

Key ecological principles for land use and management deal with time, species, place, disturbance, and the landscape. The principles result in several guidelines that serve as practical rules of thumb for incorporating ecological principles into making decisions about the land.

## INTRODUCTION

Humans are the major force of change around the globe, transforming land to provide food, shelter, and products for use. Land transformation affects many of the planet's physical, chemical, and biological systems and directly impacts 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. In this brochure, we identify ecological principles that are critical to sustaining ecosystems in the face of land-use change. We also offer guidelines for using these principles in making decisions regarding land-use change.

## Definitions

**Land cover:** the ecological state and physical appearance of the land surface (e.g., closed forests, open forests, grasslands).

**Land use:** the purpose to which land is put by humans (e.g., protected areas, forestry for timber products, plantations, row-crop agriculture, pastures, or human settlements).

**Ecosystem management:** the process of land use decision-making and land management practice that takes into account the best available understanding of the ecosystem's full suite of organisms and natural processes.

**Land management:** the way a given land use is administered by humans.

**Ecological sustainability:** the tendency of a system or process to be maintained or preserved over time without loss or decline.

**Biodiversity:** the variety of life and ecological systems at scales ranging from populations to landscapes.

**Habitat fragmentation:** the alteration of previously continuous habitat into spatially separate, smaller patches.

## 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 (e.g., forestry, agriculture, grazing, and mining);
- infrastructure for human settlement (housing, transportation, and industrial centers);
- recreational activities;
- services provided by ecological systems (e.g., 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. Local versus broad-scale perspectives on the benefits and costs of land management also provide different views. In this brochure, we focus on sustaining ecological systems which 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 should 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.

Key ecological principles deal with time, species, place, disturbance, and the landscape. While they are presented as separate entities, the principles interact in many ways.

## 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 change from season to season and year to year in response to variations in weather as well as showing long-term successional changes. Human activities can alter what makes up an ecosystem or how biological, chemical, and geological materials flow through an ecosystem. These in turn can change the pace or direction of succession and have effects lasting decades to centuries.

The time principle has several important implications for land use:

- The current composition, structure, and function of an ecological system are, in part, a consequence of historical events or conditions and current land uses may limit land use options that are available in the future.
- The full ecological effects of human activities often are not seen for many years.
- The imprint of a land use may persist on the landscape for a long time, constraining future land use for decades or centuries even after it ceases.
- Long-term effects of land use or management may be difficult to predict due to variation and change in ecosystem structure and process. This problem is exacerbated by the tendency to overlook low-frequency ecological disturbances, such as 100-year flooding, or processes that operate over periods longer than human life spans (e.g., forest succession).

#### Legacy of Past Land Use on Ecosystem Development

Past land use can constrain or control future ecosystem development. For example, the current composition of forests in parts of New England is a result of past patterns and practices in agriculture and forestry. During the 18th and 19th centuries, most of the forests in New England were either cleared for agriculture or harvested for wood products. By the late 19th century, agricultural lands were neglected, and forests regrew. However, current forest composition shows the imprint of past land use.

In a sand plain in Massachusetts, forests of pitch pine occur almost exclusively on formerly plowed lands; in contrast, stands of scrub oak occur mostly on sites that had not been plowed. Paleocological evidence suggests that pre-European fires were common on these sand plains. The impacts of fire and prior land use interact. Fire influences vegetation patterns in the sand plain of New England and can explain some of the dramatic changes in land cover that have occurred. When fire was controlled, pitch pine establishment required the exposed mineral soil and open canopy conditions that existed on formerly plowed sites. The modern vegetation on the sand plain is a result of complex human-impacted disturbance histories, with fire modifying the composition of species assemblages that developed as a result of prior land use.

#### 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 tell us about the status of other species and key habitats or the impacts of a stressor.
- Keystone species have greater effects on ecological processes than would be predicted from their abundance or biomass alone.
- Ecological engineers [e.g., the gopher tortoise or beaver] alter the habitat and, in doing so, modify the fates and opportunities of other species.
- 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 (of a food web) or provide critical links for energy transfer within complex food webs.

