LEARNING LANDSCAPE ECOLOGY

A Practical Guide to Concepts and Techniques

Sarah E. Gergel
National Center for Ecological Analysis and Synthesis

Monica G. Turner
University of Wisconsin, Madison

Editors

2002

Springer

CHAPTER 13

Interpreting Landscape Patterns from Organism-Based Perspectives

Scott M. Pearson

OBJECTIVES

Conservation is a geographic problem because one of the greatest threats to biodiversity is habitat loss and fragmentation. Management plans, with purposes ranging from protecting endangered species to planning sustainable timber harvests, use maps to represent current landscape patterns and to evaluate management options. Obviously, the accuracy of these maps can affect the success of the decision-making process and the implementation of management plans. For ecosystem-level or species-based management, maps must reflect patterns relevant to ecosystem processes and species of interest. However, maps are human products; therefore, they have an implicit anthropocentric perspective. Most tend to record information pertinent to human needs and economic systems (e.g., land cover, roads, towns, political boundaries). For example, national forests have "stand maps" that record the age and type of forest stands (e.g., oak-hickory, cove hardwood, oak-pine). However, this classification system is based on merchantable timber and may not reflect stand characteristics important to wildlife or nontimber vegetation. For effective conservation, maps are needed that reflect the needs of ecosystems and nonhuman species. The objectives of this exercise are to

1. illustrate how landscape patterns, recorded on land-cover maps, can be interpreted from the perspective of different species; and

2. help students understand the uses and limitations of spatial data for producing habitat maps.

In Exercise 1, you will examine the potential limitations of habitat mapping due to the resolution of the spatial data used. In Exercise 2, you will interpret landscape patterns from a non-anthropocentric perspective and construct habitat maps for five species. In Exercise 3, land-cover and topographic data will be combined to represent the habitat of two additional species. Each team of students will need several different colors of pencils, markers or highlighter pens; a calculator; and five copies of Figure 13.1 for Exercise 2. A transparency of Figure 13.1 and a paper copy of Figure 13.2 are also needed for Exercise 3 as this part involves overlaying Figures 13.1 and 13.2. Extra copies (for printing) of the figures are included on the CD in the directory for this lab and can be viewed using Adobe Acrobat Reader software which is available for free from the World Wide Web.

INTRODUCTION

One of the challenges of ecosystem management is understanding the effects of landscape-level changes on biological diversity. Both worldwide and in the United States, land cover is altered principally by direct human use through agriculture, pasture, forestry, and development. Land-use patterns affect both terrestrial and aquatic systems (Reiners et al., 1994; Cooper, 1995) and influence biodiversity for several reasons (Turner et al., 1998). First, land-use activities may alter the relative abundances of natural habitats and result in the establishment of new land-cover types. Species richness may be enhanced by the addition of new cover types, but natural habitats are often reduced, leaving less area available for native species (Walker, 1992). Exotic species may also become established and outcompete the native biota. Second, the spatial pattern of habitats may be altered, often resulting in fragmentation of once-continuous habitat. Projecting patterns of species presence and abundance in changing landscapes remains a key challenge in sustaining biodiversity (Lubchenco, 1995; Hansen et al., 1995), and clearly, the conservation of native species and their habitat involves a landscape-level approach (Franklin, 1993, 1994; Tracy and Brussard, 1994).

