USDA Forest Service. (2002). *National and regional project results: 2002 National Forest Visitor Use Report.* Retrieved February 1, 2005, from http://www.fs.fed.us/recreation/programs/nvum/

USDA Forest Service. (2001). *National and regional project results: FY2001 National Forest Visitor Use Report.* Retrieved February 1, 2005, from http://www.fs.fed.us/recreation/programs/nvum/

USDA Forest Service. (2000). *National and regional project results: CY2000 National Forest Visitor Use Report.* Retrieved February 1, 2005, from http://www.fs.fed.us/recreation/programs/nvum/

Vias, A.C. (1999). Jobs follow people in the rural Rocky Mountain west. *Rural Development Perspectives, 14*(2), 14–23.

Chapter 11
The Natural Ecological Value of Wilderness

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The most important characteristic of an organism is that capacity for self-renewal known as health. There are two organisms whose processes of self-renewal have been subjected to human interference and control. One of these is man himself. The other is land.
—*Aldo Leopold, 1949*

In Chapters 7 through 10 of this book, we examined the social and economic benefits or values from Wilderness. In this chapter, we attempt to examine the natural ecological values of Wilderness. We define ecological value generally as the level of benefits that the space, water, minerals, biota, and all other factors that make up natural ecosystems provide to support native life forms. Ecological values can accrue to both humans and nonhumans alike. To humans, these benefits typically are bestowed externally as cleaner air and water. To nonhuman species, these ecological benefits are usually much more direct and on-site. Ecosystems contribute their greatest ecological value when they are in their most natural state. In their most natural state, they are at their peak of natural health and provide their greatest level of native life support. Native life support is the ecological value of Wilderness. Cole (2000) has argued that ecological value is directly and positively correlated with degree of naturalness. We will argue that such measurements of naturalness as we can devise or discover are our best shot at demonstrating whether Wilderness has greater ecological value than non-Wilderness lands.

Naturalness and Wildness

The Wilderness Act was put into place to protect selected wildlands in the United States from human disturbance. Landres, Morgan, and Swanson (1999) defined "natural condition" or naturalness as the relative lack of human disturbance. Haney, Wilbert, De Grood, Lee, and Thomson (1999, p. 1) stated that "the wilderness system is often promoted as a means to safeguard (natural) ecological attributes no longer found on, or at great risk within, extensively managed lands." Thus, the most significant attribute of Wilderness is its naturalness. In addition to protection of the naturalness of designated lands, the Wilderness Act also identified maintenance of "wildness" as a purpose. Cole (2001) and Turner (1996) pointed out that the concept of "untrammeled" means just this, wildness. Wildness means freedom from human manipulation of any kind, including freedom from restoration of what we understand to have been "original" natural conditions. The operative idea behind the concept of wildness is that of granting designated lands freedom or autonomy from modern human interference. Thus, natural condition, or naturalness, is an ecological condition, and wildness is status relative to modern human control or manipulation. Granting wildness eventually leads to greater "naturalness" of historically disturbed lands—or at least as much naturalness as an area can attain given

modern broad-scale external influences, such as nonpoint source pollutants, altered distribution of species, and global climate change (Landres, Morgan & Swanson, 1999).

In the early part of this chapter, a modest sampling of the voluminous literature pertaining to the interrelated ecology concepts of ecosystems, ecosystem health, and naturalness is summarized. However, the richness of this literature and of the theories in ecology and other natural sciences applicable to assessing the ecological health and condition of Wilderness far outstrip the availability of data explicitly describing Wilderness lands. Our search for broad-scale data that would enable us to put into operation a set of meaningful indicators of the ecological health of the NWPS turned up very little. Thus, an important part of our effort in this chapter is to bring more attention to the need for better data so that the ecological conditions, benefits, and values of Wilderness can be better expressed and more fully understood.

The Field of Ecology and Ways of Looking at Ecosystems

Ecology

It is believed that a German biologist, Ernst Haeckel, first coined the term defining the emerging scientific field of "ecology" in 1866. Haeckel created the term from the root Greek words *oikos*, meaning "house," and *logos*, meaning "science." An early basis for this systems point of view is in the writings of James Hutton who described the earth as a total system (Hutton, 1788; Rapport, 2002). The companion term *ecosystem* seems first to have appeared in print in 1935 in an article by a British ecologist, Arthur Tansley. In that article, Tansley defined an ecosystem as "the whole system…including not only the organism complex but also the whole complex of physical factors forming what we call the experiment of the biome.... (1935, p. 299)." The term ecosystem was further defined by Raymond Lindermann in 1942 "as the system composed of physical-chemical-biological processes active within a space-time unit of any magnitude (p. 400)." This refinement enabled ecologists to apply their field to any scale of ecosystem, from landscape to prairie pothole.

In 1953, Eugene Odum published a key book, *The Fundamentals of Ecology*. His view of nature was a comprehensive one. It added the idea that ecosystems are dynamic systems (Chaffin, 1998) that include human activities as well as natural processes. He showed that ecology can include the study of systems as broad as watersheds and weather patterns. Odum helped to introduce a paradigm shift from a view of ecosystems as persistent, stable, balanced systems in equilibrium to a view of the natural world as dynamic and constantly changing. As the field has continued to evolve and mature, more emphasis has been given to recognition of spatial and temporal variability, of humans as part of ecosystem processes and functions, and of the importance of biodiversity in ecosystem functioning (Hobbs et al., 2004).

Recent writings have included more explicit study across a spectrum of ecosystems from heavily managed and human inhabited lands to autonomous natural lands and systems (Bertollo, 1998). As ecology has broadened its perspectives to include humans in the equation, there has emerged a greater need to clarify what is meant by the concept of ecosystem health applied to both managed and natural systems. Some ecologists in earlier decades outright rejected the notion of natural ecosystem health because some form of modern human influence seemed always to be present. Most ecologists now, however, recognize and have readily adopted the idea that ecosystem health is a valid perspective across the managed-to-natural spectrum. Our concern in this chapter is, of course, with those natural ecosystems thus far included within the National Wilderness Preservation System.

Linking Naturalness, Life-Sustaining Ecosystem Health, and the Ecological Value of Wilderness

Rapport (1989) asserted that a healthy ecosystem is one that has the ability to recover from minor disturbances and absorb stress. Costanza (1992) agreed that "an ecological system is healthy and free from *distress syndrome* if it is stable and sustainable—that is, if it is active and maintains its organization and autonomy over time, and if it is resilient to stress" (Costanza, 1992, p. 9). As the field of ecology has evolved, there has been increasing recognition that the definitions of ecosystem health from scientists, such as Rapport and Costanza, apply to both managed and natural ecosystems. Ecosystems exist at different spatial scales and on a continuum from highly managed to highly natural (Angermeier, 2000). Odum (1989) observed that the landscape is divided into developed, cultivated, and natural areas. He described a natural area as being "self-supporting" and "self-sustaining," and operating without energy or economic inputs from humans (i.e., autonomous). These natural areas include wildlands and provide the physiological necessities for supporting natural life. A healthy, natural life-support system is the environment, organisms, processes, and resources that interact to meet native life-sustaining needs (Odum, 1989).

In managed systems, there is explicit acknowledgment of the role of the human, as both inhabitant and manager. The health of managed ecosystems has been described as the set of conditions needing to exist where biotic and abiotic influences do not threaten management objectives (McIntire, 1988).

In natural systems, on the other hand, ecosystem health refers to the set of natural conditions needing to exist to support native life forms. It stands to reason that the more healthy the managed or natural systems, the better those systems are able to support the life forms within them.

The medical professions' view of human health is a useful analogy of the meaning of natural ecosystem health. Dahms and Geils (1997) described a key characteristic of human health as being that of homeostasis (i.e., system resistance to change). Homeostasis is one of the most common properties of highly complex open systems. A *homeostatic system* is one that maintains its structure and functions through a multiplicity of dynamic equilibriums rigorously controlled by interdependent regulation mechanisms. For the human body, a change measured against the standard of inherent condition and internal balances typically indicates a change in health. Like a human body has organs, ecosystems are dynamic communities of living organisms, plant, animal and other, bound by common energy pathways and nutrient cycles. Over time ecosystems can evolve, but in the short term, healthy systems exhibit the characteristic of homeostasis. They are resistant to change and work hard to maintain their inherent life support state (de Rosnay, 1997). Criteria for judging whether a natural system is healthy vary among scientific fields and individual scientists, but they typically include naturalness, normality, variability, diversity, stability, sustainability, vigor, organization, and resilience (Coates, Jones & Williams, 2002). As we see it, naturalness is the essential criteria from the list above.

Angermeier (2000) stated, "Naturalness is the foundation for...sustainable (natural) resource management (p. 379)." The health of natural resource systems lies their abilities to maintain optimum operating natural conditions (Kay, 1993). Karr and Dudley (1981) defined health as "...capacity of supporting and maintaining a balanced, integrated, adaptive community of organisms (that have) a species composition and functional organization comparable to that of the natural habitats of the region (Karr & Dudley, 1981, p. 56)." Ecosystems that are disturbed by human activity "usually exhibit reduced resistance to stress" (De Leo & Levin, 1997). Angermeier (2000) concluded that natural ecosystems seem less able to recover from anthropogenic changes than from natural disturbances.

Kolb, Wagner, and Covington (1994) asserted that healthy ecosystems can be distinguished by four qualitative attributes:

1. existence of the necessary physical environment, biotic resources, and trophic networks to support ecosystem integrity;
2. resistance and ability to recover from catastrophic change;
3. a functional equilibrium between supply and use of water, nutrients, light, and growing space for vegetation; and

4. a diversity of ages and vegetative structures that provide habitat for a variety of native species and ecosystem processes.

Another key concept in defining ecosystem health is biodiversity. Cole (2000) maintained that biodiversity "may be the most compelling reason to manage wilderness ecosystems (because it essentially defines)...naturalness (p. 83)" Christensen and colleagues (1996) stated there are three specific roles for biodiversity in ecosystem functioning: providing for essential processes, maintaining resistance to and recovery from disturbances, and adapting to long-term changes in environmental conditions. Biodiversity, or biological diversity, is the diversity of and in living nature. Biological diversity has been defined as "the variety and variability among living organisms and the ecological processes within which they occur." (Cordell & Reed, 1990, p. 32). Since 1986, the term *biodiversity* has achieved worldwide use among biologists, environmentalists, political leaders, and concerned citizens. Much of this has been driven by the growing concern over extinction of species. Another concern in biodiversity has been for the threats to the world's full range of functioning ecosystems (Davis, 1989).

We surmise, as did Cole (2000), that most ecological scientists and ecologically trained managers see naturalness as the ultimate goal for managing Wilderness. Naturalness is the ultimate "aim" of free functioning natural ecosystems. The more natural ecosystems are, such as those protected by Wilderness designation, the more healthy they are. The more healthy they are, the greater is their support of native life, and thus the greater their ecological value.

Measurement of Naturalness in Wilderness

In ecological literature, the term *natural* is commonly understood to mean a process, situation, or system free from modern human technological modification. Thus, naturalness is the way a system would function and the characteristics it would achieve in the absence of human intervention. By legal definition, Wilderness areas are natural areas where natural processes dominate and the natural landscape and habitats created by those natural processes are sustained without human intervention. This is not to say that external human activities do not influence Wilderness areas. They do. Even the most remote Wilderness area is effected by global climate change, pollutants, stratospheric ozone depletion and occasional human presence. Few would argue, however, that Wilderness areas, some of which are the last remnants of virgin forests or high alpine meadows, are more natural than a parking lot (Christensen et al., 1996). But, because no land, designated or not, is totally free from human influence, the challenge we face is to find and implement measures or indicators of relative naturalness enabling us to compare measures of naturalness between Wilderness and non-Wilderness ecosystems.

Literature Identifying Indicators of Ecosystem Health and Naturalness

When lands are modified, most ecologists would agree that they have less natural ecological integrity and ability to support natural life. But can this be measured? A number of scientists have provided ideas regarding the measurement of naturalness. A review of these ideas is useful not only to selecting feasible measures but also to setting up a discussion of needed data and measures to fill gaps in our knowledge.

Anderson (1991) proposed three indices of naturalness: the degree to which a system would change if humans were removed, the amount of energy supplied by technological humans to maintain the functioning of the system as it now exists, and the complement of native species in an area compared to the species in the area prior to settlement. Similarly, Angermeier (2000) proposed four criteria for assessing degrees of human alterations to natural ecosystems which include degree of change, degree of sustained control, spatial extent of change, and abruptness of change. Other examples of possible indicators of naturalness have been provided by Cole and Landres (1996). They listed geography, geologic composition, land forms, soils, hydrological character, elevation, water, and biologic distinctiveness as factors indicating naturalness. Other measures might include native species richness, proportion of extant species that are exotic, natural genetic diversity, degree of unbroken landscape, quality of air and water, the contribution to carbon sequestration, and/or absence of roads.

Bertello (1998) summarized a list of indicators of ecosystem health and naturalness as proposed by several authors. He included Odum, who in 1989 suggested energetics, nutrient cycling, community structure, and systems features as indicators of naturalness. Keddy, Lee, and Wisheu (1993) proposed diversity, guilds, exotics, rare species, plant biomass, and amphibian biomass. Rapport and colleagues (1998) suggested nutrients, productivity, abiotic zones, species diversity, genetic diversity, size distribution, biotic composition, and bioaccumulation of contaminants. Bertello (1998) cited a number of other authors who have suggested measures for monitoring and assessing ecosystem health and natural integrity. Some of the reoccurring parameters include measures of species richness, species composition, nutrient cycling and flow, productivity, and community structure.