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. An introduced, nonnative species can assume a focal-species role and produce numerous effects, including altering 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. The impacts of land use changes on keystone and invasive species can spread well beyond the boundaries of the land-use unit and are difficult to predict prior to changes in their abundance. Changes in the pattern of land cover can affect, and even promote, the establishment of nonnative species.

Trophic levels refer to the stages in food chains such as producers, herbivores, consumers, and decomposers. Changes in the abundance of a focal species or group of organisms at one trophic level can cascade across other trophic levels and result in dramatic changes in biological diversity, community composition, or total productivity. Changes in species composition and diversity can result from land use through alterations to such ecosystem properties as stream flow or sediment load, nutrient cycling, or productivity. The effects of land use on species composition have implications for the future productivity of ecological systems.

#### Linkages Among Species

Insect pollinators are a keystone group of species because more than two-thirds of flowering plants require them for successful reproduction. A reduction in pollinators can lead to reduced seed set and less viable offspring, subsequently affecting other species that feed on plant seeds or fruits. Changes in land use and management have negatively affected plant pollinators in many places. In both North America and Europe, pollinator density decreases as the proportion of an area occupied by agriculture increases, presumably because conversion of land to agriculture or urban areas reduces the amount of native food plants used by pollinators. Similarly, habitat fragmentation and pesticide use can reduce or eliminate pollinator populations.

The redcockaded woodpecker is an example of a keystone species that affects the habitats of other organisms. It lives in the longleaf pine/wire grass ecosystem of the southeastern United States, which severely declined between 1880 and 1986. These birds nest in mature longleaf and loblolly pine trees and excavate nest cavities in living trees. Redcockaded woodpeckers are key components because numerous other species rely on their nest cavities. These other animals have been reduced in abundance over the past century as populations of the woodpecker have declined with a reduction in pine-forest habitat by timber harvest and conversion to agriculture.

Introduced species may affect the composition and structure of systems in which they become established. Following the conversion of land to agriculture in the late 19th century, salt cedar was introduced into the western United States to provide windbreaks and to prevent soil erosion. Salt cedar invaded water drainages, riparian ecosystems, and wetland habitat over much of western North America. Its dominance in such habitats results in reduced plant and animal diversity; increased evapotranspiration; a lower water table; increased soil salinity; and, possibly, altered nutrient cycling.

#### Place principle

Local climatic, hydrologic, soil, 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 suitability of various land uses, as well as defining resident species and processes.

Rates of key ecosystem processes, such as primary production and decomposition, are limited by soil nutrients, temperature, water availability, and the temporal pattern of these factors controlled by climate and weather. 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 limitations of place without a cost.

Naturally occurring patterns of ecosystem structure and function provide models that can guide sustainable and ecologically sound land use. Only those species adapted to the environmental constraints of an area will thrive there. Precipitation limits which species are appropriate for landscape plantings as well as for managed agricultural, forestry, or grazing systems. Further, some places with unique conditions may be more important than others for conservation of the species and ecosystems they support.

Land uses that cannot be maintained within the constraints of place will be costly when viewed from long-term and broad-scale perspectives. For example, establishing croplands and ornamental lawns in arid areas is possible, but draws down fossil groundwater at a rate unsustainable by natural recharge. Only certain patterns of land use, settlement and development, building construction, or landscape design are compatible with local and regional conditions. In terrestrial systems, land-use and land-management practices that lead to soil loss or degradation reduce the long-term potential productivity of a site and can affect species composition. Land use practices can also influence local climate (e.g., the urban heat island concept). 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 should be used for the purpose to which it is best suited.

#### Using Land Within the Constraints of Place: Agricultural Ecology

For centuries, native peoples of the desert southwestern United States sustained agricultural production by using both wild desert plants and domesticated relatives of desert-adapted plants in areas with limited water and soil nutrients. They maintained production under conditions that would cause failure of plants not so adapted. These traditional agricultural systems indicate the value of using the landscape in a way consistent with sustainable ecosystem function.