Ecologists use a variety of terms to describe the spatial pattern of habitat, such as *patch*, *connected*, *fragmented*, *edge*, and *edge effects*. For the purposes of this exercise, **habitat** refers to sites having appropriate levels of the biotic (e.g., prey items, mutualists) and abiotic (e.g., moisture, temperature, light, nutrients) features required by a given species. A **patch** is a contiguous region of the same habitat type. In raster land-cover maps, such as Figure 13.1, patches are usually identified as clusters of contiguous map cells of the same cover type. When the habitat exists in the landscape as a few large patches, the habitat is said to be highly **connected.** Habitat is considered to be **fragmented** when the habitat occurs in a large number of small patches. Land-cover change that results in habitat loss often causes habitat fragmentation by breaking up the few large patches into an increased number of small ones. The boundary between two habitat types is called an **edge.** Within a patch, factors such as temperature, moisture, food resources, and the abundance of predators may be different near the edges of a patch as compared to the **interior** of a patch (Matlack, 1993). Changes in ecological factors near patch boundaries are termed **edge effects.** Because smaller habitat patches have a greater edge-to-interior ratio, edge effects tend to be more prevalent in small patches. Thus, habitat fragmentation, by creating small patches, can increase the amount of edges and edge effects throughout a landscape.

Depending on their habitat requirements and life-history attributes, species may respond quite differently to habitat loss and fragmentation. Changes that favor one species may reduce habitat for others. The abundance and spatial pattern of habitat in a landscape may vary among species that have different habitat requirements (e.g., preferences for late versus early successional stages). Moreover, life-history attributes, such as area requirements and dispersal ability, can interact with the spatial pattern of habitat (i.e., fragmented vs. connected) to affect population dynamics on a landscape. Therefore, an organism-based perspective (e.g., Wiens, 1989; Pearson et al., 1996) is needed to estimate the effects of landscape pattern on nonhuman species. This perspective should also acknowledge that species may perceive the habitat in different ways. An eagle "sees" the landscape, its habitat patches, and resources in a very different way than a beetle does. Ecologists should strive to view the landscape from the perspective of the species of interest. The following exercises address the importance of grain size on habitat mapping, show how the same map can be interpreted differently for different species, and integrate topography with land cover in mapping as ways to illustrate the importance of interpreting landscape patterns from an organismal perspective.

Study Area

The study area is located north of Asheville, North Carolina, in the Southern Blue Ridge Province of the Southern Appalachian Mountains, with elevations ranging from 660 to 1100 meters above sea level. This mountainous landscape is dominated by forests, particularly in the steeper areas at higher elevation, while many of the valleys have been cleared for agricultural and residential land uses. The study area also includes urban areas of a small town, Mars Hill, having a human population of 2200 (Figure 13.1). The mountainous areas north of the town are heavily forested. The land-cover types we will consider here are forest, nonforest, and urban. The forests of this area are mostly temperate deciduous forests interspersed with occasional conifers (e.g., pines and hemlocks). The nonforest land cover includes pastures, row crops, and lawns. Urban land cover includes cells with a high concentration of buildings and pavement. Landscape metrics for these land covers are listed in Table 13.1.

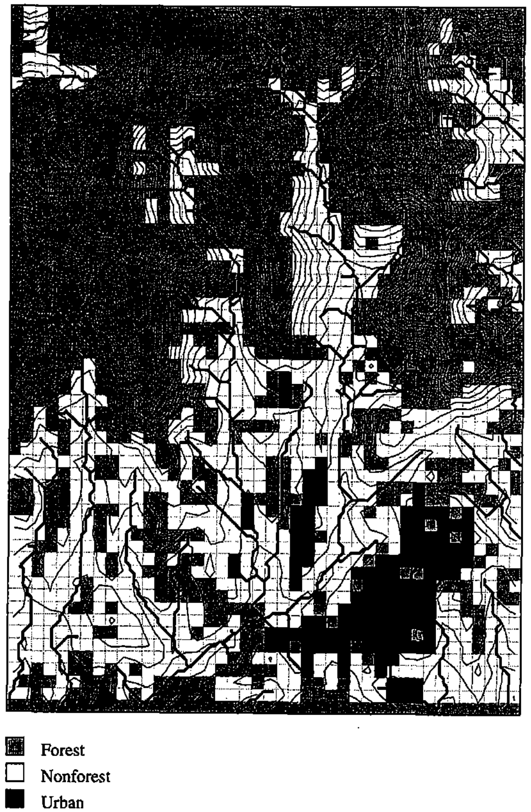

FIGURE 13.1
Land-cover map of study area. Thin lines are 10-m contours; heavier lines represent streams. Each cell is 90 × 90 m in area. The spatial extent of the map is 19.7 km^2 (3.78 × 5.22 km). A full size version of this map can be printed from the CD.