Fu-liu and Shu (2000) provided a sampling and description of additional indicators to include the Index of Biotic Integrity (IBI) developed by Karr (1981; Karr, Fausch, Angermeier, Yant & Schlosser, 1986), and an overall system health index which incorporated vigor, organization, and resilience as proposed by Costanza (1992). Ulanowicz (1980, 1986) developed the index of network ascendency which incorporates species richness, niche specialization, developed cycling and feedback, and overall activity. Jorgensen (1995) suggested energy, structure, and ecological buffer capacity as indicators. Belaoussoff and Kevan (1998) demonstrated how norms of diversity and abundance could be used. They suggested characterizing ecosystem diversity-abundance relationships within ecological communities using lognormal distributions as they change under differing degrees of disturbance.

Selecting Feasible Naturalness Indicators

While the above indicators or measures all have scientific validity and broad applications to Wilderness, they are, for the most part, impractical because of high costs for primary data collection and very limited availability of secondary data. Very little consistently collected, sufficiently fine-scale, System-wide data were found to be available to address the suggestions from the above authors. This accepted, we turned to indirect surrogate measures as our remaining option (Coates, Jones & Williams, 2002).

A search was conducted for broad-scale data that would enable measurement of the selected indicators of naturalness and apparent ecological health. Desirable were data at a fine enough resolution to enable construction of an area-by-area database. Ideally this would include soils, water quality, air quality, vegetation, wildlife populations, and wildlife habitat. In limited instances, site-specific data are available, but mostly these data are the result of an individual scientist's research to study a specific organism, species, system, area, or issue. For example, Ryan (1990) studied lichens as a measure of air quality, but not across the System. Wetmore (1992) also studied lichens. Rollins, Thomas, and Morgan (2001) looked at changes in fire patterns in selected Wilderness areas and Bader (2000) examined the value of Wilderness habitat to grizzly bears. Because system-wide data were not generally available, the search expanded to looking for broad-scale data that cover all lands—Wilderness and other lands alike.

Limited broad-scale data are becoming available, but mostly at scales too coarse to enable distinguishing conditions specific to individual Wilderness areas (especially the smaller ones in the East). An example of a national database collected at too coarse a scale for our intended purposes is the National Resources Inventory (NRI), developed by the Natural Resources Conservation Service. These data are based on observable aerial units, which are samples of the total landscape, with sampling intensity meant to serve parameter estimation at state, regional, or national levels. Most other surface-measured, broad-scale data are inconsistently measured and do not provide consistent coverage across the NWPS. An example of inconsistently collected data is the Natural Heritage data. Natural Heritage data are independently generated by

each state, using guidelines provided by NatureServe (NatureServe, 2003). Administration of these guidelines seems somewhat inconsistent across states. More promising in recent years has been amended satellite imagery, some available at 30-meter resolution. Amended data means that some other source is "overlaid" to enhance interpretation. Satellite data and the approaches used for processing the selected data for each of four selected naturalness indicators are forest fragmentation, natural land cover, distance from roads, and ecosystem representation.

Forest fragmentation is used to indicate the degree to which individual Wilderness areas and aggregates of geographically proximate Wilderness areas are intact, apparently not fragmented, and thus have retained inherent natural landscape integrity relative to other lands.

Natural land cover indicates the degree to which areas are under natural vegetative cover and thus have retained their natural landscape integrity relative to other lands).

Distance from roads is used to indicate the relative degree to which areas are insulated from roads, and thus are less likely to have been impacted by human activities and therefore have retained their inherent natural character relative to other lands.

Protecting not only the naturalness of individual areas from human activities but also a diversity of geographically spread natural areas goes even further toward sustaining life support on the earth. The greater the diversity of protected natural ecosystems, such as the 662 areas currently included in the National Wilderness Preservation System (NWPS), the greater will be the diversity of life forms protected. These 662 areas do not afford proportionate aerial representation of the range of ecosystem types to be found in the United States however. Thus, the fourth indicator of naturalness (across the System) is *ecosystem representation* defined as the diversity of ecosystems included in the NWPS, and thus within the confines of a region or subregion, that have protected broad-scale biodiversity and natural integrity, and thus diversity of species.

Background about the Data and Its Analytical Treatment

Forest Fragmentation

Forest fragmentation (or lack of it) is widely accepted as an important indicator of the capacity of natural forest ecosystems to sustain indigenous life. In the international Montreal Process, for example, fragmentation indicators are intended to show losses and degradation of large blocks of habitat that support native populations of flora and fauna (USDA Forest Service, n.d.). The assumption is that larger forest patches are more autonomous and better able to maintain natural disturbance regimes, resulting in more species, lower extinction rates, and greater genetic diversity for native interior forest species.

Fragmentation results in greater edge effect, potentially making forested areas more vulnerable to abiotic influences such as wind, and biotic influences such as exotic, early successional, and transient species (Debinski & Holt, 2000). Altered abiotic conditions can in turn influence ecosystem processes such as nutrient cycling (Debinski & Holt, 2000) through impacts on invertebrate species that are important in decomposition (Meffe & Carroll, 1997). When fragmentation results in smaller patches, large carnivores may be threatened by a reduction in available prey and exposure to human activities and hunting (Meffe & Carroll, 1997). Absence of fragmentation indicates that essential natural functions and processes are less likely to have been degraded or modified.

In this chapter, fragmentation within Wilderness areas is compared to fragmentation of all lands as a plausible indication that Wilderness designation protects areas from fragmentation and thus preserves natural ecological processes and habitats; that is, naturalness. There has been considerable recent work examining forest fragmentation at a national scale (Heilman, Strittholt, Slosser & Dellasala, 2002; Heinz Center, 2002; Riitters et al., 2002; Riitters, Wickham & Coulston, 2004). These studies generally indicate that while forest land is relatively well-connected over very large regions, fragmentation is so extensive that edge effects extending only 100 meters from forest edge potentially influence over half of all forest land. The largest reserves of core (i.e., intact or unfragmented) forest are found in areas not suited for agricultural or urban land uses, including many Wilderness Areas. Our examination of fragmentation in Wilderness relative to other lands is limited to eastern forests because the available data do not permit us to distinguish natural fragmentation from human induced fragmentation in western forests.

Following protocols described by Riitters and associates (2002), we evaluated forest fragmentation at two landscape scales and used three threshold levels to describe forest cover. The primary data source was the National Land Cover Data (NLCD), a national land-cover map at 30-meter pixel resolution that was developed from Thematic Mapper satellite imagery in 1992 (Vogelmann, Howard, Yang, Larson, Wylie & Van Driel, 2001). Briefly, each 0.09 hectare pixel of forest was classified according to the percentage forest cover in the surrounding neighborhood, for both 7 hectare (~17.5 acres) and 600 hectare (~1,400 acres) neighborhoods. For a given neighborhood size, we then applied threshold values of 60, 90, and 100 percent to label each pixel as dominant, interior, and core, respectively. A core forest pixel resides at the center of a completely forested neighborhood, while dominant and interior forest pixels reside in neighborhoods that are at least 60 and 90 percent forested, respectively. The level of fragmentation measured by these thresholds is seen as a plausible predictor of the plant and animal species present. For example, in the more fragmented dominant forest, there may be more edge or invasive species.

We then summarized the amount of forest that met the various criteria within, and outside Wilderness Areas. This was accomplished by overlaying boundary maps for all eastern Wilderness areas that contained forest land cover. Coastal Wilderness areas in the East were deleted to avoid including surface area outside of a Wilderness area along the coast that would appear as unforested (including water). The proportions of 30-meter (0.09 hectare) cells both within and outside of Wilderness as classified by the 60, 90 and 100 percent threshold levels, and for each window size (i.e., 7 hectare and 600 hectare) provided estimates for each Wilderness area of dominant, interior and core forest cover. Individual Wilderness area data were aggregated for the Eastern Region and proportions of total Wilderness acreage computed. A similar procedure was followed to compute proportions of total Eastern U.S. land area in dominant, interior, and core forest cover.

Natural Land Cover

Natural land cover is a relatively direct indication of naturalness as a condition of land (Jones et al., 2001). Natural land cover includes all land that is not developed, that is, not urban, not transportation, not agricultural (Cordell & Overdevest, 2001). Natural land is continually converted to developed uses. Between 1982 and 1997, three percent of natural range was converted to agriculture or developed uses and 11.7 million acres of natural forest cover was converted to developed uses (Cordell & Overdevest, 2001). In the eastern United States, most undeveloped natural land is in forest cover (Cordell & Overdevest, 2001). Over the past century there have been changes in forest cover that have raised concerns about carbon storage, biodiversity, water quality, nitrogen cycling, and the sustainability of forest resources. Land cover reflects ecosystem type, as well as past and current land use and management. Changes in cover caused by changes in land use have been accelerating over time as human technological ability has vastly increased. The effect of land cover change on climate can be seen throughout the United States. Agriculture has expanded and replaced grasslands in the Great Plains and Midwest. There has been a cooling effect in these areas demonstrated by a temperature change of more then one degree Fahrenheit. There has been a warming effect along the Atlantic Coast as croplands are replaced by forest and across the southwest where woodlands have replaced some desert (Roy, Hurtt, Weaver & Pacala 2003).

Land cover affects the concentrations of greenhouse gases, air and water quality, soil fertility, the capability of terrestrial and aquatic ecosystems to provide goods and services, local weather, the occurrence and spread of infectious disease, and species extinction (Stein, 2001) as well as other aspects of ecological health. The conversion of natural land to anthropogenic land uses affects the processes of water interception, infiltration, and runoff that effect flooding, water storage, and the quality of drinking water (Jones et al., 2001). Land use has significant effects on the quality of water in streams and groundwater. Basins with significant agricultural or urban development almost always contain higher than normal concentrations of nutrients and pesticides. Since 1991, USGS scientists with the National Water Quality Assessment Program have been collecting and analyzing data and information in more than 50 major river basins and aquifers across the Nation. Some of the highest levels of nitrogen and herbicides were found in streams and ground water in agricultural areas. Some of the highest levels of phosphorus and insecticides were collected from urban streams (USGS, 1999).

The data used to measure the natural land cover character of Wilderness for this chapter is referred to as National Land Cover Data 1992 (NLCD 92; Vogelmann et al., 2001). In addition to satellite imagery data, the NLCD 92 project used a variety of measures including topography, population census, agricultural statistics, soil characteristics, land cover maps, and wetlands data. The NLCD 92 scale resolution is 30 meters square, roughly the size of a baseball diamond. There are 21 land cover classes within the NLCD 92 that can be mapped consistently at 30 meters resolution across the United States. The data accessed for this analysis represented the number of square meters in each of the 21 NLCD land cover classes (e.g., water, barren land, shrubland, herbaceous upland natural/seminatural vegetation, wetlands, developed land, forested upland, non-natural woody, and herbaceous planted/cultivated). These 21 NLCD classes were subsequently aggregated into six broad cover classes, including five representing natural cover (i.e., water, grassland, wetland, forest, and shrubland). An additional non-natural land cover class including all other land cover classifications (e.g., agricultural, developed land) were combined to form a sixth class labeled "other."

Approximate total land area in each of these six land cover classes was calculated by overlaying GIS shape files for each of the designated areas in the NWPS with land cover classification boundaries. This step provided approximations because of inevitable incompatibilities in map data between different data sources. These approximate estimates of area in each of the land cover classes, for each Wilderness area, were divided by each area's total acreage to estimate the percentage of each Wilderness area in each land cover class. These percentages were used to recompute the number of acres in each class by multiplying each by the official acreage for each Wilderness area found at the Wilderness.net web site.

Distance from Roads

One of the leading contributors to habitat fragmentation and diminution of natural land cover is maintenance and expansion of the nation's road network. The United States was spanned by an extensive road network estimated in 2002 to include over 6.3 million kilometers of public roads of all types (U.S. Department of Transportation, 2002). For comparison, the U.S. Environmental Protection Agency (n.d.) estimated that there are only 5.3 million kilometers of streams and rivers in the country. Thus, roads exceed the linear expanse of streams in the United States by a substantial margin, and that margin is growing. Public road length, including interstates, principal and minor arterials, major and minor collectors, and local roads, grew by over 99,000 kilometers between 1993 to 2002. In some states there were especially large increases, such as Florida growing by 11,230 kilometers, Colorado by 12,210 kilometers, and Texas by 12,290 kilometers. In other states there were smaller increases, including Washington with 4,427 kilometers and Vermont with about a 200 kilometers increase (USDT, 1993, 2002).

Forman and Alexander (1998), Spellerberg (1998), Trombulak and Frissell (2000), and Forman and colleagues (2002) reviewed the ecological impacts of roads on terrestrial and aquatic systems. The distance from a road that is ecologically impacted is often referred to as the road ecological influence zone. Research indicates that road influence zones extend tens to hundreds of meters from roads, usually disrupting wildlife movement, modifying habitat, altering water drainage patterns, introducing exotic species, modifying microclimate and chemical environment, and increasing noise levels (Riitters & Wickham, 2003). The deleterious effects of road construction also include sedimentation from erosion, increased runoff and flow rates, and filling and draining of wetlands (MDNR, 2001). Roads are precursors to future impacts because they facilitate land development and further expansion of the road network itself (Riitters & Wickham, 2003).