Native Americans of the southwest also located agricultural areas across the landscape in a way that took advantage of local variation in water availability and soils. For instance, crops were planted on flood plains following the pattern of emergence of desert annual plants after seasonal rainfall. These areas of the landscape received regular inputs of silt as well as water, and the flowering and fruiting of the native annuals provided cues to the best times for agricultural planting and production. The interspersed patches of agriculture with natural vegetation also increased access to a reliable pool of pollinators and soil mutualists, such as bacteria and mycorrhizal fungi, that were adapted to local soils and plants.

#### Disturbance principle

The type, intensity, and duration of disturbance shape the characteristics of populations, communities, and ecosystems. Disturbances are events that disrupt ecological systems; they may occur naturally (e.g., wildfires, storms, or floods) or be induced by human actions, such as clearing for agriculture, clearcutting in forests, building roads, or altering stream channels. The effects of disturbances are controlled in large part by their intensity, duration, frequency, timing, and the size and shape of the area affected. Disturbances may affect both above- and below-ground processes and can impact communities and ecosystems by changing the number and kinds of species present; causing inputs or losses of dead organic matter and nutrients that affect productivity and habitat structure; and creating landscape patterns that influence many ecological factors, from movements and densities of organisms to functional attributes of ecosystems.

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. In addition, the susceptibility of an ecosystem to other disturbances may be altered.

Land managers and planners should be aware of the prevalence of disturbance in nature. Disturbances that are both intense and infrequent, such as hurricanes or 100-yr floods, will continue to produce "surprises." Ecosystems change, with or without disturbance; thus, attempts to maintain landscape conditions in a particular state will be futile over the long term. Attempts to control disturbances are generally ineffectual and 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. 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 impacts. 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.

Understanding natural disturbances can help guide land-use decisions, but the differences between natural and human-made disturbances must be recognized. 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.

### Effects of Altered Disturbance Regimes

Episodic disturbance shapes the structure and function of ecosystems by changing the composition of communities, altering linkages in food webs, modifying fluxes of nutrients, and altering the basic physical structure of ecosystems. Shifts in land use can cause profound changes in disturbance regimes and, in so doing, can drive fundamental changes in ecosystems remote from areas where the original land-use change occurred.

An example of such change is seen in riparian communities along the North Platte River in Wyoming and Nebraska. Damming of the North Platte to provide water for agriculture and cities and the resulting changes in its hydrology caused widespread change in the river and its surrounding biotic communities. Historically, the Platte was subject to annual floods, creating a broad floodplain and braided channel. These floods prevented the establishment of woody vegetation, which occurred primarily as scattered stands of cottonwood and willow. Reduction in peak flows by the dam increased habitat suitable for woody plants by reducing the scouring effect of spring floods and by shrinking areas that were submerged. As a result, a variety of successional woody species (including eastern red cedar, Russian olive, and green ash) encroached onto formerly active river channels while recruitment of cottonwoods declined in some areas. These trends led to marked shifts in the composition of plant and animal communities and in the structure of landscapes surrounding the river.

### Landscape principle

The size, shape, and spatial relationships of land-cover types influence the dynamics of populations, communities, and ecosystems. The spatial arrangement of ecosystems comprises the landscape and all ecological processes respond, at least in part, to this landscape template. The kinds of organisms that can exist are limited by the sizes, shapes, and patterns of habitat across a landscape.

Human-settlement patterns and land-use decisions often fragment the landscape or otherwise alter land-cover patterns. 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, as well as alter ecosystem processes. However, landscape fragmentation is not always necessarily destructive of ecological function or biodiversity because a patchwork of habitat types often maintains more types of organisms and more diversity of ecosystem process than does a large area of uniform habitat. Making a naturally patchy landscape less patchy may also have adverse effects.