TABLE 13.1
LANDSCAPE PATTERN METRICS FOR FIGURE 13.1. AREA AND PATCH SIZE ARE MEASURED IN THE NUMBER OF 90 × 90-M CELLS.

Land Cover	Total Area (cells)	Number of Patches	Mean Patch Size (cells)	Size of Largest Patch (cells)
Forest	1349	37	23.8	1133
Nonforest	910	14	42.6	791
Urban	135	6	14.7	25

EXERCISES

EXERCISE 1
The Importance of Grain Size

Habitat maps are produced from spatial data that have a certain spatial resolution. For example, the cell size of a **Thematic Mapper** (TM) image is typically 30 × 30 meters. The land-cover map used for this exercise was produced from a 1991 TM image (Figure 13.1) and is stored in raster (i.e., grid-based) format. TM is a type of satellite used to gather digital photographs. Regions within the photograph are classified into discrete land-cover categories. The resulting land-cover classes can be represented in **raster** format, using a large rectangular array of numbers, similar to a checkerboard. Each number represents the land-cover type for the cell. One pixel (cell) of a TM image usually represents a 30 × 30-meter area on the ground, so the "size" of a cell in the derived map cannot be smaller than this size; however, during land-cover classification, cells may be aggregated into a more coarse resolution (e.g., 90 × 90 m). The size of an individual map cell determines the spatial resolution or **grain** of the map; the spatial **extent** of the map is its total area (e.g., N-S distance × W-E distance).

The value of a cell in a land-cover map may represent either (1) a point measured in the middle of the cell or (2) an average of the conditions in cells—thus, cells in a raster habitat map may contain much microsite variability that is not captured by the cell value. **Microsites** are the small or fine-scale locations within a map cell. For a mayfly species capable of living in small creeks, a microsite for this insect would be in the creek (as opposed to on top of a dry rock). Because a map cell may cover such a large area (relative to an insect), many microsites within the cell may not be suitable. Furthermore, because a small creek (2–3 m across) represents such a small proportion of the land area, it would not show up in a TM image; however, larger streams, rivers, and ponds would be recorded.

Question 1. Consider an insect species that requires small headwater streams. Can habitat for this species be accurately mapped using data with a 90 × 90-meter resolution? Justify your answer. If you answered yes, then explain your assumption(s) about the relationship between the cell values and the abundance of suitable microsites.

Question 2. How does the grain of spatial data affect our ability to map species' habitats?

EXERCISE 2
Habitat Maps for Different Species

One of the challenges of ecosystem management is determining how a set of species with diverse habitat needs will be affected by landscape-level changes. Species may respond to landscape patterns in different ways depending on their habitat needs. Producing more habitat for one species by manipulating land cover may reduce habitat for others. Next, you will make habitat maps for five different species. The land-cover map (Figure 13.1) will be used to produce habitat maps using a mapping procedure based on the habitat requirements of each species (Table 13.2). Then, you will compare the abundance and spatial distribution of suitable habitats for these five species.

Impatiens capensis (jewelweed) is a native plant that thrives in spring seeps, bogs, and streamsides. This species is tolerant of shade but does best in the presence of sunlight and plenty of moisture. It is an annual that produces a large number of seeds. The seeds are borne in pods that fly apart when ripe (hence the other name of "touch-me-not").

Seiurus aurocapillus (Ovenbird) is a Neotropical migrant songbird that nests throughout the eastern United States. It nests and forages on the ground in deciduous forests and is sensitive to forest fragmentation. It is often absent from small patches of forest (< 25 ha) and occurs in greatest abundance in landscapes with a large percentage of forest. Thus, this species seems to decline with increasing forest fragmentation.