Attention has recently focused more on the broad-scale impacts of roads at regional levels (e.g., Heilman, Strittholt, Slosser & Dellasala, 2002; National Research Council, 1997; Wickham et al., 1999; Wickham, O'Neill, Riitters, Smith, Wade & Jones, 2002). Nationally, using total highway length statistics for 1985 and assumptions concerning road density, spatial distribution of roads, traffic volumes, widths of road influence zones, and other factors, Forman (2000) estimated that 22 percent of the total land area of the country was at that time ecologically affected by roads. This was based on the assumption of a 100-meter influence zone near secondary roads, 305–365-meter influence zone near primary roads, and 810-meter zone near some urban roads. Based on the estimate that humans can drive to within one kilometer of 82 percent of all land in the United States, very little land area is untouched by the impact of roads and their uses. The presence of roads also influences potential impact from other sources as they open the way for future development (Riitters & Wickham, 2003).

The data used to calculate the proportion of Wilderness within 127 meters, 382 meters, 1,000 meters, and 5,000 meters from the nearest road were abstracted from an earlier study by Riitters and Wickham (2003). That original study examined the proportion of U.S. land that is close enough to a road such that is it likely to experience an ecological effect; that is, it is within the road influence zone. The 1992 NLCD land cover map (Vogelmann et al., 2001) and the national road map (GDT, 2002), which identified public roads ranging from interstate highways to four-wheel drive trails, were the basic sources used to assign a "road" land-cover classification to each 30-meter cell of land area in the United States. The GDT road map was also gridded into 30-meter cells in order to overlay it with the NLCD map. If an NLCD cell overlapped a road map cell then it was relabeled as a "road" cell, as opposed to another land cover class, such as forest. Distance to the nearest road cell was calculated for all grid cells. The resulting records for each Wilderness area in the country showed the proportion of land area within each of several discrete distances from the nearest road (including 127 m, 382 m, 1,000 m and 5,000 m). Data representing the proportion of Wilderness within the above distances from roads were aggregated for the East and West regions for comparison with the proportion of all land in the United States within these distances. In this study we examine the amount of Wilderness that is beyond each of the distances to the nearest road (e.g., How much Wilderness is more then 5,000 meters from the nearest road?).

Ecosystem Representation

Haney and associates (1999) stated that "wilderness might be expected to be sufficiently large or otherwise configured so as to contain all ecosystem structure, community types, or species representative of a bioregion (p. 2)." Organisms at the ecosystem level mediate flows of energy and materials and the mediation of these flows contributes to ecological health and life support. When organism diversity reaches low levels, such as those typically found in managed (i.e., modified) ecosystems, then the magnitude and stability of ecosystem functioning may be significantly altered (Naeem et al., 1999). To maintain biodiversity, it is desirable to preserve the integrity of entire natural landscapes (Dailey et al., 1997).

Ecosystems can be viewed at multiple scales, just as human communities can be viewed at different scales from the global to continental to local. They can be viewed at broad scales to include ecosystem regions (i.e., ecoregions), or they can be viewed at smaller scales, such as isolated canyon communities or puddles left after a rain. Whatever the scale, there is tremendous diversity of ecosystems across the United States and world. Although many ecosystem types have already been and currently are being altered by human land conversions in the United States, preserving representatives of the remaining diversity of ecosystems, as well as biodiversity within those ecosystems, is a primary goal of Wilderness protection.

Ecosystem identification typically begins with macroclimate as the most significant factor on earth determining the distribution of various life forms. As climate changes, so too does the distribution of mammals, fish, tree species, and all other forms of life. For example, Dymond, Carver, and Phillips (2003) found that low latitude and good climate are important determinants of species richness. The extant distribution of types of ecosystems across the United States is a direct result of evolving climate over tens of thousands of years. Most of this country's ecosystem types have been heavily transformed by human settlement and land uses in a matter of just two or three centuries, and mostly as a result of the last few decades. What remains of the untransformed ecosystems are essential to the continued existence of the diversity of life forms still found within these ecosystems. Thus, a focus on measuring ecosystem representation is one way to measure the biodiversity protection benefit of Wilderness. It is one dimension of the capacity of Wilderness to support natural life, as well as to provide ecological services to humans (Naeem et al., 1999; Risser, 1995). Noss (1990) acknowledged that Wilderness designation might be "the only opportunity to maintain the ecological gradients and mosaics that constitute native biodiversity at the landscape level."

Ecoregions have been defined by the World Wildlife Fund (2004) as

> a large area of land or water that contains a geographically distinct assemblage of natural communities that
> (a) share a large majority of their species and ecological dynamics,
> (b) share similar environmental conditions, and
> (c) interact ecologically in ways that are critical for their long-term persistence.

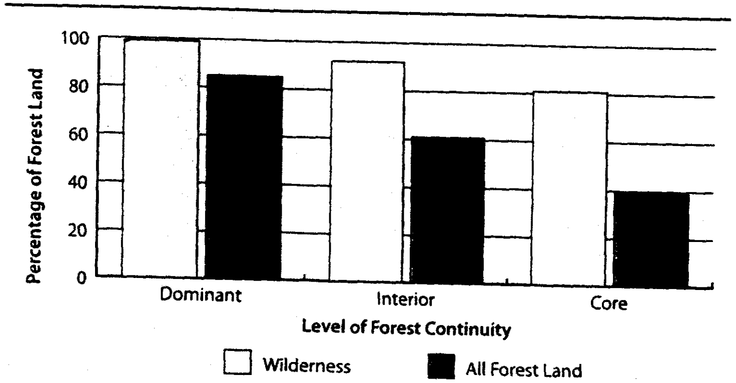
Others have defined ecoregions as areas of ecological potential based on combinations of biophysical parameters such as climate and topography. Ecoregions transcend artificial human boundaries such as state lines or agency jurisdictions. We adopted the "Bailey system" for identifying ecosystems (Bailey, 2002). The system Bailey and his colleagues have developed and refined is meant to be comprehensive, across terrestrial and aquatic ecosystems. It is perhaps the best-known and most widely adopted ecosystem and ecoregional classification system (Bailey, 1995). This system for classifying ecological regions and subregions in the United States identifies domains, divisions, provinces, and sections. These groupings reflect similarities in climate, ecological processes, vegetation, and groups of species (Stein, 2001). The broadest scale of ecological regions are domains, which primarily reflect climate differences. The four Domains in the Bailey system are the Polar, Humid Temperate, Dry, and Humid Tropical. Polar Domain ecosystems are located at higher latitudes and are influenced mostly by arctic and polar air flows and include tundra and subarctic mountains. In the middle latitudes, the Humid Temperate Domain is regulated by both polar and tropical air masses. The Dry Domain is defined by the presence or absence of water and includes the deserts, steppes, high mountains, and dry coniferous forest division. The Humid Tropical Domain is found at low latitudes and controlled by equatorial and tropical air masses, such as the Everglades on southern tip of Florida. Domains are broken down into divisions that are subdivided into provinces based on vegetational macrofeatures (see the descriptive statistics on divisions in Chapter 5 of this book).

Spatial data representing area and boundaries by Bailey's ecoregion type (down to the province level) were accessed for this chapter using data from the USDA Forest Service. Within this database a narrative description and numeric code were provided for each ecological province. Wilderness boundary map data (Wilderness Institute, 2003) were overlaid onto mapped data of ecoregion boundaries in order to estimate land area within Wilderness boundaries representing each of Bailey's ecoregional provinces. For analysis, these overlays were visually mapped, as well as tabulated by computing percentages of total area within each ecological province protected by Wilderness.

Results

Fragmentation

The comparisons in Figures 11.1 and 11.2 indicate that eastern Wilderness forest land is less fragmented and thus in more natural condition than non-Wilderness



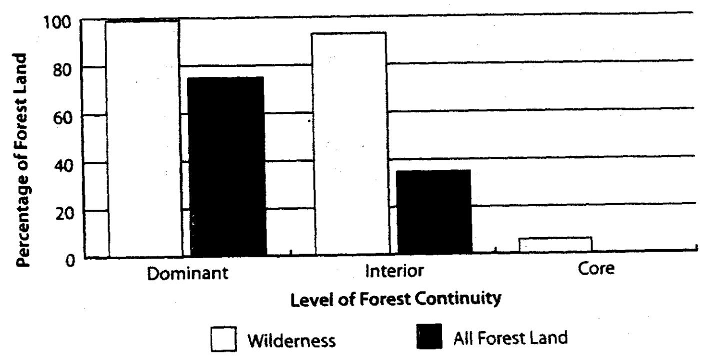
Sources: Riiters et al., 2002; Wilderness Institute, 2003

Figure 11.1 Percentages of forest land in Wilderness and all other forest land in the East by level of forest continuity at the 7-hectare landscape scale

forests. For both Wilderness and non-Wilderness forest lands, measured fragmentation is dependent on both landscape scale and fragmentation threshold. Figure 11.1 compares proportions of forest land at the 7-hectare landscape scale. Shown are percentages of eastern Wilderness forest land and all eastern forest land that are in dominant forest cover (60% or more), percentages classified as interior forest (90% or more), and percentages classified as core forest (i.e., all or 100% of 30m cells within the 7-ha landscape window are forested).

Much greater percentages of Wilderness relative to non-Wilderness forest at the more resolute 7-hectare landscape scale were found to exist across the three classes of forest continuity (i.e., dominant, interior, and core). Specifically, 99 percent of the Wilderness forest was classified as dominant, 92 percent was classified as interior, and 81 percent was classified as core (i.e., continuous) forest. The percentage of Wilderness forest not fragmented (i.e., core or continuous forest) is more than twice that of all other forest lands. This is an indication that unprotected forest lands are much more fragmented than Wilderness forest lands. Thus, Wilderness lands have retained much greater degrees of their natural integrity and connectivity.

Figure 11.2 compares percentages of eastern Wilderness forest land and all other eastern forest land that is classified as dominant, interior, and core forest at a much broader 600-hectare landscape scale. Measures of fragmentation at this scale tend to be much more sensitive to broken or discontinuous patterns of forest cover because the broader net that is cast is more sensitive to lands not forested. In other words, at this broader scale, one would expect greater incidence of nonforest plots of land relative to the location of any



Sources: Riiters et al., 2002; Wilderness Institute, 2003

Figure 11.2 Percentages of forest land in Wilderness and all other forest land in the East by level of forest continuity at the 600-hectare landscape scale single 30-meter cell. This greater sensitivity is evident when comparing bar heights for non-Wilderness forest between Figures 11.1 and 11.2. At this 600-hectare landscape scale, substantially smaller percentages of non-Wilderness forest lands met the dominant, interior, or core forest thresholds. At this broader scale as well, a much smaller percentage (only around 6%) of Wilderness forest was found to be core forest. At the 7-hectare scale, 40 percent of non-Wilderness eastern forest met the core forest threshold criteria. No non-Wilderness eastern forest met the threshold for being classified as core forest at the 600-hectare scale.

The results in Figure 11.2 comparing Wilderness and all other forest lands indicate even more strongly than the 7-hectare-scale results in Figure 11.1 that Wilderness designation leads to greater retention of naturalness; that is, forest continuity and habitat integrity. The decrease from 81 percent core forest in the 7-hectare-landscape in comparison to 6 percent core forest in the 600-hectare landscape demonstrates that this conclusion is scale-dependent. The broader the landscape net cast, the more likely is it that some fragmentation within or bordering Wilderness forests will be found.

Few Wilderness forests do not meet the dominant or interior forest thresholds, at either landscape scale. This is because Wilderness areas, themselves relatively unfragmented, tend more to be located within large tracts of public forest land with relatively little development. Among non-Wilderness forests, more fragmentation is apparent. Percentages of continuous non-Wilderness forest classed as either dominant, interior, or core are smaller than for Wilderness forest. At these lower percentages of continuous forest cover, it is much more likely that even small changes in forest cover will have a great impact on natural processes and species that depend on connected forest. Less then two percent of forested Wilderness land did not meet the dominant cover criteria. About 15 percent of all non-Wilderness forest land in the East was less than 60 percent forested at the 7-hectare landscape scale and about 25 percent of all forested land was less then 60 percent forested at the 600-hectare scale. Overall, these estimates of different levels of connected forests provide substantial evidence that forest land protected through Wilderness designation is less fragmented than other forest land in the East. Indeed, Wilderness areas appear to contain the only measurable remnants of core forest extending 1,000 or more hectares.

Land Cover

As described earlier, the U.S. Geological Service maintains data describing land area across the United States by various land cover types. These data represent pixels from satellite imagery classified by apparent dominant land cover. We aggregated the original 21 classes into six land cover types, five types of natural cover, plus a catchall sixth type representing all "Other" land

uses (e.g., agricultural, urban lands). We use the term *natural* here to mean land area that is vegetated, under water, wetland, and similar undeveloped lands. We do not assume that the five cover types imply complete naturalness; rather, we assume undeveloped forest, wetlands, water area and shrubland is more natural and thus represents (in an indicator of) more naturalness than the Other land cover type. (We will refer to the undeveloped land categories as natural land cover.) Tables 11.1 through 11.4 (pp. 223–226) show for each U.S. Census Division the acres of land protected as Wilderness, percentage of Wilderness by land cover, total acres of all land, and percentage of all land by land cover class.

