57	18.15	0.2227	—	—	—	—	—	—	—
3040101	0	60.67	49.03	31.11	25.15	0.0026	2.73	2.45	5.18	2.51	4.85	2.34	1.88
4120101	5.82	19.82	6.26	1.55	1.31	0.194	—	—	—	—	—	—	—
4130002	0	47.84	32.74	18.68	15.68	0.0119	—	—	—	—	—	—	—
5010001	0	76.18	67.35	55.74	51.58	0.0108	—	—	—	—	—	—	—
5010002	0	51.79	35.22	15.49	13.37	0.0294	—	—	—	—	—	—	—
5010003	0	71.56	62.53	55.53	50.1	0.0211	—	—	—	—	—	—	—
5010004	0	28.38	11.56	1.56	1.38	0.207	—	—	—	—	—	—	—
5010005	0.04	70.06	61.51	53.3	49.42	0.0135	—	—	—	—	—	—	—
5010006	0.03	44.12	27.17	9.57	8.16	0.024	10.82	9.12	19.94	6.5	14.17	7.67	7.71
5010007	0.08	50.76	37.46	23.23	20.8	0.038	8.63	9.19	17.82	9.34	18.06	8.72	5.33
5010008	0.54	44.11	29.65	15.29	13.96	0.3209	5.81	9.53	15.34	9.64	15.43	5.79	3.84
5010009	2	29.9	15.34	3	2.04	0.0516	5.81	8.21	14.01	8.79	14.51	5.72	3.57
5020001	0.08	63.21	51.2	41.13	36.21	0.0247	3.89	8.87	12.77	8.48	12.05	3.57	2.79
5020002	0.04	44.65	26.22	9.3	7.35	0.0202	4.21	14.51	18.72	13.99	17.66	3.67	2.48
5020003	0.54	49.69	31.51	17.21	13.66	0.0777	4.26	12.24	16.5	10.77	14.73	3.96	2.63
5020004	0	74.06	65.63	58.37	52.02	0.009	2.92	5.31	8.23	5.11	7.99	2.88	2.22
5020005	2.38	27.37	12.41	3.15	2.73	0.1839	5.56	7.24	12.8	5.41	9.33	3.92	3.25
5020006	1.19	46.1	34.6	23.72	20.98	0.133	6.28	10.28	16.56	10.87	17.34	6.47	3.84
5030101	2.88	28.32	13.74	2.75	2.13	0.0937	—	—	—	—	—	—	—
5030102	1.19	10.02	1.22	0	0	0.3218	—	—	—	—	—	—	—
5030103	0.06	11.38	1.75	0	0	0.134	—	—	—	—	—	—	—
5030104	0.1	25.5	9.46	0.15	0.15	0.1971	—	—	—	—	—	—	—
5030105	0.06	23.79	9.89	1.96	1.65	0.1131	5.54	16.04	21.57	13.08	17.46	4.38	2.65
5030106	0.13	39.52	21.92	9.19	6.56	0.0372	—	—	—	—	—	—	—
5030201	0.03	68.27	57.06	47.82	37.49	0.0117	—	—	—	—	—	—	—
5030202	1.41	41.77	26.32	10.25	8.43	0.2004	—	—	—	—	—	—	—
5030203	0.16	68.59	58.65	48.55	39.75	0.0099	—	—	—	—	—	—	—
5050001	2.12	38.77	26.82	16.19	14.96	0.08	13.17	4.67	17.84	4.17	15.37	11.2	7.5
5050002	0.31	59.44	47.4	32.46	29.34	0.0236	—	—	—	—	—	—	—
5050003	0.42	65.77	56.66	47.25	42.89	0.0208	4.91	3.77	8.69	3.32	8.59	5.27	3.8
5050004	0.28	67.96	57.26	47.88	39.43	0.0142	—	—	—	—	—	—	—
5050005	0	78.63	72.19	67.43	59.85	0.0144	5.05	2.73	7.77	2.17	6.48	4.31	4.27
5050006	0.06	80.31	76.16	71.8	63.56	0.0067	—	—	—	—	—	—	—
5050007	0.01	84.73	80.66	80.63	70.8	0.0025	6.12	2.02	8.14	1.19	4.83	3.64	5.69
5050008	0.61	57.63	45.7	31.3	25.78	0.2334	—	—	—	—	—	—	—
5050009	0.01	83.41	80.34	81.19	70.46	0.0027	—	—	—	—	—	—	—