TABLE 13.2
HABITAT REQUIREMENTS AND MAPPING PROCEDURE FOR FIVE SPECIES. HABITAT REQUIREMENTS WERE TAKEN FROM WEBSTER ET AL. (1985), HABITAT REQUIREMENTS (1988), WOFFORD (1989), HAMEL (1992), AND ROBINSON ET AL. (1995).

Species	Habitat Required	Mapping Procedure
Jewelweed (*Impatiens capensis*)	Moist to hydric sites; streamsides	Cells of any land cover adjacent to or crossed by streams
Ovenbird (*Seiurus aurocapillus*)	Forest interior sites	Deciduous forest cells at least 180 m (i.e., two cells) away from nonforest and urban cells
Mountain dusky salamander (*Desmognathus ochrophaeus*)	Forests with streams	Forest cells crossed by or adjacent to streams
Indigo Bunting (*Passerina cyanea*)	Forest edge	Forest cells adjacent to nonforest and nonforest cells adjacent to forest
House mouse (*Mus musculus*)	Urban areas and nonforest	All urban cells, nonforest cells, and cells adjacent to urban cells

Desmognathus ochrophaeus (mountain dusky salamander) is one of the few members of the genus *Desmognathus* that is terrestrial. It spends a great deal of time underground, emerging to forage on the surface during warm, damp evenings. The salamander occurs along streamsides in shady, moist forests of the Southern Appalachians at low elevations. Precipitation increases with elevation in this region; thus, at elevations above 1220 meters, this species can leave the streamsides and be found in mesic forest sites.

Passerina cyanea (Indigo Bunting) is a finchlike neotropical migrant bird. This species nests in shrubs in old fields and along forest edges. Closely related to the Northern Cardinal, it feeds on insects, fruits, and seeds. The colorful males of this species are a favorite of bird watchers; the birds sing all day during late spring and summer.

Mus musculus (house mouse) is an exotic mammal introduced from Europe. It is a commensal with humans, achieving its greatest abundance in human dwellings. This species is also capable of living in the farmlands surrounding human settlements, but does not persist in forests. Not surprisingly, its abundance in the landscape is correlated with the amount and intensity of nonforest land uses. It can become a pest by destroying food items in homes and farms.

1. Your first step is to create habitat maps. Classify a land-cover map (Figure 13.1) using the mapping procedure for the species listed in Table 13.2. You can print multiple copies of the land-cover map from the CD. Use one copy of the land-cover map for each species. Color in suitable cells using a green, yellow, or red pencil, marker, or highlighter. Your instructor may create teams of students and assign a single species to each team member.
2. Next, quantify habitat abundance and pattern. A **patch** of habitat is defined as a group of *contiguous* cells of the suitable habitat. For this exercise, suitable cells contiguous on the diagonal (adjacent corners) are considered to be of the same patch, as well as those cells that share a flat edge (the eight-neighbor rule). For each patch of suitable habitat, record its size by counting the number of cells. Record the number and sizes of patches in Table 13.3, which can be printed from the CD.
3. Calculate the total area of suitable habitat (in cells) and mean patch size, and note the size of the largest patch for each species.

Using your maps, answer the following questions

Question 3. Visually compare the habitat maps for the five species. For which species does the habitat *appear* to be most connected? For which species is the habitat most fragmented?

Question 4. Which of the patch-based statistics in Table 13.3 would you use to *quantify* habitat fragmentation or connectivity?

PART 3
Using Topography to Refine Habitat Types

A quick inspection of the land-cover map (Figure 13.1) reveals patches of forest, field, and urban cover types. Within any of these covers, there is variation in environmental parameters (e.g., temperature, light, moisture) that affect habitat suitability. In this part, you will use topography to refine the habitat classification of cells with the same cover type. Realize, of course, that many other sources of spatial information may be used to refine cover types, such as geology maps, hydrology maps, and distances to certain features such as roads and buildings calculated with a Geographic Information System (GIS).

