1
Ecological Guidelines for Land Use and Management

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1.1 Introduction

During the past few millennia, humans have emerged as the major force of change around the globe. The large environmental changes wrought by our actions include modification of the global climate system, reduction in stratospheric ozone, alteration of the earth's biogeochemical cycles, changes in the distribution and abundance of biological resources, and decreasing water quantity and quality (Meyer and Turner 1994; IPCC 1996; Mahlman 1997; Vitousek et al. 1997). One of the most pervasive aspects of human-induced change involves the widespread transformation of land through efforts to provide food, shelter, and products for our use. Land transformation is perhaps the most profound result of human actions because it affects so many of the planet's physical and biological systems (Kates et al. 1990). In fact, land-use changes directly impact the ability of the earth to continue providing the goods and services upon which humans depend.

Unfortunately, potential ecological consequences are not always considered in making decisions regarding land use. Moreover, the unique perspective and body of knowledge offered by ecological science rarely are brought to bear in decision-making processes on private lands. In response to this need, the Ecological Society of America established a committee to examine the ways that land-use decisions are made and the ways that ecologists could help inform those decisions. This chapter reports the principles and guidelines developed by that committee. The full report is in Dale et al. (2000). This chapter presents ecological principles that are critical to sustaining the structure and function of ecosystems in the face of rapid land-use change and discusses their implications. It also offers guidelines for using these principles in making decisions regarding land-use change. Throughout, the chapter offers specific examples to illustrate decision-making processes, relevant ecological principles, and guidelines for making choices about land use at spatial scales ranging from the individual site to

the landscape. The rest of the chapters in this volume further flesh out these principles and guidelines through specific case studies.

1.1.1 Trends and Patterns of Land-Use Change

Changes in the cover, use, and management of land have occurred throughout history in most parts of the world as population has changed and human civilizations have risen and fallen (e.g., Perlin 1989; Turner et al. 1990). Over the centuries, two important trends are evident: the total land area dedicated to human uses (e.g., settlement, agriculture, forestry, and mining) has grown dramatically, and increasing production of goods and services has intensified both use and control of the land (Richards 1990). At the end of the twentieth century, almost all of the earth's habitable surface is dedicated to human use, mostly for production of food and fiber. Some is used for conservation, but even that area is mapped, zoned, and controlled.

The major anthropogenic causes of change in land cover and land use include population and associated infrastructure; economic factors, such as prices and input costs; technological capacity; political systems, institutions, and policies; and sociocultural factors, such as attitudes, preferences, and values (Kates et al. 1990; Liu et al. 1993; Turner et al. 1993; Riebsame et al. 1994; Diamond and Noonan 1996). Human population growth can be considered an ultimate cause for many land-use changes (Fig. 1.1). However, population expansion is affected by many factors, such as political dynamics and policy decisions that influence local and regional trends in urbanization and colonization. Moreover, local demography and variability

FIGURE 1.1. Human settlement in the Brazilian Amazon replaces the native tropical forest.

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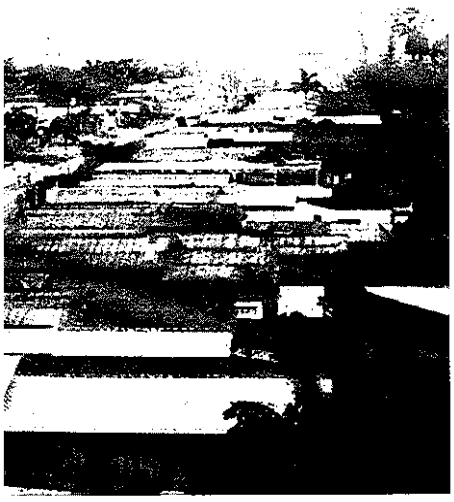

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in per capita resource consumption can modify the effects of population. In Brazil, for example, one of the highest rates of deforestation currently occurs in the state of Rondônia, where a high rate of land-cover change results from road establishment and paving and government policies that have allowed colonists to immigrate and clear forests so farms can be established. The rate of natural resource exploitation also depends on technological advances in resource extraction and enhancement, such as logging, mining, hydroelectric power, fertilizers, pesticides, and irrigation. The relative importance of these factors varies with the situation and the spatial scale of analysis.

1.1.2 Challenges of Ecologically Sustainable Land Use

A critical challenge for land use and management involves reconciling conflicting goals and uses of the land. The diverse goals for use of the land include resource-extractive activities, such as forestry, agriculture, grazing, and mining; infrastructure for human settlement, including housing, transportation, and industrial centers; recreational activities; services provided by ecological systems, such as flood control and water supply and filtration; support of aesthetic, cultural, and religious values; and sustaining the compositional and structural complexity of ecological systems. These goals often conflict with one another, and difficult land-use decisions may develop as stakeholders pursue different land-use goals. For example, conflicts often arise between those who want to extract timber and those who are interested in the scenic values of forests. Local versus broad-scale perspectives on the benefits and costs of land management also provide different views of the implications of land actions. Understanding how land-use decisions affect the achievement of these goals can help achieve balance among the different goals. The focus of this book is on the last goal, sustaining ecological systems, for land-use decisions and practices rarely are undertaken with ecological sustainability in mind. Sustaining ecological systems also indirectly supports other values, including ecosystem services, cultural and aesthetic values, recreation, and sustainable extractive uses of the land.

To meet the challenge of sustaining ecological systems, an ecological perspective must be incorporated into land-use and land-management decisions. Specifying ecological principles and understanding their implications for land-use and land-management decisions are essential steps on the path toward ecologically-based land use, for the resulting guidelines translate theory into practical steps for land managers. Ecological principles and guidelines for land use and management elucidate the consequences of land uses for ecological systems. Thus, a major intent of this chapter is to set forth ecological principles relevant to land use and management and to develop them into guidelines for use of the land.

Trends in land-use change have increased the interdependence of ecological and human systems because there are few ecological systems

that are not directly or indirectly impacted by human actions. However, the consequences of land-use decisions for both humans and ecological systems often are not felt immediately. Planning is needed to avert long-term or broad-scale harmful ecological effects resulting from unwise land-use choices. Therefore, planning should be based on a sound ecological basis.

1.2 Ecological Principles for Land Use and Management

The major lessons of ecological science for land management can be summarized in numerous ways. This chapter organizes ecological information into five principles that have implications for land management. The principles deal with *time, place, species, disturbance,* and the *landscape*. The principles are presented as separate entities, although they interact in many ways. They are translated into specific guidelines in a later section.