Larger patches of habitat generally contain more species (and often a greater number of individuals) than smaller patches of the same habitat. Larger patches also frequently contain more local environmental variability. 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. The abundance of edge and interior habitat varies with patch size; large patches are likely to contain both edge and interior species, whereas small patches will contain only edge species.

The extent and pattern of habitat connectivity can affect the distribution of species by making some areas accessible and others inaccessible. The amount of connectivity needed varies among species and depends on two factors: the abundance and spatial arrangement of the habitat and the movement capabilities of the organism.

While gradual reduction in habitat may have gradual effects, once a certain threshold is reached, the effects become dramatic. Land-cover changes are most likely to have substantial effects when habitat is low to intermediate in abundance and small changes may cause large impacts.

The ecological importance of a habitat patch may be much greater than is suggested by its size and distribution across the landscape. 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. For example, 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. 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 eutrophication, acidification, and other water quality problems. Thus, the presence and location of particular vegetation types can strongly affect the movement of materials across the landscape and can contribute to the maintenance of desirable water quality.

### Wolves in a Human-Dominated Landscape

The status and future of wide-ranging animals in regions increasingly dominated by humans is often a concern to natural-resource managers. Recovery of the gray wolf, listed in 1973 as an endangered species, illustrates this challenge. The wolf was extirpated throughout most of the conterminous U.S. following European settlement, with remnant populations persisting only in northeast Minnesota and on Isle Royale, Michigan.

Natural recolonization in the western Great Lakes region has led to recovery of wolf populations, and the Wisconsin and Michigan populations each number between 80 and 90 animals. Wolf recovery resulted largely from legal protection and changed public attitudes. In addition, large populations of deer, resulting in part from the fragmented forest landscapes typical of the region today, provide a ready source of prey. But how do the current landscape patterns in this human-dominated region influence the wolf habitat and populations?

Wolf habitat use is affected by a number of landscape-scale considerations. Wolves avoided certain landcover classes, such as agriculture and deciduous forests, and favored forests with at least some conifers. Public lands received more use, and private lands were avoided. Wolf packs were also most likely to occur in areas with low road densities; no wolfpack territory was bisected by a major highway. Rapid increases in the wolf population since 1993 have occurred in northern Michigan, where favorable habitat is more abundant and more highly connected than in Wisconsin. In Wisconsin, favorable wolf habitat occurs in relatively small, isolated areas separated by lands with greater road density and human development. Adult mortality in Wisconsin has been high, with dispersing wolves being most vulnerable as they cross lands with more intensive human use. Colonization of the fragmented habitat in Wisconsin may remain dependent on dispersers arriving from larger, saturated populations in Minnesota.

### GUIDELINES FOR LAND USE

Ecologically based guidelines are proposed here as a way to assist land managers and others 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 emphasize that decisions should be made within an appropriate spatial and temporal context. For example, the ecological implications of a decision may last for decades or even centuries.

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. These guidelines are best seen as a checklist of factors to be considered in making a land-use decision.

#### Ecological Guidelines for Land Use

- **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 -management practices that are compatible with the natural potential of the area.**

#### *Examine Impacts of Local Decisions in a Regional Context*

The spatial array of habitats and ecosystems shapes local conditions and responses and local changes can have broad-scale impacts over the landscape. Therefore, it is critical to examine both the limitations placed on a location by the regional conditions and the implications of decisions for the larger area. This guideline suggests two considerations for planning land use:

- identify the surrounding region that is likely to affect and be affected by the local project and
- examine how adjoining jurisdictions are using and managing their lands.

Once the regional context is identified, examine regional data (e.g., land-cover classes, soils, patterns of water movement, historical disturbance regimes, and habitats of focal species and other species of special concern). 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.

Some land uses offer more flexibility in terms of future or adjoining uses than do others. The ecological constraints of an area determine the flexibility of diverse land uses for that area. 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.