Topographic features such as terrain shape and aspect can exert a strong influence on habitat suitability in mountainous regions (Whittaker, 1956; McNab, 1996). Sites with a concave terrain shape, such as ravines, tend to accumulate water and be moist, while convex sites, such as ridges, are drier. Aspect can also affect moisture and temperature. In the northern hemisphere, north-facing aspects receive less insolation and are therefore cooler and moister than south-facing aspects. Maps of terrain shape and aspect can be derived from elevation maps.

Figure 13.2 shows a map of terrain shape for the same area as the land-cover map (Figure 13.1). Three classes of terrain shape are identified: (1) coves or ravines, (2) side slopes or flats, and (3) ridges or peaks. Cell size for Figure 13.2 is 30 × 30 meters. This map of terrain shape can be used in conjunction with the land-cover maps to identify the habitat of two trees of the deciduous forest: **basswood** (*Tilia americana*), a mesophytic species, and **scarlet oak** (*Quercus coccinea*), a xerophytic species. The cove sites are suitable for basswood, and the ridge sites are suitable for scarlet oak.

1. Map the coves and ridge areas as follows. Print out a paper copy of the map of terrain shape (Figure 13.2) from the CD. Then, create a transparency of the land-cover map (Figure 13.1). Using Figure 13.1 as an overlay on Figure 13.2, color the cells of deciduous forest that are found in cove and ridge zones. Use contrasting colors for the cove and ridge cells.
2. Count the cells and patches (as in Exercise 2) and record your results in Table 13.4, which can be printed from the CD.
3. Tally the number of patches. Calculate the mean patch size and the area of the largest patch. Be sure to state your units (cells or hectares) on Table 13.4.

Use the data in Table 13.4 to answer these questions:

Question 5. Compare the relative abundance of habitat for basswood and scarlet oak. What proportion of the forest land cover is suitable for each species?

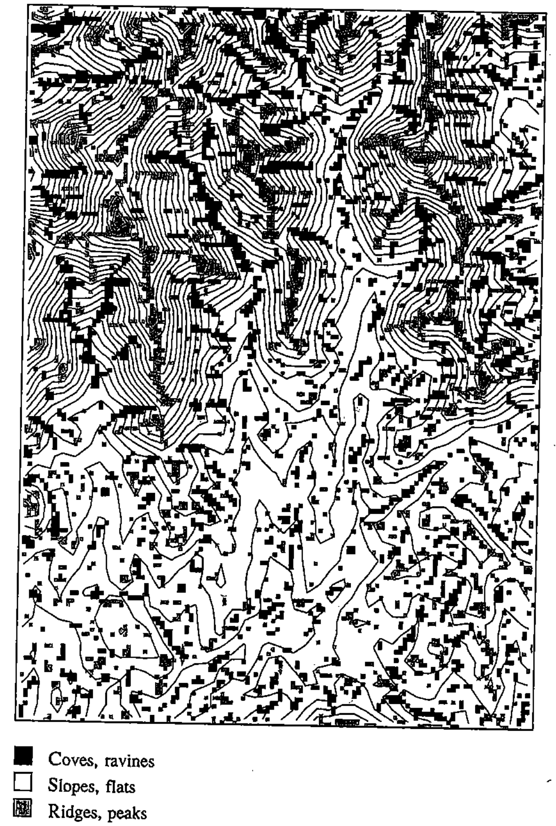

FIGURE 13.2
Map of terrain shape for study area. Thin lines are 10-m contours. The region covered and spatial extent of this map are identical to Figure 13.1; however, cells are 30 × 30 m in area. A full size version of this map can be printed from the CD.

Question 6. Compare the level of habitat fragmentation for these species. Is there a difference in the relative connectivity of cove and ridge sites in this landscape?

DISCUSSION QUESTIONS

Answer the following questions using your maps and data.