1.2.1 Time Principle

Ecological processes function at many time scales, some long, some short; and ecosystems change through time. Metabolic processes occur on the scale of seconds to minutes, decomposition occurs over hours to decades, and soil formation occurs at the scale of decades to centuries. Additionally, ecosystems characteristically change from season to season and year to year in response to variations in weather as well as showing long-term successional changes (Odum 1969). Early successional communities often are dominated by a few short-lived and relatively small species that grow rapidly and decompose readily after death. In contrast, later successional communities tend to be dominated by a mixture of longer-living species and contain higher standing crops of vegetation that both grow and decompose more slowly. Human activities that alter community composition or biogeochemical cycles can change the pace or direction of ecosystem succession and thus have effects lasting decades to centuries.

The time principle has several important implications for land use. First, the current composition, structure, and function of an ecological system are, in part, a consequence of historical events or conditions that occurred decades to centuries before. An ecosystem may have species or soil characteristics that reflect legacies from past land use (Foster 1992; Motzkin et al. 1996). Therefore, historical information may be needed to understand the nature of the ecosystem, including its responses to changes in use or other perturbations, and current land uses may limit those choices that are available in the future.

Second, the full ecological effects of human activities often are not seen for many years because of the time it takes for a given action to propagate through components of the system. For example, changes in nutrient inputs may alter plant growth rates and species composition (Inouye and Tilman 1995), but these changes in a plant levels, nutrient pools, and soil orga develop much more slowly.

Third, the imprint of land use m time, constraining future land use fo pattern imposed on a forested lan persist for many decades after all Establishing roads and controlling fi lasting effects. Rapid return to previc occur and should not be expected.

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1.2.2 Species Principle

Particular species and networks of in ecosystem-level effects. These focal diverse ways. Indicator species are indicative of the status of a larger fu the status of key habitats, or sym Keystone species have greater effect be predicted from their abundance Ecological engineers (e.g., the gopl beaver [*Castor canadensis*]) alter the fates and opportunities of other sp Rogers 1997). Umbrella species eith multiple habitats and thus overlap t species. Link species exert critical rol across trophic levels or provide cri complex food webs. Trophic cascade of a focal species or guild of organism other trophic levels, resulting in dra community composition, or total pr many species, including those with w (Power 1992; Polis and Winemiller abundance of top predatory fishes m and alter the productivity of a lake (C 1992). In addition, some species (such game species, sensitive species, and because of their rarity) also require them.

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Third, the imprint of land use may persist on the landscape for a long time, constraining future land use for decades or centuries. For example, the pattern imposed on a forested landscape by extensive clear-cutting may persist for many decades after all harvesting stops (Wallin et al. 1994). Establishing roads and controlling fire or flood regimes have similarly long-lasting effects. Rapid return to previous ecological conditions often does not occur and should not be expected.

Finally, both the variation and the change that characterize ecosystem structure and process mean that the long-term effects of land use or management may be difficult to predict. This problem is exacerbated by the tendency to overlook low-frequency ecological disturbances, such as 100-year flooding or storm events (Dale et al. 1998) or processes that operate over periods longer than human life spans (e.g., forest succession).

1.2.2 Species Principle

Particular species and networks of interacting species have key, broad-scale ecosystem-level effects. These focal species affect ecological systems in diverse ways. Indicator species are important because their condition is indicative of the status of a larger functional group of species, reflective of the status of key habitats, or symptomatic of the action of a stressor. Keystone species have greater effects on ecological processes than would be predicted from their abundance or biomass alone (Power et al. 1996). Ecological engineers (e.g., the gopher tortoise [*Gopherus polyphemus*] or beaver [*Castor canadensis*]) alter the habitat and, in doing so, modify the fates and opportunities of other species (Jones et al. 1994; Naiman and Rogers 1997). Umbrella species either have large area requirements or use multiple habitats and thus overlap the habitat requirements of many other species. Link species exert critical roles in the transfer of matter and energy across trophic levels or provide critical links for energy transfer within complex food webs. Trophic cascades occur when changes in the abundance of a focal species or guild of organisms at one trophic level propagate across other trophic levels, resulting in dramatic changes in biological diversity, community composition, or total productivity. Such cascades often affect many species, including those with which the guild does not interact directly (Power 1992; Polis and Winemiller 1996). For instance, changes in the abundance of top predatory fishes may change phytoplankton composition and alter the productivity of a lake (Carpenter and Kitchell 1988; Carpenter 1992). In addition, some species (such as threatened and endangered species, game species, sensitive species, and those that are vulnerable to society because of their rarity) also require attention because of public interest in them.

The impacts of changes in the abundance and distribution of focal species are diverse. For example, keystone species affect ecosystems through such processes as competition, mutualism, dispersal, pollination, and disease and by modifying habitats and abiotic factors. Because effects of keystones are diverse and involve multiple steps, they are often unexpected despite their fundamental importance to biological diversity and ecosystem dynamics (Paine 1969, 1995; Power et al. 1996). The removal of a keystone species can radically change the diversity and trophic dynamics of a system. Changes in land use that affect keystone species may spread well beyond the boundaries of a land-use unit, extending land covers that are inhospitable to some species and favorable to others, adding barriers to movement or dispersal, introducing new predators or competitors, or changing the existing trophic or competitive dynamics. While keystone species have been found in all ecosystems, they are difficult to identify, and their effects are difficult to predict prior to a change in their abundance (Power et al. 1996).

A nonnative species can assume a focal-species role when introduced into an ecosystem and produce numerous effects on the ecosystems. Nonnative species have altered community composition and ecosystem processes via their roles as predators, competitors, pathogens, or vectors of disease and through effects on water balance, productivity, and habitat structure (Drake et al. 1989). However, determining whether a particular nonnative species will become a focal species when introduced to a new ecosystem is very difficult (Drake et al. 1989). Changes in land use often affect the establishment of nonnative species. For example, both agriculture and grazing typically introduce and spread nonnative species. In these situations, the nonnative species often are used at very high densities and can significantly alter environmental conditions, thereby reducing the abundance of native species. Furthermore, changes in the *pattern* of land cover can promote the establishment of nonnative species, for example, by creating corridors of disturbed habitat that alter movement patterns (Getz et al. 1978; DeFerrari and Naiman 1994).