HUC	EDGE600	INT7	INT65	INT600	INTALL	FORDIF	NDVI DEC	NDVI INC	NDVI TOT	1ST INC	1ST TOT	1ST DEC	NDVI 3%
5070101	0	86.64	83.9	87.77	76.09	0.0011	—	—	—	—	—	—	—
5070102	0.24	73.52	67.08	62.67	52.92	0.0801	—	—	—	—	—	—	—
5070201	0	86.65	84.27	87.63	76.84	0.0117	—	—	—	—	—	—	—
5070202	0	84.12	82.57	82.89	72.68	0.001	—	—	—	—	—	—	—
5070204	0.61	50.41	38.03	20.94	16.39	0.1134	—	—	—	—	—	—	—
5090101	5.25	42.41	28.67	11.72	8.97	0.1194	—	—	—	—	—	—	—
5090102	0	77.05	70.78	68.35	58.04	0.0025	—	—	—	—	—	—	—
6010101	0	56.19	44.82	29.9	27.45	0.0545	—	—	—	—	—	—	—
6010102	3.73	38.6	31.54	22.9	21.64	0.2629	—	—	—	—	—	—	—
6010205	0.27	54.39	43.7	30.61	26.87	0.0516	—	—	—	—	—	—	—
6010206	0	50.48	40.56	30.39	25.64	0.0684	—	—	—	—	—	—	—

Suggested Further Reading

Appleton, E.L. 1995. A cross media approach to saving the Chesapeake Bay. Environ. Sci. Tech. 29:550–555.

Bourgeron, P.S. and M.E. Jensen. 1993. An overview of ecological principles for ecosystem management. Pp. 49–60 *in* Jensen, M.E., and P.S. Bourgeron (eds.), Eastside Forest Ecosystem Health Assessment, Vol II, Ecosystem Management: Principles and Applications. United States Forest Service, Missoula, Montana.

Cooper, S.R. 1995. Chesapeake Bay watershed historical land use: impact on water quality and diatom communities. Ecol. Appl. 5:703–723.

Correll, D.L., T.E. Jordan, and D.E. Weller. 1994. The Chesapeake Bay Watershed: effects of land use and geology on dissolved nitrogen concentrations. Pp. 639–648 *in* Toward a Sustainable Coastal Watershed, Chesapeake Research Consortium Publication No. 149.

EPA (Environmental Protection Agency). 1994. Landscape monitoring and assessment research plan. 620/R–94/009, United States Environmental Protection Agency, Office of Research and Development, Washington, D.C.

EPA (Environmental Protection Agency). 1995. Water quality functions of riparian forest buffer systems in the Chesapeake Bay Watershed. Report of the Nutrient Subcommittee of the Chesapeake Bay Program. EPA 903–R–95–004, United States Environmental Protection Agency, Annapolis, MD.

ESRI (Environmental Systems Research Institute). 1994. ARC/INFO Version 7. ESRI, Inc. Redlands, California.

Forman, R. T. T., and M. Godron. 1986. Landscape Ecology. John Wiley and Sons, NY.

Franklin, J. F. 1992. Scientific basis for new perspectives in forests and streams. Pp. 25–72 *in* R. J. Naiman (ed.). Watershed Management. Springer–Verlag, NY.

Frenzel, S.A., and R.B. Swanson. 1996. Relations of fish community composition to environmental variables in streams of central Nebraska, USA. Environ. Man. 20:689–795.

Golley, F.B. 1993. Development of landscape ecology and its relationship to environmental management. Pp. 37–44 *in* Jensen, M.E., and P.S. Bourgeron (eds.), East side Forest Ecosystem Health Assessment, Vol II, Ecosystem Management: Principles and Applications. United States Forest Service, Missoula, Montana.

Hunsaker, C.T., and D.E. Carpenter (eds.). 1990. Ecological indicators for the Environmental Monitoring and Assessment Program. EPA 600/3–90/060. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC.

Hunsaker, C.T., D.A. Levine, S.P. Timmins, B.L. Jackson, and R.V. O'Neill. 1992. Landscape characterization for assessing regional water quality. Pp. 997–1006 *in* D.H. McKenzie, D.E. Hyatt, and V.J. McDonald (eds.), Ecological Indicators. Elsevier Appl. Sci., New York.

Hunsaker, C.T., and D.A. Levine. 1995. Hierarchical approaches to the study of water quality in rivers. Bioscience 45:193–203.

Jones, K.B., J. Walker, K.H. Riitters, J.D. Wickham, and C. Nicoll. 1996. Indicators of landscape integrity. Pp 155–168 *in* J. Walker and D.J. Reuter (eds.), Indicators of catchment health: a technical perspective. CSIRO Publishing, Melbourne, Australia.