In the Northeast Census Region (Table 11.1), there are two divisions, the Middle Atlantic and New England. These divisions stretch from Pennsylvania to Maine. In the Middle Atlantic Division, there are a total of over 20 thousand acres of land in Wilderness. Over half of this land is forest, over one quarter is wetland, and nearly 18 percent is water. Compared with all land, Wilderness has much greater percentages in natural cover overall with over 95 percent falling within one of the five "natural" cover types. In contrast, over 30 percent of Middle Atlantic total area falls into the Other land cover class. Only about 12 percent

Table 11.1 Number of acres and percentages of Wilderness and of all land in each cover class[1] by division in the Northeast Census Region

Northeast Census Region	Total acres of Wilderness	Percentage of Wilderness in Census Division	Total acres of all lands	Percentage of all land in Census Division
Middle Atlantic	20,367		69,893,246	
Water	3,600	17.7	6,381,352	9.1
Forest	10,519	51.7	40,589,169	58.1
Wetland	5,286	26.0	1,706,202	2.4
Grassland	0	0.0	0	0.0
Shrubland	0	0.0	0	0.0
Other	962	4.7	21,216,523	30.4
New England	179,485		46,072,452	
Water	1,708	1.0	6,023,678	13.1
Forest	171,867	95.8	31,450,648	68.3
Wetland	3,104	1.7	2,150,126	4.7
Grassland	0	0.0	0	0.0
Shrubland	49	0.0	131,968	0.3
Other	2,757	1.5	6,316,032	13.7

[1] The Forest class combined the NLCD land cover classes Deciduous Forest, Evergreen Forest, and Mixed Forest. The Water category was created by combining Open Water and Perennial Ice/Snow. Wetlands included Woody Wetlands and Emergent Herbaceous Wetlands. Grasslands were represented by the NLCD category Grasslands/and Herbaceous and finally Shrublands equals Shrubland. The Other category includes all other classifications (e.g., agriculture and developed land).

Sources: Vogelmann et al., 2001; Wilderness Institute, 2003 is either water or wetlands. Although a relatively high proportion of all land is forested, it includes some planted forests and a great deal of managed area.

In the New England Division, over 98 percent of the land in the Wilderness System is in natural cover, mostly forest. Almost 96 percent of New England Wilderness is forested. Only 1.5 percent falls within the Other category, likely indicating human disturbance near Wilderness boundaries where the relative coarseness of the satellite imagery cannot discriminate well between land just inside and land just outside of a Wilderness boundary. Nearly 14 percent of non-Wilderness land in the New England Division falls into the Other land cover category. Over two thirds of all land is forested. These percentages indicate, as with the Middle Atlantic Division, that lands protected as Wilderness have substantially greater levels of natural land cover.

Table 11.2 Number of acres and percentages of Wilderness and of all land in each cover class[1] by division in the South Census Region

South Census Region	Total acres of Wilderness	Percentage of Wilderness in Census Division	Total acres of all lands	Percentage of all land in Census Division
South Atlantic	2,314,583		187,185,771	
Water	584,626	25.3	17,167,716	9.2
Forest	494,732	21.4	91,015,369	48.6
Wetland	1,122,204	48.5	24,206,769	12.9
Grassland	95,999	4.2	3,567,428	1.9
Shrubland	844	0.0	1,375,934	0.7
Other	16,176	0.7	49,852,555	26.6
East South Central	129,726		117,377,714	
Water	2,279	1.8	3,339,798	2.9
Forest	118,358	91.2	69,496,313	59.2
Wetland	4,997	3.9	6,580,470	5.6
Grassland	0	0.0	3,696	0.0
Shrubland	0	0.0	0	0.0
Other	4,091	3.2	37,957,437	32.3
West South Central	279,124		283,830,122	
Water	7,004	2.5	12,333,740	4.4
Forest	217,658	78.0	62,951,857	22.2
Wetland	8,720	3.1	13,769,070	4.9
Grassland	11,040	4.0	48,875,858	17.2
Shrubland	27,278	9.8	54,122,960	19.1
Other	7,426	2.7	91,776,637	32.3

[1] The Forest class combined the NLCD land cover classes Deciduous Forest, Evergreen Forest, and Mixed Forest. The Water category was created by combining Open Water and Perennial Ice/Snow. Wetlands included Woody Wetlands and Emergent Herbaceous Wetlands. Grasslands were represented by the NLCD category Grasslands/and Herbaceous and finally Shrublands equals Shrubland. The Other category includes all other classifications (e.g., agriculture and developed land).

Sources: Vogelmann et al., 2001; Wilderness Institute, 2003

There are around 2.7 million acres of federal lands protected as Wilderness in the South (Table 11.2). As with the Northeast Region, these protected lands among the divisions of the South are mostly in natural cover, ranging from just over 99 percent in the South Atlantic Division to just under 97 percent in the East South Central. In the East and West South Central Divisions, most of the cover in Wilderness is forest. In the South Atlantic, with such Wilderness Areas as the Everglades and Okefenokee Swamp, almost three quarters of the total area is either water or wetlands. Just over 21 percent is forest. In contrast, among all land in the South, much higher percentages are in the Other land use category. This includes nearly 27 percent in the South Atlantic and 32 percent in each of the other two Southern Divisions. These results indicate that in this region as well, Wilderness designation has, as expected, resulted in protection for much greater levels of natural land cover.

The Upper Midwest includes the East North Central and West North Central Divisions. These divisions together stretch from Ohio to Kansas to North Dakota. In the East North Central there are about 332 thousand acres of protected Wilderness (Table 11.3). In the West North Central, there are over one million acres of protected Wilderness, including the Boundary Waters Canoe Area in

Table 11.3 Number of acres and percentages of Wilderness and of all land in each cover class[1] by division in the Midwest Census Region

Midwest Census Region	Total acres of Wilderness	Percentage of Wilderness in Census Division	Total acres of all lands	Percentage of all land in Census Division
East North Central	332,093		187,009,685	
Water	17,646	5.3	31,563,555	16.9
Forest	209,282	63.0	46,974,048	25.1
Wetland	98,634	29.7	11,304,689	6.0
Grassland	668	0.2	1,354,051	0.7
Shrubland	0	0.0	14,207	0.0
Other	5,862	1.8	95,799,135	51.2
West North Central	1,012,294		333,016,281	
Water	148,759	14.7	8,319,855	2.5
Forest	625,152	61.8	36,170,273	10.9
Wetland	116,526	11.5	16,166,711	4.9
Grassland	74,296	7.3	85,562,607	25.7
Shrubland	9,077	0.9	3,586,058	1.1
Other	38,483	3.8	183,210,777	55.0

[1] The Forest class combined the NLCD land cover classes Deciduous Forest, Evergreen Forest, and Mixed Forest. The Water category was created by combining Open Water and Perennial Ice/Snow. Wetlands included Woody Wetlands and Emergent Herbaceous Wetlands. Grasslands were represented by the NLCD category Grasslands/and Herbaceous and finally Shrublands equals Shrubland. The Other category includes all other classifications (e.g., agriculture and developed land).

Sources: Vogelmann et al., 2001; Wilderness Institute, 2003 northern Minnesota. As with the other regions we have examined thus far, only small percentages of Wilderness acreage fall within the Other category of land cover. Again, these small percentages of seemingly disturbed and developed land uses are likely the result of the coarseness of the grid pattern laid across Wilderness and adjoining lands, making fine distinctions between them difficult. Over 61 percent of Wilderness lands in both of these Upper Midwest Divisions are forested. Five percent in the East North Central and nearly 15 percent in the West North Central are water. Nearly 30 percent in the East North Central and over 11 percent in the West North Central are wetlands. Over half of all land in these Upper Midwest Divisions are disturbed from their prehistoric natural conditions and are in use for human residency, commercial operations, transportation, or crop production. Only 11 percent in the West North Central and 25 percent in the East North Central is forested. In the West North Central, nearly 26 percent is in grassland cover, mostly grazed grassland.

Table 11.4 shows results for the vast West Census Region covering states from New Mexico to Washington (excluding Alaska because land cover data were not available at the time of this analysis). There are almost 33 million acres of Wilderness in these contiguous Western states. In the Mountain Division, stretching from the Mexican border to the Canadian border, over 43 percent of Wilderness is forested. In the Pacific Division, 34 percent is forested. Over 46 percent in the Mountain and over 54 percent in the Pacific Divisions are grasslands or shrublands. Around 10 percent in both Divisions fall into the Other category, indicating mostly the difficulty of distinguishing between disturbed/managed lands and natural covers, such as stretches of desert void of vegetation. Due to the vastness of the public lands in the West and Pacific Divisions, and because of the sparseness of the human population in many rural areas of these divisions, comparisons of natural cover between Wilderness and all land are not as distinctive. However, percentages of all land in the Other, more disturbed category are greater in both divisions than are the percentages in the more disturbed categories of cover in Wilderness land.

Table 11.4 Number of acres and percentages of Wilderness and of all land in each cover class[1] by division in the West Census Region

West Census Region	Total acres of Wilderness	Percentage of Wilderness in Census Division	Total acres of all lands	Percentage of all land in Census Division
Mountain	15,569,924		552,510,837	
Water	136,467	0.9	5,021,370	0.9
Forest	6,713,845	43.1	107,953,105	19.5
Wetland	25,356	0.2	2,008,357	0.4
Grassland	2,085,987	13.4	145,231,555	26.3
Shrubland	5,109,633	32.8	226,916,346	41.1
Other	1,498,700	9.6	65,380,104	11.8
Pacific	17,231,941		213,355,725	
Water	191,484	1.1	9,520,746	4.5
Forest	5,865,577	34.0	76,410,972	35.8
Wetland	3,568	0.0	1,077,470	0.5
Grassland	835,450	4.9	21,990,654	10.3
Shrubland	8,480,386	49.2	67,930,205	31.8
Other	1,855,595	10.8	36,425,678	17.1

[1] The Forest class combined the NLCD land cover classes Deciduous Forest, Evergreen Forest, and Mixed Forest. The Water category was created by combining Open Water and Perennial Ice/Snow. Wetlands included Woody Wetlands and Emergent Herbaceous Wetlands. Grasslands were represented by the NLCD category Grasslands/and Herbaceous and finally Shrublands equals Shrubland. The Other category includes all other classifications (e.g., agriculture and developed land).

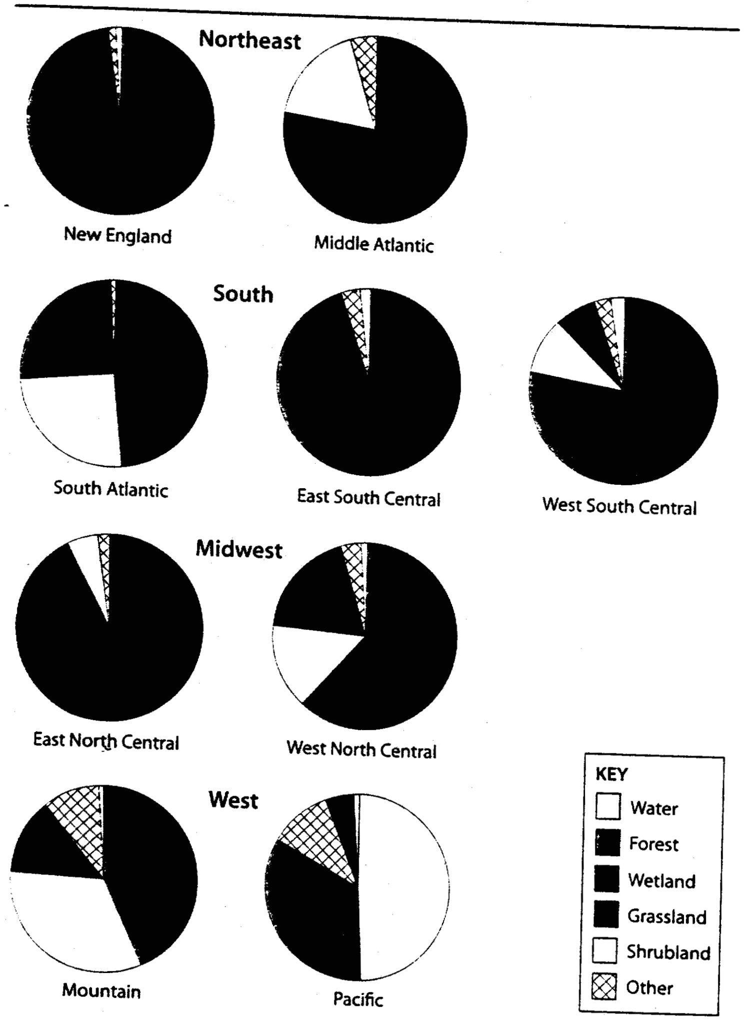
Sources: Vogelmann et al., 2001; Wilderness Institute, 2003

Figure 11.3 (p. 228) summarizes the percentages of Wilderness in land cover classes by Census Division. It visually illustrates that not only does Wilderness designation protect more of the naturalness character of land but also that over the last 40 years, it has preserved a diversity of land cover types. These range from the water and wetlands of the South Atlantic and the forests of the Northeast to the more arid grasslands and shrublands of the West.