#### *Plan for Long-Term Change and Unexpected Events*

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 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 depending on whether they were previously woodlots, pasture, or croplands.
- Cumulative effects are illustrated by events that together determine a unique trajectory of effects that could not be predicted from any one event. 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.

Land-use decisions should be implemented with some consideration as to the physical, biological, aesthetic or economic constraints they will place on future uses of the land. External effects, which can extend beyond the boundaries of individual ownership and affect surrounding owners, must also be considered.

Planning for the long term requires consideration of the potential for unexpected events, such as variations in temperature or precipitation patterns or disturbances. Estimating the occurrence and implications of these unanticipated events is difficult, but land-use plans should attempt to include them and estimate likely changes.

Long-term planning should also recognize that one cannot simply extrapolate historical land-use impacts forward to predict future consequences of land use. Transitions of land from one use or cover type to another often are not predictable because of changes in demographics, public policy, market economies, and technological and ecological factors.

#### *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. 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, physical features, hydrology, soils, and associated species. Once the inventory is complete, effects of land-use decisions on these landscape elements and species can be routinely 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.

*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 occurs during agriculture and the loss of wetlands and their associated ecological processes and species are two examples. To prevent diminishment, those resources at risk must first be determined. For example, in the southwestern United States, water might be the most important resource. Evaluation of whether a resource is at risk is an ongoing process as the abundance and distribution of resources change. Ways to avoid actions that would jeopardize natural resources should be identified and considered. Some land actions are inappropriate in a particular setting or time, and they should be avoided. Examples are farming on steep slopes, which might produce soil loss; logging, grazing, or farming too close to streambanks, which may jeopardize water quality and aquatic habitats; and growing plants with high water demands in arid areas.

*Retain Large Contiguous or Connected Areas that Contain Critical Habitats*

Large areas are often important to maintaining key organisms and ecosystem processes. Habitat patch size is critical to the survival of a species or population when it is rare or disconnected. In most parts of the nation, large areas of natural habitats are becoming less common as they are fragmented into smaller habitat patches suitable for fewer species. A useful management approach generally favors protecting large areas and smaller areas that are well-connected to other habitats.

Habitat connectivity is not always a positive attribute for species and ecosystems. Land uses that serve as connectors to species' movement can have long-term positive effects on populations; but, at the same time, corridors can facilitate the spread of nonnative species or diseases.

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

*Minimize the Introduction and Spread of Nonnative Species*

Nonnative organisms often have negative effects on native species and the structure and functioning of ecological systems. Land-use decisions must consider the potential for the introduction and spread of nonnative species. For example, kudzu, first used for erosion control, is now overwhelming and killing native trees. Land planning should consider vehicle movement along transportation routes, the planting of native species, and control of pets. For example, the spread of the gypsy moth is correlated with overseas transportation of eggs, larvae, and adults in the cargo holds of ships or along roads when egg sacs are attached to vehicles or outdoor furniture. The introduction of aquatic organisms (e.g., the zebra mussel) transported incidentally with shipping traffic is a comparable example for aquatic ecosystems. Many of these introductions have had devastating effects.

Growing native species can reduce the need for planting nonnative species, particularly in urban, suburban, or other developed areas. The planted native species can then reseed themselves. Native species are also adapted to long-term variations in climate or disturbance regimes to which nonnative species often succumb. Environmental conditions associated with native vegetation may also deter the spread of nonnatives.

*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, while at a broad scale, patterns of watershed processes may be altered, for example, by changing drainage patterns as a result of development. How proposed actions might affect other systems (or lands) should be examined. 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. For example, parts of golf courses can be designed to serve as wildlife habitat, 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.

*Implement Land-Use and -Management Practices that are Compatible with the Natural Potential of the Area*

Because local physical and biotic conditions affect ecological processes, the natural potential for productivity and for nutrient and water cycling partially determine the appropriate land-use and -management practices for a site. Land-use practices that fall within these place limits are usually cost-effective in terms of human resources and future costs caused by unwarranted changes on the land. Implementing land-use and -management practices that are compatible with the natural potential of the area requires that land managers have an understanding of the site potential.