Changes in species composition and diversity can result from land use through alterations to such ecosystem properties as stream turbidity (which often occurs with increased soil erosion), nutrient cycling, or productivity (e.g., Rosenzweig and Abramsky 1993). Additions of water or fertilizer also typically alter and often reduce biodiversity (Harms et al. 1987; Warner 1994; Naiman et al. 1995). The effects of land use on species composition have implications for the future productivity of ecological systems. Low-diversity systems are likely to experience large variations in realized productivity through time, as species differ in their productive potential under different conditions of weather or resource supply (Mitchell 1984; McNaughton 1993; Rosenzweig and Abramsky 1993; Tilman 1996). Moreover, low species diversity can cause resources to be used less fully than they might be in a more ecologically diverse community of primary producers (Ewel et al. 1991). Herbivores can affect the productivity of the plant communities they graze (Mc can initiate trophic cascades that primary-producer community (Ca predators has been used as a rem and undesired algae in lakes.

1.2.3 Place Principle

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plant communities they graze (McNaughton 1979, 1993), and top predators can initiate trophic cascades that influence productivity by changing the primary-producer community (Carpenter 1992). In fact, the introduction of predators has been used as a remediation tool to control agricultural pests and undesired algae in lakes.

1.2.3 Place Principle

Local climatic, hydrologic, edaphic, and geomorphologic factors as well as biotic interactions strongly affect ecological processes and the abundance and distribution of species at any one place. Local environmental conditions reflect location along gradients of elevation, longitude, and latitude and the multitude of microscale physical, chemical, and edaphic factors that vary within these gradients. These factors constrain the locations of agriculture, forestry, and other land uses, as well as provide the ecosystem with a particular "look." A Great Basin site looks different and has a different landscape structure from that of the Sonoran Desert, an arid montane grassland, an eastern deciduous forest, or the Great Plains. Moreover, local environmental conditions constrain the patterns of land use and the styles of architecture and development that work most efficiently and that are aesthetically pleasing.

Alternatively, the constraints of place provide opportunities to use ecological patterns and processes as models for efficient and sustainable land use. Rates of key ecosystem processes, such as primary production and decomposition, are limited by soil nutrients, temperature, water availability, and the temporal pattern of availability of these factors as mediated by climate and weather (Chabot and Mooney 1985; Givnish 1986; Frank and Inouye 1994). Thus, only certain ranges of ecological-process rates can persist in a locale without continued management inputs (e.g., irrigation of crops growing in a desert). Chronic human intervention may broaden these ranges but cannot entirely evade the constraints of place. For instance, enhanced productivity on desert uplands can be supported over the short term by additions of water; however, higher productivity generally cannot be sustained in arid land soils over the long run because of the degrading effects of high evapotranspiration rates and resulting salinization.

Agricultural production requires favorable conditions of temperature, soil, nutrients, and water, key limiting factors for plant growth and productivity. The temporal pattern of these factors is a consequence of climate and weather, restricting the location of agriculture and the suitability of particular crops. Using plants appropriate for a particular place and situating agricultural and natural patches of vegetation in an appropriate landscape context can extend sustainable agricultural land use, reduce the impacts of agriculture on adjacent areas, and more efficiently use resources. Many uses of land have failed because species composition and ecosystem processes have not been appropriately matched with the local physical,

chemical, and climatic conditions. For example, the Dust Bowl in the central United States resulted from unsustainable use of Great Plains arid grassland for dryland row-crop agriculture (Sears 1980; Glantz 1994; Diamond 1997).

Naturally occurring patterns of ecosystem structure and function provide models for sustainable and ecologically sound agriculture (Carroll et al. 1990; Soulé and Piper 1992). Only those species whose adaptations suit the environmental constraints particular to an area will thrive there. For instance, arid regions cannot support plants that are unable to survive high heat and low water availability. Precipitation constrains choice of species for landscape plantings as well as for managed agricultural, forestry, or grazing systems. It also makes some places more important than others for conservation of species and ecosystems. Species lost as a consequence of land-cover changes or with increases in land-use intensity may not be easily restored or replaced. Agricultural plants may be selected to mimic the structure, physiology, growth, and flowering/fruiting phenology of local communities as a mechanism to match productive potential with local patterns of conditions suitable for production. Similarly, the use of multiple crops, typical of traditional low-technology agriculture, has attracted recent attention as a way of increasing the efficiency of resource use, stabilizing production across years of varying weather conditions, and reducing the impact of herbivores.

Land uses that cannot be maintained within the constraints of place will be costly when viewed from long-term and broad-scale perspectives. Only certain patterns of land use, settlement and development, building construction, or landscape design are compatible with local and regional hydrologic, geomorphic, and biogeochemical cycles. In terrestrial systems, land-use and land-management practices that lead to soil loss reduce the long-term potential productivity of a site. Additions of water and nutrients may exceed levels that can be used directly by primary producers, given the natural limitations of species and climate. The excess water and nutrients from enriched systems may move into adjacent areas and influence ecosystems by such processes as runoff. Similarly, sustainable settlement is limited to suitable places on the landscape. For instance, houses or communities built on transient lake-shore dunes, major flood plains, eroding seashores, or sites prone to fires are highly vulnerable to loss over the long term. Ideally, the land will be used for the purpose to which it is best suited. It does not make sense to put cities on prime farmland, requiring that more moderately productive farmland be used to provide the same quantity of food production. However, socioeconomic and political pressures have strong influences on land-use decisions.

1.2.4 Disturbance Principle

The type, intensity, and duration of disturbance shape the characteristics of populations, communities, and ecosystems. Disturbances are events that disrupt ecological systems. Disturbances may occur naturally (e.g., wildfires [Romme and Despain 1989], storm 1996], or floods [Poff et al. 1997]) o clearing for agriculture, clear-cuttin stream channels. The effects of distu their intensity, duration, frequency, shape of the area affected) (Sousa et al. 1987*a*; Reice 1994; Turner et a to have many important effects on enhancing or limiting biological d initiating succession (Cowles 1911; V Lewin and van der Maarel 1992); c matter and nutrients that affect pr 1992; Scatena et al. 1996); and crea many ecological factors, from mov functional attributes of ecosystems (Forman 1995) (Fig. 1.2). Disturban and temporal heterogeneity on ec bances can have secondary effects, development, plowing, or clear-cutti 1993).

Land-use changes that alter natu disturbances are likely to cause cha bution, community composition, and In addition, the susceptibility of an e altered. For example, forest fragmen the remaining forest to a variety of o pest epidemics, invasion by nonnativ and Forman 1987).