Distance to Roads

Research has indicated that road influences can extend tens to hundreds of meters from the roads themselves, disrupting wildlife, water, and microclimate and raising noise levels (Forman et al., 2002). Such influences also can include sedimentation from eroding road banks and ditches, increased runoff, and destruction of wetlands (MDNR, 2001). In relation to the road distance data presented in Table 5.7 (p. 77), we have examined proportions of Wilderness acreage beyond different distances from roads, and thus the likelihood that road influences are more or less likely being exerted upon the naturalness of Wilderness. In Chapter 5, we provided estimates of acreage and proportion of Wilderness area within about 140 feet, within about 1,250 feet (about ¼ mile) and within about 17,000 feet of a road (a little over three miles) for each of the four major regions of the United States. Based on work by Riitters and Wickham (2003), this analysis was presented as one of the dimensions for characterizing the NWPS. We found that between about 70 (in the Northeast) and 44 percent (in the West) of designated Wilderness is within 3.2 miles (around 17,000 feet) from the nearest road (Table 5.7, p. 77). Road networks in the South, Northeast and Midwest, where much less public lands lie, are more densely developed and are rapidly increasing in length and coverage.

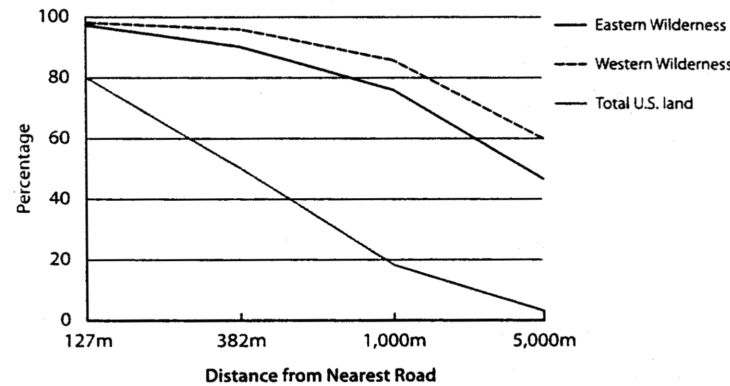
Figure 11.4 and Table 11.5 (page 229) show additional analyses of the proportions of Wilderness land in the East and West, and proportions of all land in the United States, that are more than 127, 382, 1,000, and 5,000 meters from the nearest road (excluding Alaska, for which fine-scale road data are



Note: The Forest class combined the NLCD land cover classes Decidous Forest, Evergreen Forest, and Mixed Forest. The Water category was created by combining Open Water and Perennial Ice/Snow. Wetlands included Woody Wetlands and Emergent Herbaceous Wetlands. Grasslands were represented by the NLCD category Grasslands/and Herbaceous and finally Shrublands equals Shrubland. The Other category includes all other classsifications (e.g., agriculture and developed land).

Figure 11.3 Percentages of Wilderness land in each land cover class by Census Division of the United States

not available). Distance of land from roads was calculated using broad-scale coverage of 30-meter grid cells. As one would expect of national coverage data, estimates of proportions of land area are subject to some error due to the coarseness of grid cells relative to Wilderness boundaries. However, from regional and national perspectives, 30-meter grid data are relatively fine scale and good indicators of overall road-land locations. The measure we sought was location of cells with roads relative to the location of cells with Wilderness, regardless of Wilderness boundary locations.



Sources: Riitters and Wickham, 2003; Wilderness Institute, 2003

Figure 11.4 Percentages of eastern and western Wilderness and of all U.S. land at four distances from the nearest road

Table 11.5 Percentages of Eastern and Western Wilderness lands and of all U.S. lands from nearest road at four distances[1]

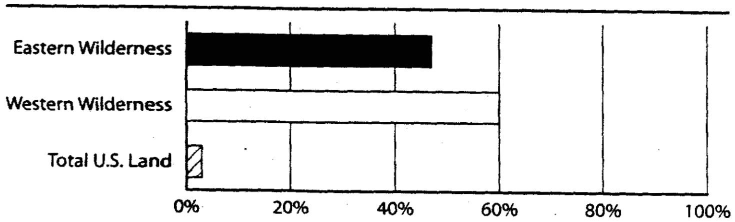
Distance from the nearest road	Percentage of land in Eastern Wilderness	Percentage of land in Western Wilderness	Percentage of Total U.S. Land
>127 m	97.00	98.00	80.00
>382 m	90.00	95.00	50.00
>1,000 m	76.00	86.00	18.00
>5,000 m	47.00	60.00	3.00

[1] Measurements from grid cells containing Wilderness to those containing roads were taken on a diagonal with the diagonal of each 30 m cell being 42.2 m in length. Thus all of the distances in this study are multiples of 42.2 m. Some of these distances were rounded off (e.g., 1,060 m to 1,000 m; 5,176 m to 5,000 m).

Sources: Riitters and Wickham, 2003; Wilderness Institute, 2003

The delineation for East and West Regions in Figure 11.4 and Table 11.5 is the Mississippi river. Table 11.5 shows the percentages of land in Eastern and Western Wilderness and in the United States as a whole that are more than the four different distances shown from a road. In both the East and in the West, approximately 97 percent of Wilderness land area is more than 127 meters (a little over 400 feet) from a nearest road. Only about 80 percent of all U.S. land, however, was more than this relatively short distance from a road. In the East, 90 percent of designated Wilderness was more than 382 meters from the nearest road, and in the West, 95 percent was farther than 382 meters. These percentages are very high compared with only about 50 percent of total U.S. land area that is farther than this distance, about 1,275 feet. From these computations, it is clear that Wilderness designation results in smaller proportions of the protected land being relatively close to roads, and thus less under their influence.

Figure 11.4, a visual representation of the data in Table 11.5, shows that there are lower percentages of total U.S. land area than the percentages of Wilderness beyond all of the four distances from roads (i.e., 127 m, 382 m, 1,000 m, 5,000 m). Especially beyond the distances of 1,000 and 5,000 meters, the percentage of all U.S. land is much lower than the amount of Wilderness in both the East and the West. In fact, Figure 11.5 compares percentages of Wilderness in the East and West with percentages of all U.S. land that is beyond 5,000 meters of the nearest road. Of all U.S. land, only 3 percent is farther than 5,000 meters from a road. In contrast, 47 percent of Wilderness in the East and 60 percent of Wilderness in the West is beyond 5,000 meters of a road. As well, Figure 11.5 shows that greater percentages of Wilderness in the West, compared with the East, is beyond 5,000 meters. From the research reviewed earlier, one can interpret these results as indicating that Wilderness land is less under the influence of roads, and thus has likely retained more of its natural character than most other land in the United States.



Source: Wilderness Institute, 2003; Riitters and Wickham, 2003

Figure 11.5 Percentage of land area beyond 5,000 meters of the nearest road

Ecosystem Diversity

Davis (1989) and many others have pointed out the importance of natural biodiversity for both current and future generations, and for the future of all life on this planet. One dimension of natural biodiversity is the extant and variety of ecosystems—the broader the diversity of natural ecosystems, the broader the diversity of natural habitats and life conditions supporting a broader diversity of native species and life forms. From high-mountain deserts in Arizona to wetlands, such as the Everglades of Florida, to the grasslands of South Dakota, a wide array of ecosystems have been included through designation of Wilderness areas. Because of the critical habitat Wilderness areas can sometimes protect, as of 1990 more than one half of current Wilderness areas protected one or more federal- or state-listed species classified then as threatened and/or endangered (Cordell & Reed, 1990). In this section, we cover the extent and diversity of ecosystems as classified by the Bailey system at the provincial scale.

Plates 16 through 19 (see Appendix) show the spatial distribution of Wilderness mapped across the United States using *Bailey's Province-level Ecosystem* classification system. Covered are the 48 contiguous states and Alaska. These figures are self-explanatory. In addition, Tables 11.6 through 11.9 show the total acres of Wilderness, total acres of all land, and percent of all land protected as Wilderness for all provinces in each of the Bailey's ecosystem domains. Table 11.6 covers the Tundra and Subarctic Divisions of the Polar Domain. The last column indicates the percentage of the total land area in each

Table 11.6 Acres in Wilderness, total acres in the United States, and percent of U.S. total in Wilderness by ecosystem domain and province: Polar Domain and its Provinces

Domain and Provinces	Total Acres Protected by Wilderness	Total Acres in the Domain	Percent Protected by Wilderness
Polar Domain	43,494,160	332,736,000	13.07
Arctic Tundra	0	12,224,000	0.00
Bering Tundra (Northern)	1,009,107	30,016,000	3.36
Bering Tundra (Southern)	1,568,146	15,104,000	10.38
Brooks Range Tundra–Polar Desert	19,452,783	65,024,000	29.92
Seward Peninsula Tundra–Meadow	0	13,184,000	0.00
Ahklun Mountains Tundra–Meadow	2,354,540	10,688,000	22.03
Aleutian Oceanic Meadow–Heath	4,847,465	14,208,000	34.12
Yukon Intermontane Plateaus Tayga	1,560,365	35,904,000	4.35
Coastal Trough Humid Tayga	0	10,048,000	0.00
Upper Yukon Tayga	0	8,320,000	0.00
Yukon Intermontane Plateaus Tayga–Meadow	1,796,597	35,200,000	5.10
Alaska Range Humid Tayga–Tundra–Meadow	10,298,473	39,040,000	26.38
Upper Yukon Tayga–Meadow	606,683	43,776,000	1.39

Sources: Bailey, 1995; U.S. Geological Survey et al., 1994; Wilderness Institute, 2003 province that has been designated Wilderness. In the Polar Domain, the best-represented provinces are the Aleutian Oceanic Meadow–Heath, Brooks Range Tundra–Polar Desert, Alaska Range Humid Tayga–Tundra, and Ahklun Mountains Tundra–Meadow provinces at 34, 30, 26, and 22 percent of total land area protected, respectively. Much smaller percentages of other provinces in the Polar Domain have been designated. Overall, just over 13 percent of the Polar Domain land area is within the National Wilderness Preservation System. The total area of this domain is just under 333 million acres.

Table 11.7 Acres in Wilderness, total acres in the United States, and percent of U.S. total in Wilderness by ecosystem domain and province: Humid Temperate Domain and its Provinces

Domain and Provinces	Total Acres Protected by Wilderness	Total Acres in the Domain	Percent Protected by Wilderness
Humid Temperate Domain	29,229,831	1,035,264,000	2.82
Laurentian Mixed Forest	1,418,825	94,272,000	1.51
Adirondack–New England Mixed Forest–Coniferous Forest–Alpine Meadow	163,736	27,904,000	0.59
Eastern Broadleaf Forest (Oceanic)	37,405	66,880,000	0.06
Eastern Broadleaf Forest (Continental)	159,224	172,800,000	0.09
Central Appalachian Broadleaf Forest–Coniferous Forest–Meadow	515,477	43,584,000	1.18
Ozark Broadleaf Forest–Meadow	65,698	4,096,000	1.60
Southeastern Mixed Forest	84,816	123,520,000	0.07
Outer Coastal Plain Mixed Forest	654,197	111,232,000	0.59
Lower Mississippi Riverine Forest	4,177	28,352,000	0.01
Ouachita Mixed Forest–Meadow	48,667	5,632,000	0.86
Pacific Lowland Mixed Forest	56,393	9,536,000	0.59
Cascade Mixed Forest–Coniferous Forest–Alpine Meadow	5,181,413	34,176,000	15.16
Pacific Coastal Mountains Forest–Meadow	10,068,353	25,600,000	39.33
Pacific Gulf Coastal Forest–Meadow	3,853,579	15,296,000	25.19
Prairie Parkland (Temporate)	0	139,648,000	0.00
Prairie Parkland (Subtropical)	2,277	51,264,000	0.00
California Coastal Chapparral Forest and Shrub	214,859	6,592,000	3.26
California Dry Steppe Province	0	12,288,000	0.00
California Coastal Steppe, Mixed Forest, and Redwood Forest	44,443	2,944,000	1.51
Sierran Steppe–Mixed Forest–Coniferous Forest–Alpine Meadow	5,276,431	43,712,000	12.07
California Coastal Range Open Woodland–Shrub–Coniferous Forest–Meadow	1,379,861	15,936,000	8.66

Sources: Bailey, 1995; U.S. Geological Survey et al., 1994; Wilderness Institute, 2003

Table 11.7 includes provinces in the Humid Temperate Domain, which ranges from prairie and continental to subtropical, marine, and Mediterranean climates. Best represented of the provinces within this Domain are the Pacific Coastal Mountains Forest–Meadow, Pacific Gulf Coastal Forest–Meadow, Cascade Mixed Forest–Coniferous Forest–Alpine Meadow, Sierran Steppe–Mixed Forest–Coniferous Forest–Alpine Meadow, and California Coastal Range Open Woodland–Shrub–Coniferous Forest–Meadow provinces. Under 3 percent of the total area of this domain of over one billion acres has been designated. This domain makes nearly one half of the overall land area of the United States.

