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.

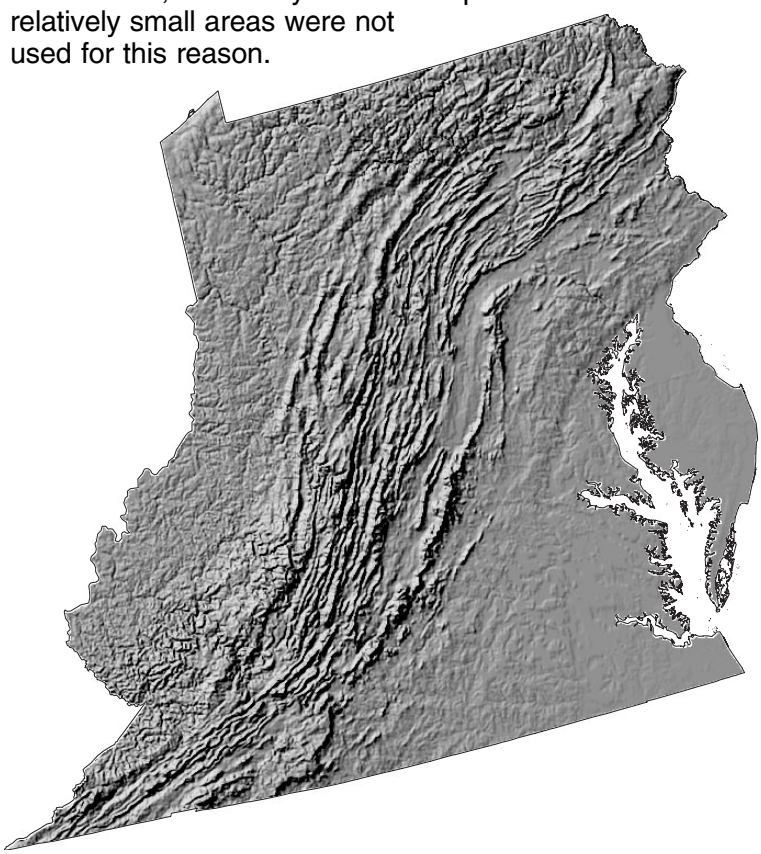


Figure 3.1

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.

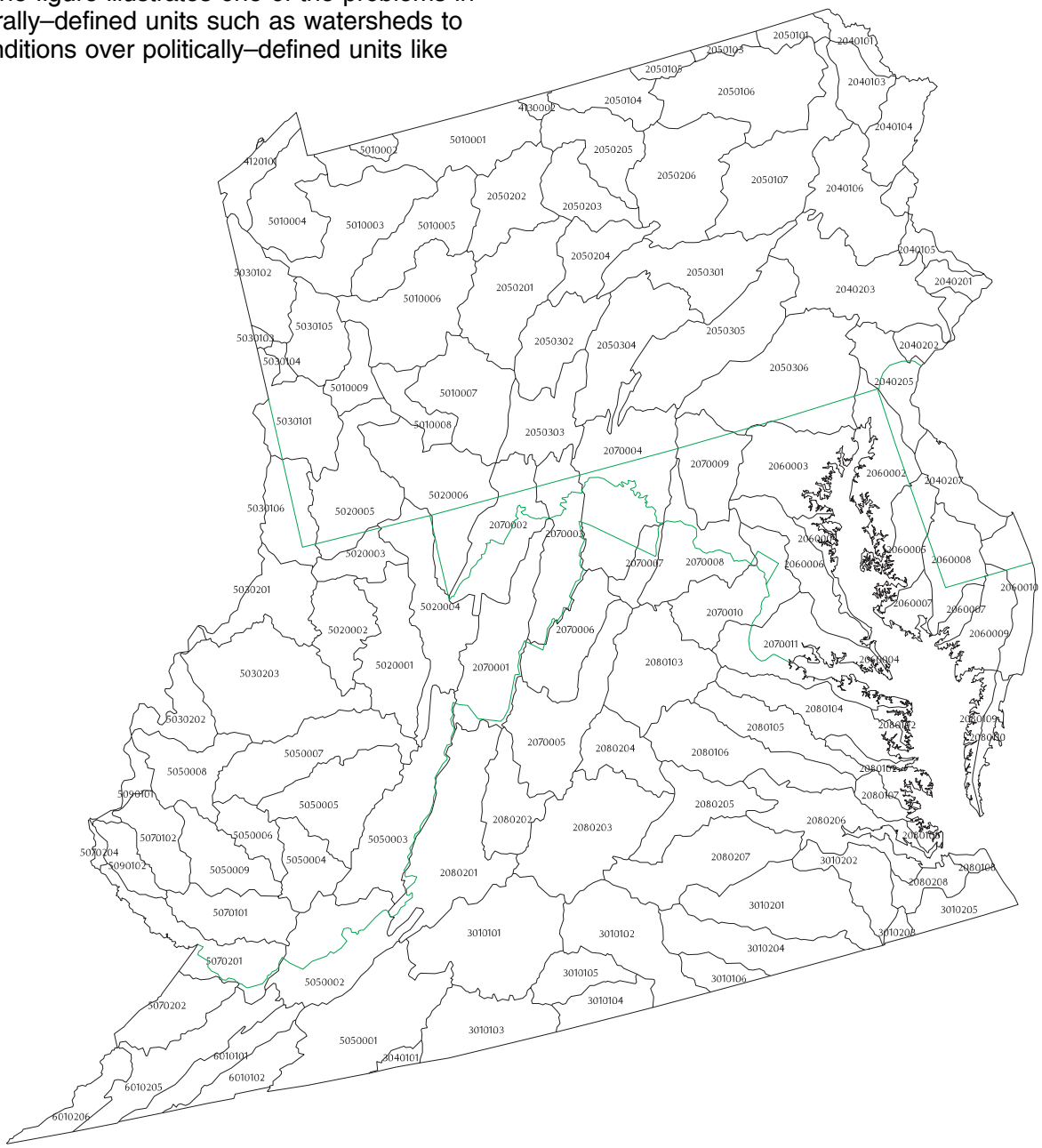


Figure 3.3.

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.

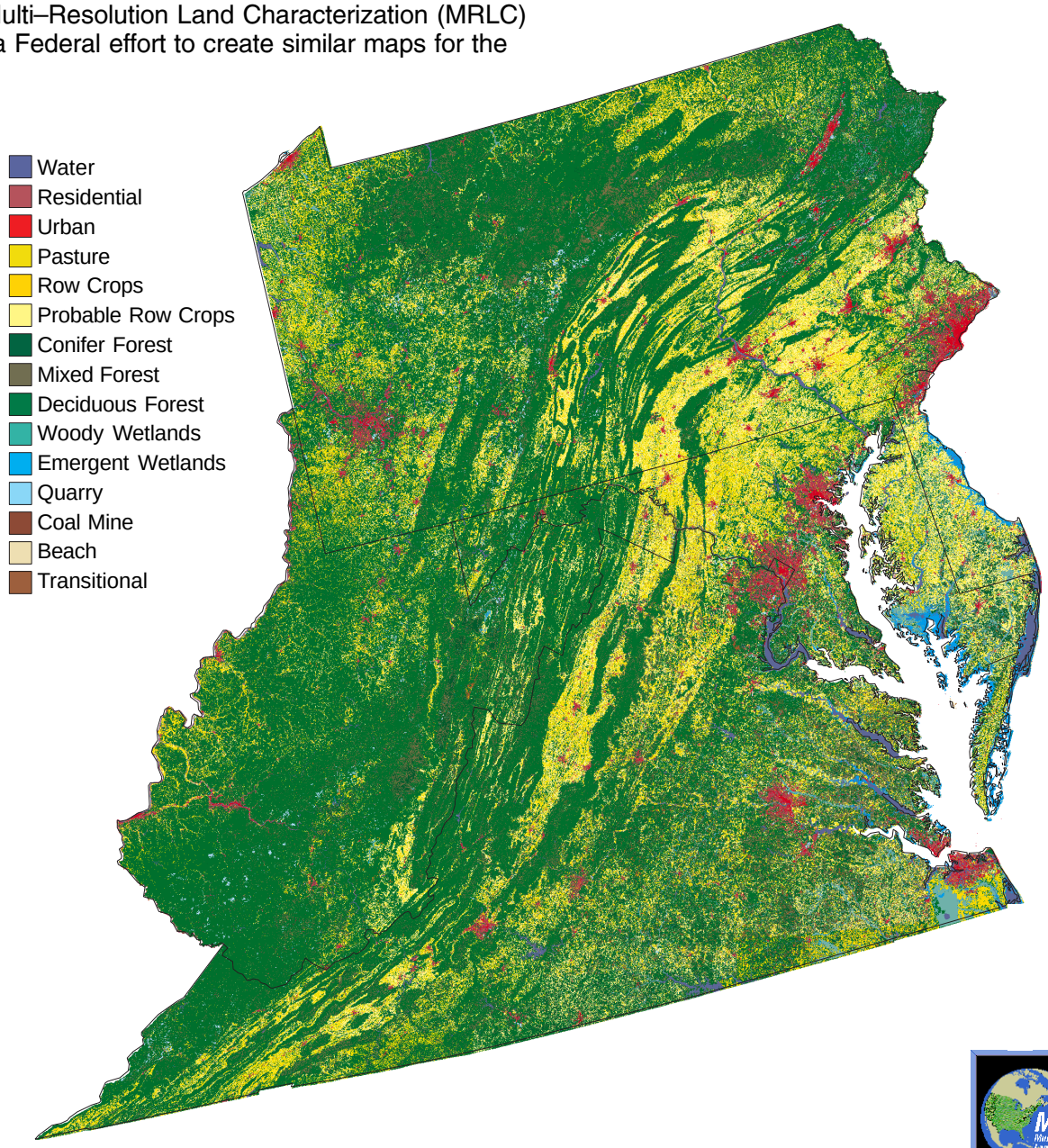


Figure 3.4.

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%.

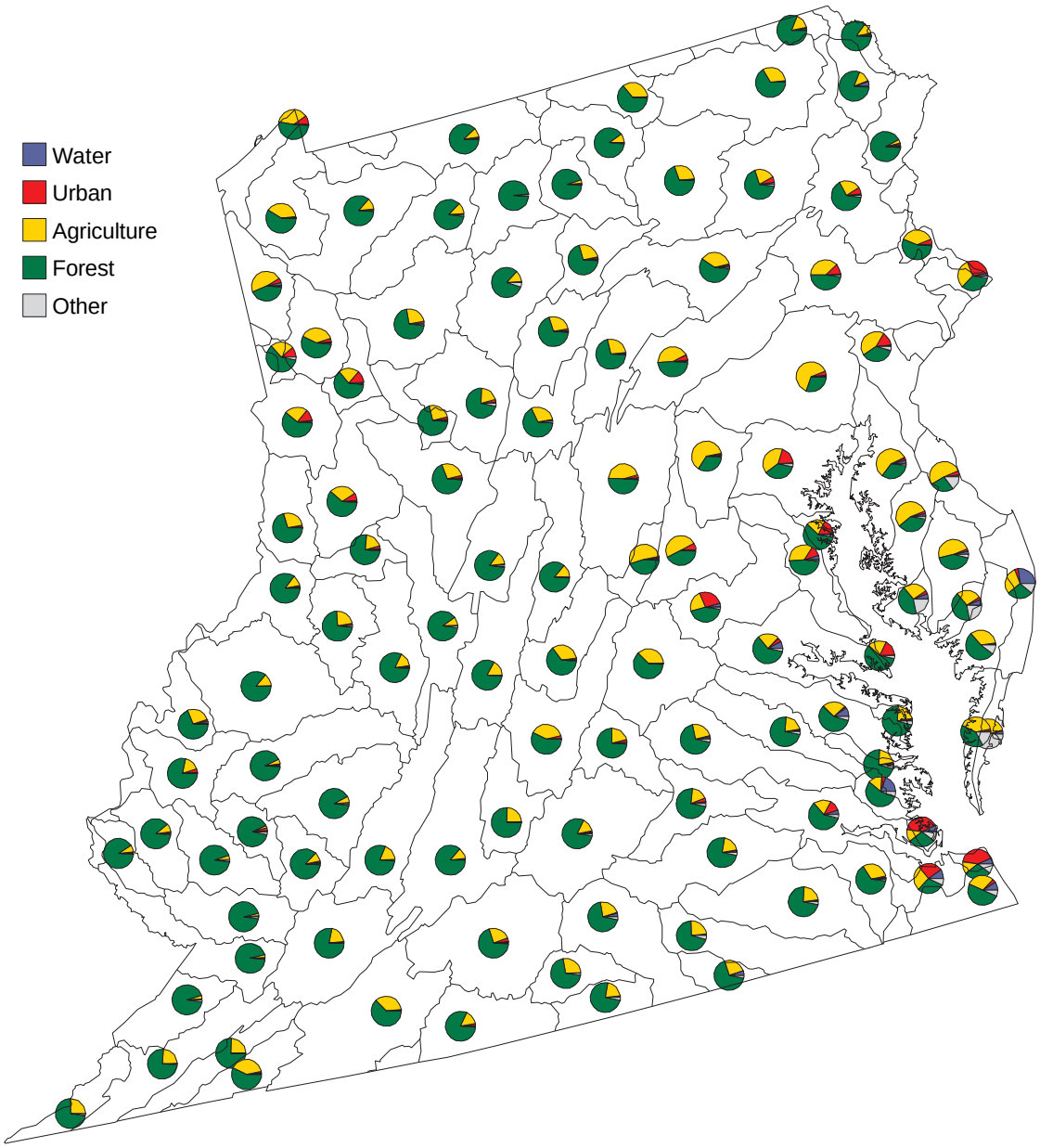


Figure 3.5

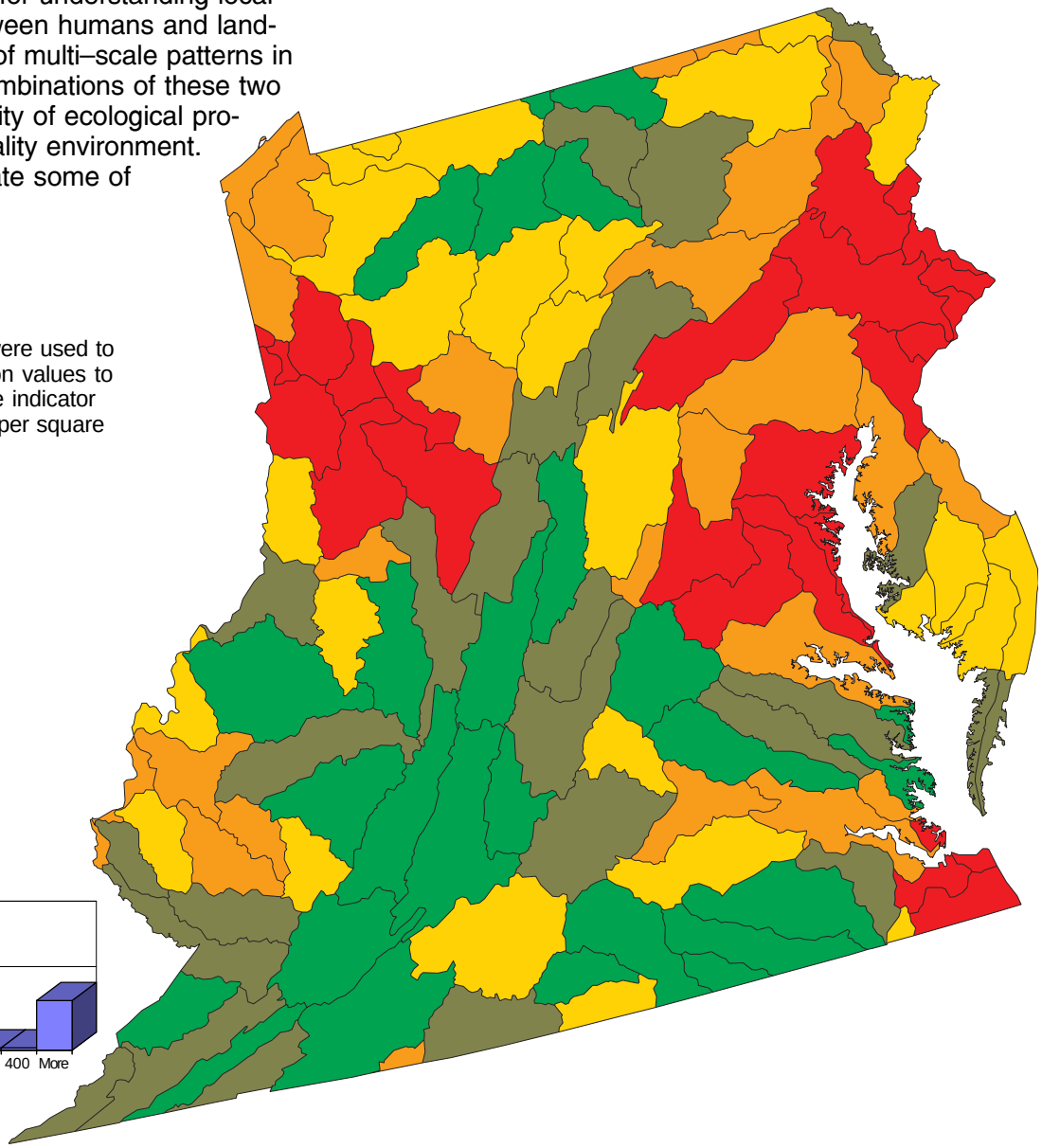
Proportion of forest, agriculture, urban, water, and other land cover types for watersheds in the mid–Atlantic region.

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



Census data and road maps were used to translate county-level population values to watershed-level estimates. The indicator value is the number of people per square kilometer.

Quintile	Data Range (Pop./Sq.Km.)
1	< 37
2	37 - 67
3	67 - 111
4	111 - 280
5	> 280

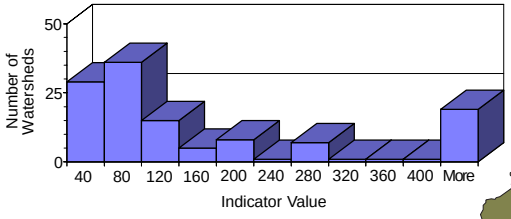


Figure 3.6

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

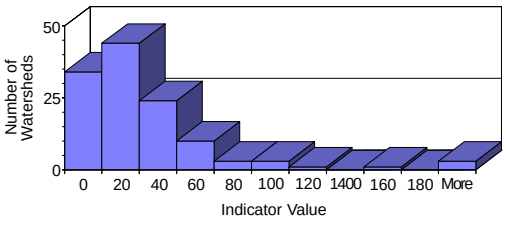
Patterns of human population density can be seen in this satellite image of United States cities at night. (Source: Defense Meteorological Satellite Program City Lights Program)

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.

The total population was estimated for each watershed for 1970 and 1990. The percentage change was determined by subtracting the 1970 value from the 1990 value, and then dividing the result by the 1970 value.