1. The Ovenbird is restricted to forest-interior cells. Compare the total number of cells of Ovenbird habitat to the total number of forest cells (Table 13.1). What percentage of the forest cells is unsuitable for the ovenbird because of edge effects?
2. Limitations in dispersal ability may prevent some species from recolonizing patches that have experienced local extinctions. Lungless salamanders, including the mountain dusky salamander, are such species because they can seldom cross dry, open land-cover types. If we assume that these salamanders cannot cross more than two

cells of *unsuitable* habitat (count cells on the diagonal as equal to cells in cardinal directions), how many of the existing patches of salamander habitat are completely isolated (with respect to potential colonists) from any other patches?

3. Refer to the habitat maps for Exercise 2.
   (a) If urban expansion in this landscape increases the extent of nonforest and urban land covers, how will each of the species discussed in Exercise 2 be affected?
   (b) Will these effects depend on the location and amount of urban expansion?
   (c) Using the lay of the land as depicted in Figure 13.2, can you predict where urban expansion is likely to occur? How?
4. Suppose that we evaluate the landscape from the perspective of another species, such as a Broad-winged Hawk (*Buteo platypterus*), which requires the same habitat as the Ovenbird but has a minimum area requirement (e.g., territory size) of 50 cells (40.5 ha).
   (a) What proportion of the patches would be too small?
   (b) What proportion of the forested cells would therefore be unsuitable?
   (c) What effect would your predicted expansion of nonforest and urban land covers have on this species?
5. Given a scenario of future urban growth *and* the potential to regulate the location of that growth, what portions of the landscape would you protect? Which species would influence your strategy?
6. What is the value of using additional spatial data, such as terrain shape, soils, geology, to refine land-cover types? What are the limitations of this approach? If the grain of the two data sets differs, what is the resolution of the resulting habitat map?

BIBLIOGRAPHY

Note. An asterisk preceding the entry indicates that it is a suggested reading.

*ANDRES, BRAD A. 1994. Coastal zone use by postbreeding shorebirds in northern Alaska. *Journal of Wildlife Management* 58:206–212. This study addresses the impact of oil development on shorebird habitats and discusses management implications. It uses a vegetation map derived from Landsat imagery.

COOPER, S. R. 1995. Chesapeake Bay watershed historical land use: Impact on water quality and diatom communities. *Ecological Applications* 5:703–723.

EHRLICH, P. R., D. S. DOBKIN, AND D. WHEYE. 1988. *The Birders Handbook: A Field Guide to the Natural History of North American Birds*. Simon & Schuster, New York.

FRANKLIN, J. F. 1993. Preserving biodiversity: Species, ecosystem, or landscapes. *Ecological Applications* 3:202–205.

FRANKLIN, J. F. 1994. Response to Tracy and Brussard. *Ecological Applications* 4: 208–209.

HAMEL, P. B. 1992. *The Land Manager's Guide to Birds of the South*. The Nature Conservancy, Chapel Hill, North Carolina.

*HANSEN, A. J., S. L. GARMAN, B. MARKS AND D. L. URBAN. 1993. An approach for managing vertebrate diversity across multiple-use landscapes. *Ecological Applications* 3: 481–496. Describes an approach to balancing commodity production with the needs of terrestrial vertebrates. The approach is demonstrated for a watershed in western Oregon, balancing timber production with habitats used by birds.

HANSEN, A. J., S. L. GARMAN, J. F., WEIGAND, G. L URBAN, W. C. MCCOMB, AND M. G. RAPHAEL. 1995. Alternative silvicultural regimes in the Pacific Northwest: Simulations of ecological and economic effects. *Ecological Applications* 5:535–554.

*HE, H. S., D. J. MLADENOFF, V. C. RADELOFF, AND T. R. CROW. 1998. Integration of GIS data and classified satellite imagery for regional forest assessment. *Ecological Applications* 8:1072–1083. Demonstrates how satellite imagery and other spatial data can be combined to assess forest composition over a large region. The resulting maps could be used as input for modeling forest dynamics and to guide future management decisions.