Table 11.8 Acres in Wilderness, total acres in the United States, and percent of U.S. total in Wilderness by ecosystem domain and province: Dry Domain and its Provinces

Domain and Provinces	Total Acres Protected by Wilderness	Total Acres in the Domain	Percent Protected by Wilderness
Dry Domain	30,871,249	919,872,000	3.36
Great Plains Steppe and Shrub	9,536	11,264,000	0.08
Colorado Plateau Semi-Desert	1,187,966	48,192,000	2.47
Southwest Plateau and Plains Dry Steppe and Shrub	32,559	102,976,000	0.03
Arizona-New Mexico Mountains Semi-Desert–Open Woodland–Coniferous Forest–Alpine Meadow	1,313,602	32,128,000	4.09
Chihuahuan Semi-Desert	509,280	54,528,000	0.93
American Semi-Desert and Desert	9,981,523	56,128,000	17.78
Great Plains–Palouse Dry Steppe	518,590	186,048,000	0.28
Great Plains Steppe	12,006	85,760,000	0.01
Southern Rocky Mountain Steppe–Open Woodland–Coniferous Forest–Alpine Meadow	7,790,087	65,472,000	11.90
Middle Rocky Mountain Steppe–Coniferous Forest–Alpine Meadow	5,877,772	52,352,000	11.23
Northern Rocky Mountain Forest–Steppe–Coniferous Forest–Alpine Meadow	1,018,063	24,384,000	4.18
Black Hills Coniferous Forest	9,957	2,368,000	0.42
Intermountain Semi-Desert and Desert	1,028,430	68,544,000	1.50
Intermountain Semi-Desert	961,677	101,824,000	0.94
Nevada-Utah Mountains–Semi-Desert–Coniferous Forest–Alpine Meadow	620,200	27,904,000	2.22

Sources: Bailey, 1995; U.S. Geological Survey et al., 1994; Wilderness Institute, 2003

Table 11.8 includes provinces of the Dry Domain. Best represented of the provinces in this Domain are the American Semi-Desert and Desert, Southern Rocky Mountain Steppe, and the Middle Rocky Mountain Steppe-Coniferous Forest. Just under 3.4 percent of this domain is included within the Wilderness System. The total land area making up this domain is about 920 million acres. Together with the Temperate Domain, these two domains represent approximately 85 percent of the total U.S. land area.

Table 11.9 covers the Humid Tropical Domain, which is made up of only three provinces. The only one of these provinces represented within the National Wilderness Preservation System is the Everglades, totaling about 1.4 million acres. Not represented are ecosystems in Puerto Rico and Hawaii. The Everglades Wilderness, however, is nearly 20 percent of the Humid Tropical Domain's total of nearly 7.4 million acres.

Overall, of the 52 different provinces in the Bailey system covering ecosystems in the United States, only nine are not represented to some degree within the NWPS. The provinces within each domain that are best represented have been noted. Least represented are provinces in the East, the prairies of the Midwest, the tropical forests of Puerto Rico, and the Hawaiian Islands. Nevertheless, much of the diversity of ecosystems across the United States have been included—a diversity that represents many different natural ecosystems which provide essential support for native fauna and flora. For some provinces, however, the extent or area protected is small.

Data Gaps and Promising Programs

Overall, there appear to be considerable gaps in data needed to fully cover the many indicators recommended in the literature for describing and monitoring the health and naturalness of Wilderness. In this chapter, we have equated natural ecosystem health with naturalness as the necessary conditions for Wilderness to have ecological value. While we found a number of studies that

Table 11.9 Acres in Wilderness, total acres in the United States, and percent of U.S. total in Wilderness by ecosystem domain and province: Humid Tropical Domain and its Provinces

Domain and Provinces	Total Acres Protected by Wilderness	Total Acres in the Domain	Percent Protected by Wilderness
Humid Tropical Domain	1,447,381	7,360,000	19.67
Everglades	1,447,381	4,992,000	28.99
Puerto Rico	0	2,368,000	0.00
Hawaiian Islands	0	4,160,000	0.00

Sources: Bailey, 1995; U.S. Geological Survey et al., 1994; Wilderness Institute, 2003

focused on the ecological health of Wilderness, most were focused on specific areas, organisms, or issues. Few studies had taken a broad-scale approach, and limited broad-scale data were found for assessing the health and naturalness of the NWPS as a whole. As well, there is a general lack of essential synoptic data with assessments backed by field studies and appropriate analytical methods (Patil, Brooks, Myers, Rapport & Taillie, 2001). In reviewing ecological monitoring in Wilderness, Susan Bratton concluded, "...wilderness legislation has done little to encourage environmental monitoring. The sites which have extensive monitoring programs have them because of other legislation, or because of management histories which have little to do with the Wilderness Act" (Landres, 1995, p. 10). In this section of this chapter on ecological value, briefly presents some of the promising emerging programs that might help fill some of the data gaps in Wilderness monitoring. None of these programs were sufficiently developed by the time of analysis for this chapter for use as data sources.

Emerging Broad-Scale Data Sources

Broad-scale data providing coverage nationally and regionally are likely to be much more available in the future. These braod-scale data are increasingly resolute, enabling increasingly fine-grained examinations of Wilderness and other lands. Through mapping and other spatial analytics, changing land conditions can be monitored and emerging problems can be identified.

Gap Analysis Program (GAP)

GAP analysis is a systematic method for identifying the degree to which native animal species and natural communities are represented in any existing mix of conservation lands. The native species and communities not represented in the existing network of conservation lands constitute "gaps." GAP analysis was started in 1987 by Michael Scott and involved overlaying maps of land cover and species occurrence onto maps of protected areas using GIS technology. The resulting maps show areas of biological significance relative to protection status (USGS, 2004a). The purpose of GAP is to provide broad geographic information on the status of species, whether threatened, rare or not (Jennings & Scott, 1997). There is an aquatic component to GAP intended to focus on aquatic habitats and taxa, complementary to terrestrial gap analysis (USGS, 2004b). GAP "seeks to identify habitat types and species not adequately represented in the current network of biodiversity management areas" (Gap Analysis Program, 2000). Spatial distributions of GAP data with Wilderness boundary data enable assessment of the species makeup of Wilderness and identification of gaps perhaps needing management attention. Thus GAP represents a growing potential for assessing the ecological health and naturalness of Wilderness. Full data for every state of the United States is not yet available.

Natural Heritage Program

The NWPS can serve as a refuge for rare species and natural communities. Because rare species and communities are the focus of the Natural Heritage Program (NHP), its data also represent a potential for assessing Wilderness health. While the GAP includes all native species and natural land cover, the Natural Heritage Program analyzes only rare and endangered species and significant natural communities. The status of more than 30,000 species in the United States has been assessed by Natural Heritage scientists (Stein, 2001). The NHP's mission is to "develop, manage, and distribute authoritative information critical to the conservation of the world's biological diversity" (NatureServe, 2003). Like GAP, the NHP offers growing potential for monitoring the health and naturalness condition of Wilderness. Direct applicability at this time is limited because the methods used to gather and report data (and to complete analysis) vary from state to state. But the processes and comparability of the NHP data are improving and do offer potential for future monitoring of Wilderness.

Earth Observing System

Landres, Spildie, and Queen (2001) published a paper on the uses of GIS and broad-scale data for monitoring Wilderness, including the National Aeronautic and Space Administration's Earth Observation System satellite. As we have done in this chapter, these frequent, relatively high-resolution data, along with advancing systems of spatial analytic tools, are becoming ever more useful for monitoring Wilderness conditions. NASA's Earth Observing System provides "long-term, consistent measurements of many of the key physical characteristics of landscapes that can be used to identify shifts in variety and extent of natural system components. These data can provide overall assessments of both human-induced and natural disturbances, from local to global levels of resolution. Currently there are 24 measurements that include aspects of the atmosphere, land (e.g., land cover and land-use change, vegetation dynamics, fire occurrence), ocean, and cryosphere (e.g., land ice, snow cover; NASA 2004). These and other satellite data may be used in future studies.

Environmental Monitoring and Assessment Program (EMAP)

The U.S. Environmental Protection Agency (USEPA) has established the nationwide EMAP system (Landres, 1995). The objective of the EMAP program is to develop tools to monitor and assess the status of ecological resources in the United States and to "develop scientific understanding for translating environmental monitoring data from multiple spatial and temporal scales into assessments of current ecological conditions..." (USEPA, n.d.). This program employs indicators (as we have done in this chapter) to monitor the conditions of ecological resources, conduct large regional projects through multiagency monitoring, and guide monitoring with an improved understanding of ecosystem integrity and dynamics. This research supports the National Environmental Monitoring Initiative of the Committee on Environment and Natural Resources. The National inventory includes the 34 national research and monitoring programs funded by the majority of the federal environmental monitoring programs funded by the majority of the federal environmental monitoring budget. These inventories include spatially continuous monitoring over large regions, including remote sensing, monitoring large regions using aerial sampling, and studies on particular research sites (USEPA, n.d.). The data gathered for this program includes many Wilderness sites (Landres, 1995).

NPS Inventory and Monitoring Program

The National Park Service's Inventory and Monitoring Program was developed to "provide monitoring data to detect long-term trends and...ecological consequences of environmental change" (Fettig & Thomas, 2004). Monitoring includes species occurrence and distribution, water resources and their chemistry, air quality, meteorological conditions, soils, geologic features, and vegetation. The NPS is cooperating with state geologic agencies to produce maps and assessments. The 270 National Parks are organized into 32 monitoring networks. Key indicators, "vital signs," are monitored in each network to detect changes significant to the natural ecological health over time (NPS, 2003). The NPS has recently identified and prioritized potential vital signs related specifically for Wilderness conditions in the Southern Colorado Plateau Inventory and Monitoring Network (Fettig & Thomas, 2004). Such "vital signs" data is likely to be very important to monitoring ecological health and naturalness of at least NPS Wilderness in the future.

USGS–NPS Vegetation Mapping

One of the inventories in the NPS Inventory and Monitoring Program is vegetation mapping. This work is being done cooperatively between the National Biological Survey and the National Park Service of the Department of Interior (NBS/NPS). The Vegetation Mapping Survey was developed to generate vegetation maps for National Park units using a uniform, hierarchical classification system. Products include digital vegetation maps, digital meta data, textual descriptions, and keys to the vegetation classes (U.S. Geological Survey, 1994). Different parks currently are at different stages of completion. The classification standards may ultimately serve as models for detailed mapping of vegetation in Wilderness areas outside of the National Park System as well.

Air Quality Monitoring

Another measure for assessing natural qualities in Wilderness areas is air quality. The Clean Air Act mandates the "affirmative responsibility" to prevent deterioration of air quality in Class I areas (including Wilderness areas). Because of this mandate, systematic sampling protocols have been developed to monitor Air Quality Related Values (AQRVs) in Wilderness. Specific protocols have been developed for Pacific Northwest and California Wilderness (Landres, 1995). AQRVs include flora, fauna, soil, water, visibility, and odor (Holland-Sears, 1998). Over time, these data can be used in building a database of ecological attributes, and the sampling protocols used to monitor air quality across U.S. Wilderness areas.

National Hydrography Dataset

The National Hydrography Dataset (NHD) was created by integrating the USGS Digital Line Graph (DLG) hydrography data with drainage network information from the EPA Reach File Version 3 (RF3). The NHD is currently being used to study the value of water originating in Wilderness (Spildie, 2004). The NHD is a comprehensive set of digital spatial data containing coverages of surface water features such as lakes, ponds, streams, rivers, springs, and wells. These features are combined to from "reaches," which allow the user to link water-related data to the surface water drainage network. Linking data to the network enables display and analysis of data in upstream and downstream order (USGS, 2004c). There are several applications already available on the Internet (http://nhd.usgs.gov/applications.html). In future developments, data describing water quality can be linked to surface drainage systems for comparison of the quality of water flowing from Wilderness with quality of water flowing from urban and agricultural areas.

National Monitoring Protocol

The Aldo Leopold Wilderness Research Institute is collaboratively developing a National Monitoring Protocol for the four federal agencies that manage Wilderness. The protocol is based on the legislative definition of Wilderness and its attributes and centers on four qualities. These include untrammeled, undeveloped, outstanding opportunities for solitude, and naturalness. For each of these qualities, core indicators have been developed which can be practically and reliably monitored (Landres, 2004). At this point, data availability are the primary impediment to implementation of this work.

The Value of Water from Wilderness

Many of the areas protected by the NWPS are located in the headwaters of major drainages that provide water to downstream cities and metropolitan areas. The Value of Water from Wilderness project is under design by the Aldo Leopold Wilderness Research Institute for assessing the value of water coming from Wilderness and other protected areas. A pilot for this project is under way

in the Fresno, California, area. This area was selected because it contains a metropolitan area with hydrographic connectivity to Wilderness (Spildie, 2004).

Other Contributing Studies

A number of other studies offer potential for improving our capacity to monitor and assess the ecological value of Wilderness. A few of these are described here.

Protecting Water Resources

The Trust for Public Land and the American Water Works Association (AWWA) recently released a report that provides scientific, economic, and public health linkages to protection of drinking water sources and recharge lands. The major conclusion was that protection of land is the only way to prevent contamination by nonpoint source pollutants. Protection provides greater groundwater services, cleaner water downstream, and less flooding and soil erosion (Ernst, 2004).

Montana Aquatics Study

A study that compared aquatic ecosystem health in watersheds containing Wilderness to those with no Wilderness protection found that the watersheds with more land protection were the healthier (Hitt & Frissell, 2000). They found that existence of Wilderness was a significant contributor to regional aquatic ecosystem conservation. Over 70 percent of the healthiest watersheds contained Wilderness, or were watersheds within Wilderness boundaries.

Southern Appalachian Wilderness Study

Haney and colleagues (1999) conducted a study which examined the ecological capacity of a multiunit Wilderness system in the Southern Appalachian region. They defined ecological capacity as ability to adequately protect a suite of designated natural attributes. This study provides an example of methods for assessing the ecological capacity of Wilderness in large-scale ecosystems, such as the Southern Appalachians.