Land managers and planners s disturbance in nature. Disturbances such as hurricanes or 100-year flood (Turner et al. 1997*a*; Turner and D time principle, communities and disturbance; thus, attempts to maint state will be futile over the long disturbances are generally ineffectual of a natural disturbance may have th example, suppression of fire in fire-ad fuels and increases the likelihood aftermath of the fires at Yellowstone the large scale of those fires was, in actions that created connected patche Similarly, flood-control efforts have f still subject to infrequent large even Midwest), resulting in tremendous e

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[Romme and Despain 1989], storms [Boose et al. 1994; Lugo and Scatena 1996], or floods [Poff et al. 1997]) or be induced by human actions, such as clearing for agriculture, clear-cutting in forests, building roads, or altering stream channels. The effects of disturbances are controlled in large part by their intensity, duration, frequency, timing, and spatial impacts (the size and shape of the area affected) (Sousa 1984; Pickett and White 1985; Pickett et al. 1987*a*; Reice 1994; Turner et al. 1997*a*). Disturbance has been shown to have many important effects on communities and ecosystems, including enhancing or limiting biological diversity (Hastings 1980; Sousa 1984); initiating succession (Cowles 1911; Watt 1947; Pickett et al. 1987*a*,*b*; Glenn-Lewin and van der Maarel 1992); causing inputs or losses of dead organic matter and nutrients that affect productivity and habitat structure (Peet 1992; Scatena et al. 1996); and creating landscape patterns that influence many ecological factors, from movements and densities of organisms to functional attributes of ecosystems (Turner 1987; Turner et al. 1994, 1997*b*; Forman 1995) (Fig. 1.2). Disturbance and succession impose both spatial and temporal heterogeneity on ecological systems. Additionally, disturbances can have secondary effects, such as fragmentation caused by road development, plowing, or clear-cutting (Franklin and Forman 1987; Roland 1993).

Land-use changes that alter natural disturbance regimes or initiate new disturbances are likely to cause changes in species' abundance and distribution, community composition, and ecosystem function (Yarie et al. 1998). In addition, the susceptibility of an ecosystem to other disturbances may be altered. For example, forest fragmentation may enhance the susceptibility of the remaining forest to a variety of other disturbances, including windthrow, pest epidemics, invasion by nonnative species, and nest parasitism (Franklin and Forman 1987).

Land managers and planners should be aware of the ubiquity of disturbance in nature. Disturbances that are both intense and infrequent, such as hurricanes or 100-year floods, will continue to produce "surprises" (Turner et al. 1997*a*; Turner and Dale 1998). As discussed above for the time principle, communities and ecosystems change, with or without disturbance; thus, attempts to maintain landscape conditions in a particular state will be futile over the long term. Further, attempts to control disturbances are generally ineffectual (Dale et al. 1998). In fact, suppression of a natural disturbance may have the opposite effect of that intended. For example, suppression of fire in fire-adapted systems results in the buildup of fuels and increases the likelihood of severe, uncontrollable fires. In the aftermath of the fires at Yellowstone National Park, it was recognized that the large scale of those fires was, in part, the result of previous fire-control actions that created connected patches of fire-prone forests (Schullery 1989). Similarly, flood-control efforts have facilitated development in areas that are still subject to infrequent large events (e.g., the 1993 floods in the upper Midwest), resulting in tremendous economic and ecological loss (Haeuber

FIGURE 1.2. Long-leaf pine forests depend on low-intensity fires to reduce hard wood ingrowth and eliminate competing tree species.

and Michener 1998; Sparks 1996; Sparks et al. 1998). Land-use policy that is based on the understanding that ecosystems are dynamic in both time and space can often deal with changes induced by disturbances (Turner et al. 1995; Dale et al. 1998; Haeuber and Michener 1998).

Natural disturbances can provide a model upon which to base land-use activities, but the differences between natural and human activities must be recognized. For example, timber harvest has sometimes been considered a surrogate for natural fire, but some
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causes little soil disturbance, and of
coarse wood remains to decompo
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subsidies provided by dead woody
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1.2.5 Landscape Principle

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surrogate for natural fire, but some of the ecological attributes and effects of these two disturbances are markedly different. Natural forest fire typically causes little soil disturbance, and often fine fuels are consumed, while large, coarse wood remains to decompose after the fire. Timber harvest often results in considerable soil disturbance, and fine branches may remain while large wood is removed. This removal of wood also impacts forest streams, which are strongly influenced by the physical structure and nutrient subsidies provided by dead woody debris (Harmon et al. 1986; Bilby and Bisson 1998).

Continued expansion of human settlement into disturbance-prone landscapes is likely to result in increased conflicts between human values and the maintenance of natural-disturbance regimes necessary to sustain such landscapes. For example, building homes in conifer forests that have recurrent wildfires results in conflicts that endanger human life as well as entail financial risks.

1.2.5 Landscape Principle

The size, shape, and spatial relationships of land-cover types influence the dynamics of populations, communities, and ecosystems. The spatial array of habitats or ecosystems comprises the landscape, and all ecological processes respond, at least in part, to this landscape template (Urban et al. 1987; Turner 1989; Forman 1995; Pickett and Cadenasso 1995). The kinds of organisms that can exist (including their movement patterns, interactions, and influence over such ecosystem processes as decomposition and nutrient fluxes) are constrained by the sizes, shapes, and patterns of interspersion of habitat across a landscape. Landscape fragmentation is not necessarily destructive of ecological function or of diverse biological communities, because a patchwork of habitat types often maintains more types of organisms and more diversity of ecosystem processes than does a large area of homogeneous habitat (e.g., Wilson et al. 1997). However, large decreases in the size of habitat patches or increases in the distance between habitat patches of the same type can greatly reduce or eliminate populations of organisms (Lovejoy et al. 1986; Saunders et al. 1991; Noss and Csuti 1994; Hansson et al. 1995; Fahrig 1997; Schwartz 1997) as well as alter ecosystem processes. Making a naturally patchy landscape less patchy (more uniform) may also have adverse affects.

Human-settlement patterns and individual land-use decisions often fragment the landscape or otherwise alter land-cover patterns. Effects of habitat fragmentation on species are numerous (e.g., Saunders et al. 1991; Noss and Csuti 1994; Andren 1997), and the richness of native species is almost always reduced.

Larger patches of habitat generally contain more species (and often a greater number of individuals) than smaller patches of the same habitat (Wiens 1996). Larger patches also frequently contain more local environmental

variability, such as differences in microclimate, more structural variation in plants, and greater diversity of topographic positions. This variability provides more opportunities for organisms with different requirements and tolerances to find suitable sites within the patch. In addition, the edges and interiors of patches may have quite different conditions, favoring some species over others, and the abundance of edge and interior habitat varies with patch size (Temple 1986). Large patches are likely to contain both edge and interior species, whereas small patches will contain only edge species.