LUBCHENCO, J. 1995. The role of science in formulating a biodiversity strategy. *BioScience*, Special supplement, pp. 7–9.

MCNAB, W. H. 1996. Classification of local- and landscape-scale ecological types in the southern Appalachian Mountains. *Environmental Monitoring and Assessment* 39:215–229.

MATLACK, G. R. 1993. Microenvironment variation within and among forest edge sites in the eastern United States. *Biological Conservation* 66:185–194.

PEARSON, S. M., M. G. TURNER, R. H. GARDNER, AND R. V. O'NEILL. 1996. An organism-based perspective of habitat fragmentation. In *Biodiversity in Managed Landscapes: Theory and Practice*, R. C. Szaro, ed. Oxford University Press, Oxford, UK.

REINERS, W. A., A. F. BOUWMAN, W. F. J. PARSONS, AND M. KELLER. 1994. Tropical rain forest conversion to pasture: Changes in vegetation and soil properties. *Ecological Applications* 4:363–377.

ROBINSON, S. K., F. R. THOMPSON III, T. M. DONOVAN, D. R. WHITEHEAD, AND J. FAABORG. 1995. Regional forest fragmentation and the nesting success of migratory birds. *Science* 267:1987–1990.

*RUDIS, V. A., AND J. B. TANSEY. 1995. Regional assessment of remote forests and black bear habitat from forest resource surveys. *Journal of Wildlife Management* 59:170–181. The authors develop a model from forest inventory data and bear censuses to develop a map of suitable habitat for 12 states in the southern United States and evaluate the relative connection and isolation of habitat patches.

*STOLZENBURG, W. 1998. When nature draws the map. *Nature Conservancy* 48:12–23. A layman's introduction to using multiple geographic data sets for mapping ecosystems. It illustrates examples from the eastern and western United States as wells as the Caribbean. The article discusses strategies for conservation efforts on a regional scale.

TRACY, C. R., AND P. R. BRUSSARD. 1994. Preserving biodiversity: Species in landscapes. *Ecological Applications* 4:205–207.

TURNER, M. G., S. R. CARPENTER, E. J. GUSTAFSON, R. J. NAIMAN, AND S. M. PEARSON. 1998. Land use. In *Status and Trends of the Nation's Biological Resources*, M. J. Mac, P. A. Opler, C. E. Puckett Haecker, and P. D. Doran, eds. U. S. Dept. of Interior, U.S. Geological Survey, Washington, DC.

WALKER, B. H. 1992. Biodiversity and ecological redundancy. *Conservation Biology* 6:18–23.

WEBSTER, W. D., J. F. PARNELL, AND W. C. BRIGGS JR. 1985. *Mammals of the Carolinas, Virginia, and Maryland*. University of North Carolina Press, Chapel Hill, North Carolina.

WHITTAKER, R. H. 1956. Vegetation of the Great Smoky Mountains. *Ecological Monographs* 26:1–86.

WIENS, J. A. 1989. Spatial scaling in ecology. *Functional Ecology* 3:385–397.

*WIENS, J. A., AND B. T. MILNE. 1989. Scaling of "landscapes" in landscape ecology, or, landscape ecology from a beetle's perspective. *Landscape Ecology* 3:87–96. Describes research conducted with beetles on "microlandscapes" in grasslands. The fractal structure of microlandscapes affected movement patterns.

*WISER, S. K., R. K. PEET, AND P. S. WHITE. 1998. Prediction of rare-plant occurrence: A southern Appalachian example. *Ecological Applications* 8:909–920. Uses a combination of field-collected data and topographic characteristics to generate predictive equations for four species of rare plants. This analysis sought to understand factors influencing the distribution of these species so that additional populations might be discovered and important habitats protected. The utility of such models is critically examined.

WOFFORD, B. E. 1989. *Guide to the Vascular Plants of the Blue Ridge.* University of Georgia Press, Athens, Georgia.