Quintile	Data Range (Pct. Change)
1	< -1.0
2	-1.0 - 3.0
3	3.0 - 18.0
4	18.0 - 38.0
5	>38.0



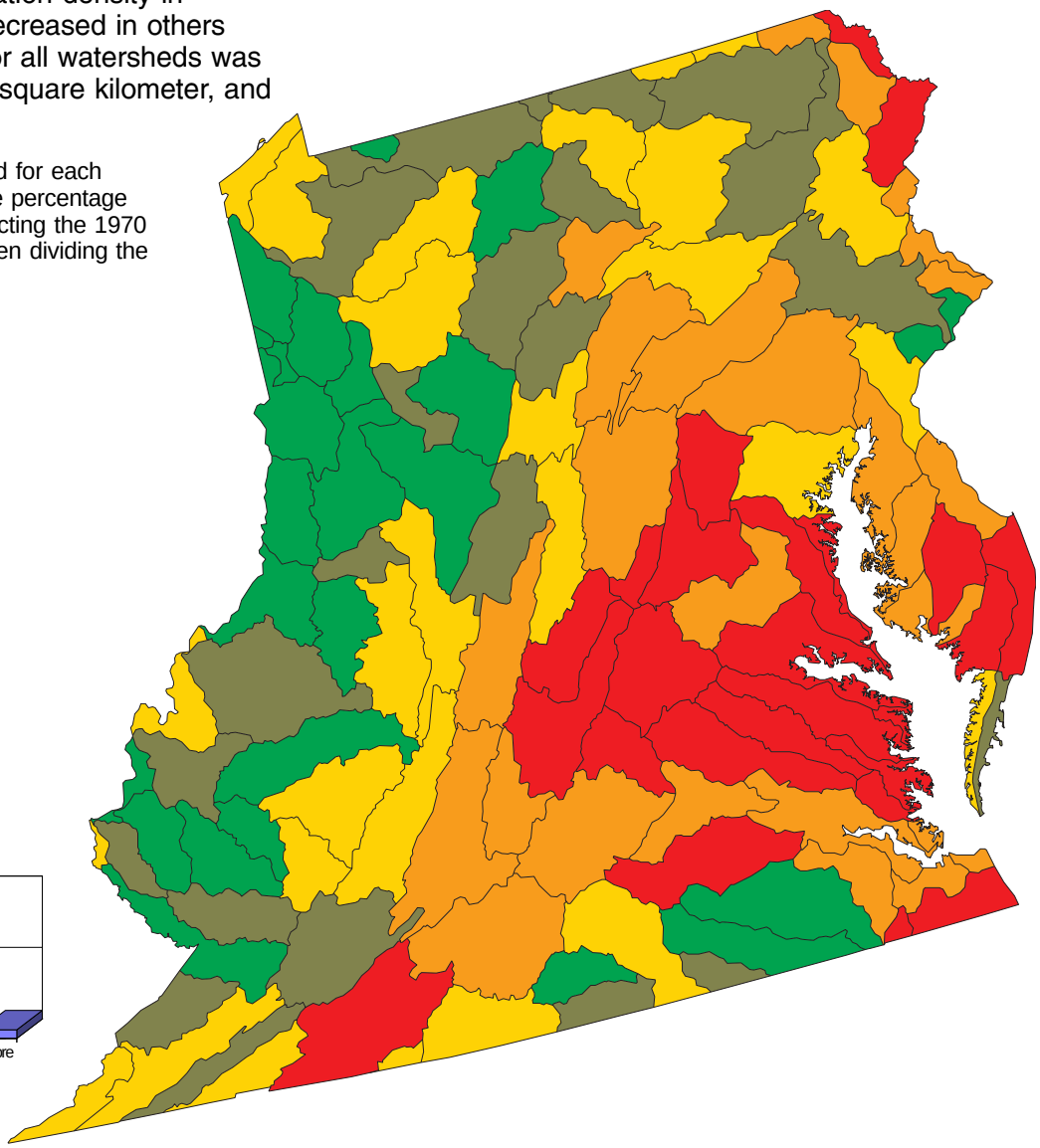


Figure 3.7

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.

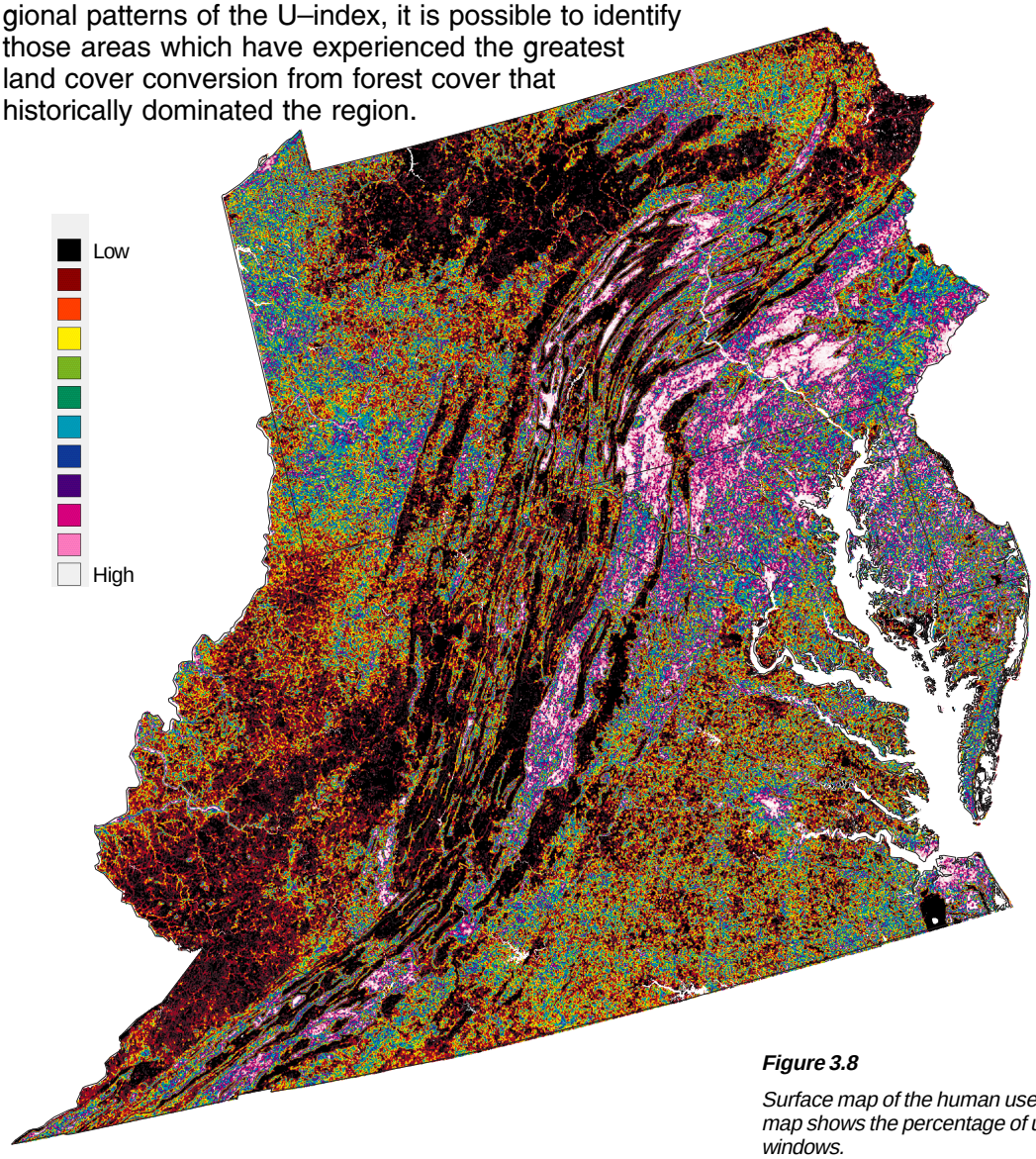


Figure 3.8

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.

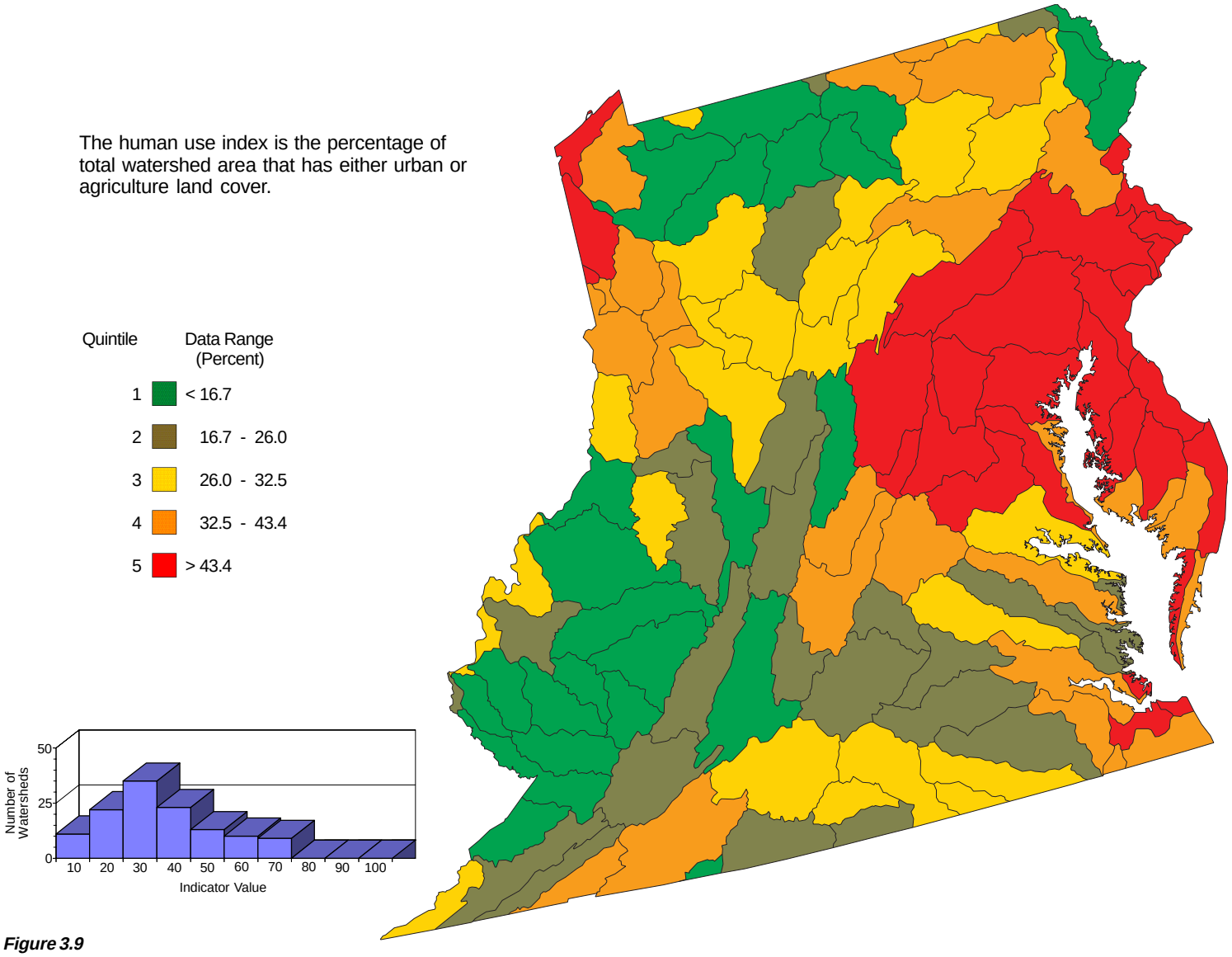


Figure 3.9

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.

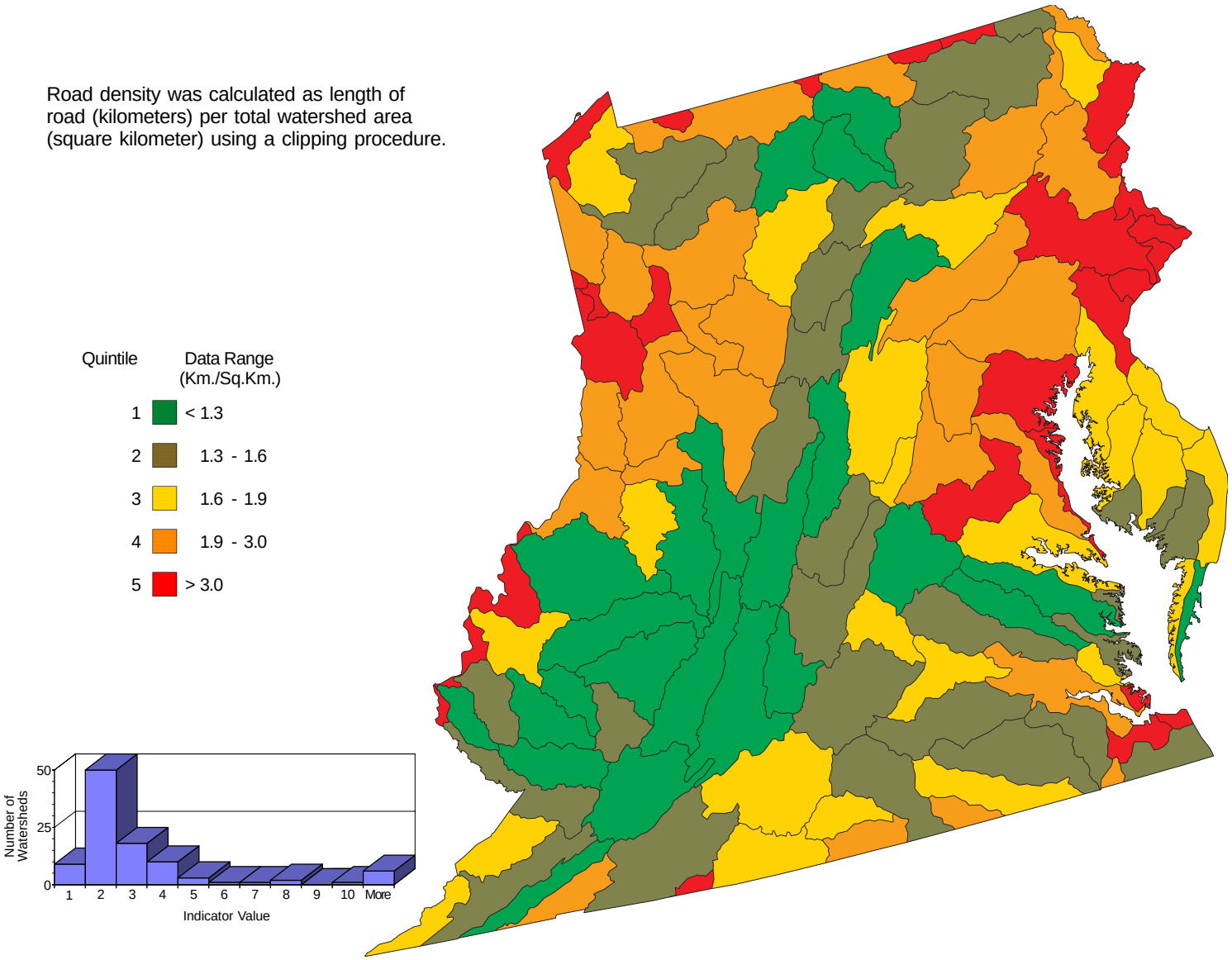


Figure 3.11

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.

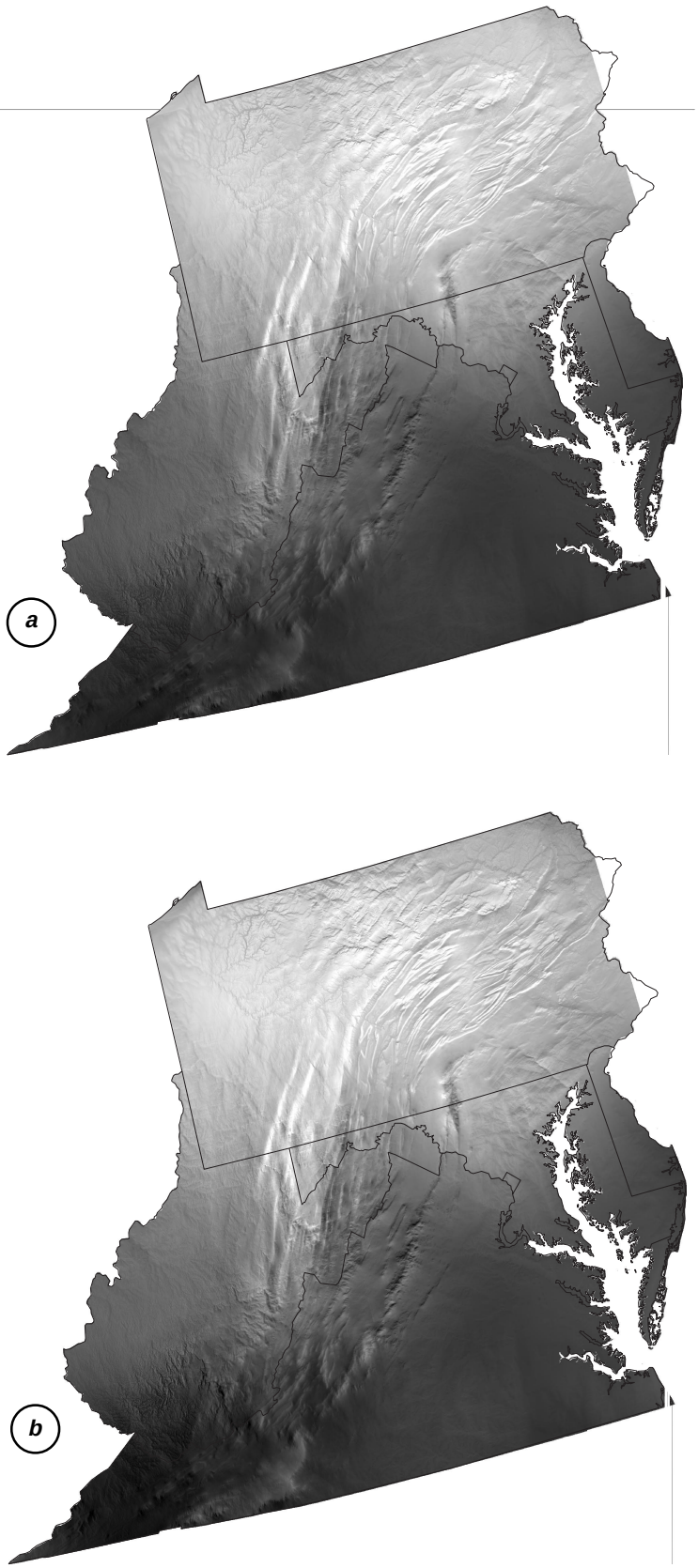
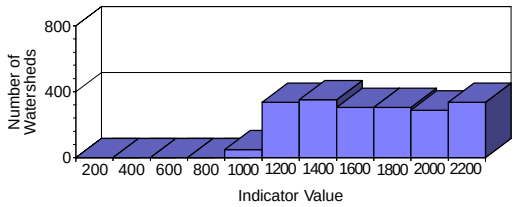


Figure 3.12a

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.

Quintile	Data Range (Kg./Ha. x 100)
1	< 1213
2	1213 - 1456
3	1456 - 1677
4	1677 - 1965
5	> 1965



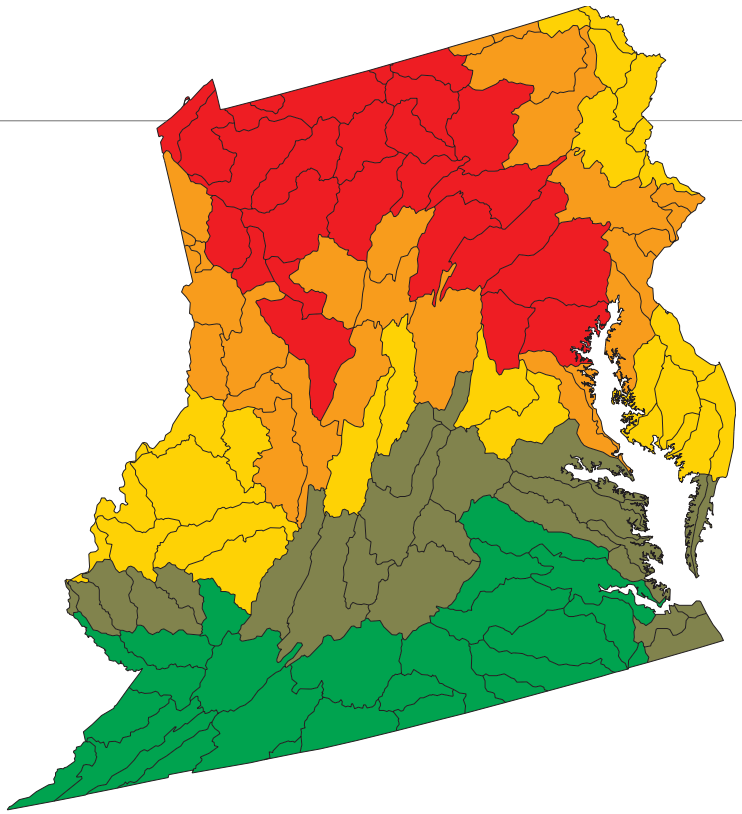
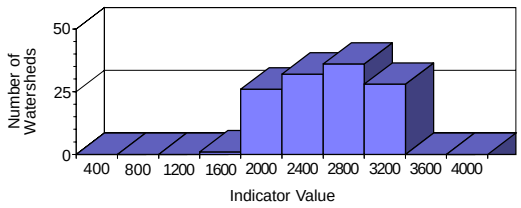


Figure 3.13

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.