Habitat connectivity can constrain the spatial distribution of species by making some areas accessible and others inaccessible (Burgess and Sharpe 1981; Pulliam et al. 1992). Connectivity is a threshold dynamic, meaning that gradual reduction of habitat may have gradual effects on the presence or abundance of a species, but the effects tend to be dramatic after the threshold is passed (Andren 1997). Land-cover changes are most likely to have substantial effects when habitat is low to intermediate in abundance (Pearson et al. 1996). Under these conditions, small changes in habitat abundance may cause the connectivity threshold to be passed. The threshold of connectivity varies among species and depends on two factors: (1) the abundance and spatial arrangement of the habitat and (2) the movement or dispersal capabilities of the organism (Gardner et al. 1989; Pearson et al. 1996).

Local ecological dynamics (e.g., the abundance of organisms at a place) may be explained by attributes of the surrounding landscape as well as by characteristics of the immediate locale (e.g., Franklin 1993; Pearson 1993). Valone and Brown (1995) found that rates of immigration by, and extinction of, small rodents in habitat patches was affected by competition from other species and by habitat structure. Therefore, understanding the implications of local land-use decisions requires interpreting them within the context of the surrounding landscape.

The ecological import of a habitat patch may be much greater than is suggested by its spatial extent. Some habitats, such as bodies of water or riparian corridors, are small and discontinuous, but nevertheless have ecological impacts that greatly exceed their spatial extent (Naiman and Décamps 1997). For example, wetlands and bodies of water in general are low in spatial extent but high in their contributions to the compositional and structural complexity of an ecoregion. In addition, the presence of riparian vegetation, which may occur as relatively narrow bands along a stream or as small patches of wetland, generally reduces the amount of nutrients being transported to the stream (e.g., Peterjohn and Correll 1984; Charbonneau and Kondolf 1993; Detenbeck et al. 1993; Soranno et al. 1996; Weller et al. 1998). This filtering by the vegetation is an ecologically important function because excess nutrients that unintentionally end up in lakes, streams, and coastal waters are a major cause of water quality problems, such as acidification and eutrophication. Thus, the presence and location of particular vegetation types can strongly affect the movement of materials across the landscape ar
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1.3 Guidelines for Land U

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1.3 Guidelines for Land Use

Ecologically based guidelines are proposed here as a way to facilitate land managers considering the ecological ramifications of land-use decisions. These guidelines are meant to be flexible and to apply to diverse land-use situations. The guidelines recognize that the same parcel of land can be used to accomplish multiple goals and require that decisions be made within an appropriate spatial and temporal context. For example, the ecological implications of a decision may last for decades or even centuries, long outliving the political effects and impacts. Furthermore, all aspects of a decision need to be considered in setting the time frame and spatial scale for impact analysis. In specific cases, the relevant guidelines can be developed into prescriptions for action. One could think of these guidelines as a checklist of factors to be considered in making a land-use decision:

- ☐ Examine the impacts of local decisions in a regional context.
- ☐ Plan for long-term change and unexpected events.
- ☐ Preserve rare landscape elements, critical habitats, and associated species.
- ☐ Avoid land uses that deplete natural resources over a broad area.
- ☐ Retain large contiguous or connected areas that contain critical habitats.
- ☐ Minimize the introduction and spread of nonnative species.
- ☐ Avoid or compensate for effects of development on ecological processes.
- ☐ Implement land-use and land-management practices that are compatible with the natural potential of the area.

Checking the applicability of each guideline to specific land-use decisions provides a means to translate the ecological principles described in the previous section into practice.

1.3.1 Examine Impacts of Local Decisions in a Regional Context

As embodied in the landscape principle, the spatial array of habitats and ecosystems shapes local conditions and responses (e.g., Risser 1985; Patterson 1987) and, by the same logic, local changes can have broad-scale impacts over the landscape. Therefore, it is critical to examine both the constraints placed on a location by the regional conditions and the implications of decisions for the larger area. This guideline dictates two considerations for planning land use: identifying the surrounding region that is likely to affect and be affected by the local project and examining how adjoining jurisdictions are using and managing their lands. Once the

regional context is identified, regional data should be examined. Items to include in a regional data inventory include land-cover classes, soils, patterns of water movement, historical disturbance regimes, and habitats of focal species and other species of special concern (see Diaz and Apostol [1992] and Sessions et al. [1997] for a thorough discussion). The focal species typically represent a diversity of functional roles that are possible within a place and reflect the environmental fluctuations that provide opportunities and constraints for species. In some cases, an attribute (such as soils) can be used as a surrogate for other information that is dependent on that feature (such as vegetation). Recent technological advances (such as the development of geographic information systems (GIS) and the general availability of databases for soils, roads, and land cover on the Internet) make regional analysis a possibility even for small projects (e.g., Mann et al., 1999).

Where one has the luxury of planning land use and management in a pristine site, both local and broad-scale decisions can be considered simultaneously. Forman (1995) suggests that land-use planning begin with determining nature's arrangement of landscape elements and land cover and then considering models of optimal spatial arrangements and existing human uses. Following this initial step, he suggests that the desired landscape mosaic be planned first for water and biodiversity; then for cultivation, grazing, and wood products; then for sewage and other wastes; and finally for homes and industry. Planning under pristine conditions is typically not possible. Rather, the extant state of development of the region generally constrains opportunities for land management.

This guideline implies a hierarchy of flexibility in land uses, and it implicitly recognizes ecological constraints as the primary determinants in this hierarchy. A viable housing site is much more flexible in placement than an agricultural area or a wetland dedicated to improving water quality and sustaining wildlife. Optimizing concurrently for several objectives requires planners to recognize that some land uses have lower site flexibility than other uses. However, given that most situations involve existing land uses and built structures, this guideline calls for examining local decisions within the regional context of ecological concerns as well as in relation to the social, economic, and political perspectives that are typically considered.