Landscape Change and Ecological Resources

A study conducted by Jones and associates (2001) used satellite imagery and land cover data to assess landscape change in a large region over a 20-year period. The focus was on birds and nitrogen yield to assess the effects of landscape change on ecosystem health in the mid-Atlantic region.

Eastern National Park Vegetation Mapping Project

The University of Georgia Center for Remote Sensing and Mapping Science has created databases and detailed vegetation maps of the Great Smoky Mountain National Park, the Everglade National Park, and other protected lands in Florida (Purdy, 2003). The primary focus is on the Great Smokey Mountains

National Park, an area of over 500,000 acres with 100 species of trees, more than 1,570 species of flowering plants, and another 4,000 nonflowering species. The resulting maps provide richness of detail accurate to within 15 feet (Purdy, 2003), and offers a model likely useful in the future to track natural and man-made disturbances to Wilderness and to measure naturalness.

Wilderness in Australia

Mackey, Lesslie, Lindenmayer, Nix, and Incoll (1998) studied designated Wilderness in Australia by overlaying National Wilderness Inventory (NWI) data with national-level data on threatened vertebrate animal species and plants. The NWI developed a set of indicators which measure and quantify the remoteness and naturalness of an area. This study found that high numbers of threatened species correlate with low Wilderness quality (i.e., remoteness and naturalness) with more threatened species in areas that have been heavily impacted by society.

Predicting Regional Biodiversity

Hansen, Waring, Phillips, Swenson, and Loehle (2003) integrated the use of traditional environmental variables, such as habitat type, with biophysical factors, such as climate, topography, and vegetation, to predict richness and abundance of bird, tree, and shrub species across the Pacific and Inland Northwest. The methods used integrate satellite data and computer simulation in ways that could be used nationally to predict and monitor biodiversity in Wilderness and non-Wilderness areas.

Summary

The Wilderness Act was passed to protect the naturalness of selected wildlands in the United States. In this chapter we focused on the idea that degree of naturalness is the key indicator of the life-sustaining health and ecological value of lands in the NWPS. We reasoned that the more natural are Wilderness lands, relative to other lands, the greater is their ecological value. The literature we reviewed supports this line of reasoning.

By legal definition, Wilderness areas are natural areas where natural processes dominate and the natural landscape is sustained without direct human intervention. In this chapter, we examined four measures that can be interpreted as indicators of naturalness. The objective was to examine whether Wilderness designation seems to be doing what it was meant to do; that is, prevent human activities so that it can provide self-determined natural life support. In today's society with its shifting values and viewpoints, knowing whether

designation is actually protecting the essential natural character of Wilderness lands is an important question.

A wide range of potential measures of naturalness and ecosystem health have been identified in the literature. Unfortunately, data to support implementation of most of these measures is thus far quite limited. This accepted, we depended on four surrogate measures of naturalness including fragmentation, land cover, distance from roads, and ecosystem representation. Findings for each of these four measures are summarized briefly next.

Summary by Indicator

There has been considerable recent work examining ecosystem fragmentation, but little of it has examined types of ecosystems other than Eastern forests. For this reason, the analysis of fragmentation in Wilderness lands for this chapter, as compared to other lands, was limited to forests. Findings showed that overall there is substantial evidence that forest land protected through Wilderness designation is very little fragmented relative to other forest land in the East. We interpret this result as evidence that Wilderness forests are more natural and healthy, and thus have more ecological value than non-Wilderness forests.

Land cover is another indicator of the naturalness of land. Human activities alter land cover and can cause deterioration of the native life support services those lands provide. Results from an analysis of the level of undeveloped land cover in Wilderness indicates that Wilderness has been effective in protecting naturalness. This protection is especially prominent in the Northeast, South, and Midwest regions. Natural land cover was a little less helpful in assessing naturalness in the West region because in that region it is more difficult to distinguish between disturbed managed lands and "barren" natural land covers, such as stretches of desert void of vegetation. Nonetheless, Western Wilderness was shown to be considerably more natural than any other Western land compared.

Distance from roads was also used as an indicator of the naturalness of Wilderness. We examined the amount of Wilderness beyond specified distances from a nearest road. Generally, much greater percentages of Wilderness in both the East and West were beyond nearest roads as compared with percentages of all other lands in those regions. As well, more land in western Wilderness was beyond nearest roads than in eastern Wilderness. More land further from roads indicates that Wilderness is more natural, less subject to human disturbance, and of greater ecological value.

In addition to protection of species, genes, and other "microdiversity," protection of broad-scale biodiversity across the range of types of ecosystems in the United States is highly important. Ecoregions have been defined as relatively large units of land and water with distinct assemblages of natural communities and species and with boundaries that approximate the original extent of natural communities. We adopted the "Bailey system" of ecosystem classification (Bailey, 2002). The analysis of spatial data indicated that a wide range of ecosystem types has been protected under the Wilderness System. These include high-mountain deserts in Arizona, wetlands such as the Everglades of Florida, and grasslands such as in South Dakota. Overall, of the 52 different ecosystem types labeled in the Bailey system as provinces, only 9 are not represented to some degree within the NWPS. Least represented are provinces in the East, prairies of the Midwest, forests of Puerto Rico, and Hawaii's islands.

The four measures used to assess the naturalness of Wilderness showed clearly that designation distinguishes lands included from lands not included. This distinction shows up as an apparent higher level of naturalness and better ecological health. As such, Wilderness is better able to provide life support to native life forms. Wilderness is less fragmented, has greater amounts of vegetated land cover, and has greater proportions of area that are remote from roads. Generally, as well, Wilderness protects an important dimension of biodiversity; that is, ecosystem diversity. A considerable amount of research remains to be done to more fully understand the ecological value of Wilderness as a tool for assuring support for natural life. We are encouraged at the number of state and federal agencies, universities, and private groups with research and development programs aimed at improving monitoring of the condition and value of Wilderness, and other wildlands. It is our hope that these programs will quickly advance Wilderness assessment and monitoring capacities well beyond what is described in this chapter.

There are many pressures not only on unprotected wildlands, public and private, but also on Wilderness lands. These include fragmentation, road construction, off-road vehicle use, energy drilling, mining, urban growth and other human activities (Campaign for America's Wilderness, 2002). Designating Wilderness may be the last hope for protecting the health, naturalness, and ecological value of this country's wildlands. The assessment presented in this chapter indicates this to be the case.

Literature Cited

Anderson, J.E. (1991). A conceptual framework for evaluating and quantifying naturalness. *Conservation Biology, 5*(3), 347–352.

Angermeier, P.L. (2000). The natural imperative for biological conservation. *Conservation Biology, 14*(2), 373–381.

Bader, M. (2000). *Spatial needs of grizzly bears in the U.S. northern Rockies.* Missoula, MT: Alliance for the Wild Rockies.

Bailey, R.G. (1995). *Description of the ecoregions of the United States* (Misc. Pub. 1391). Washington, DC: USDA Forest Service.

Bailey, R.G. (2002). *Ecoregion-based design for sustainability.* New York, NY: Springer.

Belaoussoff, S. and Kevan, P.G. (1998). Toward an ecological approach for the assessment of ecosystem health. *Ecosystem Health, 4*(1), 4–8.

Bertollo, P. (1998). Assessing ecosystem health in governed landscapes: A framework for developing core indicators. *Ecosystem Health, 4*(1), 33–51.

Campaign for America's Wilderness. (2002). *America's wilderness heritage in crisis: Our vanishing wild landscape.* Washington, DC: Campaign for America's Wilderness.

Chaffin, T. (1998). *Whole-earth mentor: A conversation with Eugene P. Odum*—includes excerpt from Odum's "Ecology: A bridge between science and society" interview. Retrieved November 8, 2004, from http://www.findarticles.com/p/articles/mi_m1134/is_n8_v107/ai_21191216

Christensen, N.L., Bartuska, A.M., Brown, J.H., Carpenter, S., D'Antonio, C., Francis, R., et al. (1996). The report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. *Ecological Application, 6*(3), 665–691.

Coates, B., Jones, A.R., and Williams, R.J. (2002). Is "ecosystem health" a useful concept for coastal managers? *Coast to Coast,* 55–58.

Cole, D.N. (2000). Paradox of the primevil: Ecological restoration in wilderness. *Ecological Restoration, 18*(2), 77.

Cole, D.N. (2001). Management dilemmas that will shape Wilderness in the 21st century. *Journal of Forestry, 99*(1), 4–8.

Cole, D.N. and Landres, P.B. (1996). Threats to wilderness ecosystems: Impacts and research needs. *Ecological Applications, 6*(1), 168–184.

Cordell, H.K. and Overdevest, C. (2001). *Footprints on the land: An assessment of demographic trends and the future of natural lands inthe United States.* Champaign, IL: Sagamore Publishing.

Cordell, H.K. and Reed, P.C. (1990). Untrammeled by man: Preserving diversity through wilderness. In *Preparing to manage Wilderness in the 21st century,* Proceedings of the Conference (GTR SE-66; pp. 1–4). Athens, GA: USDA Forest Service, Southeastern Forest Experiment Station.

Costanza, R. (1992). Toward an operational definition of ecosystem health. In R. Costanza, B.G. Norton, and B.D. Haskell (Eds.), *Ecosystem health: New goals for environmental management* (pp. 239–256). Washington, DC: Island Press.

Dahms, C.W. and Geils, B.W. (Eds.). (1997). An assessment of forest ecosystem health in the Southwest (GTR RM-295). Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

Dailey, G.C., Alexander, S., Ehrlich, P.R., Goudler, L., Lubchenco, J., Matson, P.A., et al. (1997). Ecosystem services: Benefits supplied to human societies by natural ecosystems. *Issues in Ecology,* 2.

Davis, G.D. (1989). Preservation of natural diversity: The role of ecosystem representation with-in wilderness. In P.C. Reed, H.K. Cordell, and H.R. Freilich (Eds.), *Wilderness benchmark 1988: Proceedings of the National Wilderness Colloquium* (GTR SE-51; pp. 76–82). Asheville, NC: USDA Forest Service, Southeastern Forest Experiment Station.

Debinski, D.M. and Holt, R.D. (2000). A survey and overview of habitat fragmentation experiments. *Conservation Ecology, 14*(2), 342–355.

De Leo, G.A. and Levin, S. (1997). The multifaceted aspects of ecosystem integrity [online]. *Conservation Ecology, 1*(1), 3. Retrieved November 9, 2004, from http://www.consecol.org/vol1/iss1/art3

de Rosnay, J. (1997). Homeostasis: Resistance to change. *Principia Cybernetica Web.* Retrieved November 9, 2004, from http://pcp.lanl.gov/HOMEOSTA.html

Dymond, C., Carver, S., and Phillips, O. (2003). Investigating the environmental cause of global wilderness and species richness distributions. In A. Watson and J. Sproull (Comp.), *Science and stewardship to protect and sustain wilderness values: Seventh world wilderness congress symposium* (RMRS-P-27; pp. 231–237). Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station.

Ernst, C. (2004). *Protecting the source: Land conservation and the future of America's drinking water.* Retrieved November 9, 2004, from http://www.wvnet.org/downloads/posted%20june102004/TPL_2004_protecting_the_source.pdf

Fettig, S.M. and Thomas, L. (2004, September). *Identifying potential signs for monitoring wilderness and wild land values* (#051407). Paper presented at the meeting of the Monitoring Science & Technology Symposium, Fort Collins, CO.

Forman, R.T.T. (2000). Estimate of the area affected ecologically by road system of the United States. *Conservation Biology, 14,* 31–35.

Forman, R.T.T. and Alexander, L.E. (1998). Roads and their major ecological effects. *Annual Review of Ecology and Systematics, 29,* 207–231.

Forman, R.T.T., Sperling, D., Bissonette, J.A., Clevenger, A.P., Cutshall, C.D., Dale, V.H. et al. (2002). *Road ecology: Science and solutions.* Washington, DC: Island Press.

Fu-liu, X. and Shu, T. (2000). On the study of ecosystem health: State of the art. *Journal of Environmental Sciences, 12*(1), 33.

Gap Analysis Program. (2000). *A handbook for conducting gap analysis.* Retrieved November 9, 2004, from http://www.gap.uidaho.edu/handbook

GDT (Geographic Data Technology). (2002). *Dynamap/2000 user manual.* Lebanon, NH: Geographic Data Technology.

Haney, J.C., Wilbert, M., De Grood, C., Lee, D.S., and Thomson, J. (1999). *Gauging the ecological capacity of Southern Appalachian reserves: Does wilderness matter?* Retrieved November 9, 2004, from http://www.wilderness.org/Library/Documents/upload/Gauging_the_Ecological_Capacity_of_Southern_Appalachian_Reserves.pdf

Hansen, A., Waring, R., Phillips, L., Swenson, J., and Loehle, C. (2003). *Using biophysical factors to predict regional biodiversity potential in the Pacific and inland Northwest.* Retrieved November 9, 2004, from http://www.homepage.montana.edu/~hansen/documents/downloadables/MSU_OSU_reportfinal.pdf

Heilman, G.E., Jr., Strittholt, J.R., Slosser, N.C., and Dellasala, D.A. (2002). Forest fragmentation of the conterminous United States: assessing forest intactness through road density and spatial characteristics. *BioScience, 52,* 411–422.