Kepner, W.G., K.B. Jones, D.J. Chaloud, J.D. Wickham, K.H. Riitters, and R.V. O'Neill. 1995. Mid–Atlantic landscape indicators project plan. EPA 620/R–95/003, U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

Kuchler, A.H. 1964. Potential natural vegetation of the conterminous United States. American Geogr. Soc. Spec. Publ. No. 36, Washington, D.C.

Lapin, M., and B.V. Barnes. 1995. Using the landscape ecosystem approach to assess species and ecosystem diversity. Cons. Biol. 9:1148–1158.

Lowrance, R.R, R.L. Todd, J. Fail, O. Hendrickson, R. Leonard, and L.E. Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. BioScience 34:374–377.

Noss, R.F., and A.Y. Cooperrider. 1994. Saving Nature's Legacy: Protecting and Restoring Biodiversity. Island Press, Washington, D.C.

Ojima, D.S., K.A. Galvin, and B.L. Turner II. 1994. The global impact of land–use change. BioScience 44:300–304.

O'Neill, R.V., D.L. DeAngelis, J.B. Waide, and T.F.H. Allen. 1986. A Hierarchical Concept of Ecosystems. Princeton University Press, Princeton, NJ.

O'Neill, R.V., J.R. Krummel, R.H. Gardner, G. Sugihara, B.Jackson, D.L. DeAngelis, B.T. Milne, M.G. Turner, B. Zygmunt, S.W. Christensen, V.H. Dale, and R.L. Graham. 1988. Indices of landscape pattern. Landscape Ecol. 1:153–162.

O'Neill, R.V., C.T. Hunsaker, K.B. Jones, K.H. Riitters, J.D. Wickham, P. Schwarz, I.A. Goodman, B. Jackson, and W.S. Baillargeon. 1997. Monitoring environmental quality at the landscape scale. BioScience 47(8): 513-519.

Reckhow, K.H., M.N. Beaulac, and J.T. Simpson. 1980. Modeling phosphorous loading and lake response under uncertainty: A manual and compilation of export coeffiecients. U.S. Environmental Protection Agency, EPA 440/5-80-011.

Riitters, K.H, R.V. O'Neill, C.T. Hunsaker, J.D. Wickham, D.H. Yankee, S.P. Timmins, K.B. Jones, and B.L. Jackson. 1995. A factor analysis of landscape pattern and structure metrics. Landscape Ecol. 10:23–29.

Riitters, K.H., J.D. Wickham, and K.B. Jones. 1996. A landscape atlas of the Chesapeake Bay Watershed. Second Edition. Tennessee Valley Authority, Norris, TN. 29 pp.

Riitters, K.H., R.V. O'Neill, and K.B. Jones. 1997. Assessing habitat suitability at multiple scales: a landscape–level approach. Biol. Cons. 81:191–202.

Roth, N.E., J.D. Allan, and D.L. Erickson. 1996. Landscape influences on stream biotic integrity assessed at multiple scales. Landscape Ecology 11:141–156.

Saunders, D.A., R.J. Hobbs, and C.R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Cons. Biol. 5:18–32.

Schlosser, I.J., and J.R. Karr. 1981. Water quality in agricultural watersheds: impact of riparian vegetation during base flow. Water Resources Bull. 17:233–240.

Sparks, R.E. 1995. Need for ecosystem management of large rivers and their floodplains. BioScience 45:168–182.

Turner, S. J., R. V. O'Neill, W. Conley, M. R. Conley, and H. C. Humphries. 1991. Pattern and Scale: Statistics for Landscape Ecology. Pp. 17–41 *in* M. G. Turner and R. H. Gardner (eds.). Quantitative Methods in Landscape Ecology. Springer–Verlag, NY.

Waring, R.H., and W.H. Schlesinger. 1985. Forest Ecosystems, Concepts and Management. Academic Press, Inc., Orlando.

Wickham, J.D., and D. Norton. 1994. Mapping and analyzing landscape patterns. Landscape Ecol. 9:7–23.

Wischmeier, W. H., and D. D. Smith. 1978. Predicting rainfall erosion loss: A guide to conservation planning. Agricultural handbook 537. U. S. Department of Agriculture, Washington, D.C.

Young, W.J., F.M.Marsten, and J.R. Davis. 1996 Nutrient exports and land use in Australian catchments. Journal of Environmental Management, 57: 165-183.