Ideally, land-use models that incorporate both ecological and other concerns about impacts of land activities could be used to design and explore implications of land-use decisions in a regional context. Land-use models that truly integrate the social, economic, and ecological considerations are in their infancy, and no consensus has yet been reached about what approaches are best for this task. Therefore, many diverse approaches have been advanced (Wilkie and Finn 1988; Southworth et al. 1991; Baker 1992; Lee et al. 1992; Dale et al. 1993, 1994*a*,*b*; Riebsame et al. 1994; Gilruth et al. 1995; Turner et al. 1996; Wear et al. 1996). Development and use of these models have improved understanding of the relationship between the many factors that affect land-use decisions and their impacts

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1.3.2 Plan for Long-Term Change and Unexpected Events

The time principle indicates that impacts of land-use decisions can, and often do, vary over time. Long-term changes that occur as a response to land-use decisions can be classified into two categories: delayed and cumulative. Delayed impacts may not be observed for years or decades. An example is the composition of forest communities in New England; today, those forests differ substantially among areas that were previously woodlots, pasture, or croplands (Foster 1992). Cumulative effects are illustrated by events that together determine a unique trajectory of effects that could not be predicted from any one event (Paine et al. 1998). For example, at Walker Branch Watershed in East Tennessee, patterns of calcium cycling are determined not only by past land uses (timber harvest versus agriculture) but also by the history of insect outbreaks in the recovering forest (Dale et al. 1990).

Future options for land use are constrained by the decisions made today as well as by those made in the past. These constraints are conspicuous in forested systems, where options for areas to harvest may be limited by the pattern of available timber left from past cuts (Turner et al. 1996). In addition, areas that are urbanized are unlikely to be available for any other land uses because urbanization locks in a pattern on the landscape that is hard to reverse. This difficulty of reversal also holds for suburban sprawl and the development of vacation or retirement homes.

The concept of externalities must be considered in the context of this guideline. Land actions should be implemented with some consideration as to the physical, biological, aesthetic, or economic constraints that are placed on future uses of the land. External effects can extend beyond the boundaries of individual ownership and thus have the potential to affect surrounding owners.

Planning for the long term requires consideration of the potential for unexpected events, such as variations in temperature or precipitation patterns or disturbances. Although disturbances shape the characteristics of ecosystems, estimating the occurrence and implications of these unanticipated events is difficult. Nevertheless, land-use plans must include them. For example, the western coast of the United States has a high potential for volcanic eruption, which would have severe effects. Yet, predicting exact impacts is not possible. Climate change is occurring, but global-climate-projection models cannot determine the temperature and precipitation changes that will happen in any one place. Thus, potential impacts of

land-use changes on future dynamics should be recognized but cannot be precisely specified, as yet. Similarly, land-use changes that affect natural water drainages can cause catastrophic flooding during extreme rain events (Sparks 1996). Although it will not be possible to foresee all extreme events or the effects of a land-use decision on natural variations, it is important to estimate likely changes.

Long-term planning must also recognize that one cannot simply extrapolate historical land-use impacts forward to predict future consequences of land use. The transitions of land from one use or cover type to another often are not stable from one period to another (Turner et al. 1996; Wear et al. 1996) because of changes in demographics, public policy, market economies, and technological and ecological factors. Thus, models produce projections of potential scenarios rather than predictions of future events. It is difficult to model (or even understand) the full complex of interactions among the factors that determine land-use patterns, yet models offer a useful tool to consider potential long-term and broad-scale implications of land-use decisions.

1.3.3 Preserve Rare Landscape Elements and Associated Species

Rare landscape elements provide critical habitats or ecological processes. For example, in the Southern Appalachian Mountains, 84% of the federally listed terrestrial plant and animal species occur in rare communities (Southern Appalachian Assessment 1996). While these communities occupy a small area of land, they contain features important for the region's biological diversity. Therefore, rare landscape elements need to be identified, usually via an inventory and analysis of vegetation types, hydrology, soils, and physical features that identifies the presence and location of rare landscape elements and, when possible, associated species (e.g., see Mann et al. 1999). Once the inventory is complete, effects of alternative land-use decisions on these landscape elements and species can be estimated. These effects can then be considered in view of the overall goal for the project, the distribution of elements and species across the landscape, and their susceptibility, given likely future land changes in the vicinity and region. Strategies to avoid or mitigate serious impacts can then be developed and implemented. This guideline to preserve rare landscape elements and associated species derives from both the species and place principles.

1.3.4 Avoid Land Uses That Deplete Natural Resources Over a Broad Area

Depletion of natural resources disrupts natural processes in ways that often are irreversible over long periods of time. The loss of soil via erosion that

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occurs during agriculture and the loss of wetlands and their associated ecological processes and species are two examples. This guideline entails prevention of the rapid or gradual diminishment of resources, such as water or soil. This task first requires the determination of resources at risk. For example, in the southwestern United States, water might be the most important resource; but elsewhere, water might not be a limiting factor, yet it may not be readily replaced. The evaluation of resources at risk is thus an ongoing process as the abundance and distribution of resources change. This guideline also calls for the deliberation of ways to avoid actions that would jeopardize natural resources. Some land actions are inappropriate in a particular setting or time, and they should be avoided. Examples of inappropriate actions are farming on steep slopes, which might produce soil loss; logging on stream sides, which may jeopardize the habitat for aquatic organisms; and planting hydrophilic plants in areas that require substantial watering (e.g., lawns grown in arid areas).

1.3.5 Retain Large Contiguous or Connected Areas That Contain Critical Habitats

Large areas are often important to maintaining key organisms and or supporting ecosystem processes (e.g., Brown 1978; Newmark 1995). Habitats are places on the landscape that contain the unique set of physical and biological conditions necessary to support a species or guild. Thus, the features of a habitat must be interpreted in the context of the species or guild that defines them. Habitat becomes critical to the survival of a species or population when it is rare or disconnected. Thus, this guideline derives from both the place and landscape principles. Size and connectivity of patches provide ecological benefits. The presence of animals in an area can be predicted by the size of their home range and their ability to cross gaps of inhospitable habitat (Dale et al. 1994*b*; Mladenoff et al. 1995). However, habitat connectivity is not always a positive attribute for species and ecosystems. Land uses that serve as barriers to species' movement can have long-term negative effects on populations (e.g., Merriam et al. 1989); but, at the same time, corridors can facilitate the spread of nonnative species or diseases (see the next guideline). Additionally, habitats do not need to be in natural areas to provide benefits for wildlife. For example, golf courses in the southeastern United States often contain enough long-leaf pine (*Pinus palustris*) to provide habitat for the endangered red cockaded woodpecker (*Pocoides borealis*).