Heinz Center (The H. John Heinz III Center for Science, Economics and the Environment). (2002). *The state of the nation's ecosystems: Measuring the lands, waters, and living resources of the United States.* Cambridge, UK: Cambridge University Press.

Hitt, N.P. and Frissell, C. (2000). *An evaluation of wilderness and aquatic biointegrity in Western Montana.* Retrieved November 9, 2004, from http://www.wilderness.net/library/documents/Hitt_2_17.pdf

Hobbs, R.J., Arico, S., Aronson, J., Baron, J.S., Bridgewater, P., Cramer, V.A., et al. (2004). *Emerging ecosystems: Theoretical and management aspects of the new ecological world order.* Retrieved on November 5, 2004, from http://www.unesco.org/mab/EE/hobbs.pdf

Holland-Sears, A. (1998). *Air resource management plan: White River National Forest.* Retrieved February 14, 2005, from http://www.fs.fed.us/r6/aq/natarm/whiteriver.pdf

Hutton, J. (1788). *Theory of the earth; or an investigation of the laws observable in the composition, dissolution, and restoration of land upon the globe.* Retrieved February 14, 2005, from http://www.mala.bc.ca/~johnstoi/essays/Hutton.htm.

Jennings, M. and Scott, M.J. (1997). *Official description of the national Gap Analysis Program.* Retrieved on February 11, 2005, from http://www.gap.uidaho.edu/About/Overview/GapDescription/#Mission

Jones, K.B., Neale, A.C., Wade, T.G., Wickham, J.D., Cross, C.L., Edmonds, C.M. et al. (2001). The consequences of landscape change on ecological resources: An assessment of the United States Mid-Atlantic Region, 1973–1993. *Ecosystem Health, 7*(4), 229–242.

Jorgensen, S. (1995). The application of ecological indicators to assess the ecological condition of a lake. *Lakes and Reservoirs: Research and Management, 1,* 177–182.

Karr, J.R. (1981). Assessment of biotic integrity using fish communities. *Fisheries, 6,* 21–27.

Karr, J.R. and Dudley, D.R. (1981). Ecological perspectives in water quality goals. *Environmental Management, 5,* 55-68.

Karr, J.R., Fausch, K.D., Angermeier, P.L., Yant, P.R., and Schlosser, I.J. (1986). *Assessing biological integrity in running waters: A method and its rational* [M]. Champaign, IL: Illinois Natural History Survey, Special Publication 5.

Kay, J.J. (1993). On the nature of ecological integrity. In S. Woodley, J. Kay, and G. Fransis (Eds.), *Ecological integrity and the management of ecosystems* (pp. 201–213). Waterloo, ON: St. Lucie Press.

Keddy, P.A., Lee, H.T., and Wisheu, I.C. (1993). Choosing indicators of ecosystem integrity: Wetlands as a model system. In S. Woodley, J. Kay, and G. Fransis

(Eds.), *Ecological integrity and the management of ecosystems* (pp. 61–79). Delray Beach, FL: St. Lucie Press.

Kolb, T.E., Wagner, M.R., and Covington, W.W. (1994). Concepts of forest health: Utilitarian and ecosystem perspectives. *Journal of Forestry, 92*(7), 10–15.

Landres, P. (2004). Developing indicators to monitor the "outstanding opportunities" quality of Wilderness character. *International Journal of Wilderness, 10*(3), 8–11, 20.

Landres, P.B. (1995). The role of ecological monitoring in managing wilderness. *TRENDS/Wilderness Research, 32*(1), 10–13.

Landres, P. B., Morgan, P., and Swanson, F.J. (1999). Overview of the use of natural variability in managing ecological systems. *Ecological Applications, 9*(4), 1179–1188.

Landres, P., Spildie, D.R., and Queen, L.P. (2001). *GIS applications to wilderness management: potential uses and limitations* (GTR RMRS-80). Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station.

Leopold, A. (1949). *A Sand County almanac.* New York, NY: Oxford Press.

Lindermann, R.L. (1942). The trophic-dynamic aspect of ecology. *Ecology, 23,* 399–418.

Mackey, B.G., Lesslie, R.G., Lindenmayer, D.B., Nix, H.A., and Incoll, R.D. (1998). *The role of wilderness in nature conservation.* Retrieved November 12, 2004, from http://www.heritage.gov.au/anlr/code/pubs/rolewild.html

McIntire, T. (Ed.). (1988). *Forest health through silviculture and integrated pest management: A strategic plan.* Washington, DC: USDA Forest Service.

Meffe, G.K. and Carroll, C.R. (1997). *Principles in conservation biology* (2nd ed). Sunderland, MA: Sinauer Associates, Inc.

MDNR (Maryland Department of Natural Resources). (2001). *Maryland's greenprint program: Summary of methods to identify and evaluate Maryland's green infrastructure.* Retrieved November 12, 2004, from http://www.dnr.state.md.us/education/growfromhere/lesson4/greenprint/gpevaluation.pdf

Naeem, S., Chapin, F.S., Costanza, R., Ehrlich, P.R., Golley, F.B., Hooper, D.U. et al. (1999). *Biodiversity and ecosystem functioning: Maintaining natural life support processes.* Retrieved November 12, 2004, from http://www.epa.gov/watertrain/pdf/issue4.pdf

NASA. (2004). *The earth observing system: EOS program description.* Retrieved November 12, 2004, from http://eospso.gsfc.nasa.gov/eos_homepage/description.php

National Park Service, U.S. Department of the Interior (2003). *Park vital signs monitoring: A commitment to resource protection.* Retrieved November 12, 2004, from http://www.cnr.uidaho.edu/rrt496/Vital_signs_brochure.pdf

National Research Council. (1997). *Toward a sustainable future: Addressing the long-term effects of motor vehicle transportation on climate and ecology.* Washington, DC: National Academy Press.

NatureServe (2003). *About us.* Retrieved November 12, 2004, from http://www.natureserve.org/aboutus/index.jsp

Noss, R.F. (1990). What can wilderness do for biodiversity? In P.C. Reed (Ed.), *Preparing to manage wilderness in the 21st Century: Proceedings of the conference* (GTR SE-66; pp. 49-61). Asheville, NC: USDA Forest Service, Southeastern Forest Experiment Station.

Odum, E.P. (1989). *Ecology and our endangered life-support systems.* Sunderland, MA: Sinauer Associates, Inc.

Patil, G.P., Brooks, R.P., Myers, W.L. Rapport, D.J., and Taillie, C. (2001). Ecosystem health and its measurement at landscape scale: Toward the next generation of quantitative assessments. *Ecosystem Health, 7*(4), 307–316.

Purdy, J. (2003). Maps protect national treasures. *University of Georgia Research Magazine* [online]. Retrieved November 15, 2004, from http://www.ovpr.uga.edu/researchnews/fall2003/maps01.htm

Rapport, D.J. (1989). What constitutes ecosystem health? *Perspectives in Biology and Medicine, 33*(1), 120–132.

Rapport, D.J. (2002). The health of ecology and the ecology of health. *Human and Ecological Risk Assessment, 8*(1), 205–213.

Rapport, D.J., Costanza, R., Epstein, P. Gaudet, C., and Levins, R. (Eds.). (1998). *Ecosystem health.* Oxford, UK: Blackwell Science.

Riitters, K.R. and Wickham, J.D. (2003). How far to the nearest road? *Frontiers in Ecology and Environment, 1*(3), 125–129.

Riitters, K.H., Wickham, J.D., and Coulston, J.W. (2004). A preliminary assessment of Montreal process indicators of forest fragmentation for the United States. *Environmental Monitoring and Assessment, 91,* 257–276.

Riitters, K.H., Wickham, J.D., O'Neill, R.V., Jones, K.B., Smith, E.R., Coulston, J.W. et al. (2002). Fragmentation of continental United States forest. *Ecosystems, 5,* 815–822.

Risser, P.G. (1995). Biodiversity and ecosystem function. *Conservation Biology, 9,* 742–746.

Rollins, M.G., Thomas, W.S., and Morgan, P. (2001). Evaluating a century of fire patterns in two Rocky Mountain wilderness areas using digital fire atlases. *Canadian Journal of Forest Research, 31*(12), 2107–2123.

Roy, B.S., Hurtt, G.C., Weaver, C.P., and Pacala, S.W. (2003). Impact of historical land cover change on the July climate of the United States. *Journal of Geophysical Resouces-Atmosphere, 108*(D24).

Ryan, B.D. (1990). *Lichens and air quality in the emigrant wilderness, California: A baseline study.* Retrieved November 15, 2004, from http://airlichen.nacse.org/airlichenPDF/Emigrant.pdf

Spellerberg, I.F. (1998).Ecological effects of roads and traffic: A literature review. *Global Ecology and Biogeography, 7,* 317–333.

Spildie, D. (2004). *The value of Wilderness water.* Aldo Leopold Wilderness Research Institute [online]. Retrieved on February 14, 2005, from http://leopold.wilderness.net/htopics/water_proj.htm.

Stein, B.A. (2001). A fragile cornucopia: Assessing the status of U.S. biodiversity. *Environment, 43*(7), 11–22.

Tansley, A. (1935). The use and abuse of vegetational concepts and terms. *Ecology, 16,* 284–307.

Trombulak, S.C. and Frissell, C.A. (2000). Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology, 14,* 18–30.

Turner, J. (1996). *The abstract wild.* Tucson, AZ: The University of Arizona Press.

Ulanowicz, R.E. (1986). *Growth and development: Ecosystems phenomenology.* New York, NY: Springer-Verlag.

Ulanowicz, R.E. (1980). An hypothesis on the development of natural communities. *Journal of Theoretical Biology, 85,* 223–245.

USDA Forest Service. (n.d.). *Ecosystem provinces.* Retrieved November 17, 2004, from http://www.fs.fed.us/colorimagemap/ecoreg1_provinces.html

USDT (U.S. Department of Transportation). (1993). *Federal Highway Administration, Highway Statistics 1993.* Retrieved February 14, 2005, from http://www.fhwa.dot.gov/ohim/hs93/Sec5.pdf

USDT (U.S. Department of Transportation). (2002). *Federal Highway Administration, Highway Statistics 2002.* Retrieved February 14, 2005, from http://www.fhwa.dot.gov/policy/ohim/hs02/xls/hm20.xls

USEPA (U.S. Environmental Protection Agency). (n.d.). *Environmental monitoring and assessment program (EMAP): About EMAP.* Retrieved November 15, 2004, from http://www.epa.gov/305b/2000report/chp2.pdf

USGS (U.S. Geological Survey). (1994). *USGS-NPS vegetation mapping program.* Retrieved February 14, 2005, from http://biology.usgs.gov/npsveg/classification/index.html.

USGS (U.S. Geological Survey). (1999, May). *The quality of our nation's waters: Nutrients and pesticides—A summary* (USGS Fact Sheet 116-99). Retrieved February 14, 2005, from http://water.usgs.gov/pubs/fs/FS_116_99/

USGS (U.S. Geological Survey). (2004a). *GAP analysis program: GAP analysis in biodiversity.* Retrieved November 15, 2004, from http://www.gap.uidaho.edu/About/Overview/IntroductionToGAShorter/default.htm

USGS (U.S. Geological Survey). (2004b). *GAP analysis program: Aquatic GAP.* Retrieved November 15, 2004, from http://www.gap.uidaho.edu/projects/Aquatic/default.htm

USGS (U.S. Geological Survey). (2004c). National hydrography dataset. Retrieved November 15, 2004, from http://nhd.usgs.gov/

U.S. Geological Survey, Bailey, R.G., McNab, W.H., Avers, P.E., and King, T. (1994). *Ecoregion and subecoregions of the United States.* Retrieved February 14, 2005, from http://www.fs.fed.us/institute/ecoregions/eco_download.html

Vogelmann, J.E., Howard, S.M., Yang, L., Larson, C.R., Wylie, B.K., and Van Driel, N. (2001). Completion of the 1990s national land cover data set for the conterminous United States from landsat thematic mapper data and ancillary data sources. *Photogrammetric Engineering and Remote Sensing, 67,* 650–652.

Vogelmann, J.E., Sohl T., and Howard, S.M. (1998). Regional characterization of land cover using multiple sources of data. *Photogrammetric Engineering and Remote Sensing, 64,* 45–57.

Wetmore, C.M. (1992). *Lichens and air quality in Hercules Glades Wilderness of Mark Twain* (National Forest. Final Report, contract #42-649). Rolla, MO: USDA Forest Service, Mark Twain National Forest.

Wickham, J.D., Jones, K.B., Riitters, K.H., O'Neill, R.V., Tankersley, R.D., Smith, E.R. et al. (1999). An integrated environmental assessment of the U.S. mid-Atlantic region. *Environmental Management, 24,* 553–560.

Wickham, J.D., O'Neill, R.V., Riitters, K.H., Smith, E., Wade, T., and Jones, K. (2002). Geographic targeting of increases in nutrient export due to future urbanization. *Ecological Applications, 12,* 93–106.

Wilderness Institute. (2003). *Wilderness information network, National Wilderness Preservation System database.* Retrieved November 16, 2004, from http://www.wilderness.net/index.cfm?fuse=NWPS&sec=advSearch

World Wildlife Fund. (2004). *Conservation science—Ecoregions.* Retrieved November 17, 2004, from http://www.worldwildlife.org/science/ecoregions.cfm

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