Quintile	Data Range (Kg./Ha. x 100)
1	< 1978
2	1978 - 2242
3	2242 - 2562
4	2562 - 2814
5	> 2814



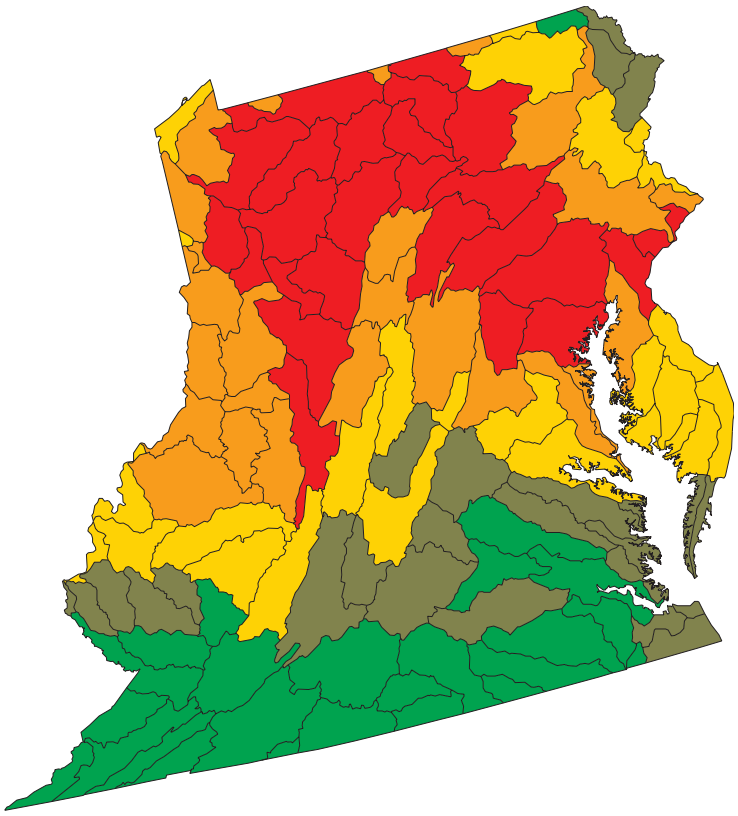
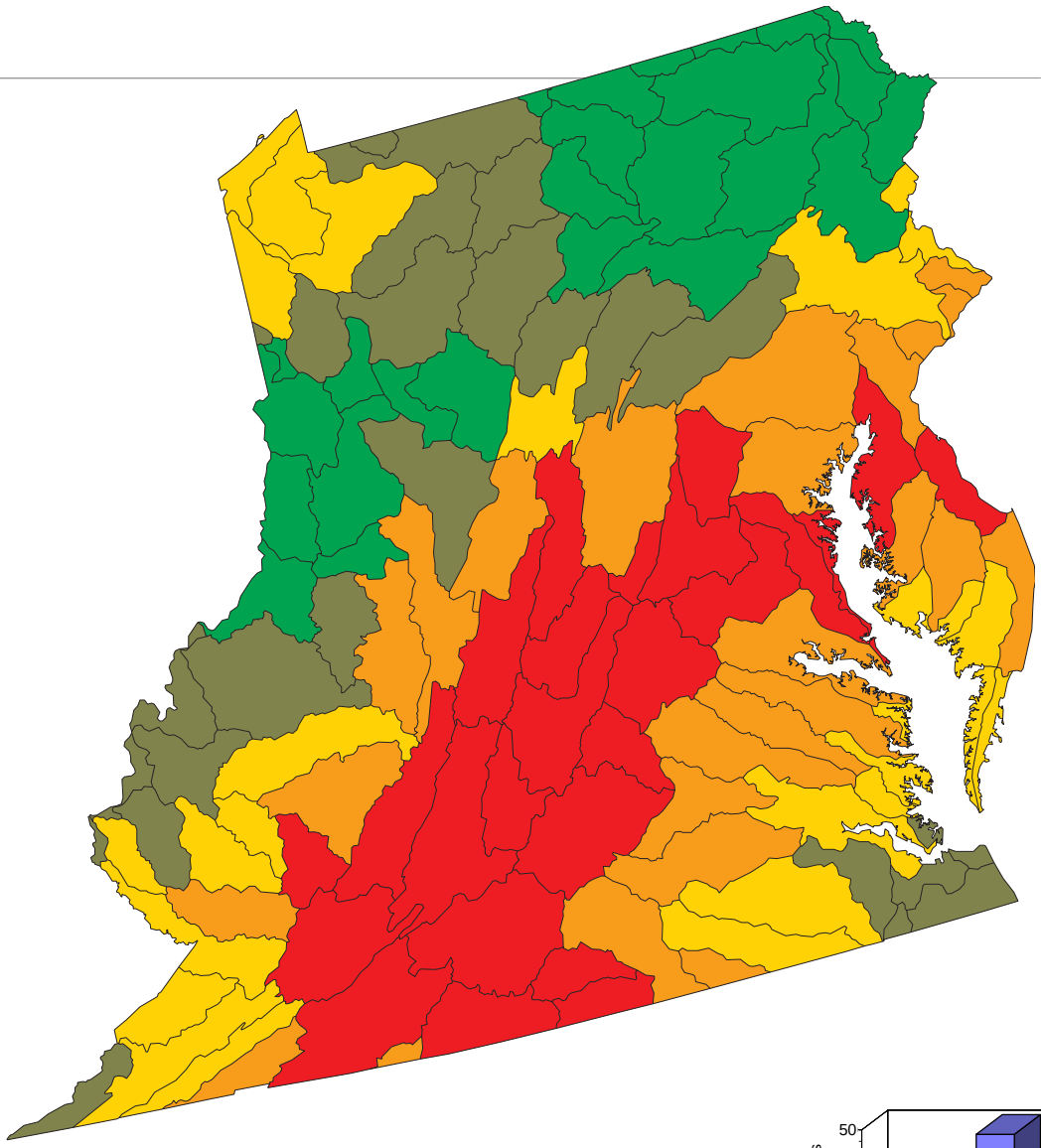


Figure 3.14

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

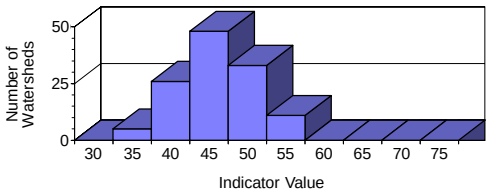


Figure 3.15

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.

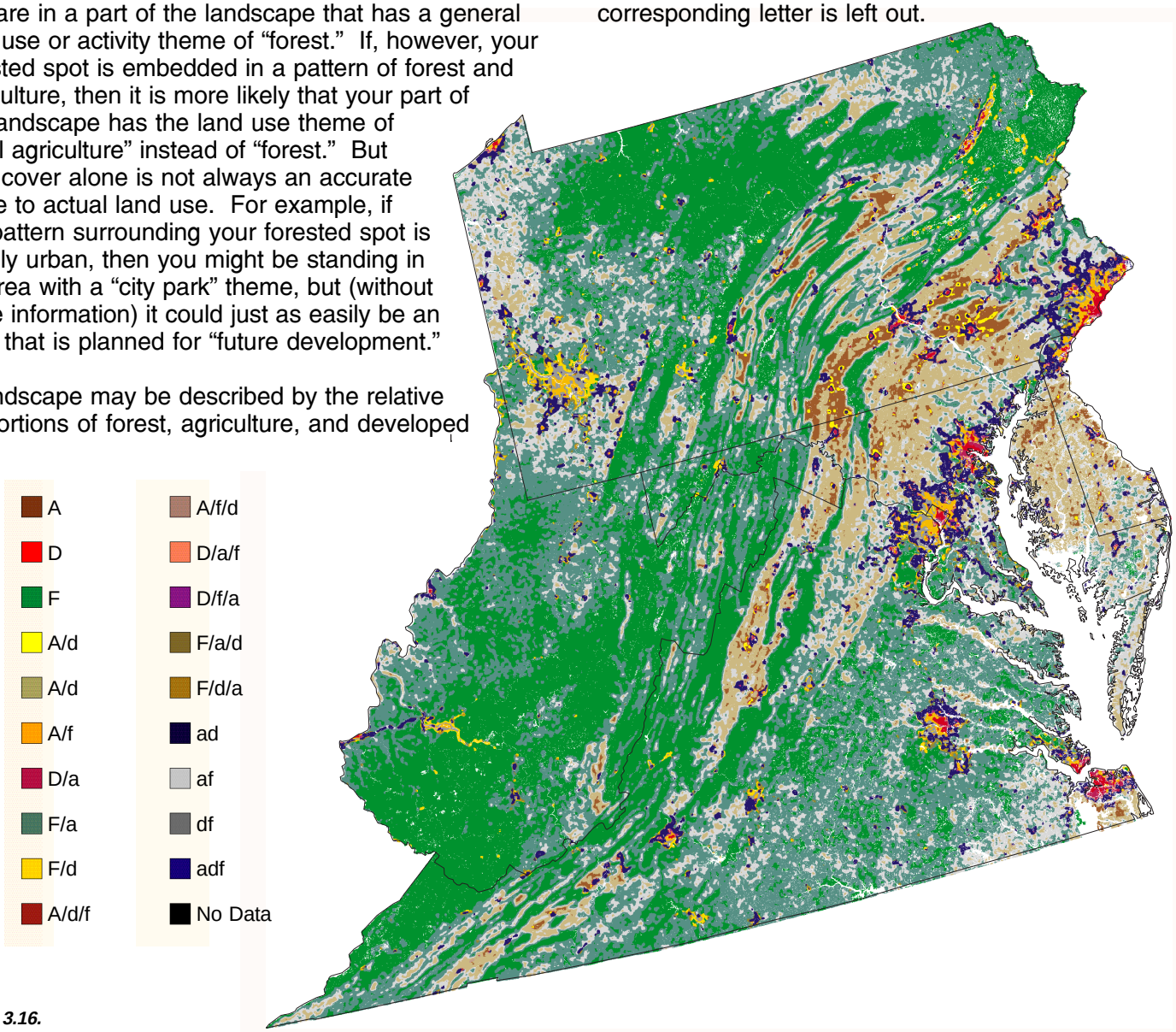


Figure 3.16.

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

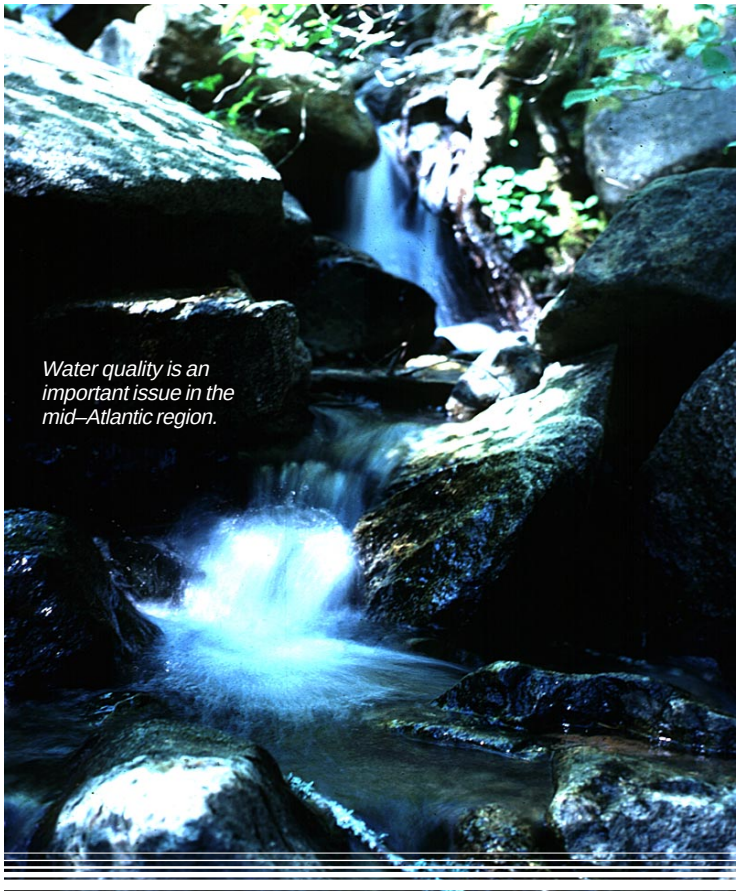
Everyone knows the importance of water. But many people do not realize how much its quality depends on the surrounding landscape. Water quality, like landscape condition, is an integrated response to environmental stress and land management practices at watershed scales.

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.



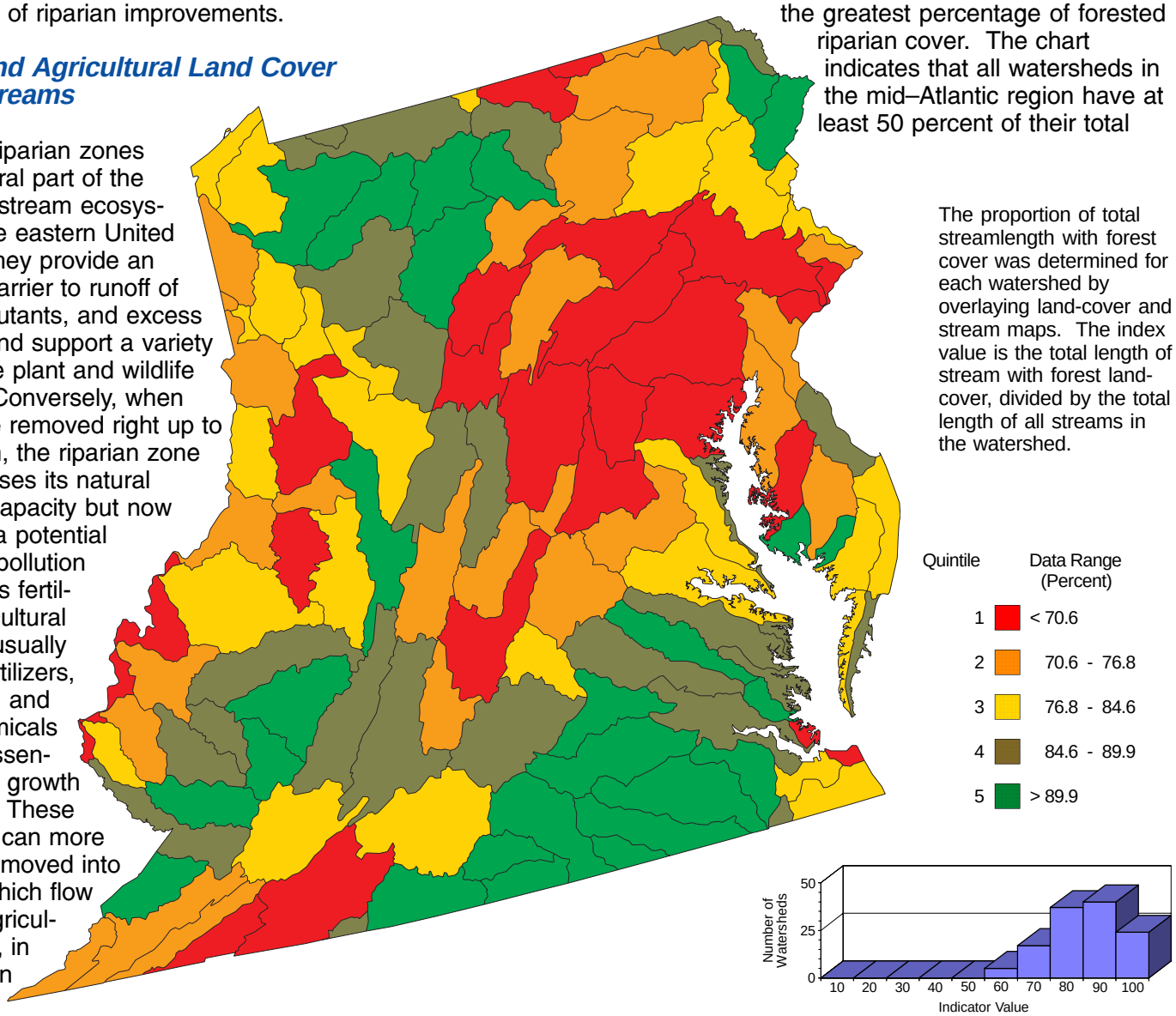
Water quality is an important issue in the mid–Atlantic region.

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



The proportion of total streamlength with forest cover was determined for each watershed by overlaying land-cover and stream maps. The index value is the total length of stream with forest land-cover, divided by the total length of all streams in the watershed.

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.

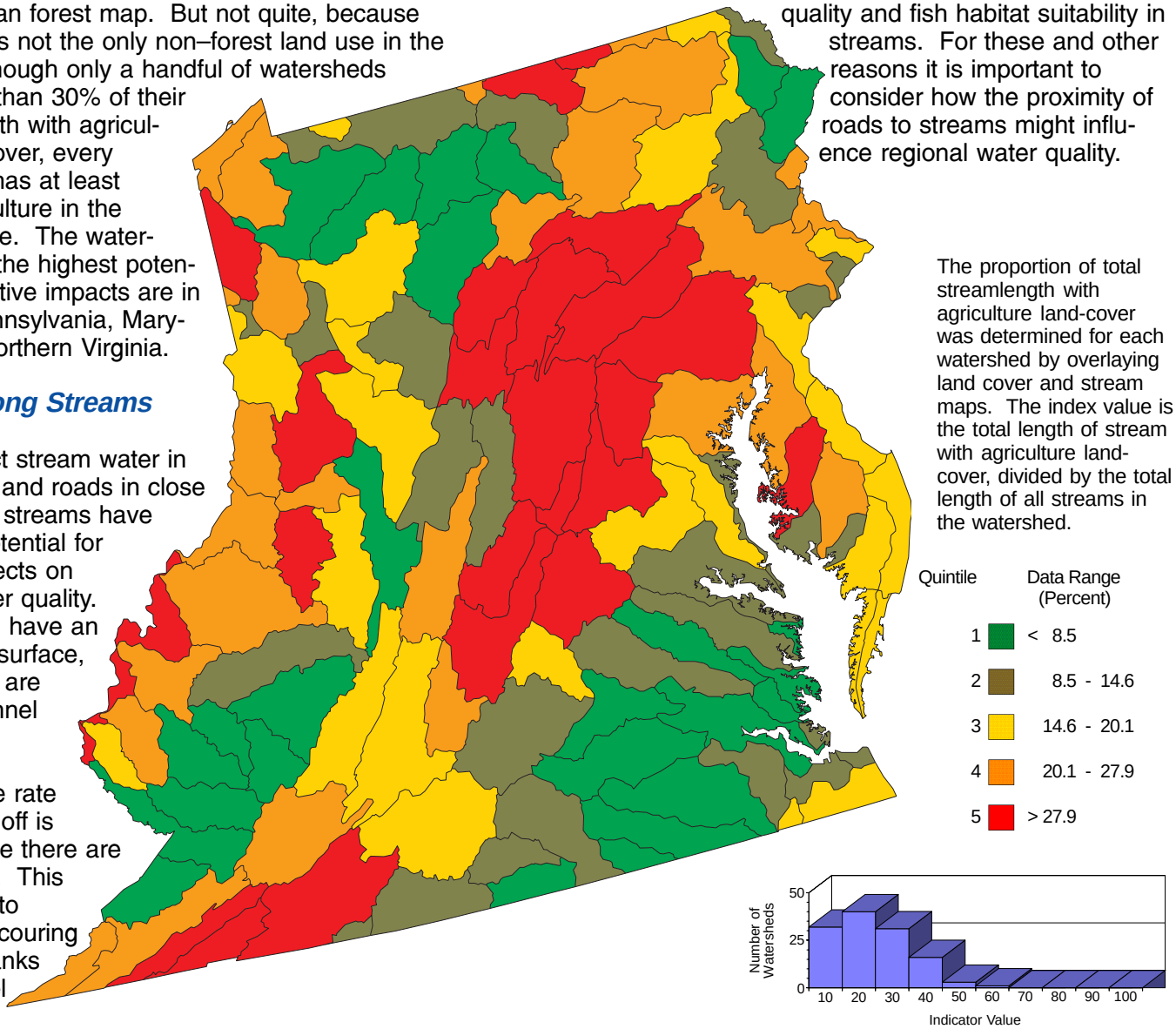


Figure 3.18

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

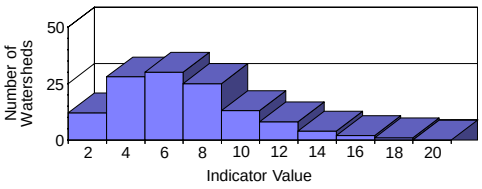
The regional pattern of roads along streams (Figure 3.19) may be surprising because many of the watersheds with a high incidence of roads along streams are located in remote areas which do not have a lot of roads in comparison to the rest of the mid–Atlantic region. The explanation lies in the topography 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.