Again, the importance of spatial connections depends on the priorities and elements of a situation. A first step in implementing the guideline is to examine the spatial connectivity of key habitats in an area, determining which patches are connected and whether the connectivity has a temporal component. Second, opportunities for connectivity must be promoted. Sometimes, those opportunities complement other planning needs. For

instance, corridors along streams must be protected during timber extraction to provide benefits for aquatic species (Naiman and Décamps 1997).

The term "connected" also should be defined in a manner specific to the situation. In some cases, two areas that are divided by a land-cover type may be artificially connected. For example, the habitat of panther (*Felis concolor coryi*) that is bisected by roads in Florida is now connected by tunnels under the highway (Foster and Humphrey 1995). For other species, such as meadow voles (*Microtus pennsylvanicus*), roads themselves serve as corridors (see Getz et al. 1978). In other cases, areas of similar habitat need not be directly adjacent but need only to be within the dispersal distance of the species of concern (e.g., migratory birds returning to nesting grounds [Robinson et al. 1995]). The connections provided by linear land-cover features, such as roads, may have both positive and negative effects (Forman and Alexander 1998), and thus the broad-scale impacts of these features require careful consideration.

1.3.6 Minimize the Introduction and Spread of Nonnative Species

The species principle indicates that nonnative organisms often have negative effects on such ecological processes as reproduction, growth, mortality, competition, predation, and herbivory (Fig. 1.3). Thus, land-use decisions must consider the potential for the introduction and spread of nonnative species. Land planning should consider vehicle movement along transportation routes, the planting of native species, and control of pets. For example, transportation routes have been very important in the spread of the spores of the pathogen *Phytophthora lateralis,* which kills Port Orford cedar (*Chamaecyparis lawsoniana*), an important timber species of southwestern Oregon (Harvey et al. 1985; Zobel et al. 1985). The USDA Forest Service has found that cleaning trucks or minimizing traffic during wet periods can dramatically reduce the transport of this pathogen between forests. Similarly, the spread of gypsy moth (*Lymantria dispar*) is correlated with overseas transportation of the eggs, larvae, and adults in the cargo holds of ships (Hofacker et al. 1993) or along roads at low elevations, where egg sacs are attached to vehicles (Sharov et al. 1997) or outdoor furniture. The great potential for vehicular transport of nonnative species was demonstrated by a case in which material was collected from the exterior surface of an automobile following a drive through central Europe; the collected matter represented 124 plant species and exhibited a high proportion of foreign propagules (Schmidt 1989). The introduction of aquatic organisms transported incidentally with shipping traffic is a comparable example for aquatic ecosystems. Many of these introductions have had devastating effects. Waterways for shipping have impacts on the movement of introduced species not unlike those of roadways.

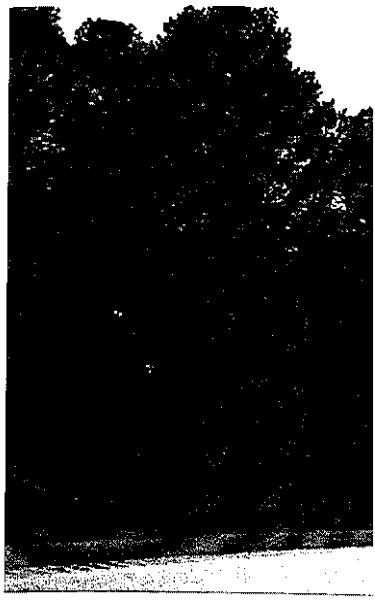

FIGURE 1.3. The introduced invasive sp
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acts on the movement of introduced

FIGURE 1.3. The introduced invasive species kudzu (*Pueraria thunbergiana*) grows over trees and eventually kills them.

Often, growing native species reduces the need for planting nonnative species, particularly in urban, suburban, or other developed areas. The planted native species can then provide propagules that may disperse and establish. As an added benefit, the native species are adapted to the local conditions and frequently become established more readily and require less maintenance than nonnatives. Native species are also adapted to long-term variations in climate or disturbance regimes to which nonnative species often succumb. Terrestrial environmental conditions associated with native vegetation may also deter the spread of nonnatives. For example, in small forest islands interspersed among alien-dominated agroecosystems in Indiana, even the smallest forest remnants retained interior habitat conditions sufficient to resist invasion by the available nonnative plant species (Brothers and Spingharn 1992). Introduced agricultural crops often result in less sustainable farming practices than does the use of native crops, as has been observed in the Brazilian Amazon (Soulé and Piper 1992).

The control of pets is an essential aspect of reducing introductions. As suburbanization expands, one of the major effects on native fauna is the introduction of exotic pets. The mosquitofish (*Gambusia affinis*), swordtail (*Xiphophorus helleri*), and other species used as pets and then released into the wild have had a dramatic impact on the native fauna (Gamradt and Kats 1996). In addition, cats (*Felis cattus* or *Felis domestica*) kill birds and small mammals (Dunn and Tessaglia 1994). In Australia, conservationists have

worked with developers and the public to ban dogs from suburban development projects that contain koala habitat because dogs strongly contribute to koala mortality in developed areas.

1.3.7 Avoid or Compensate for Effects of Development on Ecological Processes

Negative impacts of development might be avoided or mitigated by some forethought. To do so, potential impacts need to be examined at the appropriate scale. At a fine scale, the design of a structure may interrupt ecoregional processes. For example, dispersal patterns may be altered by a road, migrating birds may strike the reflective surfaces of a building, or fish may be entrained in a hydroelectric generator. At a broad scale, patterns of watershed processes may be altered, for example, by changing drainage patterns as part of the development.

Therefore, how proposed actions might affect other systems (or lands) should be examined. For example, landslides are generally site-specific so that development of places with a high potential for landslides should be avoided. Also, human uses of the land should avoid structures and uses that might have a negative impact on other systems; at the very least, ways to compensate for those anticipated effects should be determined. It is useful to look for opportunities to design land use to benefit or enhance the ecological attributes of a region (Fig. 1.4). For example, golf courses can be designed to serve as wildlife habitat (Terman 1997), or traffic in rural areas can be concentrated on fewer and more strategically placed roads, resulting in decreased traffic volumes and flows within the region as a whole and less impact on wildlife (Jaarsma 1997).

1.3.8 Implement Land-Use and Land-Management Practices That Are Compatible with the Natural Potential of the Area

The place principle implies that local physical and biotic conditions affect ecological processes. Therefore, the natural potential for productivity and for nutrient and water cycling partially determine the appropriate land-use and land-management practices for a site. Land-use practices that fall within these limits are usually cost-effective in terms of human resources and future costs caused by unwarranted changes on the land. Nevertheless, supplementing the natural resources of an area by adding nutrients through fertilization or water via irrigation is common. Even with such supplements, however, the natural limitations of the site must be recognized for cost-effective management.