**Assessing Local Conditions**

The purpose of land-use planning is to ensure that important societal attributes are sustained. These attributes fall into three groups: infrastructure (e.g., jobs, roads, schools, and firehouses), environmental resources (e.g., open spaces, parks, watersheds, natural areas, and wetlands), and public safety (e.g., avoidance of flood plains, unstable soils, and fire hazards). Land-use planning typically follows several steps in balancing emphasis on these attributes.

First, data on current local conditions are assembled. On the basis of these data, concerns about impacts of development are identified. Then, goals for maintaining values are formulated, and criteria for meeting those goals are specified. Alternative approaches to meeting the goals (e.g., regulations, incentives, or public purchase) are developed, and the best are selected and implemented. The success of the chosen approach is then evaluated relative to the criteria. This evaluation becomes part of the data used in the next iteration of the planning process.

An important step in land-use planning is trying to ascertain how a proposed use will affect current local conditions. A process for identifying the effects of development on wildlife habitat and natural communities in Larimer County, Colorado, provides an example. The process was initiated by assembling a group of stakeholders to work with ecologists to identify areas of the landscape that needed to be protected. This group included developers, landowners, planners, environmental advocates, and decision makers. The participation of stakeholders was important for several reasons. First, no single "ecological standard" can be used to assess the value of one facet of the landscape relative to

another. Ultimately, ecological knowledge must be combined with local values to arrive at such assessments. Second, the support of leaders of groups affected by the process must be enlisted.

The stakeholder group identified four landscape features based on importance to biological conservation and availability of spatial data about the features:

1. areas with one or more imperiled species,
2. habitat for economically important species,
3. areas of high species richness, and
4. rare plant communities.

These features were mapped, and a composite map was created showing all of the county as falling into one or more of the four categories. This map was used to designate areas that required a "Habitat Mitigation Plan." As a requirement for approval of all proposed developments, these plans outline procedures for on-the-ground verification and assessment of the condition of these environmental features. If the features are determined to be at risk with the proposed land use, then steps must be taken to mitigate the effects of development. Such steps include provision of setbacks, enforcement of special regulations and covenants, and transfer of development rights from other areas.

Developers can specify an area in the County and learn if it contains environmentally sensitive areas before preparing a development proposal, increasing the chances that sensitive areas will be avoided by choice rather than by regulation. Alternatively, citizen advocates can learn where development is proposed and can attend review hearings with the support of the best available data on the environmental impacts of the development under review. This mechanism allows the assessment of local conditions to be a dynamic, ongoing process, rather than a static snapshot in time.

#### Making sustained progress

Much progress has been made in managing land in ecologically sustainable ways. However, more actions are needed before ecologically based land management is broadly implemented. These guidelines must be translated to particular land uses. This translation can be done, for example, by using these principles and guidelines to shape municipal ordinances for land use practices. In addition, these guidelines can provide the basis for specifying and understanding ecological concerns relevant to the needs of specific types of land users, such as farmers or foresters.

These guidelines do not address the environmental, social, economic, and political tradeoffs that often occur in setting land policy. Tradeoffs are often based on subjective value judgments reflecting economic, social, cultural, and aesthetic preferences accorded by a society to different objectives and variation in local circumstances. For example, consideration of such tradeoffs are central components of land-use agreements in the restoration of the Everglades and in developing options for fisheries and ancient forests in the Pacific Northwest.

However, society and the ecological community have not yet converged on a consistently applicable mechanism for incorporating science into land-use policy. Positive steps in integrating scientific ideas and land-use management are being taken at both the international and national scales. At the local scale, an unprecedented increase in numbers of watershed alliances and other types of nongovernmental organizations has occurred in response to the perception that government agencies are not doing enough to manage the land sustainably. In each case, science is only a part of the solution, although an essential part.

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#### FOR MORE INFORMATION

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