Watershed Indicators

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.

The proportion of streamlength within 30 meters of a road was calculated by overlaying maps of streams and roads. The index value is the proportion of total streamlength in a watershed within 30 meters of a road

Quintile	Data Range (Percent)
1	< 2.8
2	2.8 - 4.6
3	4.6 - 6.2
4	6.2 - 8.3
5	> 8.3



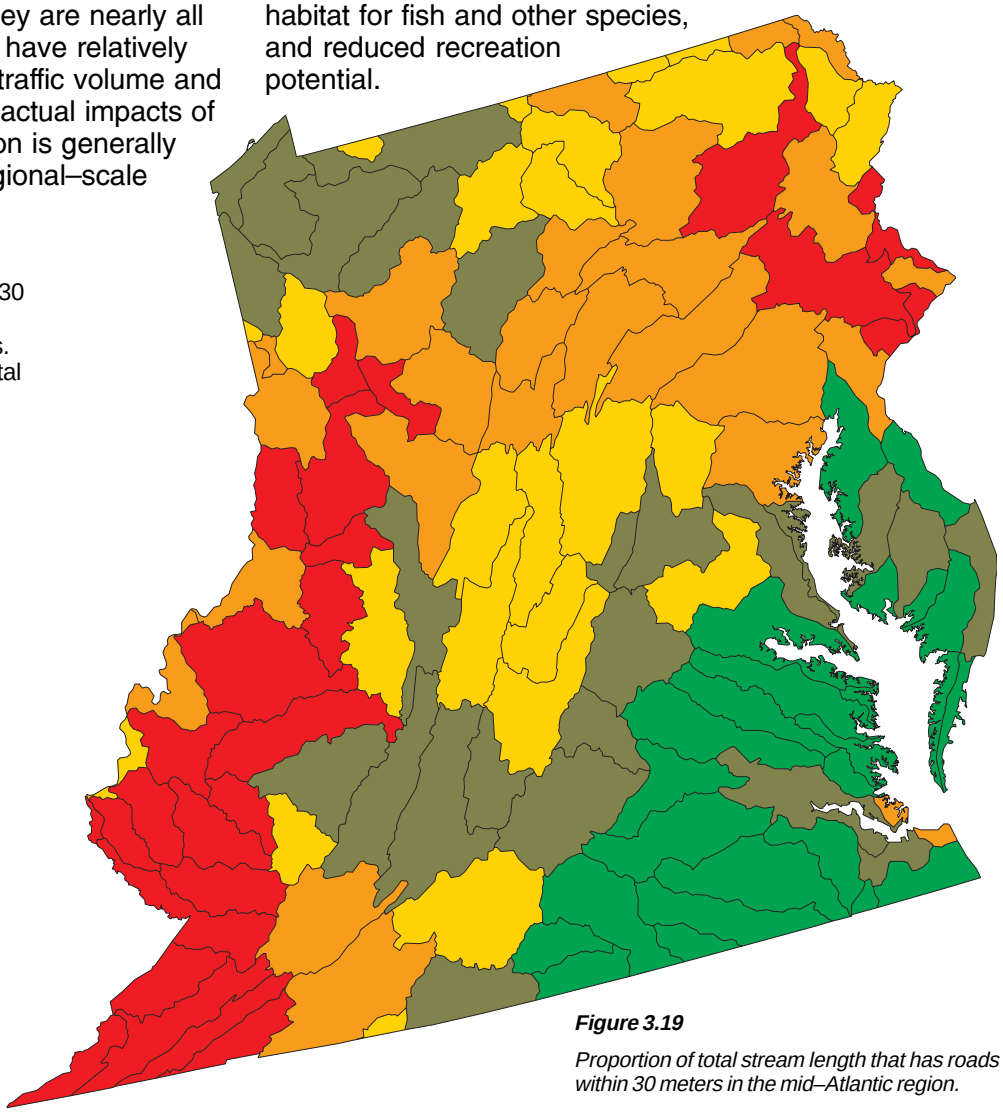


Figure 3.19

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

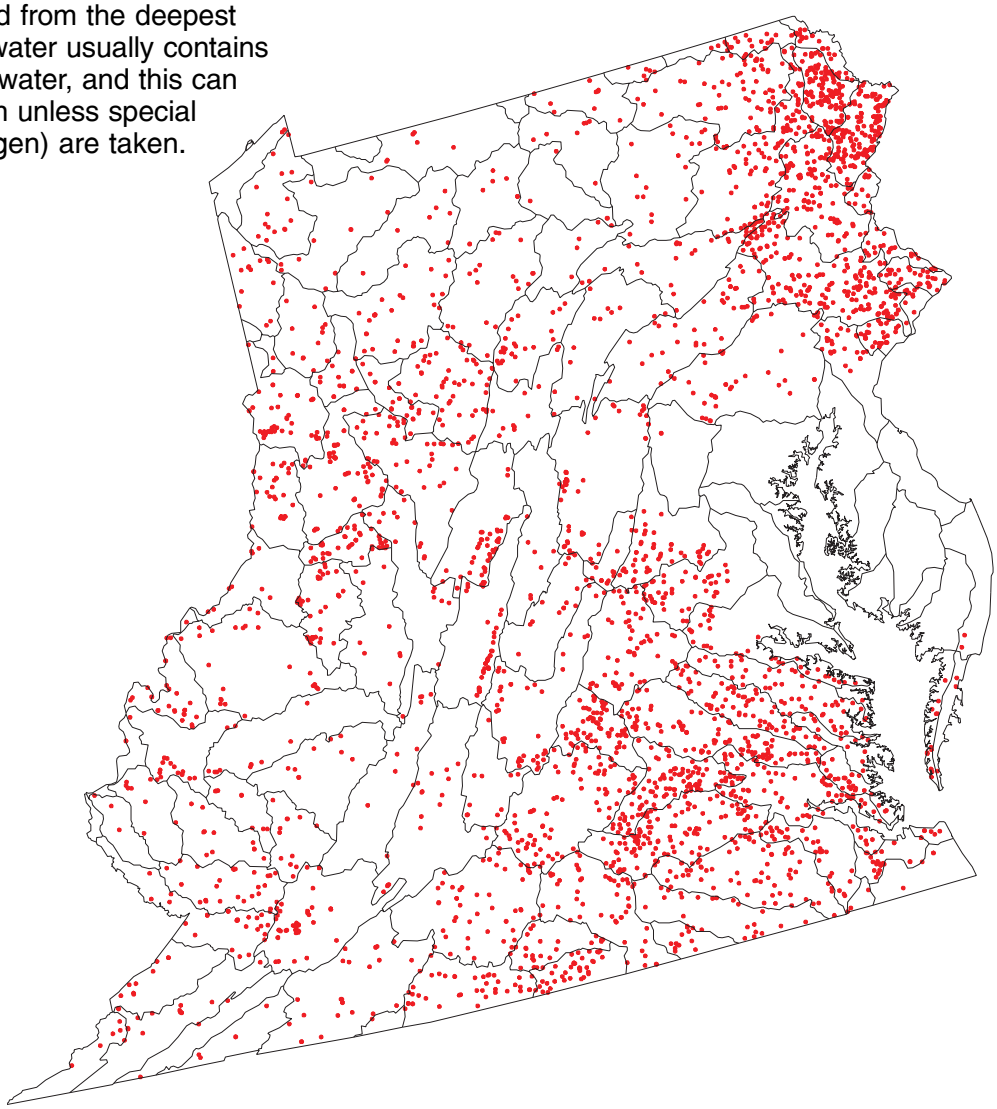


Figure 3.20

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

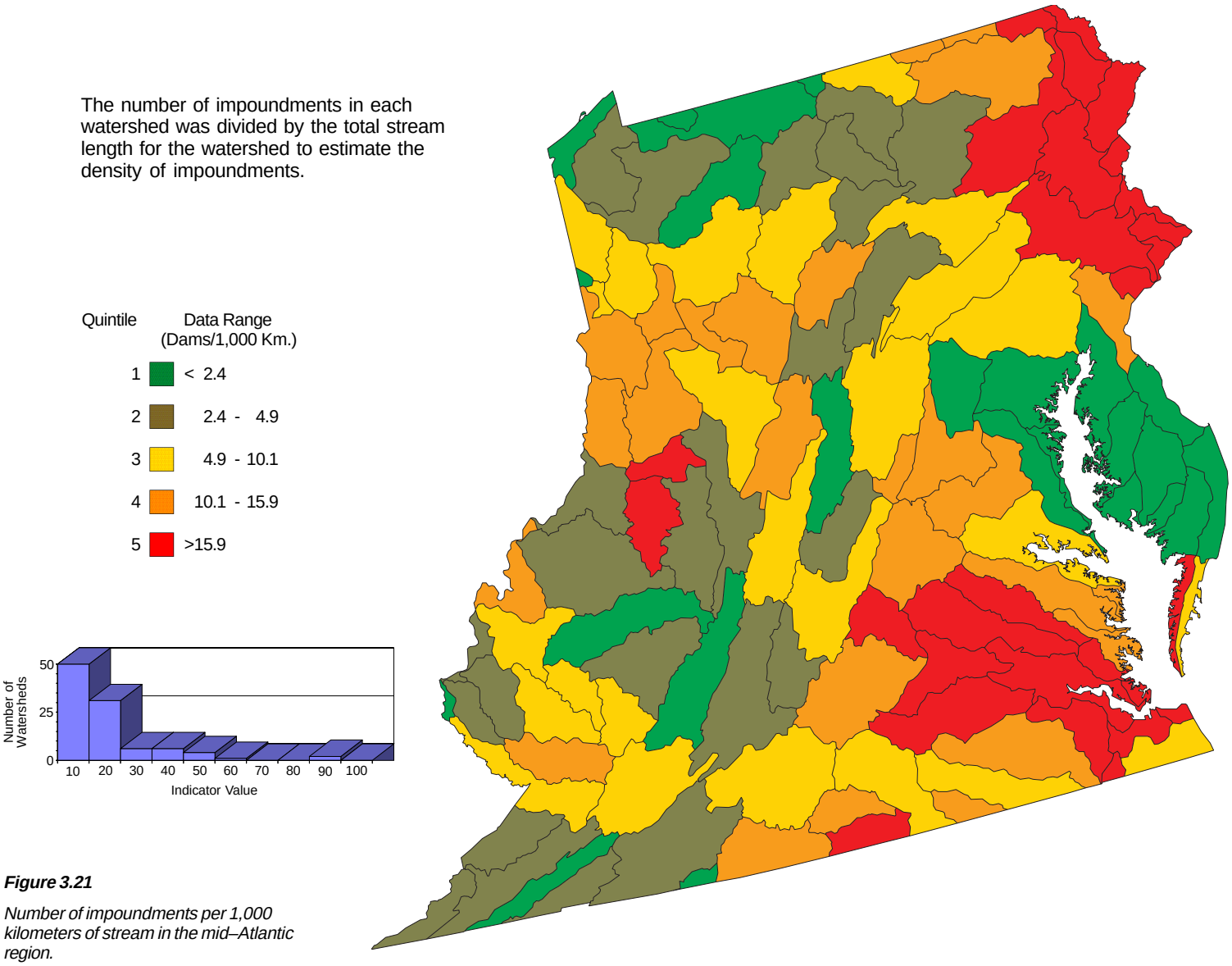


Figure 3.21

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

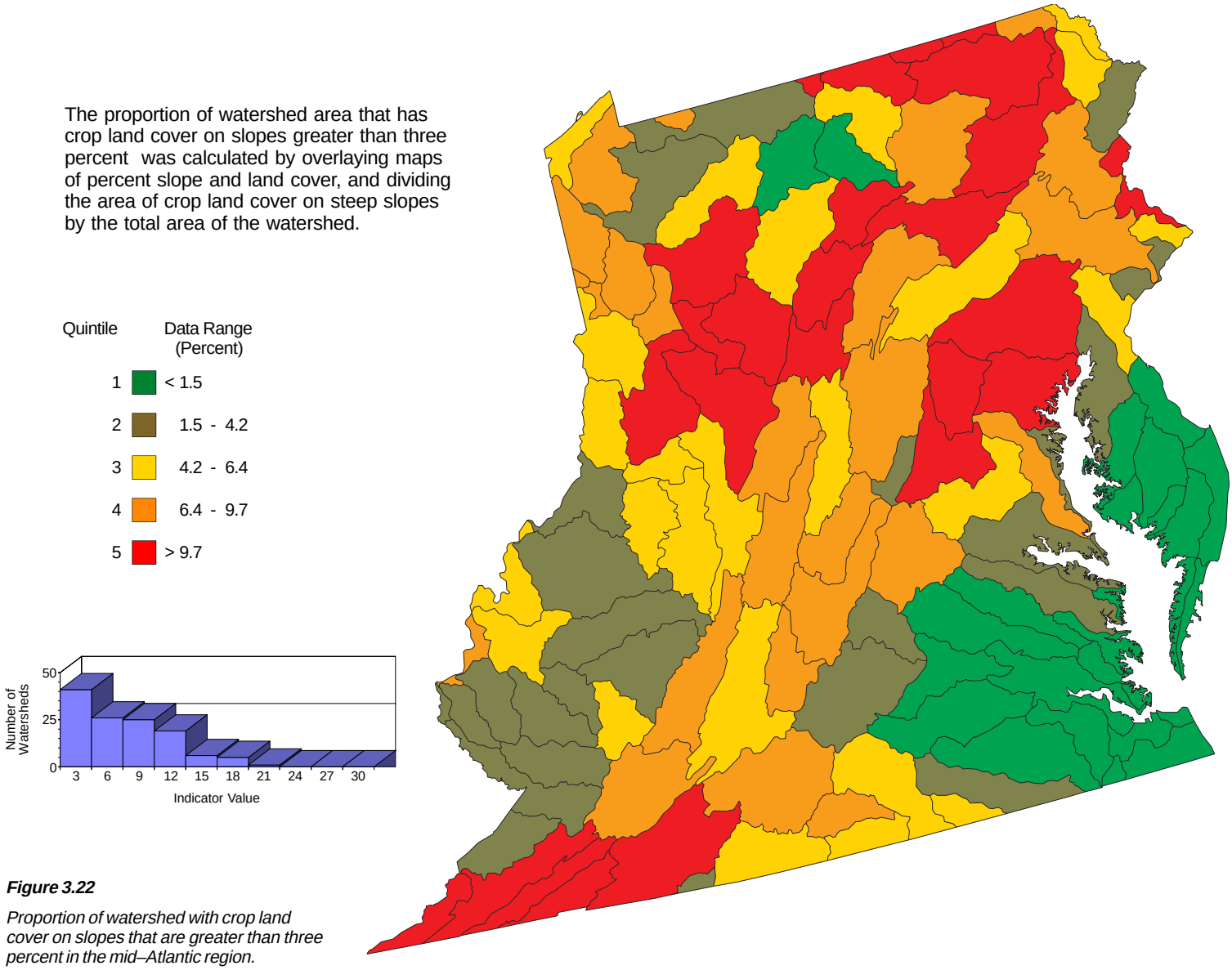


Figure 3.22

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-

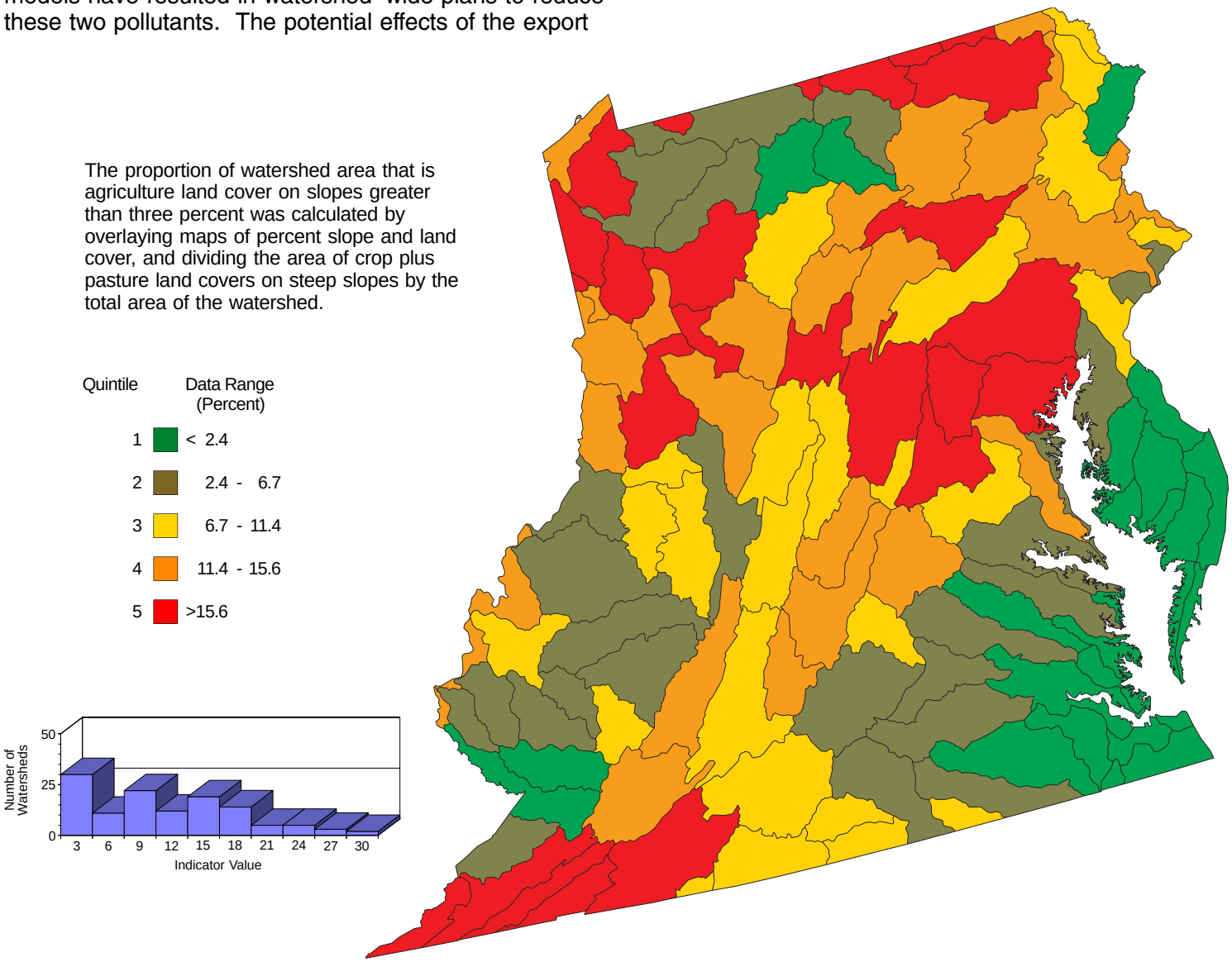


Figure 3.23

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.