Implementing land-use and land-management practices that are compatible with the natural potential of the area requires that land managers have

FIGURE 1.4. Areas adjacent to air strips such as this site at Arnold Air Force I

an understanding of the site poter native farmers) typically have a clo and other resource extraction acti the previous close association that lost. Still, land-management practi to reduce soil erosion or other res simply ignore site limitations or building shopping malls on prime use of the site potential. Also, estab or lawns where watering is necessa surmounted. Ultimately, land use a the land will be limited by the nat

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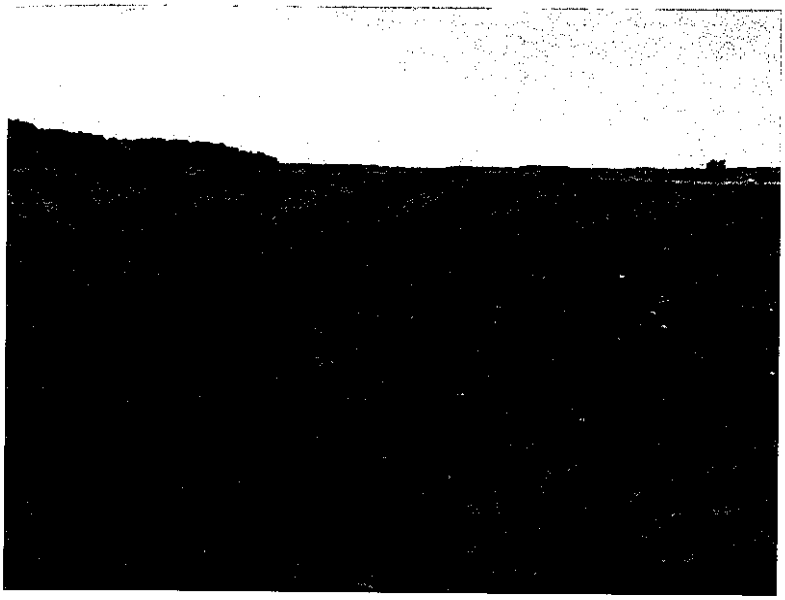

FIGURE 1.4. Areas adjacent to air strips can provide habitat for rare plants and birds, such as this site at Arnold Air Force Base in Tennessee.

an understanding of the site potential. Traditional users of the land (e.g., native farmers) typically have a close relationship with the land. As farming and other resource extraction activities become larger and more intensive, the previous close association that managers had with the land is typically lost. Still, land-management practices like no-till farming can be employed to reduce soil erosion or other resource losses. However, many land uses simply ignore site limitations or externalize site potential. For example, building shopping malls on prime agricultural land does not make the best use of the site potential. Also, establishing farms where irrigation is required or lawns where watering is necessary assumes that site constraints will be surmounted. Ultimately, land use and the products that can be derived from the land will be limited by the natural potential of the site.

1.4 Conclusions

The next step is to examine how these principles apply to particular land-use and land-management situations. The remainder of this volume tackles that task. The chapters are organized into four categories. Part II presents a diversity of examples of applying the ecological principles and guidelines. The case studies include both private and public lands, management issues from around the world, and various land-management goals (e.g., conservation

of species or habitat, protection of historically important sites, and sustainable use of natural resources with limited harvesting). Some of the chapters explicitly consider how human activities influence the ability to apply the ecological principles to land management. Part III of the book contains four chapters that use different techniques to consider future conditions of the land. These alterative futures reflect the ecological guidelines to varying degrees. The explicit presentation of future conditions allow the land owner to understand how their decisions may affect future conditions. Part IV, Making Decisions About the Land, explores ways that people and groups make decisions and how the affects of these decisions are assessed. The book ends with a chapter that explores the future of ecological perspectives in decision making. It considers opportunities and constraints to including ecological guidelines in making decisions about the land. Together, the ideas, examples, and tools in the following chapters provide illustrations of how ecology can be integrated into land management.

1.5 Summary

Throughout history, the many ways that people use and manage land have emerged as a primary cause of land-cover change around the world. Thus, land use and land management increasingly represent a fundamental source of change in the global environment. Despite their global importance, however, many decisions about the management and use of land are made with scant attention to ecological impacts. Thus, ecologists' knowledge of the functioning of the earth's ecosystems is needed to broaden the scientific basis of decisions on land use and management. In response to this need, the Ecological Society of America established a committee to examine the ways that land-use decisions are made and the ways that ecologists could help inform those decisions. This chapter reports the principle and guidelines developed by that committee. The full report is in Dale et al. (2000).

Five principles of ecological science have particular implications for land use and can assure that fundamental processes of the earth's ecosystems are sustained. These ecological principles deal with time, species, place, disturbance, and the landscape. The recognition that ecological processes occur within a *temporal* setting and change over time is fundamental to analyzing the effects of land use. In addition, individual *species* and networks of interacting species have strong and far-reaching effects on ecological processes. Furthermore, each *site* or region has a unique set of organisms and abiotic conditions influencing and constraining ecological processes. *Disturbances* are important and ubiquitous ecological events whose effects may strongly influence population, community, and ecosystem dynamics. Finally, the size, shape, and spatial relationships of habitat patches on the *landscape* affect the structure and function of ecosystems. The

responses of the land to changes i
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These principles dictate several
practical rules of thumb for incorp
decision making. These guidelines

- ☐ Examine impacts of local dec
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responses of the land to changes in use and management by people depend on expressions of these fundamental principles in nature.

These principles dictate several guidelines for land use. The guidelines give practical rules of thumb for incorporating ecological principles into land-use decision making. These guidelines suggest that land managers should

- ☐ Examine impacts of local decisions in a regional context.
- ☐ Plan for long-term change and unexpected events.
- ☐ Preserve rare landscape elements and associated species.
- ☐ Avoid land uses that deplete natural resources.
- ☐ Retain large contiguous or connected areas that contain critical habitats.
- ☐ Minimize the introduction and spread of nonnative species.
- ☐ Avoid or compensate for the effects of development on ecological processes.
- ☐ Implement land-use and land-management practices that are compatible with the natural potential of the area.

Decision makers and citizens are encouraged to consider these guidelines and to include ecological perspectives in choices on how land is used and managed. The guidelines also suggest the applied and basic research required to develop the science needed by landowners and managers if ecologically based land-use approaches are to be implemented successfully.

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