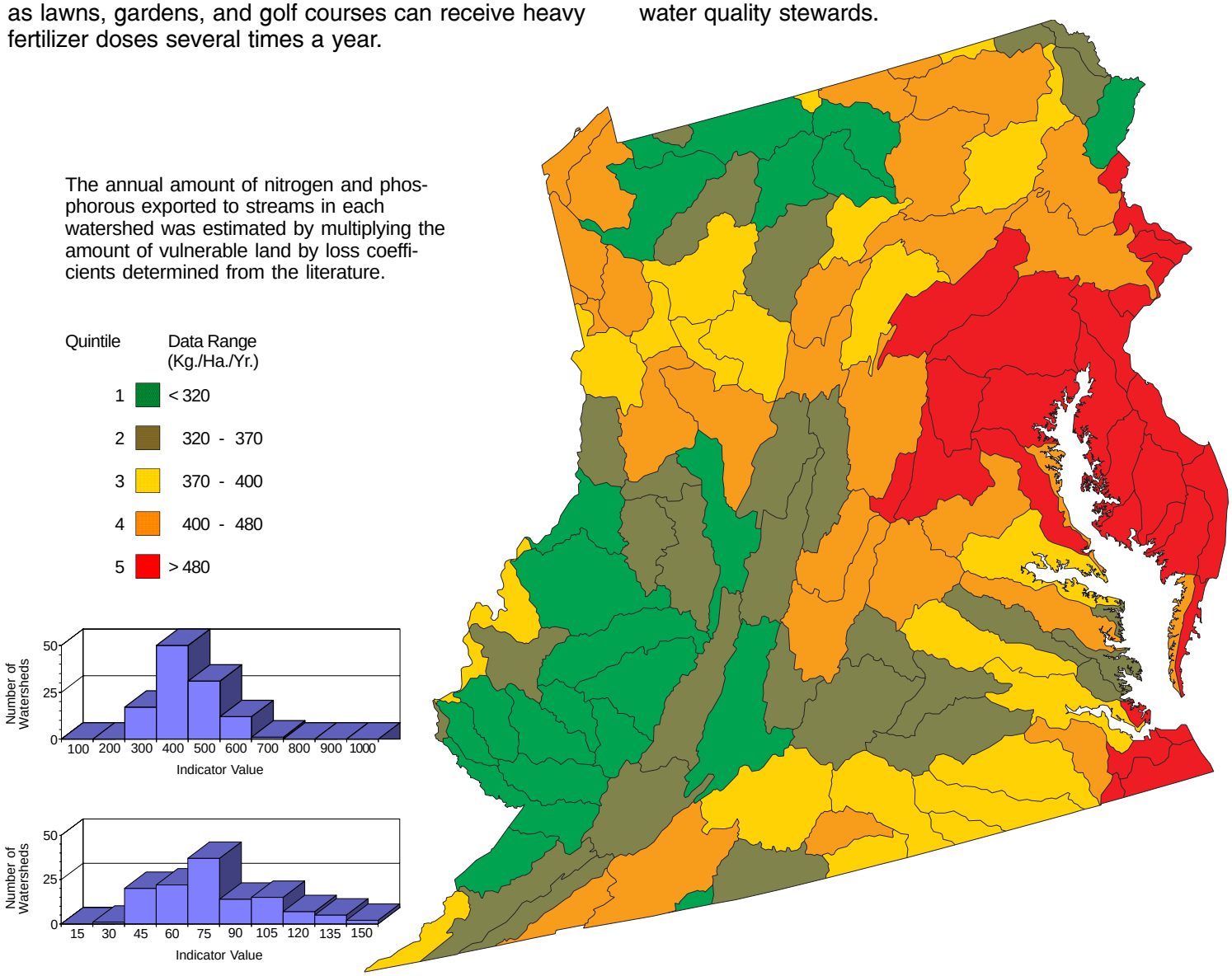


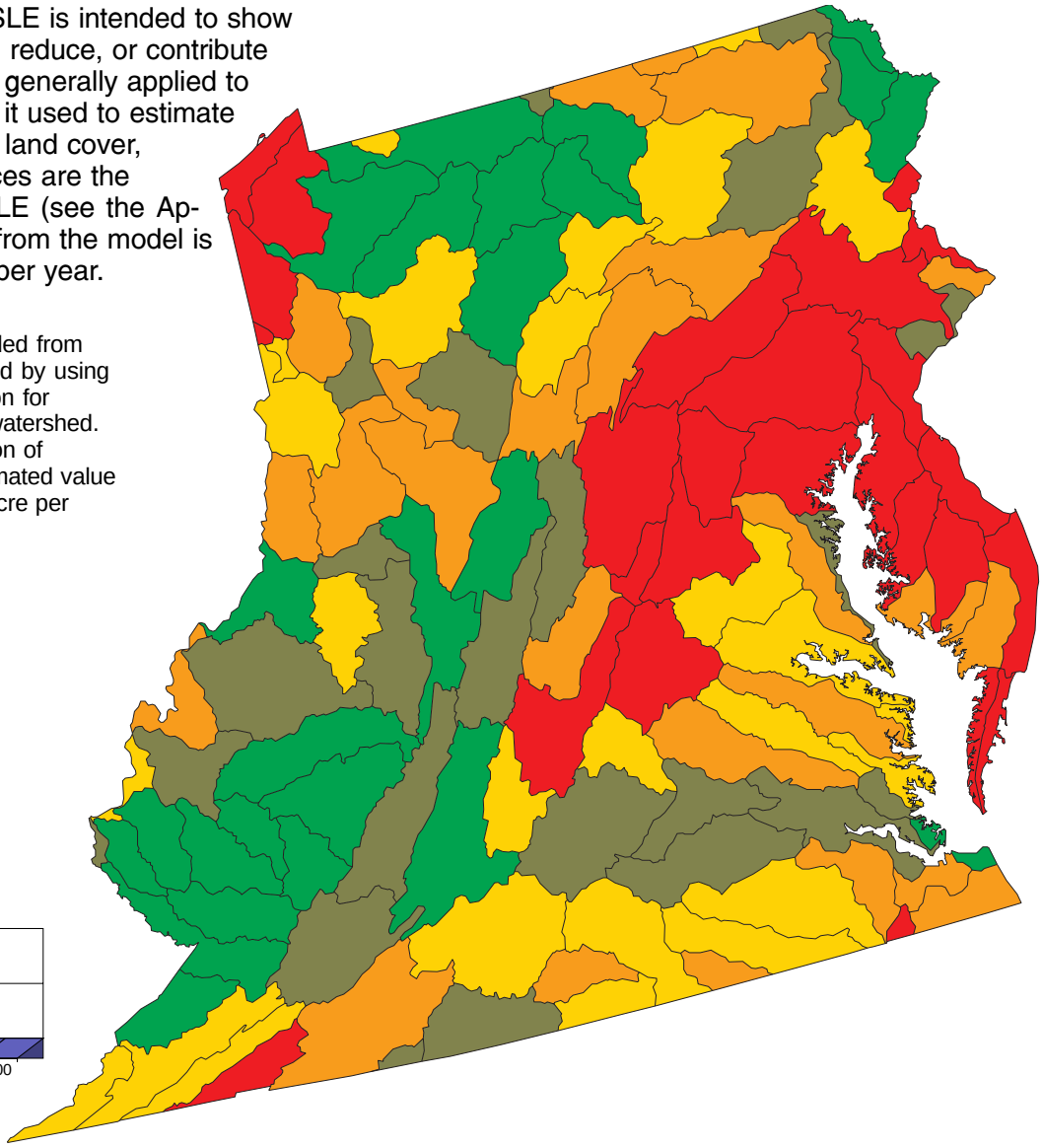
Figure 3.24

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.



The annual amount of soil eroded from agricultural pixels was estimated by using the Universal Soil Loss Equation for agricultural lands within each watershed. The index value is the proportion of watershed area where the estimated value was greater than one ton per acre per year.

Quintile	Data Range (Percent)
1	< 11.2
2	11.2 - 19.8
3	19.8 - 24.0
4	24.0 - 35.3
5	> 35.3

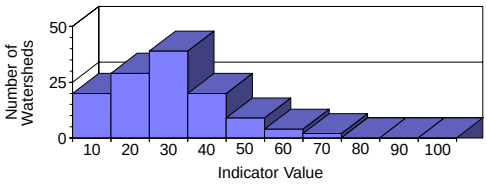


Figure 3.25

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.

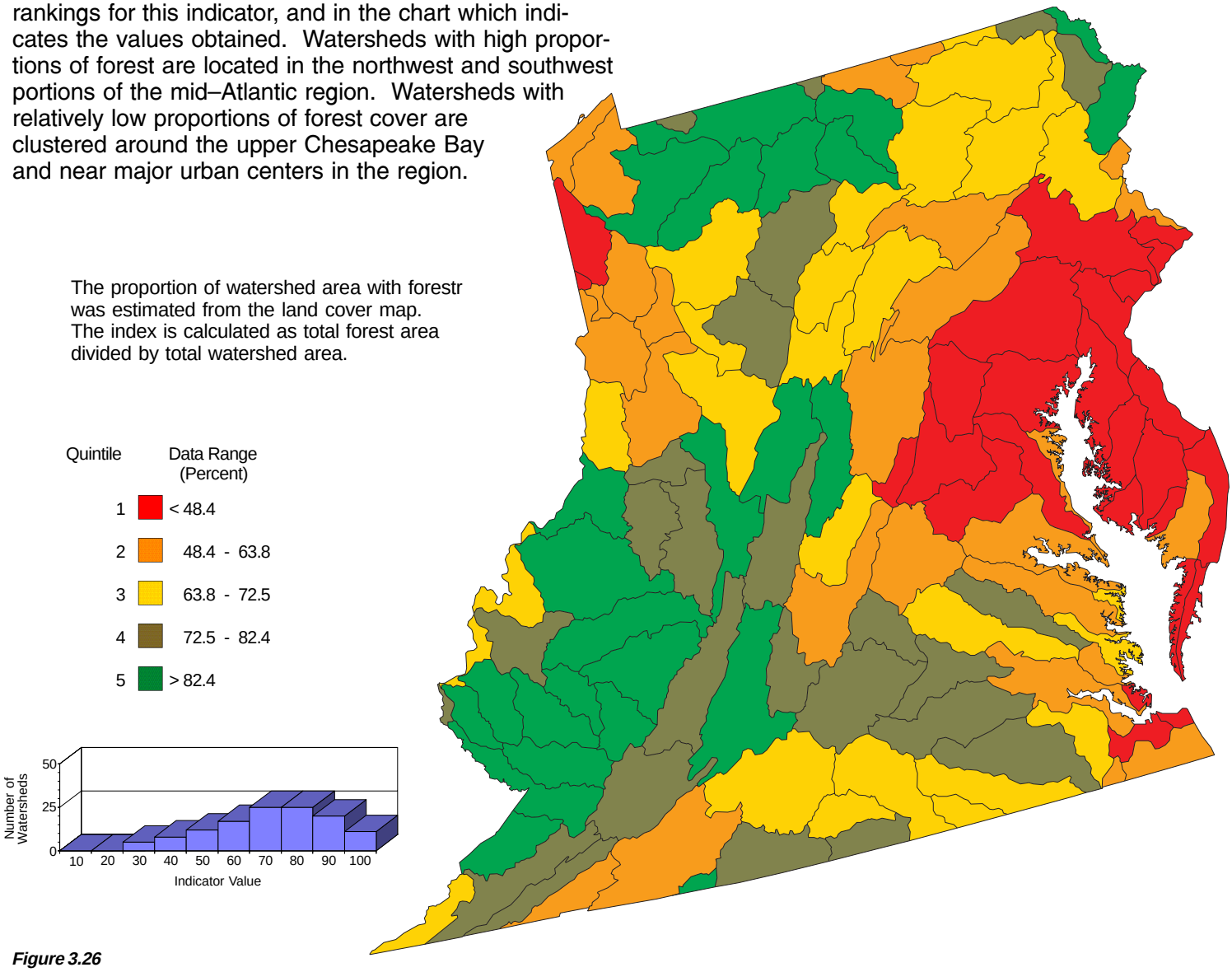


Figure 3.26

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.

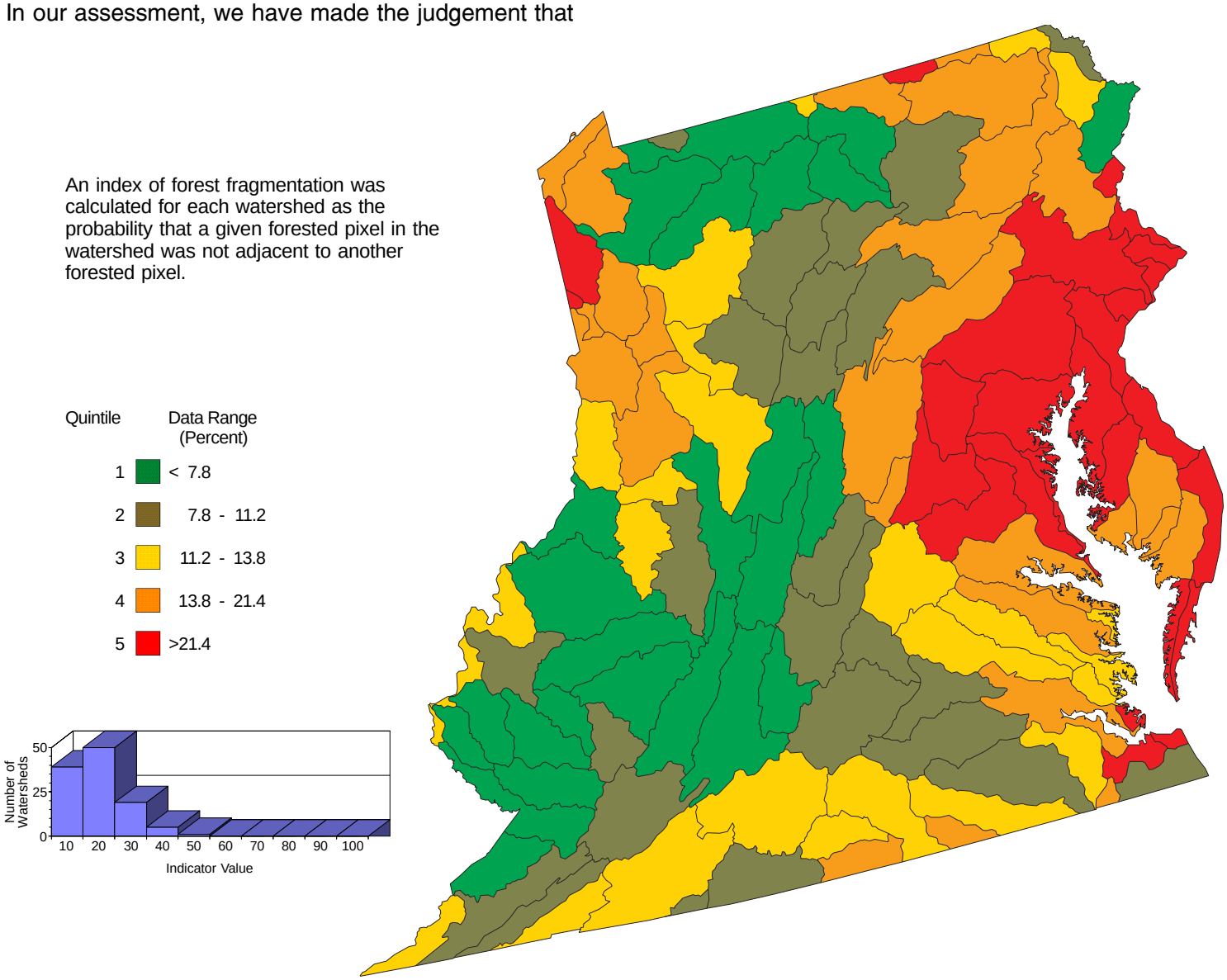


Figure 3.27.

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.

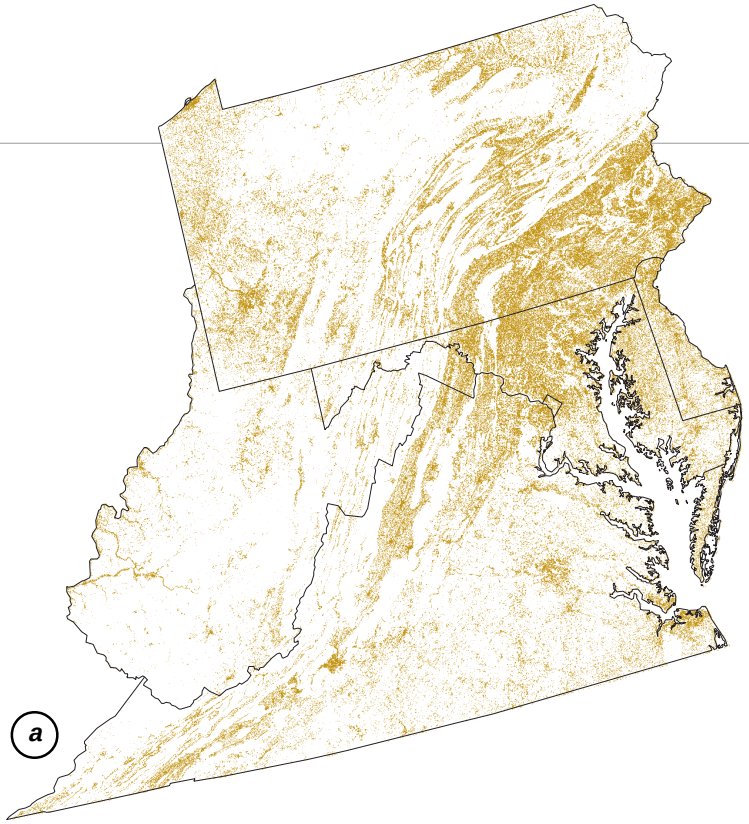


Figure 3.28.
Surface maps of forest edge habitat, shown in olive, at (a) 7 hectare, (b) 65 hectare, and (c) 600 hectare scale in the mid–Atlantic region (see text for explanation).

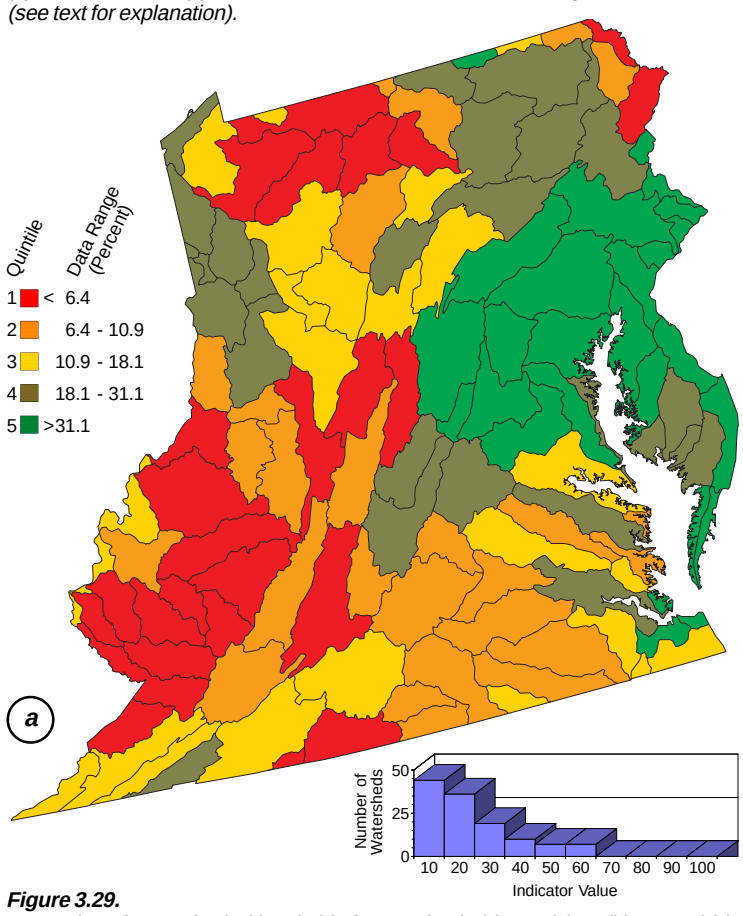
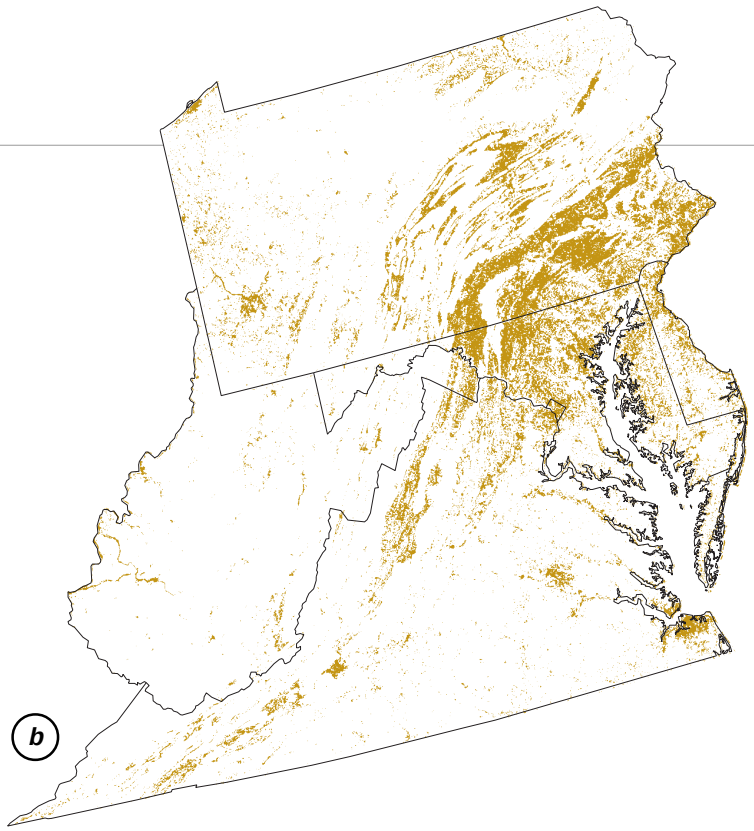
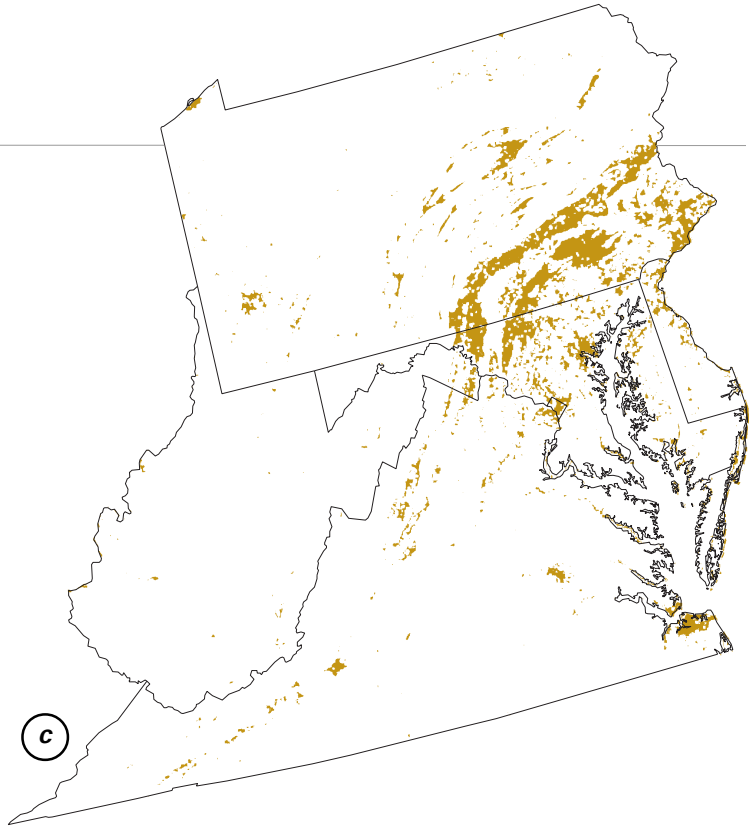
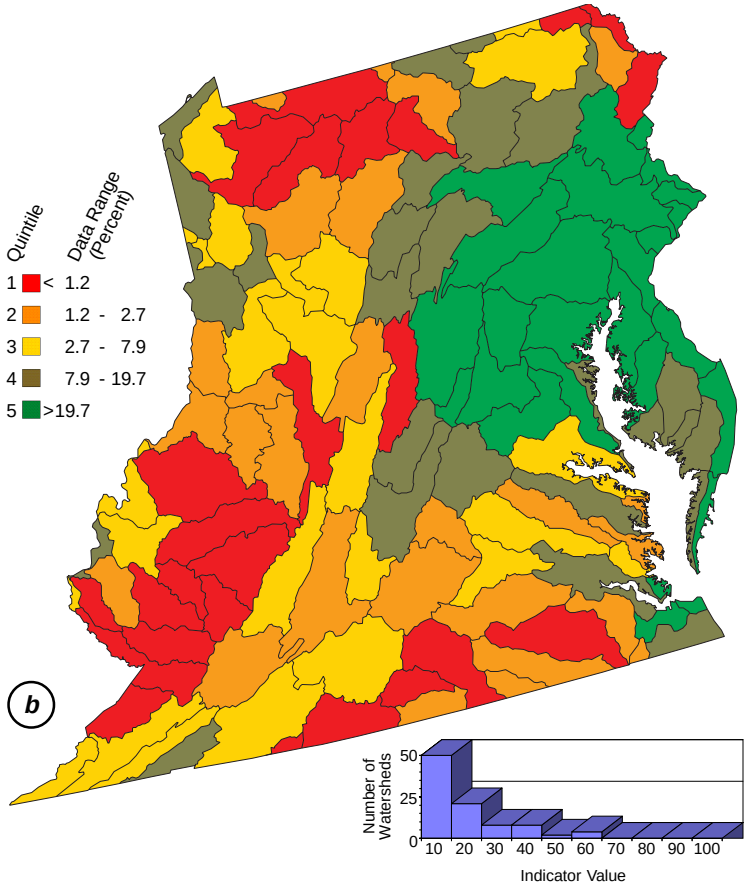
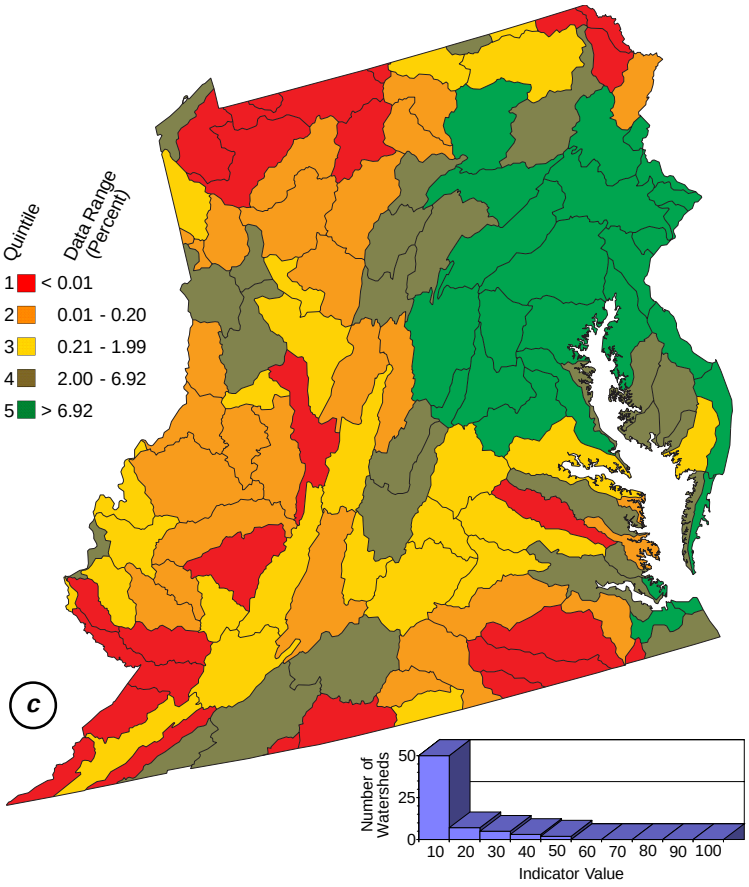


Figure 3.29.
Proportion of watershed with suitable forest edge habitat at (a) 7, (b) 65, and (c) 600 hectare scale in the mid–Atlantic region.


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
50
25
0
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
50
25
0
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.

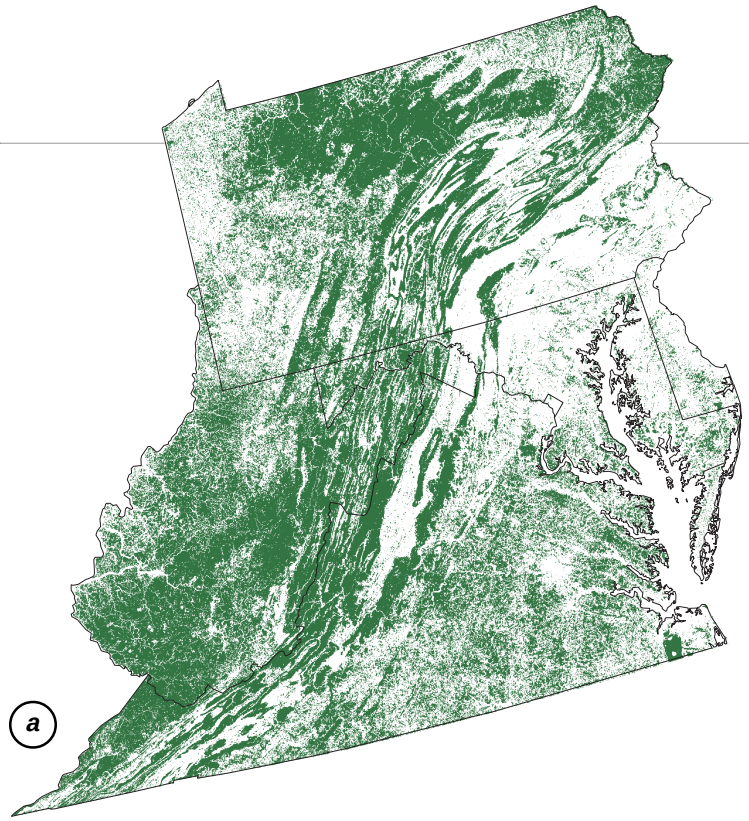


Figure 3.30
Surface map of interior forest habitat, shown in green, at (a) 7 hectare, (b) 65 hectare, and (c) 600 hectare scale in the mid–Atlantic region (see text for explanation).

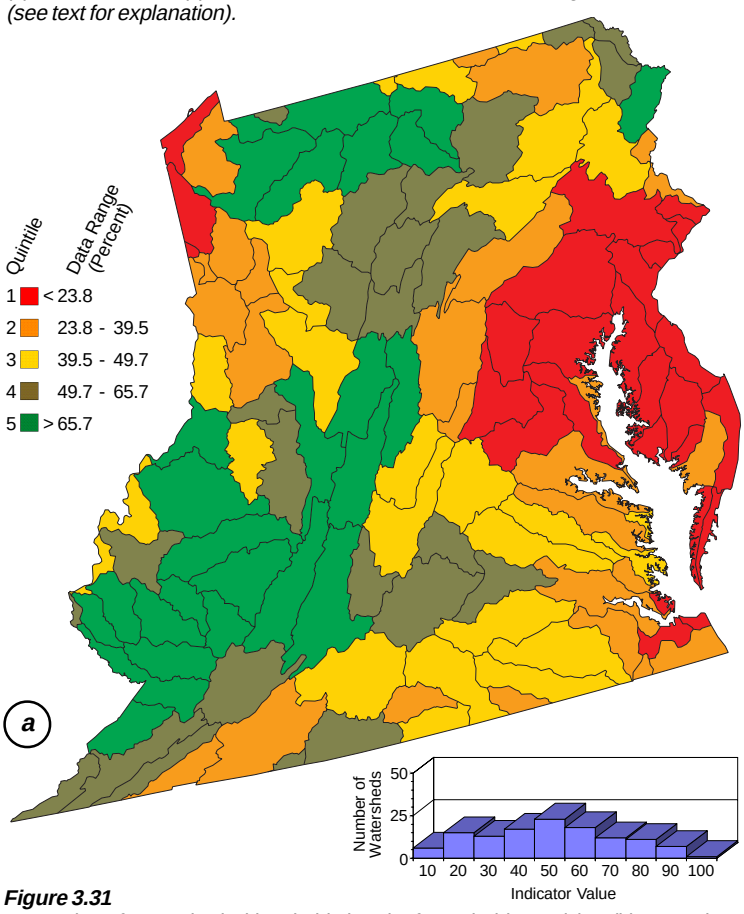
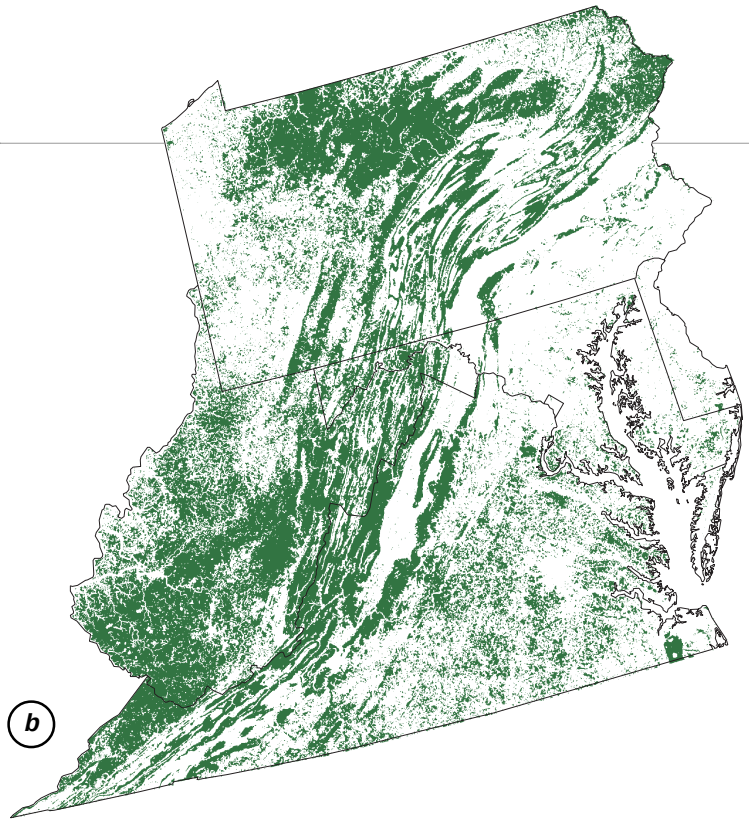
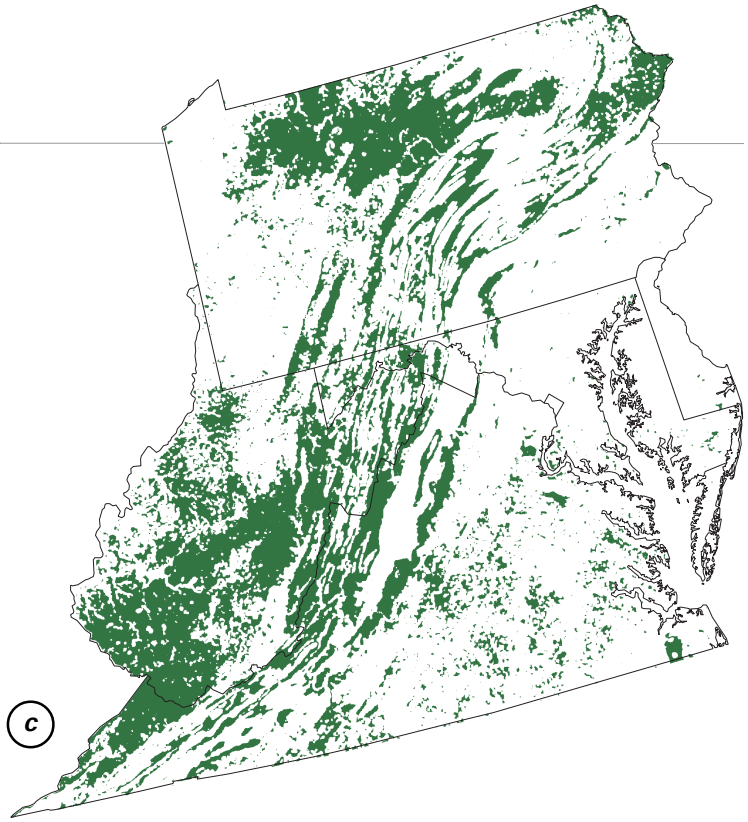
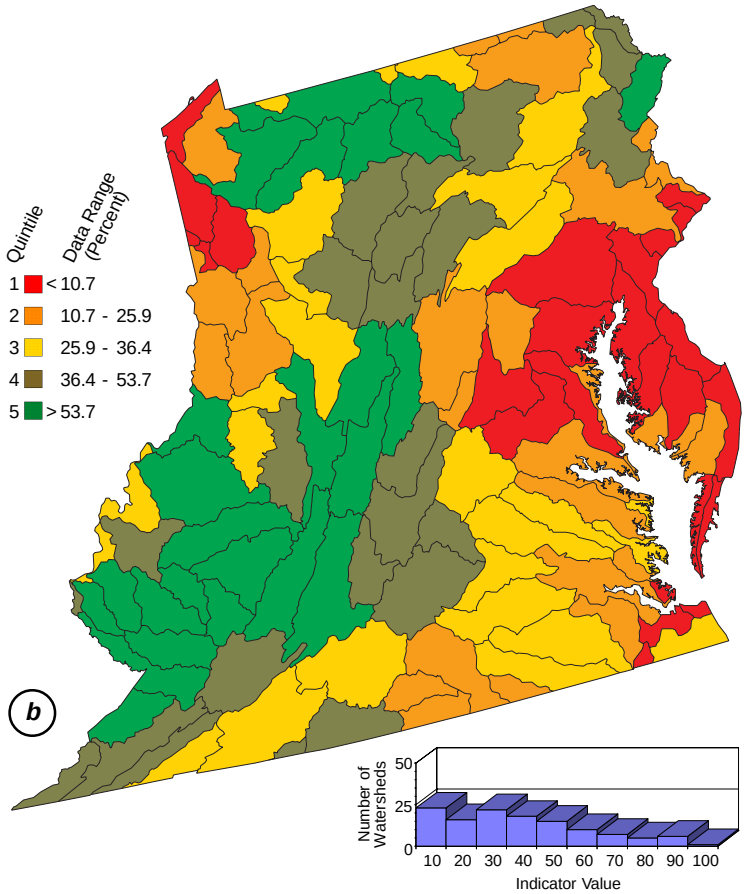


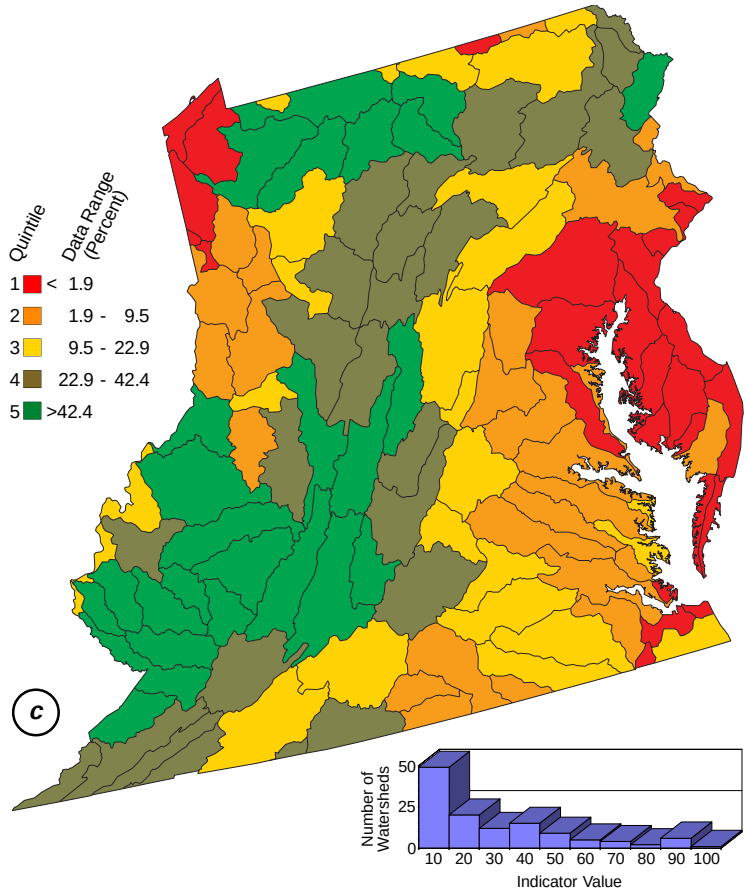
Figure 3.31
Proportion of watershed with suitable interior forest habitat at (a) 7, (b) 65, and (c) 600 hectare scale in the mid–Atlantic region.

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
b
Number of Watersheds
50
25
0
10 20 30 40 50 60 70 80 90 100
Indicator Value


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
c
Number of Watersheds
50
25
0
10 20 30 40 50 60 70 80 90 100
Indicator Value

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.

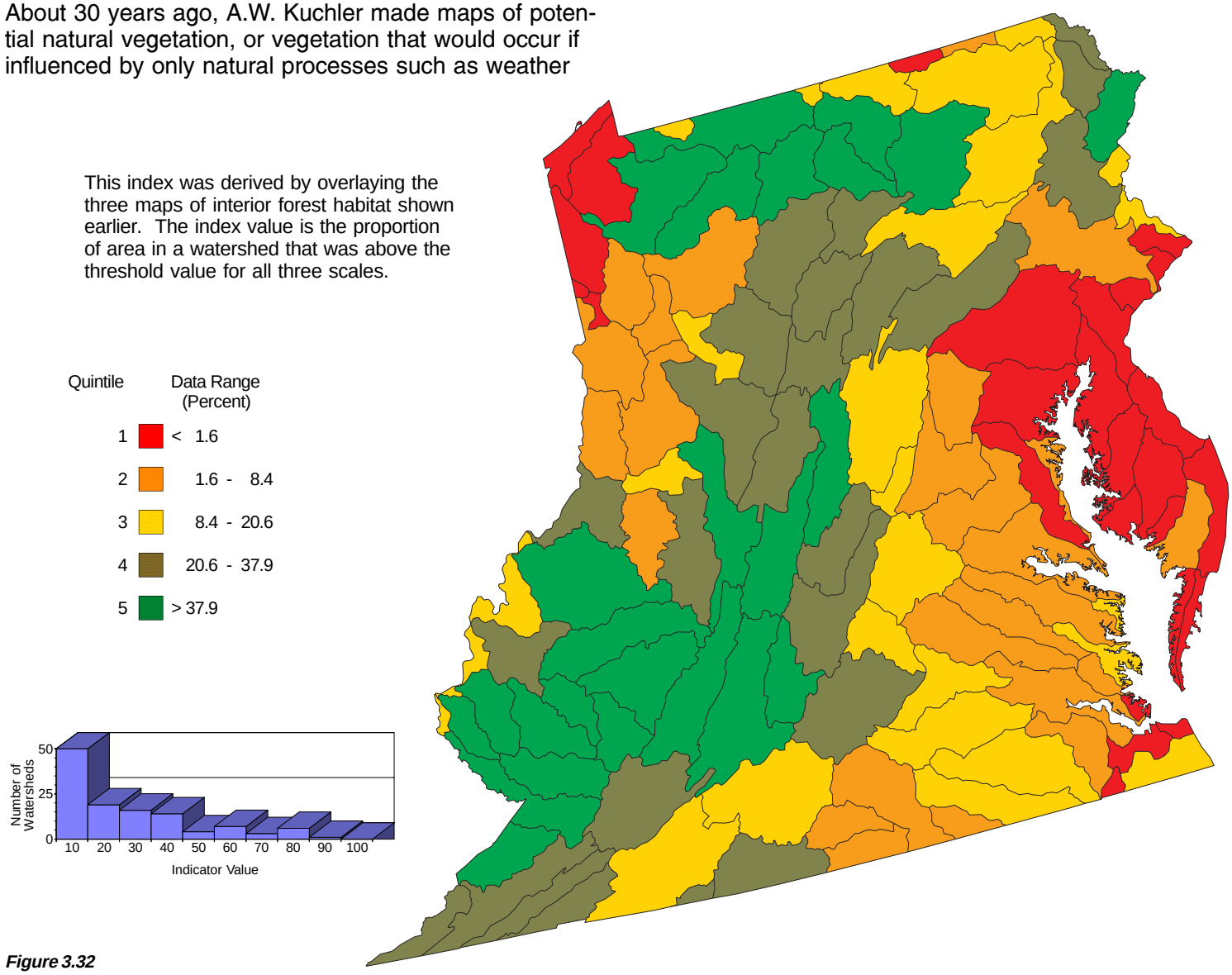


Figure 3.32

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.

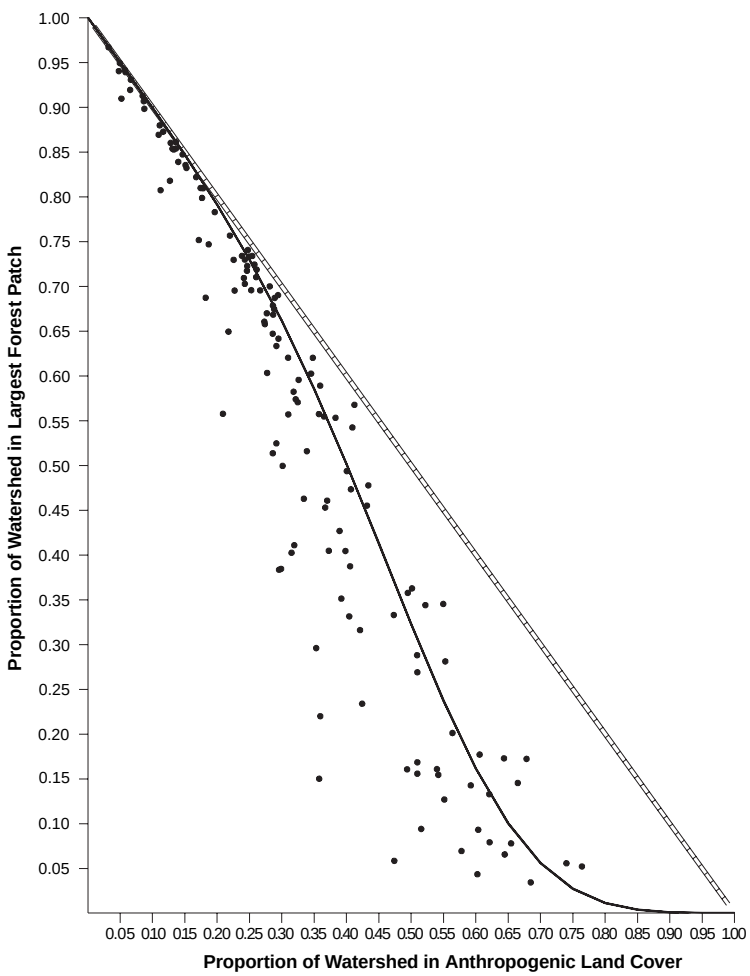


Figure 3.33

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-

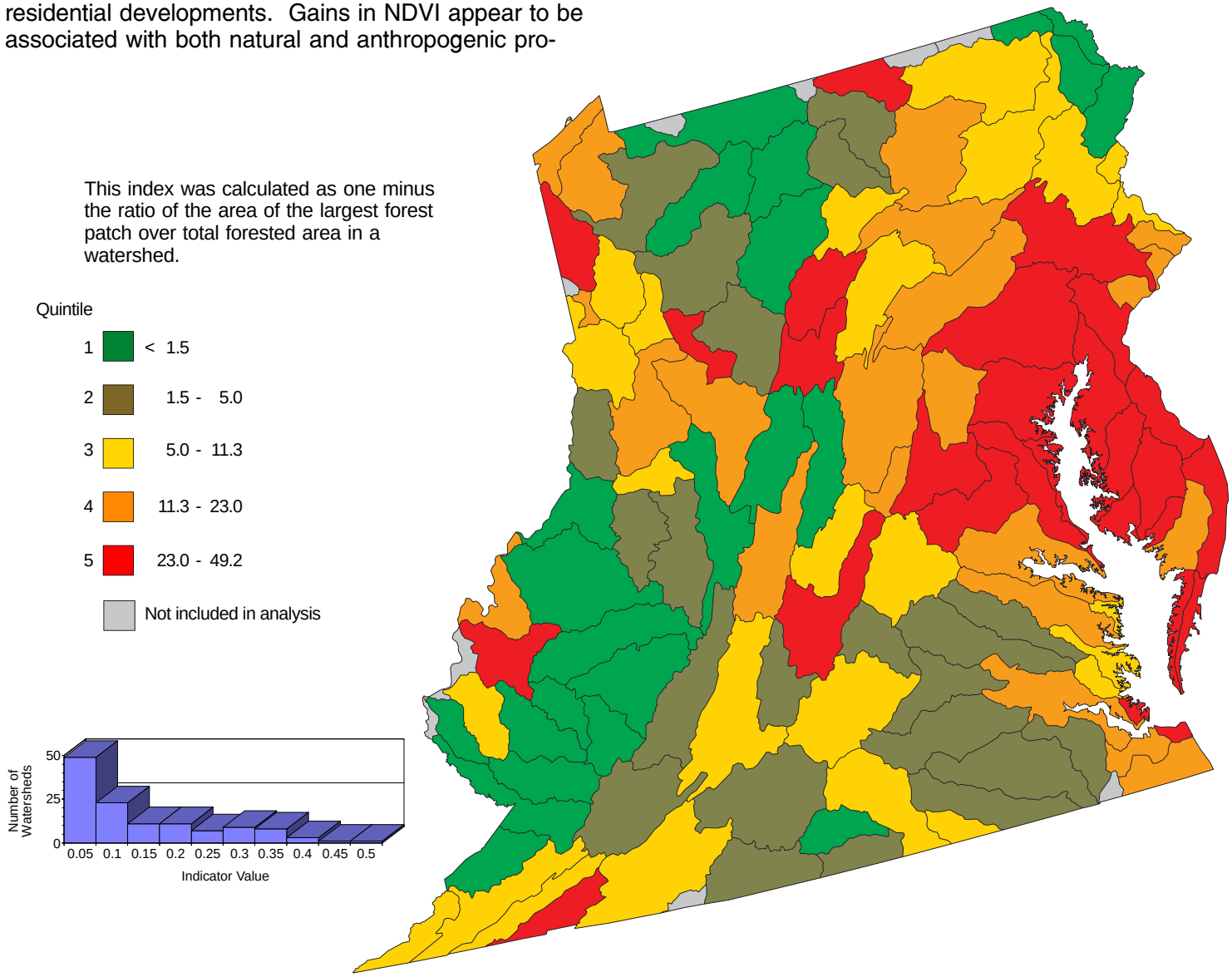


Figure 3.34.

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.

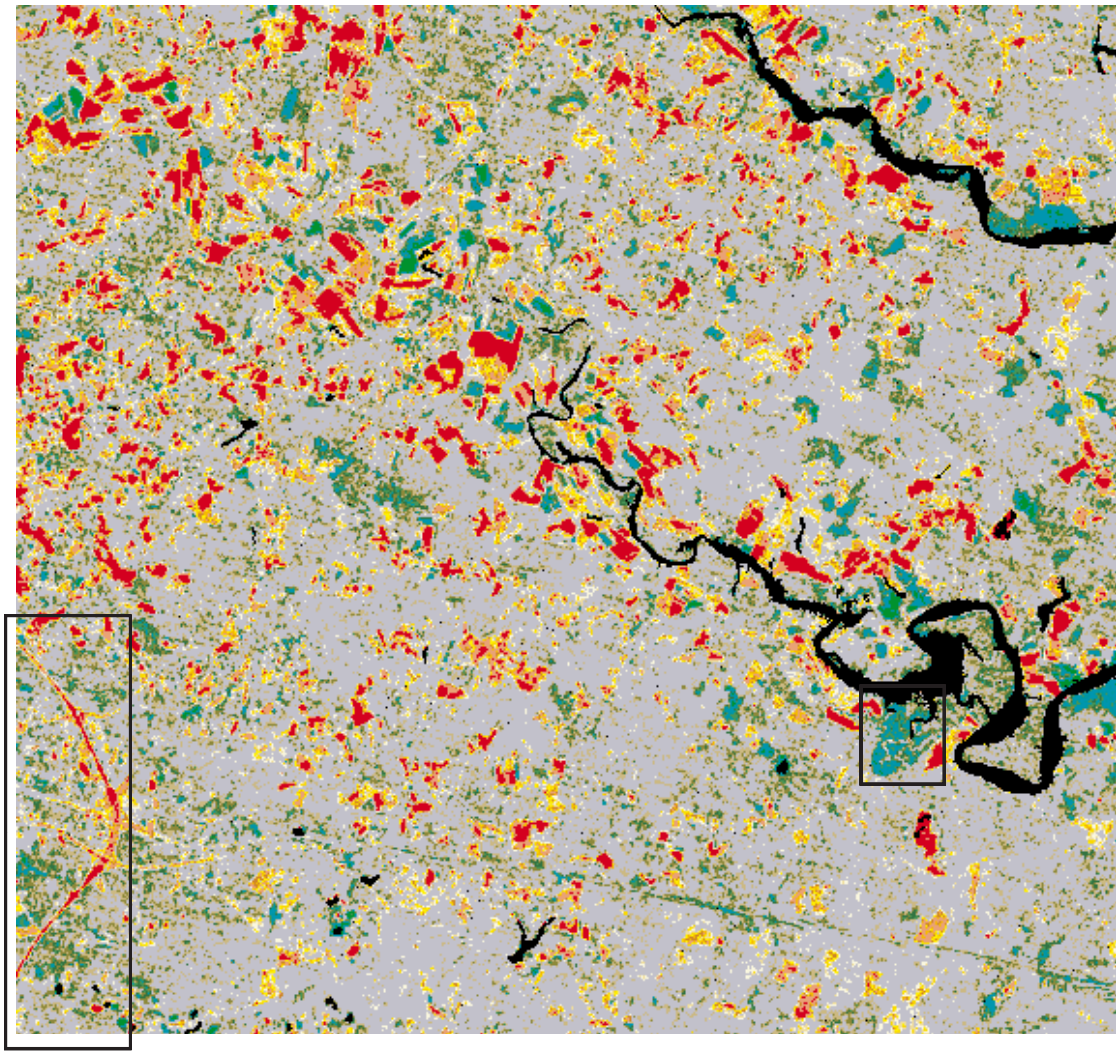


Figure 3.35.

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.

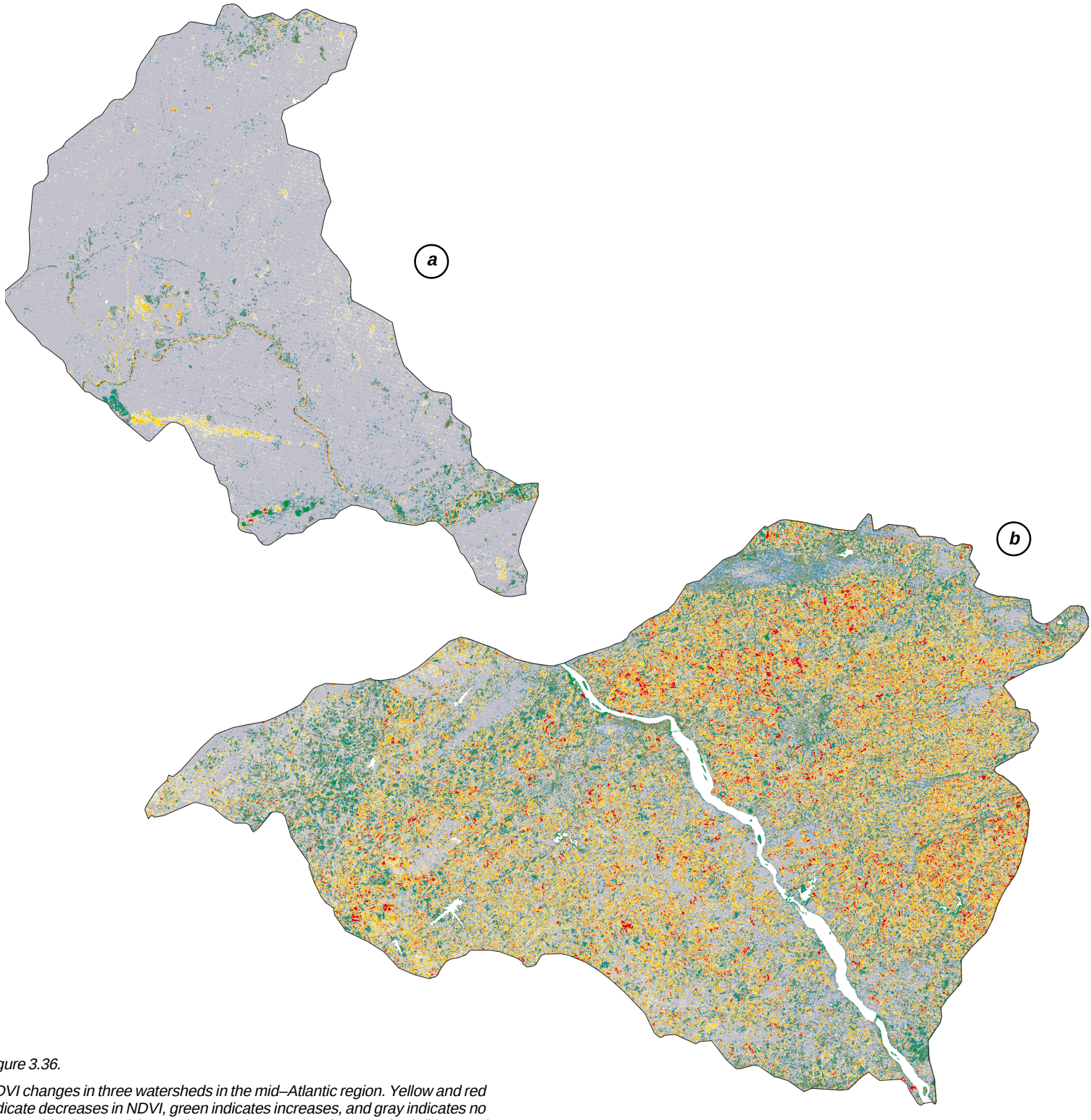
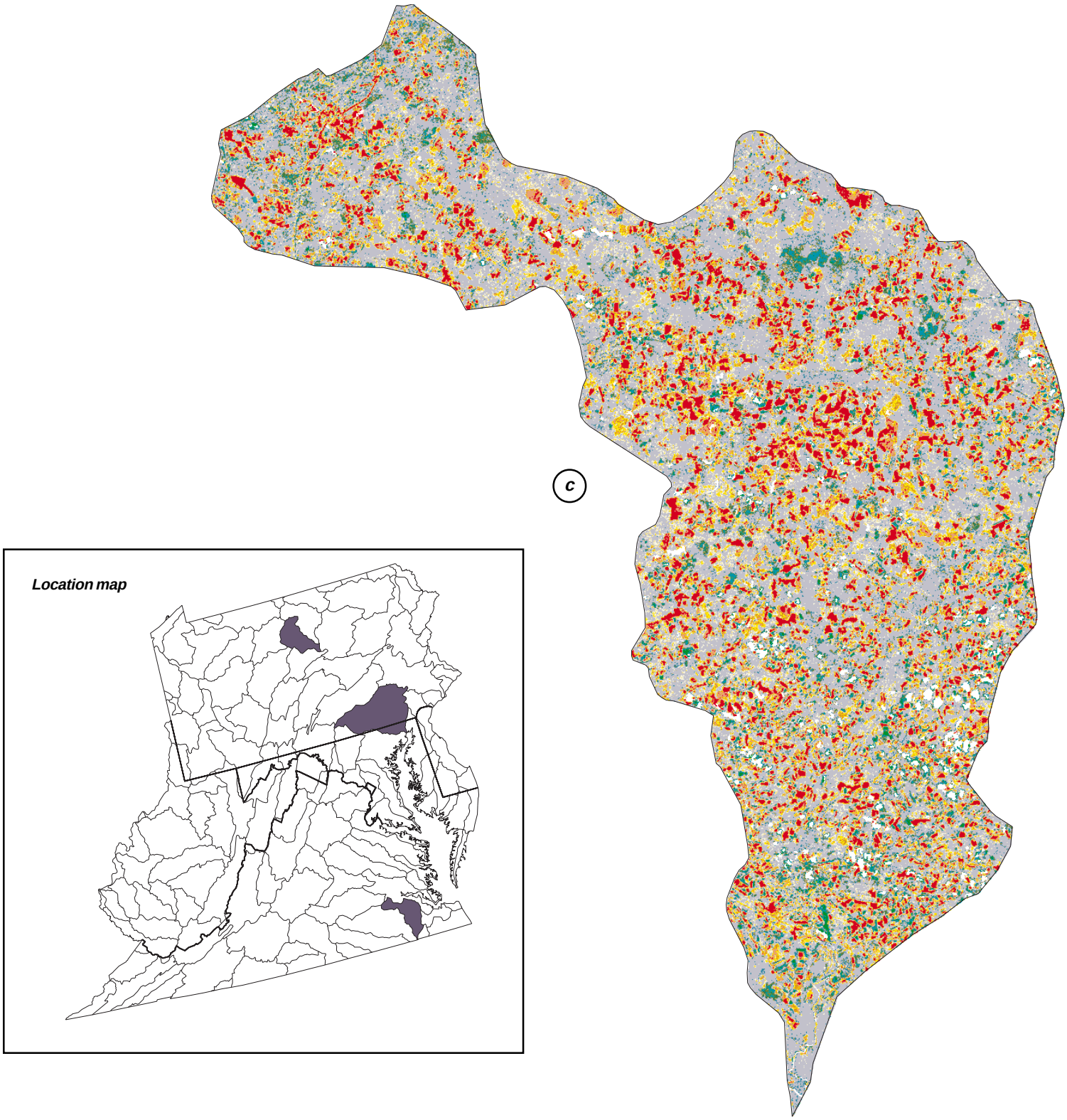


Figure 3.36.

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
Location map

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.

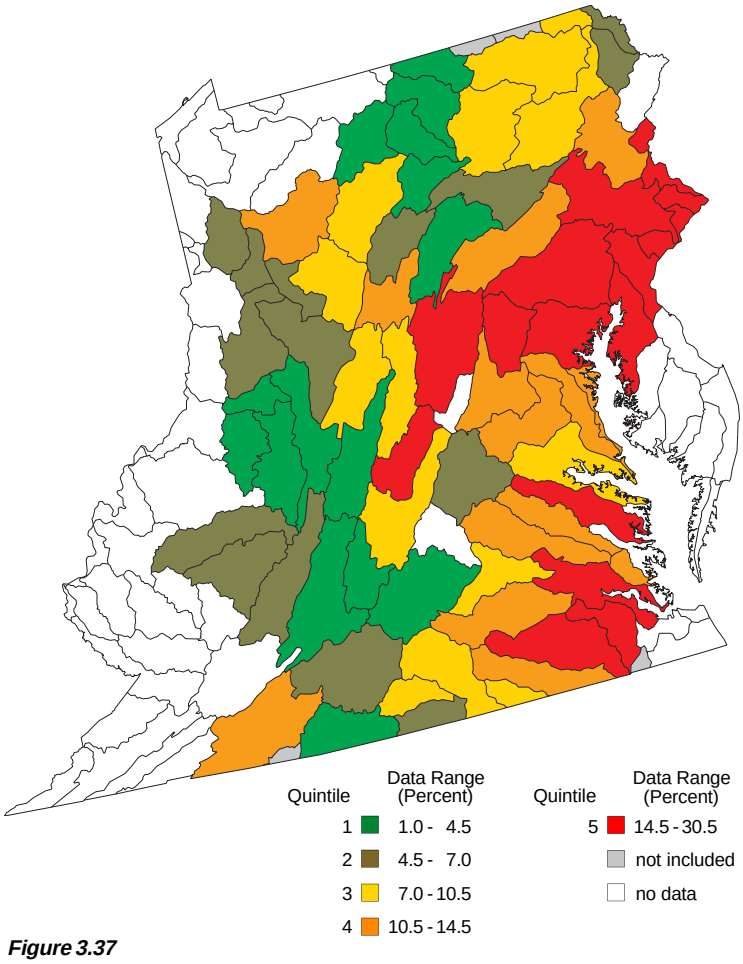


Figure 3.37

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

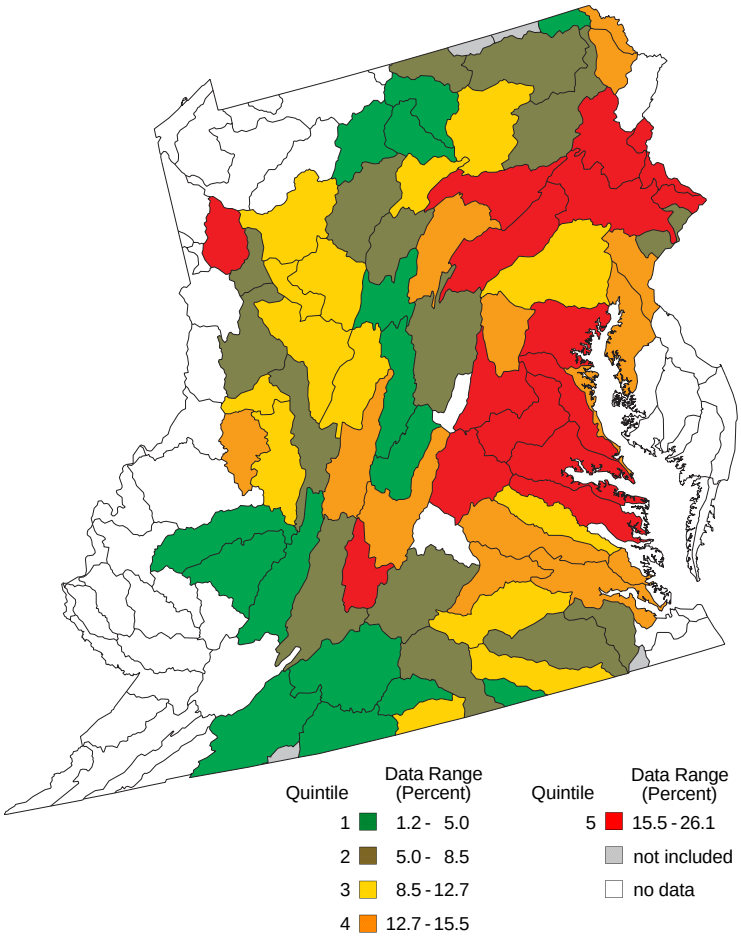


Figure 3.38

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.

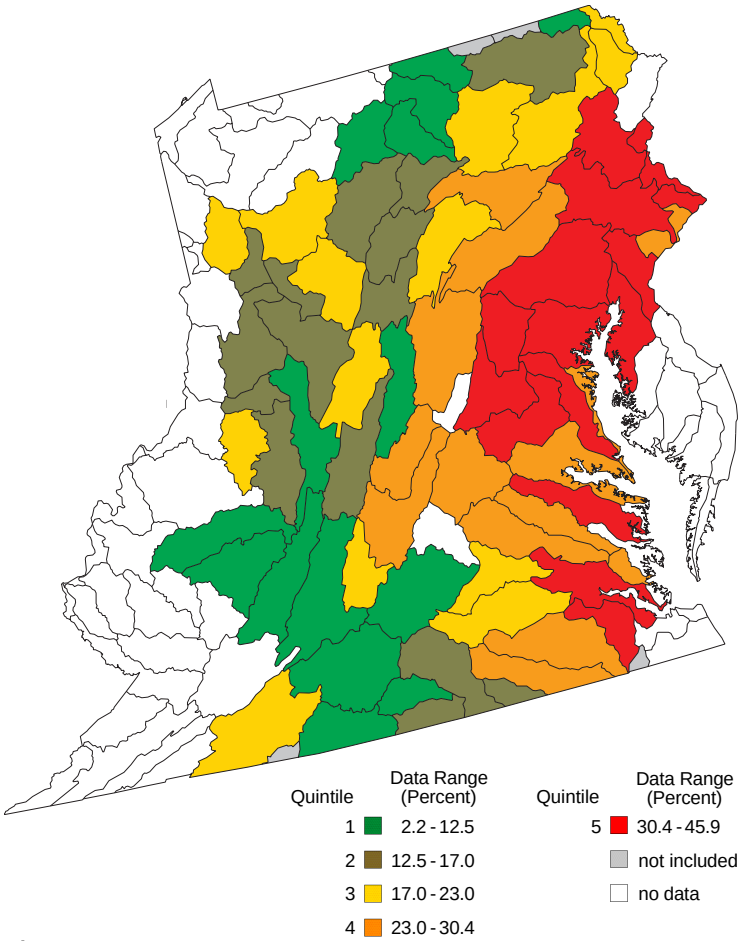


Figure 3.39

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.

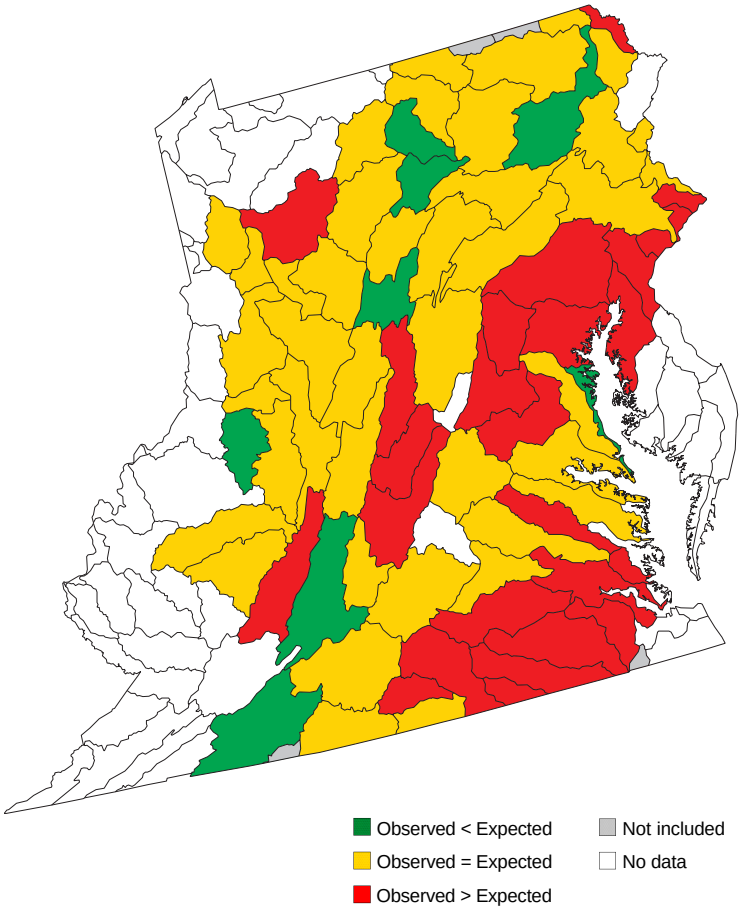


Figure 3.40

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).

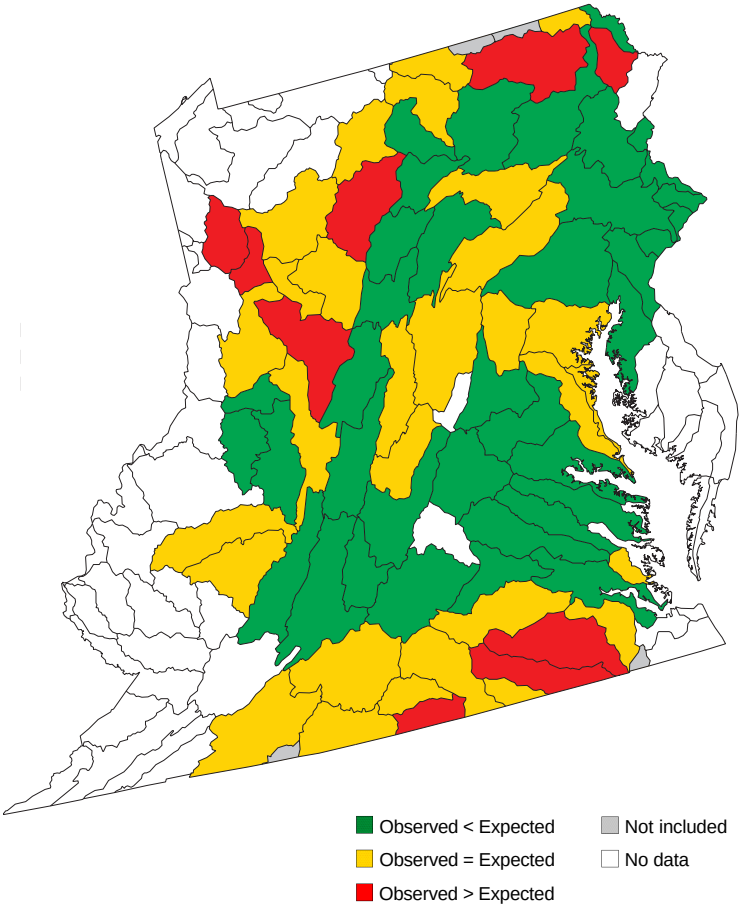


Figure 3.41

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).

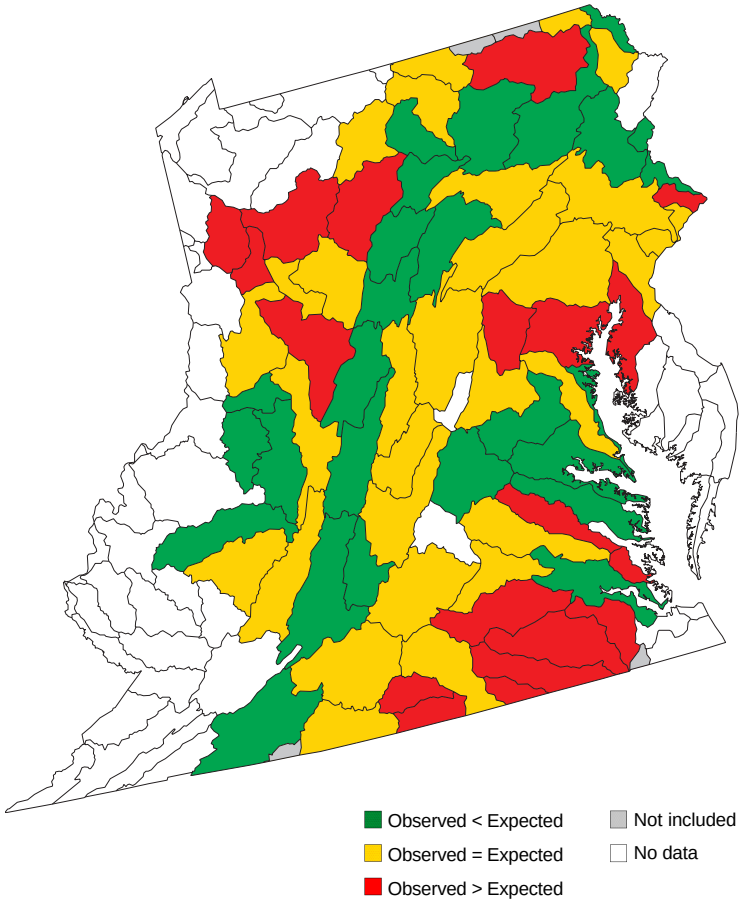


Figure 3.42

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.

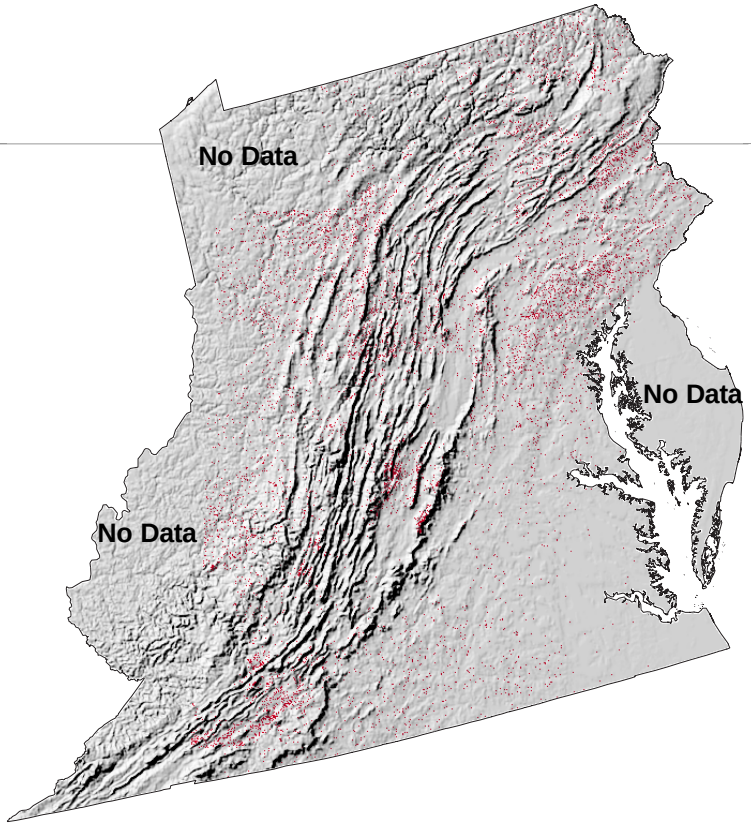


Figure 3.43
Surface map of decreases in the NDVI from 1975 to 1990 on slopes greater than three percent in the mid–Atlantic region (see text for explanation).

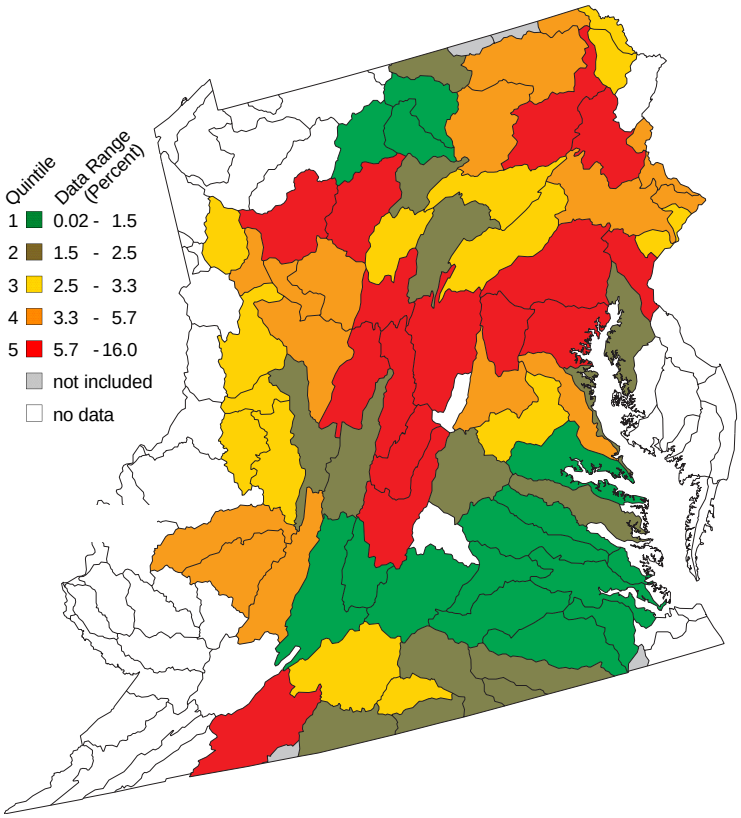


Figure 3.44
Proportion of watershed with decreases in the NDVI from 1975 to 1990 on slopes greater than three percent in the mid–Atlantic region (see text for explanation).